MEAT & LIVESTOCK
AUSTRALIA

On farm

Final Site Report
Western Australia

Sustainable Grazing Systems

Project number SGS.115B
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Contents

Highlights

- Development of the experimental protocols.
- SGS database that provided a single repository for data, easy access to the data collected and queries to extract data in a form required by the Site.
- Exchange of information and ideas between team members and those involved in other parts of SGS National Experiment.
- Involvement of farmers in a participatory R&D approach that added value to the research.
- Discovering that kikuyu a deep rooted summer active grass can both significantly reduce groundwater recharge and increase gross margins via increased carrying capacity.
- The finding that tree belts substantially reduce production from annual pastures alongside but that kikuyu a perennial grass is competitive with tree belts to the extent that herbage accumulation is unaffected and livestock production is only moderately reduced in comparison with kikuyu pasture alone.
- The finding that Tasmanian bluegum belts may require additional management to prevent soil acidification and loss of nutrients both beneath and alongside the belt.
- Experimental data that proves it is possible to develop profitable and sustainable grazing systems for the HRZ of Western Australia.
- Preparation of the Site papers for the special edition of AJEA, and the focus it provided for the analysis.
- Harvest Year, which provided the Site with time to complete the analysis and write up the results.
- New research ideas such as agroforestry systems based on trees combined with perennial pasture and deep rooted summer active perennial grasses for improved herbage accumulation and water-use.

Background

Grazing systems in the high rainfall zone of southwest Australia involve beef, dairy and to a lesser extent prime lamb and wool production on annual-based pastures. Typically these pastures comprise of subterranean clover and ryegrass which has been invaded by common pasture weeds.

Up to a third of the agricultural land within this part of Australia is threatened by salinisation. The salt originates from the ocean and is deposited inland at a rate of 20 to 200 kg/ha/annum by prevailing winds. In combination with poor drainage, this process has resulted in up to 10,000 tonnes of salt being stored under every hectare in the southwest of Western Australia.

This salt along with the groundwater is rising as a consequence of replacing the deep-rooted native vegetation with shallow-rooted crops and pastures. The original native vegetation maintained a hydrological balance by utilising excess winter rainfall at other times of the year. However, once this vegetation was replaced by shallow rooted species this balance was upset and the groundwater began to rise at rates between 0.15 and 1.5 m/annum.

If current agricultural practices continue, potentially 6.1 million ha of land will be affected by dryland salinity once the groundwater reaches a new equilibrium. Not only will dryland salinity affect agricultural production, but it will also have a negative impact on water resources, infrastructure (e.g. roads and towns) and native flora and fauna (e.g. freshwater wetlands).

Farmers with the support of the community are faced with the enormous challenge of replacing current agricultural systems with ones that are both productive and sustainable. Previous research has shown that pastures in the high rainfall zone, whether based on either perennial or annual species, will require integration with trees to restore the hydrological balance. By contrast, perennial pastures alone may be able to restore the balance in the less than 600 mm rainfall zone.

Site objectives

The objective of the Western Australian SGS Research Team is to develop productive and profitable grazing systems that minimise deep drainage thus assisting to prevent further salinisation of the landscape. The specific objectives are to:

1. To quantify the effect of Tasmanian bluegum (*E. globulus*) belts (alley system) on pasture at varying distances from the trees, seasonal sheep meat production, water use patterns and profitability in the greater than 600 mm rainfall/long growing season zone of south west Australia.

2. To quantify the impact of summer active kikuyu (*Penniesetum clandestinum* cv. Whittet) on water use patterns compared to annual only pastures in the 400 to 600 mm rainfall/long growing season zone of south west Australia.

3. To quantify cattle meat production, pasture water use, nutrient loading and profitability for perennial Kikuyu and phalaris pastures compared to annual only pastures at the paddock scale under farmer management in the 400 to 600 mm rainfall/long growing season zone of south west Australia with the aim of producing beef out of season when prices are favourable.

Overview of progress

SGS (to June 2001)

By the end of June 2001 the Site had completed the following:

1. Designed, established and run 3 trials including a large grazing experiment.
2. Completed 3 to 4 years of data collection from trial sites as per the SGS experimental protocol.
3. Entered up to 80% of the data collected into the SGS Database.
4. Undertaken preliminary data analysis.
5. Extended preliminary findings to producers via field days, including SGS National Farmwalks, and written articles.
6. Led the Pasture Theme Team and provided representation from WA on the remaining Theme Teams.
7. Provided data to SGS Themes for across site analysis.
8. Actively participated in the development of the SGS Database and SGS Pasture Model.
9. Played an active role on the SGS Regional Steering Committee including reporting research findings.

Harvest Year

Much of the progress in the harvest year focussed on more extensive Site analysis, supporting Theme and Harvest Team efforts and publishing the Site findings in a special edition of the Australian Journal of Experimental Agriculture

By the end of the Harvest Year (30 June 2002) the Site had:

1. Completed data entry into the SGS Database.
2. Undertaken extensive Site data analysis.
3. Supported Theme across-site analysis including running Site simulations using the SGS Pasture Model.
4. Contributed to Harvest Team activities.
5. Submitted articles for the special theme editions of Prograzier.
6. Completed two draft scientific papers (see appendix 1 and 2).
7. Updated Tips and Tools.

The findings of the above analyses (SGS and Harvest Year) are summarised in the findings section of this report and covered in detail in the attached drafts of the Albany and Esperance site papers as at 31st October 2002.

Findings, hunches and unanswered questions

Findings

Tree-pasture interaction trial (Albany)

The effect of Tasmanian blue gum (*Eucalyptus globulus*) belts and kikuyu (*Pennisetum clandestinum*) grass on livestock production and groundwater recharge was studied in the high rainfall zone (>600 mm/year) of South-West Western Australia from 1998-2001. The objective was to identify optimum combinations of tree belts and pasture for sustainable livestock production and the prevention of secondary salinisation. Treatments were annual pasture, in competition with trees at different orientations (east, west and south), kikuyu pasture in competition with trees at 1 orientation (west), compared with pasture in the absence of tree competition. Plots had 0, 20 or 36% of their area within 10 m of the tree belt where tree-pasture competition would be expected. Plots (0.48 ha) were stocked with Merino wether hoggets at 12 DSE/ha on annual pastures and 14 DSE/ha on kikuyu pastures. Additional sheep were placed on plots in spring and the annual pasture was destocked in autumn.

Within the growing season, herbage mass was similar across both control treatments as a result of varying stock numbers. However, in summer and autumn the kikuyu control contained between 355 and 4890 kg DM/ha more herbage than the corresponding annual pasture. While both pastures accumulated similar amounts of herbage in 1998 and 2000, kikuyu accumulated more in 1999 (11884 *vs* 9765 kg DM/ha) as a result of summer rain. Competition from trees significantly reduced annual pasture herbage accumulation (16% average reduction), although there was no difference between the levels of competition. Trees did not significantly affect kikuyu pasture herbage accumulation.

Both carrying capacity and clean wool production per hectare were significantly higher on kikuyu pasture in 1999 and 2000. Tree competition also significantly reduced the carrying capacity of both annual and kikuyu pasture by an average of 10%. Clean wool production per hectare was significantly lower on annual pasture in combination with trees (11% reduction on average), but there was less effect of competition on kikuyu pasture.

The kikuyu pasture used 115, 57 and 132 mm more water than the annual pasture in 1999, 2000 and 2001, respectively. Trees created an autumn soil water deficit that exceeded that below both control pastures by 297-442 mm.

Although the addition of tree belts to annual pasture provided useful reductions in groundwater recharge, producers would also have to accept losses in livestock production. While kikuyu alone provided significant increases in livestock production and substantial reductions in groundwater recharge, the best compromise was kikuyu in combination with tree belts.

See appendix 1 for more information on this trial.

Changes in soil characteristics when Eucalyptus globulus tree belts are planted on agricultural land in south-west Australia – A Tertiary Studentship Project

The planting of *E. globulus* at the sites studied resulted in a decline in soil pH (0-10 cm) and reduced soil concentrations of N, P, K and S. It was suggested that soil pH decline below trees may have been due to nitrate leaching, excess uptake of soil cations over anions and an export of alkalinity. Decline in soil N, P, K and S may have been attributed to a greater demand for these nutrients under the trees compared to the pasture. As current first rotation *E. globulus* planted on farms near harvesting, there has been interest among land managers concerning the ability to re-establish pastures for profitable grazing enterprises. Alternatively, tree companies have become interested in the capacity of the soil to supply nutrients to support a second rotation crop by allowing the stumps to coppice. Findings from this study suggest that to return the land to productive pastures, soil testing will be required to determine the extent of pH decline and depletion of nutrients. If needed, lime should be applied to raise the soil pH and sufficient N, P, K, S and trace element fertilisers to restore fertility. Alternatively, given the decline in nutrients below the trees, it is likely that for second rotation crops to be profitable, tree companies need to place an increased emphasis on soil nutrient testing, fertilising and liming soil below trees to ensure levels of nutrients required for growth do not fall below critical levels.

The study was limited in that soils were bulk sampled within sites, thus the data could only be used to indicate general trends. A more comprehensive study with intra-site replication across sites would be extremely useful in being able to more accurately predict soil changes. Moreover, future research directed at nutrient uptake preferences of *E. globulus* would allow the mechanisms of soil acidification to be more fully understood. Similarly, determining the ash alkalinity of leaves and quantifying the loss of leaves would also allow further understanding of the causes for soil pH decline. The other postulated cause for soil acidification, leaching of nitrate, could be further explored by quantifying differences in nitrification and subsequent leaching in soil below trees and adjoining pasture. With the increasing need to establish perennial crops on agricultural land to arrest the spread of salinity, *E. globulus* tree belts have shown promise throughout south-west Australia. Further knowledge of soil changes below belts of *E. globulus* will allow better management of soil pH and fertility to maintain productivity of trees and adjoining pasture.

See appendix 3 for more detail.

Sustainable beef production demonstration (Esperance)

Production parameters and water use of kikuyu (*Pennisetum clandestinum*) and annual-based pastures were monitored for a beef weaner production system from 1998-2000 in a paddock scale demonstration on the South- East coast of Western Australia. Kikuyu pasture carried more animals than annual pasture through the dry cow phase (late summer and autumn) in all years. The comparative quality and productivity of the kikuyu pasture in the lactation phase (winter and spring) was positively correlated with the level of winter legume present. When a similar level of winter legume was measured in the kikuyu pasture relative to the annual pasture (in 1998), the pasture quality, cow liveweight and condition and calf weaning weights were all comparable between the 2 pasture types. When a low legume component was recorded in the kikuyu pasture, the pasture quality and cow liveweight and condition were also poorer that the annual pasture.

The kikuyu pasture growing on deep sandy soil developed a larger (35 mm) soil water deficit than the annual pasture over much of the measurement period, and in particular from November to March. When integrated over a farm, to make up 40% of the total area; the resulting deep drainage from kikuyu was just over half that of an equivalent whole farm of annual pasture. This level of amelioration of deep drainage can potentially reduce the eventual extent of salinity in Western Australia by 25% and delay its onset by 40 years.

Over the 3 years of monitoring; the combined system of annual and kikuyu pasture was calculated to have a gross margin 19% higher than the annual pasture alone. The major source of difference was no requirement for supplementary feed in the kikuyu-annual pasture system. This difference was limited however, by lighter sale weights of cull cows from the kikuyu pasture in "poor legume" years. There is considerable opportunity to improve on this through achieving a consistent strong presence of legume in the kikuyu pasture through winter and spring.

See appendix 2 for more detail.

Plant water use trial (Kendenup)

Introduction

A substantial area of the temperate zone of Australia is threatened by land degradation as a consequence of the loss of excess water (eg salinisation, soil acidification, and soil erosion). One solution to this problem is to introduce high water-use perennials to current annual based pasture systems. In areas receiving more than 600 mm of annual rainfall SGS pre-experimental modelling (Bond *et al* 1997) suggested that high water-use perennials would need to include trees as well as perennial forage plants to regain hydrological balance but that below 600 mm forage perennials alone could restore balance.
The aim of the plant water use trial was to test the hypothesis that deep-rooted perennial grasses that are active outside the growing season will prevent groundwater recharge in areas receiving less than 600 mm rainfall. By comparing the water use of a pasture based on a summer active grass to a one based on annual species.

Materials and Methods

The study was conducted near Kendenup, Western Australia (34º 32' S, 117º 33' E) between 1998 and 2002. Soil type was a ferric mesotrophic brown chromosol with the following characteristics in the surface 10 cm, pH($CaCl_2$) 4.85, electrical conductivity 24.5 ms/m, organic carbon 5.43%, total nitrogen 0.419%, available phosphorus 34 mg/kg and available potassium 235 mg/kg. The annual pasture treatment was established on 1 ha of a long-term subterranean clover based pasture and the perennial pasture (kikuyu grass) treatment located on a neighbouring 1 ha sown in spring 1997. At the start of the experiment in May 1998, the annual pasture consisted of subterranean clover (94%), capeweed (*Arctotheca calendula* (L.); 2%), and annual grasses (4%). The perennial pasture consisted of kikuyu (cv. Whittet; 1%), subterranean clover (89%), capeweed (3%), and annual grasses (7%). Each 1 ha plot was isolated using interceptor drains that penetrated to the clay 'B' horizon. Plots were grazed by merino sheep managed by the producer. Stocking rates for both treatments were similar (~ 10 dse/ha). Measurements included pasture composition, herbage mass, annual herbage accumulation, kikuyu groundcover, soil moisture and groundwater height for details see Lodge 1998 or Andrew and Lodge 2003.

Results

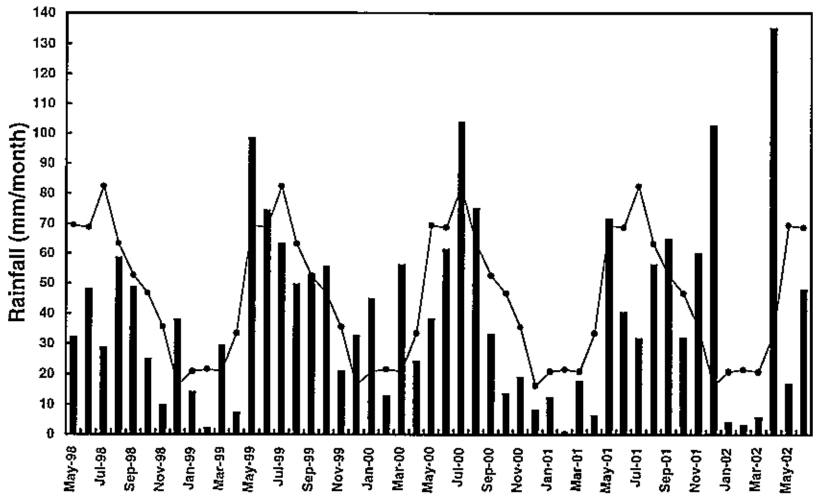


Figure 1. Average monthly rainfall (mm, bar) and long term average monthly rainfall (line) from May 1998 to June 2002 at Kendenup, Western Australia.

Rainfall

The monthly rainfall pattern spanning the 4 years of the experiment are shown in Figures 1. Annual rainfall was 501, 491 and 497 mm for 1999, 2000 and 2001, respectively. All years were below the long term average of 550 mm. Typically, opening rains occur in April and, on this basis, there was an early break (March) to the season in 1999, 2000. Monthly rainfall was adequate to support pastures from March to early November in 1999 and from March to late September 2000. Summer rain was recorded in1999-00 and 2001-02 (Fig. 1).

Botanical composition

The annual pasture (Fig. 2) typically consisted of large amounts of subterranean clover mixed with capeweed and annual ryegrass the only exception being 1999 when the pasture was dominated by capeweed and annual ryegrass. The kikuyu pasture was similar in composition during the perennial grass establishment phase in 1998/99 after which kikuyu increased in proportion particularly in summer and autumn.

Kikuyu groundcover

During the kikuyu establishment phase from October 1998 to December 1999 kikuyu groundcover slowly increased from around 5% to 17% (Fig. 3). However, groundcover increased substantially in the wet summer of 1999/00 reaching an average value of 51%. Throughout the winter and spring of 2000 kikuyu groundcover declined, only to recover to the pervious summer values in early June 2001 (Fig. 3).

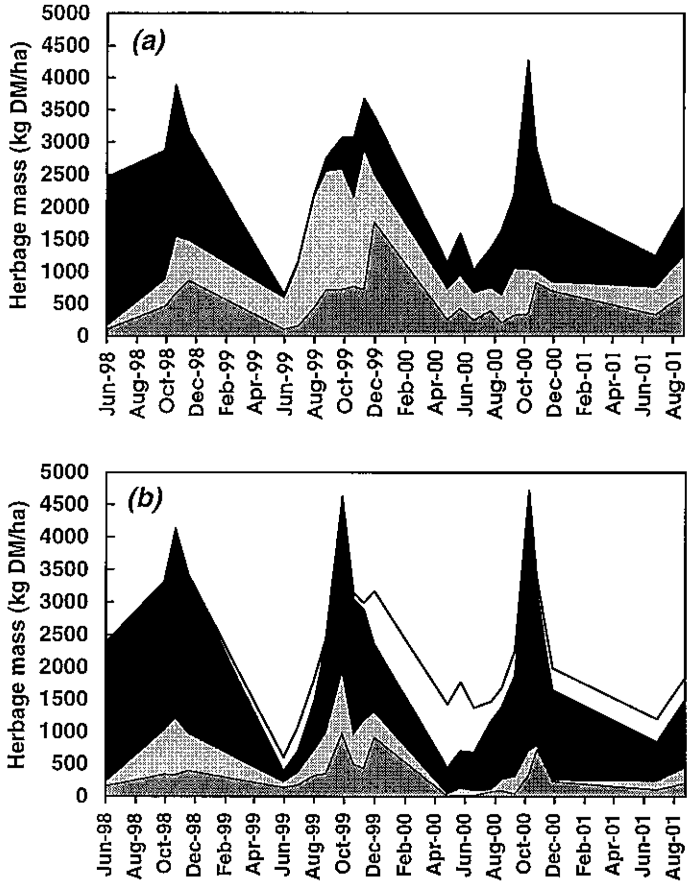


Figure 2. Botanical composition of (a) annual pasture, and, (b) kikuyu pasture from June 1998 to September 2001 at Kendenup, Western Australia (dark shading, annual grasses; light shading, broadleaf weeds; black, legumes; white, perennial grass).

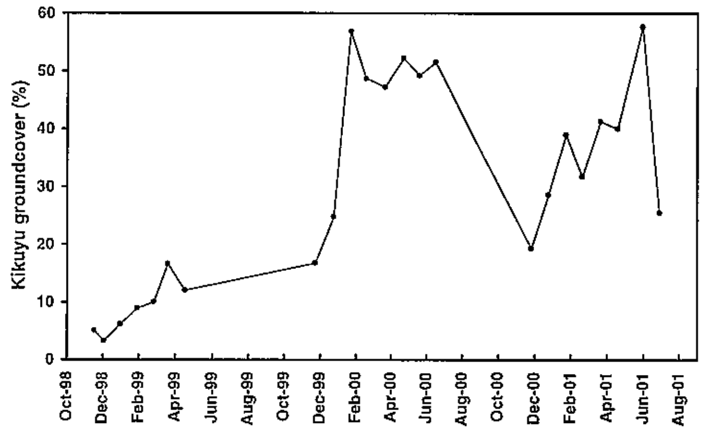


Figure 3. Percentage kikuyu groundcover from December 1998 to July 2001 at Kendenup, Western Australia.

Herbage mass

The pattern of herbage mass throughout each year was typical of that of pastures in a mediterranean environment, with a peak in spring and minimum availability in autumn (Fig. 2). Overall, the annual and kikuyu pasture had similar herbage mass with a peak of between 4000 to 4500 kgDM/ha in spring to a low of between 100 and 1000 kgDM/ha in autumn. The major difference was in green herbage mass. In autumn the kikuyu pasture consistently had green herbage at a time that the annual pasture only existed as dry residue (Fig. 4).

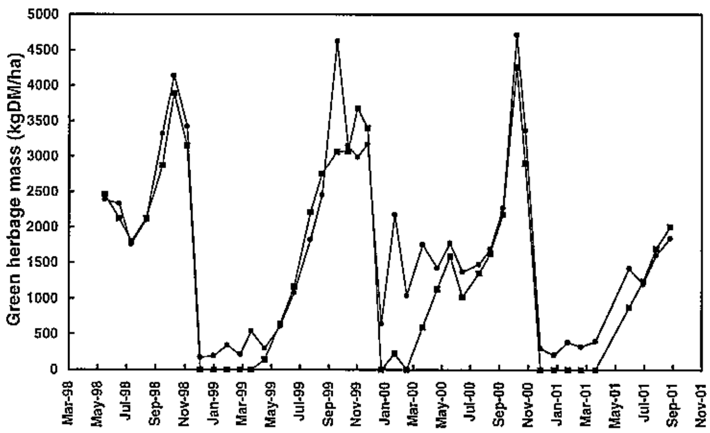


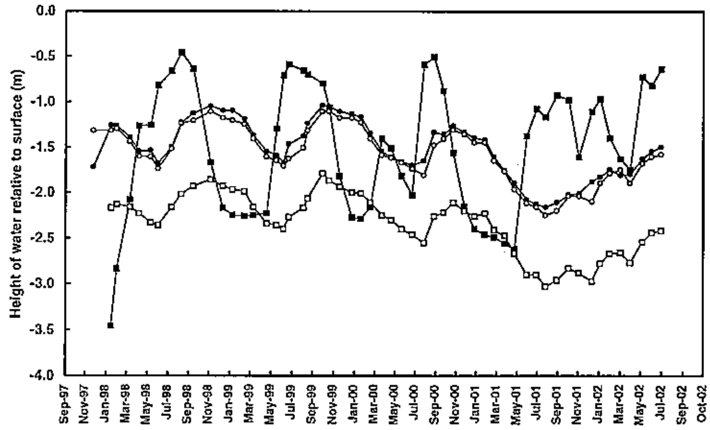
Figure 4. Green herbage mass for kikuyu (•) and annual (■) pasture at Kendenup, Western Australia

Annual herbage accumulation

Herbage accumulation for the annual pasture was 5692, 6940, and 6494 kgDM/ha.year for 1998, 1999 and 2000 respectively. In comparison the kikuyu pasture accumulated 6005 kgDM/ha.year in 1998, 8492 kgDM/ha.year in 1999 and 7293 kgDM/ha.year in 2000.

Groundwater height

Both perched (on top of a clay 'B' horizon) and groundwater heights were monitored. Beneath the annual pasture the groundwater fluctuated within 1.79 and 2.55 m of the soil surface in response to seasonal rain (Fig. 5). The only exception being the failure of the groundwater to rise in spring 2001 due to the lack of winter rainfall (Fig. 1). Perched water beneath the annual pasture typically rose to within 0.6 m of the surface in winter and receded to 2.3 m below the surface in summer (Fig. 5). The height and pattern of both perched and groundwater beneath the kikuyu pasture was identical,



fluctuating within 1.04 and 1.81 m of the surface the only exception again being the dry winter of 2001 (Fig. 5).

Figure 5. Height of water relative to surface for perched (■) and groundwater (□) system beneath annual pasture and perched (•) and groundwater (○) system beneath kikuyu pasture at Kendenup, Western Australia.

Soil water deficit (SWD)

The SWD's that developed in autumn each year beneath the kikuyu and annual pasture on the lower part of the slope were similar although kikuyu was consistently drier in 2000, 2001 and 2002 (Fig. 6a). On the upper slope the SWD's in autumn beneath the kikuyu were significantly larger than that for the annual pasture by 31 and 24 mm in 2000 and 2001, respectively, while not significant in 2002 the difference was 25 mm (Fig. 6b).

Discussion

In the high rainfall zone (HRZ, >600 mm annual rainfall) the kikuyu establishment phase normally lasts between 1 to 1.5 years, at Kendenup this establishment phase was longer (~2 years) presumably because of the lower rainfall and shorter growing season. Once established the kikuyu pasture performed similarly to those in the HRZ, that is comparable performance to an annual pasture within the growing season but with summer/autumn activity providing herbage accumulation and green feed outside the growing season. While livestock performance was not assessed in this study, based on previous work it is likely that kikuyu would have increased carrying capacity and reduced supplementary feed.

At this site the proximity of the perched water and groundwater systems to the surface confined the estimation of pasture water-use using SWD's to a depth of only 1.6 m. In addition soil moisture readings suggest that the water was closer to the surface at the lower part of the slope compared to the upper. As a consequence the kikuyu pasture did not have the opportunity to establish a substantially larger SWD than the annual pasture on the lower part of the slope due to the lateral movement of water close to the surface. However, on the upper slope the kikuyu pasture was able to establish a significantly larger SWD that typically amounted to 27 mm. Given that kikuyu roots can extend 2 m or more into the soil profile it is reasonable to suggest that kikuyu had access to groundwater and therefore used more than an additional 27 mm of water.

While it was not possible in this study to accurately determine the increase in water use by kikuyu the SWD results and presence of green leaf throughout summer suggest that kikuyu would provide useful increases in water use in the <600 mm agricultural zone along the south coast of Western Australia

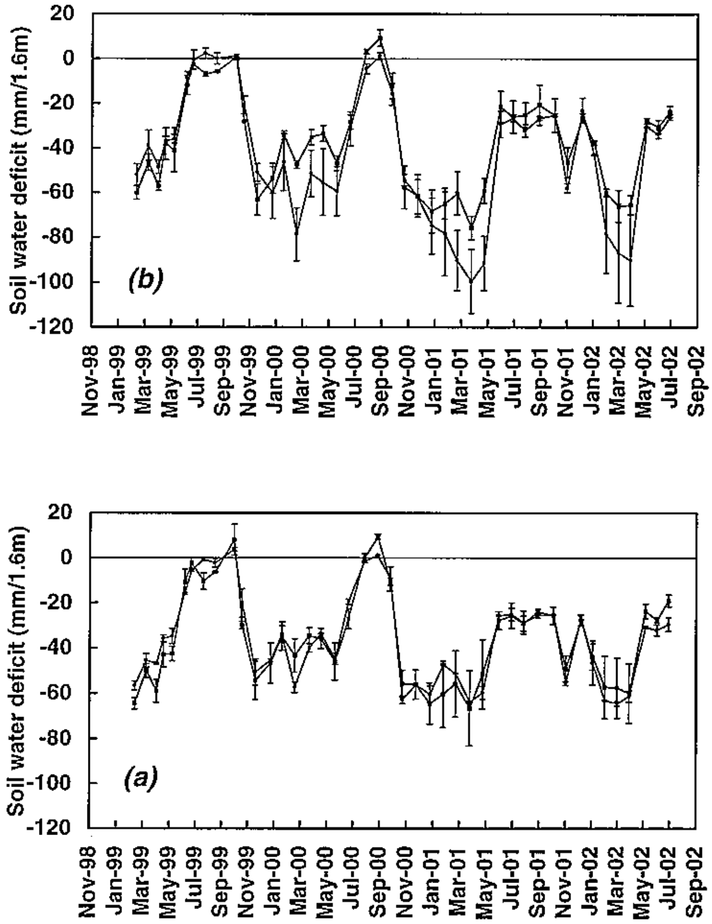


Figure 6. Soil water deficits (mm ± se per 1.6 m depth) beneath annual pasture (■), kikuyu pasture (•) on (a) lower slope and (b) upper slope from March 1999 until July 2002 at Kendenup, Western Australia.

References

Andrew MH, Lodge GM (2003) The Sustainable Grazing Systems National Experiment. 1. Introduction and methods. *Australian Journal of Experimental Agriculture* **43**,

Bond WJ, Cresswell HP, Simpson RJ, Paydar Z, Clark SG, Moore AD, Alcock DJ, Donnelly JR, Freer M, Keating BA, Huth NI, Snow VO (1997) Pre-experimentation water balance investigation for the MRC Sustainable Grazing Systems Key Program. In 'CSIRO Land and Water Consultancy Report 97-31'. (CSIRO: Australia)

Lodge GM (1998) Themes and experimental protocols for sustainable grazing systems. (Ed GM Lodge). LWRRDC Occasional Paper No.13/98. (Land & Water Resources Research & Development Corporation: Canberra)

Economics

Tree-pasture interaction trial

Figure 7 presents a gross margin analysis done using the Barlow *et al.* (2003) framework developed as part SGS. Note the analysis does not take into account the value of the trees. The difference in gross margins between treatments is largely a function of stocking rate. Kikuyu both with and without competition from trees had a gross margin at least double that of a comparable annual pasture treatment. Even kikuyu in competition with trees had a gross margin of $230/ha compared to $99/ha for the annual control. The lowest gross margin was $55/ha for the least productive treatment, annual pasture 20% affected by trees facing south. Gross margins for the annual treatments 20% affected by trees facing east and west were higher than the control due to finer wool, presumably caused by lower intake.

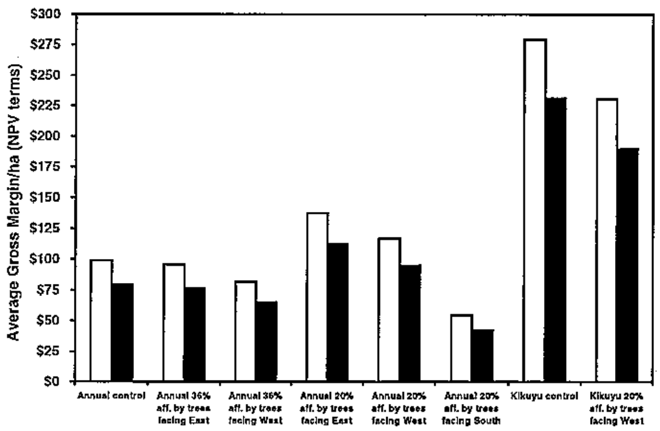


Figure 7. Gross margins ($/ha), averaged over 10 years, for tree-pasture interaction trial conducted at Albany, Western Australia. Open bar is high management skill, closed bar is district base management skill

Reference

Barlow R, Mason WK, Ellis NJS (2003) A practical framework to evaluate combined natural resource and production outcomes. *Australian Journal of Experimental Agriculture* **43**,

Sustainable beef production demonstration

See appendix 2.

Hunches

- Use of perennial pasture species in agroforestry systems will minimise loss of pasture and livestock production from competition with the trees.
- Deep rooted, summer active C_4 perennial grasses will substantially reduce groundwater recharge in soil profiles that do not inhibit the development of a deep root system.
- Summer active C_4 perennial grasses will increase herbage accumulation in wet summers.
- In a mediterranean environment summer active C_4 perennial grasses will enable producers to increase stocking rates sustainably
- Kikuyu should not exceed 40% of the total grazing area on any one farm. Beyond 40% the overall productivity of the grazing system diminishes.
- The application of nitrogenous fertilisers to kikuyu pasture, preceding rain in late spring to autumn will increase pasture digestibility and crude protein.
- Robust sustainability indicators include the proportion of days in the year that a pasture possesses green leaf, and groundcover of ≥70%.

Uncertainties

- Are the production and sustainability benefits of summer active C_4 perennial grasses alone or in combination with trees greater when considered in the context of a whole farm system compared to the paddock scale as investigated in this study
- To what extent can we extend the findings beyond the local region surrounding a Site?
- Are there alternative C_4 warm season grasses and summer active C_3 grasses that would support productive and sustainable grazing systems in southern Australia?
- Are there tufted C_4 warm season perennial grasses that are superior to kikuyu in forage quality, herbage accumulation and for cattle production?
- Is it possible to rotate C_4 perennial grasses with annual grain crops without suffering a yield penalty and at the same time reduce groundwater recharge?
- Can kikuyu pastures be profitably run as a high input system eg higher rates of fertiliser?
- What are the optimal nutrient requirements of kikuyu?
- Could desirable perennial broadleaf pasture species be useful for grazing systems in southwest WA?
- How would a kikuyu based livestock production system respond to rotational grazing?
- Could we successfully introduce a perennial legume into a kikuyu pasture to improve summer forage quality
- Would a better understanding of the relationship between leaf area index and pasture growth in kikuyu pastures lead to improved herbage accumulation and water use efficiency?
- How can perennial pasture establishment be made cheaper and simpler?
- Are there any understorey plant species that could provide forage for livestock under tree belts?

