MFM0007: Viable crop and/or pasture legumes for alkaline soils in the high rainfall zone

Felicity Turner (Mackillop Farm Management Group) and
Amanda Pearce (South Australian Research and Development Institute)
Table of Contents

1.0 Project Background .............................................. 3
2.0 Introduction ...................................................... 3
3.0 Alkaline Soils of the Southern Region ......................... 4
   3.1 South East of South Australia ............................. 4
   3.2 Western Australia .......................................... 8
4.0 Grower Responses ............................................... 10
   4.1 Current on farm practice .................................. 10
   4.2 Perceived Issues to growing legumes on target soils .... 11
   4.3 Knowledge gaps and impediments to adoption .......... 12
5.0 Literature Review ................................................. 13
   5.1 Previous research .......................................... 13
   5.2 The drainage scheme ...................................... 13
   5.3 Pasture and pulse research and adaptation ............... 16
   5.4 Management issues of crop and pasture legumes on alkaline soils of the HRZ of Southern Australia .... 17
   5.5 Identified knowledge gaps and future research opportunities .... 19
6.0 Relevance to Western Australia ................................ 20
7.0 Conclusions ....................................................... 21
8.0 Recommendations for future research .......................... 21

References .......................................................... 22

Appendix 1 .......................................................... 26
1.0 Project Background

Reportedly there are few robust legume options for incorporation into cropping systems on alkaline soils in the high rainfall zone (HRZ) of southern Australia. The potential of this zone to significantly increase its contribution to the Australian cropping industry is restricted by this lack of adapted legume, which results in growers being reliant on fertiliser nitrogen to achieve high grain yield and quality.

Although this zone has a more reliable rainfall pattern it has diverse issues such as soil constraints, waterlogging, soil borne diseases, plant diseases, weed management issues, false breaks, poor spring finishes, topography limitations and the complexity of the management of mixed farming systems. These factors often preclude direct transfer of crop sequence knowledge and technology from lower rainfall zones.

Legumes currently exist as part of the farming system in the HRZ, however their use is often limited by soil and climatic characteristics. To further develop the viable expansion of cropping in the HRZ, more reliable legume options that are supported with specific agronomic packages to enable them to meet market requirements are required.

2.0 Introduction

The concept of viable pasture legumes for the alkaline soils in the HRZ has been previously explored by researchers in the south east (SE) of South Australia (SA). Pasture and crop legumes are grown on the inter-dunal plains of this region, where black and grey Vertosols and Calcarosols predominate. These soils contain varying degrees of carbonate in their surface horizons and there are limited adapted species that will tolerate the resultant high pH. Firstly this report will provide a situation analysis of the current on-farm practices with regards to the performance and management of crop and pasture legume species across alkaline soils in the HRZ; particularly in the SE region of SA. It will explore grower perceptions, and will allow an improved understanding of the knowledge gaps and impediments to adoption of legumes on alkaline soils, including limiting factors affecting production, and end-uses of legumes in these soils.

The situation analysis will focus predominantly on the Southern region, however relevance to the Western Region will be explored.

Secondly a literature review of previous research on adapted legume crop and pasture species for the identified alkaline soils in the HRZ of southern Australia, identifying knowledge gaps for future research will be presented.

Finally, recommendations will be made with regards to knowledge and skills gaps for future investment to improve the performance, production and eventually adoption of legumes on alkaline soils in the HRZ.
3.0 Alkaline Soils of the Southern Region

Figure 1 shows the areas of alkaline soils across parts of the Southern and Western regions; the areas within the high rainfall zone (HRZ) are predominantly in the SE region of SA with pockets located in Western Australia (WA). The areas identified as alkaline have pH (CaCl₂) > 7 at 30-60cms.

The GRDC definition of HRZ is where the growing season exceeds 9 months and rainfall is one third higher than evaporation. In this study, the more commonly used definitions have been used; for the Southern Region this is areas where annual rainfall is between 500mm and 900mm (figures used by DEDGTR Vic for HRZ projects) and in Western Australia, the areas where the annual rainfall exceeds 450mm.

Figure 1. pH ranges across southern and western Australia (30-60cms) (Rossel et al. 2015) (acid <5.5pHc, neutral to acid 5.5-6.55 pHc, neutral to alkaline 6.5 to 7 pHc, and alkaline >7 pHc).

3.1 South East of South Australia

Hall et al. (2009) report Calcarosols, Chromosols and Sodosols as the major alkaline soil types of the inter-dunal plains in the upper and lower SE, with black and grey Vertosols also present (Table 1 and Figures 2.1 - 2.5), accounting for more than 600,000 ha of land (Table 1).
Of the major soils in the HRZ, B5 shallow dark clay loams over calcrete/limestone are the most common Calcarosol, with A7 calcareous clay loams on marl also present (Table. 1 and Figures 2.1, 2.2). Whereas the surface chemical and mineralogical characteristics of these soil types are often similar, it is the morphology and induration (hardness and degree of cementation/compaction) of the underlying carbonate horizons that distinguish the two apart. Water infiltration and root exploration are likely to be affected in the former soil type with the presence of hard calcrete pans and limestone, in addition to the altered nutrient availability that occurs in alkaline soils.

