School of Agriculture and Environment

Improving the Fit of New Annual Pasture Legumes in Western Australian Farming Systems: Experience from Cadiz and Casbah

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This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

April 2010

Declaration

This thesis contains no material that has been accepted for the award of any other degree or diploma in any university.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signed: ______________________

Date: ________________________

to

my dearest husband Moin

and loveliest son Rafi

"Ask the experienced
rather than the learned"

-Ancient Arabic proverb

Abstract

Annual pasture legumes (APLs) are important in Western Australian farming systems, with subterranean clovers and annual medics being dominant. However, due to potential environmental, economic and biological constraints of these species, alternatives have been sought, with a second generation of new species being introduced since 1991. Despite the views of researchers about the advantages in WA conditions of the newly released annual pasture legumes over traditional pastures, there is a perception by some industry decision makers that their level of adoption has been lower than expected. However, there was not a good method for evaluating the level of adoption. The aim of this study was therefore to enhance understanding of how to improve the fit of new annual pasture legumes in Western Australian farming systems, taking two pastures, French serradella (*Ornithopus sativus*) cv. Cadiz and Biserrula (*Biserrula Pelecinus*) cv. Casbah (Hereafter, will be referred to as Cadiz and Casbah.), as examples.

The objectives of the study were implemented in four steps. In step one, a framework, built on a three-tier hierarchy (broad adoption potential or BAP, broad attainable adoption potential or BAAP, and maximum attainable adoption potential or MAAP) was developed based on the agro-ecological suitability of the annual pasture legumes. BAP was calculated from the amount of suitable land in terms of soil and rainfall requirements for an APL. The BAAP was calculated by multiplying BAP with two coefficients related to the proportion of cropping area within a geographic region, and the crop-pasture ratio within the cropping area. The MAAP was calculated by multiplying BAAP with a coefficient related to the certainty of a successful pasture-growing season. This coefficient was derived from a Microsoft-Excell®-based Climate Reliability Calculator particularly developed for this study. The broad attainable adoption potentials (BAAP) for Cadiz and Casbah were calculated as 1.67 M ha and 1.18 M ha, respectively. These figures were about 81% less than the calculated broad adoption potential (BAP). The maximum attainable adoption potentials (MAAP) for Cadiz and Casbah in Western Australian cropping-belt were calculated as 0.99 and 0.89 M ha, respectively.

In step two, a survey was conducted to understand the salient issues that farmers consider in relation to adopting a new annual pasture legume for their farming systems. An open-ended question was used for them for the attributes they desired for their ‘dream’ pasture. Questions were also asked about their experiences of strengths and weaknesses for Cadiz and Casbah. Responses were analysed using the principles of ‘grounded theory’. Furthermore, based on farmers’ perceptions, an APL-characteristics framework was developed for Western Australia. The framework consisted of six attributes of a pasture. They are, in order

of importance calculated from the percent of farmers responses: superiority in establishment and growth (79%), ability in supplying quality feed (49%), improved potential in controlling weeds (38%), adaptability in broader agro-ecological horizon (36%), tolerant to major insect-pests (20%), and inexpensive (15%). Many farmers desired a combination of these components rather than just a single component. The two test APLs, Cadiz and Casbah, were compared under this framework based on the responses of the farmers.

In the third step, using farmers' perceptions of the salient attributes and other variables, an empirical model was developed to predict the likely adoption of any annual pasture legume in Western Australian farming systems. The model consisted of the product of two components, AAAR and TRMAP. The AAAR was the averaged annual adoption rate (as the percentage of all pastures grown in Western Australia) of the APL. TRMAP is the time, in years, required to reach the maximum adoption potential of the APL. The AAAR was related to the agronomic characteristics of the APL (the three most wanted characteristics by farmers, i.e. establishment and growth, feed supply and quality and weed control) and an 'inter-competition' factor, whereas the TRMAP was attributed to its scope of adaptation. Both AAAR and TRAMP were essentially regression models. The model performed well when tested independently for Cadiz and Casbah using inputs from two different sources, i.e. breeders and farmers. In the final step, the model was applied to predict the adoption of Cadiz and Casbah using inputs from breeders and farmers in order to understand what level of adoption breeders would have expected and to what extent farmers would support the breeders' view. Results showed that breeders were expecting Cadiz and Casbah would be adopted in about 32% and 22% of their potential areas (MAAP) compared to the achieved adoption of 23% for Cadiz and 20% for Casbah, respectively. On the other hand, model output using farmers' evaluation scores indicated that the adoption would be 20% for Cadiz and 19% for Casbah, which is much closer to the achieved adoption level. The difference between breeders' expectation and farmers' evaluation on adoption potential of Cadiz and Casbah was due to differences in evaluation scores provided by the two groups on different pasture characteristics in relation to establishment and growth, weed control and feed supply and quality. Some of the pasture characteristics desired by the farmers, such as reliable regeneration, seed settings, easy establishment, general vigor, good chemical tolerance, good feed supply and quality, suitable for wide range of soils, good insect tolerance are not commonly present when Cadiz and Casbah are grown in the farming environments.

Two issues for further consideration if the adoption levels of Cadiz and Casbah were to be increased in WA farming systems are: decreasing the knowledge gap among farmers on tactical management of APLs though extension, and improved pasture characteristics through the breeding/selection process. Furthermore, this study designed a system consisting of three major components: the maximum attainable adoption potential (MAAP), the annual pasture legume characteristics framework (APL-characteristics for Western Australia) and achievable adoption potential (AAP). This system acts as a common platform - where breeders, farmers, extension specialists and policy makers could work as a team towards improving the fit of annual pasture legumes, and potentially other crops if the required supporting information was collected, in Western Australian farming systems.

Acknowledgements

Shukar Alhamdulillah – Thanks God, thanks for giving me the patience and strength to complete this thesis.

First of all, I want to thank all who dreamt for me!!!

While I was working in the ‘Farming Systems Research and Environmental Studies’ programme, a combined project of the Bangladesh Agricultural University and 17 other organisations, I used to observe how new technologies shaped in rural communities. Everything was new learning to me as I had just completed my university honours degree and commenced the job as a junior researcher. My role was to integrate research and development work while disseminating new technologies, so that they were successfully applied in farm environments. I found many technologies did not fit well in the complex farming communities. As a young energetic and enthusiastic researcher, I spent my time including the weekends going “back and forth” to senior researchers and farmers to understand “why those happening and how to improve those”. My efforts did not go in vain. After making some modifications in the new technologies, considering farmers’ needs and capability to fit into the local systems and educating farmers on how to use them, I was able to achieve great results! I still can see big smiles on the faces of distressed rural women and girls who had been able to utilize my efforts and improve their livelihood. Since then, I have always had the aspiration to work on the issue of farming systems.

Thanks to Dr. David Bowran, Director, Agricultural Systems Research of the Department of Agriculture and Food Western Australia, for understanding my aspirations and suggesting to me the current PhD topic that needed to be addressed in Western Australian farming systems.

My thanks to Professor Graeme Robertson, retired Director of Muresk Institute, Curtin University, for encouraging me to undertake the PhD research, finding me a supervisor and helping me in the initial settlement for this study.

My sincere gratitude to both my supervisors - Dr. Roy Murray-Prior, Associate Professor, Curtin University and Technology and Dr. David Bowran, who spent many hours with me towards my PhD research.

Thanks to Dr. Moin Salam, Project Manager of Quantifying and Predicting Agricultural Systems of the Department of Agriculture and Food Western Australia for contribution on the development of research methodology and its analysis and synthesis.

My appreciation goes to Dr. Angelo Loi, pasture researcher of the Department of Agriculture and Food Western Australia, for many consultations and providing me with many documents which have been extremely useful to my PhD research.

I acknowledge Dr. Phil Nichols, pasture breeder of the Department of Agriculture and Food Western Australia, for providing me with unpublished survey data used in this study.

My thanks to Dr. Clinton Revell, manager of Profitable Pasture of the Department of Agriculture and Food Western Australia, for giving me access to many research information on annual pasture legume research.

My sincere thanks go to Dr. Dennis Van Gool of Soil Resource Management Unit of the Department of Agriculture and Food Western Australia, for developing soil and rainfall suitability maps.

I thank Associate Professor Dr. M.A. Ewing of the Centre for Legumes in Mediterranean Agriculture of the University of Western Australia for material support and suggestions.

My thanks go to my work colleagues Dr. Bill Bowden, Dr. Art Diggle, Dr. James Fisher (ex-team member), Mr Tim Maling of Quantifying and Predicting Agricultural Systems of Department of Agriculture and Food Western Australia, for their continuous support and suggestions.

My sincere thanks to Dr. Fiona Evans of the Climate and Modelling Science of the Department of Agriculture and Food Western Australia, for help in statistical analysis.

My recognition to Ms. Carol Llewellyn of the Department of Agriculture and Food Western Australia for enormous help in organising PhD research meetings and conference travel for me.

I would like to thank Mr. Joshua Smith of the Department of Agriculture and Food Western Australia for helping me to produce shire maps.

I want to extend my gratitude to Mr. Ian Longson (Ex Director General), and Dr. Mark Sweetingham (Acting Executive Director) of the Department of Agriculture and Food Western Australia for their support towards this research.

I also would like to acknowledge the farmers of Western Australia who provided me with the research information through face-to-face interviews, emails, faxes and telephoning.

My thanks to the Commonwealth Government for financial support through the Australian Postgraduate Award.

I highly acknowledge the Department of Agriculture and Food Western Australian for providing me the research support.

Thanks again to my supervisors Roy and David for allocating me conference travel grants to present my research works in one international and three national conferences. My thanks also go to Dr. Peter Batt who allocated me part of my international conference travel grant from Curtin University.

I would like to acknowledge Ms Robyn Murray-Prior for final proofreading of the manuscript.

I also greet my family, my deceased father and my elder brother who inspirited me in my higher education.

Last but not least, my heartfelt thanks go to my husband Moin and son Rafi who put up with all my rejection of family fun during my PhD study. The best thing is that they never gave up on me. Their constant help and encouragement made me today's achiever.

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Acronyms

A	Adaptability
AA	Achieved adoption
AAAR	Averaged annual adoption rate
AAP	Achievable adoption potential
APL	Annual pasture legume
BAAP	Broad attainable adoption potential
BAP	Broad adoption potential
CAR	Central agricultural region
CLIMA	Centre for legumes in Mediterranean agriculture
DAFWA	Department of Agriculture and Food Western Australia
EG	Establishment and growth
Fsq	Feed supply and quality
I	Insect tolerance
Ic	Inter competition among the existing cultivars
MAAP	Maximum attainable adoption potential
NAR	Northern agricultural region
SAR	Southern agricultural region
SOA	Scope of adaptation
TRMAP	Time required to reach the maximum adoption potential
W	Weed control
WA	Western Australia

Chapter 1

Introduction

1. Introduction

1.1 Why a good annual pasture legume for Western Australian farming systems?

Benefits of inclusion of annual pasture legumes (APLs) in the farming systems are immense. Western Australian agriculture is mixed farming (Doole, Pannell & Revell 2009), composed mainly of crop and livestock enterprises. As a direct contribution, annual pasture legumes provide feed and nutrition to farm animals especially to sheep and cattle leading to increases in their productivity. The APLs help increase the digestibility and supply palatable feed which are very important for animal growth. They also provide high protein levels to animal feed which are useful for milk, meat and wool production. Indirectly, the APLs contribute in a number of ways to the crop enterprise. As legumes, they convert atmospheric nitrogen through their symbiotic association with the soil bacteria (rhizobia), thereby increasing soil nitrogen status (Peoples & Baldock 2001). This in turn increases crop yields or reduces the rate of nitrogen application required in the following crop. APLs improve soil properties such as soil electrical conductivity (Loss, Ritchie & Rohsoiz 1993). Weeds are one of the serious issues in Western Australian agriculture (Sinden et al. 2004); APLs can contribute to controlling weed dominance (Loi, Revell & Nutt 2005) in crop rotations. Crop diseases, especially root diseases, can seriously affect crop productivity in the state (Macleod et al. 2008). APLs also help break the life cycles of many crop diseases and insect pests (Howieson, O'Hara & Carr 2000).

In spite of these advantages, there are challenges in incorporating annual pasture legumes into the current farming systems. This is because the APLs are in increasing competition with a number of break crops, both legumes and non-legumes, in providing rotational benefits in the farming systems. A recent review elaborates on such benefits in the context of Australian agriculture (Kirkegaard et al. 2008). It is, therefore, critical that attempts to increase adoption of new annual pasture legumes consider improving their fit in the context of exiting farming systems of Western Australia.

1.2 The first generation annual pasture legumes

An account of early development of annual pasture legumes in the state has been presented in the book *Agriculture in Western Australia 1829-1979*, edited by G. H. Burvil. APLs have been an integral part of the state's farming systems since 1890; when land under wheat cultivation was 0.014 million hectares, although the exact figure on pasture area is not available (Burvill 1979a). Two annual pasture legumes, subterranean clovers and medics, are presumed to have been introduced accidently around 1900 and later on were promoted to support wheat-sheep based farming systems. Subterranean clovers were used for light and acidic soils and annual medics for heavy and neutral-to-alkaline soils of Western Australia. Pasture production dramatically increased in the Western Australian Centenary Year (from 7,000 ha in 1920 to 131,000 ha in 1929) (Burvill 1979a). After 1929, farmland began to increase sharply. 'Sown pasture increased from 1.45 million ha in 1950 to 3.1 million ha in 1960 and nearly 7 million ha in 1970' (Burvill 1979b, p. 75). Until that time, many new varieties of crops and annual pastures were sown in separate or integrated farming.

During the 1930s, soil erosion, caused by wind and water, created severe concerns and led to the Soil Conservation Act 1945 (Burvill 1979b). As a result, wide-spread cultivation of subterranean clover pasture occurred to save the soil from wind and water erosion and to increase soil fertility (Burvill 1979b). During the 1950's, when wool prices increased greatly, the adoption of subterranean clover and annual medics continued to grow. By 1979, 16 registered cultivars of subterranean clover, notably, Nungarin, Geraldton, Northam, Dwalganup, Daliak, and Seaton Park, were introduced to Western Australia. Although, annual medics were sown sporadically in Western Australia during the 1940s, a new cultivar Cyprus released in 1959, became the most widely sown medic in Western Australia (Underwood & Gladstones 1979).

1.3 Potential constraints with the first generation annual pasture legumes

Although many new varieties of subterranean clover and annual medics were introduced in Western Australia and viewed as a big success in the Western Australian environment, there were some potential environmental, economical and biological constraints identified in relation to their wide-spread adoption (Howieson, O'Hara & Carr 2000). For example, subterranean clover is suitable for acidic soils and areas with annual rainfall over 400 mm (Cocks & Phillips 1979); it does not persist well when the rainfall is below this threshold (Loi et al. 2005a). On the other hand, annual medics are suitable for neutral and alkaline soils and low rainfall regions (Puckridge & French 1983); by contrast, acidic soils, unfavourable for annual medics, are common in low rainfall regions of WA (Howieson & Ewing 1989). Nichols et al. (2007) extensively detailed other constraints with these traditional pastures that include poor adaptation to a false break, seed bank depletion from soft-seeded APLs, high seed cost from re-sowing, short growing season, increased ground water recharge and salinity. Furthermore, traditionally subterranean clover and annual medics were practiced as ley-farming (1-2 years cropping, followed by self-regenerated pasture) (Underwood & Gladstones 1979). However, increasing demand for more grain production encouraged new systems of phase farming (Howieson, O'Hara & Carr 2000), where three to six years cropping is followed by a legume pasture. Traditional pasture subterranean clover is unable to regenerate after a long cycle (Loi et al. 2005a). This circumstance created a demand for selecting and/or breeding new annual pasture legumes for Western Australia that are capable to fit into the new and challenging farming systems (Ewing 1989).

1.4 Development of second-generation annual pasture legumes

Since 1991, a number of new annual pasture legumes have been developed for Western Australia by different breeding groups. This has been reviewed in detail recently by Nichols and his associates (Nichols et al. 2007). These cultivars are supposed to be adapted well to difficult soils, diverse rainfall areas and under both ley and phase farming systems. They are also considered as having better agronomic traits than traditional subterranean clover and annual medics. For example, biserrula (*Biserrula pelecinus*) cv. Casbah was introduced in 1997 as a suitable pasture species for Western Australia's most common acidic sandy soils (Howieson, Loi & Carr 1995; Loi, Revell & Nutt 2005). French serradella (*Ornithopus sativus*) cv. Cadiz was released in 1996 and is well-suited to a wide range of light to medium acid soils and areas with greater than 400 mm rainfall (Nutt & Paterson 1997). Santorini, a cultivar of French Serradella, released in 1995 grows on both acidic sands and sandy loams throughout medium rainfall areas of 350-450 mm (Nutt & Paterson 1998). Frontier (*Trifolium michelianum*) was released in 1999 (Craig et al. 2000) for low and medium rainfall (325 - 450 mm) zones of Western Australia (Revell, Nutt & Craig 2001). Prima (*Trifolium glanduliferum*) released in 2001, is suitable in the areas with greater than 350 mm annual rainfall (Nutt & Loi 2002). Biserrula (*Biserrula pelecinus*) cv. Casbah and French serradella (*Ornithopus sativus*) cv. Cadiz have created great interest to industry since their release. Both pastures have overcome the shortfalls of traditional pastures. For example, Casbah has the ability to grow in acidic soils under a low rainfall environment, where annual medics will not grow. Cadiz grows in poor acid soils where traditional subterranean clover grows poorly. Breeders and researchers claim that both pastures have high inherent capacity to be adopted in the Western Australian farming systems. However, despite their potential, there have been issues with the two pasture cultivars that have affected their level of adoption, which makes Cadiz and Casbah good cases for this study.

1.5 Adoption of newly developed annual pasture legumes

Devenish (2003) points out that annual pasture legumes play an important role in Western Australian phase farming systems. For example, he estimates that the area sown to Cadiz could be as high as 300-500,000 hectares each year. Nichols et al. (2007) mention that the rate of adoption of these new annual pasture legumes has been high. For example, Biserrula (cv. Casbah and Mauro together), one of the very high promising annual pasture legumes (Howieson, Loi & Carr 1995; Carr, Howiesson & Porqueddu 1999), have been adopted as

17% of all sown pastures. However, the question may be asked, can the level of adoption be regarded as highly successful given Biserrula has been credited with so many qualities? For example, Biserrula is a fast-growing, deep-rooted plant, which helps it survive in drought conditions. It is: more acid tolerant than other legumes, suitable in a wide range of soil textures and pH, more tolerant to heavy grazing except during the flowering season, hard seeded which protects it against summer and autumn false breaks, capable of seed survival from ingestion by animals, less costly (low seed cost), readily available (seed availability), capable of long-term persistence, capable of increasing soil nitrogen, good for producing quality hay and silage, tolerant to most diseases of annual legumes, advantageous for seed productivity (supplies good amounts of seed), and easy to harvest (Freebairn 2004; Loi et al. 2005b).

The question may be relevant as Davis and Hogg (2008) report that some issues related to newly released annual pasture legumes were identified through farmers' surveys as hindrances to their wider adoption. Pasture Australia (2007) launched a project for 2005-2015 to improve the adoption of these newly released pastures. It appears that the level of adoption of these annual pasture legumes has not achieved the level expected. Policy makers of the Department of Agriculture and Food Western Australia mentioned that the adoption of the newly released APLs has not been satisfactory (Roger O'Dwyer & Ian Longson, pers. comm. 2007). It is apparent that there is some ambiguity about the level of adoption of the newly released APLs in Western Australia. This is due to the lack of a proper technique for quantifying the adoption potentials of a pasture for Western Australian farming systems. Consequently there is a need to develop a framework for more accurately predicting the adoption potential of APLs and to improve understanding of the characteristics required when breeding APLs to fit into Western Australian farming systems.

1.6 Aims and objectives of research

Based on above background, this study was undertaken aiming to enhance understanding of how to improve the fit of new annual pasture legumes (APLs) in south-west Western Australian farming systems. It particularly intended to investigate two APLs, Cadiz and Casbah (Figure 1.1). The specific objectives of the study were:

1. To develop a system for measuring the adoption potential of an annual pasture legume based on its agro-ecological suitability.
2. To understand farmers' perceptions of an ideal pasture for their farming systems and compare the strength and weakness of Cadiz and Casbah against it.
3. To develop an empirical model to predict the achievable adoption of any annual pasture legume based on its perceived attributes.

4. To develop a framework for improving the fit of an annual pasture legume in the Western Australian farming systems.

Figure 1.1: Photo of French seradella (*Ornthopus sativus*) cv. Cadiz and Biserrula (*Biserrula pelecinus*) cv. Casbah

Source: Cadiz (http://www.clima.uwa.edu.au/research/pastures/cultivars); Casbah (Angelo Loi, personal communication)

1.7 Outline of the thesis

The thesis is presented as a series of chapters that follow a logical progression of specific objectives of the study. Chapter 2 through 5 are independently comprehensive, and are laid out in the form of scientific articles with specific objectives, reviews of the related literature and methods. Each has been developed for publications as a journal or refereed conference paper. Where the information has been published in either of these forms, checks have been made with the publishers and there are no copyright issues.

Chapter 2 presents a framework for measuring the adoption potentials of annual pasture legumes (APLs) for Western Australian farming systems. This framework is built on a three-tier hierarchy: broad adoption potential or BAP (constrained by soil and rainfall requirements), broad attainable adoption potential or BAAP (constrained by farming systems), and maximum attainable adoption potential or MAAP (constrained by seasonal uncertainty). It also provides the validation of the top hierarchy of the framework, MAAP, in eight shires of Western Australia using the two annual pasture legumes, Cadiz and Casbah.

Farmers' perceptions may be the key to successful adoption of a newly released APL in Western Australian farming systems. With this notion, Chapter 3 puts forward a pasture characteristics framework based on perceptions of Western Australian farmers. It presents a semi-quantitative analysis that results in six components of the framework and shows their relative importance. Using the six components as a yardstick, this section also shows a comparison of the attributes of the two test annual pasture legumes, Cadiz and Casbah, as rated by the farmers.

The next section (Chapter 4) is about an empirical model that was developed to estimate achievable adoption potential of any annual pasture legume for Western Australian farming systems. It reviews the universal difficulty in developing such a tool for measuring adoption of innovations. It describes, in detail, the two components of the model, the averaged annual adoption rate and the time required to reach the maximum adoption potential of an annual pasture legume. The chapter also presents the validation process of the model using independent data on the achievable adoption of Cadiz and Casbah in Western Australia. Furthermore, it illustrates some applications of the model to highlight how it could guide researchers on increasing the achievable adoption potential of annual pasture legumes through improving the pasture characteristics in the selection and/or breeding programme.

Chapter 5 elaborates on the application of the empirical model presented in Chapter 4. It details the model application to predict the likelihood of adoption of Cadiz and Casbah using inputs on scores of pasture attributes from breeders and farmers. It specifically addresses two questions: ‘Is this the level of adoption breeders were expecting?’; and ‘Do the farmers support the breeders’ view?’ In the end, this section presents an overall framework to improve the fit of newly released annual pasture legumes in the farming systems of Western Australia.

A general discussion on the whole study is presented in Chapter 6. It points out lessons learnt from this study with respect to present state of development and release of annual pasture legumes and their subsequent adoption in Western Australian farming systems.

Finally, the conclusions and implications are laid out in Chapter 7. It also lists suggestions for improvement, and limitation of the study, and directions for future research.

In the Appendices, supplementary information is provided related to the chapters. In addition, two important sets of information are provided. One is a list of the persons consulted over the period of this study (Appendix 4) and the other is a list of communications made during the study in the form of publications and presentations (Appendix 5).

Chapter 2

A framework and its application for measuring adoption potentials of annual pasture legumes in Western Australia*

*This chapter was developed from Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2010, 'A framework and its application for measuring adoption potentials of annual pasture legumes in Western Australia'. *Outlook on Agriculture* (submitted).

2. A framework and its application for measuring adoption potentials of annual pasture legumes in Western Australia

2.1 Chapter outline

This chapter starts with a discussion of why agro-ecological suitability is an important consideration when fitting annual pasture legumes in Western Australia's varied soils (land quality), unreliable yearly and seasonal rainfall and diverse farming systems. It presents a framework, derived from information on 44 shires, for measuring the adoption potentials of annual pasture legumes (APLs) for Western Australian farming systems. This framework is built on a three-tier hierarchy: broad adoption potential or BAP (constrained by soil and rainfall requirements), broad attainable adoption potential or BAAP (constrained by farming systems), and maximum attainable adoption potential or MAAP (constrained by seasonal uncertainty). Two annual pasture legumes (i.e. Cadiz and Casbah) have been tested in the framework to measure BAP, BAAP and MAAP. The chapter also details the development of the framework and its statistical validation. It concludes with the possible application of this framework.

2.2 Introduction

In order to fit an annual pasture legume (APL) into a farming system, it is beneficial to determine its adoption potential for the system. A basic requirement of any plant species to be adopted into a farming system is the agro-ecological suitability. The agro-ecological suitability usually designates soil and climate requirements. In Western Australia, soil pH, soil salinity, waterlogging status (Nichols et al. 2007) and climate are highly variable across the state. Newly released APLs have specific soil and rainfall requirements (Loi et al. 2005a). Rainfall reliability is an important factor to consider (Austen et al. 2002; George et al. 2007), since while the average rainfall may be suitable for a location, the amount of annual and/or seasonal rainfall can vary considerably between years.

It is evident that due to climate and soil water variability Australian farmers face huge losses in their crop and pasture enterprises (Austen et al. 2002). These issues require further examination to understand the full potential of a new pasture (Hill 1996; Hannaway et al. 2005) before considering it for Western Australian farming systems. At present, the potential of an APL is largely measured using a qualitative scale. For example, in highlighting the potential of Casbah, Howieson, O'Hara and Carr (2000, p. 117) state, '*Biserrula pelecinus* appears to be exceptionally promising'.

Since 1991, a large number of APLs have been released in Western Australia (Nichols et al. 2007). However, it is not certain whether their adoption has reached their potential level or not. This is due to a lack of quantification of adoption potentials of these pastures under Western Australian farming systems. Currently, information on soil and climatic suitability of an APL is largely provided by some statements. For example: 'Biserrula cultivars are suitable for use on fine textured soils with acidic and alkaline reactions, including sandy loams and clay loams….. It (Casbah) is suited to regions with 325–500 mm annual rainfall' (Loi, Revell & Nutt 2005, p. 1). Proper documentation is needed of their geographic distribution potentials (Puckridge & French 1983).

Hill (1996) used a knowledge-based logical modelling approach where he fed monthly climate data into a geographic information systems (GIS) package to produce the potential adaptation maps for nine temperate pasture species for Australia. However, his model did not include soil constraints for Western Australia. It has been mentioned that the new generation APLs have different tolerances to soil pH and soil physical and chemical conditions for their optimum production (Carr et al. 1999; Loi et al. 2000; Nichols et al. 2007). Hannaway et al. (2005) described the potential of using climate, GIS and forage specific requirements to produce potential adaptation zone maps for forage which could be very precise and bring economic benefits by putting each plant in its best location. This concept is being used in USA and China to develop forage species adaptation zone maps in broader scales. A similar system does not exist for annual pasture legumes of Western Australia.

Considering the above, a new framework was developed that classifies adoption potentials of APLs into broad, broad attainable and maximum attainable (adoption potentials) and quantified them. The objectives of this chapter are to: (i) describe the framework, (ii) quantify adoption potentials of two annual pasture legumes, Cadiz and Casbah, and (iii) validate the framework for Western Australian farming systems.

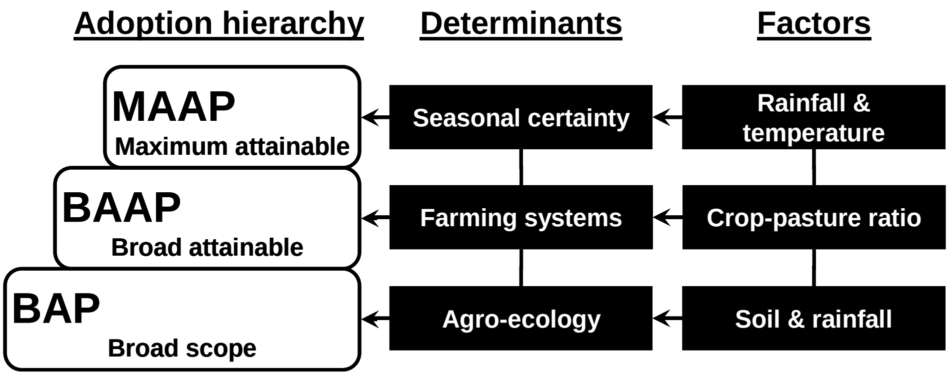
2.3 Methodology

2.3.1 The framework for measuring adoption potentials of annual pasture legumes

The framework for measuring adoption potentials of annual pasture legumes (APLs) in Western Australia presents the steps and identifies the determinants and factors associated with each step (Figure 2.1). The adoption potentials of an APL are classified into three hierarchies: broad adoption potential (BAP), broad attainable adoption potential (BAAP), and maximum attainable adoption potential (MAAP). In this framework, the BAP represents agro-ecologically suitable land for an APL. This suitability is measured on the basis of soil and rainfall requirements for an APL. Western Australian has mixed farming systems (Doole, Pannell & Revell 2009), composed mainly of crop and livestock enterprises.

Therefore, the adoption of an APL is unlikely to occur in all the land designated under BAP, as pasture enterprises constantly compete with crop for the same land (Nichols 2004). The next hierarchy, BAAP, considers this constraint, termed as farming systems in Figure 1. Furthermore, the land under BAAP may not be fully attainable due to unfavourable seasonal conditions such as droughts. The next hierarchy, MAAP, includes this constraint.

Figure 2.1: Framework* for measuring adoption potentials of annual pasture legumes in Western Australia



* The framework shows the adoption hierarchy together with associated determinants and specific factor(s) affecting each determinant. In the hierarchy, BAP is the broad adoption potential, BAAP is the broad attainable adoption potential, MAAP is the maximum attainable adoption potential

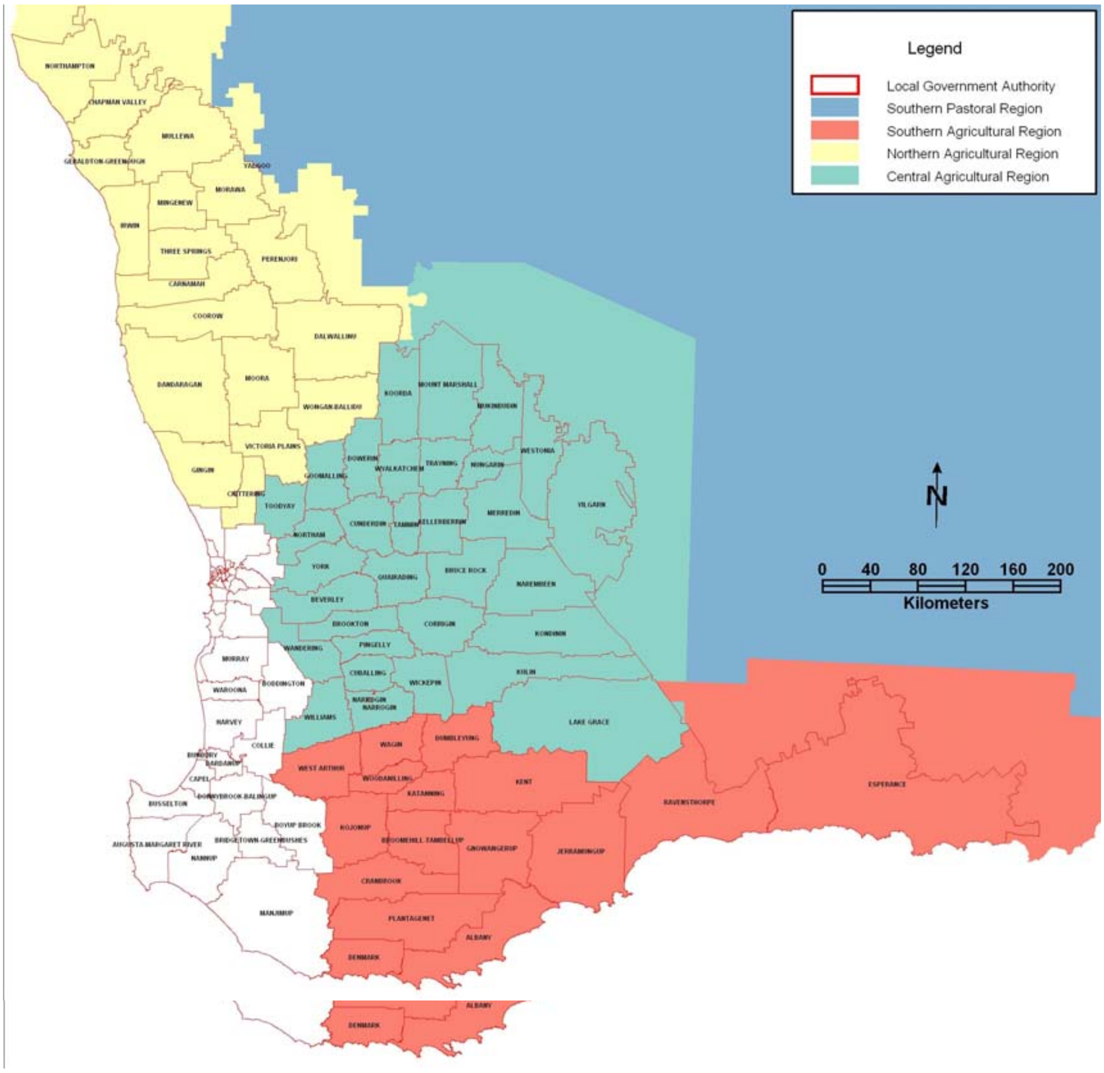
2.3.2 Annual pasture legumes (APLs) under study

The framework was applied to quantify adoption potentials of two APLs, French seradella (*Ornthopus sativus*) cv. Cadiz and biserrula (*Biserrula pelecinus*) cv. Casbah (referred to as Cadiz and Casbah hereafter). Cadiz was released in 1996 (Nutt & Paterson 1997) and Casbah in 1997 (Loi, Revell & Nutt 2005). These two pastures were chosen as they have created great interest to industry since their release. For example, Cadiz grows in poor acid soils where the dominant traditional pasture, subterranean clover, hardly grows (Nutt & Paterson 1997). On the other hand, Casbah is regarded as an exceptionally promising pasture for Western Australia (Howieson, Loi & Carr 1995; Carr et al. 1999) has the ability to grow under low rainfall in most of the acidic sandy soils where annual medics would not establish (Howieson, Loi & Carr 1995; Loi et al. 2005).

2.3.3 Study area

The study area encompassed the Western Australian cropping-belt (Figure 2.2). Based on the length of crop growing seasons, this cropping-belt is divided into three regions, the northern agricultural region (NAR), the central agricultural region (CAR) and the southern agricultural region (SAR) (Garlinge 2005). Strongly influenced by the features of its Mediterranean climates (Anderson & Garlinge 2000), the length of growing seasons gradually increases from NAR to SAR as temperature decreases. For each region, rainfall decreases from the west to the east. Dolling (2006) showed profound differences among these three regions, such as temperature, annual rainfall, active growing season rainfall (May-October) and less-active growing season rainfall (November-October), which can limit the scope of cultivation of these two APLs. Forty-four shires (local government administrative units) were included in a study area to develop the framework. Farmers from these 44 shires, who grew Cadiz and Casbah, responded to a field survey. The shires represent three agricultural regions; i.e. 16 in the northern agricultural region (NAR), 15 in the central agricultural region (CAR) and 13 in the southern agricultural region (SAR). The developed framework was tested with 16 shires (Carnamah, Coorow, Cunderdin, Dalwallinu, Dandaragan, Gingin, Greenough, Irwin, Katanning, Kulin, Moora, Morawa, Mukinbudin, Ravensthorpe, Williams and Yilgarn).