Extent to which the database and model have contributed to addressing Site objectives

SGS Database

The SGS Database was an essential tool in the process of data collection and interrogation leading to the Site analyses. The Site database provided a one-stop-shop for climate, soil, pasture and animal data required for the analyses and SGS Pasture Model simulations. The consistent format of the data provided by the database framework was particularly important in facilitating data extraction and analysis.

SGS Pasture Model

The SGS Pasture Model was used in the Harvest Year by the Site to support Theme analysis, and to explore the impact of treatments on groundwater recharge historically using long-run simulations (1971-2001) with SILO climate datasets.

Publications

In addition to the scientific publications listed below the Site published numerous articles for publications such as Prograzier and Tips and Tools.

Publications published

Sanford, P., Gladman, J. and Cransberg, L. (1997). Sheep production on an annual and perennial pasture in southwest Australia. In 'Proceedings XVIII International Grassland Congress', Canada.

Sanford P, Kemp D, Lodge G, Garden D, Grimm M, Graham J (1998) Pasture theme protocol. In 'Themes and experimental protocols for sustainable grazing systems'. (Ed. GM Lodge) pp. 12-29. Meat and Livestock Australia & Land and Water Resources Research and Development Corporation, Occasional Publication No **13/98**.

Manuscripts submitted for publication in the SGS Special Edition of the Australian Journal of Experimental Agriculture

McDowall MM, Hall DJM, Johnson DA, Bowyer J, Spicer P (2003) Kikuyu and annual pasture: a characterisation of a productive and sustainable beef production system on the South Coast of Western Australia. *Australian Journal of Experimental Agriculture* **43.**

Sanford P, Cullen BR, Dowling PM, Chapman DF, Garden DL, Lodge GM, Andrew MH, Quigley PE, Murphy SR, King WMcG, Johnston WH, Kemp DR (2003) SGS Pasture Theme: effect of climate, soil factors and management on pasture production and stability across the high rainfall zone of southern Australia. *Australian Journal of Experimental Agriculture* **43.**

Sanford P, Wang X, Greathead KD, Gladman JH, Speijers J (2003) Impact of Tasmanian blue gum belts and kikuyu-based pasture on sheep production and groundwater recharge in South-West Western Australia. *Australian Journal of Experimental Agriculture* **43.**

Planned publications

Sanford P, Greathead KD, Gladman JH, Boultwood J (2004) Impact of Tasmanian blue gum belts and kikuyu-based pasture on pasture and tree production in South-West Western Australia. *Australian Journal of Experimental Agriculture.*

Sanford P, Gladman JH, Greathead KD (2005). Plant water-use in tree-pasture and pasture only systems in southwest Australia. *Australian Journal of Experimental Agriculture.*

Wang X, Sanford P, Greathead KD, Gladman JH, Boultwood J. (2004) Impact of Tasmanian blue gum belts and kikuyu-based pasture on sheep and wool production in South-West Western Australia. *Australian Journal of Experimental Agriculture.*

Papers that could be written but for which there are no current plans

- Changes in soil characteristics when Eucalyptus globulus tree belts are planted on agricultural land in south-west Australia.
- Further exploration of the site data using the SGS Pasture Model and GrassGro.

Challenges and Opportunities

Challenges

- Identification of new summer active perennial pasture species for alternative situations or objectives (eg growing livestock out of season) that can improve livestock production while significantly reducing groundwater recharge.

- Understanding how current sustainable perennial pasture options fit in the whole farm system.
- Grazing systems that optimise the use of a range of tactics (rotational grazing, resting, set stocked) to achieve a particular pasture/livestock objective.
- Understanding how perennial based pastures and management influence soils structure and biology.
- Impact of perennial grass systems on animal health (eg intestinal worms).
- The risk that C_4 perennial grasses may pose to cropping systems (eg root disease).
- Developing agroforestry systems based on perennial pastures that efficiently utilise resources (eg water) with no decline in livestock production.
- Low cost establishment of perennial pastures.
- Development of a high input/high profit kikuyu based production system.
- Linking SGS findings to the catchment scale.
- Further use of modeling to determine optimal pasture management for production, stability and economics.
- Determining whether increasing the biodiversity of pastures in south-west Western Australia will provide production and environmental benefits.

Opportunities

- Site team could assist in the development of the new program to replace SGS, and develop a research proposal to submit to the new program or other sources of funding.
- Further Site analysis and publications.

Acknowledgments

Albany

We would like to thank Ron Adams, Jack Carr and Ray and Angela Shepherd for the use of their farms and assistance with the experiment. We are also indebted to the staff at the Western Australian Chemistry Centre for support with soil analysis, and staff at the Department of Agriculture Wool Laboratory for their help with wool analysis. Funding for this work was provided by the Department of Agriculture Western Australia, Meat & Livestock Australia and Land & Water Australia.

Esperance

We would like to thank David Johnson for the use of his property and assistance with the experiment. We are also indebted to Craig McLernon and Adrian Reid for their technical support and William D. Dalton for his assistance in carrying out the economic analysis. This project was partially funded through the Sustainable Grazing Systems Key Program; a joint initiative of Meat & Livestock Australia and Land &Water Research and Development Corporation. We would also like to acknowledge the contribution and enthusiasm of the late Carmen Saunders, without whom this project would not have been initiated.

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Financial statement

Date quarter beginning	Staffing budget		Operating costs		Total cash flow	
	Budget (days)	Actual (days)	Credit ($)	Debit ($)	Credit ($)	Debit ($)
1-Jul-01	178	179	20,490	4,771	20,490	4,771
1-Oct-01	178	201	30,490	34,235	30,490	34,235
1-Jan-01	178	176	20,491	24,236	20,491	24,236
1-Apr-01	178	185	0	33,459	0	33,459
Total	**712**	**741**	**71,471**	**96,701**	**71,471**	**96,701**
Balance						**(25,230)**

Note: There where no entries in the overseas travel or capital categories.

As part of the contract the Western Australian Site held the Pasture Theme Funds, totalling $40,000 from 1997/98 to 2001/02, of which $22,919 has been spent leaving a balance of $17,081 (refer to SGS Pasture Theme Final Report 2003). It is suggested that MLA on acceptance of the Pasture Theme and WA site final report subtract this amount from the final payment ($20,491) leaving $3,410.

Value-added by the Harvest Year process

Value added to Site findings

- The Harvest Year provided dedicated time to undertake data analysis and write the findings up in scientific papers for submission to the Australian Journal of Experimental Agriculture.
- Without the harvest year there would not have been any major use of the model.

How much have the Site findings changed from last year's report?

Last year's findings were preliminary but proved to be accurate with the exception of the following.

- Water balance estimates undertaken prior to the Harvest Year were very preliminary, the harvest year provided an opportunity to undertake a far more exhaustive analysis including modeling that resulted in revisions to deep drainage values. Initially the difference in soil water deficits between the annual and kikuyu pasture at Albany were underestimated by a factor of approximately 2. At Esperance preliminary deep drainage values for kikuyu pasture were too low.
- Preliminary analysis suggested that there was a substantial loss of pasture production on kikuyu treatments in competition with trees. Comprehensive statistical analysis in the Harvest Year revealed that this was not the case and that the perennial was far more successful at competing with trees for water and nutrients.

What is the added confidence in the findings?

Confidence in the findings has increased since there has been more time to analyse and understand the data and so provide a more valued interpretation.

What added insights/understandings have been achieved?

- Kikuyu competes well with trees for water and nutrients compared to annual pasture leading to the possibility of superior agroforestry systems which incorporate perennial pastures.
- Groundwater recharge beneath kikuyu based pasture in the >600mm rainfall zone is considerably less than expected, reducing the area required under trees to halt groundwater rise.

How much more rapidly have the Site papers been produced than would have been the case without a Harvest Year?

- At least 12 months however, it could have been as long as 2 to 3 years or never.

In hindsight, how could the Harvest Year have been made more effective?

- We should have started it a lot earlier and allowed the researchers to have more of a data focus than a Harvest Team focus.
- The SGS Model, Database and Site data should have been ready from day 1 of the Harvest Year.
- Researchers need to be able to dedicate time to do the work rather than be distracted by work elsewhere.

Appendix 1.

Albany Site paper as submitted to Australian Journal of Experimental Agriculture, November 2003.

Appendix 2.

Esperance Site paper as submitted to Australian Journal of Experimental Agriculture, November 2003.

Appendix 3.

Changes in soil characteristics when Eucalyptus globulus tree belts are planted on agricultural land in south-west Australia – A Tertiary Studentship Report

Appendix 1.

Albany Site paper as submitted to Australian Journal of Experimental Agriculture, November 2003.

Impact of Tasmanian blue gum belts and kikuyu-based pasture on sheep production and groundwater recharge in South-West Western Australia

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Short title: Impact of tree belts and kikuyu on livestock and groundwater recharge

Abstract. The effect of Tasmanian blue gum (*Eucalyptus globulus*) belts and kikuyu (*Pennisetum clandestinum*) grass on livestock production and groundwater recharge was studied in the high rainfall zone (>600 mm/year) of South-West Western Australia from 1998-2001. The objective was to identify optimum combinations of tree belts and pasture for sustainable livestock production and the prevention of secondary salinisation. Treatments were annual pasture, in competition with trees at different orientations (east, west and south), kikuyu pasture in competition with trees at 1 orientation (west), compared with pasture in the absence of tree competition. Plots had 0, 20 or 36% of their area within 10 m of the tree belt where tree-pasture competition would be expected. Plots (0.48 ha) were stocked with Merino wether hoggets at 12 DSE/ha on annual pastures and 14 DSE/ha on kikuyu pastures. Additional sheep were placed on plots in spring and the annual pasture was destocked in autumn.

Within the growing season, herbage mass was similar across both control treatments as a result of varying stock numbers. However, in summer and autumn the kikuyu control contained between 355 and 4890 kg DM/ha more herbage than the corresponding annual pasture. While both pastures accumulated similar amounts of herbage in 1998 and 2000, kikuyu accumulated more in 1999 (11884 *vs.* 9765 kg DM/ha) as a result of summer rain. Competition from trees significantly reduced annual pasture herbage accumulation (16% average reduction), although there was no difference between the levels of competition. Trees did not significantly affect kikuyu pasture herbage accumulation.

Both carrying capacity and clean wool production per hectare were significantly higher on kikuyu pasture in 1999 and 2000. Tree competition also significantly reduced the carrying capacity of both annual and kikuyu pasture by an average of 10%. Clean

wool production per hectare was significantly lower on annual pasture in combination with trees (11% reduction on average), but there was less effect of competition on kikuyu pasture.

The kikuyu pasture used 115, 57 and 132 mm more water than the annual pasture in 1999, 2000 and 2001, respectively. Trees created an autumn soil water deficit that exceeded that below both control pastures by 297-442 mm.

Although the addition of tree belts to annual pasture provided useful reductions in groundwater recharge, producers would also have to accept losses in livestock production. While kikuyu alone provided significant increases in livestock production and substantial reductions in groundwater recharge, the best compromise was kikuyu in combination with tree belts.

Introduction

The high rainfall zone (HRZ, >600mm/year) of South-West Western Australia is characterised by a mediterranean climate, infertile sandy soils and annual pastures which are a combination of legumes, annual grasses and broadleaf weeds. These pastures regenerate from a seed bank at the break of season in autumn-winter providing high quality green feed for livestock until late spring. In summer and early autumn, livestock rely on dry pasture residues and conserved feed such as hay, silage or grain. The introduction of perennials into these pastures can lengthen the growing season, which will increase carrying capacity and reduce the need for conserved feed.

In addition, perennials can also assist in reducing the incidence of secondary salinisation. Salt originating from the ocean has been deposited into the soil profile by rain and dust over many thousands of years (Allison *et al.* 1990; George *et al.* 1997). This salt along with the groundwater is now rising to the soil surface as a consequence of the replacement of the original deep-rooted native vegetation with shallow-rooted crops and pasture (George *et al.* 1997). If current agricultural practices continue potentially 6.1 million hectares of land, in South-West Western Australia will be affected by secondary salinisation (Ferdowsian *et al.* 1996).

One method for reducing the threat of salinity is to incorporate deep-rooted perennial plants into agricultural systems that mimic the original native vegetation (Hatton and Nulsen 1999). Previously studied solutions include lucerne (*Medicago sativa* L., Angus *et al.* 2001; McCallum *et al.* 2001; Ridley *et al.* 2001; Ward *et al.* 2001, 2002) and phalaris (*Phalaris aquatica* L., Scott and Sudmeyer 1993; Ridley *et al.* 1997; Dolling 2001). While lucerne has demonstrated an ability to use more water and reduce groundwater recharge (Angus *et al.* 2001; McCallum *et al.* 2001; Ridley *et al.* 2001; Ward *et al.* 2001) both species have limited application in the HRZ of South-West Western Australia because they are poorly suited to the acid soils that are common in the region. Kikuyu (*Pennisetum clandestinum* Hochst. Ex Chiov.) is a tropical perennial grass that is both productive (Sanford *et al.* 1997) and persistent in this area on acid soils. In addition, kikuyu possesses a deep root system (Ferdowsian and Greenham 1992) and green leaf through summer and autumn, which enable it to fill the 'autumn feed gap' (Sanford *et al.* 1997) and use more water (McDowall *et al.* 2003).

Unfortunately, perennial pastures alone may not be able to reduce drainage sufficiently in the HRZ (Webb 1993; Heislers and Reid 1996; Bond *et al.* 1997; Ridley *et al.* 1997; Walker *et al.* 1999). To restore the hydrological balance may require the introduction of trees into farming systems (Bond *et al.* 1997; Walker *et al.* 1999). In the

HRZ of South-West Western Australia, Tasmanian blue gums (*Eucalyptus globulus* Labill.) are grown for wood chips, with plantations currently occupying more than 130,000 hectares. Blue gums integrated with pasture in an alley farming system provide an opportunity to reduce groundwater recharge to acceptable limits while continuing livestock production and supplementing farm income (Eastham *et al.* 1994; Lefroy and Scott 1994). However, if trees are planted over a large area of the landscape to control groundwater recharge, there will be a corresponding increase in tree-pasture interface and resource competition (Stirzaker *et al.* 1999, 2002; Lefroy *et al.* 2001; Knight *et al.* 2002).

The aims of this study were to:

1. Determine whether the inclusion of kikuyu grass with subterranean clover (*Trifolium subterraneum* L.) can provide useful increases in livestock production and reductions in groundwater recharge compared with a traditional annual pasture.

2. Quantify the competition effects between Tasmanian blue gum belts (alley system) and both annual and perennial pastures.

3. Determine the impact of a blue gum alley farming system on sheep production and groundwater recharge in the HRZ of South-West Western Australia.

Materials and methods

Site details

The study was conducted near Albany, Western Australia (35° 54' S, 117° 49' E) between 1998 and 2001. Soil type was a grey sand of varying depth (0-30 cm) over a cemented lateritic layer over clay and fine sand. The watertable was located 20 m below the surface and was fresh (10 ms^{-1}). Annual pasture treatments were established on a long-term subterranean clover based pasture and the perennial pasture (kikuyu grass) treatments located on a neighbouring paddock sown by the farmer in 1995. At the start of the experiment in April 1998, the annual pasture consisted of subterranean clover (48%), erodium (*Erodium botrys* (Cav.) Bertiol.; 38%), dock (*Rumex pulcher* L.; 6%), capeweed (*Arctotheca calendula* (L.); 5%), and, winter grass (*Poa annua* L.; 3%), together with small amounts of annual ryegrass (*Lolium rigidum* Gaudin), barley grass (*Hordeum leporinum* Link), brome grass (*Bromus diandrus* Roth), chickweed (*Cerastium glomeratum* Thuill), crassula (*Crassula decumben* Thunb.), flatweed (*Hypochoeris glabra* L.), serradella (*Ornithopus* spp.), silver grass (*Vulpia myuros* L. C.C.Gmel.), and sorrel (*Acetocella vulgaris* Fourr). The perennial pasture consisted of kikuyu (cv. Whittet; 83%), subterranean clover (11%), chickweed (4%) and small amounts of annual ryegrass, barley grass, capeweed, erodium and winter grass. The Tasmanian blue gum belts adjoining the annual pasture treatments were planted north-south (Fig. 1) in 1993 and those alongside the kikuyu pasture in 1992, following ripping of the cemented laterite to a depth of approximately 1 m. Trees were planted at a density of 1250 stems/ha, in 11 rows, 4 m apart, trees 2 m apart in the rows. The trees had an average diameter at breast height (DBH) of 0.15 m, height of 13.4 m and wood volume of 98.2 m^3/ha in 1998 and average DBH of 0.17 m, height of 14.7 m and wood volume of 135.9 m^3/ha in 2000. For further information on soil characteristics and climate measurements refer to Andrew and Lodge (2003).

(Insert Fig. 1 and Table 1 here)

Experimental layout and treatments

Treatments and plots are shown in Figure 1 and Table 1. All plots were 0.48 ha in size. There was insufficient tree-pasture interface at the Site to replicate all treatments, and details of replication are shown in Table 1. Previous work by Albertson *et al.* (2000) showed that competition between Tasmanian blue gums (up to age 10 years) and annual pasture for water and nutrients was primarily confined to a zone 10 m from the tree-pasture interface. Treatments in the present study were designed to allow for this, with 0, 20 and 36% of plot area within this competition zone. Plot-treatments in competition with trees were placed along the tree belts either side of the annual pasture facing east, west and south and on the western facing belt in the kikuyu pasture (Fig. 1). Control plots were placed in the centre of each respective pasture 110-160 m from the tree belts depending on location in the annual pasture and 210 m in the kikuyu pasture.

Pasture management

Both annual and perennial based pastures were topdressed with 140 kg superphosphate/ha [(9.1% phosphorus (P), 11.5% sulfur (S)] in autumn each year and sprayed for red-legged earth mite on the 11 May, 24 June and 14 October 1998 using dimetholate (400 g a.i./L) at 100 mL/ha. Pastures were sprayed again on the 13 October 1999 and 11 October 2000 using omethoate (290 g a.i./L) at 100 mL/ha.

In winter 1998, erodium and capeweed began to dominate the annual pasture treatment. To prevent a massive seed set, plots were 'spray-grazed' on 31 August with MCPA amine (500 g/L) at 1 L/ha. Extra sheep were placed on all treatments, except for the southern facing plot, resulting in stocking rates of 19-63 sheep/ha, from 2-17 September, depending on the herbage mass.

Between 13-20 May 1999 all treatments were sown to subterranean clover (cv. Trikkala, cv. Karridale and cv. Esperance mixed 40, 40 and 20%, respectively) because of the low clover seed bank in the kikuyu pasture (29 kg/ha). Plots 6, 7, 8, 13, 14, 15, 16, 17, 18 were sown at 200 kg/ha and plots 1, 2, 3, 4, 5, 9, 10, 11, 12 at 100 kg/ha (refer to Table 1 for treatment), based on the size of the original clover seed bank.

The aim of grazing management was to prevent the annual and kikuyu treatments exceeding herbage masses of 3000 kg DM/ha and 4000 kg DM/ha, respectively by adjusting stocking rate in winter and spring. The objective of this management was to minimise differences in herbage mass and presumably leaf area that could result in differences in herbage accumulation rates independent of intensity of tree competition.

Livestock management

The first draft of Merino wether hoggets was introduced to the experiment in April 1998. Sheep grazing the annual pasture were finally removed in January 2001 and those grazing kikuyu pasture in October 2001. New drafts were introduced in early summer 1998-1999 and 1999-2000 from hoggets purchased by the host farmer. The base stocking rate for sheep grazing annual and kikuyu pasture was 12 and 14 sheep/ha, respectively. Additional sheep were placed on plots in an attempt to prevent herbage mass exceeding 3000-4000 kg DM/ha. Stock were removed from the annual pasture treatments in summer-autumn when dry herbage mass reached 800-1000 kg DM/ha to prevent soil erosion. Sheep were removed from plots for shearing in October each year and returned 3 days later.

Internal parasites were a problem in the experiment, which became apparent by the end of 1998. Following identification and control of worms in the 1998 draft, slow release Ivomectin capsules were used in the 1999 draft. Hoggets did not respond and were found to be carrying Ivomectin resistant worms. Subsequently, regular sampling for worm burdens and varied anthelmintic worm treatments were implemented.

A supplement consisting of oats and lupins in a 2:1 ratio was fed when pasture quality and quantity declined and sheep lost >100g/day liveweight, with the quantities fed being based the on rate of weight loss.

Measurements

Climate. Rainfall and air temperature were measured alongside the control plot approximately 100 m from the tree belt on the eastern side of the annual pasture paddock (Fig. 1) using the equipment described by Andrew and Lodge (2003).

Pastures. For pasture measurements, plots were divided into sampling units. The size of each unit was determined by dividing the boundary of each plot, alongside the tree belt, into 4 and then the width of the plot into 0-10 m, 10-20 m, 20-30 m and 30-50 m distances from the tree-pasture interface. Control plots were divided into sampling units based on one-quarter of the total plot area. The number of sampling units per plot is shown in Table 1.

Pasture species composition, percent green and total herbage mass was estimated every 4 weeks throughout the experiment using BOTANAL procedures (Andrew and Lodge 2003). For each sampling unit 5 estimates were taken in plots alongside the tree belt and 10 in the control plots, resulting in between 40 and 80 estimates per plot. Herbage accumulation was estimated by measuring herbage mass accumulation in 1 m^2 exclusion cages. Herbage mass was determined using the calibrated visual assessment technique of Campbell and Arnold (1973). One exclusion cage was placed in each sampling unit in plots adjoining trees and 3 exclusion cages were evenly spaced in each sampling unit in control plots. Measurements were taken every 3-4 weeks depending on herbage accumulation rate. At each sampling, 15-20 calibration quadrats ($0.1 m^2$) were cut to ground level with a scalpel, to relate visual estimates to actual herbage mass. Annual herbage accumulation was determined by totalling growth for the calender year.

Animals. Liveweight and wool production were measured according to the SGS protocols (Lodge 1998). Clean wool production per hectare was calculated using the following equation:

Clean wool (kg/ha) = greasy fleece per head x clean wool yield x proportion of fleece grown on plot x sheep grazing days per ha/number of days sheep grazed plot

Average liveweight per hectare was calculated using a core mob of sheep.

Soil water content. Six neutron moisture meter (NMM) access tubes were installed in November 1998 to a depth of 6 m beneath the trees and the annual and kikuyu pasture at the locations described in Fig. 1. Soil water content was measured at a depth of 20 cm, then at 20 cm intervals to 400 cm, 450 cm, and 500 cm each month. For further detail refer to Andrew and Lodge (2003). Soil water deficits were calculated as described by White *et al.* (2003).

Statistical analyses

Annual herbage accumulation and clean wool production data were analysed using a linear mixed model which included fixed effects of year, treatment and year.treatment. Treatment effects were subdivided into a contrast between annual pasture and kikuyu plots, and comparisons of tree-pasture combinations within annual and kikuyu pasture treatments. Several different variance-covariance structures for the between plot variance were fitted to the data, and the simplest model which did not significantly increase model deviance from the minimum deviance was chosen to estimate treatment means and standard errors.

Herbage mass and cumulative sheep grazing days were transformed (square root scale) to stabilise variance and then analysed using a linear mixed model with autoregressive correlation between sampling dates. The fixed effects model was the same as that described for annual herbage accumulation and wool data. Liveweight data was not analysed since treatment effects were confounded by changes in stocking rate.

(Insert Fig. 2 here)

Results

Seasonal conditions

The monthly temperature and rainfall patterns spanning the 4 years of the experiment are shown in Figures 2*a* and 2*b*, respectively. Annual rainfall was 705, 706, 642 and 745 mm for 1998, 1999, 2000 and 2001, respectively. All years were below the long term average of 810 mm, but this is not unusual since annual rainfall has been declining on the south coast of Western Australia. Typically, opening rains occur in April and, on this basis, there was an early break (March) to the season in 1998, 2000 and 2001 and a late break (May) in 1999. Monthly rainfall was adequate to support pastures from March-November in 1998 and from May-November in 1999. After the early break in 2000, rainfall for every month except July was well below average (Fig. 2*b*). As a consequence of the dry spring herbage accumulation was limited by moisture in this year. Summer rain was recorded in 1998-99, 1999-00 and 2001-02 (Fig. 2*b*).

(Insert Fig. 3 here)

Botanical composition

The influence of tree competition on botanical competition was minor and confined to the zone within 10 m of the tree-pasture interface. For this reason, only the botanical composition of the control pastures is presented (Fig. 3) to illustrate the difference between the perennial and annual pastures and general changes that occurred because of season and grazing.

The annual pasture (Fig. 3*a*) typically consisted of large amounts of subterranean clover mixed with broadleaf weeds (capeweed and erodium) and annual grasses (silver grass, barley grass and winter grass). In contrast, the kikuyu treatments comprised mainly of subterranean clover in the winter-spring and kikuyu in summer-autumn (Fig. 3*b*). The clover component provided feed in winter at a time when kikuyu growth was poor, while kikuyu supported production in summer-autumn when the clover existed as dry residue. Broadleaf weeds and annual grasses were minor components in the kikuyu pasture.

In winter of 1998, capeweed and erodium dominated the annual pasture treatments (92% of total herbage mass), as a result of the early break and delayed grazing pressure (Fig. 3*a*). A subsequent 'spray-graze' in late August successfully reduced the broadleaf weed component (to 39%) and subterranean clover dominated the pasture for the remainder of the experiment, with the exception of an early break to the season (March) in 2000 (Fig. 2). In the growing season of 1998, clover content in the kikuyu control plots averaged only 20% of herbage mass (Fig. 3*b*). Intensive grazing throughout the summer and autumn of 1998-99 (Fig. 4) and sowing of subterranean clover in May 1999 resulted in an increase of clover to 70% in spring of that year and 84% in spring 2000.

(Insert Fig. 4 here)

Herbage mass

The pattern of herbage mass throughout each year was typical of that of pastures in a mediterranean environment, with a peak in spring and minimum availability in autumn. Because of its summer-autumn activity the perennial pasture had between 355- to 4890 kg DM/ha more herbage though the autumn period than the annual pasture (Fig. 5).

Herbage mass should have been independent of treatment as we attempted to maintain herbage at a maximum of 3000 kg DM/ha and 4000 kg DM/ha for annual and kikuyu treatments, respectively by manipulating grazing pressure (Fig. 4; see stocking rate section). However there were differences between the annual pasture treatments (P<0.001) and the kikuyu pasture treatments (P<0.05) in 1998 (Fig. 5). Control of herbage mass in annual pastures was poor due to an early break, low stocking rate in autumn and early winter, and a 'spray-graze' in August to control broadleaf weeds. In 1998, the kikuyu treatments accumulated low quality herbage (Fig. 5) without the benefit of high quality winter growth of subterranean clover, which compromised the performance of the livestock. Control of herbage mass in all treatments was more successful in 1999 and 2000.

(Insert Fig. 5 and Table 2 here)

Annual herbage accumulation

Herbage accumulation for the annual and kikuyu control pastures was similar in 1998 and 2000, and the kikuyu pasture only out yielded its annual counterpart in 1999 as a consequence of growth outside the annual growing season (autumn 1999).

Overall, annual herbage accumulation (Table 2) declined with increasing competition from trees. The average effect of competition on annual pasture was significant ($P<0.01$, 16% reduction), but there were no significant differences among the levels of competition. There was also a significant interaction between year and effect of competition ($P<0.05$), with a significant effect in 1999, but not in 1998 or 2000. The effect of aspect was not significant. There was no significant effect of tree competition on kikuyu annual herbage accumulation. Kikuyu (K20W) accumulated more herbage annually in competition with trees than the corresponding annual pasture (A20W), irrespective of year.

Stocking rate

It was necessary to vary stocking rates considerably throughout the experimental period in response to changing herbage mass and herbage accumulation rates (Fig. 4). In summer, stocking rates on kikuyu were increased to 25-30 sheep/ha. Conversely, all sheep were removed from annual pastures in this period for 98 days in 1999 and 64 days in 2000, but increased in spring depending on treatment (Fig. 4).

Cumulative sheep grazing days per hectare (Table 3) was used as a simple measure of carrying capacity. Kikuyu pasture had a greater ($P<0.001$) carrying capacity than annual pasture in 1999 and 2000. Competition with trees significantly ($P<0.001$)

reduced the carrying capacity of both annual and kikuyu pasture by an average of 10%. However, even competing with trees, kikuyu pasture (K20W) had a greater ($P<0.01$) carrying capacity than annual pasture (A20W) in 1999 and 2000. There were pasture and year effects and the interactions were significant ($P<0.01$). For example, annual control plots had significantly more sheep grazing days than annual treatments competing with trees in 1998 and 1999, but not in 2000. On the other hand, the kikuyu control had about 43 and 16% more sheep grazing days than kikuyu in competition with trees in 1999 and 2000, respectively, but not in 1998. There was a significant effect of tree line orientation ($P<0.05$), but no effect of level of tree competition. Generally, south and west facing treatments carried fewer sheep than east facing treatments.

(Insert Table 3 and Table 4 here)

Supplementary feed

No grain was fed to sheep grazing the annual pasture in 1998 because of the early break and timing of the commencement the experiment (Table 4). However, sheep on this pasture were fed grain from January-March 1999 and December 1999-August 2000. On the kikuyu pasture grain was fed in 1998 from June-September (Table 4), because of internal parasitic worm problems and a lack of subterranean clover in the winter period. Sheep grazing these pastures were not fed grain in 1999 and 2000, following adequate control of internal worms (Table 4).

(Insert Fig. 6 here)

Sheep liveweight

The effect of treatment and changes in stocking rate on liveweight were confounded, therefore only general differences are reported.

In 1998, the average liveweight (Fig. 6) for sheep grazing the kikuyu pasture was much lower than that of those grazing annual pasture (45 *vs*. 60 kg/head respectively at finishing). This reflected the effect of intestinal worms and low subterranean clover content in the kikuyu pasture. In 1999 and 2000, the average liveweight was similar for sheep grazing annual and kikuyu pastures in winter and spring (Fig 6). However, sheep grazing dry annual pasture in summer lost body weight rapidly and were removed when dry residues declined to less than 1000 kg DM/ha. Sheep grazing kikuyu pasture maintained body weight during summer-autumn (Fig. 6) in both these years at a stocking rate of around 24 sheep/ha (Fig. 4) without supplementary feed (Table 4).

Sheep grazing the annual pasture on the south facing (A20S) and west facing (A36W) treatments in competition with trees tended to have lower liveweight (Fig. 6).

(Insert Table 5 here)

Wool production

In 1998, clean wool production per head and per hectare was lower ($P<0.05$) for sheep grazing the kikuyu control compared with the annual pasture. In 1999 and 2000, this result was reversed, with the kikuyu control recording significantly ($P<0.01$) higher clean wool production per hectare. However clean wool production per head (Table 5) was similar.

On annual pastures, competition with trees significantly ($P<0.05$) reduced clean wool production per hectare by an average of 13%. Sheep also produced less ($P<0.05$) clean wool per hectare if they were grazing south and west facing tree lines as opposed to the east facing treatments. Both kikuyu treatments produced similar amounts of clean wool in 1998. However, sheep grazing away from the trees (KNO) yielded more wool than those grazing along the tree line (K20W) in 1999 (91.8 *vs.* 60.1 kg/ha) and slightly less in 2000 (70.5 *vs.* 75.1 kg/ha).

Soil water deficit (SWD)

The SWD that developed in autumn each year beneath the kikuyu pasture was consistently larger than that for the annual pasture by 115, 57 and 132 mm in 1999, 2000 and 2001, respectively (Fig. 7). It was not possible to estimate the total size of the SWD that developed beneath the tree belt, as the trees had root systems that extended beyond the depth of measurement. However, to a depth of 5 m, the trees created a SWD that prevented the soil reaching field capacity in winter and exceeded the autumn SWD below both pastures by 297-442 mm (Fig. 7).

(Insert Fig. 7 here)

Discussion

Pasture

The major difference between the 2 pasture types studied occurred in the summer-autumn period. At that time a large proportion of kikuyu grass remained green compared with the annual pasture which existed as dry residue. By autumn the herbage mass in the annual pasture had declined to a level (800 to 1000 kg DM/ha) where sheep had to be removed from the pasture to prevent soil erosion. In comparison, depending on the year, the kikuyu pasture had 2060-6250 kg DM/ha, much of which was green. The availability of herbage in the perennial pasture had a positive effect on the carrying capacity because it occurred during the autumn feed gap, as previously reported by Sanford *et al.* (1997).