Similarly, the black and grey Vertosols (E1 and E3 soils respectively) exhibit comparable chemical properties; however, it is their clay mineralogy that can set the two apart. These soil types are commonly associated with the gilgais that are found on the western side of the inter-dunal corridors (Figure 2.4) with the black Vertosols containing predominantly smectitic swelling 2:1 clays in the surface, which lead to their characteristic self-mulching behaviour and well aggregated surface appearance. In contrast, grey clays are not usually self-mulching, and can be massive to coarsely structured and hard setting in the surface (Hall et al. 2009); they have been found to be dominated by kaolinite and illite clay minerals in the surface (Fraser 2011), which results in lower fertility (cation exchange capacity). This characteristic makes them particularly prone to the deleterious effects of sodicity (dispersion).

The other major alkaline soil type found on the inter-dunal plains in the HRZ are the shallow sand over clay on calcrete (B7) Chromosols (Figure 2.3), however the elevated pH is commonly found deeper in the soil profile than for the Calcarosol and Vertosol types. The sandy textured A horizons of this soil type are commonly neutral to acidic and often water repellent, with the pH increasing in the subsoil as the clay and carbonate content increases; the subsoils commonly exhibit low permeability and are sometimes dispersive (Hall et al. 2009). The recent expansion of the artificial drainage network into the USE is likely to have affected a large area of these soil types and it is currently unknown what affect the reduction in soil water has had on soil chemical and physical properties in this soil type.

Sodosols are also a major alkaline soil type of this region, however, they are found predominantly in the lower rainfall zone of the USE (Figure 2.5) and therefore are not discussed further here.
Table 1. Predominant soils of the plains in South East SA with alkaline horizons.

<table>
<thead>
<tr>
<th>Soil Group¹</th>
<th>Predominant soil type²</th>
<th>Key characteristics¹</th>
<th>pH &gt; 8 (H₂O)¹</th>
<th>Location¹</th>
<th>Area (ha)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A7</td>
<td>Calcareous clay loam on marl</td>
<td>Calcarosol</td>
<td>Deep, well-structured, dark coloured fertile soils that become more clayey and calcareous with depth. High inherent fertility, although nutrient availability reduced by high pH. Prone to waterlogging due to high clay content and position in landscape.</td>
<td>&gt;0.15m</td>
<td>Upper &amp; Lower SE</td>
</tr>
<tr>
<td>B5</td>
<td>Shallow dark clay loam over calcrete/limestone</td>
<td>Calcarosol</td>
<td>Black well-structured clay loam to clay soils that commonly overlay shallow calcrite. High inherent fertility, but the rootzone is impeded by calcrite or high calcareous clayey substrate. Drainage is imperfect and inundation is common. Historically the watertable was within 1.5m of the surface. These soils occur almost exclusively in the SE of SA.</td>
<td>&gt;0.05m</td>
<td>Predominantly LSE</td>
</tr>
<tr>
<td>B7</td>
<td>Shallow sand over clay on calcrete</td>
<td>Chromosol</td>
<td>Shallow sandy topsoils with thin clayey subsoils that overlay calcrite, commonly within 0.5m. Moderately low inherent fertility and limited available water. Can be acidic in the surface and alkaline at depth.</td>
<td>&gt;0.25m</td>
<td>USE &amp; LSE</td>
</tr>
<tr>
<td>E1</td>
<td>Black cracking clay</td>
<td>Black Vertosol</td>
<td>Self-mulching dark grey medium clay over a coarsely structured heavy clay that becomes calcareous with depth. Often poorly drained and can become very sticky when wet.</td>
<td>&gt;0.5 m</td>
<td>Predominantly Eastern USE and LSE</td>
</tr>
<tr>
<td>E3</td>
<td>Brown or grey cracking clay</td>
<td>Grey Vertosol</td>
<td>Moderately deep clay soils that usually are not self-mulching at the surface. High inherent fertility but can often be high in boron and suffer sodicity and high pH throughout. Slow water infiltration and can be difficult to work.</td>
<td>&gt;0.05m</td>
<td>Predominantly Eastern USE and LSE</td>
</tr>
<tr>
<td>G4</td>
<td>Sand over poorly structured clay</td>
<td>Sodosol</td>
<td>Up to 0.3m sandy topsoil overlying a hard mottled, dispersive subsoil clay that becomes increasingly calcareous with depth.</td>
<td>&gt;0.25m</td>
<td>Predominantly USE</td>
</tr>
</tbody>
</table>