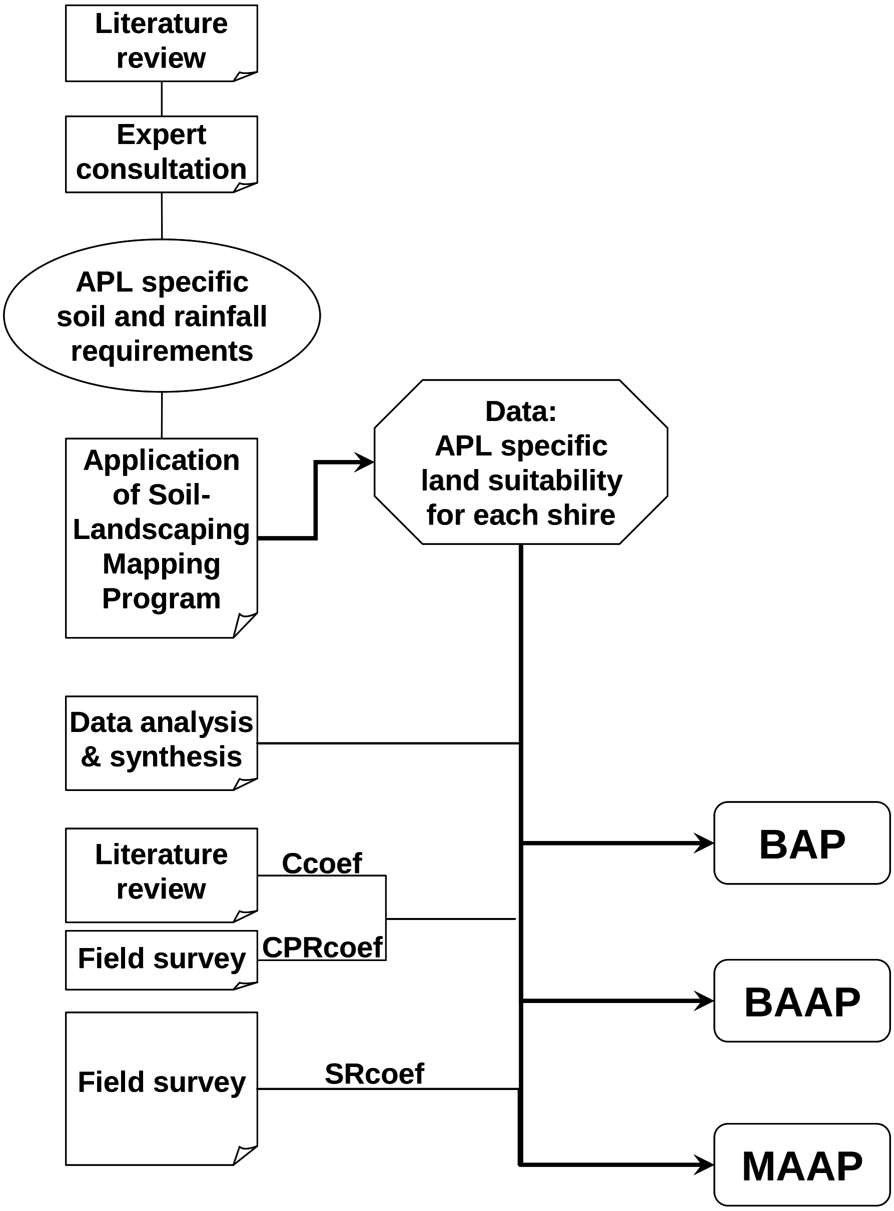
Figure 2.2: Map of Western Australian cropping-belt showing the northern, central and southern agricultural regions where this study was applied



2.3.4 Determination of adoption potentials of Cadiz and Casbah

A schematic diagram of the method applied for determining the broad adoption potential (BAP), broad attainable adoption potential (BAAP), and maximum attainable adoption potential (MAAP) of two annual pasture legumes is given in Figure 2.3.

Figure 2.3: Schematic diagram of methodology applied for determining the broad adoption potential (BAP), broad attainable adoption potential (BAAP), maximum attainable adoption potential (MAAP) of two annual pasture legumes, Cadiz and Casbah



Note: Ccoef is the proportion of cropping area within a geographic region, CPRcoef is the crop-pasture ratio within the cropping area, and SRcoef is related to the certainty of a successful pasture-growing season.

Broad adoption potential (BAP)

The broad adoption potential (BAP) is defined in this study as the agricultural land where an APL can be grown on the basis of its 'suitability to the land' (referred to as land suitability hereafter) and requirement for annual rainfall. The land suitability is a range of attributes, designated in the land evaluation standards, related to soil characteristics (van Gool, Tille & Moore 2005).

Previously, van Gool, Tille and Moore (2005) assessed the land capability for grazing sheep and cattle on broad-scale, non-irrigated land in the agricultural areas of Western Australia and proposed a generic land suitability table for pastures. This was used in this study as a reference to estimate the land suitability for Cadiz and Casbah. The reference land suitability table for pastures included 19 attributes and ratings for each attribute. In this study, 10 attributes of land quality were chosen by modifying the reference table. The land suitability attributes and their ratings used in this study are presented in Table 2.1. Table 2.2 describes the symbols, together with their units and values where applicable, used in Table 2.1. A short description of the attributes is given below.

Table 2.1: Attributes and their ratings[a]

Land suitability attribute	Rating
1. Waterlogging	N(w)-VL(w)-L(w)-M(w)-H(w) → Reference[b]
	N(w)-VL(w)-L(w)-M(w) → Cadiz
	N(w)-VL(w)-L(w) → Casbah
2. Soil water storage	L(sws)-ML(sws)-M(sws)-H(sws) → Reference
	VL(sws)-L(sws)-ML(sws)-M(sws)-H(sws) → Cadiz and Casbah
3. Soil pH (surface)	Vsac-Sac-Mac-Slsac-N-Malk-Salk → Reference
	Vsac-Sac-Mac-Slsac-N → Cadiz
	Sac-Mac-Slsac-N-Malk→ Casbah
4. Soil pH (sub-surface)	Sac-Mac-Slsac-N-Malk-Salk→ Reference
	Vsac-Sac-Mac-Slsac-N→ Cadiz
	Sac-Mac-Slsac-N-Malk→ Casbah
5. Salt spray exposure	N(slt)-S(slt) → Reference
	N(slt) → Cadiz and Casbah
6. Rooting depth	VD(r)-D(r)-M(r)-MS(r)-S(r) → Reference
	Same as reference→ Cadiz and Casbah
7. Surface soil condition	C(ss)-F(ss)-K(ss)-L(ss)-S(ss)-SM(ss) → Reference
	Same as reference→ Cadiz and Casbah
8. Soil workability	VP(wrk)-P(wrk)-F(wrk)-G(wrk) → Reference
	P(wrk)-F(wrk)-G(wrk) → Cadiz and Casbah
9. Soil surface texture	Not applicable→ Reference
	SS(st)-KS(st)-S(st)-VWCKS(st) → Cadiz
	KS(st)-S(st)-VWCKS(st) → Casbah
10. Soil profile permeability	Not applicable→ Reference
	MS(pp)-M(pp)-MR(pp)-R(pp)-VR(pp) → Cadiz and Casbah

[a] Adapted and/or modified from van Gool, Tille & Moore (2005) used in this study to calculate the land suitability for Cadiz and Casbah in Western Australian cropping-belt. Refer to Table 2.2 for description of ratings.

[b] Reference adapted from land suitability of pastures (van Gool, Tille & Moore (2005). Cadiz and Casbah have been compared against the reference value.

Table 2.2: Description of symbols, units and values used to calculate the land suitability for Cadiz and Casbah in Western Australian cropping-belt (Table 2.1)

Attribute	Symbol	Explanation	Unit	Value
Waterlogging	N(w)	Never waterlogged	day	0
	VL(w)	Very low waterlogging	day	<1
	L(w)	Low waterlogging	day	<2
	M(w)	Moderate waterlogging	day	<8
	H(w)	High waterlogging	day	<60
Soil water storage	VL(sws)	Available water capacity of top 100 cm soil is very low	mm/m	<35
	L(sws)	Available water capacity of top 100 cm soil is low	mm/m	35-70
	ML(sws)	Available water capacity of top 100 cm soil is moderately low	mm/m	70-100
	M(sws)	Available water capacity of top 100 cm soil is moderate	mm/m	100-140
	H(sws)	Available water capacity of top	mm/m	>140
Soil pH	Vsac	Very strongly acid soil	-	<4.2
	Sac	Strongly acid soil	-	4.2-4.5
	Mac	Moderately acid soil	-	4.5-5.0
	Slsac	Slightly acid soil	-	5.0-5.5
	N	Neutral soil	-	5.5-7.0
	Malk	Moderately alkaline soil	-	7.0-8.0
	Salk	Strongly alkaline soil	-	>8.0
Salt spray exposure	N(slt)	Land not exposed to regular ocean winds that spray salts to plant	-	-
	S(slt)	Land exposed to regular ocean winds where salt spray is a recurring problem leading to regular plant damage	-	-
Rooting depth	VD(r)	Very deep rooted	cm	>150
	D(r)	Deep rooted	cm	80-150
	M(r)	Moderate rooted	cm	50-80
	MS(r)	Moderately shallow rooted	cm	30-50
	S(r)	Shallow rooted	cm	15-30
Surface soil condition	C(ss)	Soil surface crust is the distinct surface layer, often laminated, up to tens of mm thick which is hard and brittle when dry and is not easily separated from underlying soil	-	-
	F(ss)	Soil surface is firm which is the coherent mass of individual particles or aggregates; surface disturbed or indented by moderate pressure of forefinger	-	-
	K(ss)	Soil surface cracking is the cracks at least 5 mm wide extending from the surface to the base of any plough layer or thin surface horizon	-	-
	L(ss)	Soil surface condition is loose which can easily be disturbed by pressure of forefinger	-	-
	S(ss)	Soil surface condition is soft which can easily disturbed by pressure of forefinger	-	-
	SM(ss)	Soil surface condition is self-mulching which designates the strongly pedal surface mulch forms on wetting and drying. Pedals are commonly less than 5 mm in least dimension	-	-
Soil workability	VP(wrk)	Ease with which soil can be cultivated for cropping is very poor	-	-
	P(wrk)	Ease with which soil can be cultivated for cropping is poor	-	-
	F(wrk)	Ease with which soil can be cultivated for cropping is fair	-	-
	G(wrk)	Ease with which soil can be cultivated for cropping is good	-	-
Soil surface texture	SS(st)	Light sand with <2% clay	-	-
	KS(st)	Coarse sand with <8% clay	-	-
	S(st)	Sand with 2-5% clay	-	-
	VWCKS(st)	Very weak clayey coarse sand with 2-4% clay	-	-
	WCS(st)	Very weak clayey sand with 2-4% clay	-	-
Soil profile permeability	MS(pp)	Moderately slow permeability of soil profile (0-50 cm) as a measure of hydraulic conductivity	mm/h	5-20
	M(pp)	Moderate permeability of soil profile (0-50 cm) as a measure of hydraulic conductivity	mm/h	20-65
	MR(pp)	Moderately rapid permeability of soil profile (0-50 cm) as a measure of hydraulic conductivity	mm/h	65-130
	R(pp)	Rapid permeability of soil profile (0-50 cm) as a measure of hydraulic conductivity	mm/h	130-250
	VR(pp)	Very rapid permeability of soil profile (0-50 cm) as a measure of hydraulic conductivity	mm/h	>250

Waterlogging: Cadiz can tolerate short periods of waterlogging but not inundation (Nutt, Loi & Revell 2009), whereas Casbah does not tolerate waterlogging or inundation (Loi, Howieson & Carr 2001). Accordingly, the reference waterlogging ratings were modified for Cadiz (waterlogging tolerance limit <2 days) and Casbah (waterlogging tolerance limit <8 days) (Angelo Loi, pers. comm. 2007) (Table 2.1).

Soil water storage: The soil water storage is the amount of water that can be stored to make available for plant water use. Here the soil water storage is defined as the difference between upper storage limit (i.e. field capacity) and the lower storage limit (i.e. wilting point), summed over the upper 100 cm of the soil profile or the rooting depth, whichever is less. Casbah seedlings can survive short periods of drought, comparatively much better than most other temperate APLs; plant survivability is also good under long periods of drought (Loi, Howieson & Carr 2001). The same is also true for Cadiz, as both have a similar root system (Nutt, Loi & Revell 2009). Therefore, the reference rating was modified to include suitability of both the APLs under very low soil water storage (available water capacity <35 mm/m) conditions (Table 2.1).

Soil pH: As has been described in the notes on the APLs (Loi, Howieson & Carr 2001; Nutt, Loi & Revell 2009), the surface pH (in CaCl2) at 0-10 cm was considered in the range of 4 to 7 for Cadiz and 4.5 to 8 for Casbah. There was no mention of subsurface pH in the literature so it was assumed similar to surface pH (Angelo Loi, pers. comm. 2007).

Salt spray exposure: This indicates exposure of land to salt spray drift from the ocean. The salt is carried in the wind and can harm plant growth and affect land capability for a range of agricultural uses. In this study those lands that are not exposed to salt spray were selected as suitable for Cadiz and Casbah.

Rooting depth: Rooting depth is the depth to the layer within the soil where the growth and penetration of the majority of plant roots are restricted. This assessment of rooting depth considers the physical restrictions including the presence of watertables. It excludes chemical restrictions that can be detected using other land qualities. As both the APLs under study can grow in a wide range of soil layers, the rooting depth chosen ranged from shallow (15 - 30 cm) to very deep (>150 cm) (van Gool, Tille & Moore 2005).

Soil surface condition: Surface condition describes the physical state of the soil surface. Reference ratings were used (Table 2.1) for both the APLs which include six soil surface conditions as suitable; cracking, surface crust, firm, loose, soft and self mulching (Table 2.2). It did not include conditions like saline and hardsetting.

Soil workability: This refers to the ease with which soil can be cultivated for cropping assuming the use of a tractor and plough and 10-15 cm depth of tillage. Machinery trafficability is included in this assessment, as tractor access is normally required for cultivation. Rocks and large stones on or near the surface make cultivation difficult and can damage machinery. Small surface stones and rocks can be pushed into heaps in many areas so they do not hinder cultivation. Heavy soils can also be hard to work, especially if they are sodic. For Cadiz and Casbah, three ratings of soil workability were selected – good, fair and poor (Table 2.1 and 2.2), and excluded the very poor rating.

Soil surface texture: Surface texture refers to the proportion of sand, silt and clay in the top 10 cm of the soil profile. Five attributes used previously (surface soil structure decline, wind erosion, subsurface compaction, trafficability and water erosion) well combined into this attribute, as van Gool, Tille & Moore (2005) mention that this attribute is determinant of many land qualities of those five. Ratings of this attribute were worked out in consultation with Mr. Brad Nutt and Dr. Angelo Loi (DAFWA) who developed Cadiz and Casbah, respectively.

Soil profile permeability: Soil permeability, measured as hydraulic conductivity, was considered in the range of 5-20 mm/h (moderately slow) to >250 mm/h (very rapid) for both Cadiz and Casbah. Slow or very slow permeable classes (hydraulic conductivity of <5 mm/h) were excluded. As mentioned earlier, the reference land suitability table included 19 attributes for designating suitable pasture land. 'Flood hazard' is excluded as waterlogging can describe this effect, 'salinity hazard' as surface spray exposure takes account of that, 'surface salinity' as soil surface condition includes this, 'subsurface acidification' as soil pH (sub-surface layer) can reflect that, 'land instability' as this is not a regular event, and 'phosphorus export' as this attribute is not related to land suitability with respect to the APLs under study. Besides, as already mentioned, five attributes referred to in the land suitability table were combined into one (soil surface texture).

The 'Soil-landscape Mapping Program' developed by the Department of Agriculture and Food Western Australia was used to determine the land suitability for the two APLs, based on the criteria stated above. Refer to Schoknecht, Tille and Purdie (2004) for an overview of soil-landscape mapping methods and outputs, and van Gool, Tille and Moore (2005) for an explanation of land qualities and land capability. The scale for assessing varied between shires from 25 to 625 ha per polygonal unit (Table 3.3).

The average annual rainfall requirements for the two APLs were determined for Cadiz as 400 to 700 mm and Casbah as 325 to 500 mm through literature review (Nutt & Paterson 1997, Loi, Revell & Nutt 2005) and expert consultation (Angelo Loi, pers. comm. 2007). The climate surfaces for rainfall were obtained from the Bureau of Meteorology (BoM). These are mean daily values for each month for 1961-1990 shown on 0.25 x 0.25 degree grid cells (approx. 2.5 km). The 'Soil-landscape Mapping Program' was then run with the defined rainfall requirements using the BoM climate surfaces data.

The mapped information was then prepared using Arcview 3.2 and Spatial Analyst. The gridded BoM climate information was matched to the centroid of each soil-landscape map unit by a unique identifier. Only matching grid cells were used and no attempt was made to summarise further. This information was exported to a Microsoft Access 97 database. It was then exported to Microsoft Excel to be used for further analysis, or exported back to Arcview for display (for details, see Vernon & van Gool 2006a).

The outputs of the 'Soil-landscape Mapping Program' designed for this study included the land area suitable for Cadiz and Casbah based on soil, and soil and rainfall suitability and actual total arable land area in each shire of Western Australian cropping-belt.

Broad attainable adoption potential (BAAP)

The BAAP was calculated by multiplying BAP with Ccoef and CPRcoef. The Ccoef is the proportion of cropping area within a geographic region, and CPRcoef is the crop-pasture ratio within the cropping area. The Ccoef for the three agricultural regions and the state was estimated from Australian Bureau of Statistics data (ABS 2005) and are shown in Table 2.3. The CPRcoef were estimated (Table 2.4) from a field survey data.

Table 2.3: Derivation of the proportion of cropping area within a geographic region (Ccoef) for three agricultural regions within Western Australian cropping-belt

Land use	Western Australian cropping-belt*			Western Australia
	NAR	CAR	SAR	
Grazing land (ha) (including rangelands)	3,516,451	3,118,088	3,690,447	10,324,986
Crops including hay (ha) (a)	1,918,295	3,801,311	2,167,896	7,887,502
Total agricultural land (ha) (b)	5,434,746	6,919,399	5,858,343	18,212,488
Ccoef (a/b)	0.35	0.55	0.37	0.43

Source: Calculated from ABS (2005) data
* NAR = northern agricultural region; CAR = central agricultural region; SAR = southern agricultural region

Table 2.4: Derivation of crop pasture ratio (CPR coef) for three agricultural regions of Western Australian cropping-belt

Cropping-belt*	Cropping area (ha) (a)	Pasture area (ha) (b)	CPRcoef (a/b)
NAR (24 farms)	63,843	46,966	0.42
CAR (52 farms)	129,541	86,824	0.40
SAR (27 farms)	34,302	37,198	0.52

Source: Unpublished pasture survey 2005 (Courtesy: Phil Nichols & Angelo Loi, DAFWA)
NAR = northern agricultural region; CAR = central agricultural region; SAR = southern agricultural region

Maximum attainable adoption potential (MAAP)

The MAAP was calculated by multiplying BAAP with SRcoef. The SRcoef is related to the certainty of a successful pasture-growing season. This coefficient was derived from the Climate Reliability Calculator particularly developed for this study which used knowledge-based logical rules according to Hill (1996). The climate constraints considered in the calculator were: annual rainfall, maximum and minimum temperature, the precipitation and evaporation ratio (P/E), and the difference between precipitation and evaporation in three seasons (summer, winter and spring). A certain amount of annual rainfall is an essential climatic requirement for growing an APL; however, the distribution of the rainfall throughout the growing seasons is equally important for survival and growth of the APL. With these assumptions, the Climate Reliability Calculator incorporated the following constraints:

- A season is suitable when soil moisture is not excessive (P/E < 0.50) during summer.
- A season is suitable when soil moisture is sufficient (P/E > 0.50) during winter.
- A season is suitable for growing an APL when it provides a minimum annual rainfall (400 and 325 mm for Cadiz and Casbah, respectively). However, if the soil moisture is sufficient during spring (P/E > 0.12 for Cadiz, and P/E > 0.07 for Casbah), the season will still be considered as suitable even if minimum annual rain is below the threshold.
- A season is suitable for growing an APL when it provides a maximum annual rainfall (700 and 500 mm for Cadiz and Casbah, respectively). However, if the soil moisture is not excessive, causing waterlogging, during spring (P/E < 0.59 for Cadiz, and P/E < 0.24 for Casbah), the season will still be considered as suitable even if maximum annual rain is above the threshold.

If all the above four constrains, specific to an APL, are fulfilled, then a season is designated as “suitable” for growing the APL.

Weather data (rainfall, maximum temperature, minimum temperature, and evaporation) for each shire of Western Australian cropping-belt for the period from 1960 to 2007 were gathered from the database of the Department of Agriculture and Food Western Australia. The Climate Reliability Calculator was developed in Microsoft Excel® by using the above algorithms and weather datasets. The main output of the calculator (SRcoef) is the percentage of favourable seasons (over a period of 47 years) for growing Cadiz and Casbah (Table 2.5). The Front-end of the calculator showing the climate certainty of annual pasture legumes, Cadiz and Casbah, in Carnamah shire of Western Australia is shown in Appendix 1 (Figures A 1 & A 2).

2.3.5 Statistical method for comparing adoption potentials

Two key aspects of the annual pasture legume framework were tested: the seasonal certainty and its relation with the adoption of Cadiz and Casbah, and the validity of the maximum attainable adoption potential (MAAP), the final output of the framework. Data from a field survey, partly published (Nichols et al. 2007), were used in this testing. The salient features of this pasture adoption survey are listed in Table A1. The relationship between seasonal certainty and adoption of Cadiz and Casbah (in terms of percentage of area under broad attainable adoption potential or BAAP) was tested in 16 shires using regression based statistics; here, the coefficient of determination (R^2) for the 1:1 or y = x line and the slope (m) of the regression line, which was forced through the origin, were determined. The standard error of the slope, the level of significance (P) and the number of points (n) employed in regression analysis are mentioned.

No data was available to compare directly the calculated maximum attainable adoption potential (MAAP). Given the situation, eight of the 16 shires (Dandaragan, Gingin, Greenough, Irwin, Kulin, Mukinbudin, Williams and Yilgarn) undertaken in this study, were randomly selected to estimate the coefficient for converting measured adoption into MAAP. The remaining eight shires (Carnamah, Coorow, Cunderdin, Dalwallinu, Katanning, Moora, Morawa and Ravensthorpe) were used to test overall validity of the framework with respect to MAAP. The performance of the framework was tested in two ways. Firstly, using a deviation approach (prediction minus observation) (Kobayashi & Salam 2000) by employing statistics viz., bias, root mean squared deviation (RMSD) and the coefficient of variation of the RMSD. Secondly, using ‘an envelope of acceptable precision’ around the reference zero line (when deviation between measurement and prediction is zero) as proposed by Mitchell & Sheehy (1997).

Table 2.5: The coefficient estimated for seasonal certainty in 44 shires of Western Australian cropping-belt

Shire	Seasonal certainty coefficient (SRcoef) Cadiz	Casbah
Boddington	98	76
Boyup Brook	93	83
Brookton	41	85
Carnamah	43	85
Chapman valley	78	93
Coorow	46	83
Corrigin	41	83
Cunderdin	37	85
Dalwallinu	39	76
Dandaragan	91	91
Dumbleyung	50	80
Esperance	96	67
Gingin	98	74
Gnowangerup	52	85
Goomalling	43	87
Greenough	83	93
Irwin	50	83
Jerramungup	59	76
Katanning	91	98
Kent	41	63
Kojonup	85	91
Kondinin	33	74
Kulin	33	15
Lake Grace	28	70
Mingenew	59	83
Moora	80	96
Morawa	15	65
Mukinbudin	9	43
Mullewa	24	57
Narembeen	26	65
Narrogin	89	96
Northam	74	91
Northampton	85	93
Ravensthorpe	37	72
Three springs	41	80
Toodyay	87	96
Trayning	28	70
Victoria Plains	74	93
West Arthur	93	93
Wickepin	57	91
Williams	89	96
Woodanilling	85	93
Yilgarn	28	63
York	74	93

2.4 Results and discussion

2.4.1 Broad adoption potential (BAP)

The broad adoption potential (or BAP) for Cadiz and Casbah across the Western Australia cropping-belt is shown in Figures 2.4 and 2.5, respectively. The BAP (in hectares) for the two APLs in each shire or council or township (as appropriate) is presented in Table A 2

(Appendix 1). Each map unit is coloured according to BAP for a pasture; the range of colour is the proportion of the area under a map unit that is agro-ecologically suitable for the pasture. Figure 2.4 shows that the BAP for Cadiz extends over wide areas of the Western Australian cropping-belt, from north to south and east to west. This probably reflects that Cadiz has a wider adaptation to a variety of soils (such as infertile, deep sands, and acidic soils) and a wide range of rainfall (CLIMA 2008).

Compared to Cadiz, the suitability of Casbah is limited, especially in the Northern and Southern Agricultural Regions (Figure 2.5). This is most likely because of survivability of Casbah is constrained by high rainfall (Loi & Nutt 2002). The maps provide visual information on potential areas for pasture adoption in Western Australia and highlight the regional and shire differences of potential pasture adoption area. Using the maps pasture researchers and extension officers can target the potential areas to improve pasture adoption.

Similar attempts were made earlier to show the potential areas for growing lupins (Vernon & van Gool 2006a), wheat (van Gool & Vernon 2005), and oats (Vernon & van Gool 2006b) in Western Australian's cropping-belt. Hill (1996) also demonstrated the potential adaptation zones for temperate pastures mainly for Southern Australia and some locations for Western Australian on the basis of climate suitability; however, he mentioned the need to incorporate data, such as soil pH, texture, moisture-holding capacity, acidity, and drainage characteristics to improve the accuracy of his system. None of those above-mentioned works quantitatively detailed the adoption potential hierarchy. Information presented here in the form of simple and easily understandable maps can benefit a number of stakeholders. For example, while information about the suitability of a pasture are delivered (Loi et al. 2000), this technique can be used to target the most suitable areas to achieve best performance from specific pastures as these have distinct preferences for soil pH, soil texture and rainfall. This information may ultimately enhance the adoption of a new pasture, because it will help pinpoint the right place for a right pasture.

Figure 2.4: The broad adoption potential area (BAP) of Cadiz in the northern, central and southern agricultural regions (refer to Figure 2.2) of Western Australia

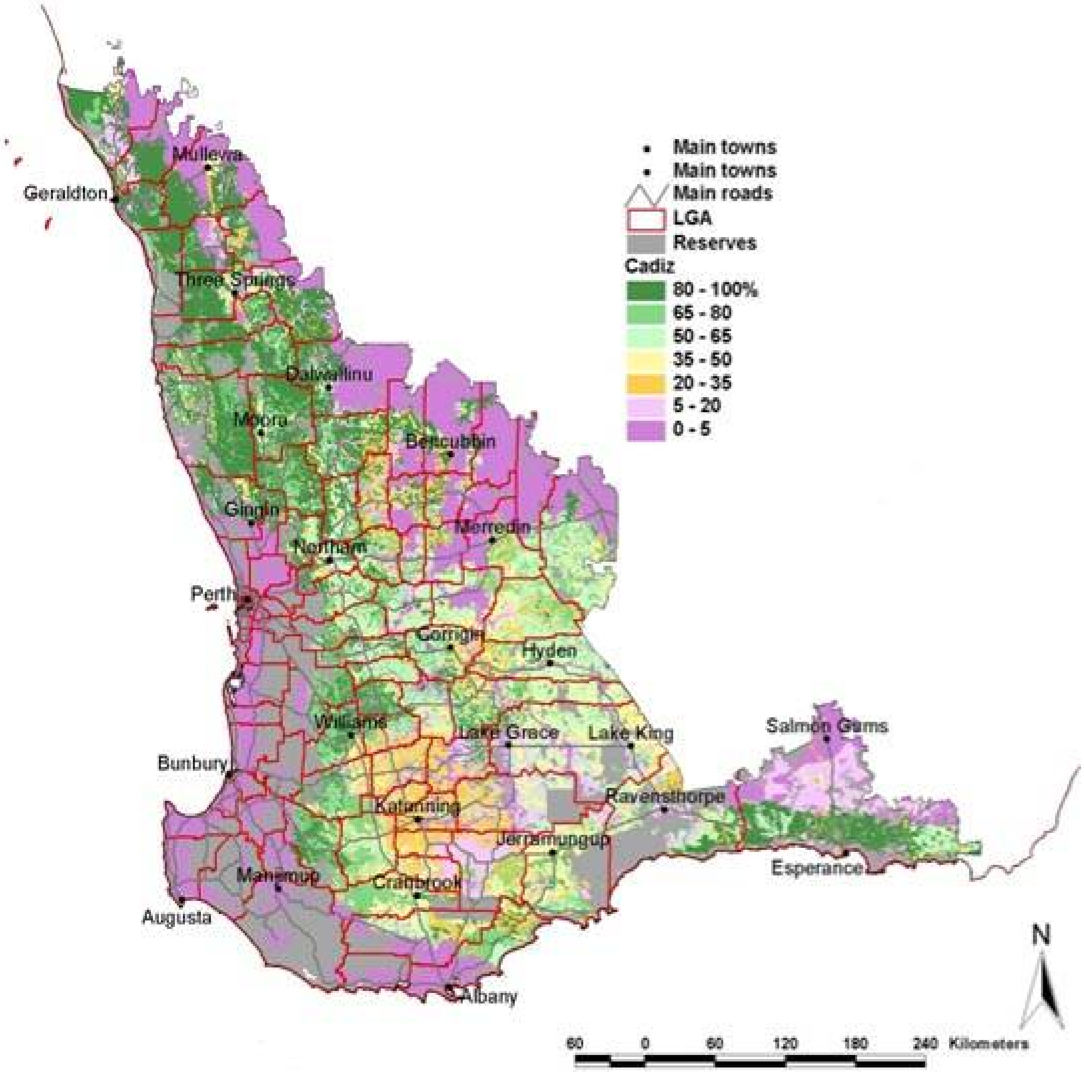
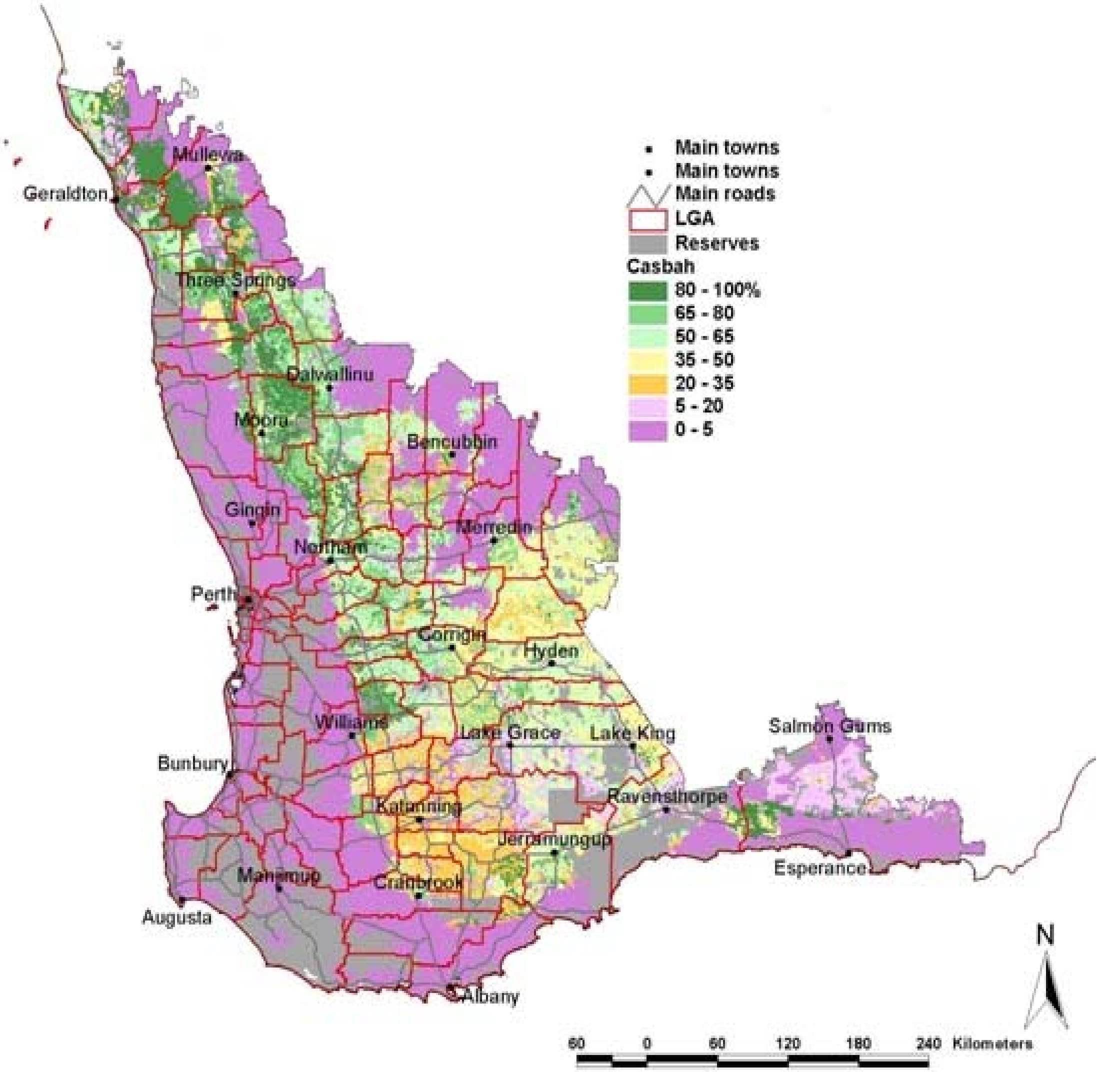


Figure 2.5: The broad adoption potential area (BAP) of Casbah in northern, central and southern agricultural regions (refer to Figure 2.2) of Western Australia



When quantified, total area under BAP for Cadiz was calculated as 9.10 M ha, this is over 48% of Western Australian cropping-belt. Table 2.6 shows, in the study area comprising of 44 shires, the BAP for Cadiz is high (70-82% of total area) in the shires of Goomalling, Boyup Brook, Williams, Greenough, Carnamah, Irwin, Victoria Plains, Moora, Three Springs, Dandaragan and Coorow and low (7-39% of total area) in Mukinbudin, Katanning, Morawa, Dumbleyung, Kent, Woodanilling, Dalwallinu, Gnowangerup, Yilgarn, Esperance and Lake Grace.

Total area under BAP for Casbah was calculated as 6.35 M ha; this accounts for about 34% of the Western Australian cropping-belt. This area is about 2.75 M ha less than the BAP for Cadiz. In none of the shires did the BAP for Casbah reach above the 75% mark. The top performing shires for Casbah (50-74% of total area) were Brookton, Mingenew, Victoria Plains, Kulin, Corrigin, Coorow, Cunderdin, Irwin, Three Springs, Greenough, Goomalling and Moora. In many shires the BAP for Casbah was low (4-24% of total area). These shires are: Williams, Mukinbudin, Dandaragan, Esperance, Kojonup, West Arthur and Ravensthorpe. On the other hand, in three shires (Boddington, Boyup Brook and Gingin) the BAP for Casbah was nil.

With respect to soil suitability alone, the adoption potential for Cadiz over Casbah was not largely different from Cadiz (Cadiz 6% greater than Casbah, data shown in Table A3). On the other hand, the combination of soil suitability and rainfall requirement showed a bigger advantage for Cadiz over Casbah of about 42% (data shown in Table A4). This indicates that the rainfall threshold is more favourable for Cadiz over Casbah, especially in the shires where rainfall is high. This is expected, since Casbah is not recommended for the areas where annual rainfall is over 500 mm as Casbah is designed to grow between 325 to 500 mm rainfall areas. Notable shires, in this study are Boddington, Boyup Brook, Dandargan, Esperance, Gingin, Kojonup, Toodyay, West Arthur and Williams. However, for adoption of a pasture at field-scale, there could be other constraints in addition to soil and rain. Thus, the BAP for Cadiz and Casbah may not be fully attainable. The second adoption hierarchy, BAAP (broad attainable adoption potential), presented below, addresses some of those issues.

