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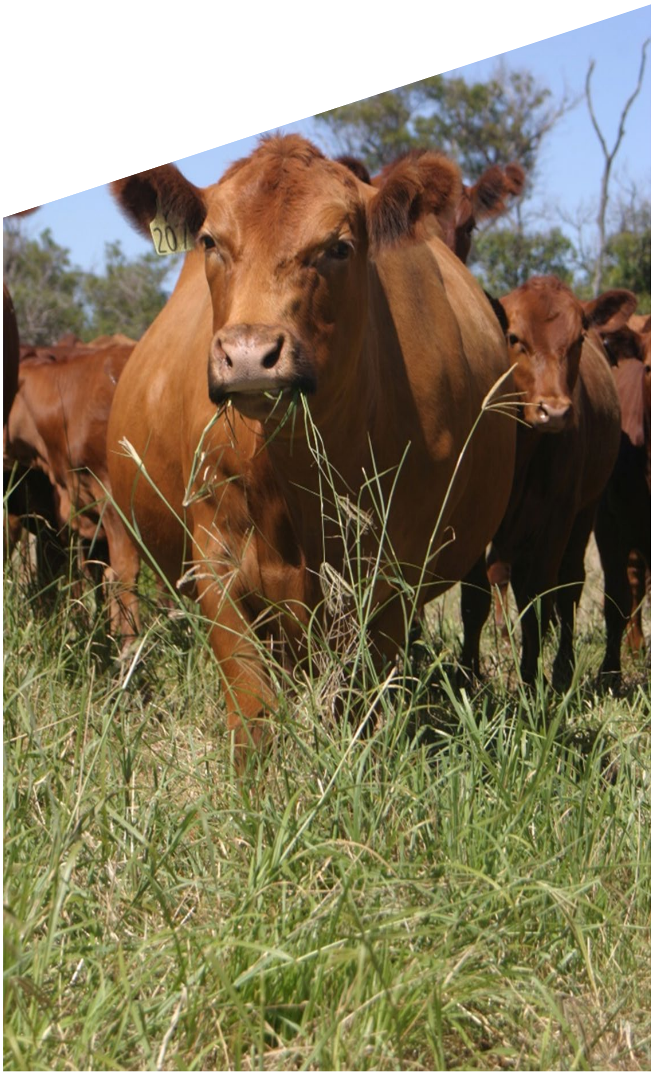

RESILIENCE IN THE FACE OF CHANGE - PASTURES FOR THE FUTURE

Virtual Symposium

March 2021

Resilience in the Face of Change – Pastures for the Future

Proceedings of an Australian Grassland Association Inc Virtual Symposium

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Program for the Virtual Symposium

Wednesday 10th March 7:00-9:00pm AEDT (4:00-6:00pm AWST)	
Plant improvement for the future	
Chair: Richard Simpson, CSIRO	
Rowan Smith (TIA)	A history of Australian pasture genetic resource collections
David Peck (SARDI)	Genetic analysis of boron tolerance in burr medic (*Medicago polymorpha* L.).
David Peck (SARDI)	Intraspecies diversity of yield, persistence, nutritive value and in vitro methane production using forage chicory.
Deirdre Harvey (NSW DPI)	Potential of commercial rhizobial strains for new and existing perennial pasture legume cultivars on the NSW Tablelands.
Robert Jeffery (UWA)	Salinity tolerance and avoidance mechanisms at germination among messina (*Melilotus siculus*) accessions from diverse origins.
Wednesday 17th March 7:00-9:00pm AEDT (4:00-6:00pm AWST)	
Pasture systems for a changing climate	
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Suzanne Boschma (NSW DPI)	Tropical perennial grasses: an opportunity to build the resilience of south-east Australian grazing systems in a changing climate
Geoff Moore (WA DPIRD)	The search for resilient perennial pastures for a Mediterranean environment in face of a changing climate – brief history for Western Australia.
Keith Pembleton (USQ)	Climate change effects on pasture based dairy systems in south-eastern Australia.
Mark Norton (NSW DPI)	Differences in dehydration tolerance affect survival of white clover and lucerne.
Rachelle Meyer (U Melb)	The potential of deep-rooted species to address the impacts of heatwaves on pastures in southeast Australia.
Wednesday 24th March 7:00-9:00pm AEDT (4:00-6:00pm AWST)	
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Mary-Jane Rogers (Ag Vic)	Management options to improve perennial ryegrass survival and resilience when irrigation is restricted during summer.
Richard Hayes (NSW DPI)	Sowing configuration changes competition and persistence of lucerne (*Medicago sativa* L.) in mixed pasture swards.
Carol Harris (NSW DPI)	*Medicago sativa* and *Desmanthus virgatus*: suitable perennial legumes in mixes with *Digitaria eriantha* in Australia during drought.
Wesley Moss (UWA)	Vacuum harvesting sucks: improving the Horwood Bagshaw Clover Harvester.
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David Rogers (WA DPIRD)	Soil test phosphorus critical values from "Better Fertiliser Decisions for Pasture" - fact or fiction?
Jonathan McLachlan (UNE)	Critical external P requirements and yield potential of nine *Desmanthus* spp. genotypes.
Ross Ballard (SARDI)	Sensitivity of the messina symbiosis to low pH.
Paul Sanford (WA DPIRD)	Identifying the cause of recent outbreaks of subterranean clover red leaf syndrome in Western Australia.
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Contents

Introduction

Welcome to the Australian Grassland Association (AGA) virtual symposium on 'Resilience in the Face of Change – Pastures for the Future'. This is the fifth in a series of AGA research symposia following on from the 'Australian Legume Symposium' (2012), 'Perennial Grasses in Pasture Production Systems' (2014), 'Livestock Productivity from Pastures' (2017) and 'Soil constraints to Pasture Productivity' (2019).

The Australian Grassland Association Inc. (AGA) was established to facilitate the ongoing improvement and development of the pasture industry. We do this through providing a forum which brings together a wide range of industry stakeholders in order to:

- Facilitate the interaction and exchange of ideas and provide an opportunity for research to be presented and published;
- Provide an opportunity for all interested stakeholders to review and contribute to the advancement of pasture-based industries through science; and
- Consider and discuss the state of the pasture industry and the research needed in order for it to meet the challenges of today and be prepared for the future.

This symposium, 'Resilience in the Face of Change – Pastures for the Future', will include themes of plant improvement, pasture systems for a changing climate, management for sustainable pastures, and adaptation to challenging soils, pasture pests and disease. As with the previous symposia, we are working a special issue of the journal Crop & Pasture Science containing the papers presented at the symposium. In the past our special issues have been highly successful and rank as some of the most viewed online.

The symposium will be conducted as a virtual event due to the COVID19-related travel restrictions. There will be opportunities to ask questions of the presenters and we encourage your participation in the discussion sessions. We thank Cussons Media who have made sure that the technology for the event runs smoothly.

We would also like to thank the symposium sponsors Dairy Australia, Meat & Livestock Australia, Barenbrug, PGG Wrightson Seeds and the Cooperative Research Centre for High Performance Soils.

We trust you will have an informative and enjoyable symposium.