¹Hall et al. 2009
²Isbell 1996
Figures 2.1 – 2.5  Maps depicting the distribution of the major soil types in the SE with alkaline horizons. Soil types of major significance in the High Rainfall Zone are shown in 2.2, 2.3 and 2.4 (Maschmedt 2011).
3.2 Western Australia

Figure 3 shows the (WA) areas that are identified as being in the HRZ and alkaline in nature. The area around Jerramungup through to Ravensthorpe and south to the coast is the key identified area (Figure 4). The other area identified is south of Geraldton around Dongara. There are loamy/clay soils in this region as indicated by the green areas on the map – these were initially alkaline but have become more neutral over time. There are also alkaline coastal sands as indicated by the purple areas on the map – this area is relatively small and is dominated by livestock and pastures.

Figure 3. Western Australia; alkaline soil in the HRZ (Holmes 2015).
The alkaline soils on the South Coast of Western Australia are generally clays and shallow loamy duplex soils. The distinguishing features of these soils include hard loams and clay at the surface, with dense poorly drained loamy to light clay subsoils. The subsoils can range from mildly acidic to highly alkaline with carbonate at depth, and saline and sodic subsoils are common (Hall, 2014; Hall and Ryan 2015).

These soils are described by the Australian soil classification system as yellow or brown Chromosols, yellow or brown Sodosols (508), grey or yellow Dermosols, and grey or yellow Kandasols (621).
4.0 Grower Responses

Information was obtained from a cross-section of growers across the SE of SA to gain an understanding of current farm practices, and the issues with regards to growing legumes on alkaline soils across the region.

This information was obtained through a series of processes, including facilitated group sessions and face to face interviews (42 growers and agribusiness representatives), phone interviews (29 growers and agribusiness representatives; including some from WA) and email surveys (18 responses). These were conducted from February through to April 2015.

4.1 Current on farm practice

Growers were asked questions around their current farm practices; their farming system, the role of legumes in their system, and their soils.

Farming System:

86% of farmers who responded had mixed farming systems, where cropping and livestock were both an important part of their system.

12% of farmers were 100% livestock, with pasture renovation being carried out regularly, and opportunistic hay production. If needed, these farmers brought in feed from off-farm to fill livestock gaps as opposed to producing it themselves.

4% of farmers were 100% cropping, however some of these leased out their stubbles and grazing land to neighbours, with one working collaboratively with a livestock business to grow feed, including agisting stock on dual purpose crops.

Role of legumes in the system

100% of growers (from across all farming systems) were aware of and listed multiple benefits of having legumes in the system. The reasons legumes were seen to be important included;

- Nitrogen benefits;
- Break crop benefits (disease and weed control in cropping systems were the main reasons listed);
- General soil health benefits (ie. a more sustainable system), and
- Livestock benefits; legumes as grazing species in mixed farming systems provide a balanced grazing feed base, and pulse stubbles provide quality feed over the dry summer period.

Legume species currently grown

100% of growers were growing legumes on their farm; key species and their end-uses included;
- Faba beans and broad beans – for grain production and stubble value to livestock enterprise
- Clovers (sub-clover, shaftal, strawberry and balansa) – for small seed production and for grazing
- Medics – for grazing
- Lucerne – for grazing

Some other secondary species that a few people had tried included spring-sown peas, sulla and vetch (vetch predominantly on the lighter ground).

Growers have reported that these identified key legume species are widely grown across the black vertosols in the interdunal plains (refer to Table 1), but ‘issues’ start to arise on the grey vertosols and the calcarosols across the region (ie. those soils with high pH throughout the profile, and that are not self-mulching).

**4.2 Perceived issues to growing legumes on target soils**

60% of the growers surveyed had some of the identified target soils (ie. either grey vertosols or calcarosols) on their farms, where they experienced issues growing legumes. These soils have a high clay content and tend to experience extended periods of inundation. The occurrence of these soils amongst growers varied from whole farm areas through to pockets within paddocks.

Growers identified the following as perceived issues/impediments to growing legumes on these target soils:
- Soil pH;
- Soil temperature - is it affecting production or the uptake of nutrients?;
- Crop nutrition – the supply and accessibility of nutrients;
- Waterlogging - prolonged anaerobic conditions; and
- Weed control - poor crop or pasture competition results in increased weed populations.

Historically faba beans and broad beans have been tried on this country, they are described as “establishing and growing well until they ‘hit a barrier’, where they then become waterlogged and die”. The beans that survive and grow through the cold, wet winter months often go on to produce smaller beans (2nd grade bean), and therefore do not meet market standards.