Table 2.6: Land suitable for broad adoption potential (BAP), broad achievable adoption potential (BAAP) and maximum attainable adoption potential (MAAP) for Cadiz and Casbah in 44 shires of Western Australian cropping-belt

Shire	Total area (ha)	Percentage of total area					
		Cadiz			Casbah		
		BAP	BAAP	MAAP	BAP	BAAP	MAAP
Boddington	59,694	53	10	10	0	0	0
Boyup Brook	177,815	71	14	13	0	0	0
Brookton	139,585	64	14	6	50	11	9
Carnamah	182,885	74	11	5	48	7	6
Chapman valley	299,356	43	6	5	41	6	6
Coorow	271,542	82	12	6	52	8	6
Corrigin	262,994	51	11	5	52	11	9
Cunderdin	185,507	56	12	5	58	13	11
Dalwallinu	543,754	31	5	2	26	4	3
Dandaragan	392,806	82	12	11	8	1	1
Dumbleyung	237,041	29	6	3	26	5	4
Esperance	1,518,200	35	7	6	11	2	1
Gingin	149,860	57	12	12	0	0	0
Gnowangerup	370,102	33	6	3	37	7	6
Goomalling	179,875	70	15	7	67	15	13
Greenough	157,116	73	11	9	64	9	9
Irwin	131,234	76	11	6	59	9	7
Jerramungup	431,455	47	9	5	33	6	5
Katanning	141,424	27	5	5	27	5	5
Kent	432,464	29	6	2	28	5	3
Kojonup	274,592	54	10	9	14	3	2
Kondinin	379,551	48	11	3	48	11	8
Kulin	428,630	52	11	4	51	11	2
Lake Grace	806,573	39	7	2	39	7	5
Mingenew	183,190	56	8	5	50	7	6
Moora	346,810	79	12	9	74	11	10
Morawa	255,723	29	4	1	29	4	3
Mukinbudin	252,048	7	1	0	6	1	1
Mullewa	467,165	46	7	2	44	6	4
Narembeen	369,505	49	11	3	45	10	6
Narrogin	144,473	49	11	10	44	10	9
Northam	117,827	63	14	10	42	9	8
Northampton	372,331	43	6	5	40	6	6
Ravensthorpe	399,843	44	8	3	24	5	3
Three springs	222,141	80	12	5	63	9	7
Toodyay	909,89	67	15	13	26	6	5
Trayning	1,577,39	30	7	2	29	6	4
Victoria Plains	237,589	79	17	13	50	11	10
West Arthur	219,146	56	11	10	14	3	3
Wickepin	197,718	49	11	6	47	10	9
Williams	172,308	72	14	12	4	1	1
Woodanilling	106,747	31	6	5	30	6	5
Yilgarn	591,197	35	8	2	30	7	4
York	153,340	64	14	10	46	10	10
Western Australia	**18,818,633**	**48**	**9.0**	**5.3**	**34**	**6.3**	**4.8**

2.4.2 Broad attainable adoption potential (BAAP)

The total area under BAAP for Cadiz was calculated as 1.69 M ha; this accounts for about 9% of the total Western Australian cropping-belt. It is about 7.40 M ha less than what was calculated for BAP. The shires with the highest BAAP for Cadiz (ranging between 14 to 17% of total area) were Boyup Brook, Northam, Williams, Brookton, York, Toodyay, Trayning, Goomalling and Victoria Plains. On the other extreme, Mukinbudin, Morawa, Dalwallinu, Katanning, Dumbleyung, Kent, Woodanilling, Chapman Valley, Northampton and Gnowangerup were poorly suited for growing Cadiz (ranging between 1 and 6% of total area) (Table 2.6).

Total area under BAAP for Casbah was calculated as 1.18 M ha; this accounts for about 6% of the total Western Australian cropping-belt. It is about 5.17 M ha less than what was calculated for BAP. The shires with the high BAAP for Casbah (ranging between 10 and 15% of total area) were Narrogin, Narembeen, York, Wickepin, Kondinin, Moora, Brookton, Victoria Plains, Kulin, Corrigin, Cunderdin and Goomalling. On the other hand, Boddington, Boyup Brook, Gingin, Williams, Dandaragan, Mukinbudin, Esperance, Kojonup, West Arthur, Dalwallinu and Morawa were either not or poorly suitable for growing Casbah (ranging between 0 and 4% of total area) (Table 2.6).

The areas under BAAP for Cadiz and Casbah were estimated as about 81% less than the area for BAP. The difference between the BAP and BAAP was large because factors related to farming systems, in addition to soil and rainfall constraints, were incorporated in the calculation of BAAP. The farming systems factors considered in calculating BAAP were the proportion of cropping area within the geographic region, and the crop-pasture ratio within the cropping area. Such considerations are practical and justified because of the mixed farming systems in Western Australia where lands for pastures compete with cropping lands (Table 2.3). There are few reports that measure adoption potential in relation to suitable soil type and existing rotational systems for annual pasture legumes (comparable to these calculations of BAAP), nationally or for Western Australia. Abadi, Ewing & Longnecher (2001) reported Australia-wide the potential niche for Cadiz and Casbah as 3.0 and 5.0 M ha, respectively. For Western Australia, such adoption potentials were assumed to be 2.4 M ha and 0.30 M ha, respectively for Cadiz and Casbah (CLIMA 1998). Estimations from this study - Cadiz (1.67 M ha) and Casbah (1.18 M ha) – contradicted the report. It is very difficult and would not be appropriate to discuss these differences further, as the CLIMA report was based entirely on personal assumptions, not on a defined methodology.

2.4.3 Maximum attainable adoption potential (MAAP)

The total MAAP area for Cadiz was calculated as 0.99 M ha; this accounts for about 5.3% of total Western Australian cropping-belt. The shires with the high MAAP for Cadiz (ranging between 10 and 13% of total area) were Narrogin, Boddington, West Arthur, Northam, York, Dandaragan, Gingin, Williams, Boyup Brook, Toodyay and Victoria Plains. However, Mukinbudin, Morawa, Mullewa, Dalwallinu, Lake Grace, Yilgarn, Kent, Dumbleyung, Narembeen, Ravensthorpe, Gnowangerup and Kondinin were considered as poorly suitable (ranging between 0 to 2% total area) (Table 2.6).

Total area under MAAP for Casbah was calculated as 0.89 M ha; this accounts for about 4.8% of total Western Australian cropping-belt. The shires with the high MAAP for Casbah (ranging between 8 to 13%) were Narrogin, Greenough, Kulin, Irwin, Cunderdin, West Arthur, Boddington, Victoria Plains, Coorow, Brookton, Goomalling and Dandaragan. The shires Narembeen, Williams, Boyup Brook, Mukinbudin, Carnamah, Toodyay, Chapman valley, Northam, Wickepin and Kojonup were considered as less suitable (ranging between 0 to 2% total area) for growing Casbah (Table 2.6). These indicate that between the APLs, the MAAP for Cadiz is about 10% higher than Casbah. This gap between Cadiz and Casbah is much smaller compared to their BAP or BAAP. This indicates that seasonal uncertainty is a problem with Cadiz especially in the medium rainfall regions, such as the shires of Carnamah, Corrow, Morawa, Three Springs, Brookton, Corrigin, Cunderdin, Goomalling, Kondinin, Kulin, and Narembeen.

2.4.4 Validity of the framework for measuring adoption potential of annual pasture legumes in Western Australia

In structuring the framework, one question may arise on the justification for using seasonal certainty as a factor of adoption of an annual pasture legume into farming systems. It is well recognised that increasingly variable seasons, as observed in the recent decade in Australia, are likely to pose greater risks to the viability and sustainability of annual crop and pasture systems (Crossley, Tunbridge & McDonald 2009). Bishop et al. (1997) cited by Crossley et al. (2009), identified unreliability of seasons as one of the major barriers to adoption of perennial pastures in Victoria. The same could be applied for adoption of annual pasture legumes in Western Australia. The percentage of measured adoption area from the survey was used to calculate the adoption of broad achievable adoption potential (BAAP) area for Cadiz and Casbah and correlated with percentage of seasonal suitability to test whether adoption area relates to seasonal suitability. Results using this framework show a linear relationship between percentage of seasons suitable to grow and percentage of area under broad achievable adoption potential or BAAP for Cadiz and Casbah in 16 tested shires of Western Australia (Figure 2.6). This linear relationship was statistically significant for both the pastures (Cadiz: adjusted R^2 = 0.90, slope = 0.24, standard error = 0.012, P<0.001, n = 16; Casbah: adjusted R^2 = 0.91, slope = 0.23, standard error = 0.009, P<0.001, n = 16). The validity of these results was also tested under a wide range of seasonal suitability for growing both Cadiz (ranged between 9 and 98%) and Casbah (ranged between 15 and 98%). Results of this study clearly indicate a linear relationship exists between adoption of a pasture and the seasonal certainty to grow it in an environment.

2.4.5 Relationship between MAAP and actual adoption

The maximum attainable adoption potential or MAAP was higher (by about a factor of 4.25) than actual adoption for Cadiz (adjusted R^2 = 0.85). A similar relationship (about a factor of 4.37) was observed for Casbah (Figure 2.7). In other words, about 25% (calculated in this study as 23% for Cadiz and 24% for Casbah) of the area under MAAP may be converted into actual adoption. There could be a number of reasons of this; for example, a new pasture can face competition with the existing pastures for the same land. There could be individual preferences for a particular type of pasture. Previously, CLIMA (1998) assumed that Cadiz and Casbah could be adopted in 30% and 25%, respectively, of their 'area suitable for adoption' (comparable to MAAP).

Figure 2.6: Comparison between seasonal certainty and measured adoption of two annual pasture legumes, Cadiz and Casbah, in 16 shires of Western Australia

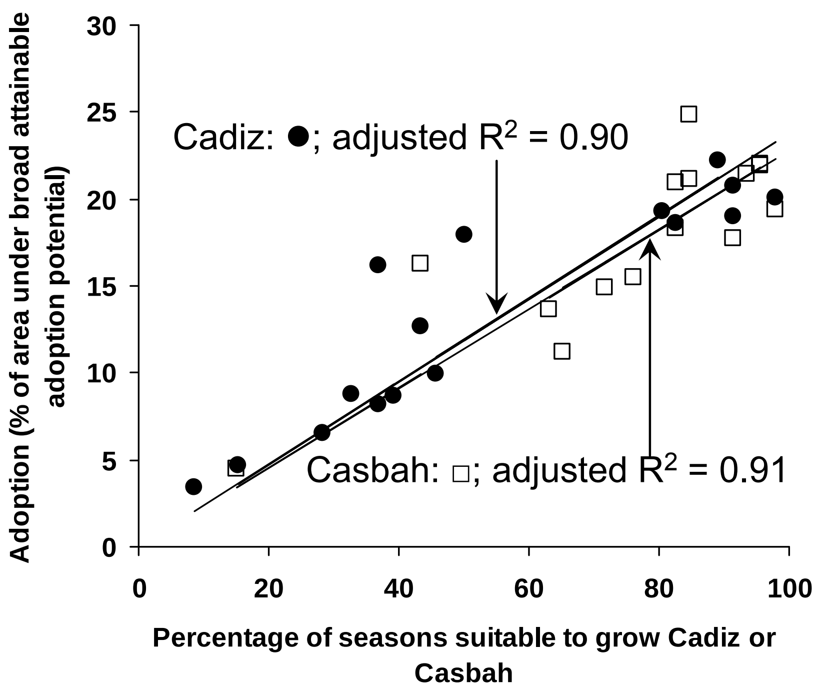
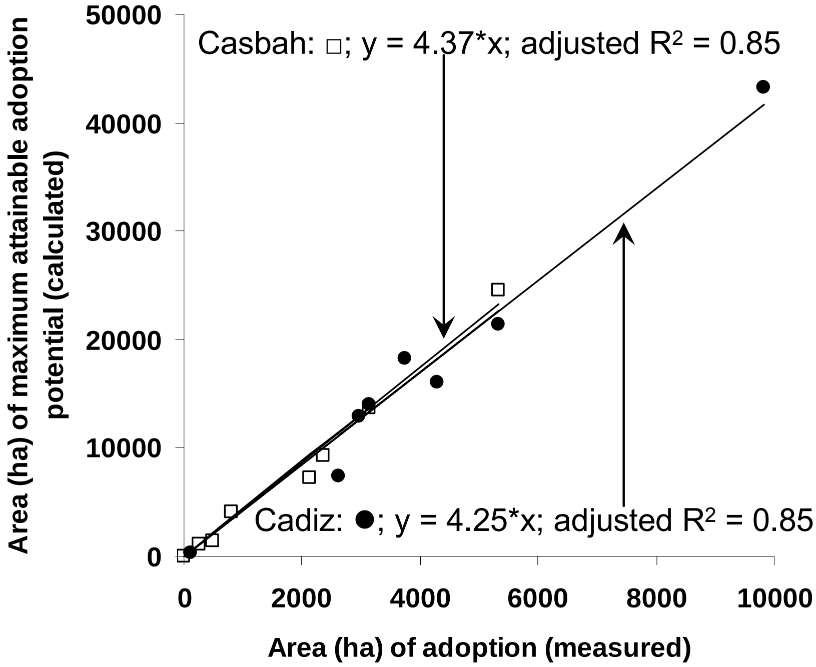


Figure 2.7: Relationship between measured adoption and calculated maximum attainable adoption potential (MAAP) of two annual pasture legumes, Cadiz and Casbah, in eight shires of Western Australia



2.4.6 Validation of MAAP

Using the coefficient for converting measured adoption into MAAP (Figure 2.7), the calculated MAAP was compared in eight shires of Western Australia using different sets of data for that used to validate MAAP. Results show the calculated MAAP mostly agreed well with the measured MAAP for both Cadiz (Figure 2.8) and Casbah (Figure 2.9), although relatively better agreement for Casbah than Cadiz.

In the studied shires, the average MAAP for Cadiz was calculated as 11,915 ha which is 894 ha less than the measured MAAP. On the other hand, the average MAAP for Casbah was calculated as 16,021 ha which is 160 ha more than the measured MAAP. The mean distance between the measured and calculated MAAP (calculated as root mean squared deviation or RMSD) was 2756 ha for Cadiz, whereas it was lower, 1645 ha, for Casbah. Compared to the average measured area of adoption of Cadiz (12,810 ha) and Casbah (15,861 ha) in eight shires of Western Australia, the RMSD values appear to be good.

Figure 2.8: Comparison between measured and calculated maximum attainable adoption potential (MAAP) of Cadiz in eight shires of Western Australia

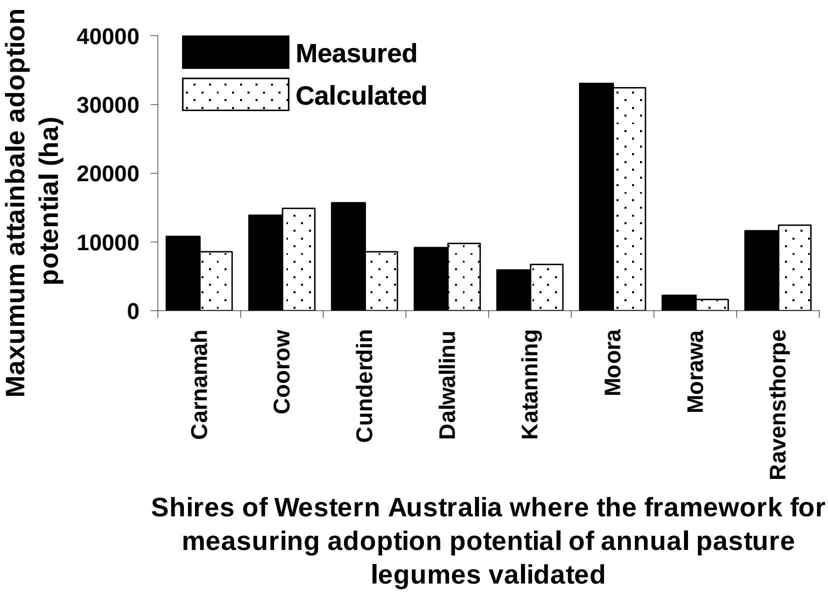
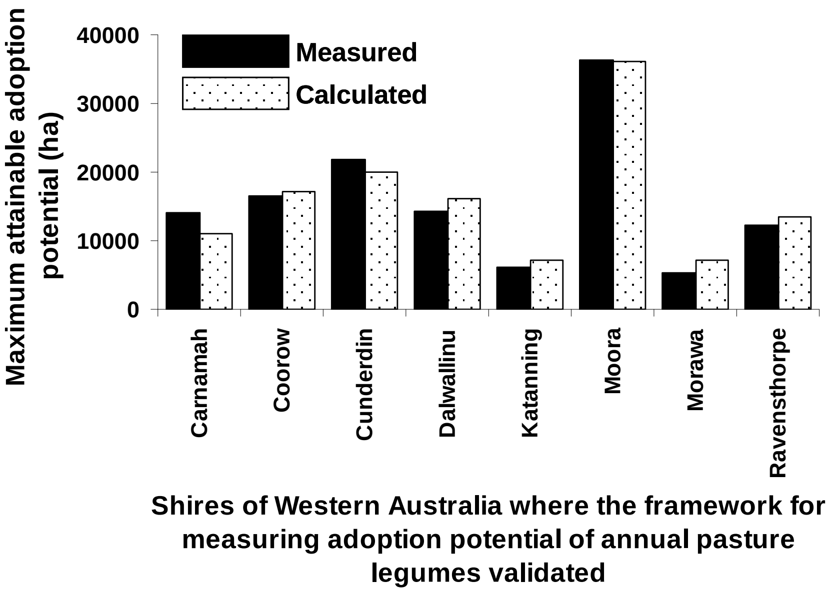
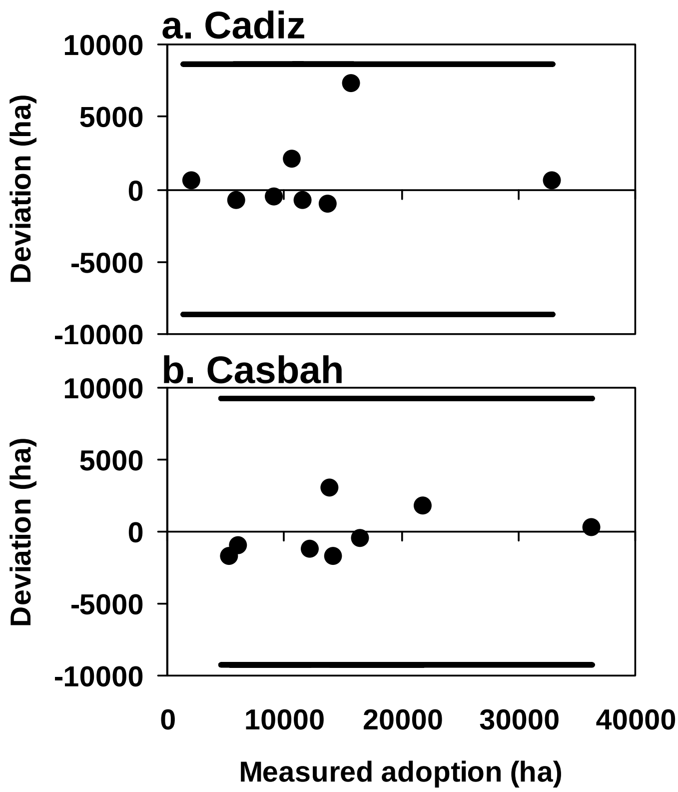


Figure 2.9: Comparison between measured and calculated maximum attainable adoption potential (MAAP) of Casbah in eight shires of Western Australia



Questions may arise regarding statistical validity of the output of the framework. We tested the validity using two approaches. Firstly, the coefficient of variation (CV) of RMSD was used. The CV (RMSD) for Cadiz was 22% and Casbah was 10%. Is a CV value of 22% acceptable? In relation to field experiments, Johnson and Welch (1939) (cited by Patel et al. 2001) mentioned that 33% has often been stated as the permissible upper fiducial limit of CV. Patel et al. (2001) worked out the fiducial limit of CV at 95% confidence for 906 field experiments using the theory of truncated t-distribution (as described by Johnson and Welch (1939); they found 23% could be considered as a yardstick for CV% for those experiments. Considering this, the value of 22% CV for Cadiz probably lies within acceptable limits. In the second approach, as suggested by Mitchell and Sheehy (1997), to judge a model's capability to predict, use an envelope of acceptable precision using standard deviation of measurements. Results using this approach indicated that the deviations were randomly scattered above and below the reference zero line both for Cadiz (Figure 2.10a) and Casbah (Figure 2.10b) and all points fell within the envelope indicating the acceptable performance of the framework for measuring the adoption potentials of annual pasture legumes in Western Australia.

Figure 2.10: Deviation of calculated maximum attainable adoption potential or MAAP from measured MAAP for two annual pasture legumes in eight shires of Western Australia.



Note: The envelope of acceptable precision (the area between two bold lines in each graph) is the standard deviation (8,626 for Cadiz and 9,255 for Casbah). The calculated MAAP is the output from the newly developed framework for measuring adoption potentials of annual pasture legumes in Western Australia

2.5 Conclusions

In this chapter, a framework has been developed for measuring adoption potentials of annual pasture legumes in Western Australia. This framework is built on a three-tier hierarchy of adoption potential. They are the broad adoption potential (BAP), the broad attainable adoption potential (BAAP) and the maximum attainable adoption potential (MAAP). The framework was applied for two annual pasture legumes, Cadiz and Casbah, to determine the BAP, BAAP and MAAP in Western Australian cropping-belt. A map showing BAP areas pinpoints the locations where a pasture is agro-ecologically suitable. This information can help a farmer think about whether to grow the pasture and an extension officer whether to put extension effort into an area. The area under BAAP for Cadiz and Casbah was calculated as 1.67 M ha and 1.18 M ha, respectively. These figures are 81% less than the calculated BAP. Total area under MAAP in Western Australian cropping-belt for Cadiz and Casbah calculated as 0.99 and 0.89 M ha, respectively. The final output of the framework, MAAP, was tested with different measured data in eight shires of Western Australia for both Cadiz and Casbah. The result show that the MAAP is acceptable. Defining the areas and locations where a pasture can potentially be adopted has a number of benefits for enhancing the adoption of a new pasture. For example, pasture researchers can target the potential locations for extension activities to achieve the best performance from the pastures; stakeholders can allocate resources to the potential areas for better pasture production; researchers can make appropriate planning decisions for trialling a pasture in a certain location.

As discussed above, the agro-ecological suitability is an important indicator for potential adoption of an annual pasture legume (APL) in a region. However, the actual adoption of the APL may vary. For example, measured (achieved) adoption of Cadiz and Casbah was 0.23 and 0.18 M ha, respectively (based on calculation detailed in Chapter 5). This shows a gap between MAAP and current adoption in Cadiz and Casbah of 77% and 80%, respectively. This may vary according to “farm circumstances”. It is the farmers who play the leading role in their “farm circumstances”. Studies indicate that successful adoption of an agricultural innovation depends on farmers’ perceptions (Adesina & Zinnah 1993, Adesina & Baidu-Forson 1995). Therefore, the following chapter investigates farmers’ perception of APL characteristics in relation to their adoption.

Chapter 3*

A ‘Dream’ pasture and its comparison with two existing annual pasture legumes for Western Australian farming systems: a farmers’ eye view*

*This chapter was developed from Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2008, ‘Pasture characteristics perceived by farmers of Western Australia in relation to adoption of annual pasture legumes’, in Proceedings of 14th Agronomy Conference, September 21-25, Adelaide, South Australia.

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Salam, K.P., Murray-Prior, R., Bowran, D. & Salam M.U. 2010, ‘A ‘Dream’ pasture and its comparison with two existing annual pasture legumes for Western Australian farming systems: a farmers’ eye view’, Livestock Research for Rural Development, vol 22, no. 9 (Sept issue).

3. A ‘Dream’ pasture and its comparison with two existing annual pasture legumes for Western Australian farming systems: a farmers’ eye view

3.1 Chapter outline

This chapter begins with the introduction why farmers’ perceptions of an annual pasture are vital for the fit of any pasture legumes in the Western Australian farming systems. The chapter details the methodology of a survey conducted for this study. It introduces a “pasture characteristics framework” that was developed from collating, analysing and synthesising of farmer survey data. The framework is used to compare the two annual pasture legumes i.e. Cadiz and Casbah and to suggest strengths and weaknesses of Cadiz and Casbah in relation to the framework. It concludes with suggestions for its future application in the pasture breeding industry.

3.2 Introduction

It is the farmers who are the ultimate decision makers on whether to select an enterprise or adopt a technology for their farms. Such decisions are made on the basis of farming circumstances or farming systems. A farming system is not merely a ‘collection of crops and animals to which one can apply to his input or that and expect immediate results. Rather, it is a complicated interwoven mesh of soils, plants, animals, implements, workers, other inputs, environmental influences with the strands held and manipulated by a person called farmer who given his preferences and aspirations, attempts to produce outputs and technology available to them. It is the farmer’s unique understanding of his immediate environment both natural and socio-economic that results in his farming systems’ (Hossain & Salam 1993, p. 5). This indicates the importance of knowing farmers’ individual understandings of a technology – its essential attributes – to fit it effectively into their systems.

Western Australia has 18.2 million hectares of arable land in its cropping-belt (ABS 2008), where the farming systems are predominantly a mixture of crops and pastures (Dolling 2006). Depending on regions, the ratio of crop and pasture varies between 0% and 50% (Salam et al. 2010b). In this system, annual pasture legumes (APLs) occupy almost 91% of total pasture (annual and perennial pasture legumes and grass) (Nichols et al. 2007). The importance of APLs in Western Australian farming systems is well recognised (Puckridge & French 1983; Kenny 1984; Loi 1999; Howieson, O’Hara & Carr 2000). This led to the development and release of increasing numbers of commercial APLs since 1990. For example, Cadiz (*Ornithopus sativus*) has been particularly developed for low fertility, acid soils (Nutt & Paterson 1997); Santorini is a cultivar of yellow serradella (*Ornithopus compressus*), which was released to enhance the uptake of serradella in medium rainfall areas (350 - 450 mm), particularly where the rainfall is greater than 400 mm (Nutt & Paterson 1998); Casbah (*Biserrula pelecinus*) is suitable for use on fine-textured soils with acidic and alkaline reactions, including sandy loams and clay loams (Loi, Revell & Nutt 2005); Frontier is a new early-maturing cultivar of Balansa clover (*Trifolium michelianum*) that has potential in low and medium rainfall (325 - 450 mm annual average) zones of Western Australia (Revell & Nutt 2001). Almost all the efforts towards development of those APLs were concentrated on agro-ecological suitability.

Agro-ecological suitability is an essential factor for optimum productivity of a crop or pasture species (Cossins 1988; Van Ittersum, Rabbing & van Latesteijn 1998; Thornton et al. 2009) therefore it plays an important role in adoption. Cadiz and Casbah, two APLs introduced in 1996 and 1997, respectively, were thought to be well adopted in the Western Australian cropping-belt (Howieson, O'Hara & Carr 2000). In the previous chapter, the maximum attainable adoption potential was calculated for Cadiz as 0.99 and Casbah as 0.89 million hectares; on the contrary their achieved adoption was estimated as 0.23 and 0.18 million ha, respectively (Salam et al. 2009a). This indicates that fitting APLs in Western Australian farming systems may require meeting 'farmers preferred attributes' in addition to their agro-ecological suitability.

Pasture Australia (2007) identified barriers that lead to modest outcomes from research and development investment on pasture. Some of the listed barriers included: poor understanding of farming system's need, absence of partnerships among researchers, farmers and other industry stakeholders.

Adoption of an innovation depends on many factors and can vary with context (Feder & Umali 1993; Rogers 2003; Pannell et al. 2006). User's perceptions of a new innovation are important in its adoption. This is evident in engineering technologies. For example, it was emphasised that pre-use expectations were important in adopting electronic messaging (Rice et al. 1990). Perceived usefulness and attitude influencing the adoption of Smartphones by health professionals in the USA has been described (Park & Chen 2007). Researchers observed that perceived risk was the inhibiting factor in adopting e-services (Pavlou 2003). In the field of agriculture, research included the testing of perceived risk as one of the several explanations for why farmers grow more than one variety of the same crop (Smale, Just & Leathers 1994). A farmer's perceived net economic benefits of an innovation are important in its adoption (Pannell et al. 2006). It is thus evident that a farmer's perception of a new innovation can be an important variable to study to understand adoption of an innovation, as has been done by others (Rogers 2003; Hintze, Renkow & Sain 2003; Adrian, Norwood &

Mask 2005). It has been emphasised that it is important to understand and assess farmers' perceived attributes of a new technology in order to achieve its successful adoption (Batz, Peters & Janssen 1999). Currently, to the best of my knowledge, there is no comprehensive documentation on characteristics of annual pasture legumes perceived by the farmers of Western Australia.

Consequently, this study was undertaken to understand the perceptions of Western Australian farmers on annual pasture legumes for their systems and thereby develop a pasture characteristics framework. The specific objectives of this study were: (i) to identify the broad attributes of APLs perceived by the farmers, and (ii) to use the pasture characteristics framework developed from these attributes to understand the adoption status of two APLs, Cadiz and Casbah.

3.3 Methodology

3.3.1 Data collection

A survey was conducted to understand Western Australian farmers' perceptions about attributes that would influence their adoption of annual pasture legumes in their farming systems. For this, an open-ended questionnaire was developed following several discussions with researchers, policy makers, agri-business experts and farming systems practitioners who were associated with pastures research and development in the state. Past experience showed that farmers were reluctant to answer lengthy questions. Therefore, the questionnaire was kept to one page to achieve the best responses from farmers. The approach of open-ended questioning was applied to understand the breadth and depth of the issues (Kendall & Kendall 2008) experienced by farmers in their environments. It has been mentioned (Patton 1990) that qualitative enquiry through open-ended questioning will allow respondents to respond in their own terms without imposing predetermined responses. One particular question was formulated in the survey questionnaire - "What is your dream pasture species?" The word "dream" was chosen here carefully to help open up the farmers' mind and to encourage speaking up about their feelings towards new APL species. Questions were also asked regarding their experiences with two APLs, Cadiz and Casbah and their strengths and weaknesses in their farming systems.

The survey was conducted during July through December 2007 by means of face-to-face interviews, personal mail-outs and general distribution of questionnaires tagged with agricultural information booklets, to achieve a larger response rate. The face-to-face interviews were conducted on two days, 29 and 30th August 2007, during the "Dowerin Field Days" (Appendix 2, Figures A 2.1 & A 2.2). The significance of this field day, as the oldest field day in Western Australia, is that it is the biggest showcase of agricultural machinery and information in the state. Farmers from different locations within and outside of the state, come to this event to exchange their views on their agricultural practices. It created an opportunity to talk with many farmers and understand their perceptions of APLs. In this step, either the questions in the questionnaire were discussed openly and freely with the farmers and the conversation was recorded, or farmers who volunteered to do so, completed the questionnaire. For personal mail outs, the mailing addresses of the farmers were collected from the database of the Department of Agriculture and Food Western Australia, and the questionnaires were mailed together with a note on project objectives and explanation of why the information was needed. They were also included with an agricultural information booklet, known as “Agricultural memos”. The Agricultural memos are distributed freely and published bi-monthly by the Department of Agriculture and Food Western Australia during the cropping season to update seasonal tactics.

3.3.2 Data analysis

Development of the pasture characteristics framework

The development of the pasture characteristics framework was essentially a qualitative analysis. In reviewing five traditions in qualitative research – biography, phenomenology, grounded theory, ethnography and case study – it was emphasised that only grounded theory leads to the creation of a theory that relates to a particular situation (Creswell 1998). Researchers also agree that the major difference between the grounded theory and other approaches to qualitative research is its emphasis upon theory development (Strauss & Corbin 1998). In the development of the pasture characteristics framework, grounded theory (Glaser and Strauss 1999) was used as the methodology. For this, farmers’ responses were sorted and broken down into distinct units of meaning. Distinct units of each respondent were compared with each other to highlight the common key points mentioned by respondents. Thereafter, key points or codes were constantly compared with each other and grouped into broader concepts at a higher, more abstract level which is referred to as categories (Pandit 2009). Categories were then grouped into broader groups of similar concepts, or “Emerging Core Variables” (Tavakol, Torabi & Zeinaloo 2006), which is referred to as a “component”. The relative strength of each emerging core variable was measured as the percent of respondents mentioning it.

Development of component-assembly for a Western Australian pasture characteristics framework

Farmers’ responses to the dream pasture question were analysed using systems approach (Spedding 1975) and synthesised into the APL characteristics framework. In many cases, farmers’ responses spread over more than one component. The component-assembly shows the various criteria and associations the farmers of Western Australia asked for in the ‘dream’ pasture. The component-assembly of the dream pasture was quantified as percent of respondents mentioning it.

Comparison of farmers’ perceptions of Cadiz and Casbah attributes with characteristics of a dream pasture

Farmers, who had previous experience with Cadiz and Casbah, also attributed characteristics to Cadiz and Casbah. Those attributions were synthesised into six components of the newly developed APL characteristics framework. Thereafter, the components (quantified as percent respondents) were compared between the dream pasture and Cadiz and Casbah. In addition, the attributes put forward by the respondent farmers as strengths and weaknesses of Cadiz and Casbah in relation to pasture characteristics were compared. Because of the sampling method, analysis method and low numbers of respondents it is not possible to analyse for statistical differences. Instead the results can be viewed as hypotheses about the differences, which would require further study to verify.

3.4 Results

3.4.1 APL-Characteristics Framework

Seventy-eight farmers voluntarily responded to the survey, representing 36 shires (Appendix 2, Figure A 2.3), out of 103 shires in the Western Australian cropping-belt. A shire is as an local government administrative unit, similar to shires as they were in the UK and equivalent to a county in the USA. Those 36 shires represented all the three broad regions in the cropping-belt, northern, central and southern agricultural regions (details of the regional division can be found in (Salam et al. 2010b).

The APL-characteristics for Western Australian farming systems derived from the study are shown in Figure 3.1. In this study, 221 responses on perceived pasture characteristics were sorted into 47 distinct responses, based on distinctness in meaning (Figure 3.1). Forty-seven responses were classified into 35 codes, which were ultimately converged into nine categories and six emerging core variables (Figure 3.1). The six emerging core variables are referred to as the components of the Western Australian pasture characteristics framework. These six components are: superiority in establishment and growth (establishment and growth (EG)), ability in supplying feed and its quality (feed supply and quality (Fsq)), improved potential in controlling weeds (weed control (W)), adaptability in broader agro-ecological horizon (adaptability (A)), tolerant of major insect-pests (insect tolerance (I)) and inexpensive (economic (E)). Establishment and growth was the most sought-after characteristic mentioned by 79% farmers (Figure 3.2), this was followed by feed supply and quality (49% farmers) and weed control (38% farmers). Adaptability was mentioned by 36%

farmers, with insect tolerance mentioned by 20% farmers. Only 15% of the respondent farmers mentioned the economic component.