Within the growing season, the 2 pasture types performed similarly in their herbage accumulation, presumably because production in both was driven by subterranean clover. The only notable differences were greater herbage mass early in the season in the annual pasture and the large quantity of herbage the kikuyu pasture carried through the 1998 season.

These findings are consistent with previous studies that have demonstrated that kikuyu grass is summer active in South-West Western Australia (Elliott 1933; Hawley 1978; Sanford *et al.* 1997; Greathead *et al.* 1998), eastern Australia (Kemp 1975; Fulkerson *et al.* 1999) and New Zealand (Lambert *et al.* 1979) when provided with adequate soil moisture and/or summer rain.

Kikuyu originated from the highland plateaux of east and central Africa where it is subjected to minimum and maximum temperatures of 2-8°C and 16-22°C, respectively (Mears 1970). It's cold tolerance and C_4 photosynthetic pathway partly explain its success in temperate climates. In theory, C_4 species such as kikuyu should exhibit higher efficiencies of radiation, nutrient and water use than C_3 species enabling them to maintain green herbage mass through summer on relatively infertile and moisture limiting soils.

Absence of broadleaf weeds in the kikuyu pasture indicated that capeweed and erodium were displaced by kikuyu possibly through competition for resources (e.g. moisture; Dear and Cocks 1997), allelopathy (Chou *et al.* 1987) or an inability to recruit new plants (Bourdôt 1996).

Based on these findings, kikuyu was an ideal companion species for subterranean clover in pastures in the HRZ of South-West Western Australia. Clover drives pasture production in the growing season and provides nitrogen (N) to the grass. Outside the normal growing season kikuyu remains green and responds to summer moisture. To maintain this relationship, farmers need to control red-legged earth mite (Wallace and Mahon 1963) and apply considerable grazing pressure prior to the break of season in autumn to allow subterranean clover to establish.

In this experiment, tree competition consistently reduced annual herbage accumulation in annual pastures. This confirmed the results of a number of studies undertaken in southern Australia that have observed lower yields by annual crops and pastures within the root zone of windbreaks or tree belts (Bicknell 1991; Burke 1991; Lefroy and Stirzaker 1999; Bird *et al.* 2002; Knight *et al.* 2002; Nuberg *et al.* 2002; Sudmeyer *et al.* 2002; Woodall and Ward 2002). The reduction in plant growth has been attributed to competition between trees and pasture for soil moisture, nutrients and light (Nuberg 1998; Bird 1998; Schroth 1999). Unpublished data from our study suggested that most of the variation in annual herbage accumulation within the root competition zone could be accounted for by a decline in soil fertility and moisture. This is consistent with the effect of tree belts that are moderately permeable to wind and do not provide sufficient shelter to livestock, so that they transfer nutrients close to the tree-pasture interface. In New Zealand, Hawke and Gillingham (1996) showed that impermeable tree belts can increase pasture production close to the belt as a result of nutrient transfer by livestock seeking shelter from the wind.

In contrast to annual pasture, there was no significant decline in kikuyu pasture herbage accumulation as a result of tree competition in our experiment. Since both kikuyu (Samarakoon *et al.* 1990) and subterranean clover (Watson *et al.*1984) are shade tolerant, kikuyu was presumably more successful in competing with the trees for soil nutrients and moisture, or was less affected by the decline in soil nutrients and periodic moisture stress. Schroth (1999) also concluded that perennial forage species were generally more competitive with trees in comparison with annual crops and pasture because of their deeper and denser root systems. This offers the prospect of developing agroforestry systems based on trees and perennial pasture plants that are little affected by tree competition, yet maximise the efficient use of water and nutrients.

Beyond the tree root zone, but within the wind shelter of the trees (~ 20 tree heights) an increase in yield is expected as a result of favourable changes in the microclimate (e.g. improved warmth and humidity; Cleugh 1998). Unfortunately, at the Site used in this study there were no pastures studied that were greater than 20 tree heights from tree belts and so outside the shelter zone. Therefore it was not possible to draw any conclusions regarding the possible positive effect of tree belts on annual herbage accumulation. However, the characteristic peak in yield that other studies have identified at a particular distance from the tree-pasture interface (Bicknell 1991; Burke 1991; Lefroy and Stirzaker 1999) was not observed. The current study broadly supported the view of Sudmeyer *et al.* (2002) that yield gains through shelter were similar or less than the losses through competition. Therefore, producers in South-West Western Australia were unlikely to regain lost pasture production beneath tree belts through yield increases in the shelter zone.

Livestock

Results from this experiment suggested that pastures based on kikuyu would increase returns per hectare compared with an annual pasture. These increased returns were related to the kikuyu pasture supporting a production system that produced more clean wool per hectare, while requiring less supplementary feed. Significantly higher clean wool production per hectare resulted from higher stocking rates and so more sheep grazing days. These results were consistent with the findings of Greathead *et al.* (1998) that demonstrated sheep grazing kikuyu pasture in South-West Western Australia consistently produced more wool, because the pasture could sustain higher stocking rates.

Sheep grazing kikuyu pasture maintained higher liveweight in summer in the absence of supplementary feed. In contrast, sheep on annual pasture lost weight rapidly, were fed supplement and eventually had to be removed from the plots, as pasture dry residues became critically low. Sanford *et al.* (1997) found that during summer and autumn, sheep maintained weight on both annual and kikuyu pasture until April-May, at which time liveweight declined on the annual sward as feed availability limited intake.

Based on this study and previous investigations, this suggested that in environments where kikuyu remains green in summer and autumn, producers could expect to consistently run higher stocking rates and maintain heavier liveweights.

Low animal production on the kikuyu pasture in 1998 was attributed to intestinal worm problems and low clover content. Joyce (1974) pointed out that poor performance of sheep grazing kikuyu grass could be related to inadequate intake, complicated by protein deficiency. However, the main nutritional limitation of kikuyu is a lack of readily digestible energy and a relatively low digestibility of structural carbohydrates (Marais 2001). Unpublished data from our study showed that in winter the feed value of kikuyu was below that of clover, but in summer and autumn, the dry matter digestibility of clover declined to $<50\%$ while kikuyu remained $>60\%$. This suggested that in winter, a high proportion of subterranean clover was essential in a kikuyu pasture for satisfactory animal production.

Irrespective of pasture type, competition with trees significantly reduced carrying capacity and clean wool production per hectare. In a review of factors affecting animal performance in pine agroforestory, Percival *et al.* (1986) reported that ewe liveweights, wool weights and lamb growth rates were generally lower with increasing tree density, possibly because of lower herbage availability rather than lower feed quality.

Sheep in the south facing treatment tended to have lower liveweight and wool production compared to the other annual treatments. This may not only have been related to availability of pasture, but also to the negative effect of shelter on animal performance. In a similar study in New Zealand, Hawke *et al.* (1999) found that average annual pasture production was lower close to tree belts on a southern aspect. In our experiment, annual pasture on the south face of the tree belt accumulated the lowest amount of herbage. Percival *et al.* (1986) have reported a reduction in the ambient temperature related to tree shelter. This was likely to result in increased intake for body maintenance, reducing animal performance if less feed were available.

Groundwater recharge

Based on the SWD that developed beneath the tree belt during the experimental period, groundwater recharge did not occur below the trees unless water moved down the soil profile *via* preferred pathways. This finding was supported by other studies that have demonstrated that trees can lower water tables under a wide range of landscape conditions in Western Australia (Schofield *et al.* 1989; George 1992; Stolte *et al.* 1997; Raper 1998). However, a survey by George *et al.* (1999) in Western Australia suggested it was unlikely that tree belts have any effect on groundwater 10-30 m from the tree-pasture interface.

Based on the SWD results, kikuyu used an average 101 mm more water than the annual pasture presumably because of higher amounts of green leaf in summer and deeper root system. As a consequence, it was likely that groundwater recharge declined beneath kikuyu and this pasture type could assist in delaying the onset of salinisation by decades (McDowall *et al.* 2003; White *et al.* 2003). Analysis by White *et al.* (2003), using the SGS Pasture Model (Johnson *et al.* 2003), supported this conclusion suggesting that kikuyu on average would reduce groundwater recharge at the Site by 137 mm/year. Furthermore, other studies indicated that in the HRZ kikuyu was able to use more water than phalaris (Scott and Sudmeyer 1993; Ridley *et al.* 1997; Chapman *et al.* 2003) and similar amounts to lucerne (Ridley *et al.* 2001).

The best compromise between production and sustainability in this investigation was kikuyu pasture in combination with blue gum tree belts. Future work within the HRZ needs to focus on developing profitable grazing systems, which include high water use perennial pastures and trees.

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List of Figures

Figure 6. Seasonal pattern of average liveweight (kg/head) for sheep grazing annual and kikuyu pasture in 1998, 1999 and 2000 [ANO (●), A20W (■), A20E (▲), A20S (◆), A36W (+), A36E (×), KNO (○), K20W (□)].

Figure 7. Soil water deficits (mm ± se per 5 m depth) beneath annual pasture (■), kikuyu pasture (●) and centre of blue gum tree belt (▲) from December 1998 until January 2002 at Albany, Western Australia.

Table 1. Details of treatments, plots and sampling at experimental Site, Albany Western Australia

Refer to Figure 1 for location of plots

Treatments	Pasture base	Orientation (facing)	Treatment code	Plot No	Number of sampling units per plot
Control, no competition with trees	Annual	-	ANO	6, 7, 8, 9	4
	Kikuyu	-	KNO	13, 15 (includes 14, 16 in 1998)	4
20% of pasture in competition with tree belt	Annual	West	A20W	10, 12	16
	Kikuyu	West	K20W	17, 18	16
	Annual	East	A20E	1, 3	16
	Annual	South	A20S	5	16
36% of pasture in competition with tree belt	Annual	West	A36W	11	12
	Annual	East	A36E	2, 4	12

Table 2. Effect of tree competition and pasture type on annual herbage accumulation (kgDM/ha.yr) at Albany Western Australia from 1998-2000

Standard errors shown in parentheses are for comparing treatments within years

Treatment	1998	1999	2000
ANO	11092 (508)	9765 (531)	8965 (466)
KNO	11093 (508)	11884 (726)	7611 (569)
A20W	9937 (718)	8092 (751)	7930 (659)
K20W	10525 (718)	11796 (751)	8749 (659)
A20E	10954 (718)	7725 (751)	9182 (659)
A20S	8993 (1015)	6854 (1062)	6984 (932)
A36W	9698 (1015)	6690 (1062)	7056 (932)
A36E	9926 (718)	7309 (751)	8417 (659)

Table 3. Cumulative grazing sheep days per hectare for sheep grazing annual and kikuyu pasture

Treatment	Cumulative grazing sheep days/ha		
	1998	1999	2000
ANO	3368^{a}	5105^{bc}	3847^{c}
KNO	3165^{b}	8553^{a}	7608^{a}
A20W	3207^{ab}	4307^{d}	3858^{c}
K20W	3165^{ab}	5943^{b}	6542^{b}
A20E	3128^{b}	4596^{cd}	4085^{c}
A20S	2714^{c}	4020^{d}	3763^{c}
A36E	2951^{bc}	4478^{cd}	3858^{c}
A36W	2975^{b}	4260^{d}	3763^{c}

Means within columns with different superscript were significantly different ($P<0.05$).

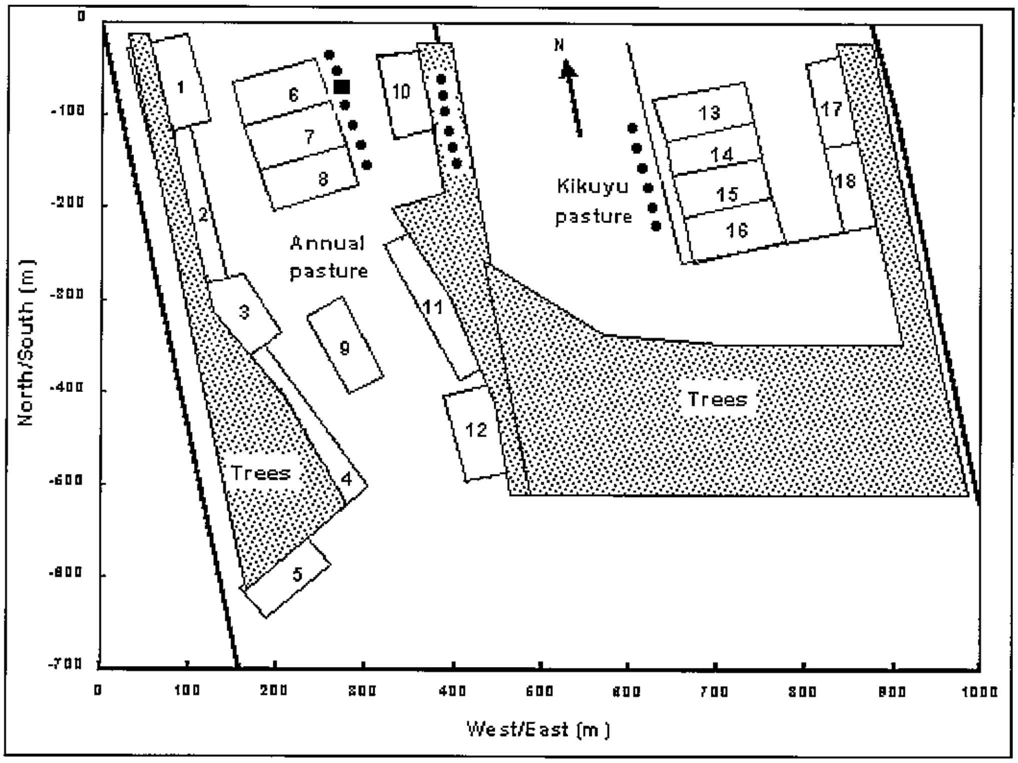
Table 4. Grain fed (kg/ha) to sheep grazing annual and kikuyu pasture

Treatment	Total grain feed to sheep (kg/ha)		
	1998	1999	2000
ANO	0	70	336
KNO	264	0	0
A20W	0	59	451
K20W	264	0	0
A36W	0	49	585
A20E	0	113	429
A36E	0	81	455
A20S	0	113	585

Table 5. Clean wool production (kg/head and kg/ha) for sheep grazing annual and kikuyu pasture

Standard errors shown in parentheses are for comparing means of the treatments within years

Year	ANO	KNO	A20W	K20W	A20E	A20S	A36E	A36W
			Clean wool	*production*	*(kg/head)*			
1998	4.30 (0.12)	3.03 (0.11)	4.11 (0.16)	3.11 (0.15)	4.15 (0.16)	3.96 (0.23)	4.13 (0.16)	4.68 (0.23)
1999	4.36 (0.12)	4.44 (0.12)	4.32 (0.16)	4.19 (0.16)	4.31 (0.16)	4.36 (0.23)	4.46 (0.16)	4.00 (0.23)
2000	3.84 (0.12)	3.92 (0.15)	3.73 (0.16)	4.86 (0.15)	4.09 (0.16)	3.42 (0.23)	3.99 (0.16)	3.41 (0.23)
			Clean wool	*production*	*(kg/ha)*			
1998	34.3 (1.22)	22.6 (1.15)	31.1 (1.72)	23.2 (1.60)	30.7 (1.72)	25.4 (2.44)	28.8 (1.72)	32.9 (2.44)
1999	53.7 (2.20)	91.8 (6.50)	44.7 (3.09)	60.1 (9.20)	47.7 (3.09)	42.2 (4.37)	48.0 (3.09)	41.0 (4.37)
2000	34.7 (1.54)	70.5 (4.92)	33.8 (2.17)	75.1(4.92)	39.3 (2.17)	30.2 (3.07)	36.3 (2.17)	30.2 (3.07)


N
Annual
pasture
Kikuyu
pasture
Trees
Trees
1
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3
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5
6
7
8
9
10
11
12
13
14
15
16
17
18
North/South (m)
West/East (m)
0
-100
-200
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-500
-600
-700
0
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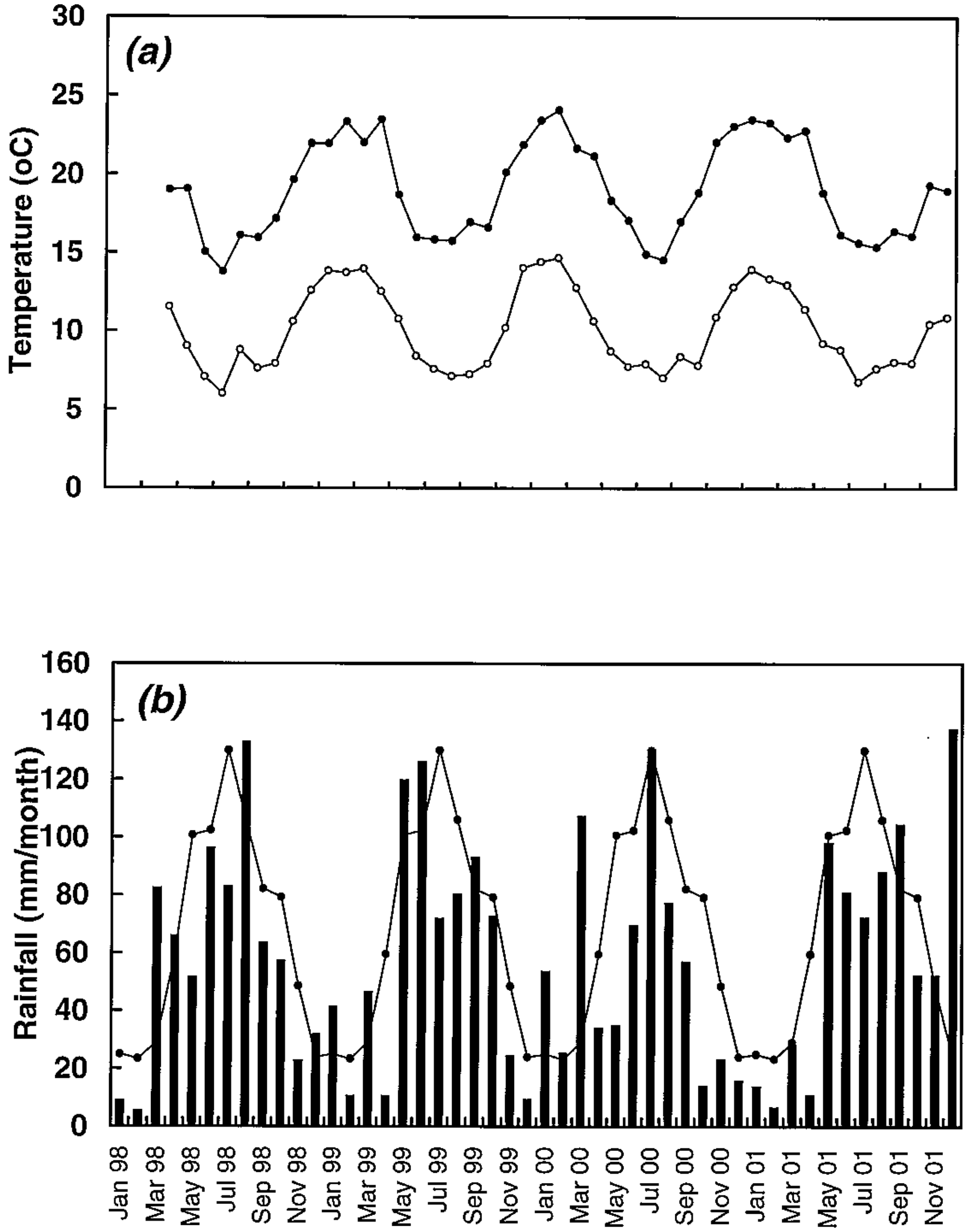
600
700
800
900
1000

Figure 1.


(a)
Temperature (oC)
30
25
20
15
10
5
0
(b)
Rainfall (mm/month)
160
140
120
100
80
60
40
20
0
Jan 98
Mar 98
May 98
Jul 98
Sep 98
Nov 98
Jan 99
Mar 99
May 99
Jul 99
Sep 99
Nov 99
Jan 00
Mar 00
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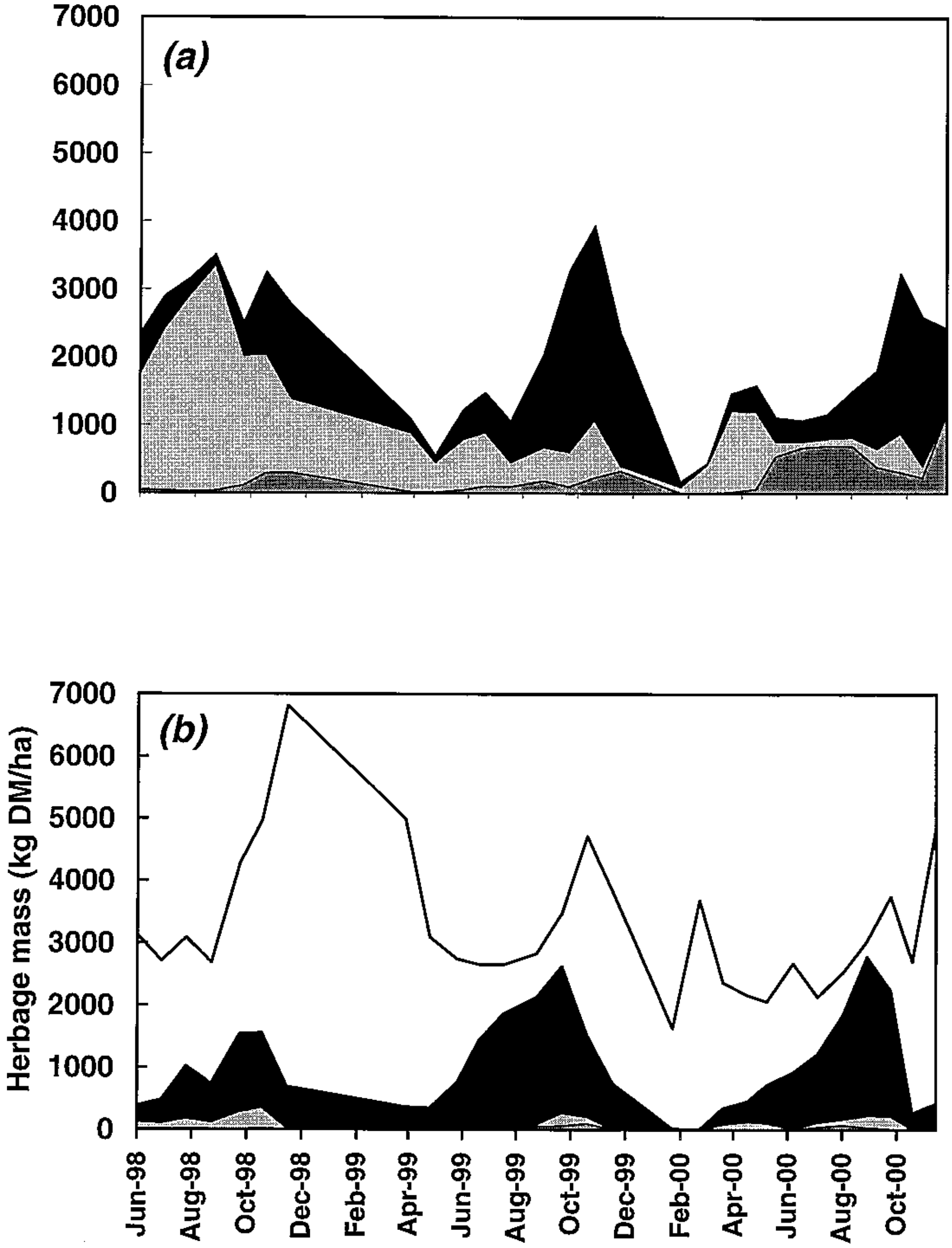
Sep 01
Nov 01

Figure 2.



(a)
7000
6000
5000
4000
3000
2000
1000
0
(b)
Herbage mass (kg DM/ha)
Jun-98
Aug-98
Oct-98
Dec-98
Feb-99
Apr-99
Jun-99
Aug-99
Oct-99
Dec-99
Feb-00
Apr-00
Jun-00
Aug-00
Oct-00

Figure 3.

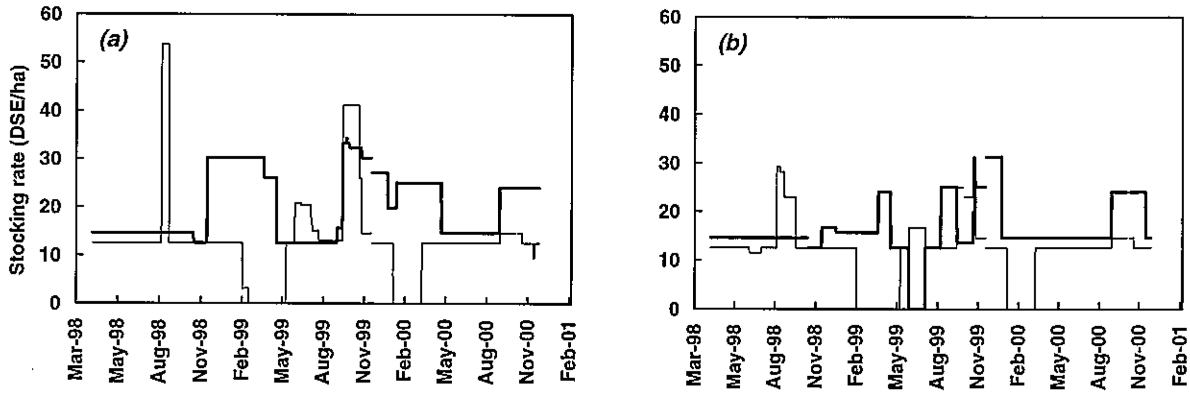

(a)
(b)
Stocking rate (DSE/ha)
0
10
20
30
40
50
60
Mar-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
Nov-99
Feb-00
May-00
Aug-00
Nov-00
Feb-01

Figure 4.

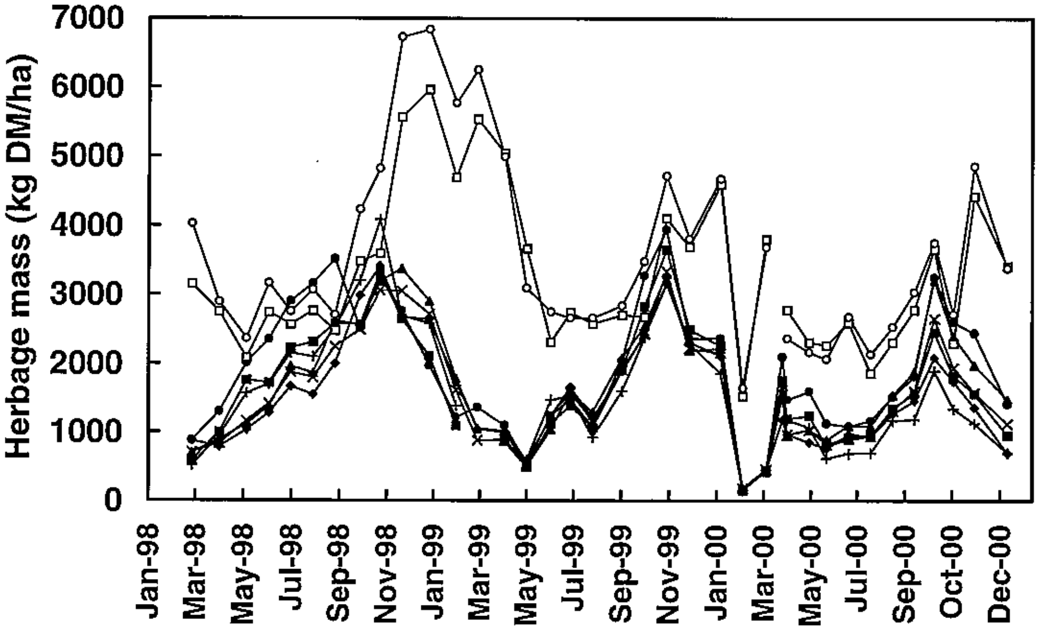

Herbage mass (kg DM/ha)
7000
6000
5000
4000
3000
2000
1000
0
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Oct-00
Dec-00

Figure 5.

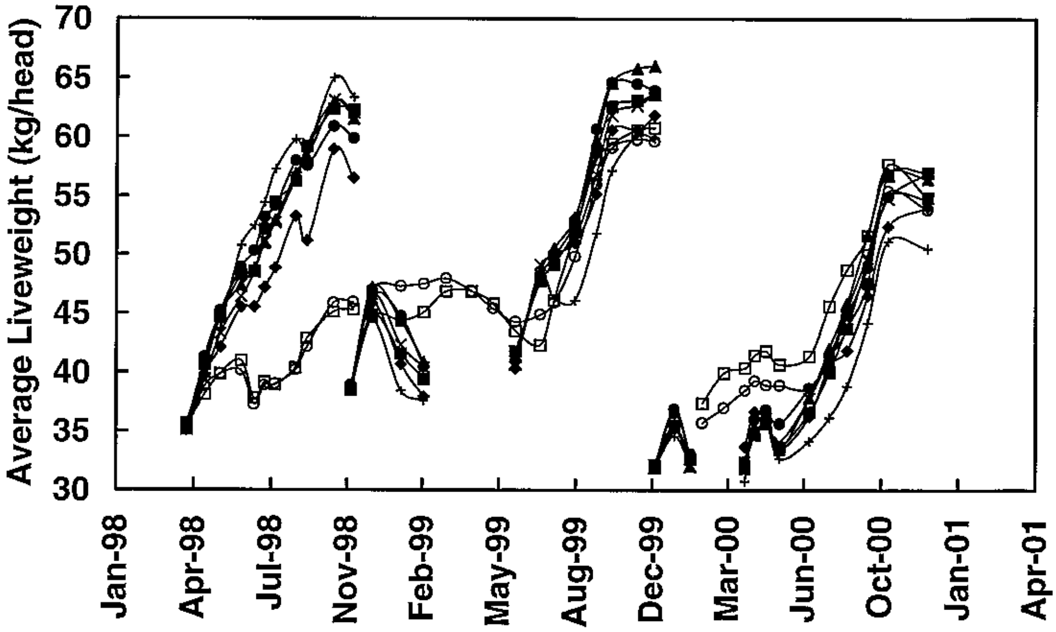

Average Liveweight (kg/head)
70
65
60
55
50
45
40
35
30
Jan-98
Apr-98
Jul-98
Nov-98
Feb-99
May-99
Aug-99
Dec-99
Mar-00
Jun-00
Oct-00
Jan-01
Apr-01

Figure 6.

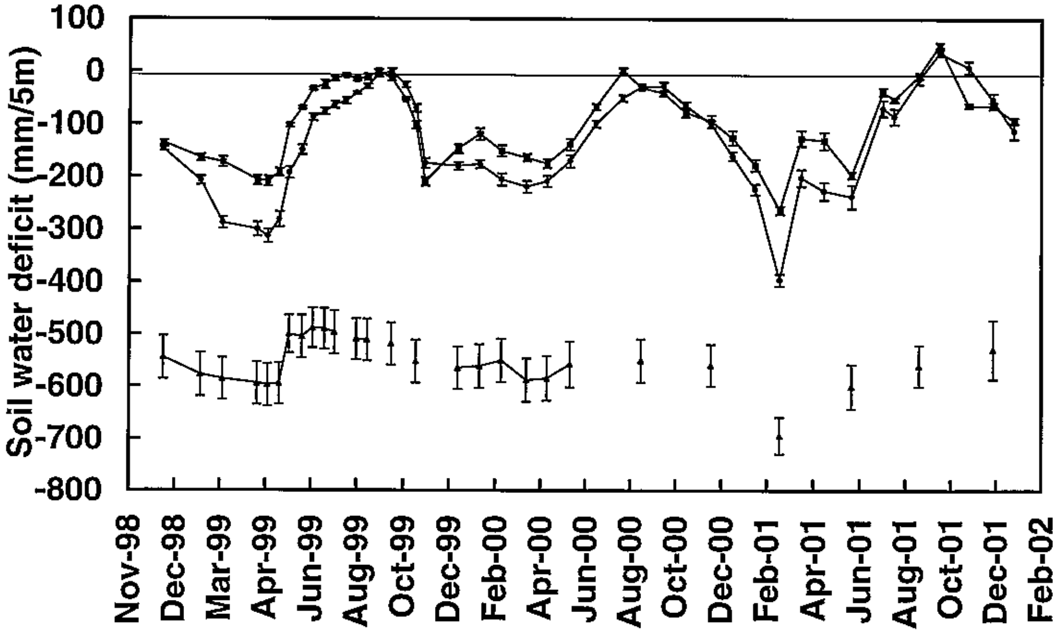

Soil water deficit (mm/5m)
100
0
-100
-200
-300
-400
-500
-600
-700
-800
Nov-98
Dec-98
Mar-99
Apr-99
Jun-99
Aug-99
Oct-99
Dec-99
Feb-00
Apr-00
Jun-00
Aug-00
Oct-00
Dec-00
Feb-01
Apr-01
Jun-01
Aug-01
Oct-01
Dec-01
Feb-02

Figure 7.