Suggested reasons from growers as to the poor performance of beans include:
- High pH; stopping something from happening in the soil – possibly adequate nutrients but plants unable to access due to high pH;
- Poor root establishment, roots don’t travel down into the soil and turn black;
- Not getting effective nodulation and/or can’t access nitrogen; and
- Iron and/or trace-element deficiencies aren’t understood well and coupled with inaccessible paddocks in winter months prevent these deficiencies from being adequately addressed.
Other legume options that growers have tried on these soils include:
- Peas - spring sown peas survive, but often become a hay/grazing option if low spring rainfall is received;
- Clovers - go dormant over winter then start to grow better in spring. Clovers have management issues with pests (particularly snails); and
- Lucerne - autumn and August establishment can be successful, but August/Spring establishment is reported as being more effective. Persistence is an issue with lucerne, with plants turning yellow and becoming unpalatable, although the plants generally grow through the winter to provide spring feed.

All of the growers who cropped (either in a mixed farming system or 100% cropping) suggested that beans are the preferred pulse option as there are existing markets, delivery points and the additional benefits to the mixed farming system with added feed value of stubbles and crop residues.

Clover seed production is in some cases a viable option, but only if the grower has an existing contract or relationship with a seed supplier. The small seeds market is extremely volatile, and it is generally only long-term growers who can obtain contracts.

Clover species for grazing is also a possibility, however the lack of winter growth is of great concern, as is the management of annual ryegrass in these stands.

4.3 Knowledge gaps and impediments to adoption

Growers were asked “what did they need to know” to help them successfully grow legumes on these soils.

Key responses included;
- Beans - what is limiting production and profitability (evaluation of strategies to mitigate limitations);
- Soils – what is happening; are plants able to access nutrients:
  - If not why not?;
  - What are the additional nutrient requirements of these soils?; and
  - Is there the ability to remediate soils to reduce pH or increase iron availability?
- Evaluation of legume crop and pasture species on the grey Vertosol and Calcarosol soils
  - Variety specific agronomy packages to maximise rotational benefits;
- Quantify rotational benefits of the suitable legume species; effectiveness of N\textsubscript{2} fixation of various crop and pasture legumes and effects on weed seed-banks; and
- Is nodulation effective and is inoculation required and/or effective (only 30% inoculated beans every year; the remainder were relying on soil borne inoculum still being present in the soil.
5.0 Literature review

5.1 Previous research

The cropping area on alkaline soils in the SE of SA has historically been relatively small. As a consequence there has been limited research on crop and/or pasture legumes for this area.

Craig and Rowe (1992) identified the lack of productive and persistent annual pasture legumes suitable for this environment, reporting that subterranean clover \((Trifolium subterraneum)\), annual medics, Persian clover \((Trifolium resupinatum)\) and strawberry clover \((Trifolium fragiferum)\) are sown with minimal success. Subterranean clover fails as a result of high soil pH, while the annual medics do not survive waterlogging. Persian clover is well adapted but lacks persistence and strawberry clover is also adapted but often fails to persist over the dry summer period. As a result of this knowledge gap Craig and Rowe (1992) evaluated fifty-three species to identify suitable productive and persistent pasture legumes. Relatively few offered promise, attributed to inundation and poor adaption of species to soil type. Persian clover performed strongly and subsequent testing led to the development of cultivar Kyambro Persian clover, a hard-seeded variety adapted to waterlogging and alkaline soils (Craig 1985). Kyambro Persian clover is no longer available and has not been superseded, leaving a serious deficiency in suitable pasture legumes. Other species of interest identified were \(Trifolium clusii\), \(Trifolium lappaceum\), \(Trifolium leucanthum\), \(Trifolium meironense\) and \(Trifolium setiferum\), none of which have been commercialised.

In the HRZ Zhang et al. (2006) has highlighted the poor adaption of crop cultivars, due to the higher rainfall, the longer and cooler growing seasons and the longer period of high frost risk. It has been reported by various studies (Kirkegaard et al. 2008; Riffkin et al. 2012) that crops must be adapted physiologically to the longer growing seasons that occur in the HRZ.

Since this research was undertaken the regional landscape has altered drastically with the recent expansion of the drainage network (1997 to present), a gradual reduction in rainfall and the widespread lowering of standing water levels throughout the region. There is limited knowledge on the impact of the change in hydrology on soils, sub-soil constraints and the subsequent potential change in legume adaption to these environments.

5.2 The drainage scheme

The landscape of south east South Australia is characterised by a series of relic coastal dune ranges that run parallel to the current coastline in a north westerly orientation, separated mostly by low-lying inter-dunal corridor plains. The topography of the region provides little natural relief for surface water runoff, which when combined with the presence of a shallow unconfined aquifer and relatively high rainfall has historically resulted in surface water inundation on the inter-dunal plains in most years.
Whereas the dune ranges are characterised by sandy soils with low inherent fertility, the plains are typically more fertile, possessing clay in the surface and sub-surface horizons and given the climate of the region, are considered to be some of the most agriculturally productive and valuable soils in the State. Their production potential can, however, be impaired due to the presence of carbonates in the soil (with varying degrees of induration), hostile chemical condition (high pH, sodicity, salinity, boron), poor internal drainage and the seasonal surface water inundation previously discussed.