Figure 3.1: Farmers' responses sorted on perceived pasture characteristics into thirty-five codes, nine categories and six emerging core variables

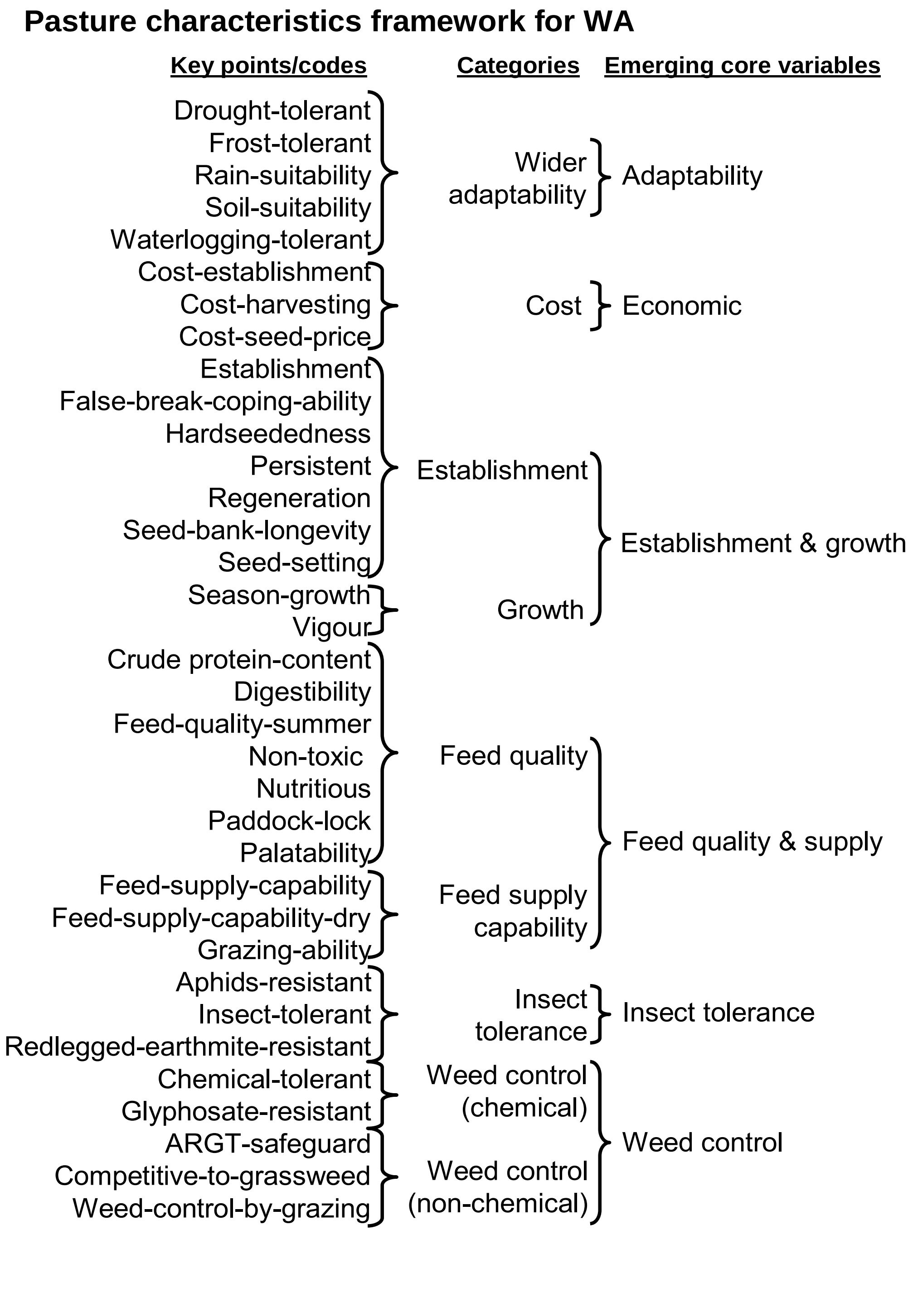
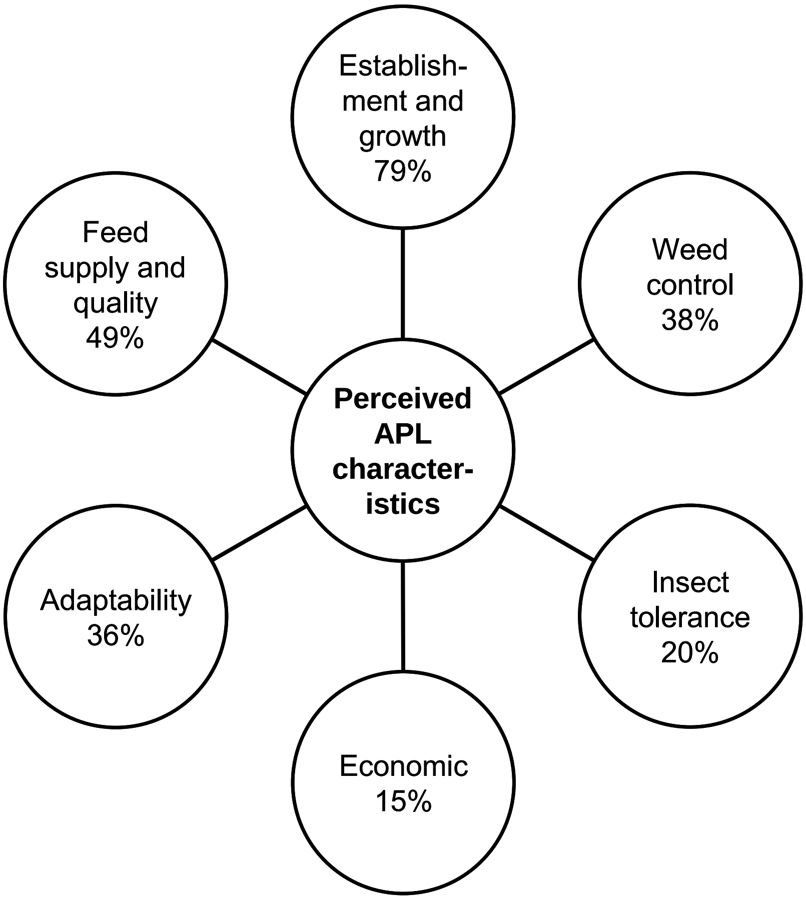


Figure 3.2: Pasture characteristics framework showing its six components. Each sought-after component shown with percentage of respondents



3.4.2 The perceived component-assembly of Western Australian pasture characteristics framework

The six components of the Western Australian pasture characteristics framework were mentioned either singly or in combination with others to give 27 different combinations of components (Table 3.1). Of those combinations, 17 (representing 79% of farmers) included the establishment and growth component either by itself or together with other components. The remaining 10 combinations (representing 21% of farmers) did not include establishment and growth. In fact, 13% of farmers' (the highest of any combination) mentioned establishment and growth as the only characteristics for their dream pasture. The next best combination, mentioned by 10% of farmers, was establishment and growth in combination with feed supply and quality, and weed control (Table 3.1).

Table 3.1: Twenty-seven combinations of the components of a 'dream pasture' for Western Australian farming systems derived from farmer responses

Component / component combination	Respondent (%)
Establishment & growth	13
Establishment & growth-Adaptation	5
Establishment & growth-Adaptation-Economic	2
Establishment & growth-Economic	3
Establishment & growth-Feed supply & quality	8
Establishment & growth-Feed supply & quality-Adaptation	3
Establishment & growth-Feed supply & quality-Adaptation-Insect tolerance	2
Establishment & growth-Feed supply & quality-Economic	3
Establishment & growth-Feed supply & quality-Insect tolerance	2
Establishment & growth-Feed supply & quality-Weed control	10
Establishment & growth-Feed supply & quality-Weed control-Adaptation	5
Establishment & growth-Feed supply & quality-Weed control-Adaptation-Insect tolerance	3
Establishment & growth-Feed supply & quality-Weed control-Adaptation-Insect tolerance-Economic	2
Establishment & growth-Feed supply & quality-Weed control-Insect tolerance	3
Establishment & growth-Insect tolerance	3
Establishment & growth-Weed control	7
Establishment & growth-Weed control-Adaptation	5
Adaptation	2
Adaptation-Insect tolerance	2
Economic	3
Feed supply & quality	2
Feed supply & quality-Adaptation	3
Feed supply & quality-Adaptation-Insect tolerance	2
Feed supply & quality-Economic	2
Insect tolerance	3
Weed control	2
Weed control-Adaptation	2

3.4.3 Strength and weakness of Cadiz and Casbah

Fifty-nine percent of farmers mentioned that Casbah was hard-seeded in their farming systems, but this was not mentioned for Cadiz (Table 3.2). More farmers mentioned hard-seededness in Casbah than for the dream pasture (28% farmers expressed their need for this attribute together with early germination).

Farmers had divided opinions about the reliability of regeneration with both Cadiz and Casbah. About 13% of farmers viewed reliable regeneration as an attribute in their dream pasture, and 6-9% farmers found it in Cadiz and Casbah, whereas an almost similar percentage did not. Fifty percent of farmers mentioned that Cadiz had a weakness in coping with a 'false' break, whereas 3% farmers mentioned it as strength of Casbah. An ability to cope with a false break was mentioned by 10% of farmers, as a need in their dream pasture. A few farmers (2-3%) rated seed-setting as a strength of Cadiz and Casbah, which is much below the expectation (11% farmers) measured for dream pasture. Although, no farmers mentioned seed bank longevity as a strength of Cadiz and Casbah, 3% farmers expressed this attribute in their dream pasture; on the contrary, 2% farmers mentioned Cadiz had weakness in this attribute. A good number of farmers (22%) mentioned that Casbah had a weakness on easy establishment, slightly higher than Cadiz (15% farmers). These figures are close to what farmers desired in their dream pasture (20%). The rating on the strength of Cadiz and Casbah related to general vigour was almost similar (13-16% farmers), whereas for early vigour the rating was mixed. Six percent of farmers stated Casbah had early vigour, whereas 9% farmers mentioned it as a weakness in Casbah. No farmer mentioned persistence as a strength with either. On the contrary, 15% of farmers referred to it as weakness with Cadiz. Eleven percent of farmers cited this attribute to be included in a dream pasture.

None of the farmers mentioned that Cadiz and Casbah had good chemical tolerance in weed control. In contrast, 30% farmers wanted this attribute in their dream pasture. Competition with grass weeds was not mentioned as a strength for Cadiz and Casbah, whereas 11% farmers wanted this attribute in the dream pasture. Moreover, 8% farmers stated that Cadiz had a weakness on this attribute. On the positive side, 31% farmers found Casbah had the strength in controlling weed through grazing, whereas on the negative side, 13% farmers mentioned that Cadiz did not have this strength.

Few (3% with Casbah) farmers mentioned the ability of the APLs to supply feed through grazing compared to the expectation (10%) with the dream pasture. Almost an equally divided opinion was delivered by the farmers in relation to early feed supply of Cadiz, 15% stated it as strength and 17% as a weakness; 8% of farmers wanted this quality in their dream pasture. Cadiz had strength in late feed supply, expressed by 23% of farmers. However, few (6%) farmers expressed this as weakness in Cadiz. A few farmers (3%) mentioned that Casbah was capable of supplying dry feed for summer. An extremely large number (69%) of farmers put forward that Casbah had a toxic substance (causing photosensitisation) compared to very few with Cadiz (2% farmers). By comparison, 15% of farmers mentioned they wanted their dream pasture to be toxic-free. Casbah was regarded as slightly more nutritious than Cadiz, as expressed by 6% and 4% farmers, respectively. However, 31% farmers mentioned that their dream pasture should have good nutrients, good crude protein (CP), digestible, and good dry matter (DM).

Neither of the pastures was perceived as suitable to a wide range of soils, with only 4% and 3% of farmers stating it as strength for Cadiz and Casbah. Few (4%) farmers mentioned that Cadiz was suited to acidic soils, whereas none mentioned it for Casbah. Cadiz (10%) is perceived as better adapted to sandy soils than Casbah (3%). Nineteen percent of farmers perceive Casbah has good drought tolerance, whereas 9% did not.

Table 3.2: Strengths and weaknesses in the attributes of two annual pasture legumes, Cadiz and Casbah*

Attributes	Dream pasture	Strength		Weakness	
		Cadiz	Casbah	Cadiz	Casbah
Establishment & growth					
Hard seededness	20	-	59	-	-
Early germinating hard seededness	8	-	-	-	-
Reliable regeneration	13	6	9	8	6
False break coping ability	10	-	3	50	-
Seed setting	11	2	3	-	-
Seed bank longevity	3	-	-	2	-
Easy establishment	20	-	-	15	22
Vigour – general	28	13	16	-	3
Vigour – early	11	-	6	-	9
Growth duration – short	10	-	-	-	-
Growth duration – long	3	-	-	-	-
Persistence	11	-	-	15	-
Weed control					
Good chemical tolerant	30	-	-	-	-
Good competitive with grass weed	11	-	-	8	-
Grazing capacity to control weed	5	-	31	13	3
Safeguard for ARGT	2	-	-	-	-
Feed supply & quality					
Ability to graze	10	-	3	-	-
Early feed supply	8	15	22	17	3
Late feed supply	8	23	3	6	3
No paddock lock	5	-	-	-	-
Dry feed for summer	3	-	3	-	-
Non-toxic	15	-	-	2	69
Highly nutritious	11	4	6	-	-
Highly Palatable	10	-	-	-	3
Palatable when dry	2	-	-	4	-
Good quality dry feed over summer	2	6	-	-	-
Good CP	5	-	-	-	-
High digestible	2	-	-	-	-
Adaptation					
Suitable to wide range of soils	8	4	3	-	-
Suitable to acidic soils	3	4	-	-	-
Suitable to saline soils	3	-	-	-	-
Adapted for sandy soils	2	10	3	-	-
Drought tolerant	13	-	19	4	9
Frost tolerant	3	-	-	-	-
Waterlogging tolerant	3	-	-	-	-
Adapted for low rainfall	7	-	-	2	-
Adapted for medium rainfall	2	-	-	-	-
Insect tolerance					
Tolerant to insect damage	20	4	3	17	3
Resistant to redlegged earthmite	5	-	-	-	3
Resistant to aphids	2	-	-	-	9
Economics					
Low seed price	7	15	6	-	-
Low establishment cost	5	4	3	-	-
Low harvesting cost	3	17	3	2	9
Miscellaneous					
Good N boost/legume	-	21	28	-	-
Fitting into cropping systems	-	10	-	-	-
Wind erosion	-	-	-	4	-

* Results presented as a percentage of respondents

Farmers had divided opinions on tolerance of the APLs to insect damage. Some viewed Cadiz and Casbah as tolerant (4 % & 3%), but others (17% and 3%) said otherwise. With respect to redlegged earthmite and aphids, Casbah was rated not resistant to these pests. On economics, farmers found seed price, establishment cost and harvest cost were low for both the APLs, although some believed harvesting costs were high.

Farmers largely agreed that Cadiz (21%) and Casbah (28%,) were good legumes for boosting nitrogen for the next crops. They also found Cadiz fitted well with their cropping systems, but some had a problem with wind erosion.

3.5 Discussion

Farmers' perceptions about a specific kind of technology are based on the need for it in their farming systems. Pannell et al. (2006, p. 1408) remark, 'The core common theme from several decades of research on technology adoption is that landholder adoption of a conservation practice depends on their expectation that it will allow them to better achieve their goals. If the landholder does not perceive that goals are likely to be met, adoption will certainly not follow'. A similar message has been revealed from other studies (Adesina & Zinnah 1993, Adesina & Baidu-Forson 1995; Langyintuo & Mekuria 2005). These indicate successful adoption of an agricultural innovation depends on farmers' perceptions. Recognising this importance, this study framed the characteristics of annual pasture legumes for Western Australian farming systems, since detailed information on this was not available in the literature. Using a grounded theory approach to analyse the 221 responses of 61 farmers from 36 shires of the Western Australian cropping-belt, a pasture characteristics framework was developed that consists of six components: superiority in establishment and growth (establishment and growth), ability in supplying feed and maintaining its quality (feed supply and quality), improved potential in controlling weeds (weed control), adaptability in broader agro-ecological horizon (adaptability), tolerant of major insect-pests (insect tolerance) and inexpensive (economic).

With 79% of farmers mentioning establishment and growth, either alone (13%) or in combination with other characteristics (66%), it appears easy establishment is a high priority for farmers of Western Australia. A recent survey of farmers using similar structure and questions conducted nine months later than this study (Davis and Hogg, 2008) also revealed that establishment and growth related characteristics of annual pasture legumes were the most sought-after by the farmers of Western Australia. Current APLs require special techniques to achieve better establishment. Biserrula requires special establishment techniques i.e. topdressing, direct drilling, full seed bed preparation, sowing seed shallow in the soil and controlling weeds (Freebairn 2004). Learning all these establishment techniques can be a barrier to adoption. As a quality, hard seededness (seed coat impermeability) helps seed to germinate in favourable weather (Taylor 1993) and increases seed bank longevity for many years. Hard seededness ensures APL seeds survive in very dry summers; however, the level of hard seededness can vary and affect germination levels of an APL (Patane, Cosentino & Copani 2008). Again, lack of hard seededness of an APL (such as Cadiz) causes sensitivity to a false-break (unseasonal rain). For example, sudden and short downpours of rain during the summer cause APL seedlings to germinate. These germinated seedlings do not get adequate follow-up rain and ultimately die in hot weather. This causes low seed bank density; therefore, farmers need to re-sow to maintain adequate seed bank density. Persistence is also an important attribute of an APL which ensures plants survive droughts, heavy grazing pressure and maintain higher long-term productivity (Evans 1996). Biserrula has deep root systems, which allows it to use stored soil water and survive against drought. General vigour is also important, which ensures growth of the APL. Being long seasoned ensures an APL provides longer green feed supply for grazing animals and hay production (Sulas 2005).

Next to establishment and growth, feed supply and quality and weed control were perceived by 49% and 38% of farmers, respectively. Of the farmers who mentioned establishment and growth as a characteristic of a dream pasture, 50% also opted for feed supply and quality and 44% for weed control. Farmers' responses appeared to be in the line with two major objectives of pasture farming in Western Australia. Farmers in the cropping belt who have livestock (mainly merino sheep), need APLs that supply ample feed and maintain feed quality (i.e. sufficient dry matter, high crude protein and good digestibility and absence of toxic ingredients). Summer and autumn are crucial for livestock as feed supply and quality deteriorate by these times of year (McFarland et al. 2006). Livestock farmers want APLs that minimize the autumn and summer feed gap (Ghadim 2000) by producing a longer feed supply. Weeds are also a big problem for Western Australian farmers, particularly since some of the weeds have developed herbicide resistance, a serious production issue for Australian cropping systems (Jones et al. 2005). Annual ryegrass (*Lolium rigidum* Gaudin) and wild radish (*Raphanus raphanistrum* L) are the most widespread and economically damaging weeds in the Western Australia cropping region (Owen et al. 2007). These weeds are developing multiple or cross herbicide resistance due to continuous herbicide use (Gibson, Kingwell & Doole 2008). Some farmers grow APLs in crop rotation to control weeds. Therefore, farmers want APLs to be tolerant to chemicals, so that they can control weeds. They also want APLs to be competitive, growing faster than weeds and to persist under heavy grazing, so that they can control weeds without using chemicals.

Western Australian farmers face agro-climatic hazards; thus 36% perceived that pastures should have the ability to withstand those hazards. Therefore, farmers seek APLs adapted to suit the wide range of climatic conditions (temperature fluctuation, rainfall variation, drought, frost) and different soil types (acidic, saline, sandy) of Western Australia. For example, Australia had major droughts incidents in 1965, 1967, 1972, 1977, 1980, 1982, 1994, 2002 and regional drought incidents in 1997, 1976, 1991 and 1987. In the 2002 drought, Western Australia grain production fell 50% from normal at an opportunity cost of $1.6 billion (Stephens et al. 2003). It has been predicted that due to climate change Western Australia farm profit could be reduced by 12% towards 2030 (Kingwell and John 2003). It has also been predicted that frequency of soil-moisture-based droughts would be increased by 80% in Western Australia (Mpelasoka et al. 2008). A requirement for APLs to withstand climate variability and maintain productivity under conditions of severe climate variability is therefore highly desirable. Characteristics including: ability to cope with drought stress, short seasoned to avoid the drought period, low water requirements could be beneficial for an APL. Waterlogging is also an issue for the Western Australian farmers in some regions. For example, some of APLs (Cadiz and Casbah) do not tolerate waterlogging at all and die within 1 to 2 days after the onset of severe waterlogging (Dr Angelo Loi 2007, pers. com.).

Most farmers face biological stresses mainly from redlegged earth mite. Redlegged earth mite (*Halotydeus destructor*) is the major pest in legume pastures, costing over A$100 million annually (Ridsdill-Smith 1991). Redlegged earth mite damages seedlings and reduces plant growth, causing loss in production. It also reduces the palatability of pasture legumes, which ultimately restricts consumption of pasture legumes by livestock (Umina 2008).

Surprisingly, few farmers (15%) perceived cost as a significant component of the Western Australian pasture characteristics framework. Falconer (2008) found in her case studies that farmers of low rainfall zones adopted a dry sowing technique for APLs to cope with climate variability. Financially they did not gain much in adopting this new technique but they were happy with their decision. They believed that although the new technique did not give financial benefits directly, it saved their properties being damaged by water erosion. It is a clear indication that farmers of Western Australia are not completely rigid about the cost of technology, but rather they look for good comprehensive returns from the system that incorporates the new APL.

The responses of farmers on perceived pasture characteristics were multilayered. Most of the farmers (75%) mentioned more than one component in the pasture characteristics framework. Farmers viewed the six components of pasture characteristics framework, discussed above, in 27 options, singly or in combinations.

This study also compared Cadiz and Casbah in relation to the components of Western Australian pasture characteristics framework. Overall, Casbah appeared to be better suited than Cadiz to farmer requirements based on the pasture characteristics framework. Farmers rated Cadiz poorly on the weed control component. Cadiz is sensitive to broad-leafed herbicides, which makes it harder to control broad-leafed weeds in Cadiz stands (Nutt & Paterson 1998). Cadiz has been recorded as sensitive to Tigrex (diflufenican and MCPA), MCPA, Jaguar (diflufenican and bromoxynil), Igran (terbutryne), glyphosate and Gramoxone (paraquat) herbicides (Revell & Rose 2001; Gillam 2007).

Both Cadiz and Casbah also appear to have deficiencies in establishment and growth capability when compared to expectations of the pasture characteristics framework. There could be a number of reasons for this. Firstly, Cadiz and Casbah need a good level of land preparation before sowing. Land must be free of weeds as Cadiz and Casbah can not tolerant many herbicides, especially broad-leafed weeds. For successful establishment and growth, consecutive weed clearance programs need to be done in the year prior to sowing. Spray topping with glyphosate or paraquat (a common weed control technique) can not be used in the first year of Casbah establishment as these can decrease seed production by up to 85%. Secondly, Casbah seed must be inoculated with its unique inoculant "Biserrula Special" (Loi et al. 2005b). Thirdly, a substantial amount of fertiliser may be needed for successful establishment of Cadiz and Casbah. For example, for Casbah 150kg/ha superphosphate or super potash (5.5%P, 19.6%K) is recommended for a sandy soil (Loi et al. 2005b) and for Cadiz 120-150 kg/ha superphosphate and 200 kg/ha potash are advised for seed production (Nutt & Paterson 1997). Fourthly, a careful grazing plan, i.e. light grazing is necessary in the first year to ensure Cadiz or Casbah has good establishment and regeneration in subsequent years. Fifthly, Cadiz is a plant with soft-seed, so it germinates easily on false break, which decreases the seed bank, thus re-seeding may be necessary for re-establishment (Nutt & Paterson 1997). However, farmers of Western Australia are used to depending on regenerating pasture, such as subterranean clover and medics, which self-regenerate after the cropping phase. Re-sowing of Cadiz each year is not seen as a usual practice by farmers. Finally, a good pest management programme is often required for successful establishment of Cadiz and Casbah. Both pastures are prone to redlegged earth mite attack. Moreover, cowpea aphid and blue-green aphid are often a problem with Cadiz, whereas bud-worm may cause serious damage to Casbah. Spraying insecticides may be essential for managing these insects. These factors provide a ready explanation for why farmers are not totally satisfied with the establishment and growth attributes associated with Cadiz and Casbah.

A large number of farmers (69%) rated photosensitisation as a weakness of Casbah. Photosensitisation is like sunburn and usually affects an animal's ears, muzzle, tail and backline, where the affected areas start to swell (Loi et al. 2005a). In severe cases, there may be skin lesions, secondary infections, wool and animal losses (DAFWA 2006). However, the problem is manageable. For example, it has been advised that grazing sheep should be avoided, if possible, during spring (Loi et al. 2005) noting that young, and bare shorn animals are especially sensitive to photosensitisation (DAFWA 2006). It appears that some farmers managed the photosensitisation issue better than others. During the survey, three farmers mentioned that they had good profits from cultivating Casbah even though they faced the problem of photosensitisation. They mentioned that they knew how to deal with that the problem. For example, one farmer mentioned that 40 of his sheep were affected by photosensitisation. He had good selling price of all his sheep except the one which lost an ear (due to photosensitisation) as the shipping company did not accept that particular animal. However he was able to sell that sheep in a local market.

This study shows, as indicated by 31% farmers, that Casbah has the strength in controlling weeds through selective grazing. Animals within a short period of grazing avoid Casbah plants as it tastes bitter and prefer weeds, which is great benefit for reducing herbicide tolerant weeds, such as annual ryegrass.

Overall, both APLs have potentials and both have some weaknesses. In future research, pasture breeders can improve adoption of these APLs through correcting these weaknesses and educating farmers on tactical management issues. The pasture characteristics framework developed from this study can be used as a research guideline while developing or selecting a new pasture for Western Australian farmers.

3.6 Conclusions

The framework for annual pasture legumes for Western Australia developed in this study identified six components of pasture characteristics perceived by farmers of Western Australia as important for the adoption of annual pasture legumes. These are: superiority in establishment and growth (establishment and growth), ability in supplying quality feed (feed supply and quality), improved potential in controlling weeds (weed control), adaptability in broader agro-ecological horizon (adaptability), tolerant to major insect-pests (insect tolerance) and inexpensive (economic). It also revealed the relative importance of the components. More than three quarters of the respondent farmers viewed establishment and growth as the most critical component in the framework. This probably was a major hindrance to Cadiz and Casbah reaching close to their agro-ecological potentials (maximum attainable adoption potential for Cadiz of 0.99 and Casbah of 0.89 million hectares versus their achieved adoption 0.23 and 0.18 million hectares, respectively (Salam et al. 2010b). The adoption of Cadiz was also probably affected by its poor performance on weed management. On the other hand, the adoption of Casbah was probably constrained by the occurrence of toxicity causing photosensitisation.

There are two implications of this study. One, the framework for annual pasture legumes may be used as a tool or an indicator for understanding adoption potential of any annual future pasture legume in Western Australia. Second, the framework may act as a guide to pasture breeders while breeding or selecting a pasture for Western Australia.

The newly developed APL characteristics framework is based on the opinions of 78 volunteer farmers across Western Australian grain-belt. A further research may be carried out to test this framework on a larger sample of farmers. Since the pasture characteristics framework was developed using current perceptions of Western Australian farmers about annual pasture legumes, changes in the farming situations in future may alter the perceptions of pasture characteristics. Therefore, a periodic survey may be necessary to account for any changes in perceptions of pasture characteristics, so that the framework can be used confidently.

This chapter pin-points the attributes or characteristics of an annual pasture legume perceived by farmers of Western Australia for it to fit into their farming systems. The achievable adoption potential of an APL will then depend on how such characteristics are incorporated into the APL. The question may be raised: can the achievable adoption potential be measured in relation to APL characteristics? The following chapter explores a method for quantifying the qualitative variables of the pasture characteristics framework in order to measure the achievable adoption potential of annual pasture legumes for the Western Australian grain-belt.

Chapter 4

An empirical model to estimate achievable adoption potential of annual pasture legumes in Western Australian farming systems*

*This chapter was developed from Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2009, 'An empirical model to estimate achievable adoption potential of annual pasture legumes in Western Australian farming systems', The International Journal of Technology, Knowledge and Society, vol. 5, no. 6, pp. 43-64.

4. An empirical model to estimate achievable adoption potential of annual pasture legumes in Western Australian farming systems

4.1 Chapter outline

This chapter begins with the exploration of two widely used adoption theories, i.e. Roger's adoption diffusion theory and Technology Acceptance Model (TAM), in relation to determine the variables that can be used to quantify the adoption of a technology. After investigation of these two models and related articles, an empirical model is developed from the understanding of farmers' perceptions for an annual pasture legume in their current farming systems, outlined in the previous chapter. It details the development (which includes two components), testing and application of the model. It concludes with a summary and future application for different stakeholders.

4.2 Introduction

Over 20 new annual pasture legumes (APL) have been released in Western Australia (WA) since 1991 (Nichols et al. 2007). However, there is a lack of understanding of whether the adoption of these APLs has been successful or not because there is not an accurate technique for quantifying the adoption potential of an APL for WA farming systems. In Chapter 2, a system was outlined to determine the maximum attainable adoption potential (MAAP) of an APL considering factors such as soil and rainfall requirements, proportion of cropping area within a geographic region, crop-pasture ratio and seasonal certainty (Salam et al. 2007; Salam et al. 2010b). The first step for calculating MAAP was to determine the broad agro-ecological suitability of an APL on the basis of rainfall and soil constraints such as pH, soil profile, soil physical and chemical properties, and waterlogging. Next, the constraints were run in the Land Resource Mapping Program (van Gool, Tille & Moore 2005). Based on this methodology, the MAAP of two APLs - Cadiz and Casbah - was determined for WA. It was observed that a significant gap existed between the MAAP and current adoption levels of these two APLs. However, it was not certain what proportion of the estimated MAAP could be achievable.

Innovation and technology characteristics have a major influence on the adoption of technologies. Two approaches, 'Diffusion of Innovations' theory (Rogers 2003) and 'TAM - Technology Acceptance Model' (Davis 1989), are frequently used to explain the spread of an 'innovation' or a 'technology'. Rogers (2003, p. 12) defines innovation as 'an idea, practice, or object that is perceived as new by an individual or other unit of adoption', whereas technology refers to 'inventions – including tools, techniques and processes – that people make and use to survive and prosper' (World Book 2003, p. 74). Rogers (2003) identified five variables that influence the adoption of innovations. They are: (i) perceived attributes of innovations, (ii) type of innovation-decision, (iii) communication channels, (iv) nature of the social system, and (v) extent of change agents' promotion efforts.

Western Australian farmers have a higher proportion of diploma or bachelor degrees than other states (ABS 2006). They have a good leadership attitude, for example, 73% of them lead the way in managing or preventing salinity, a serious constraint to agricultural productivity (ABS 2003). Australian farmers also educate themselves through formal or informal job training (Bamberry, Dunn & Lamont 1997). As a farming business is complex, farmers think of themselves as managers rather than thinking of themselves as farmers (ABS 2006). Eighty-three percent of farmers are selecting recommended cultivars from the Crop Variety Sowing Guide recommendation (Littlewood 2003, Murray-Prior et al. 2006). This indicates that the second to fifth variables of adoption are least important in relation to technology adoption in Western Australia. Therefore, the adoption of technologies may largely be determined by perceived attributes of the innovation i.e. variable one. Rogers (2003) further identified five characteristics of an innovation that influence the degree of adoption of that innovation in a social system. They are relative advantage, compatibility, complexity, trialability and observability. In TAM, the technology adoption decisions are driven by an individual's attitude towards the use of the innovation. User acceptance of different technologies is determined by perceived ease of use and perceived usefulness (Bozbay & Yasin 2008). Conceptually, the components of TAM are similar to constructs considered in 'Diffusion of Innovations' theory (Moore & Benasat 1991).

In the field of agriculture, it has been emphasised that farmers' perceptions of new technology significantly influence the adoption decision (Adesina & Baidu-Forson 1995). For example, farmers adopt a modern crop variety only when they perceive that it has more desirable characteristics than the local varieties (Langyintuo & Mekuria 2005). Pannell et al. (2006) have given a comprehensive picture of factors which influence adoption decisions about agricultural innovations, but emphasise the importance of the innovation itself (relative advantage, compatibility, complexity, trialability and observability). Pannell et al. (2006, p. 1408), analysing several decades of research on technology adoption, further remark that 'landholders' adoption of a conservation practice depends on their expectation that it will allow them to better achieve their goals. If the landholder does not perceive that goals are likely to be met, adoption will certainly not follow'. Thus, it has been strongly suggested that farmers' perceptions of technology-specific characteristics should be considered in evaluating the determinants of adoption decisions for agricultural technologies (Adesina & Zinnah 1993).

Attempts have been made to quantify the adoption of agricultural innovations in relation to characteristics of innovations as defined in the Rogers' model (Rogers 2003). On the other hand TAM has been used extensively in the field of information technology (Tornatzky & Klein 1982; Moore & Benasat 1991) but by only a few in the agricultural field (Adrian, Norwood & Mask 2005). Batz, Janssen and Peters (2003) used three characteristics of innovations - relative investment, relative complexity and relative risk – to predict the adoption of dairy technologies in Kenya. More recently, Bozbay and Yasin (2008) developed a model for predicting use of Smartphone in relation to five attributes of the innovation – relative advantage, compatibility, ease of use, results demonstrability and visibility. Bozbay and Yasin (2008) mentioned that their study was probably limited by sampling error, among other factors. On the other hand, Batz, Janssen and Peters (2003) suggested exploring other technology characteristics that might influence farmers' adoption decisions. They also suggest a combination of qualitative and quantitative approaches are needed to identify relative characteristics of a technology.

In the previous chapter, a qualitative pasture characteristics framework was developed in relation to the likelihood of adoption of an APL under WA farming systems. This framework was derived from farmers' perceptions deduced from a field survey. It would be valuable if a quantitative relationship could be established between the perceived pasture characteristics and achievable adoption potential of an APL designed for WA farming systems. A review of the literature and discussions with researchers has indicated that a model capable of quantifying the achievable adoption potential of an APL for WA farming systems has not been developed.

Prior knowledge about the likelihood of adoption of an APL, based on its intended characteristics, may be beneficial for a number of stakeholders. For example, under increasing economic constraints, funding agencies may grant project funding for breeding an APL if its adoption potential exceeds a certain limit. Senior management of research and development (R&D) organisation may want to know if a significant gap exists between current adoption and achievable adoption potential of an APL so that priorities can be set accordingly. A breeder may be interested to know the likely improvement in adoption of a proposed APL if a certain attribute is incorporated into it.

Considering the above, a simple empirical model was developed for measuring achievable adoption potential of an annual pasture legume designed for Western Australian farming systems. The aims of this chapter are to: (i) describe the model, (ii) test the model with observed adoption of two cultivars of annual pasture legume, and (iii) illustrate application of the model for improving the fit of the two APLs under Western Australian farming systems.

4.3 Methodology

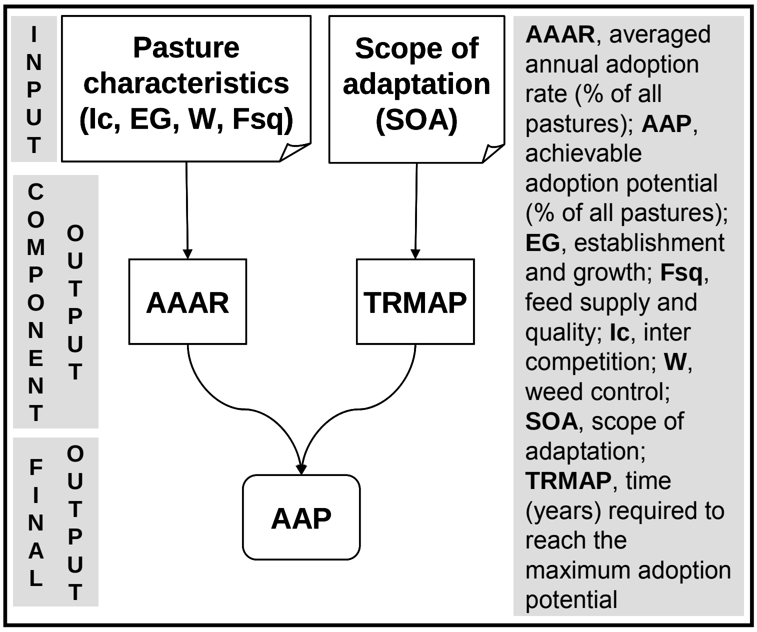
4.3.1 Model development

Figure 4.1 shows the flow diagram of the model. The model estimates the achievable adoption potential (AAP), expressed as the percentage of all annual pasture legumes sown in the Western Australian farming systems.

$$\textbf{AAP = AAAR x TRMAP} \qquad \textbf{Eq. (1)}$$

Where, AAAR is the averaged annual adoption rate (as the percentage of all pasture species/cultivars) of the APL, and TRMAP is the time, in years, required to reach the maximum adoption potential of the APL. The AAAR and TRMAP are the two components of the model. The AAAR is related to the agronomic characteristics of the APL and 'inter-competition' among the existing species factor, whereas the TRMAP is attributed to its scope of adaptation.