Appendix 2.

Esperance Site paper as submitted to Australian Journal of Experimental Agriculture, November 2003.

Kikuyu and annual pasture: a characterisation of a productive and sustainable beef production system on the South Coast of Western Australia

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Short Title. Kikuyu and annual pasture in WA

Abstract. Production parameters and water use of kikuyu (*Pennisetum clandestinum*) and annual-based pastures were monitored for a beef weaner production system from 1998-2000 in a paddock scale demonstration on the South- East coast of Western Australia. Kikuyu pasture carried more animals than annual pasture through the dry cow phase (late summer and autumn) in all years. The comparative quality and productivity of the kikuyu pasture in the lactation phase (winter and spring) was positively correlated with the level of winter legume present. When a similar level of winter legume was measured in the kikuyu pasture relative to the annual pasture (in 1998), the pasture quality, cow liveweight and condition and calf weaning weights were all comparable between the 2 pasture types. When a low legume component was recorded in the kikuyu pasture, the pasture quality and cow liveweight and condition were also poorer that the annual pasture.

The kikuyu pasture growing on deep sandy soil developed a larger (35 mm) soil water deficit than the annual pasture over much of the measurement period, and in particular from November to March. When integrated over a farm, to make up 40% of the total area; the resulting deep drainage from kikuyu was just over half that of an equivalent whole farm of annual pasture. This level of amelioration of deep drainage can potentially reduce the eventual extent of salinity in Western Australia by 25% and delay its onset by 40 years.

Over the 3 years of monitoring; the combined system of annual and kikuyu pasture was calculated to have a gross margin 19% higher than the annual pasture alone. The major source of difference was no requirement for supplementary feed in the kikuyu-annual pasture system. This difference was limited however, by lighter sale weights of cull cows from the kikuyu pasture in "poor legume" years. There is considerable opportunity to improve on this through achieving a consistent strong presence of legume in the kikuyu pasture through winter and spring.

Introduction

In southern Western Australia, secondary salinity is predicted to cover 30% of the agricultural landscape by 2070, assuming current land use management (Ferdowsian *et al.* 1996; State Salinity Council 2000). In Mediterranean climates, plant based solutions to salinity depend on depleting stored water prior to the winter months, when rainfall invariably exceeds potential evapotranspiration resulting in excessive leakage beyond the root zone (Ridley *et al.* 1997). Summer-active perennial pastures have the potential to reduce soil water storage to the extent that they are seen as part of the solution to reducing secondary salinity (Cransberg and McFarlane 1994; Dunin *et al.* 1999; Hatton and Nulsen 1999). George *et al.* (2002) estimate that perennial species covering 50% of the agricultural landscape have the potential to prevent 2 million hectares becoming saline and can significantly extend the period over which salinity develops. Despite the benefits of perennial pastures in land remediation, they occupy <2% of the agricultural land in south eastern Western Australia (Buchanan and Saunders, personal communication). The corresponding value for annual clover based pastures is >55% of agricultural land (ABS 2001). The area of perennial plants required to significantly reduce salinity is high. Temperate perennial species have been trialed widely by producers on the South Coast with limited success. Unreliable establishment, poor persistence, competition with cropping land and no clear production benefit, have been some factors contributing to poor uptake of temperate perennial species in this region (Lemon, personal communication).

Kikuyu grass (*Pennisetum clandestinum* Hochst. ex Chiov) is a stoloniferous, rhizomatous, C_4 perennial grass species, which is a native of the highlands of central East Africa. It was introduced to Western Australia in the 1920s and is now endemic to the >600 mm rainfall zone of southern Western Australia. It is relatively easy to establish and has proven persistence. As a summer active perennial pasture, it potentially has some major environmental benefits including increased plant water use over the summer, and greatly reduced risk of wind erosion due to the stoloniferous nature of the sward (Greathead *et al.* 1998). There is very little information available regarding the productivity parameters of kikuyu pasture in a <600mm rainfall, mediterranean beef production system. Some of the fundamental characteristics of kikuyu suggest that it may be complementary to a subterranean-clover (*Trifolium subterraneum* L.), annual grass-based pasture system. The most obvious of these is the summer active nature of kikuyu grass, which potentially provides out-of-season green feed and reduces the requirement for supplementary feeding.

There are presently very few documented examples of productive and profitable farming systems in Western Australia, which include sufficient perennial component to reduce the risk of salinity. The Site investigated in this paper is potentially one such example.

The aim of this study was to characterise an annual pasture–kikuyu grazing system. Productivity and environmental factors including cattle production and stocking rates, pasture production, quality and composition and soil water storage and depletion, catchment runoff and modelled water balance components, and overall profitability using gross margin and net present value analysis, made up the parameters.

Materials and methods

The research presented in this paper was conducted between June 1997 and October 2000 on Ireland Farm, a commercial cattle property located 40 km north of Esperance (latitude 121° 44'; longitude 34° 40'). Approximately 40% of the pastures on the property had a perennial component consisting of kikuyu (*P. clandestinum* -) or phalaris (*Phalaris aquatica* L cv. Australian). The remainder of the pastures were dominated by annual species including subterranean clover, capeweed (*Arctotheca calendula* (L.) Levyns), geranium (*Erodium* spp.) silver grass (*Vulpia bromoides (L.) Gray*), ryegrass (*Lolium rigidum* Gaudin), brome (Bromus spp.), and barley grass *(Hordeum* *leporinum Link*). The long term average annual rainfall for the Site is 523 mm, of which 77% falls from April to the end of October. The soils at the Site form part of the Esperance Sandplain Fleming series (Overheu *et al.*. 1993) and are classified as basic mesonatric yellow sodosols (Isbell 1996).

Livestock production, pasture agronomy and soil water measurements were collected in commercial paddocks ranging in size from 40-105 hectares. The kikuyu measurements were all collected in the same paddock for the duration of the experiment. However, the annual treatment was rotated around 3 neighbouring paddocks, as each was in the pasture phase of a crop rotation. Treatment and pasture types are shown in Table 1.

Insert Table 1 near here

Comparisons were made between the 2 pasture species on the deep sands (DSAnnual *vs.* DSKikuyu) for the soil water and pasture agronomy measurements. In terms of livestock production, DSAnnual and DSKikuyu formed part of a single system.

Livestock measurements

Paddocks were grazed with mature mixed age Hereford breeding cows. Calving commenced in the third week of April. Liveweight and fat depth of the cows were measured pre-calving, post-calving, post-joining, end of green feed period and weaning. Liveweight was measured after 1-h off feed using digital scales. Fat depth was measured at the P8 site (8 cm from the spinal midline, opposite the sacral crest) on the rump using a Toshiba Sonolayer SAL32B Real Time Ultrasound Scanner with an 11 cm transducer (Wilson 1995)

Liveweight of calves was measured using the same method on the 4 coinciding dates from post-calving until weaning.

Cows were randomly allocated to either the DSAnnual or DSKikuyu pasture at the pre-calving weigh in March of each year. Dry cows were culled at the post calving weigh, and replaced with a cow-calf unit. Cows were pregnancy tested in October of each year, and non-pregnant cows were removed from the experiment at weaning. The lactation period varied slightly from year to year, as the weaning date was determined by cow condition. Cows needed to be at least 7 mm fat at the P8 site (condition score 3) at weaning to allow for condition loss in early lactation, and still achieve a satisfactory conception rate during joining. Cows from DSAnnual and DSKikuyu were always weaned on the same date.

Grazing management

The stocking rates on the paddocks were determined by a number of factors including, total herbage mass (total HM, kg DM/ha), cow liveweight and condition, pasture quality and any sward management imperatives. Grazing management over the year was divided into 2 key periods; pre-calving to weaning weigh dates (defined as the lactation phase), and the weaning to pre-calving weigh dates (defined as the dry cow phase).

The "lactation phase" stocking rate aimed to maintain total HM of DSKikuyu at 1000 kg DM/ha more than DSAnnual during the growing season. This difference was designed to account for the prostrate non-leaf plant material present in the kikuyu sward, which contributed little to feed available to grazing livestock (Murtagh *et al.* 1986). Average cow P8 fat depth declining to <3 mm was also a trigger to reduce stocking rate. The over-riding principle of stocking rate decisions was to utilise both types of pastures to their maximum capacity, within the constraints of animal production targets. The need to still generate a spring surplus for post senescence consumption was also an additional constraint.

The "dry cow phase" grazing management was determined by a need to de-stock the annual paddock before the total HM declined to <1000 kg DM/ha in order to reduce the risk of wind erosion on sandy soil to an acceptable level (Findlater *et al.* 1990). For a period between January and March (dry cow phase) each year the DSAnnual paddock was de-stocked (Table 2), and the DSKikuyu pasture was given an autumn "crash-graze" for some or all of this period. The aim of this was to reduce the competition from the kikuyu grass to promote a successful germination of temperate annual species at the break of season (Fulkerson *et al.* 1996). A target of 1000 kg DM/ha of total HM was set, as this represented a kikuyu sward height of approximately 2 cm. This was intended to cause minimal shading competition to germinating companion species. The length and intensity of the crash graze was dependent upon the spring residual and subsequent DM production from any summer rainfall on the DSKikuyu treatment.

Insert Table 2 near here

Pasture management

All pastures were topdressed in autumn with 100 kg/ha of single superphosphate [9.1% phosphorus (P), 11.5% sulfur (S)]. Pastures were sprayed with 85 ml/ha of Rogor (Dimethoate) in July 1997 to control redlegged earth mite (RLEM, *Halotydeus destructor*). A double spray 21 days apart was applied in May and June of 1998 in order to break the egg-laying cycle of the RLEM (Michael, personal communication). Pastures were monitored for RLEM presence in autumn and winter of 1999 and 2000, but did not require spraying. Urea was applied at 100 kg/ha [46 units nitrogen (N)] to DSKikuyu on 20 April 1998.

Species composition, total dry matter, herbage accumulation and pasture quality

Species composition was estimated on a quarterly basis from May 1998 to October 2000 using BOTANAL procedures as described by Andrew and Lodge (2003). Forty paired (80) readings were taken in each paddock in a zig zag configuration on each sampling date.

Total herbage mass, green herbage mass (green HM, kg DM/ha), herbage accumulation (kg DM/ha.day) and pasture quality, were estimated on a monthly basis, from June 1997 to November 2000.

Total HM was assessed by estimating, then harvesting the kg DM/ha from 5 – 9 calibration quadrats in each treatment paddock, with the aim of accounting for the complete range of estimates carried out on the sampling date. Visual estimates were then taken at 80 locations in a zig zag configuration across the paddock. These harvested calibration estimates were oven dried at 60°C to constant weight, then weighed, and plotted against the estimated weights to generate a linear or quadratic relationship. The average of the paddock estimates was then calculated and plotted on the fitted line to determine the calibrated estimate of total herbage mass.

Herbage accumulation was estimated using weldmesh exclusion cages (118 by 96 by 23 cm) at 20 sites evenly distributed across each treatment paddock. Cages were moved monthly, with the starting and finishing kg DM/ha under the cage being calibrated against the same fitted relationship as the Total HM for the paddock. Two (31.5 x 31.5 cm) quadrat estimates were taken under each exclusion cage. The calibrated starting total HM was subtracted from the calibrated finishing total HM for each cage, and divided by the number of days between start and finish. The post-senescence DSAnnual herbage accumulation was not measured as there was no green HM, so herbage accumulation was assumed to be zero. The DSKikuyu pasture was measured through all summers other than from November 1997 to April 1998, which was the driest summer on record. Change in green HM was not detectable by the measurement technique used over this period.

Pasture quality was assessed by cutting 6 quadrats of pasture from each paddock on each monthly sampling date. These samples were bulked, then divided. Half was hand-sorted into functional species groups the other remained a mixed sample. They were then dried to constant weight at 60^0C, and analysed to determine dry matter digestibility (DMD, %; Aufrere *et al.* (1988), metabolisable energy (MJ ME/kg), and crude protein (%).

The equation to calculate metabolisable energy used was; $ME = 0.156(0.98DMD-4.8)$.

Soil water measurement

Comparisons in soil water content (SWC) were made between 2 paddocks, namely the DSKikuyu treatment and 1 of the DSAnnual paddocks. Volumetric soil water content (θv) was measured with a Campbell Pacific Nuclear 503 neutron moisture meter (NMM). Paired PVC access tubes (50 mm ID) were installed within each treatment. Due to variation in depth to clay within the DSKikuyu treatment, 3 additional access tubes were inserted; 2 in a deep sand (>1.3 m to clay) without gravel and a further tube in a shallower (<0.9 m to clay) sand series. Volumetric SWC was measured at 0.2 m intervals to a depth of 1.7 m between October 1997 and February 2000. The NMM was calibrated by regressing the count rate ratio (CR) against SWC derived from soil samples extracted from around access tubes (Greacen 1981). Separate NMM calibration equations were used for the surface sand ($CR=2.6\theta v + 0.06$, $R^2 = 0.95$, $n=16$), sand >0.3 m ($CR=3.0\theta v + 0.15$, $R^2 = 0.86$, $n=20$) and clay ($CR=1.44\theta v + 0.38$, $R^2 = 0.82$, $n=7$) layers. Soil water deficits (SWD) were calculated as the difference between the profile field capacity and actual stored water to a depth of 1.8 m. The profile field capacity was defined as the mean of the 5 highest soil water storage values measured during the measurement period (White *et al.* 2003). Due to soil water measurements being taken in only 1 of the DSAnnual paddocks , the DSAnnual treatment includes measurements for a canola crop recorded between May and November 1999.

Water balance

For treatments that differed statistically in their soil water storage, other components of the soil water balance were estimated. The water balance model had the form:

$$P = Et + DD + Ro + \Delta S \qquad (1)$$

where Et is evapotranspiration, P is precipitation, DD is deep drainage, Ro is runoff and ΔS is the change (increase) in soil water storage. In this study, only P and ΔS were measured for each treatment. Consequently a water balance of $P = Et + \Delta S$ can be derived, however, it assumes that the Ro and DD components of the water balance were zero. Given that runoff was measured at the Site and ground water was discharging at the surface within the property's boundaries, such a water balance model is inappropriate. Furthermore, the episodic nature of the summer rainfall necessitated a daily water balance.

In order to approximate the Et, DD and Ro components of the water balance, a simple cascading bucket water balance was used based on AgET (formally known as Wattle; Argent and

George 1997). A modified Penman equation (I Foster, personal communication) was used to calculate pan evaporation from weather station data as follows:

$$Epan = \frac{s.Rn + \rho Cp(\Delta e)/ra}{(s+\gamma).L} \qquad (2)$$

where s is the vapor pressure gradient, Rn is net radiation, ρ is the density of air, Cp is the specific heat of air (1010 J $kg^{-1}m^{-3}$), Δe is the vapour pressure deficit, ra is the aerodynamic resistance, γ is the psychometric constant (0.66 mb C^{-1}), and L is the latent heat of evaporation. *Epan* was converted into actual evapotrnspiration (*Ea*) using the following equation:

$$Ea = Epan*Kp*Kc*CSf \qquad (3)$$

Where Kp is the pan factor (0.8), Kc is the crop factor and CSf is a crop stress function which regulates evapotranspiration based on the plant available water content (*AWC*) of the soil profile: $CSf = 1\text{-}exp(-c(AWC\%/100))$ where $2<c<10$ (English *et al.* 1981).

Statistical analyses

Repeated measures analysis was used to identify seasonal and total differences in stored water between the DSAnnual and DSKikuyu treatments. This was done using the REML procedure in GenStat ® (2001). The analysis required for the fitting of a cubic spline model to the water storage data and testing whether the resulting profiles differed between the treatments was as outlined by Orchard *et al.* (2000). Significance of the spline term or variance component was estimated by looking at a sequence of models and testing whether the change of deviance, "d", (deviance = -2(log-likelihood)) of the reduced model from full model, was significant. As reported in Orchard *et al.* (2000), the *P*-value was given by 0.5 $Pr(X^2 > d)$ where X^2 is distributed as a Chi-squared distribution on 1 degree-of-freedom.

Repeated measures analysis using the REML procedure in GenStat (2001) was also used to compare the DSAnnual and DSKikuyu cow and calf live-weight and cow fat depth profiles. Since there were unequal times of measurement the power correlation option in linear mixed-model specification of the VSTRUCTURE was used, as described in The GenStat Guide to Statistics (2000).

Since the initial weight and fat depth of each set of cows may have been slightly different for the 2 paddocks, this was used as a covariate. Predictions of the means were made at the average of the initial weight and fat depth.

Economic analysis

An economic analysis used the practical framework developed by Barlow *et al.* (2003), to evaluate resource and production outcomes for annual pasture, and a combination of annual and kikuyu pasture. Grazfeed (reference) was used to estimate the quantity of supplement required had the cows remained on the annual pasture over the "destocked" period. Stocking rates and liveweights were calculated by averaging the relevant treatment stocking rates and liveweights over the years 1998-2000. Year round stocking rates were assumed to be the same as the "lactation phase" stocking rate for the annual pasture and an average of the kikuyu and annual year round stocking rate for the kikuyu/annual system. Financial analysis of the production data was based around gross margin analysis and discounted cash flow or net present value (NPV) analysis.

Results

Rainfall

Rainfall diverged markedly from the long term average during the summer months (Fig. 1). For the 4-month period beginning December 1997. Only 16 mm of rain fell, compared with the long term average of 99 mm. During the subsequent summers of 1998-99 and 1999-2000 the December to March rainfall was 314 and 240 mm, respectively. These years represent the driest and wettest summers on record. Late autumn and early winter rainfall in 1999 and 2000 was well below average. However, May to October rainfall for 1998 (355 mm) and 1999 (361 mm) was only moderately lower than the long term average (399 mm). In

2000, the May to October rainfall was only 201 mm, which was almost half of the long term average.

Insert Figure 1 near here

Soil water storage and extraction

Dry summer: October – April 1998. The DSKikuyu treatment generated a maximum SWD of more than 150 mm. The equivalent reduction in soil water storage for the DSAnnual treatment was 50–60 mm. The SWD response for this period differed significantly between the 2 treatments ($Pr\ X^2>d = 0.007$, Fig. 2). By the end of March 1998 the DSKikuyu had depleted soil water to the calculated profile wilting point of 152 mm/1.8m. The depth of sand had only a limited effect on the size of the SWD to a depth of 1.8 m (data not presented). Soils with shallower depths to clay (0.9 m and 1.1 m) generated the largest SWD. This is indicative of the higher available water holding capacity of the clay subsoils compared with the deep sand subsoils.

Insert Figures 2 and 3 near here.

The depth to which water was extracted differed markedly between the DSKikuyu and DSAnnual treatments. The DSAnnual treatment used more water (18 mm) to a depth of 0.5 m than the DSKikuyu (Fig. 3). However, below 0.5 m the DSKikuyu treatment extracted 87 mm compared with the DSAnnual where no water was extracted. It is evident that water was still being used by the Kikuyu below 1.8 m, whereas there was no evidence of water extraction below 0.9 m for the DSAnnual treatment.

Wet summers and winters : April 1998 – February 2000. In autumn and early winter 1998, the SWD for all the treatments converged so that by early August 1998 differences in SWD between the treatments was <20 mm (Fig. 2). This difference increased to 46 mm during early summer 1998 with the SWD for the DS Kikuyu treatment being 90 mm. As a result of 220 mm of rainfall during January 1999 the SWD converged and did not differ markedly between the treatments until the following December. The early summer months of 1999-2000 resulted in SWD for the DSKikuyu treatment being 35–45 mm less than the DSAnnual. On average, the SWD for the DSKikuyu treatment was 35 mm lower than that of the DSAnnual for the duration of the experiment.

Soil water balance

The soil water balance model accounted for 62 and 85% of actual water storage (mm/1.8m) over the 2-year measurement period for the DSAnnual and DSKikuyu treatments (Fig. 4). The model tended to over-predict evapotranspiration of the annual pasture during the initial spring and summer of 1997-98 resulting in more water being removed from the profile than was actually recorded. Thereafter predicted and actual soil water contents were similar. The model over-predicted DSKikuyu soil water storage during January 1999, however there was general agreement between the predicted and actual water storage at all other times.

Insert Figure 4 and Table 5 near here

The predicted deep drainage and runoff values for the DSKikuyu treatment (56 mm) were 7 times lower than in the DSAnnual treatment (Table 5). This was attributed to the longer growing season and the greater depth to which water was able to be extracted by the DSKikuyu treatment, resulting in increased evapotranspiration. Another reason for the lower recharge and runoff associated with the kikuyu was the DSKikuyu treatment having a greater depth of A horizon (1.1 m) as opposed to the DSAnnual treatment (0.65 m of A horizon). The higher total porosity of the A horizon resulted in more water being potentially stored prior to modelled runoff and deep drainage commencing. Interchanging the soil parameters and depths between the DSKikuyu and DSAnnual treatments resulted in the kikuyu treatment having only a 3-fold reduction in deep drainage and runoff compared with the annual pasture (data not presented).

During the wet summers of early 1999 and 2000 approximately 60 and 56 mm of deep drainage were predicted for the DSAnnual treatment. In contrast, all of the predicted deep drainage (46 mm) for the DSKikuyu treatment occurred in winter growing season and only 10 mm of runoff was predicted fro the DSKikuyu treatment during the wet summers. The model also showed no runoff occurring during the winter of 1998 for either the DSKikuyu or DSAnnual treatments (Fig. 5*a* and 5*b*). The predicted partition ratio (White *et al.* 2003) of deep drainage:runoff+deep drainage was 0.82 and 0.72 for the DSKikuyu and DSAnnual treatments, respectively.

Insert Figures 5a and 5b near here

Total and green herbage mass

The herbage mass (kg DM/ha) profile of the DSAnnual and DSKikuyu pasture followed a similar pattern with a spring peak and late autumn trough (Fig. 6*a* and 6*b*). The estimated total HM of the DSKikuyu pasture was rarely below that of the DSAnnual pasture.

Insert Figure 6a and 6b near here

The estimate of green HM highlighted the relatively long dry feed period through the dry summer of 1997–98, where the green herbage mass was <500 kg DM/ha for 6 and 7 months for the DSKikuyu and DSAnnual pastures, respectively (Fig. 6*a*). The wet summers of 1998-99 and 1999-00 had different dry feed patterns. There was <500 kg of green HM for 2 and 3 months for DSKikuyu and DSAnnual, respectively in 1998-99, and 0 and 2 months for DSKikuyu and DSAnnual in 1999-00 (Fig. 6*b*)

Herbage accumulation

The herbage accumulation rate of both pasture types reflected seasonal variation over the different years.

In all years (1998–2000), the DSAnnual pasture grew faster than DSKikuyu pasture in winter and early-mid spring (Fig. 7*a*, *b*, and *c*). In 1998 and 2000, the DSKikuyu pasture grew faster in late spring, however this was not the case in 1999. Peak annual herbage accumulation rate was higher for the DSAnnual pasture in all years. The DSKikuyu pasture responded more quickly than DSAnnual pasture to a summer rain event in January 1999, but similarly to the DSAnnual after a series of rain events in December and January 2000.

Insert Figures 7a,7b and 7c near here

A large negative "herbage accumulation rate" was recorded in the DSAnnual pasture at the point of senescence in spring 1998 and 2000. A small negative rate was also recorded in May 1999. A negative herbage accumulation rate was recorded for the DSKikuyu pasture in late spring 1998, 1999 and 2000, as well as a small negative rate in the month ending 6 June 2000. A severe locust attack in late spring 2000 caused a sudden disappearance of the standing green feed in the DSKikuyu pasture. The DSAnnual pasture had senesced at this point, so was not a target for the locusts.

Species composition

There were some notable differences in species composition between DSAnnual and DSKikuyu pasture. A large portion of the DSKikuyu sward consisted of kikuyu (perennial grass), particularly from January to May (Fig. 8*b*). There was also a relatively small proportion of broadleaf weeds in the DSKikuyu pasture compared with the DSAnnual pasture.

This was a similar result to that found by Greathead *et al.* (1998) when comparing annual and kikuyu pasture composition near ManyPeaks in the South-West of Western Australia.

Insert Figures 8a and 8b near here

DSAnnual had substantially more legume than DSKikuyu (Fig. 8*a* and 8*b*) from February to October 1999, and by percentage at 42 *vs.* 15% for DSAnnual *vs.* DSKikuyu, respectively. This was again the case from February to October 2000 at 20 *vs.* 10% for the DSAnnual and DSKikuyu pasture, respectively. The DSKikuyu pasture had a similar legume component to DSAnnual both in absolute and percentage terms (Fig. 8*a* and 8*b*), at 29 and 24% for the DSKikuyu and DSAnnual, respectively from May to October 1998. Kikuyu grass made up a relatively small percentage of the total of DSKikuyu in August 1998 at 26%, compared with 69 and 66% at the same time in 1999 and 2000, respectively.

Broadleaf weeds were the dominant functional species group for February, June and August in the DSAnnual pasture in 1999 and 2000, respectively, and May and August 1998 (February 1998 was not measured). Broadleaf weeds were a very small component of the overall pasture sward in the DSKikuyu pasture. May 1998 had the highest broadleaf component measured on a percentage basis, at 30% at the end of a record dry summer. Annual grasses were similar in absolute terms between the 2 pasture types over much of the measured period (slightly higher in October 1998 in the DSKikuyu paddock), and made up a relatively insignificant proportion of the total pasture sward.

Pasture quality

Averaged over the dry feed period, the DMD% of the DSKikuyu was 3-4.1% higher than the DSAnnual pasture. This difference was most pronounced in January 1999 after >50 mm rain (60.3 and 47.1% for DSKikuyu and DSAnnual, respectively), and in December

1999-January 2000 (63.0 and 58.5% for DSKikuyu and DSAnnual, respectively) again after >50 mm rain. A germination of temperate annual species was recorded in the DSAnnual pasture in February of 1999 and 2000, increasing the DMD% to 81.0 and 67.2%, respectively. After both of these wet summers, the DSAnnual pasture was significantly ($P<0.05$) more digestible than the DSKikuyu pasture (74 *vs.* 64% for 1999 and 66 *vs.* 58% for 2000 for DSAnnual and DSKikuyu, respectively) for the growing season (February to October 1999 and April to October 2000). This was not the case after the dry summer of 1997-98 where the average growing season digestibility was the same for DSAnnual and DSKikuyu.

Cattle weight and fat measurements

Cattle liveweight and P8 fat profiles were compared over the lactating periods for the years 1998-2000. The DSKikuyu cows were significantly ($P<0.05$) lighter and had less fat at the mid-winter (post –calving) weigh than the DSAnnual cows in all years (Table 3). This trend continued through to the weaning date for liveweight and fat depth in 1999 and 2000. In 1998, the DSKikuyu cows were heavier, but had the same fat depth at weaning in January 1999.

Insert Table 3 near here

Calf weights were less sensitive to seasonal variation and pasture differences. The DSAnnual calves were slightly, but not significantly heavier at weaning in 1999 (10 kg), the same weight in 2000, and the DSKikuyu calves were 15 kg heavier (not significant) at weaning in 1998

A sub-set of cattle were also weighed and fat scanned on and off the DSKikuyu pasture at the beginning and end of the autumn crash graze period in 1998, 1999 and 2000.

Liveweight changes ranged from –70 to 870 g/day. The measured P8 fat depth changes were all slightly negative and ranged from –0.03 to –0.09 mm/day over the crash graze period.

Cattle stocking regime

In the lactation phase of 1998, the DSAnnual carried 16% more cows/ha.day than the DSKikuyu (0.64 compared with 0.55, Table 4). Stocking rates were similar between the DSAnnual and DSKikuyu treatments for the 1999 and 2000 lactation periods, with the DSKikuyu pasture carrying 4 and 3% more cows/ha.day for 1999 and 2000, respectively.

Insert Table 4 near here

The DSAnnual pasture was de-stocked between weaning and pre-calving (dry cow phase) in all 3 summers, due to the total HM falling below the soil stability threshold of 1000 kg DM/ha (1500 kg DM/ha in 1998). Animals de-stocked from the DSAnnual pasture were moved to the DSKikuyu pasture until such time that either the pasture was sufficiently crash grazed or the cow's physiological needs were not being met (average fat depth <7 mm).

The crash graze period varied both in length and intensity. The DSKikuyu pasture was grazed for 68.9 cow days/ha in the dry summer of 1998 (Table 4), which achieved a significant reduction in total HM, from 2821 to 1803 kg DM/ha. There was a small quantity of green HM, which was slightly reduced from 119 to 75 kg DM/ha over the same period. Total cow days/ha for the crash graze in the wet summer of 1999 was almost doubled at 134.5. This reduced the total HM from 1701 to 561 kg/ DMha and the green HM from 831 to 561 kg DM/ha. In the following wet summer of 2000, cows were only grazed for 63.3 cow days/ha as total HM was initially close to the target 1000kg DM/ha (986 kg DM/ha). Final total and green HM was the same at 1138 kg DM/ha.

Economic analysis

The production elements from the Ireland farm that were most sensitive to profitability in the model were animal stocking rates (DSE) and liveweights (kg) at sale for "born on farm steers" and "cull cows" from each the different pasture systems.

The single critical economic management cost for the production system was supplementary feed. An estimate of supplementary feed supplied to the DSAnnual cows was calculated using Grazfeed (Donnelly *et al.* 1987). Without this cost ($20.21/ha), which is only attributable to DSAnnual, each treatment would have the same total costs per hectare. The inputs for Grazfeed reflected measured total HM, pasture quality and cow liveweights over the de-stocked autumn period.

Using a sale price of $1.80/kg carcase weight for "cull cows", the prices per head were $617 for DSAnnual, $594 for DSKikuyu and $605 for DSAnnual-DSKikuyu. Cull cow liveweights were the cow liveweights at weaning for cows grazing annual or kikuyu pasture through the lactation period. Using a sale price of $2.80/kg carcase weight for "born on property steers", the prices per head were $481 for DSAnnual, $486 for DSKikuyu and $484 for DSAnnual-DSKikuyu. A 60% carcase to liveweight yield was also assumed.

The liveweight at sale (kg) for "cull cows" on the DSAnnual was higher than for the DSAnnual-DSKikuyu grazing system, (572 *vs* 561 for DSAnnual and DSAnnual-DSKikuyu, respectively) which resulted in an increased total income for DSAnnual (Table 6). However, given that the total costs were also higher for the DSAnnual system, the economic benefits were reduced, making the DSAnnual-DSKikuyu based pastures 19% more profitable.

Insert Table 6 near here

The higher profitability of the DSAnnual-DSKikuyu grazing system can be seen in the NPV outcomes for both of these pastures, which is highlighted in Table 6 for each of the treatments.

The NPV is the present value of a future number of cash flows over a 10-year period minus the initial cost of the investment, which was assumed to be an initial application of fertiliser equal to $30/ha for each treatment (Barlow *et al.* 2003). The model used a district base stocking rate (DBS) in DSE/ha of 7 for DSAnnual and 7.8 for DSAnnual-DSKikuyu and a high skill management rate (HSR) in DSE/ha of 10.4 for DSAnnual, and 10.2 for DSAnnual-DSKikuyu to give 2 NPV calculations for each paddock.

The discount rate in the model was 7%, which is the opportunity cost of capital or the rate of return the investor can obtain if the money was invested in some other comparably risky project.