Given the productive potential of the soils of the inter-dunal plains, an extensive artificial drainage network has been engineered throughout the lower and, more recently, upper south east, with initial drain construction dating back as far as 1864 near Millicent (South East Catchment Water Management Board 2003). The drainage network in the LSE expanded steadily through the late 1800’s up to 1950, primarily channelling surface waters to the north; the construction of the Jackie Whites and Blackford drains from 1950-1972 finally diverted drain water to the coast instead.

Since this time, the private network of shallow drains has expanded considerably and from 1997 – 2009 the Upper South East Dryland Salinity and Flood Management Program was implemented to address the effects of salinity and waterlogging in the USE. This program saw the construction of a number of major drains such as the Fairview and Bald Hill (Figure 5), adding an additional 714 km of drainage network in the USE to the existing 1875 km of infrastructure in the LSE (Department for Water 2012).

It is widely believed that the artificial drainage network has facilitated the lowering of standing water levels in the unconfined aquifer throughout the SE and anecdotally is reported to have reduced the incidence and permanence of surface water inundation on the plains. This was found to be true in a study conducted by Fraser (2011), whereby standing water levels in observation well MNC001 (which is in close vicinity to the Fairview drain on the Avenue Plain) fell from a mean 0.82 m pre drain construction (1993 – 1997) to a mean 1.33 m below the surface of the soil since the drains construction in 1997; this trend was consistent for a number of other wells investigated. The study concluded that the lowering of groundwater levels in the Keilira district of the Avenue Plain had led to the partial amelioration of soil salinity (dependant on soil type), but highlighted that high soil pH was still a limitation to productivity, in addition to the expression of sodicity that had since been observed with the lowering of soil salinity (electrical conductivity). It also identified that the range of soil types and their associated clay minerals present across the inter-dunal corridor responded differently to the effects of drainage (Fraser 2011).

Much of the agriculturally productive land in the HRZ of the LSE and southern parts of the USE have historically been utilised for livestock production, however the implementation of the broad scale drainage network in combination with improved practices and drier than average seasons has seen broadacre cropping become increasingly popular throughout the region. Whereas the drainage network has successfully aided the amelioration of salinity and seasonal water inundation in some places, it has not and cannot address the issue of inherently high soil pH and sodicity without the implementation of specific management practices. Recent anecdotal evidence suggests that farmers of this region are not achieving the full productive potential of their crops and pastures and have limited success with legumes
on certain soil types, with alkalinity suspected as the major cause. ‘Grey’ soils that are unstable when wet have been identified by a number of farmers as being troublesome to manage.

Figure 5. Regional water courses and drainage infrastructure of the South East of SA (Department for Water 2001).
5.3 Pasture and pulse research and adaptation

Pastures:

Craig et al. (2013) evaluated 16 commercial annual legume cultivars and five perennial legume cultivars at an alkaline site in the HRZ, with the aim of identifying suitable legumes for the post drainage environment. The trial site is typical of the target zone, low salinity, strongly alkaline, winter waterlogged, high free lime which ties up iron and manganese. A number of annual legumes performed well although the perennial legume, lucerne, appeared to be a more consistent performer over the two years evaluated. Mogul barrel medic, Scimitar and Cavalier burr medic, Paraponto gama medic and Antas subclover were the best annual legume performers. Of interest is the new pasture species Sulla, which performed comparably to the annual legumes (Craig et al. 2013). Sulla is an erect, short-lived perennial legume, preferring fertile sandy loams-clays with pH cacl2 5.5-8.5. It is suited to production of high-quality fodder (hay or silage) or for direct grazing and can be used as a 2-year pasture phase in rotation with cereal crops. It must be noted that in the mixed farming environment of the SE cultivars would need to be carefully managed according to their grazing tolerance.

In earlier research subterranean clover failed due to the high pH. Antas subterranean clover subspecies *brachycalyicum* performed well in the alkaline soils (Craig et al. 2013). Subspecies *brachycalyicum*, ‘brachy types’, are adapted to neutral-alkaline cracking or stone soils (Katznelson and Morley 1965) and therefore may be a suitable option for this environment.

Although lucerne is grown in the region and has considerable advantages as a pasture and fodder legume, it is intolerant of waterlogged soils (Humphries and Auricht 2001). Annual medics also tend to fail in waterlogged environments. The construction of the drainage scheme may have altered the landscape in such a manner that lucerne and annual medics may be viable for the region, as suggested in Craig et al. (2013).