Figure 4.1: Schematic diagram, showing input and output sections, of the model that predicts the achievable adoption potential of any annual pasture legumes under Western Australian farming systems



Component 1: Averaged annual adoption rate (AAAR) of an APL

Two statistical methods may be employed for making predictions from data, as in the case of this study. Tree structured regressions or regression trees originated in the 1960s (Morgan & Sonquist 1963, cited by Sutton 2005) have been successfully applied for this purpose (see for example, Rovlias & Kotsou 2004). This technique is based on repeated partitioning of the dataset into more homogeneous subgroups (Vayssières, Plant & Allen-Diaz 2000) searching for combinations of values of independent variables that best predict the value of the dependent variable (Rovlias & Kotsou 2004). This technique, however, is not particularly useful when it comes to deciphering linear relationships (Rovlias & Kotsou 2004; Moisen 2008). Besides, Dusseldorp and Meulman (2001) puts forward that tree-based methods also have several shortcomings, such as they lack a formal procedure of statistical inference, and a continuous predictor variable can obtain many more possible splits than a variable with only a few categories, and therefore, may wrongly be identified as influential by the tree solution. The alternate method is multivariate analysis. This method employs several techniques that include multiple linear regression in addition to principal component regression (Pereira & Gomez 2007). In this study, the multiple linear regression technique was chosen to predict AAAR for two reasons; one, this is an exploratory phase of the research and the other, the linear relationship among the variables. Batz, Peters and Janssen (1999) and Bazbay and Yasin (2008) also considered the assumption of linearity in their studies of adoption of technologies. The AAAR is the dependent variable of a multiple regression model that consists of four independent variables. Thirteen APLs were used to develop this multiple regression model. These are Margurita, Erica, Charano, Yelbeni, Dalkeith, Nungarin, Santiago, Caliph, Mogul, Prima, Hykon, Santorini and Arrowleaf clover (Table 4.1). Pasture survey data from 125 farms of Western Australia was used to derive the value for the dependent variable (Nichols et al. 2007; Salam et al. 2008). These data showed the adoption of the 13 APLs during the cropping season of 2005 (column 4, Table 4.2), but did not directly point out what was the maximum or ceiling adoption and when it occurred. The information was not available from literature either. Therefore, further mathematical options were explored to derive ‘Maximum adoption%’ and ‘Years to reach the maximum’ (column 5 & 6, Table 4.2).

Batz, Janssen and Peters (2003) and Langyintuo and Mekuria (2005) calculated the maximum or adoption ceiling of a technology by using a logistic growth curve. This system considers estimates of three parameters (a constant term that positions the curve on the time scale, the rate or speed of the technology adoption process and the maximum or ceiling of adoption) and requires a large quantity of data to generate the estimates of the parameters, which was beyond the scope of this study. An alternative suitable option, Weibull analysis, was selected. This analysis was successfully used in many situations to measure the maximum adoption ceiling (Jansen 1992). The Weibull analysis works well with extremely small amounts of data, as in the case of the present study, and it is considered a leading method for fitting and analysing life data (Abernethy 2006); i.e. measurements of the life of products (ReliaSoft 2008). Here in this study, the annual pasture legume is considered as a product.

Table 4.1: List of the annual pasture legumes (APLs) used in model building

No	Cultivar	Common name	Scientific Name
1	Margurita	French serradella	*Ornithopus sativus*
2	Erica	French serradella	*Ornithopus sativus*
3	Charano	Yellow serradella	*Ornithopus compressus*
4	Yelbeni	Yellow serradella	*Ornithopus compressus*
5	Santorini	Yellow serradella	*Ornithopus compressus*
6	Nungarin	Subterranean clover	*Trifolium subterannean*
7	Dalkeith	Subterranean clover	*Trifolium subterannean*
8	Santiago	Annual medics	*Medicago* spp
9	Caliph	Annual medics	*Medicago* spp
10	Mogul	Annual medics	*Medicago* spp
11	Prima	Gland clover	*Trifolium glanduliferum*
12	Hykon	Rose clover	*Trifolium hirtum*
13	Arrowleaf clover	Arrowleaf clover	*Trifolium vesiculosum*

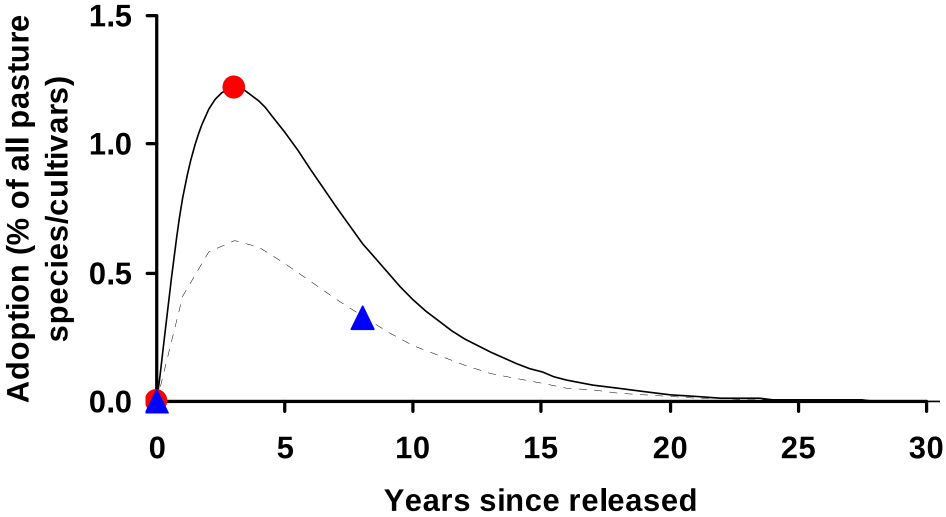
The timings of the start of adoption process or year of release of the 13 APLs were collected from literature (column 3, Table 4.2). This together with the current adoption level (column 4, Table 4.2) of these 13 APLs, derived from the survey, was used to generate adoption curves for the 13 APLs by using the 'three parameter Weibull curve fitting method' in Mathematica® Version 6.0, Wolfram Research, Inc (Appendix 3, Table A 3.1). Through the 'three parameter Weibull curve fitting method' and using two datasets i.e. year of released and measured adoption% in a year, it is possible to estimate Maximum adoption% and 'Years to reach the maximum adoption Figure 4.2, as an example, shows the generated adoption curve of two APL cultivars 'Arrowleaf clover' and 'Yelbeni'. The "Maximum adoption%" (column 5, Table 4.2) and "Years to reach the maximum adoption" (column 6, Table 4.2) were estimated from the generated curves of 13 APLs, Table 4.2 (column 6) shows the estimated maximum adoption mostly occurred around 3 years in the range between 2.5 to 11.9 years. These estimations appear to be in the line of attitudes of Western Australian farmers towards adoption for a new crop species or cultivar. For example, Ghadim et al. (1996) found that about 91% of the farmers in Western Australia would successfully grow a new legume crop within four years of its release. The adoption of new wheat cultivars during 1994-2007, as shown in Figure 4.3, also supports this. In this study, the AAAR of 13 APLs were calculated (column 7, Table 4.2) based on estimated "Maximum adoption%" and "Years to reach the maximum adoption".

Table 4.2: Current adoption* (as of 2005), and calculated maximum adoption, years to reach the maximum and averaged annual adoption rate of 13 annual pasture legumes used in the model building.

No	Annual pasture legume	Year released	Current adoption (%)	Maximum adoption (%)	Years to reach the maximum adoption	Averaged annual adoption rate
1	Margurita	2003	4.54	4.71	2.85	1.65
2	Erica	2003	2.34	2.48	2.93	0.84
3	Charano	1997	2.16	2.16	3.17	0.68
4	Yelbeni	2002	1.22	1.22	3.00	0.41
5	Santorini	1965	6.71	6.71	3.61	1.86
6	Nungarin	1976	7.34	7.34	3.14	2.34
7	Dalkeith	1995	15.84	15.84	11.94	1.33
8	Santiago	1983	0.82	1.05	3.42	0.31
9	Caliph	1988	0.43	0.85	3.13	0.27
10	Mogul	1993	0.07	0.35	3.00	0.12
11	Prima	1993	3.67	3.76	3.20	1.18
12	Hykon	2001	2.20	2.20	2.55	0.86
13	Arrowleaf	1997	0.33	0.62	3.02	0.21

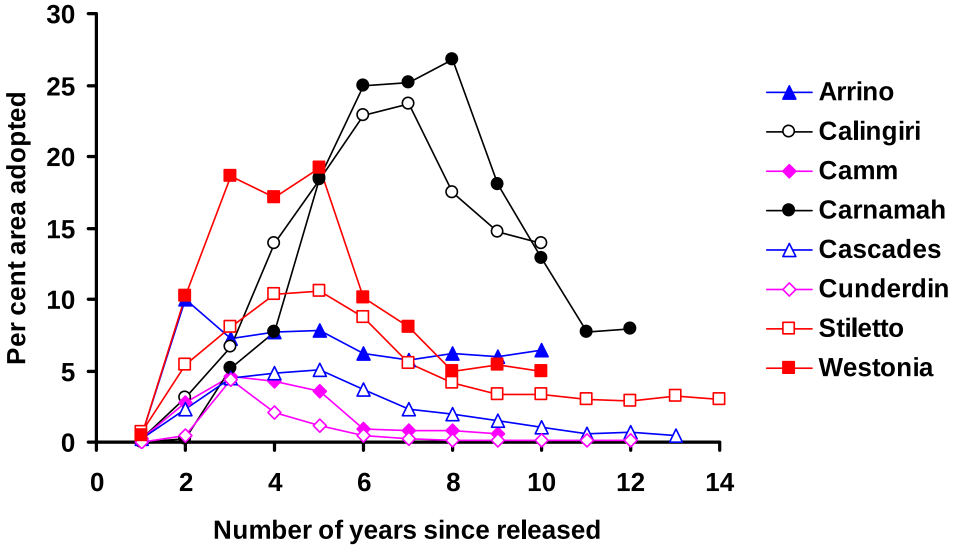
*Adoption is expressed as the percent of all pastures grown in Western Australian grain-belt. The maximum adoption and years taken to reach the maximum were calculated using Weibull method as describe in the text

Figure 4.2: The adoption curves* of two annual pasture legumes, 'Arrowleaf clover' and 'Yelbeni', being cultivated in Western Australian farming systems since 1997 and 2002, respectively



* These curves were generated by using 'three parameter Weibull curve fitting method' in Mathematica® program (version 6.0, wolfram research, inc). The symbols (filled triangle and circle) represent the measured adoption.

Figure 4.3: Years to reach peak adoption of eight selected varieties of wheat in Western Australia during the period from 1994-95 to 2007-08



The dependent variable AAAR was derived from four independent variables, which were the three important agronomic characteristics of an annual pasture legume: superiority in establishment and growth (EG), strength in controlling weeds (W) and ability to supply feed and its quality (Fsq); plus inter competition among the existing cultivars (Ic). The three agronomic characteristics (EG, W, and Fsq) were selected as independent variables based on the results from the previous chapter on pasture characteristics perceived by farmers of Western Australia in relation to adoption of annual pasture legumes (Salam et al. 2008). In that study, EG was considered as one of the most important APL characteristics perceived by 79% of the farmers followed by Fsq (49%) and W (38%). As annual pasture legumes already exist in the current farming systems of Western Australia, any new APL is likely to face competition with the existing ones. According to breeders, this sort of competition would hinder adoption of any new APL in the farming systems (Angello Loi, pers. comm. 2007). Therefore, the 'Ic' was introduced as an independent variable of the regression model to account for the level of competition. The four independent variables were represented by scores according to a scoring guide specially developed for this study (Table 4.3). There were four issues considered for designating EG (regeneration when seeds were buried in soils, regeneration when seeds stayed in soil surface, seedsetting, and persistence) and two issues each for W (tolerance to herbicides, and ability to graze in order to control weeds) and Fsq (ability to feed supply, and feed quality). For each issue of an independent variable, a score was sought in the range of 1 to 5 (Table 4.3). The scores of the independent variables in relation to 13 APLs were gathered from two pasture breeders of the Department of Agriculture and Food Western Australia and also from the literature (Table 4.4).

Table 4.3: Description of scores in relation to four independent variables of the regression model that predicts the averaged annual adoption rate (AAAR) of an APL under Western Australian farming systems

Independent Variable / Score	Description
Inter-competition among the existing APLs (Ic)	
1	Existence of few APLs resulting in no or very low competition
3	Existence of some of APLs resulting in moderate competition
5	Existence of large number of APLs resulting in severe competition
Establishment and growth (EG)	
Regeneration (seeds buried in soil)	
1	Very poor regeneration when seeds are buried in soils
3	Moderate regeneration when seeds are buried in soils
5	Excellent regeneration when seeds are buried in soils
Regeneration (seeds on surface soil)	
1	Very poor regeneration when seeds are on soil surface
3	Moderate regeneration when seeds are on soil surface
5	Excellent regeneration when seeds are on soil surface
Seedsetting	
1	Ability to set seeds is poor
3	Ability to set seeds is moderate
5	Ability to set seeds is extremely good
Persistence	
1	Poor persistence
3	Moderate persistence
5	Excellent persistence
Weed control (W)	
Herbicide tolerance	
1	No or poor tolerance to herbicides
3	Moderate tolerance to herbicides
5	Excellent tolerance to herbicides
Grazing ability to control weeds	
1	Poor grazing ability to control weed
3	Moderate grazing ability to control weed
5	Excellent grazing ability to control weed
Feed supply and quality (Fsq)	
Feed supply	
1	Poor (potential dry matter)
3	Moderate (potential dry matter)
5	Excellent (potential dry matter)
Feed quality	
1	Poor (palatability and nutritional value)
3	Moderate (palatability and nutritional value)
5	Excellent (palatability and nutritional value)

Table 4.4: Scores[a] of four pasture characteristics of 13 annual pasture legumes (APL) used in the model

No	Name of APL	Pasture characteristics			
		Inter-competition	Establishment & Growth	Weed Control	Feed Supply & Quality
		(5)[b]	(20)[b]	(10)[b]	(10)[b]
1	Margurita	5	12	7	9
2	Erica	5	10	5	8
3	Charano	4	10	3	8
4	Yelbeni	5	10	3	8
5	Santorini	4	12	7	10
6	Dalkeith	3	11	6	9
7	Nungarin	2	13	8	10
8	Santiago	3	8	3	8
9	Caliph	4	8	3	8
10	Mogul	4	8	3	8
11	Prima	5	11	6	9
12	Hykon	1	10	4	8
13	Arrowleaf clover	4	8	2	8

[a] The scores were derived from two pasture breeders of the Department of Agriculture and Food Western Australia and the literature
[b] Figures in brackets are the maximum possible score for the respective pasture characteristics i.e. Inter-competition (maximum score of 5) means existence of large number of annual pasture legumes in farming systems resulting severe competition; Establishment and Growth (maximum score of 20) means excellent regeneration of seeds buried in soil (5 score) plus excellent regeneration from seeds on surface soil (5 score) plus extremely good seedsetting (5 score) plus excellent persistence (5 score); Weed control (maximum score of 10) which includes excellent herbicide tolerance (5 score) and excellent grazing ability (5 score); Feed supply and quality (maximum score of 10) which includes excellent dry matter potential (5 score) plus excellent palatability and nutritional value (5 score).

Component 2: Time to reach the maximum adoption potential (TRMAP) of an APL

TRMAP is the scope of adaptation of an APL in the farming systems. The 'scope' is defined as how widely an annual pasture legume is suitable to ranges of soils and climate of the Western Australian cropping regions. It is hypothesised that the greater the scope of adaptation an APL has, the longer it will take to reach the peak of adoption.

$$\mathbf{TRMAP = SOAcoef \times SOA} \qquad \textbf{Eq. (2)}$$

Where, SOA is the scope of adaptation (unitless) and SOAcoef is a coefficient in relation to SOA. Eleven scales of scope were defined for any APL in Western Australian farming systems, ranging from the most restricted to absolutely wide adaptation (Table 4.5). The SOA and TRMAP of four APLs (as unavailability of all 13 APLs data) were collected from literature (Table 4.6) and used to derive the estimate of SOAcoef. TRMAP is meant to represent the duration (in years) that an adoption takes to reach the peak or ceiling. In the case of pastures in Western Australia, a value of 10 years was used to represent the ceiling adoption of all pastures (CLIMA 1998). However, this may not to be true for every pasture (Table 4.6). This is why after consulting with the pasture expert (Angelo Loi, pers. comm. 2007), the scope of adaptation concept was employed. However, the derivation of this relationship is constrained by the limited sample size, which resulted in a high correlation between TRAMP and SOA.

Table 4.5: Definition of scope of adaptation scale

Scope of Adaptation Scale	Definition
1	Most restricted adaptation
2	Largely restricted adaptation
3	Restricted adaptation
4	Moderately restricted adaptation
5	Below intermediate adaptation
6	Intermediate adaptation
7	Above intermediate adaptation
8	Moderately wide adaptation
9	Wide adaptation
10	Largely wide adaptation
11	Absolutely wide adaptation

Table 4.6: The scale of scope of adaptation and time (years) required to reach the peak of adoption for four annual pasture legumes in Western Australian farming systems

APL	Scale of scope of		Estimated adoption to peak (yrs)
	Scale	Reference	
Charano	7	Nutt and Paterson (2006a)	8
Mauro	3	Loi et al. (2006)	3
Prima	4	Nutt and Loi (2002)	4
Santorini	9	Nutt and Paterson (2006b)	10

4.3.2 Model testing

Data, published or unpublished, was not available to directly compare the achievable adoption potential (AAP) of any APL as predicted by the model. Therefore, achieved adoption of two well-known APLs of Western Australia was used to test the performance of the model (Nichols et al. 2007). These two APLs were French serradella (*Ornthopus sativus*) cultivar Cadiz and Biserrula (*Biserrula pelecinus*) cultivar Casbah. It was assumed that the adoption of Cadiz, released in 1996, and Casbah, released in 1997, would be around the peak of adoption in 2005 when the data was collected by Nichols et al. (2007). The scores of the independent variables of the AAAR component of the model were collected from two sources. One, from the breeders who developed those APLs (complied scores presented in Column 2 & 3, Table 4.7); the other, from the farmers of Western Australia through a mail-out questionnaire (Appendix 3, Figure A 3.1). Twenty-five and 18 voluntary respondents scored on the relevant independent variables of Cadiz and Casbah, respectively (complied scores presented in Column 4 & 5, Table 4.7) and were used for model testing. The data on SOA (scope of adaptation) of the TRMAP component of the model were gathered from literature and verified with the breeders who developed those APLs.

Table 4.7: Scores[a] for pasture characteristics, and scale of adaptation of two annual pasture legumes used for model testing and model prediction

Pasture characteristics, and adaptation (maximum score)	Compiled scores from breeders		Compiled scores from farmers (score ranges)	
	Cadiz	Casbah	Cadiz	Casbah
Pasture characteristics				
Inter competition (5)[b]	4	4	2-4	1-4
Establishment & growth (20)[b]	16	14	10-16	5-20
Weed control (10)[b]	6	6	2-8	2-9
Feed supply & quality (10)[b]	10	10	5-10	5-10
Adaptation				
Scope of adaptation (11)	8	6	8	6

[a] The scores are based on evaluation from two pasture breeders of the Department of Agriculture and Food Western Australia, and farmers of Western Australia (25 farmers responded on Cadiz and 18 responded on Casbah)
[b] Figure in brackets are the maximum possible score for the respective pasture characteristics i.e. Inter-competition (maximum score of 5) means existence of large number of annual pasture legumes in farming systems resulting severe competition; Establishment and Growth (maximum score of 20) means excellent regeneration of seeds buried in soil (5 score) plus excellent regeneration from seeds on surface soil (5 score) plus extremely good seedsetting (5 score) plus excellent persistence (5 score); Weed control (maximum score of 10) which includes excellent herbicide tolerance (5 score) and excellent grazing ability (5 score); Feed supply and quality (maximum score of 10) which includes excellent dry matter potential (5 score) plus excellent palatability and nutritional value (5 score).
More details on characteristics can be found in note for Table 4.4. and Table 4.5

4.3.3 Conversion of model output into adoption by agricultural land area

The adoption of an innovation especially in the field of agriculture is often expressed in relation to adopters (e.g. % farmers) or area adopted (e.g. % agricultural land). In this model, the achievable adoption potential (AAP) of an APL has been presented as the percentage of all pasture species/cultivars sown. This was done purposively, because the area under pasture in Western Australia often varies significantly between the years, not directly related to pasture species or cultivars. To present some of the results, the output of the model was derived as follows:

AAP (% agricultural land) = AAP (% all pastures) / PLCR   Eq. (3)

Where, PLCR (pasture-to-land conversion ratio) is the ratio of converting AAP as percentage of all pasture species/cultivars into AAP as percentage of agricultural land. This ratio is calculated as 15.06 based on unpublished pasture survey data for Western Australia for 2005 season.

4.3.4 Model application

The model was applied under three scenarios to show 'how' and to quantify 'to what extent' the achievable adoption potential of the two APLs, used for model testing, can be increased. These scenarios were: (i) with improved weed control potentials (W), (ii) with improved superiority in establishment and growth (EG), and (iii) with improvement on both W and EG. The scores used as model inputs to run the model under those scenarios are in Table 4.8.

Table 4.8: Input scores for two annual pasture legumes used in the model for three situations - improved weed control potentials (W+), improved superiority in establishment and growth (EG+) and improved W and EG (W+ and EG+)

Attributes[a]	**Cadiz**				**Casbah**			
	Existing[b]	**W+**	**EG+**	**W+ EG+**	**Existing**	**W+**	**EG+**	**W+ EG+**
Pasture characteristics								
Ic (5)	**4**	4	4	4	**4**	4	4	4
EG (20)	**16**	16	20	20	**14**	14	20	20
W (10)	**6**	10	6	10	**6**	10	6	10
Fsq (10)	**10**	10	10	10	**10**	10	10	10
Adaptation								
SOA (11)	**8**	8	8	8	**6**	6	6	6

[a] Ic, the inter competition among the existing cultivars; EG, the superiority in establishment and growth; W, the strength in controlling weeds; and Fsq, the ability to supply feed and its quality; scope of adaptation (SOA)
[b] The term 'existing' denotes the existing pasture attributes as scored by the breeders to represent achievable adoption potential

4.4 Results

4.4.1 Averaged annual adoption rate (AAAR) of an annual pasture legume

The influence of four pasture characteristics – the inter competition among the existing cultivars (Ic), the superiority in establishment and growth (EG), the strength in controlling weeds (W) and the ability to supply feed and its quality (Fsq) – on averaged annual adoption rate of annual pasture legumes (APLs) under Western Australian farming systems, analysed by using multiple linear regression technique, produced the model below (Eq. 4). The details of the analysis are in Table 4.9. The model had an adjusted R^2 of 0.98. This indicates that more than 98% of the total variation in the dependent variable (AAAR) was explained in the model by the combined linear function of four independent variables (Ic, EG, W & Fsq).

$$\text{AAAR} = 0.4035 - 0.105*\text{Ic} + 0.245*\text{EG} + 0.048*\text{W} + 0.311*\text{Fsq} \qquad \text{Eq. (4)}$$

The residual standard error, which measures the amount of variation in the actual data around the fitted regression, was 0.105 (n = 13 species, Table 4.9). The low residual standard error value indicates uncertainty in prediction of AAAR with this regression model was low. Also, the computed F-statistic of 133, on 4 and 8 degrees of freedom, indicates that the joint contribution of four pasture characteristics to the variation in AAAR was statistically highly significant at the 0.001 level. Therefore, in this analysis, the AAAR response of 13 annual pasture legumes to four pasture characteristics (Ic, EG, W & Fsq) can be adequately described by a multiple linear function as expressed in the equation (Eq. 4). Table 4.9 shows the contribution and significance of four individual regression terms towards explaining the AAAR. As expected, the inter competition among the existing cultivars (Ic) had a negative relationship with the averaged annual adoption rate of an APL and was significant at the 0.01 level. The other three independent variables showed a positive relationship, as hypothesised, with the AAAR. Statistically, all three were significant, EG & Fsq at the 0.001, and W at the 0.05 level (Table 4.9). This indicates that the contribution of all four pasture characteristics (Ic, EG, W & Fsq) in explaining over 98% variability in the AAAR of 13 APLs was significant.

Table 4.9: Analysis of regression of four pasture characteristics on averaged annual adoption rate (AAAR) of an annual pasture legume under Western Australian farming systems

Intercept / Independent variable*	Coefficient	t-value	Level of significance
Intercept	-4.035	-9.170	0.001
Ic	-0.105	-3.349	0.01
EG	0.245	7.164	0.001
W	0.048	2.308	0.05
Fsq	0.311	4.145	0.001

Overall statistics
R2 = 0.985; Adjusted R2 = 0.978; Residual standard error = 0.105;
Observation = 13 species; F-statistic = 133 on 4 and 8 df (degrees of freedom) significant at 0.001
F-statistic = 133 on 4 and 8 df (degrees of freedom) significant at 0.001
* Ic is the inter-competition among the existing cultivars, EG is the superiority in establishment and growth, W is the strength in controlling weeds, and Fsq is the ability to supply feed and its quality

4.4.2 Time to reach the maximum adoption potential (TRMAP) of an annual pasture legume

The effect of the scope of adaptation (SOA) on the time required to reach the maximum adoption potential (TRMAP) of an annual pasture legume under Western Australian farming systems, analysed by using simple linear regression, produced the model below (Eq. 5). The details of the analysis have been presented in Table 4.10. As a measure of goodness of fit, the model had an adjusted R^2 of 0.997 (n = 4 species). This indicates that more than 99% of the total variation in the TRMAP was explained in the model by the linear function of SOA.

$$\mathbf{TRMAP = -0.637 + 1.198 * SOA} \qquad \mathbf{Eq.\ (5)}$$

The residual standard error of the model was 0.234 and the computed F-statistic 595, on 1 and 3 degrees of freedom, was statistically significant at the 0.001 level. The computed t-statistic of the coefficient of SOA was 24.373 (standard error = 0.049). It is therefore significant at the 0.001 level. This indicates that the scope of adaptation of an annual pasture legume under Western Australian farming systems can significantly contribute in explaining the time required to reach its maximum adoption potential.

Table 4.10: Analysis of regression of scope of adaptation (SOA) on time required to reach the maximum adoption potential (TRMAP) of an annual pasture legume under Western Australian farming systems

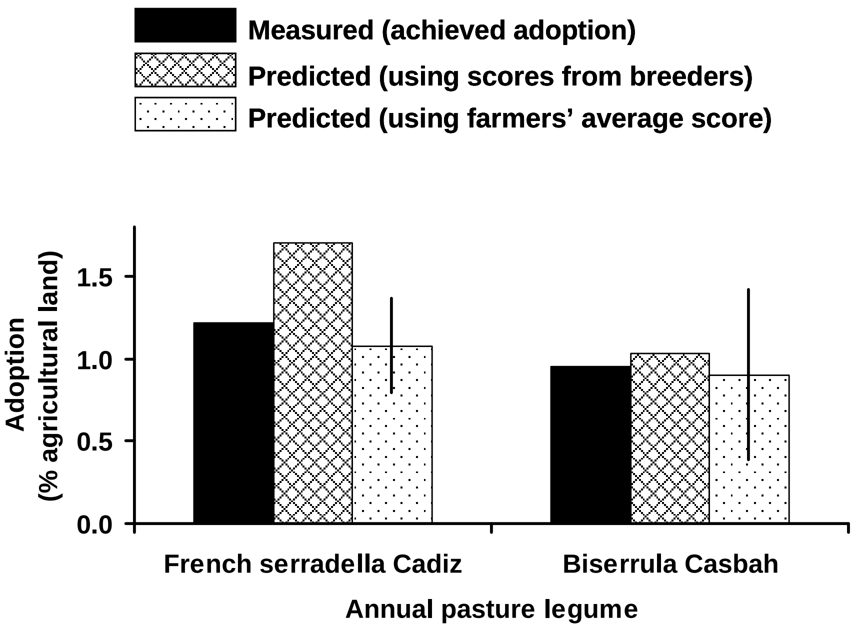
Intercept / Independent Variable	Coefficient	t-value	Level of Significance
Intercept	-0.637	-2.083	NS
SOA	1.103	24.373	0.001

Overall statistics
$R^2 = 0.997$; Adjusted $R^2 = 0.995$
Residual standard error = 0.234; Observation = 4 species
F-statistic = 595 on 1 and 3 df (degrees of freedom) significant at 0.001

4.4.3 Model testing – The achievable adoption potential (AAP) of two annual pasture legumes

The adoption of two annual pasture legumes, Cadiz and Casbah, measured during the 2005 cropping season survey was compared with the model's prediction on achievable adoption potential (AAP) under two scenarios - Scenario 1: using farmers' scores, and Scenario 2: using scores provided by two pasture breeders. In this testing, as mentioned earlier, it was assumed that the French serradella Cadiz and Biserrula Casbah were approaching the peak of adoption at the time of measurement. Figure 4.4 shows that with Scenario 1, using the farmers' inputs, the model predicted adoption potential for both of the APLs were very close to the measured data of the 2005 survey (measured 1.22% and predicted 1.08% of agricultural land for Cadiz, and measured 0.95% and predicted 0.90% for Casbah). These predictions are satisfactory, as in this scenario, farmers' averaged score was considered and there was variability between the farmers as indicated by error-bars for both the APLs. With Scenario 2, from the pasture breeders' score, the adoption was overestimated for Cadiz (measured 1.22% and predicted 1.70% of agricultural land), but was close for Casbah (measured 0.95% and predicted 1.03% of agricultural land). This result is very satisfactory as breeders' scoring is expected to be directed towards the high end of potentials. For Cadiz, that potential was not reached across the farming environments. Note, the measurement and scores for inputs were taken at different times and with different samples.

Figure 4.4: Prediction* of achievable adoption potential of two annual pasture legumes under Western Australian farming systems compared with measured adoption

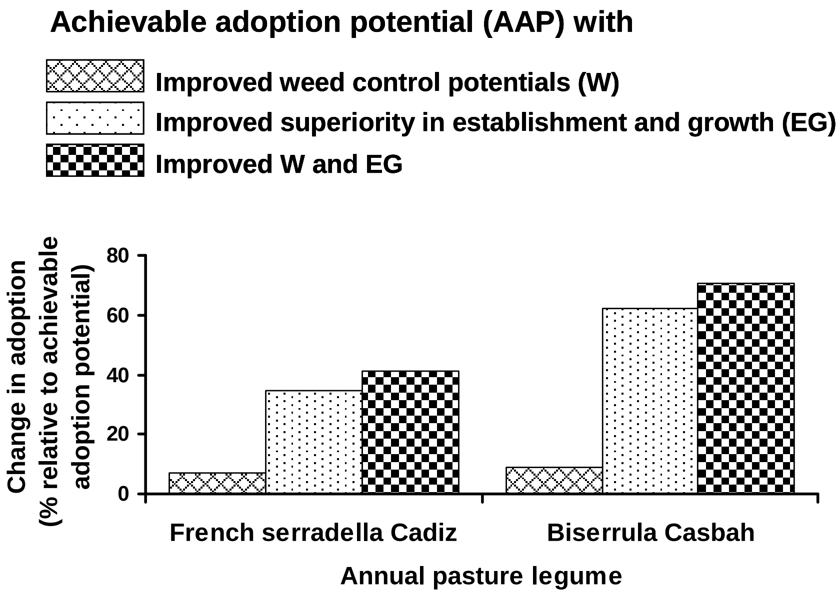


*Prediction use model with inputs from two sources, scores from breeders and farmers. Vertical line shows the standard deviation of model outputs arising from variability in farmer scores. Measured achieved adoption was derived from Nichols et al. (2007).

4.4.4 Application of the model – A guide on how to increase the achievable adoption potential (AAP) of annual pasture legumes

The model was applied to show how and to what extent the achievable adoption potential (AAP) of APLs can be increased through improving the pasture characteristics as a part of selection and/or breeding programme. Figure 4.5 shows that with improving weed control ability, the area under Cadiz may be increased by about 7% compared to AAP in relation to existing pasture characteristics. Under the same scenarios, the area under Casbah may be increased by about 9%. On the other hand, the AAP can be increased for Cadiz by about 35% and for Casbah by about 62% with improvement of establishment and growth factors in the existing cultivars. By improving weed control and establishment and growth factors, breeders may ensure the increase of the AAP of Cadiz and Casbah by about 41 and 71%, respectively.

Figure 4.5: Likely changes in achievable adoption potential of two annual pasture legumes with improvement in existing pasture characteristics – weed control potential, superiority in establishment and growth, or a combination of both



4.5 Discussion and conclusions

The results of this study indicate that the achievable adoption potential of any annual pasture legume can be estimated for Western Australian farming systems using the newly developed empirical model. The model is the product of two components, one to calculate the averaged annual adoption rate and the other to generate the time required to reach the maximum adoption potential. By regressing four pasture attributes - the inter competition among the existing cultivars, the superiority in establishment and growth, the strength in controlling weeds and the ability to supply feed and its quality – the first component explained over 98% of variability in the averaged annual adoption rate of 13 annual pasture legumes. Individually, all the four pasture characteristics significantly influenced the averaged annual adoption rate of the annual pasture legumes.

Previously, a number of studies attempted to quantify the adoption of innovations in relation to characteristics of innovations as defined in Rogers' model (Rogers 2003). The success of these attempts has generally not been encouraging. For example, three characteristics of innovations - relative investment, relative complexity and relative risk – explained only 40 to 56% of variability in predicting the adoption of dairy technologies in Kenya (Batz, Janssen and Peters 2003). In the quest of better predictability, Batz and his colleagues suggested exploring other technology characteristics which might influence farmers' adoption decisions. Biggs (1990) points out that the characteristics of a technology that reflect users' contexts play the central role in the adoption decision and diffusion process. Adesina and

Zinnah (1993) strongly suggested that farmers' perceptions of technology-specific characteristics should be considered in evaluating the determinants of adoption decisions on agricultural technologies. The unique feature of the present study is that rather than considering the generic 'characteristics of innovations' defined in Rogers' model, the perceived pasture characteristics were used as defined by the farmers for their environment, the Western Australian farming systems (Salam et al. 2008). With respect to the second component of the model, the simple linear regression of the scope of adaptation (SOA) significantly explained over 99% of the total variation on the time required to reach the maximum adoption potential of an annual pasture legume under Western Australian farming systems.

Another feature of this study is that the developed model was tested independently using inputs (scores) from breeders and farmers for two annual pasture legumes, Cadiz and Casbah. In the absence of data to directly relate to the model's output, the achievable adoption potential, the measured achieved adoption data from survey in 2005 was used for this testing. It was assumed that adoption of the two annual pasture legumes tested was reaching or nearing the maximum level at the time of measurement. Therefore, the model's predictions were expected to be around or a little above the measured values. This was closely reflected in the outputs of the models resulting from the inputs from breeders. In this scenario, prediction almost equalled the measurement for Casbah and remained slightly over for French serradella Cadiz. Using the averaged score of all respondent farmers, the models estimated very closely to the 2005 survey data for both Casbah and Cadiz. However, large variability existed between the respondent farmers, where in extreme cases prediction remained well above the measured achieved adoption. Nevertheless, it may be inferred that the model performed well in this independent testing.