Discussion and Conclusions

Deep drainage

The DSKikuyu treatment developed a larger soil water deficit (SWD) than the DSAnnual throughout much of the measurement period, particularly from November through to March. Given that water extraction was occurring beyond the depths measured, the values presented are likely to underestimate the true magnitude of the SWD. As a consequence of the higher SWD, the modelled deep drainage estimates for kikuyu were substantially lower than the annual pasture. However, when integrated over the farm area which consisted of 40% kikuyu and 60% annual pasture, the resulting farm scale deep drainage (180 mm) was just over half that of the annual pasture (Table 2). Halving deep drainage in WA, has the potential to reduce the eventual extent of salinity by 25% and delay the onset of salinity by 40 years (George *et al.* 2001).

The water balance model presented in this paper is simplistic and does not take into account subsurface runoff (through flow) or infiltration excess flow. Through flow is a major component of stream flow in southern WA (McKergow *et al.* 2003). Consequently the model under-predicted runoff. During the winter of 1998 *c.*20 mm of runoff was measured in a creek running through the property, yet no runoff was predicted for either the DSKikuyu or DSAnnual treatments. Consequently the partion ratio (PR = DD/(Ro+DD : White *et al.* 2001) for the Sodosols presented in this paper (0.72 – 0.82) were considerably higher than those determined by White *et al.* (2003). Despite the model imperfections, the relative differences between the modelled treatments clearly show the benefits of kikuyu in reducing deep drainage and runoff compared to the annual pasture, which was also noted by White *et al.* (2003).

Herbage accumulation, quality and composition

There was reasonable alignment between relative herbage accumulations of the DSKikuyu and DSAnnual pasture and cow liveweight changes through the lactation phase. The poorer winter herbage accumulation rates of the DSKikuyu pasture were reflected in lower cow liveweights in this period. The spring herbage accumulation rate in DSKikuyu pasture in 1998 was reflected in a higher liveweight at weaning for the cows grazing the DSKikuyu pasture. This was not the case in 2000, however the result was confounded by a heavy locust infestation in the post senescence period of the annual pasture, which had a large effect on the DSKikuyu pasture.

Late spring negative estimates of herbage accumulation occurred in all years and represented the period when the pasture was senescing. Herbage accumulation was assumed to be zero in the DSAnnual pasture from senescence until germination the following year. Perhaps ongoing measurements of the rate of loss in the senesced pasture would have provided a more useful comparison with the DSKikuyu pasture over the "dry feed" period.

The negative estimates recorded in winter were also likely to be as a result of pasture losses, but may also have been an indication of moisture stress. This occurred in June 1999 (DSAnnual) and June 2000 (DSKikuyu), after 2 consecutive months of below average rainfall. Murtagh (1988) and Mears (1970) also found the growth of kikuyu to be very sensitive to water supply, despite being capable of extracting water from the top 1.2 m to wilting point (Mears 1970) to survive. The soil water storage on the DSAnnual in June 1999 was <350 mm/1.8m, which was similar to the level of soil water storage after the driest summer on record of 1998.

There was considerable variation between monthly measurements within the same pasture type, for DDM%, with less variability in the dry feed period. Some of this variation could be accounted for by a lack of standardisation of sampling time of day. Trevaskis *et al.* (2001) found the water soluble carbohydrates of kikuyu grass varied from 41-80 g/kg depending on whether they were cut in the early morning or late afternoon.

The relative productivity of the 2 pastures over the growing season was influenced strongly by the winter legume content in the kikuyu pasture. The 1998 growing season provide a good case study of a kikuyu pasture with a strong legume component. The 2 pastures recorded a very similar average DMD (%) (74 and 73% for DSAnnual and DSKikuyu, respectively), had similar cow liveweight and fat depth patterns over the period, and slightly (but not significantly) heavier calf weaning weights. The 1999 and 2000 growing seasons were examples of comparatively poor presence of legume in the DSKikuyu pasture from June to October. The average "growing season" pasture quality for the DSAnnual and DSKikuyu pasture differed accordingly (DMD% of 74 *vs.* 64%, respectively for 1999, and 62 *vs.* 58%, respectively for 2000). In both years, the energy available for growth and lactation for the cattle grazing the DSKikuyu pasture was therefore limited by the low pasture DMD% (SCA 1990). The DSKikuyu pasture had significantly lower cow liveweights and fat depths, and similar or lower calf weaning weights.

The aim of reducing the total HM to <1000 kg DM/ha through the crash grazing had little relationship with the winter and spring legume component in the DSKikuyu pasture in the following season. The 1997-98 summer crash graze did not achieve the target of <1000 kg DM/ha, and the 1998-99 and 1999-00 crash grazes reached lows of 561 and 986 kg DM/ha, respectively. Despite this, the resulting legume component in the DSKikuyu pasture was superior through the growing season of 1998, relative to 1999 and 2000. The use of green HM was perhaps a better indicator of sward competition from kikuyu in autumn. There was close to zero kg DM/ha of green HM in the kikuyu pasture at commencement of the 1998 green feed season. This contrasted with the final result for the 1998-99 and 1999-00 crash graze periods, where the green HM of the DSKikuyu pasture was close to 1000kg DM/ha at the commencement of the following lactation period.

Competition from kikuyu grass at the season break may have been a major factor in the poor final legume content in the DSKikuyu pasture in 1999 and 2000. Both of these years were characterised by a relatively strong presence of green HM in the DSKikuyu pasture in April, followed by a 3-month period of below average rainfall in early winter.

Fulkerson and Slack (1996) found that defoliating kikuyu grass to a height of 5 cm when it began to shade the companion legume (white clover), in autumn resulted in a significant increase in the legume component. The DSKikuyu pasture was grazed to a height of approximately 2 cm, and so it was unlikely that shading was of similar importance.

Moisture competition may assume more importance in this environment. The recorded soil water storage was in the vicinity of 220 mm/1.8mm for DSKikuyu for both of the late autumn periods in 1999 and 2000. This contrasted with the DSAnnual pasture in this period, which was closer to 360 mm/1.8m.

Cattle liveweight and stocking rate

The DSKikuyu pasture carried more cattle than the DSAnnual pasture over both very wet and very dry summer (dry cow phase) periods. The liveweight and P8 fat depth changes in the crash graze period were within a safe rate of change for late pregnant cows provided the cows were in "good condition" prior to calving (NRC 1984). A slight loss in condition of the cows during this period was recorded frequently, but cow liveweight loss was of more concern.

The strategy to reduce the build up of stoloniferous material had a dual benefit of increasing the proportion of leaf to stem and dead material and therefore increasing the quality of available kikuyu (Reeves *et al.* 1996). This helped to promote the germination and survival of legume seedlings through kikuyu's winter dormant period (Mears 1970).

The length or intensity (cow days/ha) of the crash graze period required to reduce the total HM to the target 1000 kg DM/ha was higher in years with higher summer rainfall and spring residual feed. The longest crash graze period (134.5 cow days/ha) was in summer 1998–99. At this time the highest summer rainfall was recorded over the experimental period, resulting in an estimated herbage accumulation rate of 15 and 17 kg DM/ha.day in the DSKikuyu pasture for January and February, respectively. It also followed the highest spring peak feed surplus at 4061 kg DM/ha. The measured cow liveweight loss of -70 g/day during the crash graze period in 1999 was perhaps operating close to the limit of grazing pressure late pregnant cows could tolerate.

Doyle *et al.* (1996) reported a strong positive correlation between the rate of loss of dead annual pasture and the estimated maximum amount of pasture HM accumulated at the end of spring. He also suggested that grazing was a relatively small contributor to the total amount of dry feed at the end of summer. The amount of summer rainfall was perhaps a stronger indicator of the length or intensity of crash grazing required.

The crash graze periods for summers of 1997-98 and 1999-2000 were less than half that of 1998–99 (68.9 and 63.3 cow days/ha, respectively). The 1997-98 summer was the driest summer recorded for the experimental period, and no growth was recorded in the DSKikuyu pasture from late November until after the season break in mid-May. In contrast, the 1999–2000 summer had a similar amount of rainfall to the 1998-99 wet summer, but followed a relatively low peak spring surplus of 2509 kg DM/ha. The cow liveweight gain of 870 g/day in the crash graze period of 2000 suggested that a higher grazing pressure could have been used.

The most feed limiting time of the year for temperate annual pastures is the post-senescence late summer and autumn period, where available dry matter and feed quality are at their lowest. The higher cow day/ha crash graze requirement for kikuyu pasture over wet summers, complemented the significant extra loss of both feed quality and quantity usually experienced on a senesced annual pasture after a summer rain event. Rossiter *et al.* (1994) recorded a mean loss of 28% of herbage mass and a decline from 55 to 47% DMD in senesced annual pasture after a 96 mm summer rainfall event. This decline to below 55% DMD would have limited intake by stock if selective consumption of green feed or supplements were not available (Doyle *et al.* 1996). A January low of 47.1% DMD was recorded in the DSAnnual paddock in 1999, immediately after a major rainfall event. This was not the case in 2000, however as significant summer rainfall fell from December to February, and the lowest recorded DMD% for the DSAnnual pasture was 57.2% for December 1999, after which time there was a germination of predominantly broadleaf weeds.

It may be difficult to achieve the required level of pasture removal in a kikuyu pasture, when summer moisture is not limiting using late pregnant cows. Van Saun *et al.* (1996) warned that inadequate dry cow nutrition could result in a substantial drain of maternal nutrient reserves which risks having a detrimental impact on subsequent lactation performance and calf viability. Dry animals with a lower maintenance requirement (SCA 1990) could be used to apply greater grazing pressure to a kikuyu pasture sward in autumn than was able to be achieved with late pregnant cows and perhaps reduce the competitive vigour of the kikuyu pasture particularly after a wet summer.

The full implications of the lower winter and spring liveweights and conditions of the cows grazing DSKikuyu pasture in the 1999 and 2000 lactation phases was not demonstrated in this study; as the animals were re-randomised at the commencement of each calving period. The ongoing impact of lower liveweight and in particular condition was therefore not measured. This is potentially important for achieving acceptable conception rates in ongoing years. Greathead (personal communication) found an interaction between the rate of weight change during joining and the condition score at the start of joining. Cows in condition score 1 at the start of joining needed to be gaining weight at 0.23 kg/day or more in order to achieve an overall conception rate of 89%. There was a sharp decline in conception rate below this threshold rate of gain if the cows were in condition score 1 at the commencement of joining. Poor spring liveweight and condition of cows grazing kikuyu pasture could result in a higher risk of poor conception rates in the following year unless the winter legume component is comparable to that of annual pasture.

A beef production system was demonstrated where cattle were run at higher than the district average stocking rate without supplementary feeding over 3 growing seasons by varying the grazing pressures on the temperate annual and kikuyu pastures to capitalise on their respective productive growth periods. This system had no additional inputs relative to a "normal" annual pasture production system. The system also halved the estimated deep drainage that would be generated by an annual pasture system, of particular importance in reducing the risk of developing secondary salinity in the landscape.

A summer crash graze of the DSKikuyu pasture was designed to achieve the multiple benefits of minimising the risk of wind erosion on the DSAnnual pasture through destocking (Findlater *et al.* 1990) whilst increasing the quality of animal intake and promoting the presence of legumes in the DSKikuyu pasture. The occurrence of extremely wet and dry summers during the experiment represented a significant opportunity, as some measure of the range of summer productivity of kikuyu pasture was able to be gained.

The economic analysis compared an annual pasture system with a kikuyu only and a combination of kikuyu and annual pasture (50-50%). There was a 19% increase in gross margin/ha for the kikuyu/annual system compared with the annual pasture system. The difference was generated by a removal of supplementary feeding costs with the inclusion of kikuyu in the grazing system. The difference was reduced to a degree by the lighter liveweights of the cows grazing kikuyu pasture at weaning in 2 of the 3 years. This translated to a lower income for the kikuyu system from cull cows, and potentially increases the risk of poorer conception rates in subsequent years. It is important to note that this outcome did not occur 1998, where a good legume stand was established in the kikuyu pasture through the growing season. The comparative profitability of the kikuyu pasture could be further enhanced by achieving a strong winter legume stand more than one year in three. The potential benefits of this outcome is quantified to a degree by the gross margin of the DSAnnual-DSKikuyu combined pasture in 1998, which was 44% higher than the DSAnnual due to the similar "cull" cow liveweights, and stocking rates and no supplementation.

In summary, a well managed kikuyu pasture can play an important role in a grazing system as a pasture which allows significantly less deep drainage, and reduces the need for supplementary feeding whilst providing a productive and profitable addition to annual pasture.

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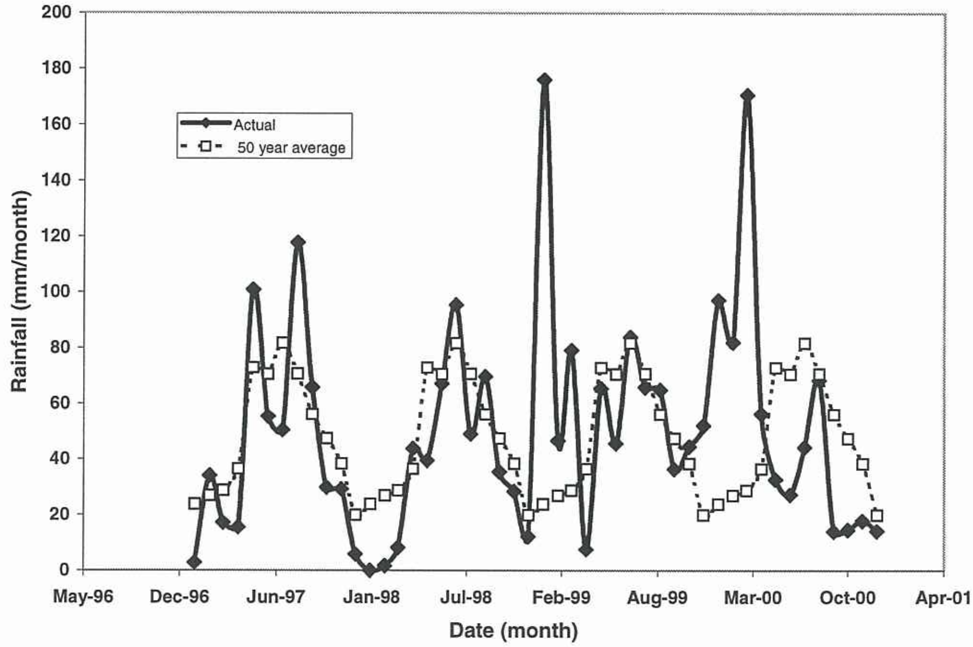

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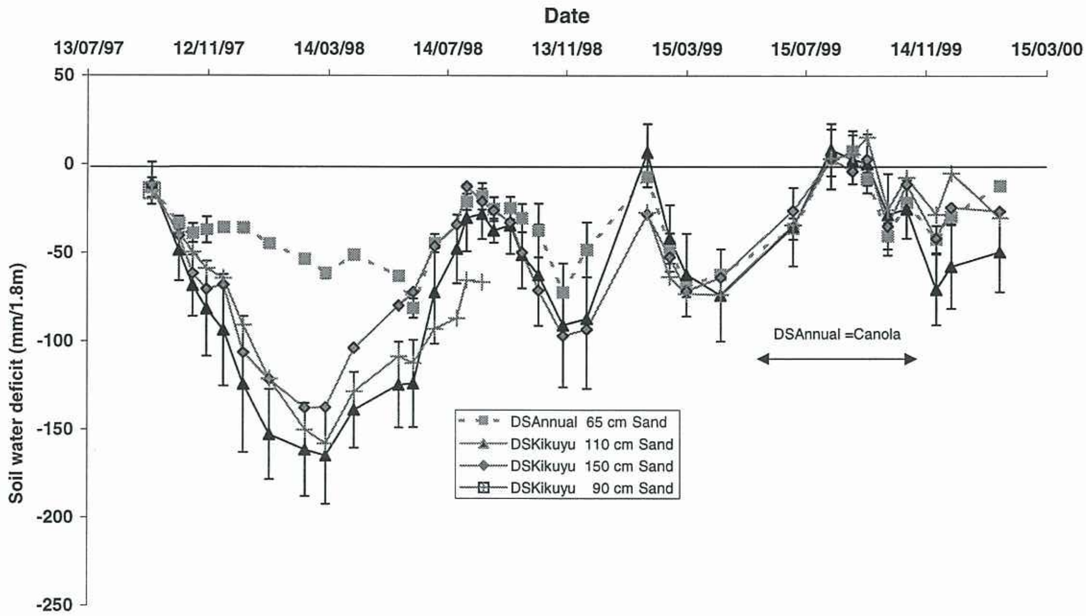

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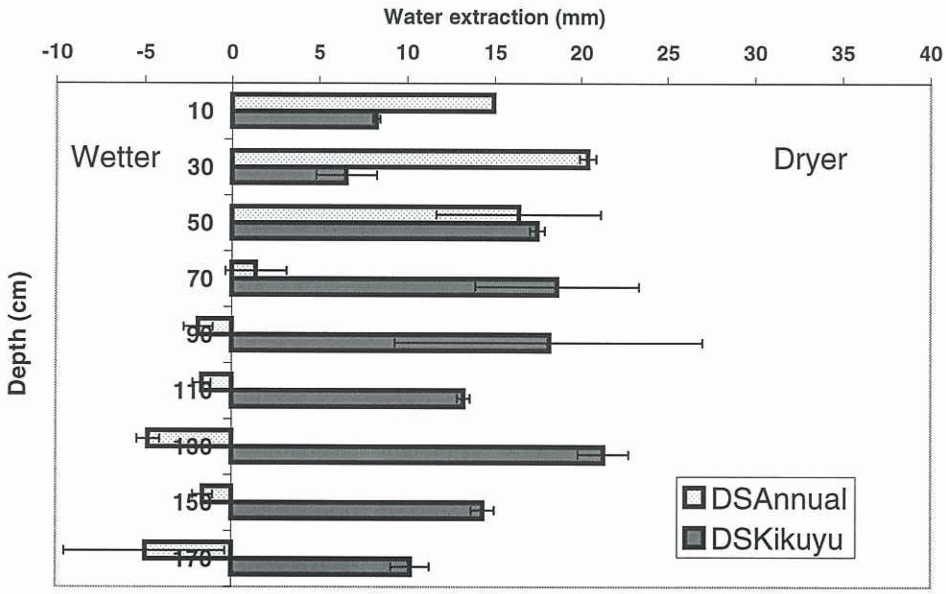


Water extraction (mm)
-10
-5
0
5
10
15
20
25
30
35
40
Depth (cm)
10
30
50
70
90
110
130
150
170
Wetter
Dryer
DSAnnual
DSKikuyu

Figure 4

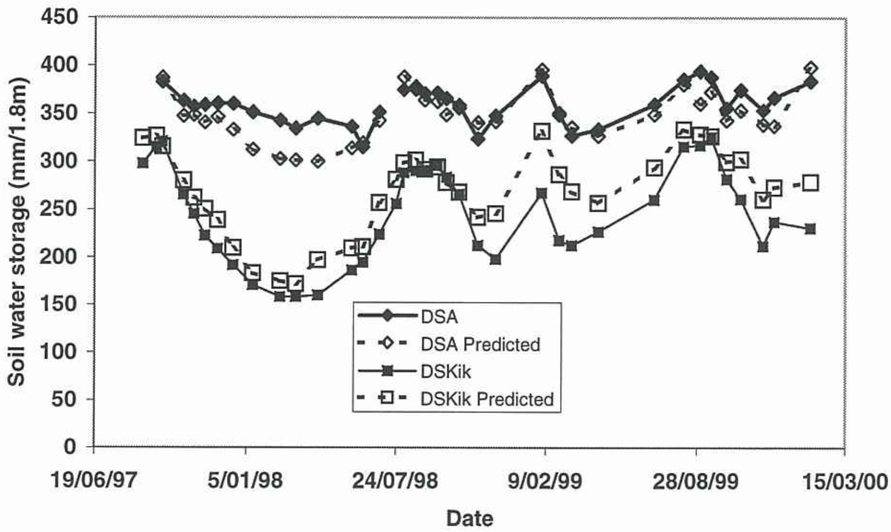

450
400
350
300
250
200
150
100
50
0
Soil water storage (mm/1.8m)
19/06/97
5/01/98
24/07/98
9/02/99
28/08/99
15/03/00
Date
DSA
DSA Predicted
DSKik
DSKik Predicted

Figure 5a

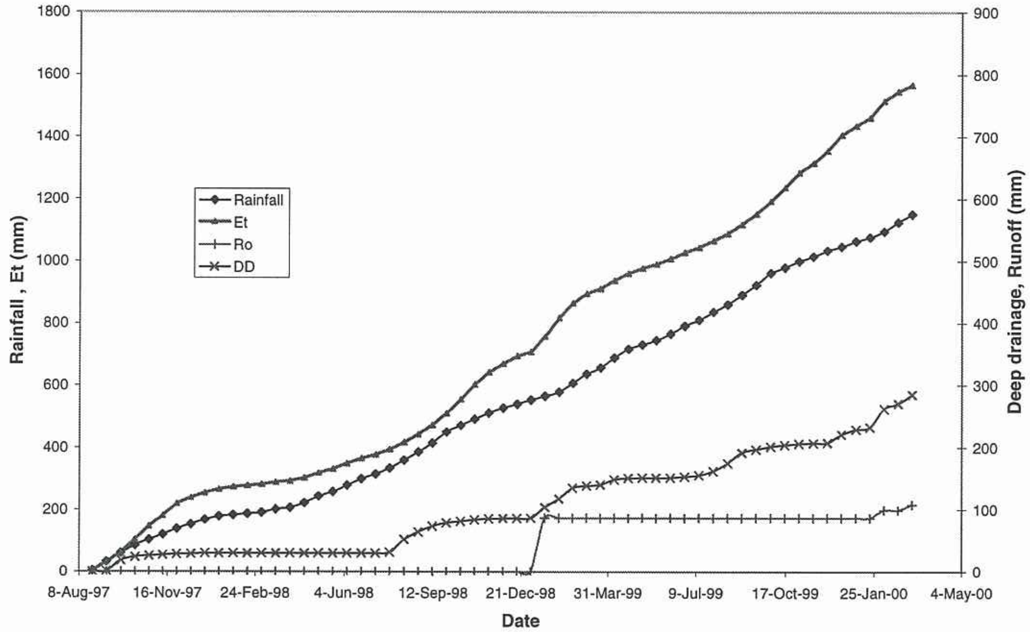


Figure 5b

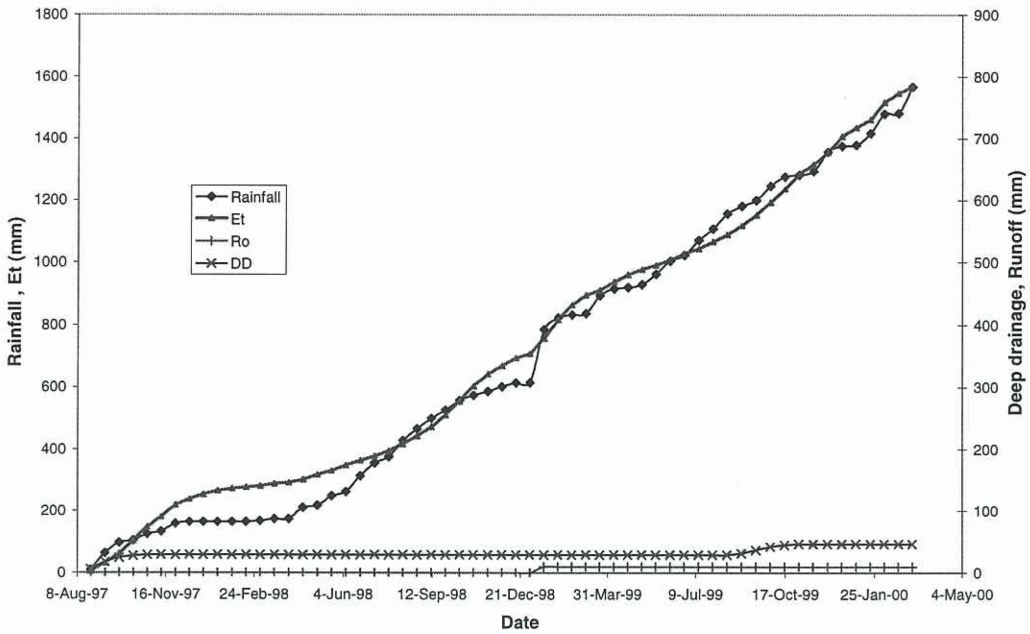
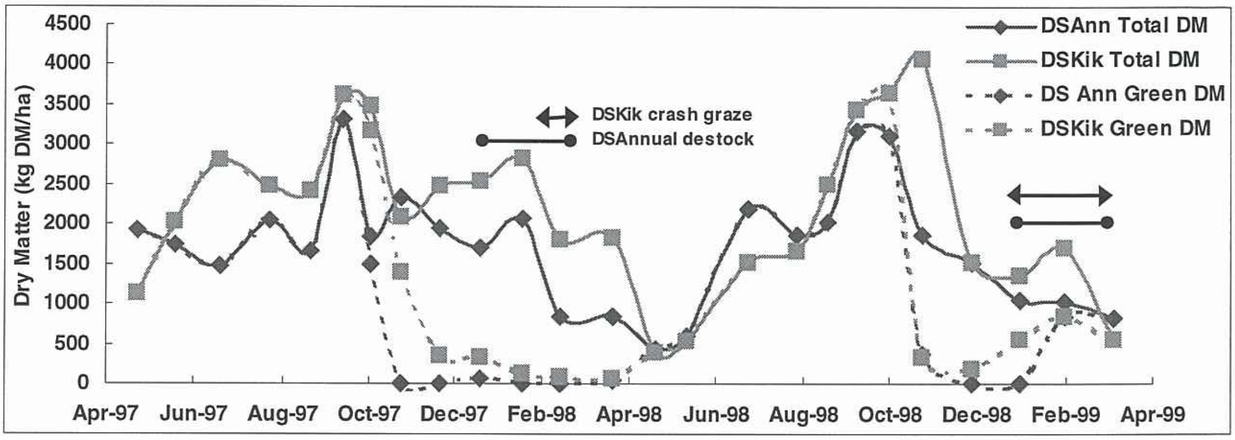


Figure 6a



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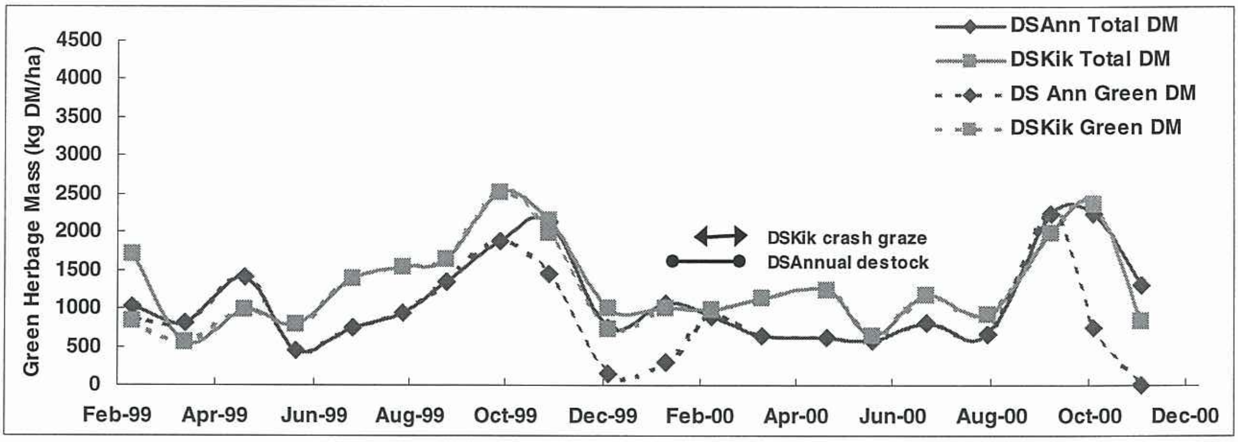


Figure 7a*

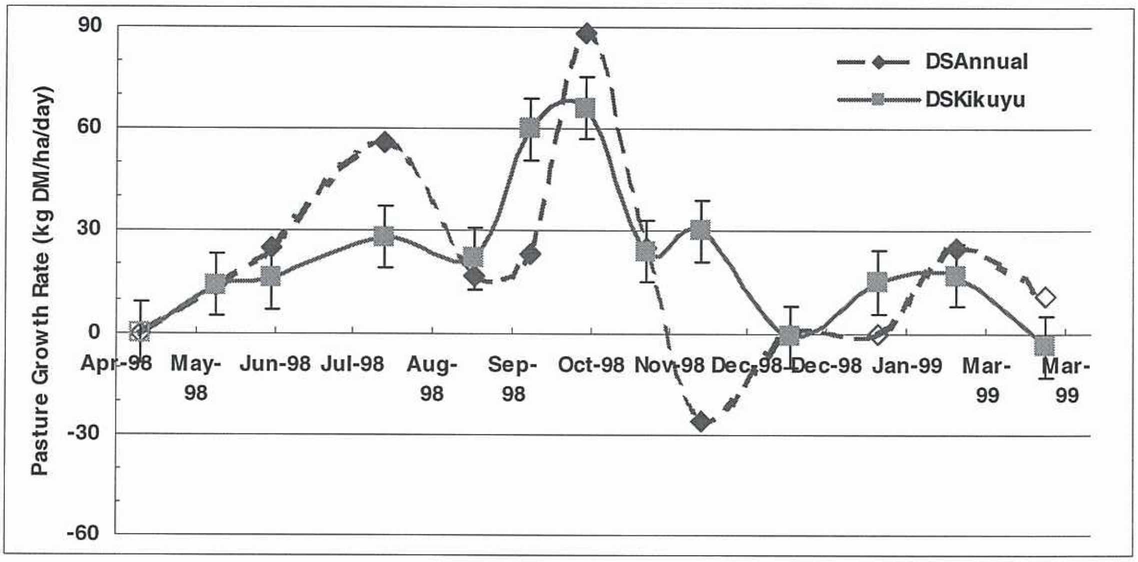


Figure 7b

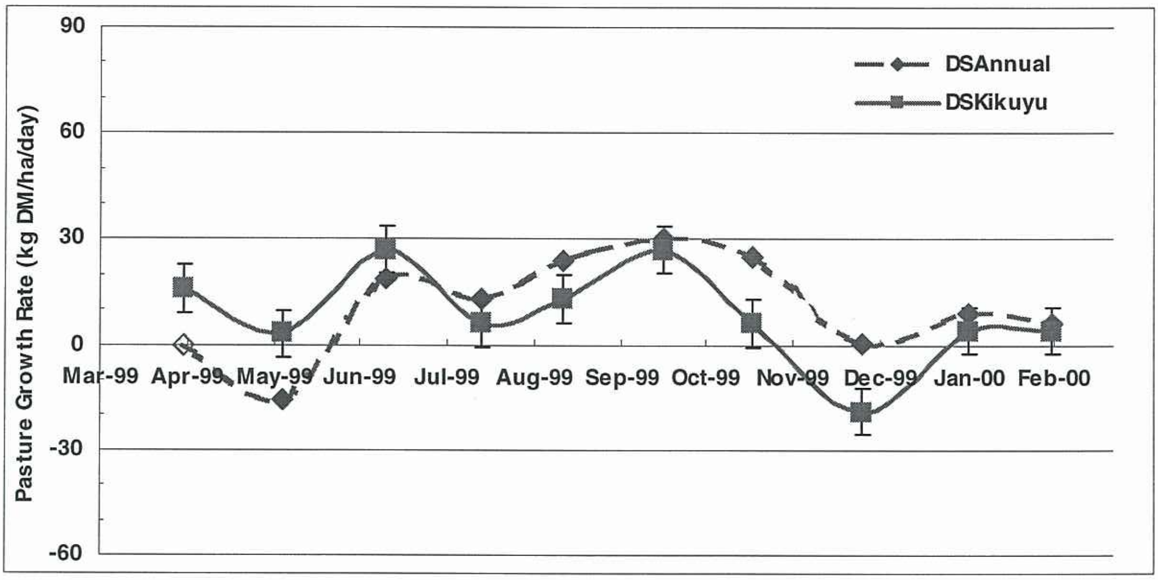
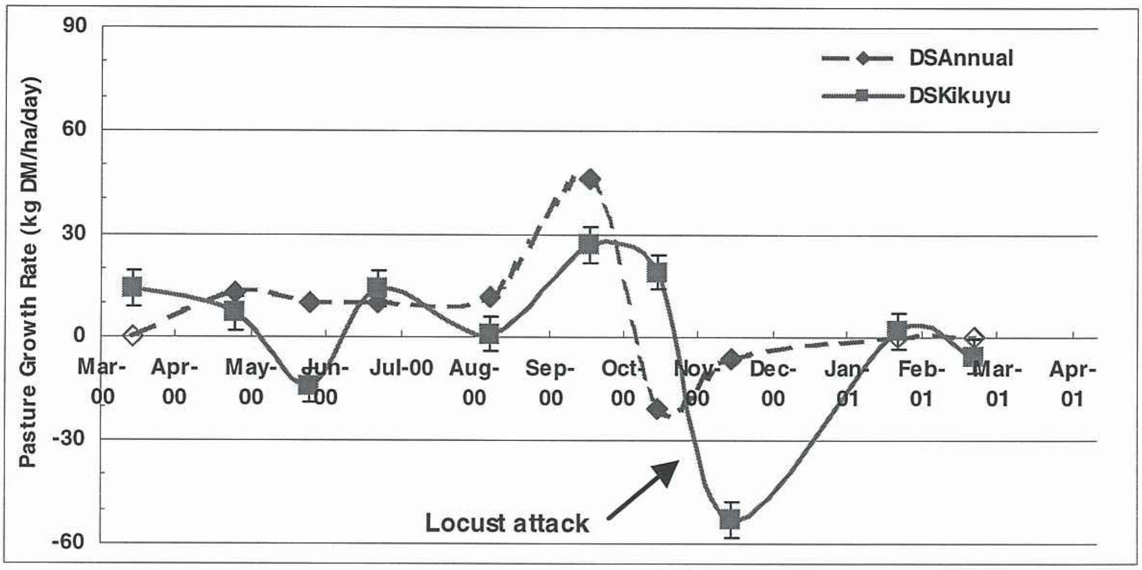