*Melilotus albus* (Evans and Kearney 2003) (cultivar Jota) has been reported as being productive on neutral to alkaline soils in the high rainfall zone of south-western Victoria, although not waterlogged soils. Messina (*Melilotus siculus*) is currently being developed for saline waterlogged environments (Nichols et al. 2012). Both *Melilotus* species have been evaluated in the SE of SA and may have a productive place in the mixed farming landscape of the alkaline soils in the HRZ.

Pulses:

The development and adaptation of pulses for the HRZ has not been as extensive as it has been for wheat and canola. The majority of effort in pulse cultivar and agronomy package development has been focused in the MRZ and LRZ.

Despite this, faba beans and broad beans varieties and agronomic management continue to be evaluated on a small scale on alkaline soils in the HRZ via the GRDC National Variety Trials, Pulse Breeding Australia faba bean trials, Southern Pulse Agronomy Trials (i.e. Brand et al. 2013, 2012, 2011, 2010) and Mackillop Farm Management Trials (i.e. Mackillop Farm Management Group 2014, 2013,
2012, 2011). In current variety evaluation trials there are faba bean lines that are being targeted for the HRZ.

Manafest faba bean (Hawthorne and Paull 1999) was developed by Dr. Jeffery Paull, Dr. Ron Knight (Waite Institute Faba Bean breeding Program) and Wayne Hawthorne (SARDI) and is suited to the SE of SA. It was selected for the SE because it tolerates iron and manganese chlorosis, has increased early vigor and good yields. This variety will be re-evaluated in Mackillop Farm Management Group bean variety trial on an alkaline soil in the HRZ in 2015.

Solaiman et al. (2007) compared several cool-season pulses, which showed that faba bean was most tolerant of waterlogging followed in order by yellow lupin, grass pea, narrow-leaved lupin, chickpea, lentil and field pea. Subsequent screening identified variation in waterlogging tolerance within the faba bean species suggesting genetic improvement of tolerance is possible.

Copping et al. (2000) highlighted potential pulse crops for the lower SE and found that lentils do not tolerate waterlogging, peas tolerate mild waterlogging (and therefore may be suitable, as a number of growers currently have them in their rotations) and chickpeas will not tolerate waterlogging and have a high threat of disease, making them unsuitable. Vetch may be an option as it can be grown successfully on sandy soils through to clays and it is versatile (multi-purpose grain, grazing, green manure and hay, although the market size for vetch grain is limited) option for growers. Vetch was also amongst the best performing species in Craig et al. (2013).

Extensive literature review has found limited research on these soils and associated legume options, not only in the SE of SA but nationally and internationally.

5.4 Management issues of crop and pasture legumes on alkaline soils in the HRZ of Southern Australia

Soils:

It is important that grower’s soil sample their paddocks regularly and consider these results when selecting species and cultivars. Current practice involves only sporadic sampling of paddocks; often the sampling is conducted at different times in the season and lacks a consistent approach and path to allow for on-going monitoring. The large variation in pH both within and between paddocks can vary the production of the same species. Given the reduced incidence of surface water inundation now observed across the region many farmers may now be able to grow more diverse species than originally thought (Craig et al. 2013). In addition, it is likely that some of the soils are also affected by the deleterious effects of sodicity, which leads to dispersion and waterlogging in the surface horizons when wet, and high soil strength when dry. Boron toxicity may also play a part in reducing productivity, in addition to the reduced availability of phosphorous and iron. Thorough chemical investigation of the soil types affected is required and farmers need to implement appropriate management strategies to overcome the chemical and physical constraints that are present.
**Grazing:**

As the HRZ of the SE is dominated by mixed farming systems the tolerance of species/cultivars to grazing must be considered, as not all are suited to grazing and grower practice must reflect this.

**Nitrogen fixation:**

Paramount to crop/pasture legume success is nodulation and N₂ fixation. In Australia the symbiotic performance of legume crops and pastures is highly variable in the field and extensive reviews (i.e. Peoples and Baldock 2001; Unkovich et al. 1997) have highlighted the large variation in percent of shoot nitrogen derived from fixation for several major crop and pasture legumes, such as field peas and subterranean clover. Peoples and Baldock (2001) also found that N₂ fixed for annual pasture legumes does not correlate well with annual rainfall. The high variability observed demonstrates the complexity of N₂ fixation in the field which is influenced by numerous abiotic (temperature, soil chemistry, soil physical properties, agricultural chemistry) and biotic (pathogens, rhizobial and other microbial populations) factors in the soil (Drew and Ballard 2010). Faba beans have been shown to require inoculation with the appropriate rhizobia particularly where they are subjected to any transient waterlogging (Slattery et al. 2003; Johnson et al. 2006). Research on nodulation and N₂ fixation problems on alkaline soils tends to be focused on lower rainfall environments (i.e. Brockwell 2001; Drew and Ballard 2010) with HRZ research focused on different soil types (not alkaline soils), reiterating the uniqueness and limited knowledge of the alkaline soils found in the HRZ.