Having achieved satisfactory performance of the model, it was applied in this study to highlight how it might guide researchers on how and to what extent the achievable adoption potential of annual pasture legumes could be increased through improving the pasture characteristics as a part of selection and/or breeding programme. For example, an improvement on weed control, and establishment and growth attributes in French serradella Cadiz can result in 7% and 35% increases in achievable adoption potential, respectively; combining both could increase this potential to 41%. There could be other usages of the model. For example, a funding body may wish to get an idea on the achievable adoption potential of an annual pasture legume before funding a project for pasture breeding. Senior management of a Research and Development (R&D) organisation may want to know if a significant gap exists between current adoption and achievable adoption potential of an annual pasture legume so that priorities can set accordingly to alleviate the gap. Thus, the model has been intended to be used as a research tool. But it can also be of benefit to other stakeholders.

This chapter shows that the newly developed empirical model can confidently predict the achievable adoption potential (AAP) of an APL in Western Australian farming systems. The model is run with the scores of model variables provided by individuals (breeders and farmers) as the inputs. Differences in breeders' expectations and farmers' experiences with the APLs are highlighted by the differences in their respective predictions of AAPs when their scores for the variables are used in the model. Difference in perceptions between breeders and farmers could ultimately affect the fit of APLs in Western Australian farming systems. The following chapter discusses these issues.

Chapter 5

Cadiz and Casbah pastures in Western Australia: breeders' expectation, farmers' evaluation and achieved adoption*

*This chapter was developed from Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2009, 'Cadiz and Casbah pastures in Western Australia: breeders' expectation, farmers' evaluation and achieved adoption', Extension Farming Systems Journal vol. 5, no. 1, pp. 103-112.

5. Cadiz and Casbah pastures in Western Australia: breeders' expectation, farmers' evaluation and achieved adoption

5.1 Chapter outline

This chapter elaborates the application of the frameworks developed for this project (MAAP in chapter 2, pasture characteristics framework in chapter 3 and AAP in chapter 4). With the developed framework, the chapter examines two questions: Is this the level of adoption breeders had been expecting? Do the farmers support the breeders view? The AAP model was applied to predict the adoption of Cadiz and Casbah using farmers and breeders scores on respective pasture characteristics. The chapter presents an overall framework to improve the fit of newly released annual pasture legumes in the farming systems of Western Australia. It concludes with a statement of the implications and limitations of the model.

5.2 Introduction

Pasture is an integral part of Western Australian (WA) farming systems. In the broad-scale agricultural regions of WA, pasture-crop ratios vary between 0 to 50% (Salam et al 2010b). In these areas, pasture has historically been annual regenerating legumes, practiced as ley-farming (1-2 years cropping, followed by self-regenerated pasture) (Underwood & Gladstones 1979). Two pasture species, i.e. subterranean clover and annual medics, had been dominant in traditional ley-farming. The constraints of subterranean clover and annual medics in WA farming systems have been widely documented. For example, subterranean clover is suitable for acidic soils and areas with annual rainfall over 400 mm (Cocks & Philip 1979); it does not persist well when the rainfall is below this threshold (Loi et al. 2005a). On the other hand, annual medics are suitable for neutral and alkaline soils and low rainfall regions (Puckridge & French 1983); by contrast, acidic soils, unfavourable for annual medics, are common in low rainfall regions of WA (Howieson & Ewing 1989). Lately, Western Australian traditional ley farming has shifted to phase farming (i.e. three to six years cropping then a legume pasture) (Reeves & Ewing 1993; Howieson, O'Hara & Carr 2000). In these systems, with a long-delayed cycle, subterranean clover is unable to regenerate reliably (Loi et al. 2005a).

To overcome these constraints, a second generation of annual pasture legumes (APLs) have been introduced in WA farming systems (Loi et al. 2005), and since 1991 more than twenty APLs have been released (Nichols et al. 2007). For example, *Biserrula pelecinus* cultivar Casbah (Casbah) was introduced in WA in 1997 as an exceptionally promising pasture (Howieson, Loi & Carr 1995; Carr et al. 1999). It was considered a potential pasture for its ability to grow under low rainfall in most of the acidic sandy soils where annual medics failed to establish (Howieson, Loi & Carr 1995; Loi, Revell & Nutt 2005). Another APL, soft-seeded French serradella (*Ornthopus sativus*) cultivar Cadiz (Cadiz) was introduced in 1996, which would grow in poor acid soils where subterranean clover does not grow (Nutt & Paterson 1997).

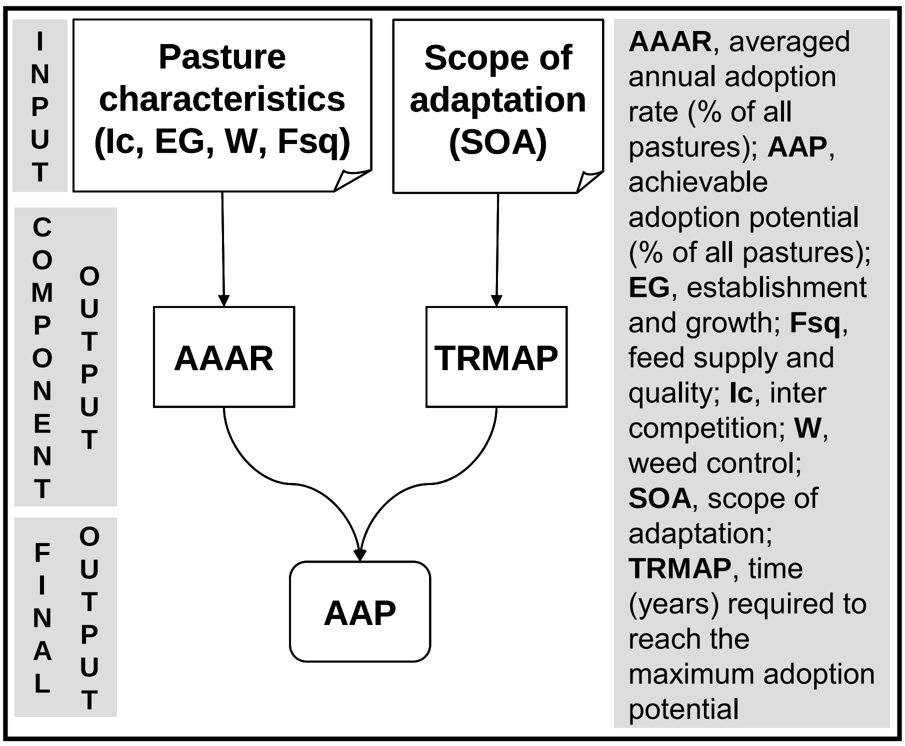
However, there is a lack of information about the adoption of the newly released APLs (Salam et al. 2008). This is mainly because there is no formal record of the area of these pastures sown annually in WA. Seed sales information can not be used as it has restricted public access and is not reliable. Moreover, there is no system to measure the potential adoption of the pasture cultivars released. Salam et al. (2010b) propose that agro-ecological suitability is an essential criterion for fitting a plant species/cultivar into an agricultural system. For an APL, soil and climate requirements usually determine the agro-ecological suitability. This suitability can constrain the maximum attainable adoption potential (MAAP) of any APL into an agricultural system. The MAAP of two APLs, Cadiz and Casbah, was determined in Chapter 1 (Salam et al. 2010b). The MAAP was based on suitable soil and rainfall requirements, moderated by percent cropping land and percent pasture within cropping land, and then adjusted by seasonal certainty. When MAAP was compared with achieved adoption (AA), measured from a field survey (Nichols et al. 2007), the results indicated that a significant gap existed between the AA and MAAP.

With this background, this chapter addresses some key questions in relation to improving the fit of annual pasture legumes in Western Australian farming system: (i) Is the level of adoption what the breeders had been expecting for Cadiz and Casbah?; (ii) Do the farmers support the breeders' view?; (iii) Why the difference, if any, between the views of breeders and farmers; and (iv) How to improve, if there is any scope, the fit of annual pasture legumes in WA farming systems with interventions through research and development (R & D).

5.3 Methodology

Breeders' expectations and farmers' evaluation scores on adoption of Cadiz and Casbah were based on data from Table 4.3. Breeders' expectation was based on their perception of those two pastures, whereas farmers' evaluations were based on their different levels of experience in growing them. In that study, an empirical model, achievable adoption potential (AAP) of APL, was outlined (see details in Chapter 4). The model consisted of two components, calculating the averaged annual adoption rate (AAAR) and quantifying the time required to reach the maximum adoption potential (TRMAP) of an annual pasture legume (Figure 5.1). The former part of the model was developed using multiple linear regression analysis and the latter with simple linear regression analysis. The former part (ie. AAAR) had an adjusted R^2 of 0.978 and was significant at 0.001. This indicates that more than 98% of AAAR was explained in the model by the combined linear function of four independent variables (in this case, Ic, EG, W & Fsq). The later part (ie. TRMAP) of the model had an adjusted R^2 of 0.997 and was significant at 0.001. The model explained 99.5% of the total variation in TRMAP (dependent variable) by the linear function of SOA (scope of adaptation, explained in detail in Chapter 4, Section 4.4.2). A model was developed from the data gathered from two separate surveys undertaken from 2007 to 2008. Multiple approaches were applied to gather data by means of face-to-face interviews, personal mail-outs and general distribution of questionnaires tagged with an agricultural information booklet. Data was analysed using systems (Spedding 1975) and grounded theory (Glaser and Strauss 1999) approaches. Details of this data collection and pasture characteristics framework can be found in Salam et al. (2010a). The model was used to determine the adoption of an APL, expressed as achievable adoption potential (AAP). The AAP is the calculated adoption potential of an APL based on scores on four pasture characteristics, which were the inputs of the model (Figure 5.1). The scores are superiority of an APL in establishment and growth, its strength in controlling weeds, its ability to supply feed and quality of feed, and the competition it can face from other available pasture species.

Figure 5.1: Schematic diagram, showing input and output sections, of the model that predicts the achievable adoption potential of any annual pasture legumes under Western Australian farming systems



Source: Data from Salam et al. 2009b

Questionnaires were developed on the basis of scores of pasture characteristics (see Salam et al. 2009b) and distributed to the farmers of WA through mail and faxes, addresses obtained from the Department of Agriculture and Food telephone lists. The same questionnaires were given to the two pasture breeders who were involved in the WA pasture industry. As they were also engaged in developing these two APLs, they developed expectations that these pastures would perform in a certain way against the pasture characteristics. Therefore, they were asked to score Cadiz and Casbah on the pasture characteristics. Their scores were analysed and incorporated in the model (see details on model development and statistical analysis in Chapter 4, section 4.3.1) of achievable adoption potential of an APL, to quantify the breeders' expected adoption. Information for farmers' evaluations came from 25 farmers who grow Cadiz and 18 farmers who grow Casbah voluntarily provided scores for similar pasture characteristics through the questionnaires. Other farmers who had not sown Cadiz and Casbah before did not respond to the questionnaires. Since, these two APLs were released more than 10 years ago, the farmers who responded to the questionnaires had either adopted the APLs and continued to grow, or had discontinued after several years of adoption. Both groups were considered as they had developed enough knowledge about the performance of these APLs in relation to the pasture characteristics. Scores were analysed and averaged and incorporated in the model to quantify farmers' evaluations of adoption for Cadiz and Casbah. The measured adoption, breeders' expectations and farmers' evaluation were expressed as percentage of the maximum attainable adoption potential (MAAP).

5.4 Adoption of Cadiz and Casbah in WA farming systems

5.4.1 Breeders' expectations and farmers' evaluations

The measured achieved adoption was derived from a survey in 2005 by Nichols et al. (2007) and used in this study to compare with breeders' expectations and farmers' evaluations. Figure 5.2 shows that breeders expected about 9% higher adoption (32% of MAAP) in Cadiz compared to its measured adoption (23% of MAAP). In the case of Casbah, breeders' expectation (22% of MAAP) was only 2% higher than measured adoption (20% of MAAP). Farmers' expected the adoption of Cadiz would have been 20% of MAAP and Casbah would have been 19% of MAAP (Figure 5.3). This indicates farmers' evaluation was within 3% and 1% of measured adoption for Cadiz and Casbah, respectively. Thus, breeders' expectation for the adoption of Cadiz in the Western Australian farming systems was much higher than farmers' expectation. In the case of adoption of Casbah, the expectation of breeders' also differed from the farmers' evaluation, but the difference was much smaller than for the adoption of Cadiz.

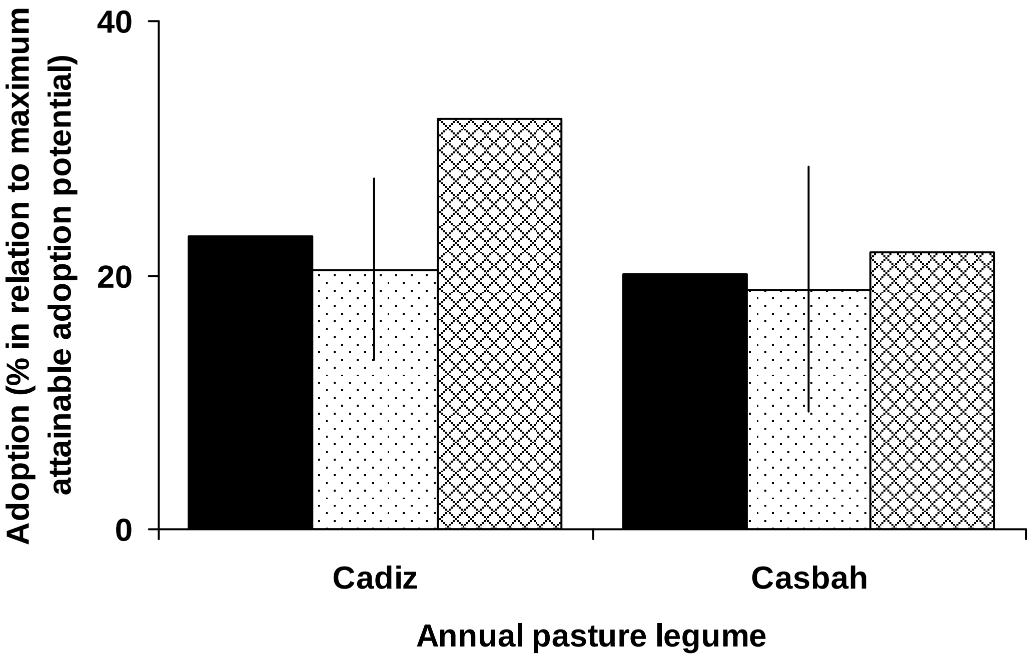
5.4.2 Why the difference between breeders' expectation and farmers' evaluation?

The difference between breeders' expectation and farmers' evaluation on adoption potential of Cadiz and Casbah is discussed here on the basis of evaluation scores provided by the two groups on different aspects of pasture characteristics: establishment and growth (that includes regeneration ability when seeds stay on surface soil [RSS] and are buried [RSB]; seed setting [SS] and persistence [P]); ability to control weeds (tolerance to herbicide [HT]) and grazing ability to control weeds [GA]); ability to supply feed [FS]; and feed quality [FQ].

Figure 5.3 shows breeders expected Cadiz would provide better establishment and growth through perfect regeneration and seed setting attributes. Farmers, on the other hand, evaluated those characteristics with lower scales, but found persistence better (double the breeders' value). Both had almost similar views about weed control through grazing (GA), but breeders rated Cadiz higher on tolerance of herbicides (HT). On feed supply and feed quality attributes of Cadiz, breeders' view was excellent (perfect score), while farmers rated it slightly lower.

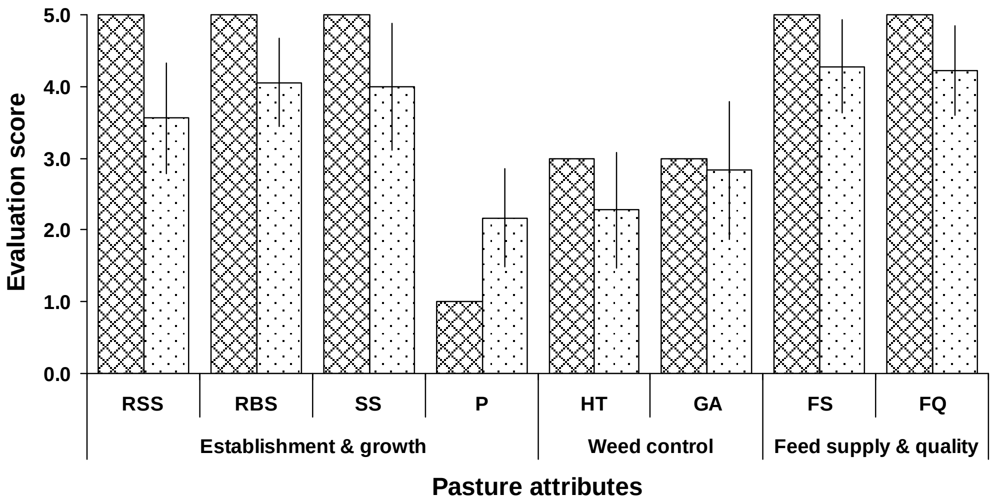
In the case of Casbah (Figure 5.4), there was a mixed view on the establishment and growth attributes, and weed control abilities. Breeders expected higher seed setting and persistence, whereas farmers evaluated it better for regeneration ability. Farmers rated it higher for herbicide tolerance, while breeders expected superior weed control with grazing. Both feed supply and feed quality attributes of Casbah were evaluated lower by farmers.

Figure 5.2: The achieved adoption and predicted achievable adoption potential (based on farmers' and breeders' inputs) of two annual pasture legumes in Western Australian farming systems.



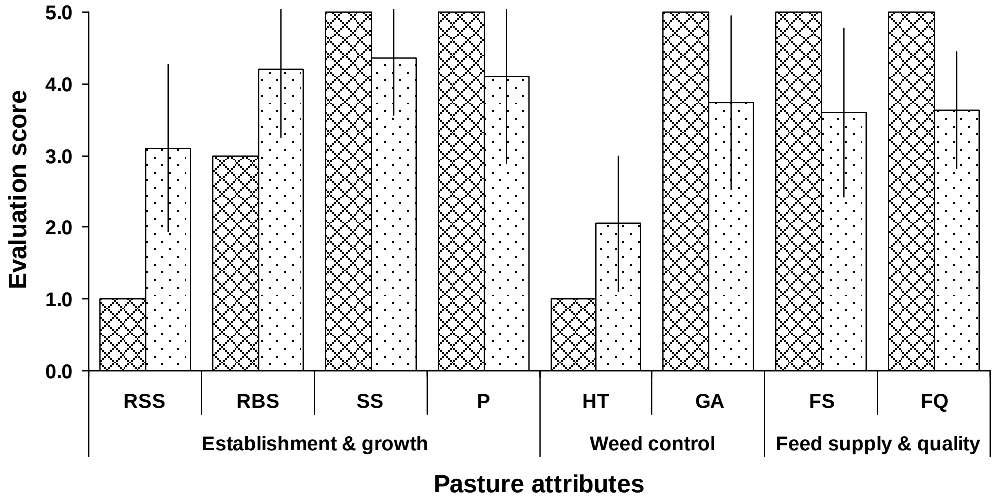
A vertical line represents the standard deviation (SD). SD was not available for achieved adoption (as the figures were derived from secondary data) and achievable adoption potential-breeders expectations (due to small sample size).

Figure 5.3: Evaluation scores of pasture characteristics from breeders and farmers for Cadiz in Western Australian farming systems.



Pasture attributes: RSS- Regeneration ability when seeds remain on soil surface; RBS- Regeneration ability when seeds remain buried; SS-Seedsetting; P- Persistence; HT- Tolerance to herbicides; GA- Grazing ability to control weeds; FS- Potential to supply feed; FQ- Feed quality.
A vertical line represents the standard deviation (SD). SD was not available for breeders' scores (due to small sample size)

Figure 5.4: Evaluation scores of pasture characteristics from breeders and farmers for Casbah in Western Australian farming systems.



Pasture attributes: RSS- Regeneration ability when seeds remain on soil surface; RBS- Regeneration ability when seeds remain buried; SS- Seedsetting; P- Persistence; HT- Tolerance to herbicides; GA- Grazing ability to control weed; FS- Potential to supply feed; FQ- Feed quality
A vertical line represents the standard deviation (SD). SD was not available for breeders' scores due to small sample size.

5.5 Towards improving adoption of Cadiz and Casbah in Western Australian farming systems

The results raise two issues for further consideration if the adoption levels of Cadiz and Casbah were to be increased in WA farming systems: Decreasing the knowledge gap, and breeding for improved pasture characteristics.

5.5.1 Decreasing the 'knowledge-gap'

There was a wide range in individual farmers' scores for achievable adoption of both Cadiz and Casbah. This range was bigger for Casbah than Cadiz, with scores ranging from 16% to 27% for Cadiz (Figure 5.5) and 3% to 32% for Casbah (Figure 5.6).

Figure 5.5 shows a comparison between the calculated adoption potential and the achieved adoption of Cadiz. Only 20% of farmers had scores exceeding the level of achieved adoption; however most were not far below the achieved level. Conversely, the distribution of adoption potential in Casbah, as shown in Figure 5.6, indicates that 50% of the farmers' evaluated adoption of Casbah as very close or above the achieved adoption (20%). The remaining 50% of farmers rated it much lower.

The differences in farmer ratings of the species raise two questions. What are the reasons for the differences in ratings of a species? Why the much smaller range for Cadiz in comparison with Casbah?

Figure 5.5: Distribution of farmers' scores for adoption potential of Cadiz compared with achieved adoption, breeders' expectation and likely adoption with improved pasture characteristics

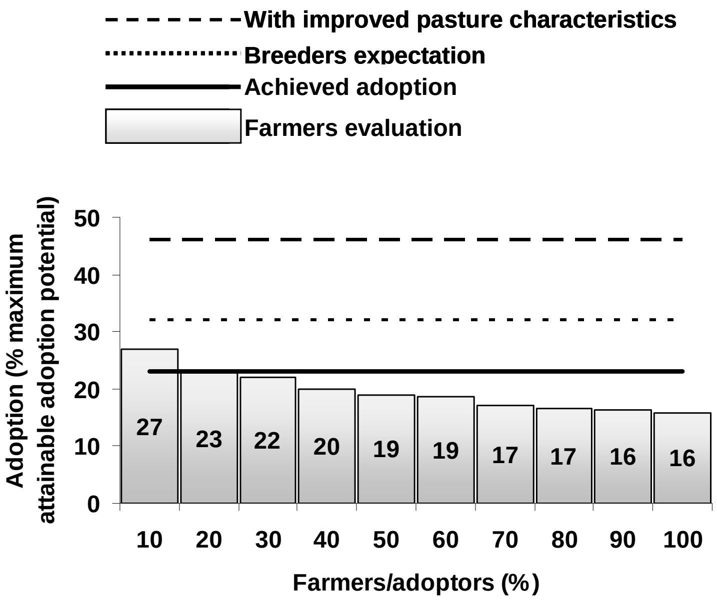
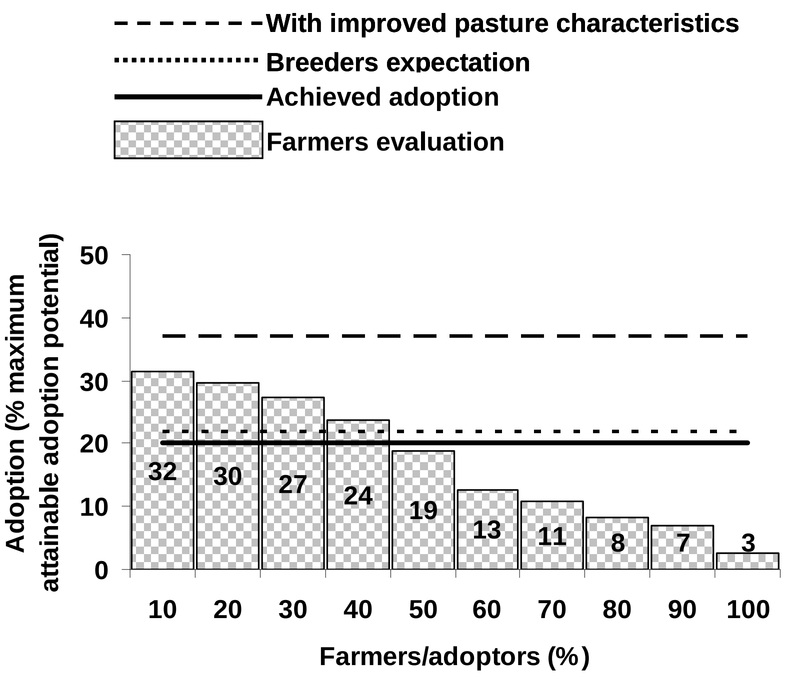


Figure 5.6: Distribution of farmers' scores for adoption potential of Casbah compared with achieved adoption, breeders' expectation and likely adoption with improved pasture characteristics



One possible explanation might be the cost of the technology, although it was probably not a major factor since there is no substantial difference in seed price between Cadiz, Casbah and other APLs. Most of the Western Australian farmers interviewed were not concerned about seed price but they were enthusiastic to grow APLs which can impact on their systems by increasing crop yield through nitrogen fixation. The results from the survey conducted in 2007 (see Chapter 3), indicated that 85% of the WA farmers who grow pastures do not perceive 'cost' as a barrier provided its performance in establishment, growth and weed control is good. During the face-to-face interviews, some of the farmers opined that they would not mind spending a few extra dollars provided they had APLs with superior performance in germination and establishment. They also claim that if APLs do not germinate or are difficult to establish, then all other costs, such as soil preparation, fertiliser cost, weed clearing cost, would be a more important consideration.

A similar study by Davis and Hogg (2008) also found that 50% of 14 farmers discontinued use of APLs because of unreliable establishment and poor persistence. Those farmers, whose scores exceeded the level of achieved adoption (Figure 5.5 and 5.6), may have had more appropriate knowledge about growing Cadiz and Casbah than the other farmers. This knowledge may be in relation to weed control or better ways of establishing these APLs. There could also be variation between the farmers in using better practices that can affect the adoption of an innovation - this notion is supported by Ghadim and Pannel (1999). Taeymans (1999) argues agricultural production is becoming increasingly knowledge-based and science intensive. Therefore a 'knowledge-gap' can exist between 'how-to-use' the technology and 'what-is-applied' in the field.

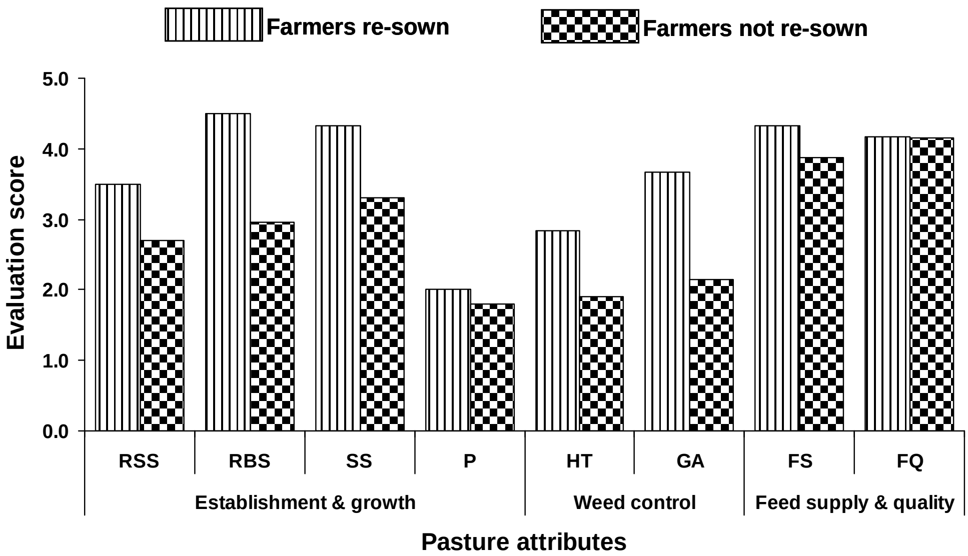
The existence of a 'knowledge-gap' has been recognised for pasture (GRDC 2006). This 'knowledge-gap' can be filled in two ways. First, provide information that is specific to growing environments during the pre-release phase of a pasture cultivar. Such information could be made available in a similar way to how the national crop variety information is made available to farmers (GRDC 2006). Pasture breeders and associated personnel would have a major role in this respect. Secondly, in the post-release phase, extension specialists have a major role. As a discipline, agricultural extension is central in formulating and disseminating knowledge and in teaching farmers to be competent decision makers (SDC 1995, pp. 2-3).

Agricultural extension can be a leading part of a system of actors; others include researchers and farmers' groups who influence farmers' decisions. In relation to this study, extension can play an important role by analysing the overall situation of current adoption of Cadiz and Casbah in WA, identifying the characteristics of the farmers and applying appropriate techniques to help farmers who experience problems with pasture varieties, thereby influencing adoption (Harper et al. 1990). Hackney et al. (2008) mention that lack of information about establishment and sowing techniques for new annual pasture legumes is inhibiting their adoption.

Davis and Hogg (2008) recommend that proper extension tools needs to be developed to increase the adoption of APLs in Western Australia. They suggest extension should address current associated problems in APLs adoption, such as seed preparation, sowing and break of season management issues, insect damage and broadleaf weed control. This situation can be improved by providing simple and clear information on better establishment and sowing techniques to the farmers (Keys & Orchard 2000).

The following example indicates how an appropriate practice can lead to better success in pasture adoption. Cadiz is a plant with soft-seed (Nutt & Paterson 1997); therefore, it is recommended that farmers re-sow this pasture for desired establishment (Nutt & Paterson 1997). Based on interviews in the study, some respondent farmers understood or accepted this recommended technique and re-sowed Cadiz after a cropping phase. Some farmers (67%) did not follow or were not aware of this technique and used the traditional practice of relying on regeneration of Cadiz from previous years. A comparison of these two groups (see Figure 5.7), shows farmers who re-sowed had higher scores for establishment and growth, weed control and feed supply than those who used traditional practice (regeneration). If the adoption is calculated using the evaluated-score of those two groups, the adoption (AAP) would have been about 23% according to the farmers who re-sowed compared to 19% for those who used traditional practice.

Figure 5.7: A comparison of scores for characteristics of Cadiz between farmers who established pasture through re-sowing and through regenerating



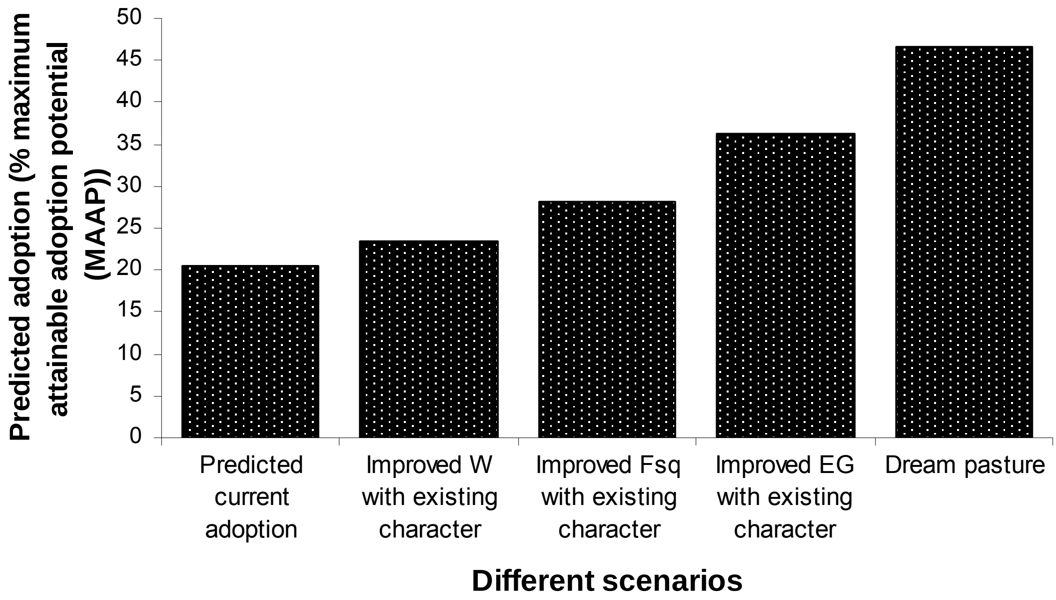
Pasture attributes: RSS-Regeneration ability when seeds remain on surface soil; RBS-Regeneration ability when seeds remain buried; SS-Seedsetting; P-Persistence; HT- Tolerance to herbicides; GA- Grazing ability to control weed; FS- Potential to supply feed; and FQ-Feed quality

There is an additional reason for the wider range in farmers' ratings for Casbah in comparison to Cadiz that is thought to have had a negative impact on the adoption of Casbah. A few years after its release, several cases of photosensitivity were reported in spring grazing ewes and lambs in Western Australia. Photosensitisation is like sunburn and usually affects animal's ears, muzzle, tail and backline. Affected areas start to swell and animal will rub affected areas abundantly (Loi, Revell & Nutt 2005). Several media statements released by the Department of Agriculture and Food Western Australia (DAFWA) warned against photosensitisation and its consequent issues including wool loss (Revell & Revell 2006). In spite of that, overall, this study indicates farmers' evaluation of Casbah was positive.

5.5.2 Breeding for improved pasture characteristics

While adoption of APLs such as Cadiz and Casbah can be increased through extension efforts, their levels of adoption can only be pushed to a certain limit. If, for an example, all the pasture farmers of Western Australia possessed the same experience of Cadiz and Casbah cultivation as do the top 10% of respondent farmers, who acquired best management skill in soil preparation, sowing and establishment techniques, pest control, grazing management, weed control, the model suggests the adoption of Cadiz and Casbah would be 27% and 32% of MAAP, respectively (Figures 5.5 & 5.6). In that case, the adoption of Casbah would have greatly exceeded breeders' expectations (22% of MAAP). By comparison, the adoption of Cadiz would remain considerably below the breeders' expectation (32% of MAAP). It appears farmers may prefer the inherent characteristics of Casbah, therefore strengthening extension would probably enhance its adoption. On the other hand, adoption of Cadiz may not reach breeders' expectation with its inherent characteristics. In that case, it would require improvement of pasture characteristics through breeding. For an example: by improving the existing attributes of Cadiz related to weed control (W), feed quality and supply (Fsq) and establishment and growth (EG) the adoption could be increased by 23%, 28% and 36% (of MAAP) respectively (Figure 5.8). However, if all attributes of the existing Cadiz were the same as farmers' dream pasture, adoption might reach 47% of MAAP that is a 56% increase from the predicted current adoption (20% of MAAP) using farmers' average scores.

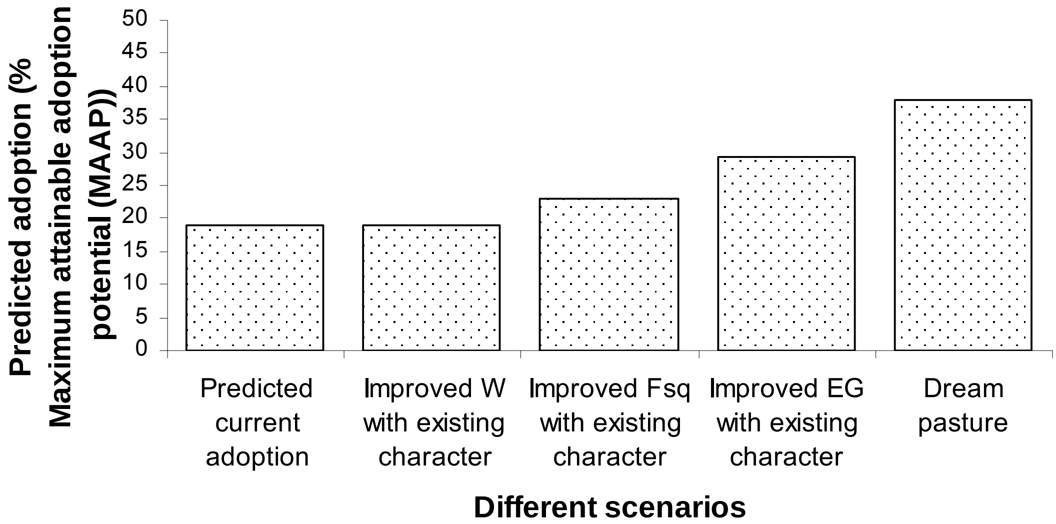
Figure 5.8: Comparison of possible scenarios for adoption of French serradella Cadiz if it were possible to improve existing attributes*



* Predicted current based on existing attributes. Possible scenarios include: improving weed control potential (W), improving feed quality and supply (Fsq), improving superiority in establishment and growth (EG) and with attributes of farmers' dream pasture

Similarly, the model also predicts that by improving the existing Casbah attributes related to weed control (W), feed quality and supply (Fsq) and establishment and growth (EG) adoption could be increased by 19%, 23% and 29% (of MAAP) respectively (Figure 5.9). However, if all attributes are added to the existing Casbah based on farmers' dream pasture, adoption could reach 38% of MAAP, that is a 50% increase from predicted current adoption (19% of MAAP) using farmers' average scores. On the other hand, if only establishment and growth (EG), most desired APL characteristics by 79% farmers, attribute were improved for Cadiz and Casbah, adoption could be increased by 44% and 36% (of predicted current adoption) respectively.