Kind Regards,

Australian Grassland Association committee

A history of Australian pasture genetic resource collections

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Abstract: The introduction of exotic pasture germplasm has formed the foundation of many Australian grazing systems. Scientists have searched the world for plants to improve the feedbase, amassing collections of diverse genetic material, creating genebanks that have made a large contribution to feedbase productivity. These genebanks contain an enormous range of legumes, grasses, herbs and shrubs with growth habits ranging from small herbaceous plants to woody trees and life cycles from annuals to short and long-term perennial plants. They have been collected from cool temperate to tropical climates and arid to high rainfall zones.

Hundreds of cultivars have been developed from material either collected by Australian plant breeders overseas or introduced from overseas genebanks. The collection of this germplasm has enabled plant breeders to extend the area of adaptation of species into climates, soils and systems previously considered marginal. The importance to Australian and world agriculture is increasing as plant breeders seek traits to meet the challenges of a changing climate and animal production systems. Furthermore, urbanisation, landscape degradation and political instability are making it increasingly difficult to collect pasture and forage germplasm from native grasslands in many countries. This emphasises the need to maintain and improve the capacity of the Australian Pastures Genebank (APG). The APG houses approximately 85,000 accessions and is a modern, online source of diversity for plant scientists around the world. This paper summarises the history of the founding genebank collections, their environment and farming systems focus and the visionary and resourceful individuals that built them.

Notes:

Genetic analysis of boron tolerance in burr medic (*Medicago polymorpha* L.)

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Abstract: Soils with toxic levels of boron are widespread in the cereal-livestock zone of southern Australia. The annual pasture legume burr medic (*Medicago polymorpha* L.) is widely grown in rotation with grain crops in this zone but current cultivars are susceptible to high levels of boron. Putative boron tolerant burr medic accessions have previously been reported in unreplicated mass screening. We confirmed the boron tolerance of several lines and developed four F2 populations by crossing two tolerant accessions with two susceptible cultivars. Boron tolerance was inherited in 3:1 (tolerant: susceptible) ratio and we identified a molecular marker that accounts for 0.84 of the variation. The boron tolerant accessions along with the boron marker will allow for the efficient introgression of boron tolerance into widely adapted genetic backgrounds. Boron and salinity frequently occur together in the cereal livestock zone of southern Australia. The burr medic cultivars Scimitar and Cavalier are salt tolerant and the identification of Boron tolerant accessions and a molecular marker will allow breeders to efficiently develop cultivars that are tolerant of the two most widespread subsoil constraints.

Notes:

Intraspecies diversity of yield, persistence, nutritive value and in vitro methane production using forage chicory

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Abstract: The herbage production, nutritive value and *in vitro* methane production of a diverse range of individually spaced chicory (*Cichorium intybus* L.) plants were studied for a full year to determine how much inter and intra population variation exists for these key traits. The cultivars differed in seasonal dry matter distribution, with Choice being the only cultivar to provide high yields throughout the year. Wild accessions were low yielding, but some plants previously selected from wild accessions were high yielding. High nutritional value of chicory was confirmed with mean dry matter digestibility of 75.1, 63.7 and 72.4 % in spring, summer and autumn respectively. Nutritional value was linked with plant development, with plants that delay reproductive development maintaining higher dry matter digestibility. A large amount of variation between and within cultivars, accessions and selections was found for all dry matter and nutritional parameters, however the differences in their methanogenic potential were limited. Puna, Puna II, Choice and several wild accessions had greater persistence than cultivars Commander, Grouse and Le Lacerta. Plant breeders will be able to exploit the variation measured for dry matter production, nutritive value, persistence and methane production for developing new chicory cultivar/s for Australian conditions which will increase the value of this species to a broader range of livestock producers.

Notes:

Potential of commercial rhizobial strains for new and existing perennial pasture legume cultivars on the NSW Tablelands

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Abstract: Perennial legumes have potential to increase pasture productivity due to their ability to use summer rainfall and fix nitrogen. However, in the high rainfall zone (600-850mm) of south-eastern Australia pasture legume productivity is unreliable. Improvement to the establishment and persistence of perennial legumes by improving nodulation and managing soil constraints within this system has the potential to greatly increase pasture profitably, maintain sufficient feed year round and improve pasture recovery following drought. Relatively few viable pasture legume options exist for this environment, and pasture mixtures are likely to include subterranean clover. So it is critical that the compatibility and competitiveness attributes of host plant-rhizobia associations are understood. Typically rhizobial species have a host range and only form an effective symbiosis (a functional nodule) with certain legume species. We studied the effectiveness and cross-host compatibility of commercial rhizobial strains for perennial legumes. Fifteen legume cultivars (white clover (five cultivars), talish clover (1), red clover (2), strawberry clover (1), Caucasian clover (1), birdsfoot trefoil (1), lucerne (2) and subterranean clover (2)) were assessed for nodulation and biomass growth against five commercial rhizobial strains (CC283b, RRI128, SU343, TA1 and WSM1325). Moreover, we studied nodulation of 20 cultivars of legumes (as above with the addition of sulphur clover, pink seredella, yellow seredella and sainfoin) in a newly established pasture (Mandurama, NSW) and considered persistence of effective nodulation in three year old mixed serradella- subterranean clover pasture (Gunning, NSW). We found that sites with a history of inoculation have competitive populations of rhizobia with variable effectiveness for a given host. Some commercial inoculants for perennial legumes suited to the NSW tablelands can form root-nodules with more than one legume species, and in some cases this may compromise N-fixation. Within the same legume species, some cultivars formed effective root nodules with certain rhizobial strains, while others did not. Most of the rhizobial strains in nodules correlated with the commercial inoculant used prior to sowing. Our results show that ensuring effective nodulation of legumes is critical for driving pasture production particularly where multiple legume species are sown in a mix.

Notes:

Salinity tolerance and avoidance mechanisms at germination among messina (*Melilotus siculus*) accessions from diverse origins

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Abstract: Pasture productivity in saline regions of southern Australia is constrained by the lack of pasture legumes with salinity tolerance. Seasonally high concentrations of soil surface salinity and frequent drought periods following the autumn break of season create difficulties for regenerating annual pasture species, which need to have high seedling salinity tolerance and/or avoid germinating at these times to survive. Field studies have shown the annual pasture legume messina (*Melilotus siculus*) has higher survival, biomass production and persistence in saline waterlogged environments than other pasture legumes used in these environments, particularly balansa clover (*Trifolium michelianum*), burr medic (*Medicago polymorpha*) and white melilot (*Melilotus albus*), resulting in the release of cv. Neptune. This study aimed to understand the mechanisms and quantify differences between balansa clover cv. Frontier, burr medic cv. Scimitar, white melilot cv. Jota and among cv. Neptune and 21 accessions of messina for their ability to germinate and establish seedlings under saline conditions. Traits examined included salt tolerance at germination, the ability to recover germination in non-saline conditions following exposure to salinity and the timing of hard (impermeable) seed softening over the summer-autumn period. There was considerable species variation in salt tolerance at germination. After 14 days at 300 mM NaCl germination rates, compared to 0 mM NaCl, were 12%, 27% and 65%, for Frontier balansa clover, Jota white melilot and Scimitar burr medic respectively, while germination of Neptune (99%) and 18 other messina accessions did not differ from non-saline controls. However, no genotype germinated at 600 mM NaCl. All genotypes, except Scimitar and Jota, recovered some germination in 0 mM NaCl, following 14 days incubation at 600 mM NaCl, with Frontier having 64% and Neptune 54% germination relative to their 28 day non-saline controls, while 4 other messina accessions had >70% germination. This shows their relative ability to survive the periodic flushing and accumulation of surface salts that commonly occur following sporadic germinating rainfall events in autumn-early winter. Seed softening events, whereby the hard seed proportion became significantly lower than the initial levels of freshly harvested seed, occurred on March 17 for Frontier, April 14 for Scimitar, Jota and Neptune and varied from March 17 to July 7 for the other messina accessions. The delayed seed softening acts as another salinity avoidance mechanism by deferring germination until more reliable rainfall is likely. This study showed the accumulation of salinity tolerance and avoidance mechanisms at germination contributes to the superior adaptation of messina to saline environments, while other species used in these environments had at least one adaptive trait. It also demonstrated that other messina genotypes had superior traits to Neptune that could be exploited for plant breeding.