**Disease and pest management and weed control:**

Plant disease is identified as a major constraint in the HRZ. Studies focusing on crops other than legumes i.e. canola, have highlighted the potential yield losses due to plant diseases that can be expected (Kirkegaard et al. 2006; Lisson et al. 2007). Agronomic management of pulses is evaluated in small trials in the target environment, but the majority of research is targeted for the MRZ and the LRZ (i.e. Brand et al. 2013, 2012, 2011, 2010). The major diseases in pulses (particularly beans) across the region include ascochyta, chocolate spot, rust, cercospera and alternaria. Growers generally follow a set spraying regime to pro-actively manage disease at the critical stages (Hawthorne et al. 2012); the challenge is when the paddock either becomes impassable due to waterlogging, or adverse spraying conditions persist for weeks at a time.

Pest management in these environments is extremely challenging; snail species (including Cochlicella Barbera – the small pointed conical; Cochlicella acuta – the round pointed conical and the common round snail Theba Pisana are all widespread across these alkaline soils, and due to the lack of trafficability in winter, often challenging to control. The coastal environment makes it difficult to achieve ground temperatures high enough to use a lot of the cultural methods outlined in the GRDC ‘BashEm BurnEm BaitEm’ publication, and small seeded legume crops and regenerated pastures are often impacted, with the snails sitting on the emerging seedling and destroying the growing point.

Weed control is often a driving force behind which species growers select. With the increase in resistance of ryegrass to the major pre-emergent and selective herbicides (i.e. Owen et al. 2007;
Boutsalis et al. 2008; Boutsalis et al. 2012; Aman et al. 2008) a reduction in reliance upon herbicides for control of weeds is desirable. In the HRZ weeds continue to germinate as the crop matures, making it more problematic compared to drier areas. Pasture phases in crops rotation can be used to target problematic weeds. Pasture-topping and crop-topping are strategies that are increasingly being used as weed control measures. Research in weed control and management is being undertaken in the HRZ (i.e. Celestina 2012; Hisdon and Celestina 2012; Vague and Paridaen 2013; Watson and Celestina 2013) and crop-topping of pulses is currently being investigated in the target environment (Brand et al. 2013, 2012).

5.5 Identified knowledge gaps and future research opportunities

Limited evaluation of potentially adapted crop/pasture legumes:

Since the development of Kyambo Persian clover and Manafest faba bean there has been limited advancement of adapted species for alkaline soils in the HRZ. There has been no replacement for Kyambo Persian clover, resulting in a severe deficit in suitable pasture options.

There is the potential to:

- Evaluate a diverse array of commercially available crop and pasture legumes cultivars to determine if any are suitable for the target zone;
- Evaluate alternative crops such as Sulla, vetch, crimson clover and arrowleaf clover;
- Re-evaluate previously identified non-commercial species of interest (Trifolium clusii, Trifolium lappaceum, Trifolium leucanthum, Trifolium meironense and Trifolium setiferum);
- Develop agronomic management packages for adapted species specifically grazing management, weed control, pest management and disease management;
- Evaluation of grazing lucerne and annual pasture legume (such as Scimitar burr medic) to boost winter feed levels;
- Review late flowering medics (M. Arabic, M. polymorpha, M. tornata, M. truncatula);
- Conduct research into legume species specifically adapted to the HRZ (GxE); and
- Consider the collection of late season pasture accessions held by SARDI to match maturity with rainfall.

Inadequate understanding and extension of limited knowledge of the soils and crop and pasture legume species adaptability:

There is a need to evaluate soils post the expansion of the drainage scheme and in the current climatic and land-use situation. This could be done via growers re-testing paddocks or a larger scale survey.
Restricted research into nodulation and N₂ fixation on alkaline soils in the high rainfall zone:

There is no comprehensive understanding of the size and effectiveness of resident rhizobia populations in the region, and therefore recommendations cannot be given regarding inoculation of legume crops.

There is a need to increase knowledge on N₂ fixation in the region and understanding of the influencing abiotic (temperature, soil chemistry, sub-soil constraints, soil physical properties, agricultural chemistry) and biotic (pathogens, rhizobial and other microbial populations) factors in the soil.

6.0 Relevance to Western Australia

The ‘target soils’ identified by the growers in the SE of SA as causing issues with producing legumes are essentially unique to South Australia. They are predominantly the grey vertosols and calcarasols; both of which have high alkalinity at the surface, and that alkalinity increases through the profile.