Figure 7c



* Note: Open diamonds represent points where measurements were not taken as the annual pasture had senesced and was not growing, therefore growth was assumed to be zero. Error bars represent 5%LSD(P<<0.05)

Figure 8a

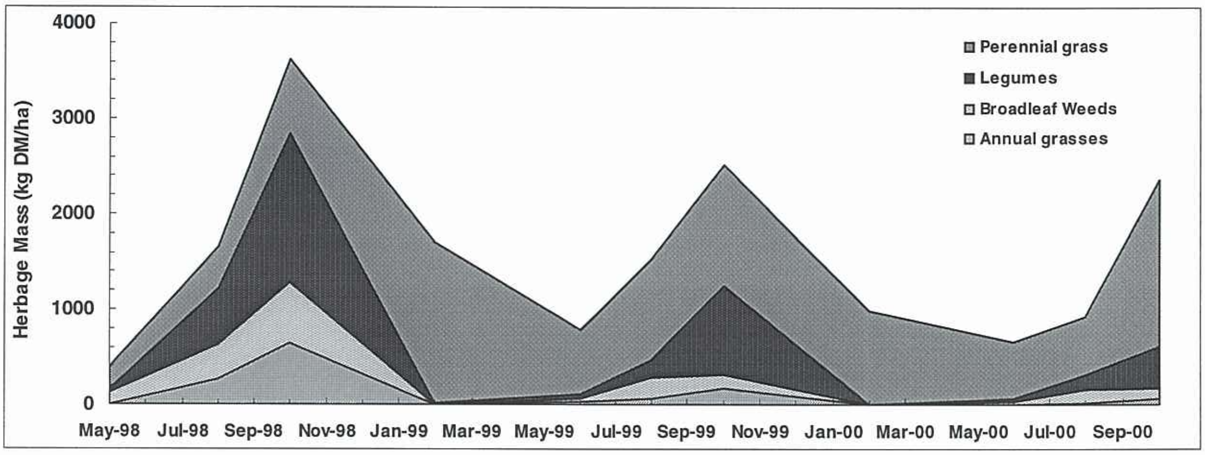


Figure 8b

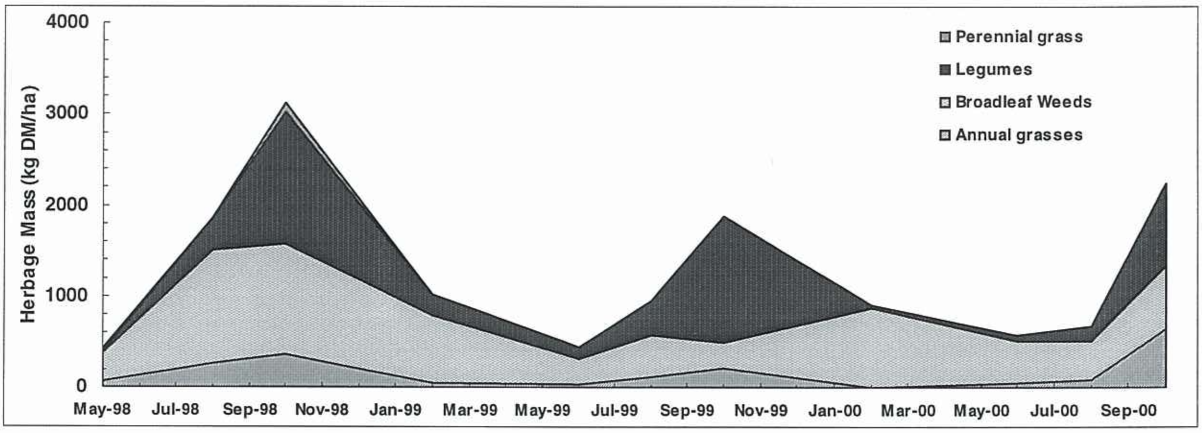


Table 1

Treatment	Soil type	Pasture type
DSAnnual	Deep sand	Temperate annual
DSKikuyu	Deep sand	Kikuyu/ annual mix

Table 2

Year	Cattle removed	Cattle re-allocated	Total time (days)
1998	22/01/98	13/03/98	50
1999	13/01/99	22/03/99	68
2000	03/02/00	15/03/00	41

Table 3

Treatment	Year	End Calve (June July)		Wean (Jan-Feb)	
		Liveweight (kg)	P8 Fat (mm)	Liveweight (kg)	P8 Fat (mm)
DSAnnual	1998	492.7*	4.89	544.6	12.46
DSKikuyu	1998	459.5*	3.23	570.6	12.36
DSAnnual	1999	500.6	7.58*	563.3*	11.20*
DSKikuyu	1999	487.5	5.39*	537.6*	7.21*
DSAnnual	2000	558.5*	10.54*	601.7*	16.36*
DSKikuyu	2000	500.6*	2.39*	536.8*	6.99*

Note: different treatments within the same year with an * are significantly different (P<<0.05)

Table 4

Pasture	Year	Phase	Total days	cows/ha/day	cow days/ha
DSAnnual	1998	lactation	304	0.64	195
DSKikuyu		lactation	304	0.55	168
DSKikuyu		dry cow	33	2.1	68.9
DSAnnual	1999	lactation	317	0.74	233
DSKikuyu		lactation	317	0.77	243
DSKikuyu		dry cow	68	2.0	134.5
DSAnnual	2000	lactation	299	0.58	174
DSKikuyu		lactation	299	0.60	178
DSKikuyu		dry cow	19	3.3	63.3

Table 5

Water Balance Parameter	DSKik	DSA
Rainfall	1567	1567
Evapotranspiration	1569	1154
Deep Drainage	46	270
Runoff	10	108
Change in soil water stored	-57	36

Table 6

	Annual	Annual /Kikuyu
DSE/ha	9.9	10.2
Costs ($/ha)		
Supp Feeding costs ($/ha)	$19	$0
Total Variable Costs ($/ha)	$110	$93
Liveweight at sale (kg)		
Cows	572	561
Steers	287	288
Total income ($/ha)	$231	$237
Gross margin/ha	**$121**	**$144**
NPV/ha HSR	**$613**	**$735**

Appendix 3.

Changes in soil characteristics when Eucalyptus globulus tree belts are planted on agricultural land in south-west Australia – A Tertiary Studentship Report

Changes in soil characteristics when *Eucalyptus globulus* tree belts are planted on agricultural land in south-west Australia

John Paul Collins

Tertiary Studentship Recipient

MEAT PROGRAM

SUSTAINABLE GRAZING SYSTEMS PROJECT

Department of Agriculture
Government of Western Australia

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INTRODUCTION AND LITERATURE REVIEW

Background

Within the high rainfall zone of southwest Australia, grazing enterprises have historically comprised beef, dairy, prime lamb and wool production on annual pastures. Such grazing systems commonly contain a mix of subterranean clover (*Trifolium subterraneum* L.) and annual ryegrass (*Lolium rigidum* Gaudin), often invaded by pasture weeds e.g. capeweed (*Arctotheca calendula*) (Sanford *et al.*, 2001). Secondary salinisation has the potential to claim up to a third of this agricultural land. Deep-rooted woody perennials have been replaced by annual pastures, which are shallow rooted, creating a hydrological imbalance. As a consequence of this imbalance excess winter rainfall is remaining in the groundwater causing the watertable to rise at a rate of 0.15 – 1.5 m/annum. As it rises, it mobilises stored salts in the profile that have been deposited inland by prevailing winds over the course of geological time. As well as severely suppressing agricultural production, secondary salinisation has had a detrimental impact on water resources, infrastructure (e.g. roads and towns) and the habitats of native flora and fauna (Government of Western Australia, 2000).

Integrating trees into pasture is one method of attempting to restore the hydrological balance. Previous research has led to the hunch that Kikuyu pasture (*Penniesetum clandestinum* cv. Whittet) combined with Tasmanian bluegum belts (*Eucalyptus globulus*), greater than 100 metres apart over 10% of the landscape, can reduce recharge by 60% or more and increase livestock production by 10 to 30% (Sanford *et al.*, 2001). It was also discovered that bluegum belts deplete soil macronutrients in the surface soil, compared to the adjacent pasture and soil pH was lower under the bluegums, suggesting acidification. Given the lack of significant changes in the soil under bluegums, it seems reasonable to attribute the effects to the trees. Such a finding has raised interest in determining the nature and extent of soil changes as a consequence of planting agricultural land to bluegums. More importantly, it has raised questions concerning implications of such soil changes beneath tree belts and adjoining pasture for landuse following tree harvest.

Soil pH

Soil pH is an integral aspect of soil fertility as it dictates the availability of nutrients for plant uptake (Hills and Miller, 2000). Acidification of agricultural land, either for cropping or grazing is a well-documented phenomenon (e.g. Noble *et al.*, 1996; Young *et al.*, 1999; Scott *et al.*, 2000). Export of alkalinity through removal of farm produce has resulted in acidification of soils. Similarly, with the application of nitrogenous fertilizers and incorporation of legumes, the nitrogen (N) fertility of agricultural soils has been increased, resulting in an enhancement of nitrate leaching and release of Hydrogen ions (H^+) into the soil solution by legumes, also driving soil acidification. Likewise, in some cases the planting of trees has also been shown to result in soil acidification. Research undertaken in New Zealand into the effect of planting *Pinus radiata* on agricultural land has demonstrated acidification of the surface soil (Table 1).

Table 1: Magnitude of pH decline below *Pinus radiata* trees planted on ex-agricultural land in New Zealand, compared to the adjacent land use or time period when previous soil samples were taken.

Decline in soil pH below trees	**Comparison landuse**	**Reference**
0.43	Native Eucalypt forest	Turner and Lamber (1988)
0.4 – 0.6 (year 19)	Young pines in year 3	Hawke and Connor (1993)
0.3	Grassland	Davis (1995)
0.4 – 0.6	Pasture	Giddens *et al.* (1997)
0.2 – 0.5	Pasture	Hawke and Knowles (1997)
0.38	Pasture	Parfitt *et al.* (1997)
0.2	Pasture	Hawke *et al.* (1999)
0.3 – 0.5	Grassland	Chen *et al.* (2000)
0.2 – 0.5 (year 25 at harvest)	Young pines in year 2	Yeates *et al.* (2000)

Given the lack of any substantial change in the physical properties (e.g. texture) of the soil under the pines and the adjacent landuse, it is reasonable to attribute the acidification to the pines. Acidification may simply reflect the cessation of previous fertilizing and liming when the land was used for pastoral production prior to forestry (Yeates *et al.* 2000). However, given that decline in pH was more pronounced with increased tree density and age (Hawke and Connor, 1993) it is evident that some processes are leading to the formation of an acidic surface soil below the trees.

Pine trees may acidify soil through the production of organic acids, released by roots. This mechanism increases nutrient availability and it is suggested that the decrease in soil pH enhances the solubility of organic Phosphorus (P) (Giddens *et al.*, 1997; Parfitt *et al.*, 1997; Chen *et al.*, 2000). An excess uptake of cations over anions by radiata pine is reflected in a greater biomass storage of nutrient cations, and constitutes another process potentially leading to soil acidification, due to H^+ release by roots (Parfitt *et al.*, 1997; Chen *et al.*, 2000). Further research has indicated an increase in deposition of organic matter under the pines, providing substrate to enhance mineralisation and subsequent nitrification. Leaching of nitrate below the root zone results in an accumulation of H^+ ions in the soil solution around the root zone, thus acidifying the soil (Parfitt *et al.*, 1997).

Giddens *et al.* (1997) suggests growth of pine is enhanced if moderate levels of Aluminium are brought into the soil solution as a result of lower pH levels. However, following harvest an alternative landuse may be sought (e.g. pasture production) and ameliorative measures will need to be implemented such as lime application to raise the pH suitable for the new landuse. Alternatively, acid tolerant crops and pastures could be investigated.

Trends in acidification below radiata pine seem to be largely mirrored in other species e.g. eucalypts. In the Ethiopian highlands, Michelsen *et al.* (1993) measured a soil pH of 5.5 under *E. globulus* (bluegum), compared to a value of 6.8 for the native forest. This was attributable to the low rate of decomposition and nutrient release from litter due to lower soil temperatures. Similarly, Prosser *et al.* (1993) measured enhanced acidification in a mixed eucalypt forest (mean pH of 4.0) compared to unimproved pasture (mean pH of 4.3). As the forest had been previously harvested and had re-coppiced, acidification of the soil was attributed to product removal and a net accumulation of organic anions in forest regrowth (Prosser *et al.*, 1993). Underneath plantations of *Eucalyptus saligna*, Rhoades and Binkley

(1996) observed a decline in pH from 5.9 to 5.0 over a 8 year period. Such a decline was thought to result in part from leaching of nitrate due to the high rainfall regime, and to a continued supply of nutrient cations, from weathering processes and fertilization (Rhoades and Binkley, 1996).

The use of *E. camuldulensis* to rehabilitate Tin-mine spoils on the Jos Plateau of Nigeria (Alexander, 1989) increased organic carbon and nitrogen levels below the trees. This resulted in a drop in soil pH to 4.7, compared to 5.1 for the unvegetated spoil. It was suggested that the soil under the trees were more acidic due to an increase in cation exchange capacity (CEC), that had not been matched by a similar increase in exchangeable bases. Enhancement of CEC resulted in a greater potential pool of cations for plant uptake, typically accompanied by release of protons from the plant (Alexander, 1989). Another study revealed exchangeable calcium (Ca^{2+}) levels of topsoil under eucalypts to be only 57% of that under corresponding grassland soils, suggesting a high demand for Ca (Musto, 1991). Depletion of Ca from the exchange complex resulted in an increase in exchangeable acidity, implying that high demand for Ca by eucalypts acidifies the topsoil.

According to Noble and Randall (1998), there is little evidence that growth of trees increase the pH of soil. However, some studies report enhanced alkalinity of soil when the trees are harvested and logging residue is left behind. An increase in soil pH was recorded in soil where radiata pines had been harvested 4 years previously and residue had been applied to the ground (Merino and Edeso, 1999). The increase in alkalinity was attributed to the release of soluble cations and hydroxide (OH^-) from the accelerated decomposition of logging residues and organic matter decomposition due to high soil temperature and moisture content (Merino and Edeso, 1999). Evidence for enhanced soil alkalinity under eucalypts was provided in a study on 35 year old *E. camuldulensis* trees planted as a windbreak, adjacent to a paddock. Soil pH was 5.2 under the trees, compared to 4.8 under pasture (Noble and Randall, 1996). It was suggested that the deep root system of the eucalypts played a role in reversing the effects of soil acidification by taking up exchangeable bases such as Ca and magnesium (Mg) from deep in the profile, and returning them to the soil surface as leaf litter containing organic anions, which would have a similar effect to applying lime to the soil. Alternatively, soil pH may have decreased in the paddock due to nitrate leaching and export of produce (Noble and Randall, 1996).

In a comprehensive study of 42 sites in the south-west of Western Australia containing *E. globulus* plantations and adjacent pasture, no observable soil pH difference between the pasture and trees were observed (Grove *et al.,* 2001). In recognizing that *E. globulus* have acidified soil in other studies, Grove *et al.* (2001) postulate that soil under the trees may have acidified, given lower exchangeable soil Ca^{2+}. Such a process seems reasonable from the outcomes of other studies showing a substantial declines in Ca^{2+} levels which have accompanied a soil pH decline (e.g. Madeira *et al.*, 1989). However, the soil pH decline may have been matched by a similar change under pasture soils, due to the potential for acidification caused by leaching of nitrate and export of farm produce (Grove *et al.*, 2001).

Given the increase in acidification below trees, Noble *et al.* (1996) investigated the ash alkalinity of leaf litter of various tree species. Decomposition of leaf litter raises the soil pH, due to the consumption of protons as organic acids oxidize. Ash alkalinity is an estimate of the organic anion content of the litter, which dictates the ability to raise the soil pH (Noble and Randall, 1996). Differences between species in ash alkalinity relate to different proportions of cations and anions taken up and differences in the proportion of nutrients withdrawn from leaves during senescence (Noble and Randall, 1996). Of all the species tested, *P. radiata* had one of the lowest ash alkalinity values (45 cmol/kg, or 44 tonne lime equivalent), partly explaining the strong acidification under *P. radiata* in New Zealand studies (e.g. Chen *et al.*, 2000). Ash alkalinity of *E. globulus* was intermediate at 108 cmol/kg, requiring approximately 20 tonne of leaf litter to get the same neutralizing value as 1 tonne of lime. Northern hemisphere deciduous trees had the highest ash alkalinity, and *Melia azederach* (white cedar) had the highest ash alkalinity (250 cmol/kg), with a neutralizing capacity similar to that of agricultural lime (Noble *et al.*, 1996).

While the application of organic matter to the soil surface has been shown to decrease soil pH through the oxidation of organic anions during decomposition (Noble *et al.*, 1996), other studies have revealed an increase in soil pH following to the application of organic matter. For example, Hue and Amien (1989) noticed that the application of green manure (e.g. lucerne) raised the soil pH. This was attributed to release of Ammonia (NH_3) from decomposing organic material, production of Hydroxide ions (OH-) by dissolution of iron (Fe) and manganese (Mn) oxides in reducing conditions, or by ligand exchange through the replacement of the terminal OH- of Al/Fe oxides by organic anions (Hue and Amien, 1989; Noble *et al.* 1996). Oxidation of organic anions during decomposition of leaf material also can potentially make a major contribution to the increase in soil pH, through the consumption of H^+ (Noble *et al.*, 1996). A study comparing organic carbon beneath a *P. radiata* plantation and native forest found organic carbon to be lower in the plantation surface soil, suggesting that decomposition of organic matter had a major role in soil acidification (Turner and Lambert, 2000).

Nutrients

Leaf litter production and its subsequent decomposition are key processes regulating the cycling of carbon and nutrients. In particular, N mineralisation and the immobilisation of inorganic N govern the availability of N (Aggangan *et al.*, 1999; O'Connell and Rance, 1999). Addition of leaf litter to the understory of a *E. globulus* plantation reduced N mineralisation, attributed to immobilisation of N in microbial tissue (Aggangan *et al.*, 1999). Despite observations of a reduction in mineralisation rates under *E. globulus* plantations (Aggangan *et al.*, 1999) it had also been observed that the total soil N status did not change as a result of planting agricultural land to *E. globulus* (O'Connell and Rance, 1999). However, reduction in mineralisation due to changes in organic matter quality and lower soil moisture content below the trees suggested a greater proportion of the soil N was immobilised into organic forms. Thus, the soil supply of N for plant growth will decline over time where plantations replace pastures (O'Connell and Rance, 1999). Retention of harvest residues is one option which will help prevent leaching of nitrate-N, improve surface soil moisture status and enhance N supply through mineralisation in the longer term (Aggangan *et al.*, 1999). Through retaining residues, the immobilisation of N in decomposing residues is promoted, providing a buffer against N loss through leaching (Aggangan *et al.*, 1999).

However, numerous studies observe a general decrease in the soil N below pine compared to an alternative landuse ranging from 8 to 35 % (e.g. Turner and Lambert, 1988; Giddens *et al.* 1997) (Table 2). Similar trends were evident for *E. globulus* (e.g. Michelsen *et al.*, 1996), but not depleted to the same extent. In some cases, no differences were attributed to the plantations of *E. globulus* (e.g. O'Connell and Rance, 1999). Depletion of soil N was possibly due to the removal of N fixing clovers and leaching of nitrate, due to enhanced nitrification during the early period of soil disturbance from planting. Retention of residue is an attractive option for preventing such losses (Grove *et al.*, 2001; O'Connell and Rance, 1999).

Table 2: Total soil N levels (%) for trees and an adjacent landuse, compiled from numerous studies.

Plantation Tree	**Soil N (%)**	**Comparison landuse**	**Soil N (%)**	**Difference (%)**	**Reference**
P. radiata	0.148	Eucalypt forest	0.225	- 34.2	Hamilton (1965)
P. radiata	0.09	Eucalypt forest	0.11	- 8.2	Turner and Lambert (1988)
P. radiata	0.269	Pasture	0.342	- 21.3	Giddens *et al.* (1997)
Pinus sp.	0.315	Grassland	0.41	- 23.2	Chen *et al.* (2000)
E. regnans	0.27	*P. radiata*	0.18	+ 33.3	Jurgensen *et al.* (1986)
E. globulus	0.4	Natural forest	0.68	- 41.2	Michelsen *et al.* (1996)
E. globulus	0.27	Pasture	0.27	0	O'Connell and Rance, 1999)

Nutrient removal and replacement costs in short-rotation eucalypt plantations were the subject of a study by Wise and Pittman (1981). Removal of nutrients (and hence replacement costs) were found to be dependent on the species and the harvesting regime. The leaves and bark of ten-year old short-rotation plantations collectively accounted for 18% of the total tree nutrients. Thus, harvesting and removing the total tree caused a disproportionate increase in nutrient removals over that from harvesting stemwood only (Wise and Pittman, 1981). During the inter-rotation period, fertilizers are required to restore the loss of nutrients required by the following tree crop. The cost of nutrient replacement for short-rotations of various eucalypts appears to be 5-6 % of the total production cost (Wise and Pittman, 1981).

Following the afforestation of pasture to pine in New Zealand, concentrations of total Phosphorus (P) and organic forms of P were lower under the pines, while concentrations of inorganic P were higher (Davis, 1995; Chen *et al.*, 2000). Such a decrease in labile forms of organic P, is evidence that conifers can take up such forms of P, which is consistent with ^{31}P labelling studies demonstrating how both orthophosphate and diester molecules decreased under recently established conifers in comparison to grasslands (Condron *et al.*, 1996). Elevated levels of inorganic P under the pines imply an increase in mineralization of organic P in the soil. Organic P mineralisation may occur through a combination of decomposition of organic matter by micro-organisms and biochemical mineralisation catalayzed by extracellular phosphatase enzymes (Chen *et al.*, 2000). However, the apparent increase in mineralisation in the forest soil is inconsistent with findings of lower microbial and phosphatase enzymes, particularly during the early stages of stand development. The decrease in soil pH under pines might enhance the solubility of organic P and increase its susceptibility to microbial attack and enzyme hydrolysis (Yeates *et al.*, 2000).

In a paired *E. globulus* plantation – pasture study measuring the effect of trees on soil fertility across 18 sites in south-west Australia, concentrations of total and extractable forms of P were generally lower in plantation soil than in pasture soils (Grove *et al.*, 2001). In the 0-10 cm fraction, pasture soils had on average 45 kg ha^{-1} more total P than plantation soils. Considering the age differences between plantations, this equated to an induced difference of 5.3 kg P ha^{-1} $year^{-1}$ by the trees. Estimated annual application of P on the pasture sites averaged 15 kg ha^{-1}. The low recovery of applied P may be attributed to leaching losses which would be greatest on the soils of lowest buffering for P (Grove *et al.*, 2001).

Data from the 18 paired *E. globulus* plantation – pasture sites indicate exchangeable Potassium (K) levels to be 0.03 cmol kg^{-1} higher under plantation (0.19) than under pasture (0.16). The plantations were fenced to exclude livestock (Grove *et al.*, 2001). Given that K had been applied to some 2/3 of the pastures it was evident various processes were responsible for a trend to a higher K under the plantation. It was proposed that there was a reduced potential for leaching, due to a greater interception of rain by the tree canopy and deep root system. In addition, it was probable that significant amounts of K were recycled in litterfall (Parfitt *et al.*, 1997). In pastures, soil K levels have the potential to exhibit a high degree of spatial variability as the K status is boosted by nutrient deposition from dung/urine of grazing livestock (Hawke and Gillingham, 1996). For example, adjacent to *P. radiata* shelterbelts in New Zealand, soil K was highest next to shelterbelts where stock had been camping, but still tended to show an increasing trend with distance from the shelterbelt up to 120 m (Hawke and Gillingham, 1996).

Evidence for changes in soil Sulphur (S) status and other elements when agricultural land is converted to plantations is scant in the scientific literature. Among other nutrients, Merino and Edeso (1999) measured changes in soil S when *P. radiata* trees were harvested and various residue management options implemented, and four years following harvest. Four years after harvest where there was substantial soil disturbance and the total S decreased. This was not attributed to the residue management options, including stem only harvested, whole-tree harvested and whole-tree harvested and ploughing. It was suggested that (sulphate) SO_4^{2-} leaching took place over the course of the four years, explaining the decrease in soil S levels (Merino and Edeso, 1996). Thus, S has a tendency to oxidize readily into SO_4^{2-}, become mobile and leach away.

Project objectives

Evidence from the scientific literature suggests disparate findings in regard to acidification below eucalypts, with some studies (e.g. Noble and Randall, 1998) revealing acidification below eucalypts and others (e.g. Grove *et al.*, 2001) documenting no change in pH between pasture and eucalypt plantations. Most studies however agree on the depletion of total pools of major nutrients such and N and P. In light of these findings, a project was established to measure the extent of changes in soil pH, soil total N, available P, available K and available S in the 0-10 cm soil layer when plantation grown *E. globulus* is planted on ex-agricultural land in the medium to high rainfall region of south-west Western Australia.

Previously documented soil changes, particularly a decrease in pH levels below belt planted *E. globulus* (Sanford *et al.*, 2001) warranted further investigation to reveal the extent of the changes and prompted heightened interest in the implications of soil changes beneath tree belts and adjoining pasture for landuse following tree harvest. Thus, project objectives that will be addressed are as follows.

- To determine the extent of changes in pH, total Nitrogen, available Phosphorus, available Potassium and available Sulphur when land previously used for agricultural purposes (i.e. grazing and cropping) is converted to *E. globulus* plantations.
- To propose implications for landuse following tree harvest, such as amelioration requirements to convert land back to profitable agricultural production

In addition, site affects that could be potentially confounding to the nature of soil change below eucalypts will be addressed. Such factors mainly include tree age, textural characteristics of the surface soil and the annual rainfall of the site.

MATERIALS AND METHODS

Fieldwork

Soil samples were collected from 11 sites across the medium to high rainfall zone of south-west Australia (Table 3). A pogo stick with a sample bag attached was used to collect approximately 30 bulked samples approximately 0.5 kg in weight, from the 0-10 cm depth between the middle two rows of belt-planted *E. globulus* and then along a gradient into adjacent pasture used for livestock grazing. Samples were collected in the zone 0-10 m from the belt, 10-20 m from the belt, 20-30 m from the belt, 30-50 m from the belt and 100 m and 150 m from the belt. At site 1, there was no sample collected 100 m from the belt. If the belts were closer than 300 m apart, no sample was taken 150 m from the belt and if belts were closer than 200 m apart, both the 100 and 150 m samples were not taken. Sampling took place in January 2000 for site 1 and in January 2001 for sites 2 to 11.

Table 3: Site characteristics of the 11 sites from which soil samples were taken beneath *E. globulus* and adjacent pasture in January 2000 or 2001 in south-west Australia (adapted from Albertson *et al.*, 2000)

Site	Location	Rainfall Mean (96-98)	Soil texture (0-10 cm)	Tree age in 2001 (years)	No. of rows in belt	Direction of belt from pasture
1	Albany	773	Fine sand	7	11	East/West
2	Napier	659	Fine sand	10	8	South
3	Redmond	775	Loamy sand	10	10	North
4	Marbellup	775	Sandy loam	6	14	North
5	Yellanup	664	Fine sand	9	10	East
6	Manurup	548	Sandy loam	9	12	West
7	Manurup	548	Sandy loam	9	12	North
8	Manurup	548	Clayey sand	9	13	East
9	Perillup	463	Loamy sand	11	15	North
10	Kendenup	463	Loamy sand	8	10	East
11	Kendenup	463	Loamy sand	8	10	West

Previous management of tree belts and adjoining pasture

Previous management at each site in terms of nutrients applied by the land manager in the form of fertilizer and ameliorant (e.g. lime) are summarised below (Table 4). All of the sites were utilised for livestock production, with Subteranneum Clover (*Trifolium subterraneum* L.) the dominant pasture species. The pasture at site 5 also contained Kikuyu (*Penniesetum clandestinum*) as a summer active grass. In addition to grazing, the paddock adjoining the tree belt at site 2 was used for cropping, with Triticale planted in 1998 and 2000, and Lupins planted in 1999. At site 7, Wheat was planted in the paddock adjoining the trees in 1998 and Canola was planted in 1999.

Table 4: Total quantities of nutrients (kg/ha) applied to the paddocks adjoining the tree belts in fertilizer and Lime or Dolomite (t/ha) by the land managers at each of the 11 sites studied in south-west Australia. Total applications were from when the trees were planted to January 2001.

Site	Nitrogen applied (kg/ha)	Phosphorus applied (kg/ha)	Potassium applied (kg/ha)	Sulphur applied (kg/ha)	Lime applied (total t/ha)
1	0	73.4	125.4	92.5	0
2	32.1	98.5	199.5	75.6	1 t
3	75.6	79.2	210.3	161.4	1.4 t
4	165.6	219.6	352.5	192	2.5 t (lime) 1 t (dolomite)
5	0	107.3	175.9	134.8	0
6	0	77.8	0	98.3	0
7	0	77.8	0	98.3	0
8	0	77.8	0	98.3	0
9	0	100.1	0	126.5	0
10	0	110.2	0	128.8	0
11	0	110.2	0	128.8	0

Following the fertilizer pellets applied during planting by a local tree company, fertilization of the *E. globulus* was the responsibility of the land managers, except for sites 4, 10 and 11 where the fertilization was done under an agreement with the company (Table 5). All sites received granulated pellets containing N and K and sometimes P, when the trees were planted.

Table 5: Total quantities of nutrients (kg/ha) applied to the soil under the belt grown *E. globulus* at each of the 11 sites sampled in January 2001 or 2002 across south-west Australia. Values are expressed as total kg/ha applied from when the trees were planted to January 2001.

Site	Nitrogen applied (kg/ha)	Phosphorus applied (kg/ha)	Potassium applied (kg/ha)	Sulphur applied (kg/ha)	Lime applied (t/ha)
1	11.6	4.2	7.7	0	0
2	64.1	27	7.7	51	0
3	11.6	4.2	7.7	0	0
4	117	44.8	70.3	34	0
5	11.6	4.2	7.7	0	0
6	45	4.8	6.3	34	0
7	45	4.8	6.3	34	0
8	45	4.8	6.3	34	0
9	11.6	4.2	7.7	0	0
10	27.5	7.6	6.3	17	0
11	27.5	7.6	6.3	17	0

Analysis of soil samples

After collection, soil samples were sieved through a 2 mm sieve and then oven dried at 104 °C. Soil pH was measured at 25 °C using a glass/calomel electrode on a suspension of 7 g soil and 35 mL deionized water that had been shaken for one hour, followed by the addition of 0.35 mL of 1M $CaCl_2$ with further shaking for one hour. Electrical conductivity was measured on the soil: water extract before the addition of 1M $CaCl_2$ using an instrument with a built in temperature compensation set at 2.1 % per degree celcius.