This manuscript has been accepted for publication in Crop & Pasture Science but the article was still in production at the time of the symposium.

Notes:

Tropical perennial grasses: an opportunity to build the resilience of south-east Australian grazing systems in a changing climate

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Abstract: Climate variability and change are critical problems confronting Australian grazing industries. Data from recent decades indicate that in south-east Australia, temperatures have been increasing while rainfall in winter and spring are decreasing. These trends are predicted to continue into the future. This change in rainfall means that summer as a proportion of the total annual rainfall is increasing. Temperate species constitute the majority of the feedbase and these climate changes are predicted to shorten their growing season. A consequence of this scenario will be an increase in the traditional late summer-early autumn feed deficit. Current options used to fill this deficit are unlikely to achieve it in the future, so new strategies and options will be required. One strategy could be the addition of summer growing species that can utilise summer rainfall when it falls. Tropical perennial grasses are responsive to summer rainfall, suited to higher temperatures, and have the potential to contribute to the solution. These species are an extensive and diverse group that include some drought and frost tolerant types. This paper considers the potential for tropical perennial grasses in south-east Australia, including a brief history of their evaluation in this area, outlines some research currently underway in NSW and some of the agronomic and social challenges that will need to be addressed.

Notes:

The search for resilient perennial pastures for a Mediterranean environment in face of a changing climate – brief history for Western Australia

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Abstract: The reality facing producers in south-western Australia is that the average annual rainfall has decreased by some 20% since the 1970s. Producers are facing a future with most likely less rainfall, more variable rainfall, perhaps more summer rain as well as potential positives like higher carbon dioxide concentrations. In the face of a changing climate moving towards a perennial-based feed-base is an attractive option, but a considerable challenge given the strongly Mediterranean environment.

In Western Australia there has been a concerted effort over many years to explore new perennial pasture options and the opportunities to expand the area of known options. This research and development has been the focus of two national co-operative research centres (Plant-based Solutions for Dryland Salinity; Future Farm Industries CRC) based in Perth as well as on-going programs within Government and the Universities. The R, D & E has covered a wide range of herbaceous perennial legumes, leguminous shrubs, herbs, temperate grasses, warm season (C4) grasses, native species as well as species for niche environments like saltland.

This paper explores the journey in search for new perennial pastures; the challenges, the possibilities – what could have been, the realities and the successes. There have been many promising species which have almost become commercially viable options, but have seemingly failed at the final hurdle. The reasons are unique to each species, but cover a broad range of issues including: seed size, feed quality, marketing, environmental weed risk, narrow soil-climate adaptation and seed production. The key examples are explored in terms of what generated the excitement and what proved too big a hurdle.

There have also been some excellent successes with widespread commercial adoption including the sub-tropical grasses kikuyu (*Pennisetum clandestinum*) on the south coast, panic grass (*Megathyrsus maximus*) and Rhodes grass (*Chloris gayana*) in the Northern Agricultural Region and tagasaste (*Chamaecytisus palmensis*). With the herbaceous legumes, lucerne (*Medicago sativa*) has undergone a full circle from a species with a role in the south-eastern wheatbelt to widespread promotion and adoption back to a much more limited role. Moving forward there is considerable interest in the newly released tedera (*Bituminaria bituminosa* var. *albomarginata*) and lebeckia (*Lebeckia ambigua*).
The lessons have been many and varied. The potential for further expansion in the area of current perennial pasture options is explored. If the search for new species is to continue what are the key lessons and potential pitfalls.

This manuscript has been accepted for publication in Crop & Pasture Science but the article was still in production at the time of the symposium.

Notes:

Climate change effects on pasture based dairy systems in south-eastern Australia

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Abstract: Increases in temperature, along with possible decreases in rainfall will influence the production of forage on Australian dairy farms. A biophysical simulation study was undertaken to compare the performance of perennial pastures and annual forage cropping systems under historical and two possible future climate scenarios for three dairy regions of south-eastern Australia. Pastures and forage cropping systems were simulated with DairyMod and APSIM, respectively. Pasture and forage crop production was simulated over 40 years using daily climate data from 1971 to 2010 for locations with heavy (Dookie, Victoria) and partial (Elliott, Tasmania) reliance on irrigation, and a dryland system (Terang, Victoria). The historical climate scenario (baseline) had no augmentation to climate data, while the two future climate scenarios had either a 1^{o}C increase in daily minimum and maximum temperatures with a concurrent 10% decrease in daily rainfall (+1/-10 scenario) or a 2^{o}C increase in temperatures with a concurrent 20% decrease in rainfall (+2/-20 scenario). The baseline, +1/-10 and +2/-20 scenarios had atmospheric CO_2 concentrations of 380, 435 and 535 ppm respectively. Mean annual dry matter yields (t DM/ha) at Dookie of the forage cropping options (irrigated annual ryegrass/irrigated maize double-crop and the irrigated annual ryegrass/dryland forage sorghum double-crop) and the pasture systems (irrigated annual ryegrass and irrigated perennial ryegrass/paspalum mixture) increased under both the future climate scenarios but more irrigation was required (2-17% for the +1/-10 scenario and 14-51% for the +2/-20 scenario). At Terang, the forage cropping systems (dryland forage wheat/forage rape double-crop and dryland annual ryegrass/dryland forage rape double-crop) increased mean annual DM yield under the future climate scenarios while the mean yield of the pasture systems (dryland perennial ryegrass and dryland tall fescue) decreased. At Elliott, the mean annual DM production of irrigated and dryland lucerne and irrigated perennial ryegrass all increased under the future climate scenarios, while the dryland perennial ryegrass decreased. There was little change in the annual DM production of a forage crop system consisting of dryland oats/forage rape double-crop, while the annual ryegrass/irrigated maize double-crop increased DM production under the future climate scenarios at Elliott. The seasonal supply of forage in both the cropping and pasture systems at all three locations altered under future climate scenarios with increased production in the colder months and decreased production during the warmer months. This study indicates that double cropping and irrigated pasture systems at all three locations appear resilient to projected changes in climate, however for irrigation systems this assumes a reliable supply of irrigation water. The implications of how a shift in the seasonality of forage supply impacts on the whole farm system requires further investigation.