The alkaline soils of the HRZ of WA are chromosols; these soils generally have a neutral to an acidic topsoil with increasing alkalinity at depth (Hall, 2014; Hall and Ryan 2015). Although these soils are also present in the SE of SA, they are generally sandy or sandy-loam topsoils, and are dominated by other issues such as water repellency in the topsoil that affect their management more than the sub-surface alkalinity. Throughout the surveying process, these soils have not been identified by growers as impeding on legume growth and productivity due to issues with high pH.
7.0 Conclusions

Through the grower consultation and review of previous research, various gaps in knowledge and skills have been identified; both at a research and grower level. The soils identified by growers as being those that do not support legume production due to alkalinity are generally unique to the SE region of SA, and the combined area of these ‘target’ soils is approximately 180,000 hectares.

Historically some research on legume species has been conducted across the region – this research has predominantly been in pastures. With the implementation of the drainage scheme, there has been an increase in broadacre cropping, and the productive capacity of the land from a grains perspective has increased dramatically.

The lack of knowledge around the behavior and management of alkaline soils and legume species adapted to these environments continues to affect whole farm profitability. In the cropping systems, there is a continued reliance on bagged nitrogen for cereal and oilseed grain production, and in mixed farming and grazing systems, there remains a large area that is utilized purely for low quality grass dominant pasture production due to the perceived soil constraints.

8.0 Recommendations for Future Research

Outcome: Legumes on alkaline soils in the HRZ maximizing whole farm profitability by maximising productivity, achieving market standards, and providing benefits to the subsequent grain crops.

This would be achieved through;

1. Education around alkaline soils under changed groundwater hydrology, and evaluation of soil amelioration/remediation and crop nutrition on legume production
2. Evaluation of crop and pasture species on the grey vertosol and calcarosol soils of the SE; with the aim to develop variety specific agronomy packages that maximize winter production, weed control and nitrogen fixation
3. Research into effects of pH on nodulation; rhizobia persistence and legume performance in the grey vertosol and calcarosol soils across the HRZ regions of the SE of SA
References


Brand J, Lines M, McMurray L, Gaynor L, Armstrong E (2010) 2010 Results Summary - Results from the DPIVic, SARDI, I&INSW and GRDC funded project: 'Expanding the Use of Pulses in South-Eastern Australia (DAV00113)'. Future Farming Systems Research Division, Department of Primary Industries, Horsham, Victoria.

Brand J, Lines M, McMurray L, Gaynor L, Armstrong E (2011) 2011 Results Summary - Results from the DPIVic, SARDI, NSW DPI and GRDC funded project: 'Expanding the Use of Pulses in South-Eastern Australia (DAV00113)'. Future Farming Systems Research Division, Department of Primary Industries, Horsham, Victoria.


Brand J, Lines M, McMurray L, Gaynor L, Armstrong E, O'Connor G, Koetz E (2013) 2013 Results Summary - Results from the DPIVic, SARDI, NSW DPI and GRDC funded project: 'Expanding the Use of Pulses in South-Eastern Australia (DAV00113)'. Future Farming Systems Research Division, Department of Primary Industries, Horsham, Victoria.


Copping K, Potter T, Hawthorne W (2000), Spring sowing options for the Mid and Lower South-East of South Australia and Kangaroo Island. Southern Farming Systems Limited, GRDC.


Holmes K (2015) Department of Agriculture Food and Western Australia.


Appendix 1

Contributors:

Researchers

- Mr. Ross Ballard, Senior Research Scientist, Plant and Soil Health – South Australian Research and Development Institute.
- Dr. Jason Brand, Senior Research Agronomist, Pulses - Department of Economic Development, Jobs, Transport and Resources.
- Mr. Andrew Craig, Former Senior Research Scientist, South Australian Research and Development Institute.
- Dr. Melissa Fraser, Sustainable Agricultural Consultant - Rural Solutions SA.
- Mr. Paul Galloway, Spatial Research Scientist, Department of Agriculture and Food, Western Australia.
- Ms. Karen Holmes, Research Officer, Department of Agriculture and Food, Western Australia.
- Mr. Jake Howie, Senior Research Scientist, Feed and Forage – South Australian Research and Development Institute.
- Mr. Larn McMurray, Senior Research Scientist, New Variety Agronomy – South Australian Research and Development Institute.
- Dr. Phillip Nichols, Senior Research Officer, Feedbase for Sheep, Department of Agriculture and Food, Western Australia.
- Dr. Jeffery Paull, School of Agriculture, Food and Wine, The University of Adelaide.
- Mr. David Peck, Senior Pasture Scientist, Feed and Forage - South Australian Research and Development Institute.
- Mr. Mark Seymour, Department of Agriculture and Food, Western Australia.
- Mr. David Hall, Department of Agriculture and Food, Western Australia.

GRDC panel members and regional cropping solutions network

- Dr. Mike Ewing, GRDC Western Panel.
- Jen Lillecrapp, HRZ RCS Facilitator.
- Trent Potter, HRZ RCS Facilitator.
- Lachie Seears, HRZ RCS Participant.

Various Agribusiness representatives and Growers from across the SE of SA, and southern WA.