Figure 5.9: Comparison of possible scenarios for adoption of Biserrula Casbah if it were possible to improve existing attributes*



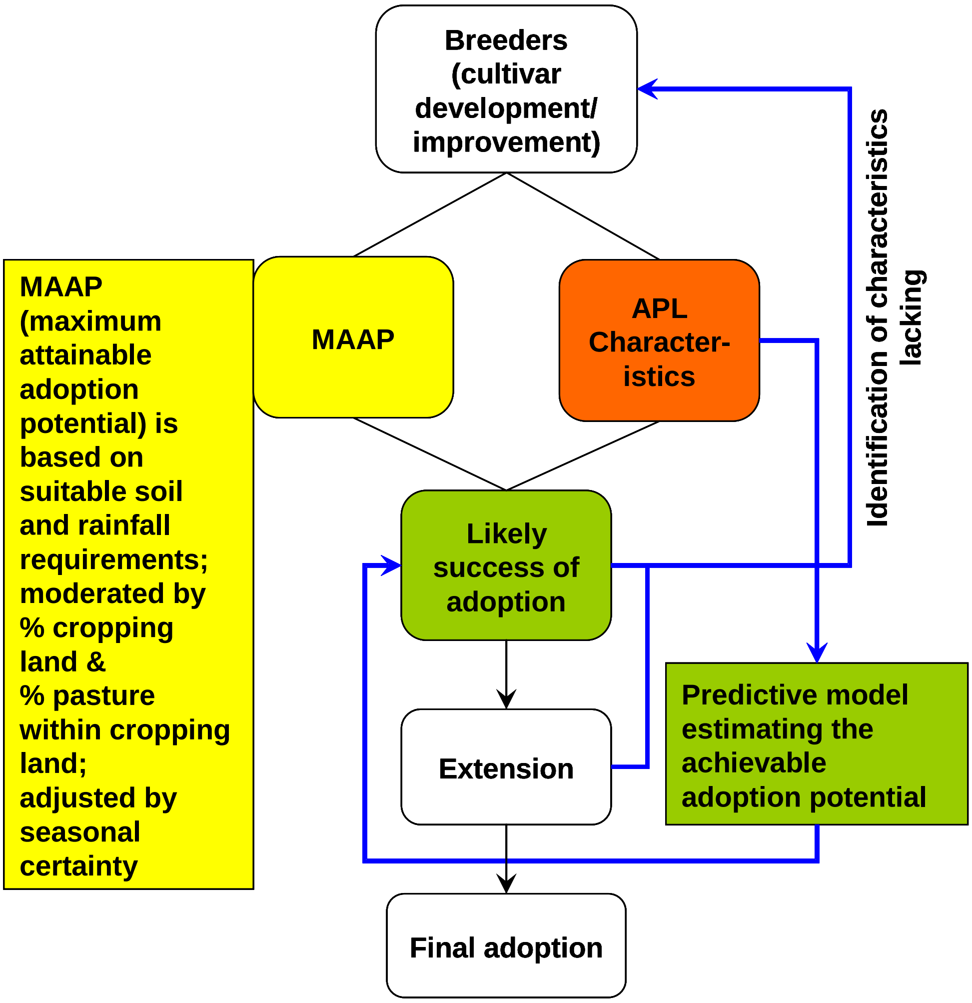
Predicted current based on existing attributes. Possible scenarios include: improving weed control potential (W), improving feed quality and supply (Fsq), improving superiority in establishment and growth (EG) and with attributes of farmers' dream pasture

5.6 A system for improving the fit of annual pasture legumes in WA farming systems

The overall study, however, provides a system for improving the fit of annual pasture legumes in WA farming systems. The system, shown in Figure 5.8, consists of three major components: the maximum attainable adoption potential (MAAP), the annual pasture legume characteristics framework (APL-characteristics for WA) and achievable adoption potential (AAP). The MAAP of a newly released pasture cultivar could be calculated based on its rainfall and soil type constraints (defined by the breeders during its release), moderated by the percentage of cropping land, and the percentage of pasture within this cropping and finally, adjusted by the seasonal certainty. The geographical distribution of MAAP could also be worked out. The likely adoption of a cultivar (AAP) could be worked out (by using a predictive model) through its inherent characteristics as defined by the breeders. The AAP and the MAAP would provide guidance for the extension effort on the adoption of the pasture cultivar. Extension personnel could also receive feedback on farmers' experience with the pasture characteristics of the cultivar and pass it on to the breeders.

This framework might assist in the development of future cultivars of APL, and help in extension work for better adoption. It is a common platform where breeders, farmers, extension specialists and policy makers can work as a team and improve the fit of an APL.

Figure 5.10: Layout of a system for improving the fit of annual pasture legumes in Western Australian farming systems



5.7 Conclusions and implications

The results suggest the maximum attainable adoption potential of an annual pasture legume can be estimated based on soil and climate requirements. Furthermore, the achievable adoption of a pasture legume can be predicted based on key APL attributes as perceived by farmers and breeders. Using the model, the achieved adoption of Cadiz in Western Australia (WA) is shown to be about 9% lower than what breeders expected; in the case of Casbah, breeders' expectation was 2% higher than what has been achieved. Model predictions based on farmers' evaluation scores largely supported the measured adoption of these two species.

In Western Australia, farmers consider adopting an APL in their farming systems based on some perceived attributes of the APL. The strength of these attributes, as perceived by breeders, was not completely reflected in most of the farming environments. This was partly because of farmers' poor knowledge about some practices in relation to growing the APLs and partly because some inherent characteristics of the APLs were not wholly desirable to farmers. This study also shows how far current adoption can be increased in these two pastures through extension and breeding programs. The approach outlined can also help improve the breeding, development and extension of future cultivars of APL.

Chapter 6

Discussion

6. Discussion

Despite the many varieties of annual pasture legumes (APLs) released into the Western Australian (WA) farming systems, the question of their satisfactory adoption remains unanswered. Policy makers and researchers often ask, “Have the APLs reached their full adoption potentials?” The main reason behind this question might be the absence of a proper tool for quantifying adoption potentials of pastures for WA farming systems. Without such a tool, the adoption potential of an APL will remain unclear and in turn, make it difficult to find the mechanisms of fitting APLs in the farming systems. Considering this issue, this study was undertaken aiming to enhance understanding of how to improve the fit of an APL in WA’s farming systems. It had four objectives: (1) To develop a system for measuring the adoption potential of an annual pasture legume based on its agro-ecological suitability; (2) To understand farmers’ perceptions of an ideal pasture for their farming systems and compare the strength and weakness of Cadiz and Casbah against it; (3) To develop an empirical model to predict the achievable adoption of any annual pasture legume based on its perceived attributes; and (4) To develop a framework for improving the fit of an annual pasture legume in the Western Australian farming systems.

This chapter summarises the discussion of the various parts of the thesis in order to give an overview of how, in answering each of the four objectives of the study, the aim of enhancing understanding of how to improve the fit of an annual pasture legume in Western Australian farming systems is achieved.

6.1 The relevance

Subterranean clover and annual medics have traditionally been overwhelming dominant pastures in Western Australian farming systems. Although many new cultivars of these annual pasture legumes (APLs) were introduced in this state and viewed as a big success in the local environment, there were potential environmental, economic and biological constraints identified in relation to their wide-spread adoption (Howieson, O’Hara & Carr 2000). Therefore, it was necessary to select and breed new (or second generation) APLs for Western Australia that would fit into the current farming systems. Since 1991, over 20 annual pasture legumes have been released in Western Australia. Despite their improvements on some characteristics over traditional APLs, there has been debate over whether the level of adoption of these APLs has been satisfactory or not. In the context of present farming systems, APLs are not just for providing feed and nutrition to animals, their role extends to immense benefits to crop and pasture rotation. If an APL fails to properly fit into the farming systems, its adoption will be severely affected. This is particularly true for the present state of farming in Western Australia as there are a number of potential grain legumes that are in competition with the APLs for rotational benefits. Considering the aspects above, this study is relevant to Western Australian agriculture and timely to the stakeholders.

6.2 Adoption potentials: what, where and how much?

The first objective of the study was to develop a system for measuring the potential of an annual pasture legume based on its agro-ecological suitability and scenarios of farm practices. Three broad factors can influence the scale of adaptation of an annual pasture legume in Western Australia. Firstly, like other plant species, each APL has its own genetic requirements for a 'specific growing environment' to reach its full potential. Such a requirement should be the first step to consider when fitting any APL into Western Australian farming systems. As Loi et al. (2000) rightly mention, each newly released APL has specific soil and rainfall requirements and its full potential can be achieved when these requirements are met. In Western Australia, soils and soil characteristics such as soil pH, soil salinity and waterlogging status are highly variable across the state (Nichols et al. 2007). Based on generic information, Schoknecht (2002) considers there are sixty soil groups present in Western Australia. Rainfall and temperatures are also widely variable in the state. Based on the length of crop growing seasons, the Western Australian cropping-belt has been divided into three regions, the northern agricultural region (NAR), the central agricultural region (CAR) and the southern agricultural region (SAR) (Garlinge 2005). The length of growing season gradually increase from NAR to SAR with decreasing temperature. For each region, rainfall decreases from the west to the east. Dolling (2006) showed profound differences among these three regions, such as temperature, annual rainfall, active growing season rainfall (May-October) and less-active growing season rainfall (November-April), which can limit the scope of cultivation of APLs, such as Cadiz and Casbah.

Secondly, the ultimate aim of this study was to explore avenues for fitting or improving the fit of APLs into existing farming systems. This warrants understanding the characteristics of Western Australian farming systems. Western Australian agriculture is mixed farming (Doole, Pannell & Revell 2009), composed mainly of crop and livestock enterprises. Therefore, adoption of an APL is unlikely to occur in all the agro-ecologically suitable land (the first broad factor), as pasture enterprises constantly compete with crops for the same land (Nichols 2004). In attempting to improve the fit of APLs into the existing farming systems, two key issues are: the proportion of cropping area within a geographic region, and the crop-pasture ratio within the cropping area.

A third factor that may moderate the agro-ecological suitability is seasonal uncertainty. Seasonal reliability of rainfall is an important factor in addition to fulfilling the basic rainfall requirements of APLs (Austen et al. 2002; George et al. 2007). The amount of annual and/or seasonal rainfall can vary considerably between years within a location. It is also evident that due to climate and soil water variability Australian farmers face huge losses in their crop and pasture (Austen et al. 2002). These issues require a thorough examination to understand and explore the full potential of a new pasture (Hill 1996; Hannaway et al. 2005) before considering it for Western Australian farming systems.

In this study, a framework is developed to quantify adoption potential of an annual pasture legume under Western Australian farming systems. In the line of discussion above, this framework is built on a three-tier hierarchy, broad adoption potential or BAP (based on suitable soil and rainfall requirements), broad attainable adoption potential or BAAP (BAP moderated by percentage of cropping land and percentage of pasture within cropping land), and maximum attainable adoption potential or MAAP (BAAP adjusted by seasonal certainty). This framework is applied to quantify the adoption potential of two annual pasture legumes, i.e. Cadiz and Casbah. The study shows that on the basis of agro-ecological suitability, the scope of adoption of Cadiz is much higher (BAP = 9.03 M ha) than Casbah (BAP = 6.35 M ha). However, when all other constraints are considered together (farming systems and seasonal certainty), the difference in adoption potential between Cadiz (MAAP = 0.99 M ha) and Casbah (MAAP = 0.89 M ha) narrows.

This study also found that the calculated maximum attainable adoption potential (MAAP) is not the actual level of adoption. For example, the actual adoption of Cadiz and Casbah in the surveyed shires was lower than MAAP by a factor of about 4.25 (Cadiz = 4.25 and Casbah = 4.37). Three inferences can be drawn from this. First, those APLs may not have reached their ceiling adoption. Second, the soil and rainfall requirements as prescribed in their release notes may not have translated in farm environments. Third, there may be other factors in addition to what has been considered in the study that have influenced the adoption of APLs. Nevertheless, the MAAP is a good indicator of the area that can be adopted by an APL under Western Australian farming systems.

The above mentioned framework provides a number of benefits for enhancing the adoption of a new pasture. For example, pasture researchers can target the potential locations for extension activities to achieve the best performance from the pastures; stakeholders can allocate resources to the potential areas for better pasture production; and researchers can make appropriate planning decisions for trialling a pasture in a certain location. Knowledge of maximum attainable adoption area of a pasture could give an idea to seed producers on the amount of seed required to satisfy expected adoption rates, but further study is required to deal with other seed adoption related issues. However, this framework can be useful for seed producers to indentify the potential pasture seed selling markets.

6.3 Keeping farmers on board

The second objective of the study was to understand farmers' perceptions of an ideal APL for their farming systems and compare the strength and weakness of Cadiz and Casbah with this ideal. Perceived attributes of an innovation have long been recognised as a major determinant of technology adoption (Rogers 2003). Farmers of Western Australia are the ultimate deciders of which APLs can fit into their farming systems. Therefore, a survey was carried out to understand the key issues that farmers consider in relation to adopting a new annual pasture legume for their farming systems.

The survey emphasised two issues. The first was an APL that farmers would dream about for their systems. Hence, one particular question was formulated in the survey questionnaire - "What is your dream pasture species?" The word "dream" was chosen here carefully to help open up the farmers' mind and to encourage speaking up about their feelings towards new APL species (Salam et al. 2008). The second involved an evaluation of Cadiz and Casbah in relation to adoption. By analysing the survey data using a 'grounded theory' approach, an APL-characteristics framework was developed for Western Australia. The six components of this are - in order of importance calculated as percent farmers who mentioned the component: superiority in establishment and growth (79%), ability in supplying quality feed (49%), potential in controlling weeds (38%), adaptability in broader agro-ecological environments (36%), tolerant to major insect-pests (20%) and inexpensive (or economic 15%). Hence agro-ecological suitability, as discussed in the previous section, is not the only yard-stick that farmers will use when considering an APL for their farms. Farmers of Western Australia desire certain attributes for annual pasture legumes that they believe would be helpful in their farming systems. They grow annual pasture legumes in their farming systems for many reasons (Ghadim, & Pannell 1991; Connell, Young & Kingwell 2006; Doole & Weetman 2009; Bathgate, Revell & Kingwell 2009) such as: to raise animals, particularly sheep; to improve soil; to control weeds; and to control pest and diseases. This study found that currently Western Australian farmers are having problems establishing and growing some of the new APLs in their systems, which is corroborated by Davis and Hogg (2008). Current APLs require special techniques to achieve better establishment. Most farmers' indicated their dream pastures require easy establishment. They also require enough feed supply and quality to meet the autumn and summer feed gap (Ghadim 2000; McFarland 2006). Weeds are also a big problem for Western Australian farmers (Jones et al. 2005). Some farmers grow APLs in crop rotation to control weeds and require an APL to be tolerant of chemicals, so that they can control weeds. They also want an APL that is competitive, by growing faster than weeds or persisting better under heavy grazing, so that they can control weeds without using chemicals. Farmers of Western Australia believe a drought tolerant

APL should withstand climate variability (Stephens et al. 2003) and maintain productivity. Farmers also require insect resistance in their dream pasture, especially against redlegged earth mite which causes production losses (Umina 2008). Cost is a factor, but it appears farmers would be willing to pay for a good APL. Farmers also desire a number of components in their dream pasture, such as 79% of farmers who mentioned the establishment and growth component either by itself or together with other components. The next best combination, mentioned by 10% of farmers, was establishment and growth in combination with feed supply and quality, and weed control.

Both Cadiz and Casbah also appear to have deficiencies in establishment and growth capability when compared to farmers' expectations from the dream pasture. Although Casbah has good hard-seededness attributes, which exceeds the dream pasture, lack of easy establishment attributes seem a big weakness. Farmers mentioned that Cadiz was weak in its ability to survive an early break without follow-up rain. Cadiz's lack of hard-seededness attributes (soft-seededness) allows seeds to germinate following summer and early autumn rain. Those seeds die when they do not get follow-up rain. Consequently, farmers need to re-sow Cadiz seed to maintain the seed bed density. Re-sowing Cadiz every year is not seen as a usual practice by the farmers. Adopting a new practice takes time and willingness, which may be a barrier to adoption of Cadiz.

Both pastures seem to be sensitive to many herbicides when compared to the dream pasture attributes. This limits good establishment in both pastures. Casbah is considered good for controlling weeds through grazing, while Cadiz is weak. Farmers found that Cadiz was better in early feed supply but not good in late feed supply, which was the opposite for Casbah. A large number of farmers mentioned that Casbah had a problem due to feed toxicity (photosensitivity).

Neither Cadiz nor Casbah had good adaptation over wide ranges of soil. However, Casbah had good drought tolerant capacity. They were less resistant against insects, especially redlegged earth mite than the dream pasture. Farmers found seed price, establishment cost and harvest cost were low for both the APLs, although some believed harvesting costs were high.

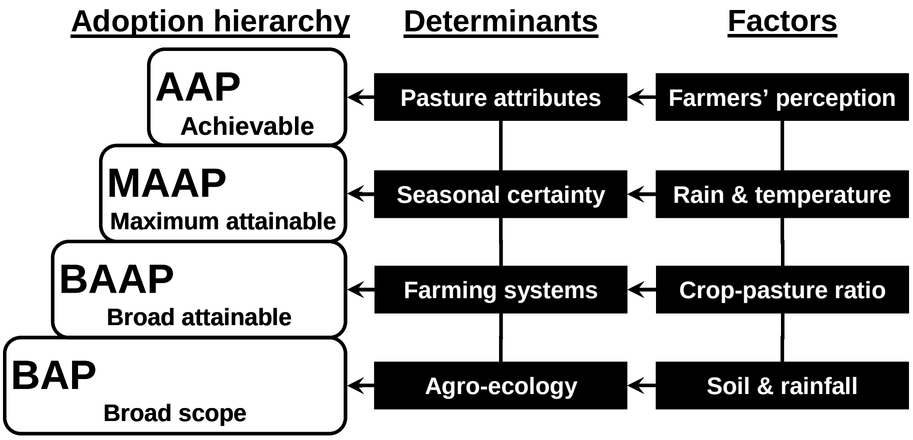
Farmers' perceptions about a specific kind of technology are based on their needs in the farming systems which are dominant in the above results. Findings of this study can potentially be used in two important ways. One, the framework for annual pasture legumes may be used as a tool or an indicator for understanding adoption potential of an annual pasture legume in Western Australia. Second, the framework may act as a guide to pasture breeders while breeding and/or selecting a pasture for Western Australia.

6.4 Predicting adoption of annual pasture legumes in Western Australia

The third objective of this study was to develop an empirical model to predict the likely adoption of an APL based on its perceived attributes. The APL-characteristics framework, as discussed above, provides an in-depth understanding about the attributes of an annual pasture legume that can influence its adoption into the farming systems of Western Australia. The question may be raised whether this can be used to measure or quantify the adoption. Yates (2001) indicates Rogers' adoption diffusion theory (Rogers 2003) can provide an answer. Rogers' diffusion of innovation theory has been applied extensively to understand the scope of adoption of a technology in various fields ranging from agriculture to health science (Hightower & Brightman 1994; Batz, Janssen & Peters 2003; Lee 2004; Bozbay & Yasin 2008). Attempts have been made to quantify the adoption of agricultural innovations in relation to characteristics of innovations as defined in Rogers' model (Rogers 2003). On the other hand, Technology Acceptance Model (Davis 1989), TAM, has been used extensively in the field of information technology (Tornatzky & Klein 1982; Moore & Benasat 1991), but only rarely in the agricultural field (Adrian, Norwood & Mask 2005). The success of these attempts has been generally not encouraging. For example, three characteristics of innovations - relative investment, relative complexity and relative risk – explained only 40 to 56% of variability while predicting the adoption of dairy technologies in Kenya (Batz, Janssen & Peters 2003). In the quest for better predictability, Batz and his colleagues suggested exploring other technological characteristics which might influence farmers' adoption decisions. The unique feature of the present study is that rather than considering the generic 'characteristics of innovations' defined in Rogers' model, the perceived pasture characteristics is used as defined by the farmers for their environment, the Western Australian farming systems. In a nutshell, Rogers' generic perceived attributes of innovations have been redefined into attributes specific to pasture technology in Western Australian farming environments.

In this study, an empirical model (Chapter 4, Figure 4.1) is developed to measure the achievable adoption potential (AAP), in which a hierarchy is proposed (Figure 6.1) above the maximum attainable adoption potential (MAAP, Chapter 2, Figure 2.1). This model considers three major pasture characteristics perceived by the farmers: superiority in establishment and growth, strength in controlling weeds, and ability to supply feed and its quality; together with two other factors – inter- competition among the existing cultivars and the scope of adaptation. The newly developed model performed well when tested independently for two annual pasture legumes, Cadiz and Casbah, using inputs from two different sources, breeders and farmers.

Figure 6.1: Modified and improved framework for measuring adoption potentials of annual pasture legumes in Western Australia



The model can be used as a research tool for plant breeders and extension practitioners to guide how to increase the achievable adoption potential of an annual pasture legume through improving the pasture characteristics in the selection and/or breeding programme. By applying the model, senior management of an R&D organisation may identify a significant gap between current adoption and achievable adoption potential of an annual pasture legume and look at strategies to alleviate the gap.

6.5 Breeders versus farmers: where they agree and where they don't?

Applying the model (presented in Chapters 4 and 5), this study found that breeders' expectations for the adoption of Cadiz in the Western Australian farming systems were higher than farmers' expectations. In the case of adoption of Casbah, the expectation of breeders' also differed from the farmers' evaluation, but the difference was much smaller than for the adoption of Cadiz. The difference in expectations appears to be because breeders expected Cadiz would provide better establishment and growth through regeneration and seed setting attributes. Farmers, on the other hand, scored those characteristics lower, but found persistence better. Both had almost similar views about weed control through grazing, but breeders rated Cadiz higher on tolerance to herbicides. On feed supply and feed quality attributes of Cadiz, breeders' rated them excellent, while farmers rated it slightly lower. In the case of Casbah, there was a mixed view on the pasture attributes. Breeders expected higher seed setting and persistence, whereas farmers evaluated it better for regeneration ability. Farmers rated it higher for herbicide tolerance, while breeders expected superior weed control with grazing. Both feed supply and feed quality attributes of Casbah were evaluated lower by farmers.

The results raise two issues for further consideration if the adoption levels of Cadiz and Casbah were to be increased in Western Australian farming systems: decreasing the knowledge gap, and breeding for improved pasture characteristics. The study found a wide range in the evaluation of an attribute by individual farmers' both for Cadiz and Casbah. This range was bigger for Casbah than Cadiz. A comparison between the calculated adoption potential and the achieved adoption of Cadiz indicates only 20% of farmers' exceeded the level of achieved adoption; however most were not far below the achieved level. Conversely, the distribution of adoption potential in Casbah, indicates that 50% of the farmers' evaluated adoption of Casbah as very close or above the achieved adoption. The remaining 50% of farmers were much lower than the achieved adoption level. This is consistent with a 'knowledge-gap' between technology use and its management. The existence of a 'knowledge-gap' has also been recognised for pasture elsewhere in Australia (GRDC 2006).

A knowledge-gap among the farmers could be minimised by extension work in both Cadiz and Casbah. Extension practitioners can provide advice on pasture management, such as land preparation, sowing and establishment techniques, fertiliser and methods of grazing and weed control. Adoption of APLs may increased through improving knowledge. For example, if the top 10% farmers, who had better skill in pasture management, would have been transformed into the rest of the farmers, then the MAAP calculated using the model would be 27% and 32% for Cadiz and Casbah, respectively. In this case, MAAP for Casbah would be higher than breeders' expectations (22%). It may infer that Casbah has inherent characteristics that require improved knowledge to be utilised and extension practitioners could improve knowledge of these characteristics. In the case of Cadiz, there would not be much improvement though extension. In that case, it would require improvement of pasture characteristics through breeding. For example, if all attributes of the existing Cadiz were the same as farmers' dream pasture, adoption might reach 47% of MAAP that is a 56% increase from the predicted current adoption (20% of MAAP) using farmers' average scores (Figure 5.8). Similarly, if all attributes are added to the existing Casbah based on farmers' dream pasture, adoption could reach 38% of MAAP, that is a 50% increase from predicted current adoption (19% of MAAP) using farmers' average scores (Figure 5.9).

6.6 Towards a system for improving the fit of annual pasture legumes in Western Australia

The final objective of this study was to develop a framework for improving the fit of an APL in the Western Australian farming systems. Accordingly, a system is proposed (Figure 5.10 in Chapter 5, Salam et al., 2009b). The system has three main components:

1. Maximum attainable adoption potential (MAAP) of an APL, which is derived from rainfall and soil type constraints (defined by the breeders during its release), moderated by the percentage of cropping land and the percentage of pasture within this cropping and finally, adjusted by the seasonal certainty. MAAP can be worked out geographically for a particular APL. Defining the areas and locations where a pasture can potentially be adopted has a number of benefits for enhancing the adoption of a new pasture. For example, pasture researchers can target the potential locations for extension activities to achieve the best performance from the pastures; stakeholders can allocate resources to the potential areas for better pasture production; and researchers can make appropriate planning decisions for trialling a pasture in a certain location.
2. Achievable adoption potential (AAP) is a predictive model that can determine the likely success in adoption of an AAP. This is a tool for breeders and policy makers who can use this pre and post release evaluation of a new pasture.
3. A pasture characteristics framework is developed from Western Australian farmers' perceived characteristics of a dream annual pasture legume from a qualitative study. This newly developed APL framework may be used as a tool for understanding adoption potential of an annual pasture legume in Western Australia, and it may also act as a guide to pasture breeders while breeding or selecting a pasture in the state.

These three components create a common platform where breeders, policy makers, extension practitioners, and farmers could work together in a participatory approach to improve the fit of a new annual pasture legume. For example, breeders and policymakers could use the AAP tool prior to releasing a new pasture legume. With this tool they can pre-assess the APL regarding its likely adoption potential. Breeders could input their scores on the attributes of the APL they expect would be available if the APL were released. If they were satisfied with the pre-evaluated scores, they could release the APL in the farming systems. Using the MAAP tool they can also select the right locations for field trails of the APL.

This tool could give stakeholders confidence and decrease experimental failure. After field trails, farmers may be more likely to adopt the APL. After two to three years, farmers would be asked to provide their scores on a pasture characteristics framework. Breeders could use those scores in the AAP model to evaluate the adoption outcome of the APL based on farmers' expectations. Breeders might then work out the differences between breeders' expectations (pre-release) and farmers' evaluation (post-release). Differences can be assessed in two ways, if there is much difference among farmers, then extension practitioners can work in that area, or if there is a technological problem (lack of attributes that farmers sought in an APL), then breeding can be improved.

This system is a continuous process, which ultimately might improve the fit of a new pasture legume in the farming systems. It involves a holistic approach which minimises the gaps among the different stakeholders. This system provides a true partnership opportunity, where nobody will work in isolation. Improving the fit of an annual pasture legume in a farming system is a complex process; a single task can not solve such a difficult issue. Only a genuine partnership and continuous and combined process of the three components can help improve the fit of an annual pasture legume in the Western Australian farming systems.

Chapter 7

Conclusions and implications

7. Conclusions and implications

7.1 Conclusions

In this study, the avenues towards improving the fit of new annual pasture legumes (APLs) were explored for Western Australian farming systems. It considered two annual pasture legumes, Cadiz and Casbah, as test APLs. The study investigated the agro-ecological suitability of the APLs, qualified their attributes through farmers' views, designated an APL characteristics framework for WA farming systems, measured the achievable adoption potential of APLs, and developed a framework for improving the fit of annual pasture legumes. Conclusions drawn from the study are listed below.

1. Unlike crops, statistics on the area under various pastures in the Western Australian cropping-belt are not well documented. This makes it difficult to ascertain whether the adoption of an APL has reached a desired level. Within this environment, a framework has been developed for measuring adoption potentials of annual pasture legumes in Western Australia. This framework is built on a four-tier hierarchy: the broad adoption potential (BAP, constrained by agro-ecology), the broad attainable adoption potential (BAAP, BAP moderated by farming systems), the maximum attainable adoption potential (MAAP, BAAP moderated by seasonal certainty) and achievable adoption potential (AAP, measured by APL characteristics perceived by the farmers).
2. The broad adoption potential (BAP) and its geographical distribution for Cadiz and Casbah across Western Australian grain-belt were presented through maps, which pinpointed where an APL would be suitable agro-ecologically. Defining the areas and locations where a pasture can potentially be adopted can have a number of benefits for enhancing the adoption of a new pasture. For example, a farmer can have a preliminary idea on whether to consider a newly released pasture for his/her farm; pasture researchers can target the potential locations for extension activities to achieve the best performance from the pastures; stakeholders can allocate resources to the potential areas for better pasture production; and researchers can make appropriate planning decisions for trialling a pasture in a certain location.
4. Using the newly developed framework, the areas of broad attainable adoption potential (BAAP) for Cadiz and Casbah were calculated as 1.67 M ha and 1.18 M ha, respectively. These figures were about 81% less than the calculated BAP. Total areas under maximum attainable adoption potential (MAAP) in Western Australian cropping-belt for Cadiz and Casbah were calculated as 0.99 and 0.89 M ha, respectively. These figures were 77 and 80%, respectively, higher than achieved adoption.

3. There is no updated documentation on farmers' perceptions of annual pasture legumes for their farming systems. This hinders feedback to be considered in breeding and/or selecting of new APLs. Using responses from farmers, an APL-characteristics framework was developed for Western Australia. The framework consisted of six attributes of pasture. They are, in order of importance calculated from the percent of farmers who mentioned them: superiority in establishment and growth (79%), ability in supplying quality feed (49%), improved potential in controlling weeds (38%), adaptability in broader agro-ecological horizon (36%), tolerant to major insect-pests (20%), and inexpensive (15%). Many farmers gave responses for a combination of these components rather than just a single component.
4. Using the salient attributes of the developed APL-characteristics framework and other variables, an empirical model was developed to predict the likely adoption (AAP) of any annual pasture legume in Western Australian farming systems. The model was tested satisfactorily with Cadiz and Casbah.
5. The model was applied to predict the adoption of Cadiz and Casbah using inputs from breeders and farmers in order to understand what level of adoption breeders would have expected and to what extent farmers agreed with the breeders' views. Results showed that breeders were expecting Cadiz and Casbah would be adopted in about 32% and 22% of their potential areas (MAAP) compared to the achieved adoption of 23% for Cadiz and 20% for Casbah. On the other hand, farmers' evaluations indicated that adoption would be 20% for Cadiz and 19% for Casbah, which is much closer to the achieved adoption level. The results indicate that farmers' experiences with the inherent characteristics of an annual pasture legume are not always consistent with breeders' perceptions. This hampers the development of an APL with appropriate agronomic attributes and its subsequent adoption.
6. The results of this study pointed out two issues for further consideration if the adoption levels of Cadiz and Casbah were to be increased in WA farming systems. These are: decreasing the knowledge gap among farmers on tactical management of APLs though extension, and improved pasture characteristics through breeding/selection process. A knowledge-gap among the farmers could be minimised by extension work in both Cadiz and Casbah. Extension practitioners can provide advice on pasture management, such as land preparation, sowing and establishment techniques, fertiliser and methods of grazing and weed control. Adoption of APLs may increased through improving knowledge. For example, if all farmers had the same skills in pasture management as the top 10% of farmers, then the MAAP calculated using the model would be 27% and 32% for Cadiz and Casbah,

respectively. In this case, MAAP for Casbah would be higher than the prediction based on breeders' expectations (22%). This implies Casbah has inherent characteristics that require improved knowledge to be utilised and extension practitioners could improve knowledge of these characteristics. In the case of Cadiz, there would not be much improvement though extension. In that case, it would require improvement of pasture characteristics through breeding. By improving establishment and growth, adoption (MAAP) could be increased by 44% and 36% over the existing Cadiz and Casbah varieties.

7. The link between APL developers and other stakeholders, such as farmers, extension agents, seed companies, and private consultants appeared to be weak. This seriously hampers various feed-back processes, which has implications for both APL development and adoption. Therefore, this study proposed a system consisting of three major components: the maximum attainable adoption potential (MAAP), the annual pasture legume characteristics framework (APL-characteristics for Western Australia) and achievable adoption potential (AAP). This system can act as a common platform - where breeders, farmers, extension specialists and policy makers could work as a team towards improving the fit of an annual pasture legume in Western Australian farming systems.

7.2 Suggestions for improving the fit of an APL

Improving the fit of an APL into the Western Australian farming systems is a complex task and requires a combination of approaches. This study was undertaken aiming to enhance understanding of how to improve the fit of new annual pasture legumes (APLs) in Western Australian farming systems. Four frameworks or tools that enhance this understanding are articulated in Chapters 2 to 5 and include: a system for measuring the adoption potential of an APL based on agro-ecological suitability; a pasture characteristics framework based on farmers' perception of an ideal pasture; an empirical model to predict the achievable adoption of an APL based on its perceived attributes; and a framework for improving the fit of an APL in the Western Australian farming systems. This study proposes the following key suggestions:

1. In the absence of field statistics, the newly developed empirical model (Chapter 4) can be used as a tool to approximate likely adoption of a newly released annual pasture legume for Western Australian farming systems.
2. The geographical distribution of potential adaptation areas of a newly released annual pasture legume may be worked out using the newly developed framework (Chapter 2) for measuring adoption potentials of annual pasture legumes in Western Australia.

This framework could pinpoint where an APL would fit environmentally, thereby locating potential adoption areas and designating potential extension domains. It could also help breeders to locate potential field testing areas during the pre-release stage of the pasture.

3. Documentation, in the form of a framework (Chapter 3), is needed to understand what farmers' are looking for in an annual pasture legume and what breeders should be incorporating into newly released cultivars. This information could be updated periodically to keep up with farmers' current needs for their farming systems.
4. To reduce any conflicts between the inherent characteristics of an annual pasture legume and farmers' experiences (Chapter 5), the former should be assessed in its adaptation domains (Chapter 2), preferably, in farmers' paddocks and by engaging them in the assessment.
5. Increased and improved extension activities could be implemented to reduce the existing knowledge-gap between the technology to use an APL and what is applied in the field. These could be based on similar assessments to those carried out in this study for Cadiz and Casbah.
6. Creating a strong linkage between stakeholders would open various feed-back processes, thereby helping both APL development and its adoption.

7.3 Limitations

There are several limitations in this study that need to be highlighted:

1. The framework for measuring adoption potentials of annual pasture legumes (APLs) was tested with limited number of samples (data representing 16 shires of Western Australia). For greater confidence on the framework, it would be ideal if more shires are included in testing. This is especially important when testing the linear relationship between seasonal certainty and adoption of APLs, a key component of the framework.
2. The newly developed pasture characteristics framework is based on current perceptions of Western Australian farmers. Any changes in the farming situations may alter such perceptions and affect the relative importance among the components of the framework. A periodic survey may be necessary to account for such changes in farmers perceptions.
3. The major component of the model, quantifying the averaged annual adoption rate, was based on independent variables in relation to the perceived pasture characteristics that were expressed by the farmers for the environments of Western Australian farming systems. As pointed out above, any changes in the perceptions may also affect the model output. Periodic surveys, as also mentioned above, can assess whether such

changes have occurred. In that situation, the model can be recalibrated and used confidently.