Link to Crop & Pasture Science publication: https://doi.org/10.1071/CP20108

Notes:

Differences in dehydration tolerance affect survival of white clover and lucerne

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Abstract: The contribution of perennial forage legumes to grazing animal production in Australia is important because of their high quality forage and their fixation of atmospheric N which is often the principal source of N for the grazing system. However, the production of these legumes tends to be highly unreliable, in comparison to grasses, for a range of reasons, including greater sensitivity to soil constraints.

Plant drought resistance is generally considered to be composed of mechanisms which are classified as either dehydration avoidant or dehydration tolerant and whether a plant species is considered to be primarily an avoider or a tolerator is determined by how much it regulates its internal water potential as soil water deficit increases. For perennial species this is an important consideration because given the importance of water deficit as a major abiotic constraint, the extent that plants are dehydration avoidant or tolerant will play a major role in their environmental adaptation.

Most of this type of research has focussed on annual crop species, particularly cereals, except for a small amount on perennial grasses, with very little attention given to perennial legumes. Consequently, while there might have anecdotal information about the relative drought tolerance of one forage species in relation to another there is very little robust, experimentally based knowledge for forage legumes.

To address this two forage legume species, white clover and lucerne were grown in pots with the same weight of soil and when the plants are exploiting all the soil volume watering ceased. A concurrent 'control' series of well-watered comparator treatments was in place. Plant and soil measurements included: pot weighing on a regular basis to determine plant water use; leaf elongation rate-to determine the relative sensitivity of growth to water deficit; plant water status by relative water content; plant and soil water status at LD_{50} (lethal dose at 50% mortality) of the species. This intensive measurement regime focused on the stage of plant growth when the species were nearing death. As the plants all had the same amount of available soil water, this technique permits determination of the extent to which the plants can tolerate dehydration. This research will feed into a plant model that should allow us to estimate the improvement in plant survival and production that might be achieved if we are able to increase the volume of soil water able to be accessed by the test species and this will help us direct research and make recommendations to improve legume growth.

This manuscript has been accepted for publication in Crop & Pasture Science but the article was still in production at the time of the symposium.

Notes:

The potential of deep-rooted species to address the impacts of heatwaves on pastures in southeast Australia

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Abstract: Declines in growing-season rainfall and increases in the frequency of heatwaves in southern Australia necessitate effective adaptation. This research used biophysical and economic modelling to determine the value of establishing a deeper-rooted compared to a shallower-rooted pasture species. The Sustainable Grazing Systems Pasture Model (SGS) modelled the growth of two pasture species differing in root depth, root distribution, and associated canopy temperature under 3 different climate scenarios at sites in northern (short growing season) and south-western (long growing season) Victoria. The metabolisable energy intake (MJ) output was used in a partial discounted net cash flow budget. Both the biophysical and economic modelling suggest that deep roots were advantageous in all climate scenarios at the long growing season site, but in no scenarios at the short growing season site, likely due to the deep-rooted species drying out the soil profile earlier. In future scenarios, production of the deep-rooted species at the long growing season site averaged 700 kg DM/ha/year more than the more shallow-rooted species, while at the site with a shorter growing season it averaged 165 kg DM/ha/year less than the shallower-rooted species. Timing of extra growth and pasture persistence strongly influenced the extent of the benefit. At the short growing season site other adaptation options, such as species with summer dormancy traits, will likely be necessary.

Notes:

Management options to improve perennial ryegrass survival and resilience when irrigation is restricted during summer

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Abstract: Future climate predictions for northern Victoria, Australia, are for less rainfall, higher temperatures and higher crop evapotranspiration. Therefore, less water will be available for irrigation. Farmers are responding to this reduced water availability by not irrigating their perennial ryegrass pastures over summer. Therefore, management strategies that improve the resilience of perennial ryegrass over summer are required. This was investigated in two on-farm experiments over three summer seasons. At each site, five perennial and two short-lived ryegrass cultivars were sown in two irrigation bays. One bay was not irrigated from late December to mid-March and the other bay was irrigated once over summer. In the middle of summer, half of each plot was grazed once. In March 2016 and 2017, half of the perennial, and all the short-lived ryegrass plots, were oversown. Measurements made included dry matter accumulation (DMA), nutritive characteristics and plant frequency.

Over the three seasons, there were differences in DMA between genotypes, with production from the short-lived ryegrasses being less than production from the perennial ryegrasses (viz. 8.7 t DM/ha vs 9.8 t DM/ha averaged over three seasons). There were no consistent effects of oversowing, irrigation management or grazing strategy on DMA. Measurements of plant frequency indicated large differences between the perennial and short-lived cultivars (viz. 79% plant presence for the perennial cultivars compared with 33% for the short-lived cultivars), some differences between the perennial cultivars, and better survival in the bay with some summer irrigation. This research will assist famers manage perennial ryegrass pastures when summer irrigation is limited.

Link to Crop & Pasture Science publication: https://doi.org/10.1071/CP20279

Notes:

Sowing configuration changes competition and persistence of lucerne (*Medicago sativa* L.) in mixed pasture swards

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Abstract: Changed spatial arrangement at sowing is often flagged as a management strategy that can help improve pasture composition in mixed swards by limiting interspecific competition early in the pasture phase. However, changed spatial configurations confer an enduring legacy that is less well understood but which impacts pasture productivity and persistence later in the pasture phase. This study sampled lucerne (*Medicago sativa* L.) and subterranean clover (*Trifolium subterraneum* L.) in established swards across nine experiments in the Riverina and Central West regions of southern NSW. Density and spatial distribution relative to the original drill row was compared in swards sown, 2-3 years prior to sampling, to a mixture of both species in contrasting spatial configurations. More than 10,000 lucerne plants were excavated in this study to determine the effect of changed spatial configuration on density and tap-root diameter. Light interception was compared between swards during spring, and soil water dynamics were monitored at two experiments to a depth of 1.5 m. Results revealed that although subterranean clover had increased capacity to colonise space between the original drill rows compared to lucerne, both species remained largely confined to the area close to the drill row even in the third year after sowing. Confining lucerne to a smaller number of drill rows by spatially separating it from other species in the sward had no impact on lucerne density on an area basis within the range of densities monitored at these dryland sites, but reduced the capacity of that species to intercept light in spring, associated with lower biomass production. This paper discusses the broader implications of this practice as a management strategy to improve the resilience and productivity of mixed pasture swards.