To measure total N (%), up to 1 g of soil was ground to < 0.15 mm, was digested by the Kjeldahl method using a copper catalyst and block digestion. The ammonia formed was measured by automated colorimetry using the salicylate-chlorine reaction of Reardon *et al.*, (1996). Available P was measured using an extract in 0.5 M $NaHCO_3$. Soil (1 g) was shaken for 16 hours at 23 °C with 100 mL of 0.5 M $NaHCO_3$ at pH 8.5 (Colwell, 1963). Phosphate was determined by automated colorimetry (Murphy and Riley, 1962). Similarly, available K was also measured using an extract in 0.5 M $NaHCO_3$. Soil available K was determined on the 1:100 extract used for the analysis of available P using atomic absorption spectroscopy with in-line neutralization of the bicarbonate extract (Jeffery, 1982). To measure available S, 3 g of soil was mixed with 20 mL of 0.25 M KCl and incubated at 40 °C for 3 hours. Measurement of S in the extract was performed using inductively coupled plasma atomic emission spectrometry (ICPAES) (Blair *et al.*, 1991).

Analysis of data

As soil pH and nutrient levels were measured on a bulk sample at each distance, the results could only be used to indicate general soil pH and nutrient levels or trends. Soil pH and nutrient levels were plotted for each site on a bar graph to reveal any underlying trends. Additionally, the effects of rainfall, soil texture and tree age were used in a multi-site analysis to determine if these factors had any bearing on soil pH and status of major nutrients in the 0-10 cm soil layer. Rates of change for soil pH and total N over the five year period since 1996 were also determined. Values for 1996 soil pH and total N were taken from Albertson *et al.* (2001) who adopted a similar sampling protocol. As the Olsen test of available P was used by Albertson *et al.* (2001) and the Colwell method used in this study a linear regression was used to estimate the Colwell equivalent from the 1996 Olsen measurement (Equation 1). The regression was taken from McCaskill (1999) which compared Olsen and Colwell topsoil (0-10 cm) samples across a range of sites over southern Australia, achieving a correlation coefficient of 0.91.

$$\text{Colwell P (mg/kg)} = \text{Olsen P (mg/kg)} \times 2.3998 \qquad [1]$$

RESULTS

Gradients of soil pH and major nutrients across 11 sites

No discernable trends were evident in the electrical conductivity data, and they are not presented. Soil pH under the trees was lower compared to the pasture at all sites, except 3 and 9 (Figure 1). In the case of site 3 and 9, the lowest soil pH was in the 0-10 m pasture zone adjacent to the tree belt. Soil pH (0-10 cm) clearly increased with greater distance from the tree belts except at sites 5 and 11, where pH rose to a maximum of 5.0 at 10-20 m from the trees, then decreased until 150 m. The greatest drop in soil pH was associated with sites 1 and 2, with site 1 exhibiting a decrease from 5.0 in the 150 m zone to 4.0 under the tree belt. Site 2 exhibited a decrease from approximately 4.5 at 150 m to 3.5 underneath the tree belt.

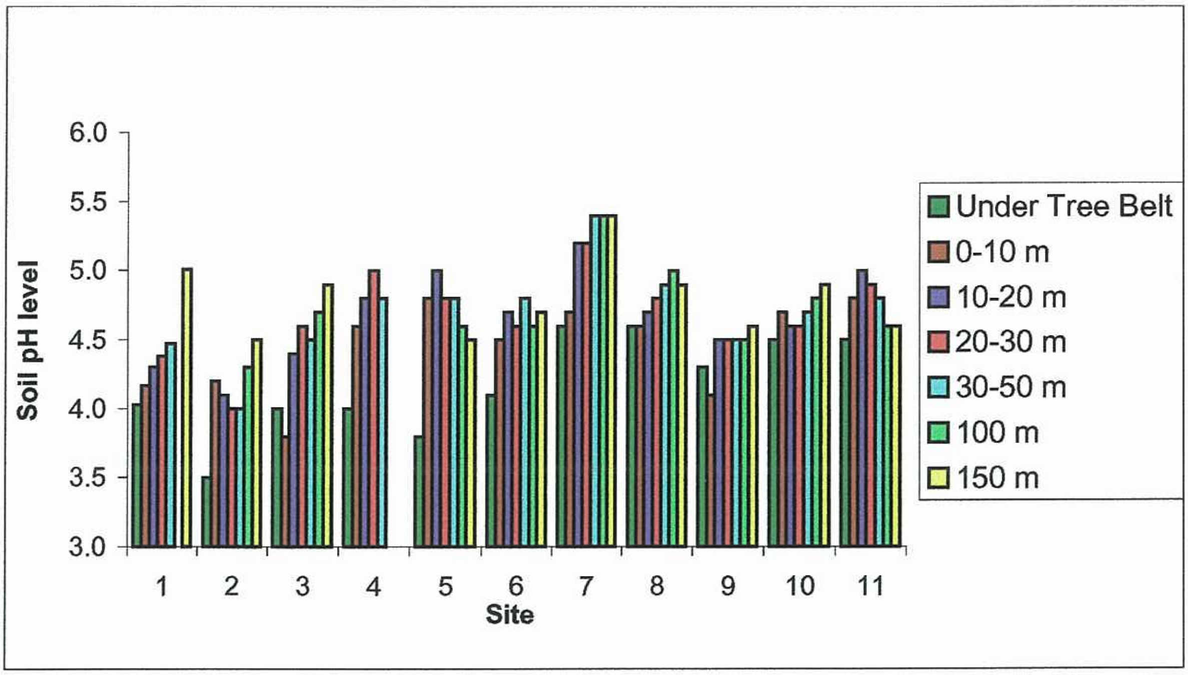

Figure 1: Soil pH (0-10 cm) below *E. globulus* tree belts and at various distances into adjoining pasture, across 11 sites in south-west Australia. Note that the 100 m interval wasn't sampled at site 1 and the 100 m and 150 m intervals are absent from site 4.

Soil N levels showed considerable spatial variation in distribution from the trees out into the pasture (Figure 2). Soil total N was lowest in the 0-10 cm fraction below the tree belt in the majority of sites (sites 1, 2, 3, 5, 6, 7, 8 and 9) and these sites also showed an increasing trend in soil N away from the belt. At site 11 samples taken between 100-150 m from the trees were most depleted in soil N, contrary to the trends at the majority of sites.

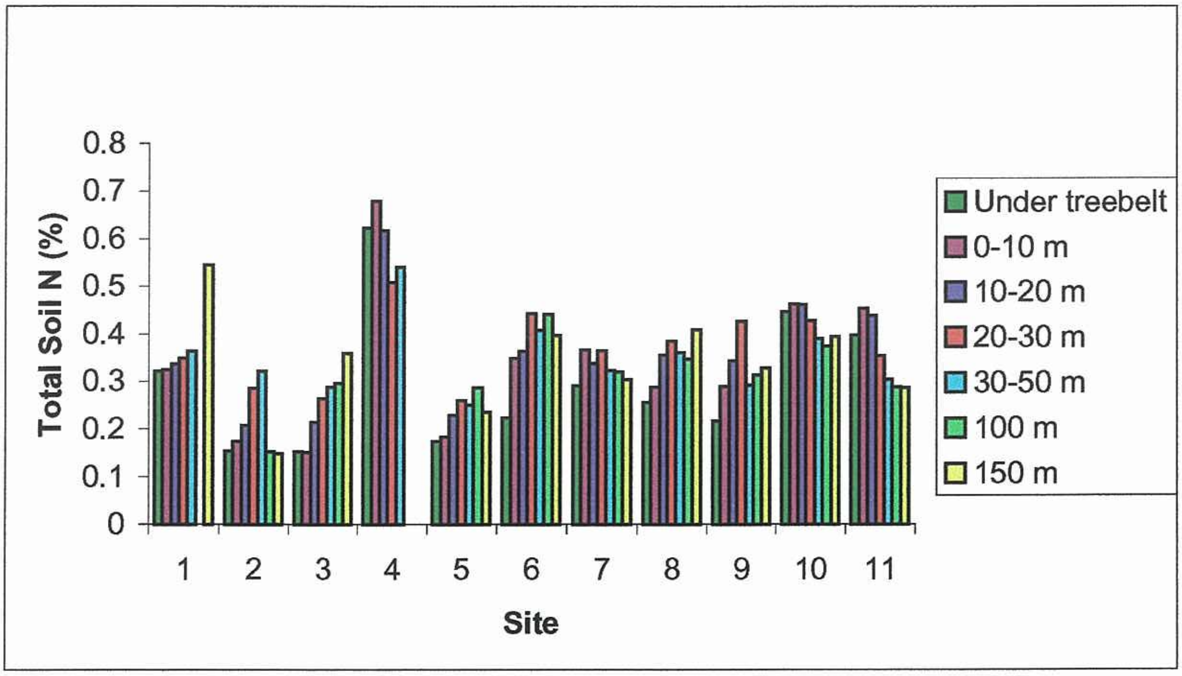

Figure 2: Soil total Nitrogen (%) (0-10 cm) below *E. globulus* tree belts and at various distances into the adjoining pasture, across 11 sites in south-west Australia. Note that the 100 m interval wasn't sampled at site 1 and that the 100 m and 150 m intervals are absent from site 4.

Trends in soil available P largely mirror results from the soil N distribution. Sites 1, 2, 3, 5, 6, 7 and 8 all displayed evidence suggesting soil P status was lowest directly below the belt or immediately adjacent to it and increasing further from the belt (Figure 3). The other sites displayed no trend in soil available P status due to the presence of the trees.

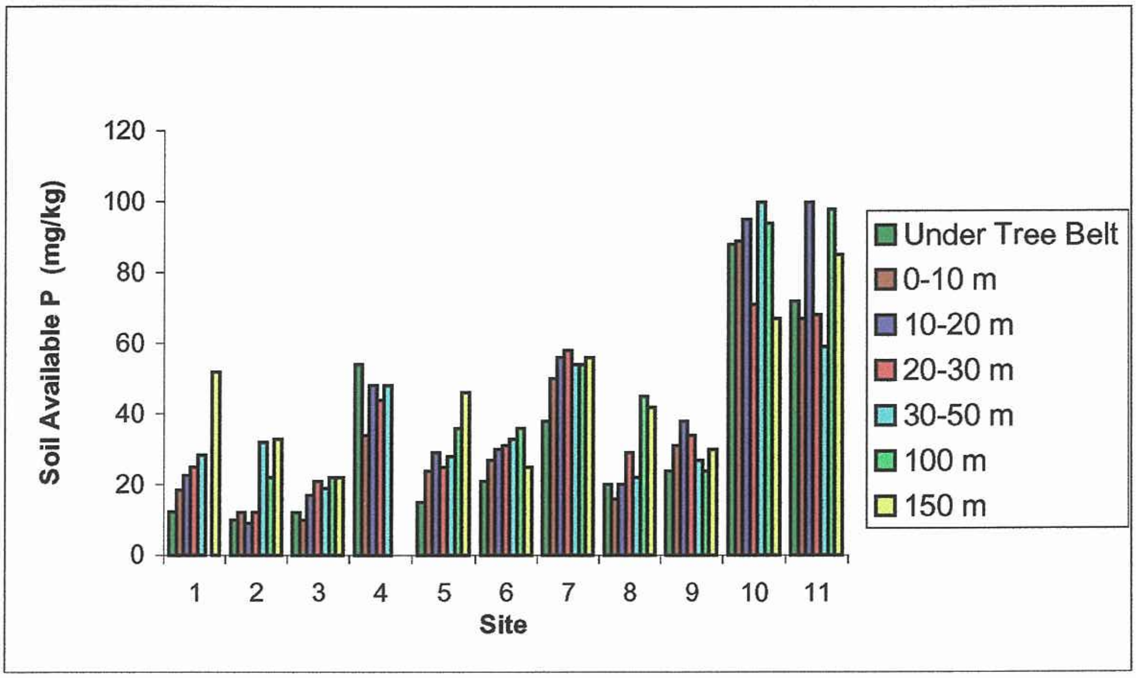

Figure 3: Soil available P (mg/kg) (0-10 cm) below *E. globulus* tree belts and at various distances into the adjoining pasture across 11 sites in south-west Australia. Note that the 100 m interval wasn't sampled at site 1 and that the 100 m and 150 m intervals are absent from site 4.

At all sites Soil available K was higher beneath the pasture compared to the tree belt (Figure 4). However, K levels were only consistently lower beneath the trees at 4 sites (3, 4, 5 and 6). Considerable variation existed in soil available K both within sites as well as between sites. For example, sites 10 and 11 had considerably greater K levels than the other sites across all sampling zones. Furthermore, site 11 has an excessively high K level of 590 mg/kg at the 10-20 m zone, compared to 300 mg/kg in the 0-10 m zone and 270 in the 10-20 m zone.

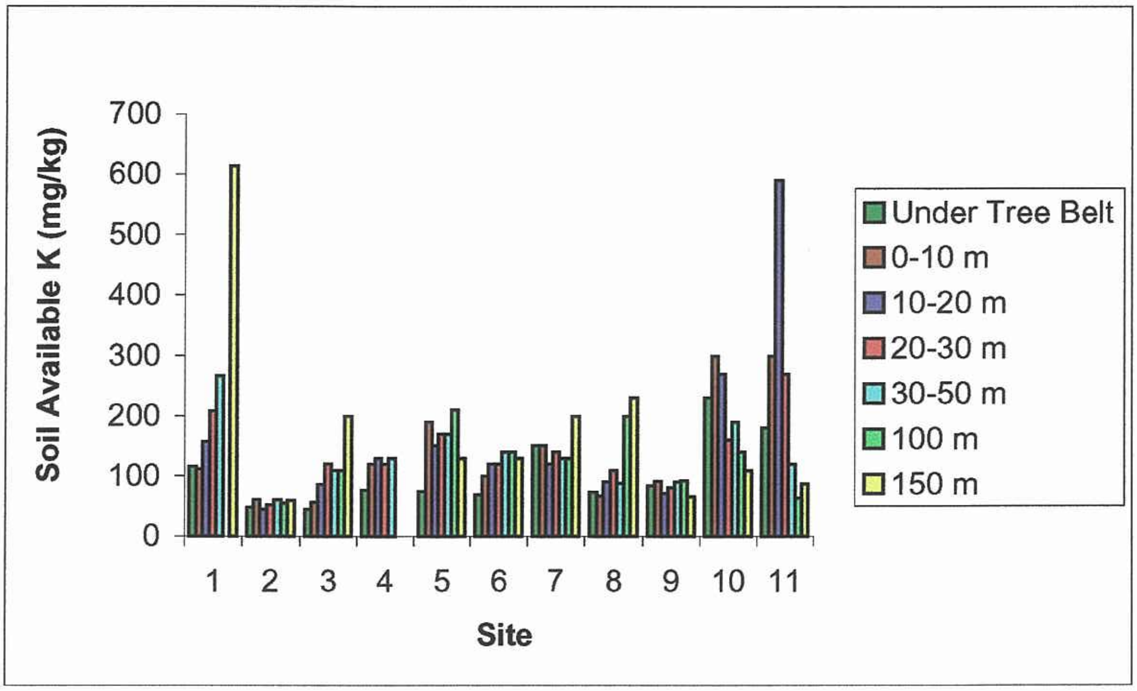

Figure 4: Soil available K (mg/kg) (0-10 cm) under *E. globulus* tree belts and at various distances into the adjoining pasture across 11 sites in south-west Australia. Note that the 100 m interval wasn't sampled at site 1 and the 100 m and 150 m intervals weren't sampled at site 4.

Results for soil available S levels reported less confident trends, as there was variation in soil available S at the majority of sites (Figure 5). However, sites 3, 4 and to a lesser extent 5 revealed an increase in soil available S with increasing proximity from the tree belt into the pasture. Site 4 was unique in that S levels reach 60 mg/kg in the 30-50 m zone, regarded as the control for this site whereas the other sites averaged from 10-30 mg/kg soil available S levels. A strong gradient was also present with soil available S dropping rapidly to 19 mg/kg at the sampling point underneath the tree belt.

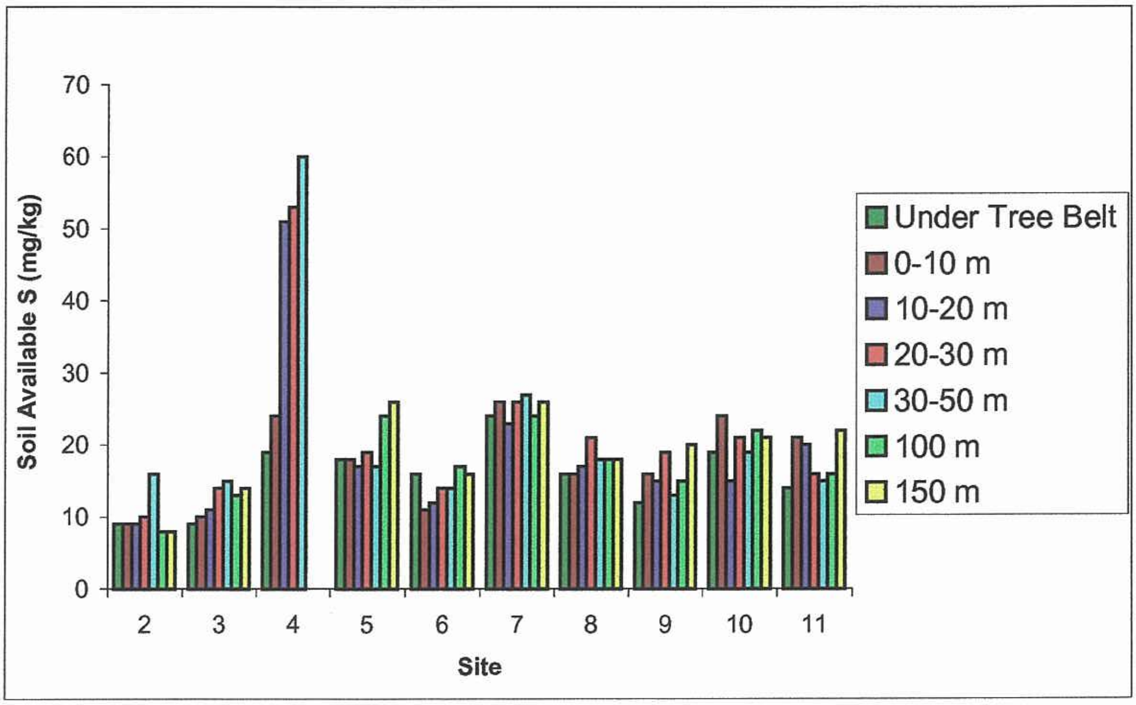

Figure 5: Soil available S levels (0-10 cm) below *E. globulus* tree belts and at various distances into the adjoining pasture across 10 sites in south-west Australia. Note that soil available S wasn't measured at site 1 and that the 100 m and 150 m intervals weren't measured at site 4.

Influence of surface soil texture, tree age and annual rainfall on soil pH and nutrients

Evidently, soil texture has an effect on soil pH (0-10 cm) under the pasture (150 m from trees), with soil pH ranging from 4.50 in fine sand to 4.96 in sandy loam (Figure 6). However, under tree belts, soil pH (0-10 cm) varies to a greater extent from 3.76 in fine sand to 4.6 in clayey sand. The data suggests there is no apparent effect of tree age on soil pH (0-10 cm) under trees or pasture (Figure 7). Likewise, rainfall has no discernable effect on soil pH (0-10 cm) under the pasture (R^2=0.01), however the relationship between rainfall and soil pH under trees is stronger (R^2=0.44) (Figure 8).

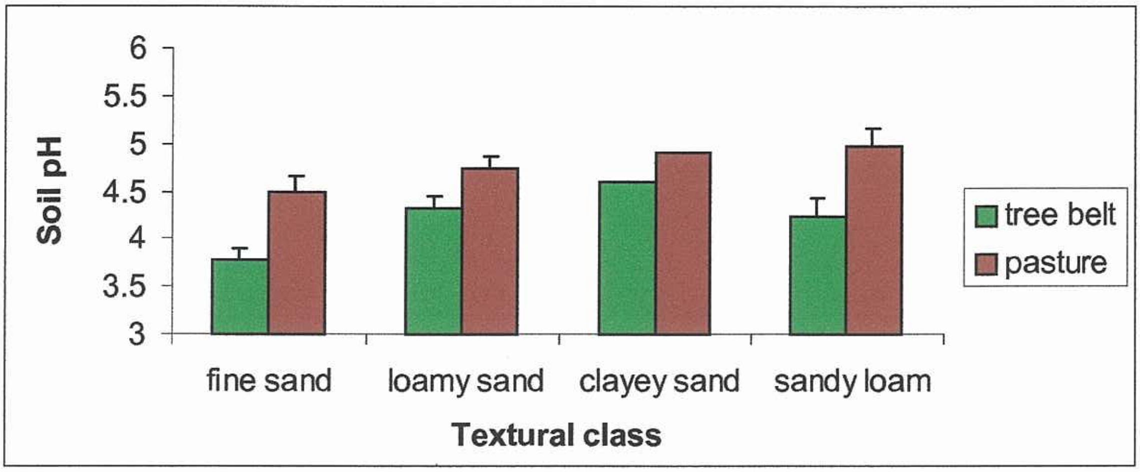

Figure 6: Influence of soil textural class (0-10 cm) on soil pH (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture at 11 sites in south-west Australia. Capped vertical bars denote standard error.

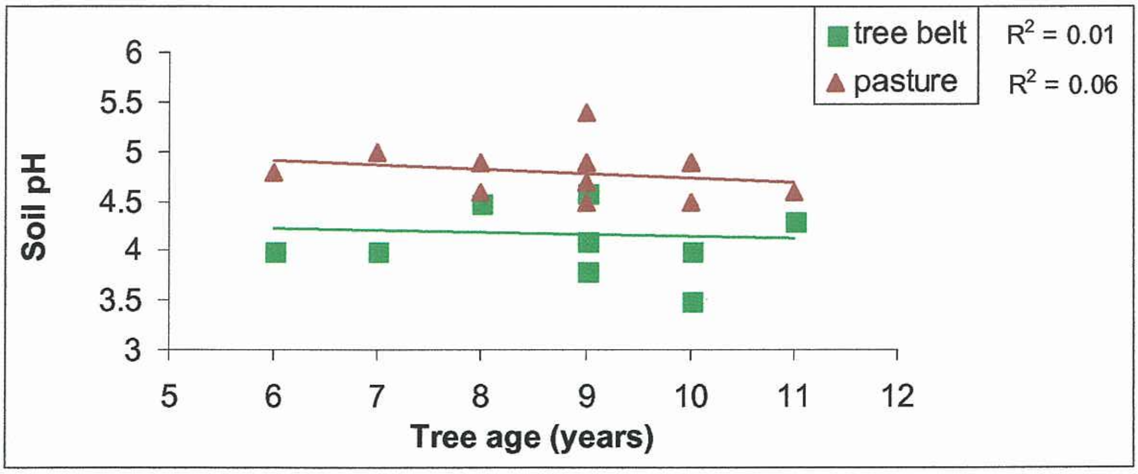

Figure 7: Influence of tree belt age on soil pH (0-10 cm) below *E. globulus* tree belts and adjacent pasture at 11 sites in south-west Australia.

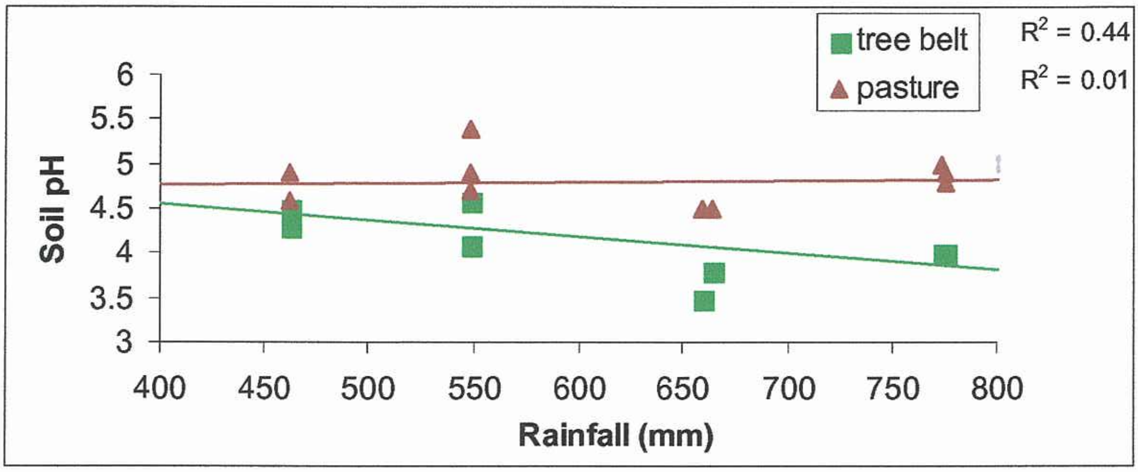

Figure 8: Influence of average annual rainfall on soil pH (0-10 cm) below *E. globulus* tree belts and adjacent pasture at 11 sites in south-west Australia.

Although there were only small differences between soil N below trees and pasture, sites characterized by a higher clay content in the surface soil (e.g. sandy loam) had a greater total N content than the sites with a fine sand (Figure 9). Soil total N levels declined as the tree belts became older (R^2=0.71) (Figure 10). There was also a correlation between tree age and soil N below the pasture, although not as strong (R^2=0.46). No correlation was apparent between average annual rainfall and soil total N (Figure 11).

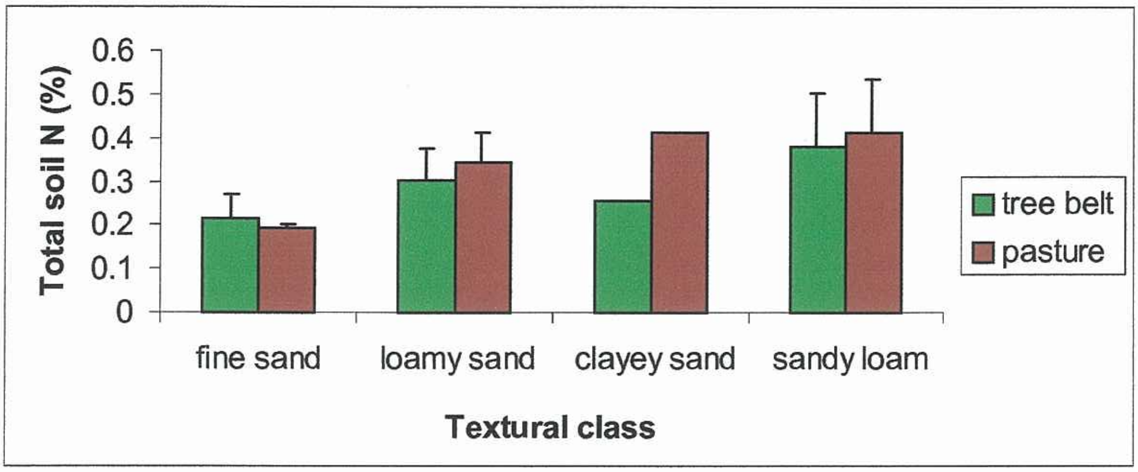

Figure 9: Influence of soil texture (0-10 cm) on total soil N (0-10 cm) (%) below *E. globulus* tree belts and adjacent pasture across 11 sites in south-west Australia. Capped vertical bars denote standard error.

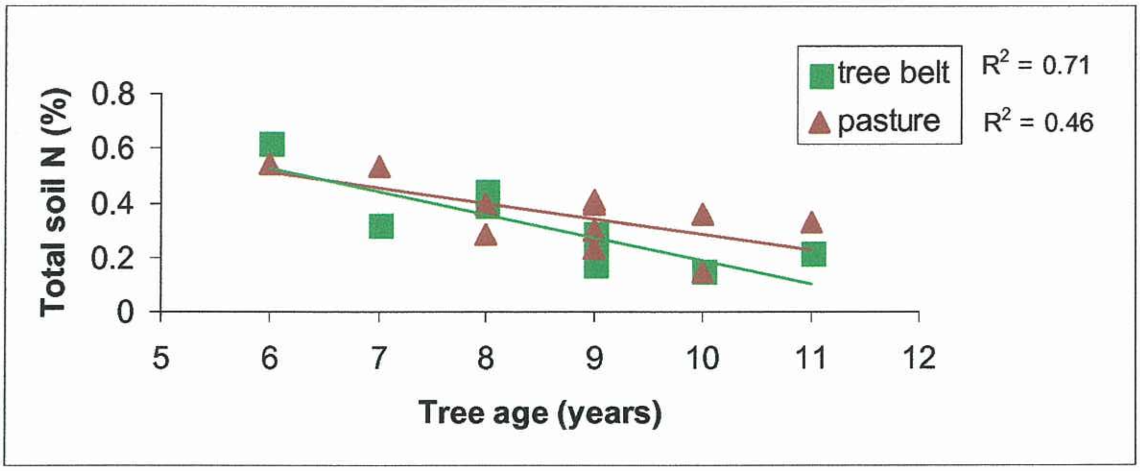

Figure 10: Influence of tree age on total soil N (0-10 cm) (%) beneath *E. globulus* tree belts and adjacent pasture across 11 sites in south-west Australia.

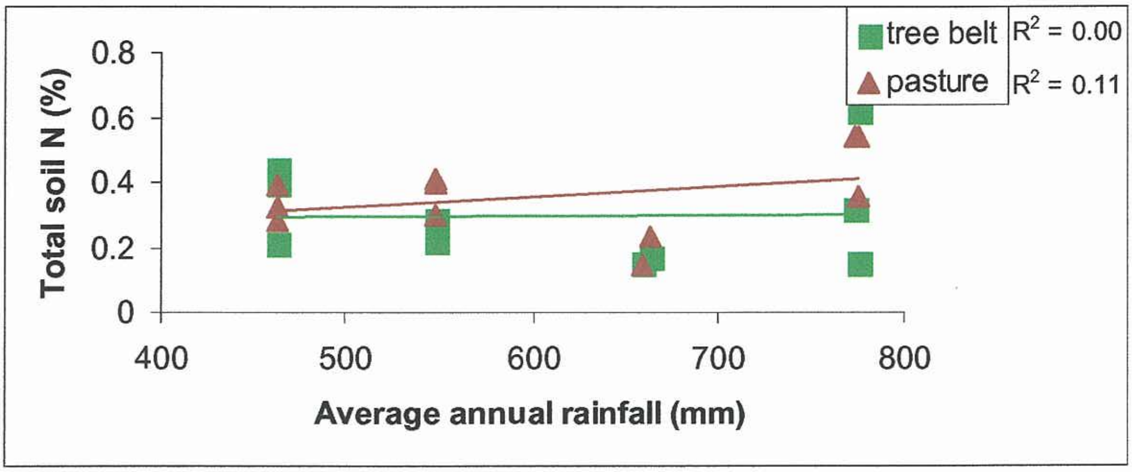

Figure 11: Influence of average annual rainfall on soil N (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 11 sites throughout south-west Australia.

Across the 11 sites that were sampled, there was no clear effect of surface soil texture on the soil available P levels (0-10 cm) (Figure 12). Soil under the pasture 150 m from the tree belt had a higher available P content than the soil under the tree belt at sites with a fine sand surface horizon. A similar trend was apparent for the clayey sand site however there was little difference for the other sites.