4. The model, as such, is unlikely to produce desirable results in other environments and perennial pastures unless the variables are verified and calibrated, as necessary.

5. The second component of the model, predicting the time required to reach the maximum adoption potential of an annual pasture legume was based on a small number of samples. Improvement on this component can be made by gathering more data for calibration.

7.4 Directions for further research

This study suggests strengthening further research in the following directions for two reasons; one, in order to gain more confidence, as addressed in Section 7.3, in the applicability of the frameworks and the empirical model developed in this study, and the second, to account for other factors, not considered in this study, associated with the improving fitting of annual pasture legumes (APLs) in Western Australian farming systems.

1. Testing the newly developed APL adoption hierarchy with a larger number of sample of shires, and with more recent data on actual adoption.

2. Testing the newly developed APL characteristics framework on a larger sample of farmers. This testing may also include collecting data on weight given by the farmers on each of the desired pasture characteristics. Such data can quantify, if any, the interactions between the components of the APL characteristics framework.

3. Calibration of the second component of the empirical model, predicting the time required to reach the maximum adoption potential of an annual pasture legume, with more datasets.

4. Present research is carried out for annual pasture legumes only, however, future direction can be lead to other crops, i.e. wheat, canola, barley, oats and lupins.

5. This study focuses on all regions of the Western Australian grain belt. As soil topography, climate and farming systems are different within the three regions (northern agricultural regions, central agricultural regions and southern agricultural regions) in Western Australia, smaller or regional scale research could be directed for further research.

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Appendices

Appendix 1: Supplementary information to Chapter 2

Table A 1.1: Salient features of pasture adoption survey 2005 conducted by the Department of Agriculture and Food Western Australia (DAFWA) and used in part in this study

Characteristics	Quantity
Total sample	125
Did not grow pasture in 2005	20
Sampled total farm area (ha)	460,669
Range of farm size (ha)	50 – 16,000
Average farm size (ha)	3685
Median farm size (ha)	3000
Pasture area in 2005 (ha)	30,584
Area under in 2005 Cadiz (ha)	5602
Area under Casbah in 2005 (ha)	4391
% Cadiz by agricultural land	1.22
% Casbah by agricultural land	0.95
% Cadiz by all pastures	18.32
% Casbah by all pastures	14.36

Source: Phil Nichols and Angelo Loi, DAFWA

Table A 1.2: Area represented in Figures 2.4 and 2.5 in relation to broad adoption potential of Cadiz and Casbah in Western Australian grain-belt, presented in alphabetic order of locations.

Location	Total area (ha)	Satisfies soil requirements (ha)		Satisfies soil and rain requirements (ha)	
		Cadiz	Cadiz	Cadiz	Cadiz
Albany (C[a])	312,501	184,724	109,540	171,310	21,527
Armadale (C)	7,007	4,009	0	2,318	0
Augusta-Margaret River (S)	56,156	41,179	0	38,416	0
Bassendean (T)	224	98	0	67	0
Bayswater (C)	1	1	0	0	0
Belmont (C)	17	10	0	5	0
Beverley (S)	170,653	109,288	109,175	105,304	80,506
Boddington (S)	59,694	47,737	31,724	47,595	0
Boyup Brook (S)	177,815	132,561	125,558	126,318	0
Bridgetown-Greenbushes (S)	51,520	40,549	6,999	38,866	0
Brookton (S)	139,585	88,737	88,737	86,477	69,405
Broomehill (S)	114,598	32,719	32,719	35,616	35,079
Bruce Rock (S)	260,362	121,108	94,185	126,068	94,601
Bunbury (C)	704	515	0	307	0
Busselton (S)	67,912	41,838	0	36,210	0
Canning (C)	18	9	0	6	0
Capel (S)	28,900	16,795	0	10,456	0
Carnamah (S)	182,885	135,109	135,109	113,663	87,829
Chapman Valley (S)	299,356	217,748	127,576	217,166	123,446
Chittering (S)	78,068	54,929	33,385	46,181	0
Cockburn (C)	19	17	0	4	0
Collie (S)	13,325	10,319	514	9,604	0
Coorow (S)	271,542	222,807	222,807	193,932	141,236
Corrigin (S)	262,994	133,326	133,326	136,593	136,593
Cranbrook (S)	240,263	132,412	124,085	124,871	27,214
Cuballing (S)	103,255	82,114	82,114	81,873	76,279
Cunderdin (S)	185,507	105,490	104,279	107,767	107,673
Dalwallinu (S)	543,754	372,806	170,727	311,480	143,555
Dandaragan (S)	392,806	322,000	322,000	263,934	30,860
Dardanup (S)	19,719	14,538	0	12,878	0
Denmark (S)	39,598	29,474	0	25,459	0
Donnybrook-Balingup (S)	59,390	51,899	0	50,972	0
Dowerin (S)	182,134	77,724	75,405	75,465	73,568
Dumbleyung (S)	237,041	68,586	68,586	62,789	62,789
Esperance (S)	1518,200	548,543	532,955	540,369	160,829
Geraldton (C)	1743	983	983	1006	1006
Gingin (S)	149,860	104,989	84,782	83,163	0
Gnowangerup (S)	370,102	122,039	122,039	139,332	137,572
Goomalling (S)	179,875	125,434	125,434	120,088	120,088
Gosnells (C)	5,329	3,305	0	2,090	0
Greenough (S)	157,116	114,922	114,922	112,944	99,971
Harvey (S)	46,824	32,594	0	26,181	0
Irwin (S)	131,234	99,671	99,671	77,462	76,888
Jerramungup (S)	431,455	201,382	201,382	200,877	143,508
Kalamunda (S)	3763	2472	0	2052	0
Katanning (S)	141,424	38,768	38,768	37,857	37,857
Kellerberrin (S)	183,711	76,247	44,201	82,693	49,922
Kent (S)	432,464	126,162	126,162	122,913	122,913
Kojonup (S)	274,592	148,079	148,079	143,573	37,830
Kondinin (S)	379,551	183,852	183,852	183,295	183,295

Location	Total area (ha)	Satisfies soil requirements (ha)		Satisfies soil and rain requirements (ha)	
		Cadiz	Cadiz	Cadiz	Cadiz
Koorda (S)	251,862	125,919	64,685	101,010	52,246
Kulin (S)	428,630	224,116	223,379	218,200	217,460
Kwinana (T)	46	36	0	8	0
Lake Grace (S)	806,573	310,675	310,675	311,561	311,561
Mandurah (C)	1,390	919	0	831	0
Manjimup (S)	68,116	53,469	4,074	50,280	0
Merredin (S)	303,704	138,933	87,822	143,691	86,202
Mingenew (S)	183,190	102,820	102,820	92,050	92,050
Moora (S)	346,810	274,643	274,643	260,136	257,324
Morawa (S)	255,723	168,472	73,870	161,072	74,353
Mount Marshall (S)	413,195	214,779	74,251	179,994	62,658
Mukinbudin (S)	252,048	113,330	16,917	99,628	14,063
Mullewa (S)	467,165	311,540	212,998	290,683	205,351
Mundaring (S)	13,730	7564	25	7210	0
Murchison (S)	0	0	0	0	0
Murray (S)	60,415	30,444	0	16,540	0
Nannup (S)	35,270	22,812	0	19,822	0
Narembeen (S)	369,505	180,051	179,974	164,836	164,645
Narrogin (S)	144,473	71,355	71,355	69,494	63,872
Narrogin (T)	523	380	380	379	379
Northam (S)	117,827	76,167	73,972	75,138	48,923
Northam (T)	2541	1415	1415	1409	1329
Northampton (S)	372,331	237,702	160,064	226,950	149,312
Nungarin (S)	98,559	30,969	3357	30,885	3357
Perenjori (S)	358,312	256,948	199,132	195,079	150,078
Pingelly (S)	120,440	73,478	73,478	73,197	72,463
Plantagenet (S)	302,012	169,106	99,597	156,090	6,947
Quairading (S)	196,764	103,480	103,480	107,745	107,624
Ravensthorpe (S)	399,843	175,782	175,782	167,318	97,757
Rockingham (C)	2697	1571	0	1100	0
Serpentine-Jarrahdale (S)	28,850	16,483	0	9444	0
Stirling (C)	6	6	0	3	0
Swan (S)	44,057	27,657	0	18,672	0
Tambellup (S)	136,441	423,44	42,344	41,622	41,273
Tammin (S)	106,679	45,291	38,279	48,203	40,607
Three Springs (S)	222,141	176,717	176,717	153,114	139,511
Toodyay (S)	90,989	61,931	60,935	60,624	23,382
Trayning (S)	157,739	61,527	46,732	60,105	45,843
Victoria Plains (S)	237,589	187,371	187,371	174,668	119,485
Wagin (S)	184,374	55,784	55,784	53,300	53,300
Wandering (S)	84,846	70,137	69,059	69,621	4083
Wanneroo (S)	15,052	12,884	0	6929	0
Waroona (S)	26,489	11,587	0	6,648	0
West Arthur (S)	219,146	124,763	123,551	120,113	30,466
Westonia (S)	220,264	105,455	13,562	103,864	11,489
Wickepin (S)	197,718	96,806	96,806	93,298	93,298
Williams (S)	172,308	126,166	124,841	125,411	6,117
Wongan-Ballidu (S)	326,906	226,025	225,215	198,806	198,228
Woodanilling (S)	106,747	33,125	33,125	31,650	31,650
Wyalkatchem (S)	155,209	57,376	42,529	56,985	41,174
Yalgoo (S)	281	256	0	208	0
Yilgarn (S)	591,197	278,535	207,262	250,859	177,018
York (S)	153,340	98,394	98,131	96,855	71,238
Special case	3	0	0	0	0
Total	18818,018	10217,682	8252,169	9538,902	5851,950

[a] In the location column, C, S and T in parentheses denote council, shire and township, respectively.

Table A 1.3: Land area calculated as soil suitability for Cadiz and Casbah under selected shires of Western Australian grain-belt (as discussed in section 2.3.1)

No.	Name of shires	Total suitable area (ha) in regards to soil	
		Cadiz	Casbah
1	Boddington	47,737	47,595
2	Boyup Brook	132,561	126,318
3	Brookton	88,737	86,477
4	Carnamah	135,109	113,663
5	Chapman valley	217,748	217,166
6	Coorow	222,807	193,932
7	Corrigin	133,326	136,593
8	Cunderdin	105,490	107,767
9	Dalwallinu	372,806	311,480
10	Dandaragan	322,000	263,934
11	Dumbleyung	68,586	62,789
12	Esperance	548,543	540,369
13	Gingin	104,989	83,163
14	Gnowangerup	122,039	139,332
15	Goomalling	125,434	120,088
16	Greenough	114,922	112,944
17	Irwin	99,671	77,462
18	Jerramungup	201,382	200,877
19	Katanning	38,768	37,857
20	Kent	126,162	122,913
21	Kojonup	148,079	143,573
22	Kondinin	183,852	183,295
23	Kulin	224,116	218,200
24	Lake Grace	310,675	311,561
25	Mingenew	102,820	92,050
26	Moora	274,643	260,136
27	Morawa	168,472	161,072
28	Mukinbudin	113,330	99,628
29	Mullewa	311,540	290,683
30	Narembeen	180,051	164,836
31	Narrogin	71,355	69,494
32	Northam	76,167	75,138
33	Northampton	237,702	226,950
34	Ravensthorpe	175,782	167,318
35	Three springs	176,717	153,114
36	Toodyay	61,931	60,624
37	Trayning	61,527	60,105
38	Victoria Plains	187,371	174,668
39	West Arthur	124,763	120,113
40	Wickepin	96,806	93,298
41	Williams	126,166	125,411
42	Woodanilling	33,125	31,650
43	Yilgarn	278,535	250,859
44	York	98,394	96,855
	Total area (ha)	7,152,738	6,733,348

Table A 1.4: Land area calculated as soil suitability and rainfall requirement for Cadiz and Casbah under selected shires of Western Australian grain-belt (as discussed in section 2.3.1)

No.	Name of shires	Total suitable area (ha) in regards to soil and rainfall	
		Cadiz	Casbah
1	Boddington	31,724	-
2	Boyup Brook	125,558	-
3	Brookton	88,737	69,405
4	Carnamah	135,109	87,829
5	Chapman valley	127,576	123,446
6	Coorow	222,807	141,236
7	Corrigin	133,326	136,593
8	Cunderdin	104,279	107,673
9	Dalwallinu	170,727	143,555
10	Dandaragan	322,000	30,860
11	Dumbleyung	68,586	62,789
12	Esperance	532,955	160,829
13	Gingin	84,782	-
14	Gnowangerup	122,039	137,572
15	Goomalling	125,434	120,088
16	Greenough	114,922	99,971
17	Irwin	99,671	76,888
18	Jerramungup	201,382	143,508
19	Katanning	38,768	37,857
20	Kent	126,162	122,913
21	Kojonup	148,079	37,830
22	Kondinin	183,852	183,295
23	Kulin	223,379	217,460
24	Lake Grace	310,675	311,561
25	Mingenew	102,820	92,050
26	Moora	274,643	257,324
27	Morawa	73,870	74,353
28	Mukinbudin	16,917	14,063
29	Mullewa	212,998	205,351
30	Narembeen	179,974	164,645
31	Narrogin	71,355	63,872
32	Northam	73,972	48,923
33	Northampton	160,064	149,312
34	Ravensthorpe	175,782	97,757
35	Three springs	176,717	139,511
36	Toodyay	60,935	23,382
37	Trayning	46,732	45,843
38	Victoria Plains	187,371	119,485
39	West Arthur	123,551	30,466
40	Wickepin	96,806	93,298
41	Williams	124,841	6,117
42	Woodanilling	33,125	31,650
43	Yilgarn	207,262	177,018
44	York	98,131	71,238
	Total area (ha)	6,340,394	4,458,816

Figure A 1.1: Front-end of Climate Reliability Calculator showing the climate certainty of annual pasture legume, Cadiz, in Carnamah shire of Western Australia

Shire: Carnamah

Pasture: Serradella (Cadiz)

Average rain	368
Total season	46
Adaptable season	20
% adaptable season	43

Parameters

	total Rain min	total Rain max	P/E	P-E	Logic		
Summer conditions			0.50	-50	< or <		Summer P/E < 0.50 or (P-E) < -50
Winter conditions			0.50		=>	and	Winter P/E => 0.50
Spring _minRain	400		0.12		=> or >	and	Minimum annual rain =>X mm or spring P/E > Y
Spring_maxRain		700	0.59		< or <	and	Maximum annual rain < A mm or spring P/E < B

Year	Summer suitability	Winter suitability	Min annual rain Spring	Max annual rain Spring	Final outcome	Actual totalRain
1961	TRUE	TRUE	TRUE	TRUE	TRUE	432
1962	TRUE	TRUE	TRUE	TRUE	TRUE	652
1963	TRUE	TRUE	TRUE	TRUE	TRUE	484
1964	TRUE	TRUE	TRUE	TRUE	TRUE	458
1965	TRUE	TRUE	TRUE	TRUE	TRUE	368
1966	TRUE	TRUE	TRUE	TRUE	TRUE	381
1967	TRUE	TRUE	TRUE	TRUE	TRUE	531
1968	TRUE	TRUE	FALSE	TRUE	FALSE	200
1969	TRUE	FALSE	FALSE	TRUE	FALSE	382
1970	TRUE	TRUE	TRUE	TRUE	TRUE	436
1971	TRUE	FALSE	TRUE	TRUE	FALSE	350
1972	TRUE	TRUE	FALSE	TRUE	FALSE	370
1973	TRUE	TRUE	TRUE	TRUE	TRUE	456
1974	TRUE	TRUE	TRUE	TRUE	TRUE	494
1975	TRUE	TRUE	TRUE	TRUE	TRUE	226
1976	TRUE	FALSE	FALSE	TRUE	FALSE	251
1977	TRUE	FALSE	TRUE	TRUE	FALSE	471
1978	TRUE	TRUE	FALSE	TRUE	FALSE	203
1979	TRUE	FALSE	FALSE	TRUE	FALSE	233
1980	TRUE	TRUE	TRUE	TRUE	TRUE	439
1981	TRUE	TRUE	FALSE	TRUE	FALSE	359
1982	TRUE	TRUE	TRUE	TRUE	TRUE	421
1983	TRUE	TRUE	TRUE	TRUE	TRUE	445
1984	TRUE	FALSE	TRUE	TRUE	FALSE	231
1985	TRUE	FALSE	FALSE	TRUE	FALSE	392
1986	TRUE	TRUE	FALSE	TRUE	FALSE	278
1987	TRUE	TRUE	FALSE	TRUE	FALSE	393
1988	TRUE	TRUE	FALSE	TRUE	FALSE	322
1989	TRUE	FALSE	TRUE	TRUE	FALSE	476
1990	TRUE	TRUE	TRUE	TRUE	TRUE	372
1991	TRUE	TRUE	TRUE	TRUE	TRUE	454
1992	TRUE	TRUE	TRUE	TRUE	TRUE	351
1993	TRUE	TRUE	FALSE	TRUE	FALSE	250
1994	TRUE	TRUE	FALSE	TRUE	FALSE	357
1995	TRUE	TRUE	TRUE	TRUE	TRUE	410
1996	TRUE	TRUE	FALSE	TRUE	FALSE	326
1997	TRUE	TRUE	FALSE	TRUE	FALSE	328
1998	TRUE	TRUE	TRUE	TRUE	TRUE	595
1999	TRUE	TRUE	TRUE	TRUE	TRUE	280
2000	TRUE	FALSE	FALSE	TRUE	FALSE	334
2001	TRUE	FALSE	TRUE	TRUE	FALSE	249
2002	TRUE	FALSE	FALSE	TRUE	FALSE	375
2003	TRUE	TRUE	FALSE	TRUE	FALSE	330
2004	TRUE	TRUE	FALSE	TRUE	FALSE	311
2005	TRUE	TRUE	FALSE	TRUE	FALSE	278
2006	TRUE	FALSE	FALSE	TRUE	FALSE	210

Annual rain factor: 32

Figure A 1.2: Front-end of Climate Reliability Calculator showing the climate certainty of annual pasture legume, Casbah, in Carnamah shire of Western Australia

Shire: Carnamah

Pasture: Biserrula (Casbah)

Average rain	368
Total season	46
Adaptable season	39
% adaptable season	85

Parameters

	total Rain min	total Rain max	P/E	P-E	Logic
Summer conditions			0.00	-1E-07	< or <
Winter conditions			0.40		=>
Spring _minRain	325		0.07		=> or >
Spring_maxRain		500	0.24		< or <

Summer P/E < 0.50 or (P-E) < -50
and Winter P/E => 0.50
and Minimum annual rain =>X mm or spring P/E > Y
and Maximum annual rain < A mm or spring P/E < B

Annual rain factor 32

Year	Summer suitability	Winter suitability	Min annual rain Spring	Max annual rain Spring	Final outcome	Actual totalRain
1961	TRUE	TRUE	TRUE	TRUE	TRUE	432
1962	TRUE	TRUE	TRUE	TRUE	TRUE	652
1963	TRUE	TRUE	TRUE	TRUE	TRUE	484
1964	TRUE	TRUE	TRUE	TRUE	TRUE	458
1965	TRUE	TRUE	TRUE	TRUE	TRUE	368
1966	TRUE	TRUE	TRUE	TRUE	TRUE	381
1967	TRUE	TRUE	TRUE	TRUE	TRUE	531
1968	TRUE	TRUE	TRUE	TRUE	TRUE	200
1969	TRUE	FALSE	TRUE	TRUE	FALSE	382
1970	TRUE	TRUE	TRUE	TRUE	TRUE	436
1971	TRUE	TRUE	TRUE	TRUE	TRUE	350
1972	TRUE	TRUE	TRUE	TRUE	TRUE	370
1973	TRUE	TRUE	TRUE	TRUE	TRUE	456
1974	TRUE	TRUE	TRUE	TRUE	TRUE	494
1975	TRUE	TRUE	TRUE	TRUE	TRUE	226
1976	TRUE	FALSE	TRUE	TRUE	FALSE	251
1977	TRUE	TRUE	TRUE	TRUE	TRUE	471
1978	TRUE	TRUE	TRUE	TRUE	TRUE	203
1979	TRUE	FALSE	FALSE	TRUE	FALSE	233
1980	TRUE	TRUE	TRUE	TRUE	TRUE	439
1981	TRUE	TRUE	TRUE	TRUE	TRUE	359
1982	TRUE	TRUE	TRUE	TRUE	TRUE	421
1983	TRUE	TRUE	TRUE	TRUE	TRUE	445
1984	TRUE	TRUE	TRUE	TRUE	TRUE	231
1985	TRUE	TRUE	TRUE	TRUE	TRUE	392
1986	TRUE	TRUE	FALSE	TRUE	FALSE	278
1987	TRUE	TRUE	TRUE	TRUE	TRUE	393
1988	TRUE	TRUE	FALSE	TRUE	FALSE	322
1989	TRUE	TRUE	TRUE	TRUE	TRUE	476
1990	TRUE	TRUE	TRUE	TRUE	TRUE	372
1991	TRUE	TRUE	TRUE	TRUE	TRUE	454
1992	TRUE	TRUE	TRUE	TRUE	TRUE	351
1993	TRUE	TRUE	TRUE	TRUE	TRUE	250
1994	TRUE	TRUE	TRUE	TRUE	TRUE	357
1995	TRUE	TRUE	TRUE	TRUE	TRUE	410
1996	TRUE	TRUE	TRUE	TRUE	TRUE	326
1997	TRUE	TRUE	TRUE	TRUE	TRUE	328
1998	TRUE	TRUE	TRUE	TRUE	TRUE	595
1999	TRUE	TRUE	TRUE	TRUE	TRUE	280
2000	TRUE	TRUE	TRUE	TRUE	TRUE	334
2001	TRUE	TRUE	TRUE	TRUE	TRUE	249
2002	TRUE	TRUE	TRUE	TRUE	TRUE	375
2003	TRUE	TRUE	TRUE	TRUE	TRUE	330
2004	TRUE	TRUE	TRUE	TRUE	TRUE	311
2005	TRUE	TRUE	FALSE	TRUE	FALSE	278
2006	TRUE	FALSE	TRUE	TRUE	FALSE	210

Appendix 2: Supplementary information to Chapter 3

Figure A 2.1: Introducing the PhD project to the farmers through a displayed poster in the Dowerin Field Days, 29 and 30 August 2007

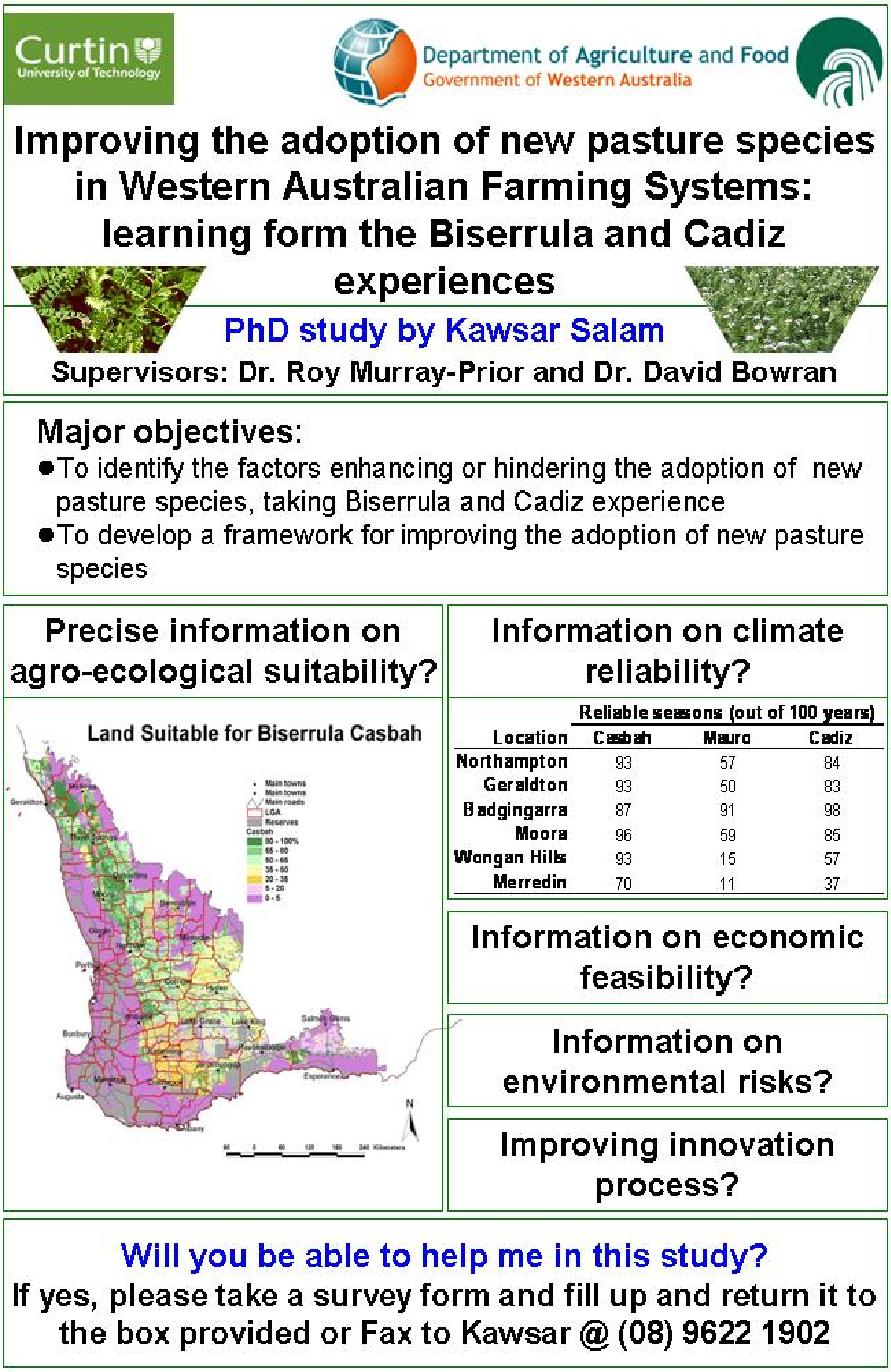


Figure A 2.2: Sample questionnaire used to gather information from farmers of Western Australian grain-belt on the characteristics of pastures that they dream for, and their experience with two annual pasture legumes, Cadiz and Casbah

Curtin University of Technology

Department of Agriculture and Food
Government of Western Australia

Please fill up this survey form and fax to Kawsar on 9622 1902 (DAFWA, Northam office)

Information will be used only for PhD study purpose to improve the development process for pasture species

Your Name:……………………………………………………………………………

Your Occupation:……………………………………Shire………………….………

Do you grow Biserrula pasture? Yes / No
If No: Used to / Planning to grow/ Not planning to grow/ Never heard of

What, if any, are the strengths of Biserrula:

What, if any, are the weaknesses of Biserrula:

Do you grow Cadiz pasture? Yes / No
If No: Used to / Planning to grow/ Not planning to grow/ Never heard of

What, if any, are the strengths of Cadiz:

What, if any, are the weaknesses of Cadiz:

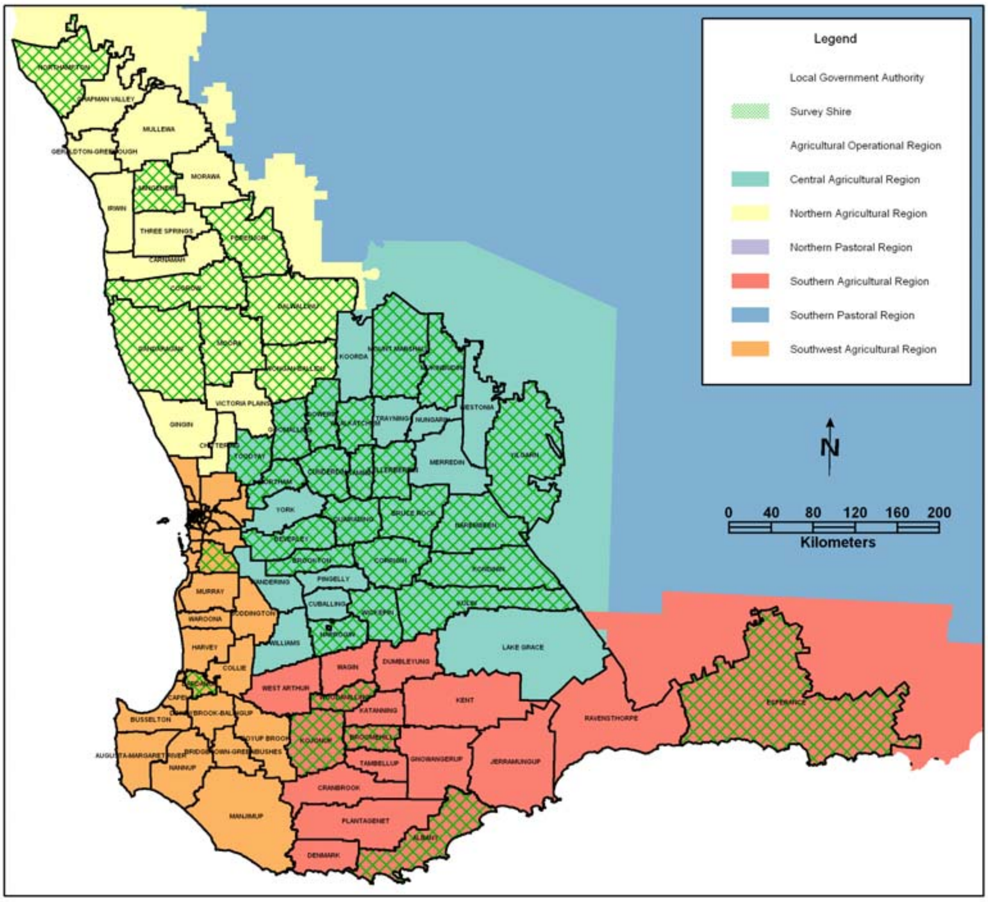
Do you have any suggestions on new pasture species research or tell me about your dream pasture species:

Can I contact you further for more info: Yes / No
If yes please provide your phone no:
Or your e-mail:

Thank you for your help.

Kawsar Salam PhD Student

Figure A 2.3: Map showing the shires (with crossed lines) of Western Australian grain-belt from where farmers' responded to the survey



Appendix 3: Supplementary information to Chapter 4

Table A 3.1: The values of three parameters for Weibull equation used to calculate the annual adoption rate (y) of 13 annual legume pastures in Western Austrlian grain-belt.

Annual pasture legume	Parameters of Wiebull equation[a]		
	a	**b**	**c**
Margurita	2.85	0.81	12.81
Erica	2.93	0.93	6.73
Charano	3.17	0.01	5.87
Santorini	3.61	0.01	18.24
Yelbeni	3.00	1.00	3.32
Dalkeith	11.94	0.02	43.06
Nungarin	3.14	0.00	19.95
Santiago	3.42	0.39	2.86
Caliph	3.13	0.72	2.30
Mogul	3.00	1.00	0.96
Prima	3.20	0.95	10.22
Hykon	3.00	1.01	0.58
Arrowleaf	3.02	0.97	1.69

[a] Wiebull equation (y = c + Exp(-(x/a)b) + (x/a)b). The parameters (a,b,c) were the derived using Mathematica® computer programme

Figure A 3.1: Sample questionnaire used to gather quantitative information from farmers of Western Australian grain-belt and two pasture breeders of the Department of Agriculture Western Australia on the of characteristics of two annual pasture legumes, Cadiz and Casbah in order to test and/or evaluate the empirical model on estimating achievable adoption potential of the two APLs

Curtin University of Technology — Department of Agriculture and Food, Government of Western Australia

Name:

Shire:

Please fill out this survey form and fax to Kawsar on 9622 1902 (DAFWA, Northam office)

Information will be used only for PhD study purpose to improve the development process for pasture species. Thanks a lot for helping me in the survey. This survey is specific to pasture attributes.

Please circle your score as 1, 2, 3, 4 or 5
1 is Poor/Low/Expensive
5 is Excellent/High/Cheap

Pasture attributes	**Casbah (Biserrula)**	**Mauro (Biserrula)**	**Cadiz (French serradella)**
Competition with other available annual pastures legumes	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Regeneration ability (when seeds on surface soil)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Regeneration ability (when seeds are buried)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Seedsetting	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Persistence	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Herbicide tolerance	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Grazing ability to control weed	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Potential DM (feed supply)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Feed quality	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Overall cost and management	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

I highly appreciate your help once again.

Mrs Kawsar Salam

PhD Student, Department of Agribusiness, Curtin University of Technology, Muresk

& TO, Centre for Cropping Systems, DAFWA, PO Box 483, Northam, WA 6401

Appendix 4: Persons consulted (different periods during 2007-2008) on various aspects of this study

- Ballard, Leigh Mr., Managing Director, Ballard Seeds, Western Australia
- Bowden, Bill Dr., Principal Research Officer, Department of Agriculture and Food Western Australia.
- Dymond, John Mr., Senior Lecturer, Department of Agribusiness and Wine Science, Curtin University.
- Dymond, Wendy Ms, Research Officer, Department of Agriculture and Food Western Australia.
- Ewing, Mark Dr., Professor, Future Farm Industries CRC, Research Director, The University of Western Australia.
- Loi, Angelo Dr., Pasture Breeder, Department of Agriculture and Food Western Australia.
- Longson, Ian Mr., Director General, Department of Agriculture and Food Western Australia.
- Nichols, Phil Dr., Pasture Breeder, Department of Agriculture and Food Western Australia.
- Nutt, Brad Dr., Pasture Breeder, Department of Agriculture and Food Western Australia.
- O'Dwyer, Roger Mr., Executive Director, Department of Agriculture and Food Western Australia.
- Revell, Clinton Dr., Senior Research Officer, Department of Agriculture and Food Western Australia.
- Wilson, Ben Mr., Elders (Northam), Western Australia

Appendix 5: Communications from this study

A5.1 Publication

A5.1.1 Refereed journal paper

Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2009, 'Cadiz and Casbah pastures in Western Australia: breeders' expectation, farmers' evaluation and achieved adoption', *Extension Farming Systems Journal*, vol. 5, no. 1, pp. 103-112.

Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2009, 'An empirical model to estimate achievable adoption potential of annual pasture legumes in Western Australian farming systems', *The International Journal of Technology, Knowledge and Society,* vol. 5, no. 6, pp. 43-64.

Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2009, 'A framework and its application for measuring adoption potentials of annual pasture legumes in Western Australia'. *Crop and Pasture Science* (submitted).

Salam, K.P., Murray-Prior, R., Bowran, D. & Salam M.U. 2010, 'A 'Dream' pasture and its comparison with two existing annual pasture legumes for Western Australian farming systems: a farmers' eye view', Livestock Research for Rural Development, vol 22, no. 9 (Sept issue).

A5.1.2 Refereed conference proceeding

Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2008, 'Pasture characteristics perceived by farmers of Western Australia in relation to adoption of annual pasture legumes', in *Proceedings of 14th Agronomy Conference,* September 21-25, Adelaide, South Australia.

Salam, K.P., Murray-Prior, R., Bowran, D. & Salam, M.U. 2009, 'A system for improving the fit of annual pasture legumes under Western Australian farming systems', in *Proceedings of Agribusiness Crop Updates 2009 (Section Farming Systems),* February 24-25, Perth, Western Australia, pp.152-155.

A5.2 Presentation

Poster: Agribusiness Livestock Updates, July 24-25 2007, Perth, Western Australia.

Oral: 14th Australian Agronomy Society Conference, September 21-25 2008, Adelaide, South Australia.

Oral: 5th International Conference on Technology, Knowledge and Society, January 30 to February 1, 2009, Huntsville, Alabama, USA.

Poster: 5th International Conference of Australasia-Pacific Extension Network, November 9-12, 2009, Busselton, Western Australia.