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Notes:

Medicago sativa and *Desmanthus virgatus*: suitable perennial legumes in mixes with *Digitaria eriantha* in Australia during drought

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Abstract: Tropical grass pastures are becoming widely sown in northern inland NSW, but lack a reliable companion legume. A range of perennial legumes were evaluated in mixtures with *Digitaria eriantha* (digit grass) to identify legumes/cultivars with superior production and persistence in mixtures with a tropical grass. Eighteen legumes were sown with digit grass at Bingara and Manilla on the North-West Slopes of NSW, Australia in December 2012. Herbage production and persistence were assessed until autumn 2016. Annual rainfall was below average most years of the study constraining herbage production but was effective for testing the persistence of the mixtures. *Medicago sativa* (lucerne) cultivars were the most productive producing 791-1011 kg DM/ha/assessment at Bingara and 1508-1955 kg DM/ha/assessment at Manilla. *Desmanthus virgatus* (desmanthus) cv. Marc was ranked second producing 552 and 323 kg DM/ha/assessment at Bingara and Manilla respectively. *Macroptilium bracteatum* (burgundy bean) had similar production to desmanthus at Bingara but the inability of plants to survive winter made it reliant on regeneration each spring. Several *Stylosanthes* spp. failed to persist but poor nodulation was noted at the Manilla site. Other species that failed to persist included *Chamaecrista rotundifolia* (round-leaf cassia) and *Lotus corniculatus* (lotus). At Bingara the lucerne cultivars were the most persistent with average plant frequencies of 41-47% followed by desmanthus cv. Marc with 33%. At Manilla, lucerne persistence ranged 17-25% while desmanthus cvv. Marc and JCU2 averaged 24%. Plant frequency of digit grass ranged 25-28% at Bingara. At Manilla, the drier site, grass frequency was more variable ranging 28-41% and lowest in mixtures with lucerne. The competitiveness of lucerne against the grass and the potential impact on long term productivity and persistence of the pasture are discussed.

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Notes:

Vacuum harvesting sucks: improving the Horwood Bagshaw Clover Harvester

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Abstract: Subterranean clover (Trifolium subterraneum L.) and annual medics (Medicago spp.) are Australia's most widely sown pasture legumes and the continued importance of these species requires a well-functioning seed production industry. However, harvesting their seed presents significant practical challenges. Sixty-year-old technology is still used to harvest seeds today: the Horwood Bagshaw Clover Harvester. Little extension or research has been directed towards the seed industry harvesters for over 20 years. Therefore, in order to understand the current use of the Horwood Bagshaw Clover Harvester, case studies and workshops of seed producers across southern Australia were conducted. As part of these activities we documented the machinery modifications made to improve harvesting and gathered feedback from producers regarding future enhancements. In this paper we present information on the current use of Horwood Bagshaw Clover Harvesters to support the development of new modifications and improvements.

Introduction

Subterranean clover (*Trifolium subterraneum* L.) and annual medics (*Medicago spp.*) are Australia's most widely sown annual pasture legumes (Nichols *et al.* 2012) and form an important part of its farming systems (Donald and Williams 1954; Puckridge and French 1983; Smith 2000; Peoples and Baldock 2001). However, harvesting subterranean clover (subclover) and annual medic seed presents significant practical and environmental challenges. Most subclovers bury their burrs and annual medics drop their mature pods onto the ground: this complicates seed harvesting as it introduces interaction with the soil. The Horwood Bagshaw (HB) Clover Harvester was developed in Australia in the early 1960s to collect these seeds from the ground. Its arrival represented a huge leap forward for the industry and it is still used today by practically all subclover and annual medic seed producers (Avery *et al.* 2001; Didar 2003).

The HB is depicted in operation in a 1964 leaflet (Figure 1). Invented by a West Australian farmer, Earnshaw, the leaflet proclaims the HB as 'new and revolutionary', using a vacuum system to suck material up from the ground. This material is then threshed and processed inside the machine to produce relatively clean seed. While this was revolutionary at the time, the design saw no significant changes despite numerous model upgrades before going out of production in the early 1990s (Boyle 1995). The fact that these harvesters are still used is a credit to their robust design, but being reliant on such old technology poses a number of challenges for current seed producers. The main issues facing the seed industry are: a slow and labour intensive harvest process; availability, reliability and maintenance of ageing HB harvesters; and soil erosion impact from pre-harvest soil preparation and vacuum harvesting (Avery *et al.* 2001; Hassall and Associates 2001; Didar 2003; Loi *et al.* 2005). All of these directly relate to the harvest technology used, the HB.

Many modifications have been made to improve the HB and get the most out of these aging machines. These modifications were often made by individual farmers and kept within their farm or local district, consequently there is little detail available on what modifications are adopted across the industry. In this paper we combine information gathered from seed producers to get a picture of the current harvest technology and make recommendations for the future.

Figure 1. Left - Horwood Bagshaw Clover Harvester descriptive leaflet from 1964 (Horwood Bagshaw 1964). Top right – external seed bin addition. Bottom right – sweeper brush addition.

Methods

Information about producers' current harvest technology was gathered from case studies and workshops. Seed producers were interviewed during the 2019 January-March harvest season to form 7 case studies: 2 subclover in WA, 2 subclover in NSW and 2 subclover and 1 medic producer in SA. Seed producers were selected in consultation with seed companies and via our own industry contacts to identify leading representative growers. Three facilitated workshops were conducted with the seed industry at Pingelly WA, Naracoorte SA and Corowa NSW.

During the case studies and workshops, information was gathered on how producers use HBs and what modifications they have made to it. They were also asked about what improvements could be made to the machine and process, and what their ideal harvester would look like.

Results and Discussion

Modifications

The most common and significant modification is the tandem drive. This innovation allows large increases in efficiency, as multiple HBs can be driven by a single tractor and operator, increasing the pickup width compared to operating a single machine. Power is supplied to the first HB as normal through the tractor's power take off (PTO), extra belts and pulleys are added to take power from the main drive shaft (driven by the tractor) and drive a shaft running along the side of the HB, connecting to the subsequent HB's input shaft as standard. This is set up so that the pickup duct of each machine is offset from each other to harvest the adjacent strip, thus increasing the effective pick-up width. This increased width is particularly significant since a single HB usually has a 1.2 m wide pickup duct, which is narrow compared to modern cereal harvesters that can be greater than 14 m in width.

In the most common configuration 3 HB units are driven in tandem, but there are instances of producers driving 4 or even 5 machines together. However, this increases the complexity of the setup and requires power to be routed differently so as not to overload the existing shafting. In this configuration power is sent from the tractor directly to the second machine, through a shaft that runs alongside the first HB. The first machine takes power from this shaft to drive its systems. This means the first machine does not see the load of the subsequent machines and more units can therefore be run together. A 5-tandem setup is shown in operation in Figure 2, together with schematics of the 2-tandem systems described. The tandem setup is not without issues, however. There are more moving parts to maintain and because the HBs are connected in series, a breakdown of one machine can put the entire train out of action until it can be repaired, replaced or removed. For this reason, producers often have back-up machines to quickly replace any breakdowns during the short harvest window. Tandem arrangements use belt drives to transfer power to the shaft running to the subsequent machine. This is a non-positive drive (belt slippage is possible) and can allow power loss and varying drive speeds through the train, but the effect of this on machine efficiency is not known.

The tandem drive was invented by farmers, but was so successful Horwood Bagshaw produced their own kits (Boyle 1995). Most other modifications are not as standardised; their use and implementation varies widely among districts. For example, a modification common in the Naracoorte region in SA is the use of a brush ahead of the pickup inlet to fluff up the ground directly prior to harvesting (Figure 2), however its effectiveness has not been quantified. External seed bin modifications (Figure 2) are used by several seed producers in different locations, but have been implemented differently. Some designs have clear benefits over others e.g. aligning the wheel axis of the bin with the HB wheel axis to assist with cornering. However, there is little-to-no shared learning or communication within the seed industry (the industry is competitive with little incentive to share), so producers often do not know about others' modifications and thus cannot adopt these improvements. Future research should evaluate HB modifications to establish which work best and provide information to producers that allows them to make the most of their HBs.