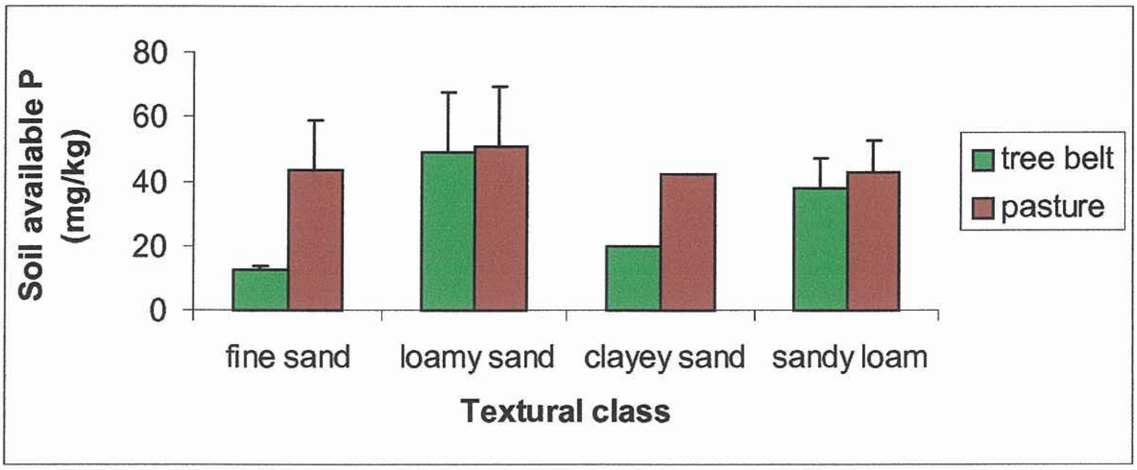

Figure 12: Influence of surface soil texture on soil available P levels (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 11 sites throughout south-west Australia. Capped vertical bars denote standard error.

No effect of tree age on soil available P levels in the surface soil were recorded, due to a scattered distribution of points when tree age was plotted against available P levels (Figure 13). The tree belt and pasture soil available P were similar at each site, except for site 1 (7 years old).

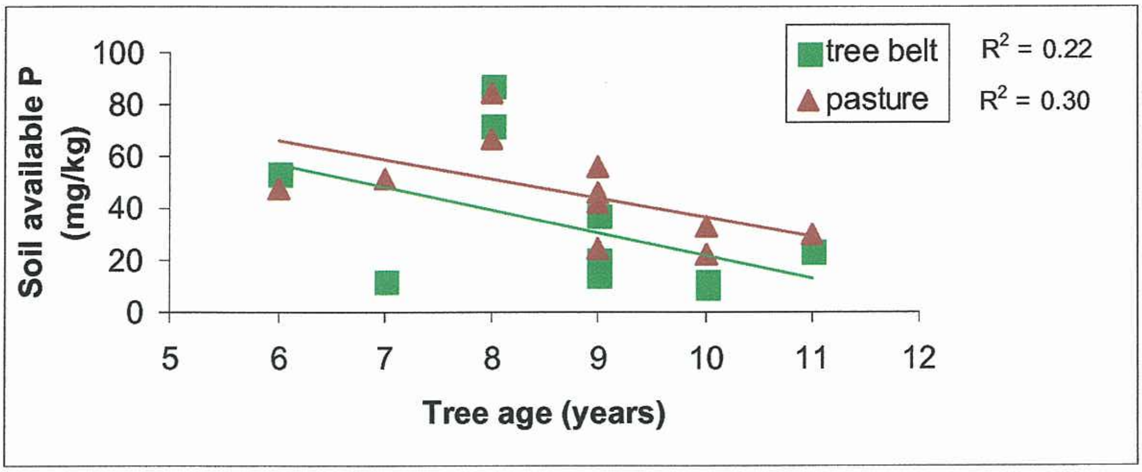

Figure 13: Influence of tree age on soil available P levels (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 11 sites throughout south-west Australia.

There was no relationship between average annual rainfall and soil available P levels, given the low R^2 values (Figure 14).

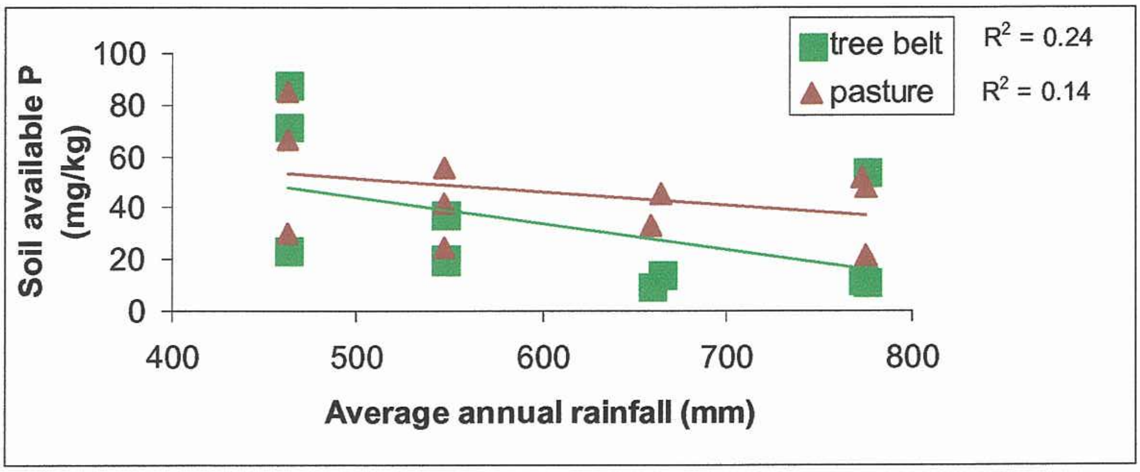

Figure 14: Influence of annual rainfall on soil available P (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 11 sites throughout south-west Australia.

As for P, there was no strong evidence of an effect of soil texture on available K in the surface soil layer (Figure 15). A large standard error associated with the pasture soil K measurements from the 3 fine sand sites indicated large variation between replicates. However, the fine sand, clayey sand and sandy loam sites hinted that soil K tended to be lower under the trees.

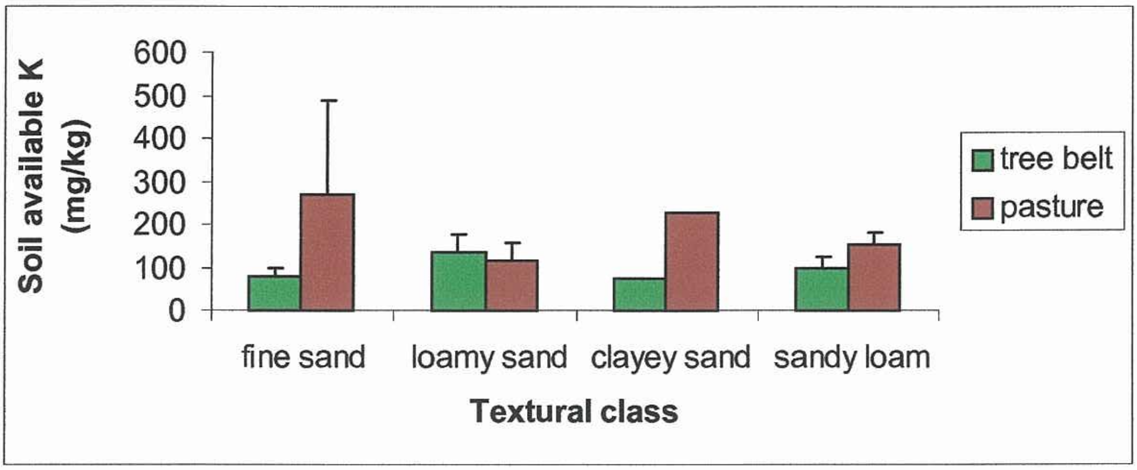

Figure 15: Influence of soil texture (0-10 cm) on available soil K (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 11 sites throughout south-west Australia. Capped vertical bars denote standard error.

Plotting tree age against soil available K in the surface soil below the tree belt and pasture revealed no clear positive trends (Figure 16). Soil available K tended to remain at similar levels between sites, regardless of tree age. The only exception was a substantial difference between soil available K below trees (7 years old) and pasture at site 1, compared to the other 10 sites.

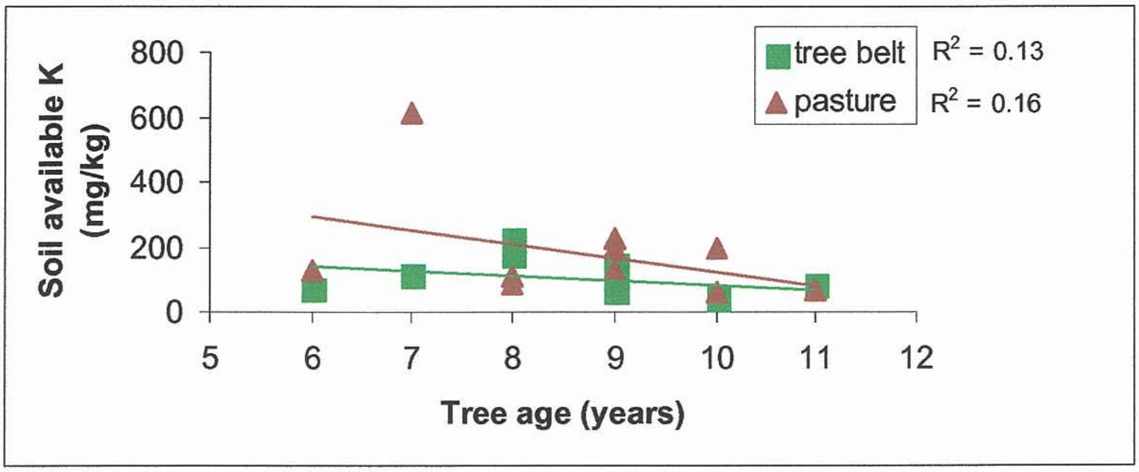

Figure 16: Influence of tree age on soil available K (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 11 sites in south-west Australia.

There was no apparent relationship between average annual rainfall and soil available K (0-10 cm) beneath trees and pasture (Figure 17).

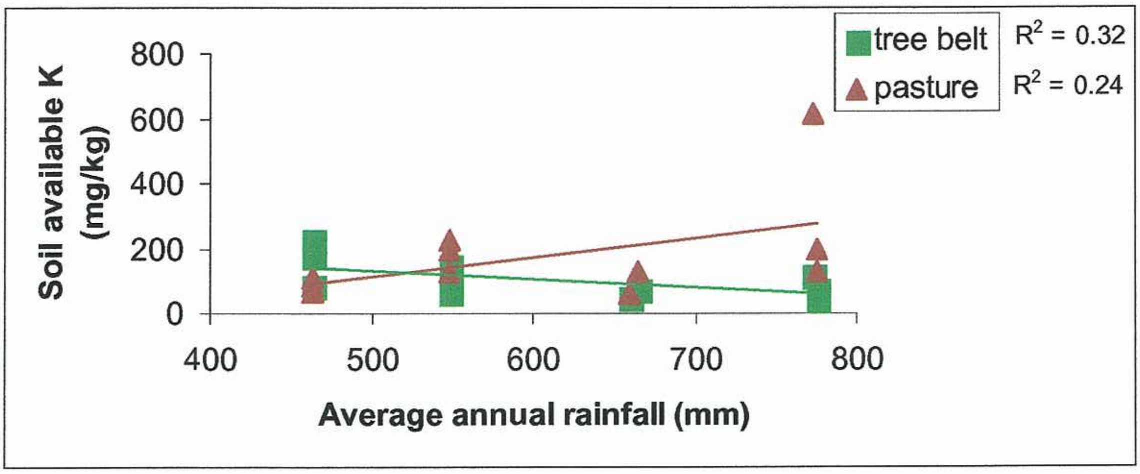

Figure 17: Influence 1996-1998 average annual rainfall on available soil K levels (0-10 cm) beneath *E. globulus* tree belts and adjoining pasture across 11 sites throughout south-west Australia.

Unlike previous nutrients (e.g. available P and available K) there was a semblance of a relationship between soil texture (0-10 cm) and available S levels (Figure 18). Available sulphur levels under pasture were marginally greater than below tree belts for all the sand classes, while soil available S below the pasture was approximately 15 mg/kg greater than under trees for the sandy loam sites.

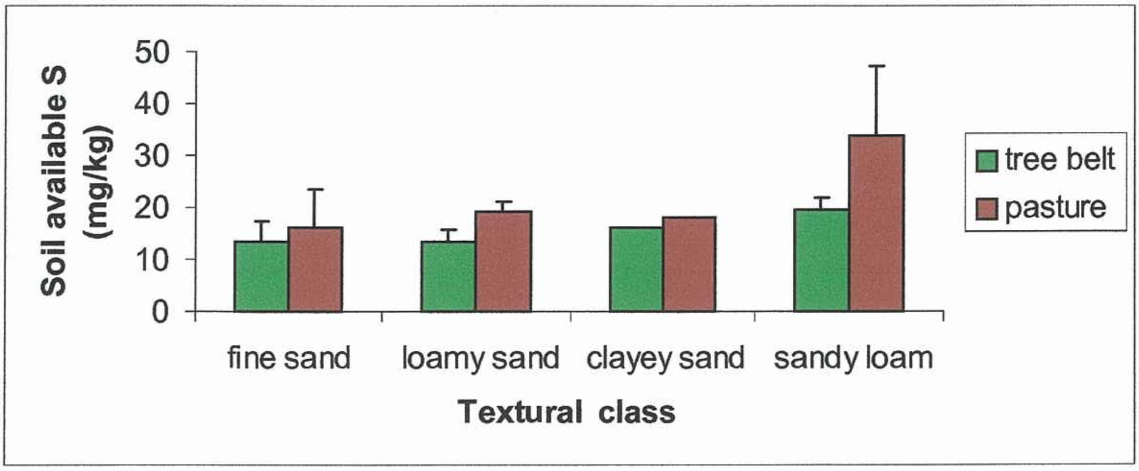

Figure 18: Influence of soil textural class (0-10 cm) on soil available S (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 10 sites in south-west Australia. Capped vertical bars denote standard error.

The multi-site analysis of the effect of tree age on soil available S revealed that a moderate relationship (R^2=0.63) existed between tree age and soil available S below the pasture, with soil available S declining as the tree age increased (Figure 19). The same relationship for the tree belt was weak (R^2=0.31) and the decline was slower.

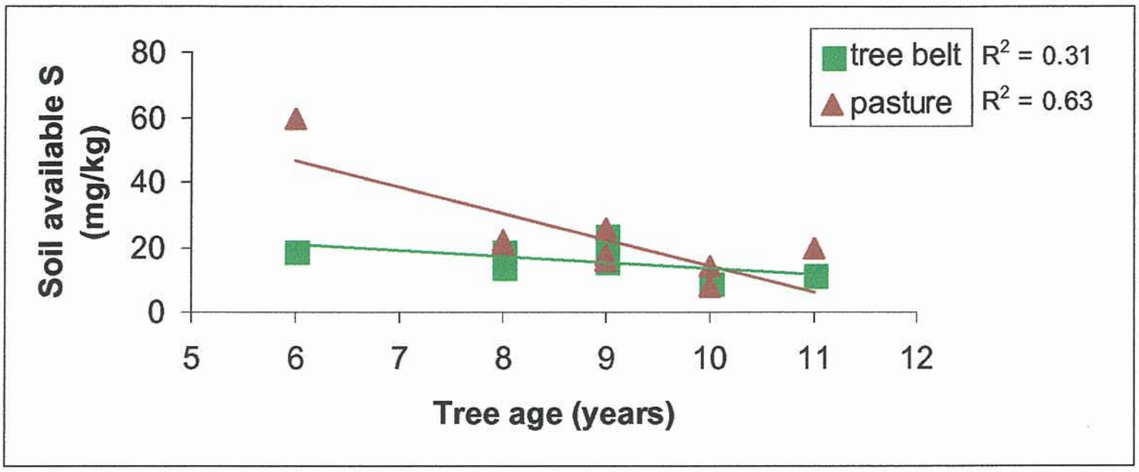

Figure 19: Influence of tree age on soil available S (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 10 sites in south-west Australia.

There was no reliable relationship between annual rainfall and soil available S (0-10 cm) (Figure 20). There was an increasing trend of soil available S as rainfall increased below pasture, although the relationship was extremely weak (R^2=0.13) and no relationship was evident below the trees.

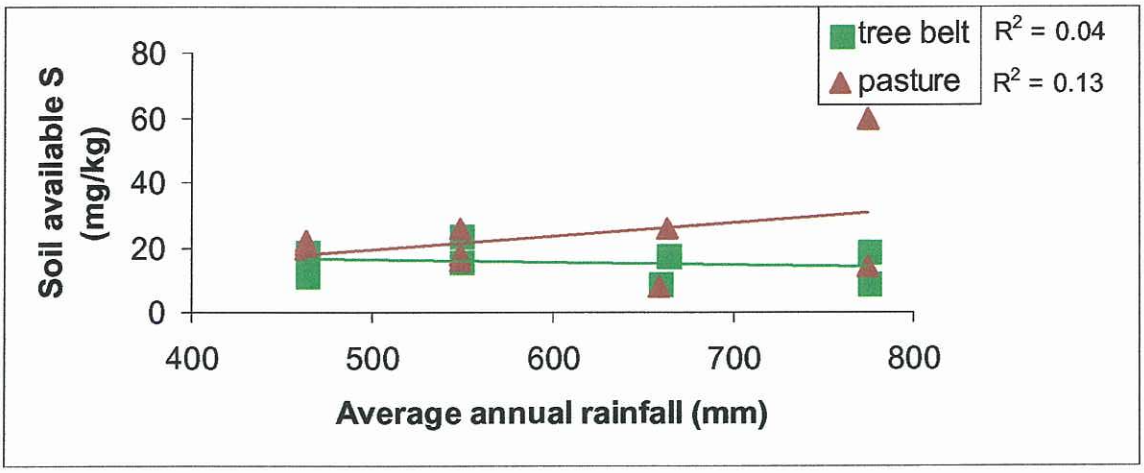

Figure 20: Influence on average annual rainfall on soil available S (0-10 cm) beneath *E. globulus* tree belts and adjacent pasture across 10 sites in south-west Australia.

Rates of change of pH, Nitrogen and Phosphorus in soil from 1996 to 2001 below the tree belts

Measurements of soil pH below the tree belts in eight of the 9 sites showed acidification of the surface soil (0-10 cm) from 1996 to 2001 (Table 6). Rates of acidification varied from 0.01 pH unit/year (site 2) to 0.2 pH unit/year (site 10).

Table 6: Changes in soil pH (0-10 cm) below *E. globulus* tree belts from 1996 to 2001 across 9 sites in south-west Australia. Note that 1996 measurements weren't taken for site 1 and data from site 5 was omitted due to sampling error.

Site	1996 pH ($CaCl_2$)	2001 pH ($CaCl_2$)	Change in pH	Change in pH per year
1	-	-	-	-
2	3.56	3.50	-0.06	-0.01
3	4.39	4.00	-0.39	-0.08
4	4.28	4.00	-0.28	-0.06
5	-	-	-	-
6	4.78	4.10	-0.68	-0.14
7	5.41	4.60	-0.81	-0.16
8	5.28	4.60	-0.68	-0.14
9	4.11	4.30	0.19	0.04
10	5.49	4.50	-0.99	-0.20
11	5.07	4.50	-0.57	-0.11

Declines in total soil N were recorded in 5 out of the 9 sites sampled, ranging from 0.01 % (e.g. Site 3) to 0.07 % (e.g. Site 11) (Table 7). Two of the remaining sites exhibited an increase in total soil N below the trees, site 4 an increase of 0.22 % and site 10 an increase of 0.04 %.

Table 7: Changes total soil N (0-10 cm) below *E. globulus* tree belts from 1996 to 2001 across 9 sites in south-west Australia. Note that 1996 measurements weren't taken for site 1 and data from site 5 was omitted due to sampling error.

Site	1996 Total Soil N (%)	2001 Total Soil N (%)	Change in Total Soil N (%)	Change in N per year (%)
1	-	-	-	-
2	0.11	0.15	+0.04	+0.01
3	0.16	0.15	-0.01	0
4	0.4	0.62	+0.22	+0.04
5	-	-	-	-
6	0.28	0.22	-0.06	-0.01
7	0.34	0.29	-0.05	-0.01
8	0.26	0.26	0	0
9	0.26	0.22	-0.04	-0.01
10	0.41	0.45	+0.04	+0.01
11	0.47	0.40	-0.07	-0.01

Five out of 9 sites sampled showed varying degrees of an increase in soil available P (Table 8). For example, at site 3 there was an increase in 3 mg/kg of available P and at site 4 there was an increase in 27 mg/kg. Losses in available P ranged considerably from 5 mg/kg (sites 6 and 9) to 34 mg/kg (site 10).

Table 8: Changes in soil available P (0-10 cm) below *E. globulus* tree belts from 1996 to 2001 across 9 sites in south-west Australia. Note that 1996 measurements weren't taken for site 1 and data from site 5 was omitted due to sampling error.

Site	1996 Soil available P (mg/kg)	2001 Soil available P (mg/kg)	Change in P (mg/kg)	Change in P per year (mg/kg)
1	-	-	-	-
2	7	10	+3	+0.7
3	2	12	+10	+2.0
4	27	54	+27	+5.3
5	-	-	-	-
6	26	21	-5	-1.0
7	30	38	+8	+1.6
8	16	20	+4	+0.8
9	29	24	-5	-0.1
10	122	88	-34	-6.8
11	80	72	-8	-1.6

DISCUSSION

Soil pH under beneath tree belts and adjoining pasture

Soil pH was lower in the soil below *E. globulus*, compared to the adjacent pastures across all sites to varying degrees, indicating that the rate of soil acidification beneath the trees was more rapid than that below pasture. Assuming that soil pH was similar across each site prior to planting trees it is reasonable to attribute the decline in soil pH to the trees. Soil pH also decreases in the pasture in the proximity of the tree belt at the majority of sites, therefore it is likely that the processes leading to acidification are present alongside the trees beneath the pasture. The finding of a lower surface soil pH under trees incorporated into pasture is supported by other studies incorporating eucalypts (Alexander, 1989; Rhoades and Binkley, 1996; Noble and Randall, 1998) and pines (Turner and Lambert, 1988; Chen *et al.*, 2000). However, other studies have revealed no drop in pH attributable to trees (Montagnini and Sancho, 1994; Grove *et al.*, 2001).

Soil pH values under *E. globulus* tended to be lower at sites receiving an annual rainfall in excess of 650 mm per year. This could partly be explained by greater leaching of anions such as NO_3^- due to excessive autumn and winter rainfall. Farm management can also explain the differences between trees and pasture. For example, lime was applied to the pasture at three sites but not to the soil below the trees.

During and immediately following the planting of trees it is likely that the demand for inorganic N was low. The wetting up of the soil following precipitation would have resulted in losses of NO_3^- below the root zone and soil acidification (Turner and Lambert, 1988; O'Connell and Rance, 1999). Nitrification is carried out by nitrifying bacteria, which consume ammonium ions (NH_4^+) and convert them to nitrate ions (NO_3^-) with Hydrogen ions (H^+) also released as a by-product. Nitrate ions are readily leached down the soil profile during rainfall events, resulting in an accumulation of H^+ in the surface soil solution and a subsequent decline in soil pH. One possible mechanism for enhanced acidification under the trees is a greater leaching of nitrate, due to higher nitrification rates attributed to greater substrate provided by ammonium, and the organic N pool. Aggangan *et al.* (1999) found an increase in organic N following the conversion of agricultural land to *E. globulus*, which would provide a greater substrate for mineralizing bacteria to work on providing conditions of soil moisture are conducive to the activity of soil microfauna.

An alternative cause of the decline in soil pH when *E. globulus* is planted on ex – agricultural land may arise from the nutrient uptake preference of *E. globulus*. Numerous studies documenting soil pH decline below pines and eucalypts (e.g. Prosser *et al.*, 1993; Parfitt *et al.*, 1997) partly attribute the cause of soil acidification to be an uptake and biomass storage of cations in excess of anions, resulting in H^+ release from the roots into the soil solution. Plants tend to actively absorb more positively charged nutrients (e.g. NH_4^+, Ca_2^+, Mg_2^+ and K^+) than negative charged nutrients (e.g. PO_4^{2-} and SO_4^{2-}) (Moore *et al.*, 1998). Studies conducted on pines growing on agricultural land in New Zealand have suggested a greater uptake of cations over anions to cause soil pH decline (Giddens *et al.*, 1997). Evidence for uptake of cations was provided by Grove *et al.* (2001), who found a depletion of Ca^{2+} ions under *E. globulus* relative to the adjacent pasture. Soil available K levels were depleted relative to adjoining pasture in all sites except one, suggesting a depletion of available K through tree uptake of K^+.

Organic matter deposition through litterfall (e.g. senesced leaves) constitutes a mechanism by which soil acidity is neutralized. Thus, literature on inter-rotation site management of eucalypt plantations (e.g. Aggangan *et al.*, 1999) recommend the retention of bark, leaf, stem and twig residues following the harvest of first rotation eucalypts. The oxidation of organic anions during decomposition of leaf material makes a major contribution to an increase in soil pH, through the consumption of H^+ ions in the soil solution (Noble *et al.,* 1996). Thus the prevention of the accumulation of leaf residue on the soil surface through wind, surface water flow or grazing may have partially contributed to the acidification of soil below *E. globulus* in this study.

The rate of acidification below *E. globulus* over five years ranged from 0.01 units/year to 0.2 units/year. This seems consistent with a decline of 0.1 pH units/year over eight years below *E. camuldulensis* (Rhoades and Binkley, 1996). Only one site recorded an increase in soil pH, by 0.04 units/year. Greatest rates of decline (>0.1 pH units/year) were confined to sites which were in a zone receiving less than 600 mm per year. These sites were not acidic in 1996 and were predisposed to higher rates of acidification.

Soil nutrients beneath tree belts and adjoining pasture

There was a general trend of decreasing total soil N from beneath the pasture to below the tree belt in all sites except three sites. As previously mentioned, the N cycle is intrinsically linked to acidification, through the process of nitrification and nitrate leaching. There is a possibility that greater leaching of nitrate under trees compared to the pasture may be a loss of N from the soil under trees, giving a lower total N. Alternatively, it is likely that the N demand of trees would be higher than the pasture due to a greater requirement for amino acids in tree biomass which is much higher than the biomass associated with pasture. The site that had the most fertilizer N applied to the tree belt also had the greatest soil N content below the trees. However, the amount of N applied was not always reflected in the soil N, potentially explained through loss of N from the leaching of nitrate. Rates of change of total N mostly varied by 0.01% or not at all for most sites. One site recorded an increase of 0.04 % from 1996 to 2001 under the trees, which was not surprising considering it had received the most N of all the sites (117 kg/ha).

Soil available P tended to be most depleted in soil (0-10 cm) under trees compared to the pasture at the majority of sites, reflecting uptake and biomass storage of P by the trees in the absence of replacement by fertilizer. One site didn't exhibit a trend of lower soil available P with closer proximity to the trees, with soil available P largely uniform across the transect, possibly attributed to the youth of the trees (6 years) or the P applied to the soil beneath the tree belt. Two sites had up to double the available P under trees than the other sites, despite having only 7.6 kg/ha of P applied to the soil under trees compared to 110.2 kg/ha of P applied to the adjoining pasture.

Soil conditions and management at the sites with approximately double the soil available P than the other sites may have been conducive to the decomposition of organic matter by micro-organisms and biochemical mineralisation, catalyzed by phosphatase enzymes (Chen *et al.*, 2000). Prior to planting, the organic matter content of the soil could have been high compared to the other sites, providing substrate for conversion of organic P to mineral P. Moreover, a greater solubilisation of phosphate due to a generally adequate pH range of 4.5-5.5, compared to more acidic soils may also partly explain a higher available P (Yeates *et al.*, 2000). Available P in the 20-30 m zone of both sites was lower than the tree belt P itself, possibly due to proliferation of lateral tree roots in this zone due to a dry soil profile under the tree belt. As the profile below the trees dries out, trees may rely more on water uptake from lateral roots that grow out into adjoining pasture. Rates of change in soil P were largely positive in wetter sites and negative in drier sites. Wetter sites could have been more conducive to mineralisation of organic matter into phosphate, hence the increases in soil available P.

Soil available K decline attributed to *E. globulus* was reported in the majority of the sites and is supported by New Zealand studies, where lower soil K levels have been found compared to pasture (Giddens et al., 1997). Previous work (Hawke *et al.*, 1999) has shown that changes in available K levels below pasture in tree – pasture systems, are largely due to animal camping, thus caution needs to be exercised in the interpretation of the results. It was likely that the available K levels of around 600 mg/kg reported at two sites was due to deposition of K in livestock droppings. Inter-site comparisons are confounded by livestock camping and fertilizer application. However, at two sites there was evidence that stock preferentially camped alongside the tree belt.

Depletion of soil available S below *E. globulus* tree belts compared to pasture was evident at five sites. The site which had the highest amount of fertilizer S applied also had the greatest soil S content. However, soil S is generally similar from the trees out into the pasture. Sites where there were no observable trends of a decrease in soil S due to the trees may have had a higher S mineralisation rate. The soil S status is known to depend on the organic matter content of the surface soil (Mason, 1998) as the supply rate of S is dictated by the rate of mineralisation of organic matter to sulphate (SO_4^{2-}). Soil disturbance (e.g. tillage) associated with ground disturbance during planting could have stimulated the rate of mineralisation, enhancing the inorganic SO_4^{2-} levels under trees and hence negating any depletion of soil S due to the trees (Mason, 1998).

Impact of soil texture, tree age and rainfall on soil fertility trends

Varying soil texture across the sites in part explained the extent of the changes in the soil pH and macronutrients below *E. globulus* tree belts and pasture. Generally, the largest difference in soil pH between trees and pasture was found on fine sandy soils compared to soils with a higher clay percentage. Light textured sandy soils would exacerbate acidification due to a lower pH buffering capacity and greater risk of nitrate leaching (Hills and Miller, 2000). Similarly, fine sands would be more conducive to nutrient leaching, which may partly explain a generally lower status of major nutrients below trees grown on these soil types. Sites with a greater percentage of clay in the topsoil, such as those with sandy loam topsoils would display a greater cation exchange capacity (Purdie, 1998), providing an enhanced ability to retain cations for uptake, however this was not reflected in the soil texture trends for soil K. However, the camping of stock may have disguised any trends in soil available K between the trees and pasture (Hawke *et al.*, 1999).

Tree age was found to explain 71% of the variation in total soil N below the tree belt and 63% of the variation in available soil S below pasture. While it seems reasonable that with increasing age, soil N is depleted below trees and soil S is depleted below pasture due to plant uptake, the weak relationships for the other nutrients suggest such regressions can't be used with confidence. The absence of relationships between annual rainfall and soil pH and macronutrient levels highlights that soil texture may be one of the primary site effects influencing soil pH and macronutrient levels.

Conclusions and implications for land use following harvest

In summary, the planting of *E. globulus* at the sites studied resulted in a decline in soil pH (0-10 cm) and reduced soil concentrations of N, P, K and S. It was suggested that soil pH decline below trees may have been due to nitrate leaching, excess uptake of soil cations over anions and an export of alkalinity. Decline in soil N, P, K and S may have been attributed to a greater demand for these nutrients under the trees compared to the pasture. As current first rotation *E. globulus* planted on farms near harvesting, there has been interest among land managers concerning the ability to re-establish pastures for profitable grazing enterprises. Alternatively, tree companies have become interested in the capacity of the soil to supply nutrients to support a second rotation crop by allowing the stumps to coppice. Findings from this study suggest that to return the land to productive pastures, soil testing will be required to determine the extent of pH decline and depletion of nutrients. If needed, lime should be applied to raise the soil pH and sufficient N, P, K, S and trace element fertilizers to restore fertility. Alternatively, given the decline in nutrients below the trees, it is likely that for second rotation crops to be profitable, tree companies need to place an increased emphasis on soil nutrient testing, fertilizing and liming soil below trees to ensure levels of nutrients required for growth do not fall below critical levels.

The present study was limited in that soils were bulk sampled within sites, thus the data could only be used to indicate general trends. A more comprehensive study with intra-site replication across sites would be extremely useful in being able to more accurately predict soil changes. Moreover, future research directed at nutrient uptake preferences of *E. globulus* would allow the mechanisms of soil acidification to be more fully understood. Similarly, determining the ash alkalinity of leaves and quantifying the loss of leaves would also allow further understanding of the causes for soil pH decline. The other postulated cause for soil acidification, leaching of nitrate, could be further explored by quantifying differences in nitrification and subsequent leaching in soil below trees and adjoining pasture. With the increasing need to establish perennial crops on agricultural land to arrest the spread of salinity, *E. globulus* tree belts have shown promise throughout south-west Australia. Further knowledge of soil changes below belts of *E. globulus* will allow better management of soil pH and fertility to maintain productivity of trees and adjoining pasture.

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