The considerable effort that has been applied to the modification of these machines underscores their importance to the seed industry, but it also highlights the reliance on ageing technology. While old and new modifications should still be investigated, it is unlikely much more can be gained whilst being constrained by the HB's original suction design. Therefore, future efforts should also aim to develop alternatives to the HB.

Harvesters for the future

When asked to imagine their ideal harvesters, many producers struggled to conceive what is possible beyond the only thing they had ever known: the Horwood Bagshaw Clover Harvester. As such, many of the suggestions were simply for a bigger, faster HB. This made it clear that increased harvest rate (wider pickup, faster forward speed) and capacity were important factors in a new machine, but once producers got beyond the constraints of the current system, an image of the harvester of the future started to form.

Most producers described their ideal machine as being able to harvest seed in one pass (no preparation passes required) with minimal dust and soil disturbance. The overall preference was for a harvester towed behind a tractor (rather than self-propelled) or an attachment onto an existing cereal header. The amount attendees would pay for this new, ideal harvester ranged from AUD$100k - AUD$400k, with the lower end coming from WA possibly due to its smaller industry. Other desirable attributes were: low soil impact, low dust emissions, fewer passes required, wear resistance, ease of repair and maintenance, adjustability and high seed storage capacity.

Some of these features are achievable using modern technology, as observed already in contemporary cereal combine harvesters (e.g. adjustability, speed, harvest width and wear resistance), but others like soil degradation and the number of passes are challenging, given that the seeds are either buried or on the ground. A new add-on to an existing combine header is a good idea since most producers already have an advanced, modern combine. However, soil ingestion would be a major issue causing excessive wear in the expensive combine and hence any pick-up would have to minimise soil ingress. There is a clear desire for new harvesting solutions and more research should be conducted. These solutions should aim to take advantage of advancements since the HB was designed and utilise existing technology from other industries.

Whilst it is likely that technical challenges for any new engineering solution could be overcome, the biggest hurdle for a new machine will be commercial manufacturing. Hassall and Associates (2001) reported that the pasture seed market is too small for the machinery industry to expend large amounts of capital to develop new harvesting technology. The current view is that there are too few seed producers in the industry to buy enough machines to make it commercially viable for manufacturers to invest in new machine development. Therefore, development of new harvest technology would require extensive industry/government investment, a recent example being the Weed Chipper, Grains Research and Development Corporation (GRDC) commercialisation project.

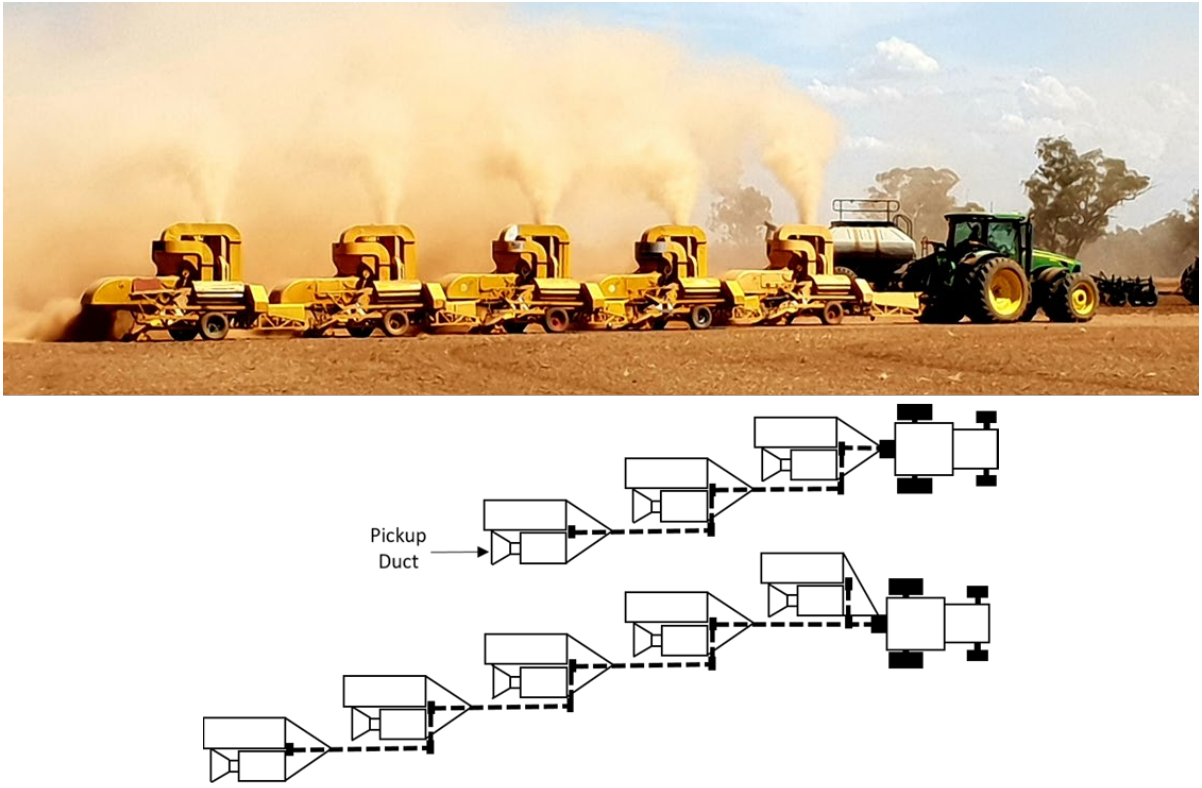

Figure 2. Tandem HB arrangements: Top – five HBs harvesting in NSW. Bottom – schematic of typical tandem arrangement (upper) and modified version allowing more machines (lower). The dashed lines represent the drivetrain connection.

Conclusion

Subclover and annual medics remain an important part of Australian agriculture. The HB also remains a crucial tool to harvest their seeds, but its aging technology is putting the seed production industry at risk. The seed harvesting process is in urgent need of innovation. Research into HB modifications can provide benefits to producers, but is limited by constraints of the original system. Ultimately, new harvesting technology is needed to bring the industry into the 21st century and revolutionise production as the HB originally did in the 1960s. Through collaboration between research, industry and government, innovative new solutions can be sought to improve subclover and medic seed harvesting, to enhance its profitability and sustainability.

Acknowledgments

We thank the seed producers who allowed us to assess their seed harvesting practices as part of the case studies and those who provided their time, knowledge and insight in the workshops. The research was conducted with funding from AgriFutures™ Australia as part of the project "*Profitable and environmentally sustainable subclover and medic seed harvesting*" (PRJ-011096). WM acknowledges the financial support provided through the Robert and Maude Gledden Postgraduate Research Scholarship, and the A.W. Howard Memorial Trust Postgraduate Research Fellowship.

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Notes:

Soil test phosphorus critical values from "Better Fertiliser Decisions for Pasture" - fact or fiction?

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Abstract: Viable pasture based grazing systems in south-western Australia have been made possible through nutrient input to soils which were impoverished when first cleared. Initial dramatic increases in production stimulated annual applications of fertilisers, particularly phosphatic fertilisers. However, excessive fertiliser application and stored soil nutrients can be tied to environmental impacts including the loss of phosphorus (P) to waterways impacting on water quality and eutrophication. A large body of evidence has been accumulated (3000 experimental years of data) to define critical P, potassium (K) and sulphur (S) soil test concentrations through an Australia-wide collaboration in the Better Fertilisers Decisions (BFD) project. Since 2009 more than 200,000 ha and 17,500 pasture-based paddocks in south-west Western Australia (WA) assessed against the BFD critical values indicate that 70% of paddocks do not require P, but often show constraints to K, S and pH. Some growers, fertiliser representatives, and agronomists are concerned that the BFD critical values for P are either not suited to WA conditions, or that contemporary pasture varieties have a greater P requirement than those varieties used to establish the BFD critical values. These stakeholders are collaborating in a project that is revisiting the response curves through an ambitious assessment of 36 pasture trials across six catchments in WA. Results from 19 trials in the first year are largely consistent with BFD, except when soil pH and P were low. Large increases in production with application of nutrients (N, K, S) in situations where nutrients other than P are limiting are evident.

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Notes:

Critical external P requirements and yield potential of nine *Desmanthus* spp. genotypes

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Abstract: Extensive grazing systems in northern Australia are dominated by C4 grasses, generally low nutrient-input and established on N and P responsive soils. Under these conditions, tropical pasture legumes improve the quality of grazing forage and facilitate the fixation of atmospheric N_2. However, poor persistence has been linked with high P requirements. The P requirements of many tropical pasture legumes have not been quantified because the legume component of a pasture is generally selected based on agronomic factors such as drought and grazing tolerance. Nine *Desmanthus* spp. genotypes were grown to determine differences in shoot yield and root morphology in response to increasing P supply. The shoot yield of each genotype increased with increasing soil P supply. However, when soil P supply was adequate for maximum growth, shoot yield was 1.8-fold higher for the best genotype when compared to that of the other genotypes. There were also substantial differences in critical external P requirement among the genotypes, but these differences did not reflect the efficiency of dry matter production per unit of applied P fertiliser. In particular, the highly productive genotype achieved a relatively high critical external P requirement yet out-yielded the other genotypes at low P levels. Lower critical external P requirements may enable *Desmanthus* spp. to compete effectively with C4 grass root systems and form resilient and productive pasture swards as climate patterns change. The results indicate that P-efficient genotypes of *Desmanthus* spp. can be identified for improved growth in the P-responsive pastures of northern Australia.

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Notes:

Sensitivity of the messina symbiosis to low pH

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Abstract: Messina (*Melilotus siculus*) is an annual pasture legume with better combined waterlogging and salt tolerance than other annual legumes. The cultivar Neptune and a new salt tolerant rhizobia (SRDI-554) were made available to growers in 2017. Since some salt-land soils are acidic, particularly in West Australia, it is important to understand messina's sensitivity to acidity in order to avoid failures during early adoption.

Acidity tolerance of the messina symbiosis (inoculated with SRDI-554, or the salt in-tolerant strain WSM-1115 recommended for medics) was examined in a hydroponic experiment and in three acidic soils (SRDI-554 only ± lime pelleting of seed), in the greenhouse.

In the hydroponic experiment, the percentage of messina plants (with SRDI-554) that formed nodules declined between pH 5.7 (43%) and 5.5 (4%). Rhizobia strain SRDI-554 was slightly more sensitive to acidity than medic rhizobia strain WSM-1115. In soils (pH_{Ca} 4.3 to 5.5) more plants formed nodules. However, without lime pelleting, nodule number was reduced to inadequate levels below pH_{Ca} 5.5. Messina demonstrated some capacity to compensate for low nodule number by increasing nodule size, but this capacity did not extend below pH_{Ca} 5.3. Lime pelleting was beneficial below pH_{Ca} 5.5.

Messina provides growers with a new legume option for salt-land pastures, but only where soil pH_{Ca} is greater than 5.5. Even this level may carry some establishment risk, but it can be reduced with the application of fine-lime to the seed before sowing. There may be opportunity to select a strain of rhizobia with both salt and acidity tolerance.

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Notes:

Identifying the cause of recent outbreaks of subterranean clover red leaf syndrome in Western Australia

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Abstract: Recent outbreaks of subterranean clover red leaf syndrome and subsequent loss of pasture has caused considerable concern amongst WA livestock producers. For the period 2017 to 2019 we collected symptomatic and asymptomatic subterranean clover plants from commercial properties that reported substantial numbers of plants with red leaves. Plants were screened for viral infection. Testing involved the development of two new molecular diagnostic techniques to more rapidly detect soybean dwarf virus (SbDV) with greater sensitivity. Of the 32 properties involved 13 tested positive and 19 negative for SbDV. Interestingly only samples collected in spring were positive for SbDV compared to no SbDV infections reported in winter. Seventy three percent of the symptomatic plants tested positive to SbDV compared to only 4% of the asymptomatic plants. Based on our findings it is clear that infection by SbDV was the primary cause of subterranean clover red leaf syndrome in the spring. The cause of the winter outbreaks remains unknown therefore it is possible that other factors such as root disease, cold conditions or waterlogging lead to leaf reddening and clover death. This finding does not rule out a viral infection outbreak in winter, as it is known aphid numbers can increase in autumn following summer rain and a green plant bridge can provide a vector for viruses to infect subterranean clover seedlings. We suggest that SbDV infection of subterranean clover could become more frequent in the future.

Key words: Pasture, legume, virus, disease, yield loss.

Introduction

Subterranean clover (*Trifolium subterraneum L.*) is the most widely used annual pasture legume in south west WA with around eight million hectares sown. Therefore an outbreak of subterranean clover red leaf syndrome and subsequent loss of pasture in 2017 caused considerable concern amongst livestock producers. Subterranean clover leaves can turn red for numerous reasons such as root diseases, cold conditions, waterlogging, nutrient deficiency, herbicide damage and virus infection. We suspected that this particular outbreak was due to virus infection because the symptom development in individual plants and patterns of spread in the pasture were most consistent with a viral cause.

Viruses known to infect subterranean clover in WA include, bean yellow mosaic virus (BYMV), subterranean clover mottle virus (SCMoV), alfalfa mosaic virus (AMV), cucumber mosaic virus (CMV), turnip yellows virus (TuYV), bean leafroll virus (BLRV), phasey bean mild yellows virus (PBMYV) and Soybean dwarf virus (SbDV; syn. subterranean clover red leaf virus) (Johnstone and Mclean 1987; McKirdy and Jones 1995; Jones 2012). However, only SbDV, BLRV and TuYV infection is known to cause reddening of the leaves and these viruses are all from the family *Luteoviridae* (Kellock 1971; Kyriakou *et al*. 1983; Peck *et al*. 2012). Based on our preliminary assessment of the outbreak we investigated the possibility that subterranean clover red leaf syndrome was caused by infection by viruses from the *Luteoviridae* family.

Methods

Sourcing subterranean plants with red leaves

From spring 2017 until spring 2019 producers provided whole subterranean clover plants with red leaves for testing, either through the mail or hand delivery. In some cases the authors collected samples from properties that reported symptoms and sent them in a chilled package overnight to the laboratory for testing. At some sites both symptomatic and asymptomatic plants were collected for comparative purposes. Samples were submitted or collected from the following locations in the south west of WA; Esperance, Brookton, Tambellup, Mount Barker, Narrikup, Kendenup, South Stirling, Albany, Gardiner, Manypeaks, Torbay, Wickepin, Pingelly, Cranbrook, Tincurrin, Green Range, Wandering, Cascade and Redmond. All of the samples were tested for viruses at the WA Department of Primary Industries and Regional Developments Diagnostic Laboratory at South Perth.

Virus testing

In 2017 in response to the outbreak, a conventional polymerase chain reaction (PCR) that could detect SbDV, TuYV, BLRV and PBMYV was utilised. PCR products were then Sanger sequenced to identify the specific virus. Following the identification of SbDV as the primary cause of the reddening leaf symptoms in 2017, two new molecular assays specific to SbDV were developed using quantitative PCR (qPCR) and loop mediated isothermal amplification (LAMP). Both methods provided sensitive detection, with LAMP providing detection within 30 minutes and qPCR providing the capacity to test larger number of samples and quantify the concentration of virus in the plant.

These two methods were used to test symptomatic plants in 2018 and 2019.

Results

From the spring of 2017 until the spring of 2019 forty one sites with symptoms submitted samples to be tested for viruses, however samples from 9 sites were in too poor condition to be analysed leaving the 32 sites reported in this paper. In 2017 the year of the outbreak, TuYV was only detected at 4 sites (19 plants) whilst SbDV was detected at 11 sites (93 plants). BLRV and PBMYV were not detected. In subsequent years plants were only tested for SbDV unless further investigation was required.

Of the 32 sites tested 13 tested positive and 19 negative for SbDV (Table 1). Interestingly only samples collected in spring (n = 13) were positive for SbDV compared to no SbDV infections reported in winter. By comparison 15 sites sampled in winter tested negative for SbDV compared to only 4 sites returning a negative in spring (Table 1). By the spring of 2018 the number of producers reporting symptoms of red leaves in subterranean clover plants had declined considerably.

Table 1. Results of subterranean clover farm samples submitted for SbDV testing from spring 2017 to winter 2019. Note no samples were submitted in autumn and summer during this period.

Season	No of sites tested positive	No of sites tested negative
Spring 2017	11	3
Winter 2018	0	13
Spring 2018	1	1
Winter 2019	0	2
Spring 2019	1	0
Total	13	19

In 2017 and 2018 many of the samples included intact paired symptomatic (n = 122) and asymptomatic (n = 92) subterranean clover plants which were tested separately. Seventy three percent (n = 89) of the symptomatic plants tested positive to SbDV compared to only 4% (n = 4) of the asymptomatic plants (Table 2).

Table 2. Results of symptomatic and asymptomatic subterranean clover farm samples submitted for SbDV testing from spring 2017 to spring 2018. Note no samples were submitted in autumn and summer during this period.

Season	Symptomatic plants		Asymptomatic plants	
	No tested positive	No tested negative	No tested positive	No tested negative
Spring 2017	73	24	2	75
Winter 2018	0	9	0	11
Spring 2018	16	0	2	2
Total	89	33	4	88

Discussion

The outbreak of subterranean clover red leaf syndrome in 2017 was first reported in the winter at the most northern sites (e.g. Brookton) yet no samples were submitted for virus testing until spring. Given that and the fact we have had no SbDV positive samples in any winter since, we have been unable to demonstrate that a virus infection causes leaf reddening in winter. It is possible another cause such as root disease, cold conditions or waterlogging was responsible. However, the results for spring 2017 and subsequent years are conclusive, particularly when based on the individual plant data, infection by the SbDV is the primary cause of leaf reddening in subterranean clover during this period of the year which is likely since many of the other possible causes such as waterlogging are less severe in spring.

Kellock (1971) first demonstrated that SbDV caused the reddening of clover leaves. SbDV is persistently transmitted by aphids in a persistent circulative and non-propagative manner. Its primary vector species is strain-specific with some strains being transmitted by the foxglove aphid (*Aulacorthum solani* Kltb.) (Ashby *et al*. 1979; Kellock 1971; Wilson and Close 1973) and others by the pea aphid (*Acyrthosiphon pisum* Harris) (Terauchi *et al*. 2001). There is no reported transmission of SbDV by seed.

Aphid numbers are highest in spring and therefore SbDV is more likely to spread then compared to other seasons again consistent with our findings. An outbreak of subterranean clover red leaf syndrome due to viral infection in winter is feasible if large aphid populations are present in autumn to infect and kill many emerging subterranean clover seedlings. Large aphid populations can arise in autumn following substantial summer rain events that support a green plant bridge. When a future outbreak occurs it is critical that investigators act as quickly as possible to determine the cause as the first sites that reported the syndrome in the winter of 2017 had lost all of their subterranean clover plants within weeks.

McLean and Price (1984) recorded the first SbDV infection in subterranean clover in WA in 1973. In the spring of 1993, McKirdy and Jones (1995) undertook a large survey of 94 subterranean pastures to determine the occurrence of SbDV across south west WA and found no infection. They did however record SbDV infection in 7 out of 21 irrigated white clover (*Trifolium repens*) pastures but concluded that infection of subterranean clover by SbDV was not a current threat to pasture productivity. Our findings albeit based on symptomatic sites suggest that the occurrence of SbDV infection has increased and therefore could become more damaging and frequent in the future, particularly in warmer winters.

Conclusions

Infection by SbDV is the primary cause of subterranean clover red leaf syndrome in the spring in WA. The cause of the outbreak in the winter of 2017 remains unknown however based on subsequent testing of symptomatic plants in the winter of 2018 and 2019 we found no evidence of SbDV or TuYV infection therefore it is possible that other factors such as root disease, cold conditions or waterlogging led to leaf reddening and clover death. This finding does not rule out an outbreak in winter, due to viral infection, as it is known aphid numbers can increase in autumn following summer rain and a green plant bridge therefore providing a vector for viruses to infect subterranean clover seedlings.

Based on the limited historical surveys of the occurrence of SbDV in subterranean clover in WA our findings suggest that SbDV infection has increased and therefore could become more damaging and frequent in the future.

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Notes:

Hidden gems: an epidemiological investigation into the association of the White Ground Pearl, *Margarodes australis*, with pasture dieback

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Abstract: Pasture dieback is a devastating condition resulting in significant death of Queensland's improved pastures (and to a lesser degree some native pastures) for over 25 years. In this time, several potential causal agents have been identified as associated with pasture dieback. However, none of these agents have been conclusively proven as the causal agent for this condition. As part of our research to identify new potential causal agents, a notorious pest of grasses, known as ground pearls (Hemiptera: Margarodidae), were found associated with multiple dieback sites. An intensive site investigation (near Gatton, south-east Queensland), with pasture dieback revealed high densities of the white ground pearl (*Margarodes australis*) in areas where dieback was most severe. Using reflectance in the near-infrared region (NIR), a negative correlation was determined between reflectance (713-728 nm) and total ground pearl cyst count at the site. The results of this exploratory study in addition to anecdotal evidence of the presence of ground pearls at other dieback sites, provides evidence that *M. australis* could be linked to pasture dieback. This research highlights the need for further investigation to either confirm or exclude this insect as the causal agent.

This manuscript has been accepted for publication in Crop & Pasture Science but the article was still in production at the time of the symposium.

Notes: