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Rural Industries Research and
Development Corporation

Productivity of Mallee Agroforestry Systems

— The effect of harvest and competition management regimes —

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The effect of harvest and competition management regimes

by Adam Peck, Rob Sudmeyer, Dan Huxtable,John Bartleand Daniel Mendham

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Foreword

The development of mallee as a large-scale, multiple-purpose woody crop for integration into wheatbelt farming systems commenced in Western Australia in the early 1990s.The major motivation for the public investment in domestication of native mallee eucalypts has been the need to remedy dryland salinity problems in the extensive wheat and sheep regions of Western Australia. Some 20% of WA wheatbelt farmers have made test plantings of mallees totalling about 14,000 ha. This has generated a robust knowledge base for planting design, establishment and management.

Deep rooted perennials have only been feasible if they are of comparable profitability to the conventional agriculture.The alley farming concept of wide-spaced narrow belts of mallees is widely used and designed to achieve good integration with the conventional agriculture. Central technologies such as breeding, growth modelling and harvest regimes, harvester and supply chain systems and processing options have all been systematically addressed, and continue to make steady progress.

This Projectfocused onthe yield of biomass within the context of regular harvest, and the impact of competition on adjacent crop and pasture. These are critical determinants of economic viability.

Growers need to achieve economically viable mallee production at a price that will also be attractive to processors.If this can be achieved, biomass production and processingis likely to find wide application across the southern wheatbelt regions of Australia.

This report provides the only available long-term, large sample measurements of mallee belt yield and competition impact.The indicatesshowed that a strong improvement in profitability might be achieved by widening the inter-row space of the standard two-row belt (currently 2 m) out to 8 m or more.

These results suggest that more production area can be achieved without the penalty of the large opportunity cost of the competition zone that the outer rows incur. In this way the large competition cost can be spread over a wider belt and a larger volume of biomass. With this innovation it is shown that mallee belt production might match or exceed profitability of conventional agriculture in the low-rainfall eastern wheatbelt, while for higher rainfall areas, increases in the margins on break-even yields (up to 45%) and biomass selling price (up to 20%) could be achieved. It is clear that mallee biomass production and processing requires a strong carbon price setting to achieve economic viability and rapid, early development.

The Project provides a firm foundation of knowledge on mallee belt biomass productivity and the opportunity cost of land. Together with continuing research in supply chain technology and biomass processing, and the introduction of a carbon tax, there is good potential for mallee industry project proposals to be able to demonstrate commercially feasible in the near future.

This Project was funded from RIRDC Core Funds which are provided by the Australian Government. It was also funded by the former Natural Heritage Trust through the Avon Catchment Council. Ongoing funding was provided by the Department of Resources, Energy and Tourism. The Western Australian Government provided funds and allocated staff to this Project through Department of Environment and Conservation and the Department of Agriculture and Food.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our National Rural Issues/Dynamic Rural Communities R&D program which invests in research that strengthens rural development and communities.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

About the Authors

Adam Peck is a research scientist with WA Department of Environment and Conservation (DEC). He has a BSc in Environmental Restoration from Murdoch University, with Honours looking at the ecology of spiders in a restored landscape. His work with DEC focuses on the yield of mallee eucalypts in the wheatbelt of WA under different harvest regimes (coppiced and uncut trees). It also encompasses mallee seed production and clonal propagation.

Rob Sudmeyer is a Senior Research Officer with the DAFWA based in Esperance and is affiliated with the Centre for Ecohydrology at the University of Western Australia. Dr. Sudmeyer has been involved in research to combat salinisation for 24 years. Over the last 15 years he has been particularly involved in researching aspects of agroforestry relating to high water using farming systems, the provision of shelter, tree/crop interactions and their management and how tree crops can be used to improve soil fertility and health. He spent 2007 as a visiting scientist at the University of Nebraska Lincoln School of Natural Resource Management. Current researchprojects include investigating the productivity of oil mallee and acacia agroforestry systems, with an emphasis on quantifying and understanding how new tree crop systems can best be incorporated into conventional farming systems.

Dan Huxtable is a consultant environmental scientist and former research scientist with the DEC. Hisproject experience includes low rainfall plantation forestry, land rehabilitation and land restoration. He has expertise in biomass and carbon measurement in vegetation, revegetation methods, soil and landscape surveys, and property planning and environmental constraints assessments.

John Bartle is an agricultural scientist with the Department of Environment and Conservation (DEC) in Western Australia (WA). His background is in research on revegetation for water balance management and salinity control in dryland agriculture. During the past two decades he has led the development of native mallee species as profitable woody crops for use within agriculture to help remedy salinity and deliver other environmental benefits. Thisproject has included development in species selection and genetics, establishment and management techniques, harvest and supply chain options, and processing and product options especially bioenergy.

Daniel Mendham is a senior research scientist with CSIRO Ecosystem sciences. His background is in research to support sustainable production of tree crops in a wide range of environments and situations. His research focuses on understanding carbon, water and nutrient cycling in tree cropping systems in order to improve their management for profitability and sustainability.

Amir Abadi is a scientist focused on economic research and business analysis. He develops specialised models and decision support tools of farming and agroforestry systems to assess the commercial and environmental impacts of innovations and drivers for their adoption. He has a particular interest in perennial plants in agriculture, their natural resource benefits, their contribution to resilience of farming in the face of climate change, their use for sequestration of carbon and as feedstock production of renewable energy and fuel. He has worked extensively on woody crops examining their commercial potential for production of biomass, wood and oil. One of his current researchprojects is focused on the assessment of economic feasibility of an industry for production and supply of biomass from dedicated short rotation coppicing mallee trees.

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Quenten Thomas is a freelance programming and modelling consultant, based in Perth.

Gary Ogden is a technical officer with CSIRO Ecosystem sciences. He has significant strengths in design and implementation of monitoring systems to understand more about the water and nutrient cycling in tree systems.

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The state government of Western Australia provided funds and allocated staff to this Project through DEC and DAFWA. The support of the Future Farm Industries Co-operative Research Centre is also gratefully acknowledged.

Abbreviations

BE:	Break even
CAI:	Current annual increment
CVI:	Crown volume index
CZ:	Competition zone
DAFWA:	Department of Agriculture and Food Western Australia
DBH:	Diameter at breast height
DEC:	Department of Environment and Conservation Western Australia
EZ:	Exclusion zone
GM:	Gross margin
H:	Tree height
Ha:	Hectare
MAI:	Mean annual increment
NPV:	Net present value
NCZ:	No cropping Zone
OB:	Outside bark
REC:	Renewable Energy Certificate
RP:	Root pruned
SBA:	Stem basal area
SE:	Standard error
WA:	Western Australia
WUE:	Water use efficiency
YCF:	Yield conversion factor

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Executive Summary

What the report is about

This report presents research results on the influence of harvest regimes on the biomass productivity of mallee belts and the impact of their competition on adjacent crop or pasture. The results are incorporated into an analysis of the likely commercial viability of mallee. Directions for further research to improve the prospects of developing large scale mallee biomass industries are identified.

Why the research is important

Mallee biomass production is an infant industry with good potential for large scale development and multiple benefits. The yield of biomass within the context of regular harvest, and the lateral competition impact of narrow belts, are critical performance parameters that will be prominent determinants of economic viability. This Project provides the only available long-term, large sample measurements of mallee belt performance.

Who is the report targeted at?

The report aims to provide hard evidence for policy makers, professions, entrepreneurs, natural resources management operatives and farmers to enable sound judgements to be made about likely viability of mallee biomass production. In particular, it hopes to sustain the confidence of the large number of farmers in WA who have undertaken pre-commercial mallee planting and indicated the grass-roots strength of the mallee concept.

Where are the relevant industries located in Australia?

No industry based on multiple purpose integrated planting of mallee has yet emerged. Large scale mallee biomass industry development has been largely based in wheatbelt region of WA. Two main foci of pre-commercial planting have emerged in the Narrogin and Kalannie districts. An engineering demonstration-scale biomass processing plant was built by Verve Energy at Narrogin, and small scale harvest and processing of mallee biomass has been initiated by farmers at Kalannie. Interest is also emerging in the central plains region of NSW in the Forbes and Condobolin districts.

What is the location of the strongest industry representation in Australia?

Mallee growers in WA have an industry association (Oil Mallee Association) that has undertaken common-interest industry development issues like the preparation of Codes of Practice and industry development plans, and which entertains a national presence at the appropriate time. The Department of Environment and Conservation carries the WA state investment in mallee industry development. This investment has been about $1 million/year for nearly two decades. Supply side R&D is now conducted under the Future Farm Industries Cooperative Research Centre, also based in WA, but with strong participation in Victoria and NSW. The Curtin Fuel and Energy Technology Institute based in Perth has made major investment in mallee bioenergy R&D and published some 30 scientific papers in the past 5 years. The Curtin group has strong links with Monash University’s Department of Mechanical and Aerospace Engineering in Victoria where mallee bioenergy research is also conducted.

Describe the industry and indicate how many producers are involved and what the production levels and markets are

Mallee biomass production and processing is an ‘infant industry’. It has well recognised prospects and attracts a wide range of support but has not yet embarked on commercial operations. In WA about 20% of wheatbelt farmers (i.e. about 1,000) have undertaken pre-commercial planting of mallee motivated by landcare outcomes but also by the potential for a new industry to emerge. It is estimated that more than 14,000 ha of mallee has been planted in WA. Potential production from this area is limited by the exploratory character and dispersal of the plantings, but areas with some concentration of planting (Narrogin and Kalannie) are well recognised as prospective industry start-up locations.

Who will benefit from this research and where are they located in Australia?

This research concerns generic issues in mallee biomass production systems. It aims to increase the knowledge base so that growers can achieve economically viable mallee production at a price that will also be attractive to processors. If this knowledge achieves a level where commercially viable biomass production is possible it will find application across the southern wheatbelt regions of Australia.

Background

The development of mallee as a biomass crop in the wheatbelt agricultural region of south-western Australia began in the early 1990’s. The concept of belts of mallee integrated into the wheatbelt cropping and pasture systems, providing non-food product opportunities as well as helping to arrest land degradation, proved popular with farmers. The farming community formed a growers association in 1996 (Oil Mallee Association, OMA) and became directly involved in the management of industry development. More than 12,000 ha of belts were established up to 2008 when the OMA published an industry development plan (OMA 2008). These plantings now form a considerable resource, not only of biomass, but also of potential information about the performance of mallee belts under a wide range of species, site and management input combinations. Few mallee belts have been harvested since they were established due to the slow development of a large scale harvest capability, and this in turn has caused biomass supply costs to remain uncertain and inhibited commercial development (Enecon 2001, McCormack et al 2009, FFI CRC 2010). The early plantings have focussed attention on yield suppression effects on adjacent crops and pastures as the mallee ages, which especially in the recent dry seasons is causing serious concern to growers. These factors gave impetus in 2005 to the establishment of this Project in order to fulfil the aims outlined below.

Aims/objectives

This Project aimed to:

1. quantify the productivity of unharvested mallees and harvested mallees subject to 4 harvest regimes and root pruning;
2. determine the lateral extent of the competition zone adjacent to mallee belts and crop and pasture yield within the competition zone for the management regimes described in objective 1;
3. use these data to assess the economic returns from integrated mallee/agriculture systems with various harvest and competition management regimes;
4. develop robust guidelines for managing integrated mallee/agriculture systems to maximise economic returns.

Methods used

19 sites were established in 2006 with randomised, replicated 20 or 25 m plots of six treatments (3 year spring and autumn harvest, 4 year spring and autumn harvest, 3 year spring root-pruned and unharvested), with a buffer of 10m on each side of the plots. The sites consisted of belts of 2, 3, 4 and 6 rows, but only 2 rows of trees were measured at each site. We report data from exterior trees only at the 9 sites with more than 2 rows in order to compare results across all sites. In autumn and spring 2006 the following non-destructive measures were taken: tree height using height staves, stem basal area at 10cm above ground level of all stems above 10mm diameter using either callipers or diameter tapes. The trees in harvest plots were subsequently decapitated near ground level with chainsaws. Approximately 25 trees at each site across a range of size classes were weighed in an enclosed trailer with a loadbar system in order to generate allometric equations. A subset of 6 of these trees at each site were then separated into 4 biomass fractions (wood, bark, twig and leaf) and weighed green and dry in order to assess biomass partitioning and moisture content. Annual non-destructive measures of all trees followed until the 2009 and 2010 coppice harvests, when the same procedures used in 2006 were followed for coppice. Coppice growth was assessed by measuring height and 2 widths of canopy to generate a total Crown Volume Index. Some sites with poor growth remained unharvested after 2006.

Crop and pasture growth was determined from measurement plots running parallel to, and 2, 4, 6, 8, 12, 16, 20, 24 and 30 m from, the belt in each treatment plot. Crop grain yield was measured by machine harvesting plots 1.7 or 1.8 m wide and either 20 or 25 m long. Pasture above-ground biomass was determined once in September each year (estimating food on offer). Soil cores were collected 20 m from the mallee belts in the centre of each control plot at each site. Cores were collected using an EVH Rhino 2100 drill rig. The cores were 44 mm in diameter and were collected to a maximum depth of 10 m or where bedrock, groundwater or a hardpan too hard to drill through was intersected.

70 trees from 10 sites were analysed for nutrient concentrations, including the macronutrients nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), sulphur (S) and the micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn).

A spread sheet model was developed to contrast the annual average farm operating surplus under conventional agriculture with the annualised net present value of mallee belts. It does this by showing the mallee performance settings required to break-even with conventional agriculture. The area of farmland over which the mallee enterprise must break-even includes that on which the trees stand, as well as an area equivalent to that lost to adjacent agriculture through competition by lateral roots from the mallee belt. The biomass is notionally supplied to power stations for electricity generation. The analysis accounts for revenues from biomass sales, Renewable Energy Certificates and the proposed Carbon Farming Initiative.

Results/key findings in relation to the objectives of the report

Large differences in standing biomass and biomass increments were observed both between sites and within sites. Yields of uncut trees (ages 9 to 16 years) ranged from 20 to over 200 green tonnes/ha by 2010. Yields of coppice ranged from 10 to over 100 green tonnes/ha at age 4 (in 2010). At most sites the most productive plot had greater than double the yield of the least productive plot, which may be due to local water redistribution and edaphic factors. In the first cycle there was a trend of better growth in autumn harvested plots. This trend was less evident in the second harvest cycle and it is still too early in the Project to identify which season may be most productive. Autumn harvested coppice was more productive than spring harvested coppice in the first cycle, but initial results suggest no differences in the second cycle. Four year old coppice standing biomass is higher than three year old coppice biomass (due to an extra year's growth); yield per year for 3 and 4 year old coppice varies by site and the optimum harvest cycle length will vary from site to site. Root pruning had little or no effect on the productivity of coppice. Allometric equations developed in this Project are an accurate way to predict above ground biomass at the site level.

Crop and pasture yields decline with proximity to mallee belts, indicating competition for nutrient and water resources between perennial trees and annual crops/pastures. On average competition extends 10-12 m, over which area agricultural yield is reduced 52%. The economic cost of competition was equivalent to forgoing agricultural production for 12 m on either side of unharvested mallee belts but harvest reduced this by between 17 and 33%, depending on the harvest frequency. Competition increases with tree age and biomass and is greater in low rainfall years and areas. The reduction in competition after harvest wanes after three years.

Harvesting mallees is likely to result in significant export of nutrient capital from sites, but the magnitude of nutrient export is similar to the rates that typically occur with removal of agricultural produce. It will be important for growers to recognise the nutrient depletion caused by mallees and re-apply sufficient nutrients to account for this when predicting mallee yield.

This Project has shown that the lateral extent and intensity of competition on crops and pasture adjacent to mallee belts is larger and less amenable to control by regular harvest or root pruning than previously anticipated. These two factors increase the opportunity cost of land for the standard narrow two-row belt to some 39% of all costs for delivered biomass for the analysis period (~50 years). The economic analysis using the new yield and competition results from this Project along with a base-case set of costs and revenues appropriate to electricity generation (including existing and foreshadowed carbon related revenues) shows that narrow two-row mallee belts will only break-even with conventional agricultural activities in the wetter parts of the WA wheatbelt, i.e. more than 400 mm rainfall per year.

It is clear that mallee biomass production and processing will require strong carbon price settings to achieve economic viability and rapid, early development.

The analysis predicted that a strong improvement in profitability might be achieved by widening the inter-row space of the standard two-row belt (currently 2 m) out to 8 m or more. This provides more mallee biomass production area without the penalty of the large opportunity cost of the competition zone that the outer rows incur. In this way the large competition cost can be spread over a wider belt and a larger volume of biomass. With this innovation it was predicted that profitable mallee belt production could be undertaken in the low-rainfall eastern wheatbelt, while for higher rainfall areas increases in the margins on break-even yields (up to 45%) and biomass selling price (up to 20%) might be achieved.

If adopted, how will this research benefit your identified industry?

The mallee biomass industry shows promise but no commercial operations have yet been established. This research was designed to generate knowledge of mallee harvest regimes and competition costs, with a view to reducing overall costs and increasing biomass yields. Potential biomass growers, processors, carbon buyers and bioenergy entrepreneurs will include these results in their assessment of potential industry viability.

Implications for relevant stakeholders:

Industry:

There are no commercial industry operators as yet. However, the results of this Project help bring commercial operations nearer. Growers and potential buyers will be especially interested in the indication of biomass prices coming from this Project. The Oil Mallee Association is an association of interested parties, mainly on the biomass production side. They will scrutinise the results of this Project closely with a view to its use in stimulating commercial development. There is strong emerging interest from small scale industry (abattoirs, feed processing, plant oil and wood products, miners) for biomass as a renewable fuel for steam, electricity and other products. Several larger industries have made their interest known. The Future Farm Industries CRC recently signed a memorandum of understanding with Renewable Oil Corporation and Virgin Airlines in relation to biomass as a feedstock for aviation fuel.

Communities:

There is strong support from by regional communities for prospective commercial development in regional towns. Biomass production is a particularly attractive because it is bulky, of low value as a raw material and has to be converted to higher value products within the region in which it is produced. Furthermore, extensive local production of mallee biomass may contribute to improvement of the environment. Hence regional communities see economic, environmental and social benefits in mallee development.

Policy makers:

There is general support for biomass production at the policy level. The results of this Project have been actively sought by the Commonwealth Department of Climate Change and Energy Efficiency for incorporation into the National Carbon Accounting System. The food or fuel debate has been a challenge for policy makers. In the case of integrated mallee production no such conflict is seen to exist because mallee belt systems are designed to complement to the existing food production systems. Furthermore, mallee is a second-generation (cellulosic) feedstock in contrast to plant oils for biodiesel and grain for fermentation to ethanol. Nevertheless there is a generally weak appreciation of the potential for bioenergy in Australia and it is rarely mentioned in the public debate. This is in striking contrast to the position internationally – the International Energy Agency in its Annual Energy Outlook series lists bioenergy as bigger than all the other renewables (including nuclear and hydro) combined (Bartle and Abadi 2010).

Recommendations for future R&D

1. Undertake field investigation of suitable existing plantings, and establish new experiments, to assess the effects of wider belt configuration on mallee yield, competition zone impact and economics.
2. Maintain the existing harvest regime and competition zone experiments to document the cumulative effects of treatments on yield and nutrient removal over 3 coppice harvest cycles.
3. Extend harvest regime and competition zone experiments into higher rainfall zones, where economic analysis indicates good potential but where data are scarce.
4. Undertake MIDAS modelling to examine whole farm optimisation of the proportions of mallee, annual crop and pasture in integrated farming systems.
5. Determine the variation in the cost of harvest and supply chain operation over a wide range of yield densities (biomass/km of row) and apply this to optimisation of belt design and harvest scheduling.
6. Develop site assessment techniques for integrated mallee belt design with potential for interception of local run-off. This will require remote sensed data for spatial analysis, surface water management, farm planning and compatibility with precision farming practices.
7. The emergence of large scale commercial mallee biomass industries will open an important opportunity to capture collateral benefits of extensive tree planting without cost. This will provide impetus to improve the economic and environmental performance of wheatbelt agriculture. To capture this potential, and to document the relevant antagonisms and synergies within agricultural systems, it is recommended that the Future Farm Industries Cooperative Research Centre method of system benefits analysis be further developed.

Recommendations for growers

In order to achieve economic performance for large scale integrated mallee planting it is recommended that account be taken of the following generic design and management indications flowing from this Project:

Harvest frequency and season

1. No adverse outcome from season of harvest was observed - this is positive given that commercial harvest will need to be active all year round.
2. The anticipated frequency of harvest may be reduced if wider two-row belts are adopted. Wider two-row belts will have a faster growth rates and this may enable more frequent harvest. It may also provide the option to take greater harvest volumes and thereby reduce harvest cost. More frequent harvest has the added advantage of reducing competition.

Crop and pasture competition

1. Growers should plan on a variable 'no-crop-zone' adjacent to belts because the impact of competition means that the variable costs of crop establishment may not be recovered. The width of this zone will vary with natural site factors, but it will also vary across the harvest cycle giving a no-crop-zone ranging from 4 to 10 m (each side).
2. There may be some benefit in root pruning but this requires further R&D.
3. Crops should be preferentially planted in the 3 years after mallee harvest when the intensity of competition will be lowest and the no-crop-zone the narrowest. The pasture phase of the crop rotation should be timed for the lead-up to mallee harvest. This also means that mallee harvest can be done during the pasture phase with less complication.

Belt planting configuration

1. This Project indicates that wide spaced two-row belts may be the most profitable planting configuration. Such belts should be less 12 m wide but only have two-rows, i.e. have an inter-row space of up to 8m. In addition to a likely increase in profitability there are several other benefits from such wide spaced two-row belts: removing inner rows eliminates risk of inner-row suppression and extra harvest cost; they grow faster and this may reduce harvest cost; more frequent harvest may be possible with reduced competition costs; the inter-row space may provide a useful path for harvest equipment. Growers should await further assessment before responding to this emerging design feature.
2. For any belt the minimum spacing between rows should be 3 m to allow access for the harvest equipment now under development.

Site selection

1. This Project indicates considerable scope for improved site assessment. Conventional techniques will not be adequate for some aspects of site selection and other site related objectives like design for interception of local run-off and compatibility with precision farming practice. This will require remote sensed data and spatial analysis techniques to be developed.

Other recommendations

1. There is a grazing risk period in the early coppice stage. This will require stock management for periods in the first year following tree harvest.

Who are the recommendations targeted at?

These recommendations are targeted at State and National R&D funding agencies, and to policy makers as evidence to demonstrate the credibility of integrated biomass production on wheatbelt farms. Recommendations for growers are targeted at present or future managers of integrated mallee/cropping systems.

1 Introduction

Author: Bartle, J

The development of mallee as a biomass crop in the wheatbelt agricultural region of south-western Australia began in the early 1990's. Since this time the practice of growing mallee in an integrated alley farming system with annual crops and pastureshas been widely adopted. Mallee development was initiated by the then Department of Conservation and Land Management (CALM, now Department of Environment and Conservation, DEC) as a contribution to combating severe degradation of natural resources in the WA wheatbelt (Bartle and Shea 2002). Although motivated by environmental concerns, CALM recognised the imperative, first stated in the State Salinity Action Plan (Government of WA 1996 a,b), that large scale revegetation with deep rooted perennial species would have to be commercially viable to facilitate adoption by farmers on the necessary scale.

The development of mallee cultivation built on knowledge and experience arising from the long history of utilisation of native mallee stands for eucalyptus oil production, particularly from the only current production areas in West Wyalong district in NSW and the Bendigo district in Victoria (Milthorpe et al 1994, Davis 2002). It was further supported by the work of Allan Barton who saw oil mallee as a potential industrial crop producing several products as well as landcare benefits (Eastham et al 1993, Barton 2000).

The mallee development strategy adopted by CALM aimed to enlist the support of farmers to conduct pre-commercial planting and carry the responsibility for developing routine establishment and management practices. This was matched by CALM brokering R&D investment in areas where practical development was not feasible, i.e. breeding and seed production; defining yield potential; devising harvest regimes, designing systems for integration of mallee belts into farms; farm level economic analysis; harvester and supply chain development; and options for large scale commercial processing and markets.

The concept of belts of mallee integrated into the wheatbelt cropping and pasture systems, providing non-food product opportunities as well as helping to arrest land degradation, proved popular with farmers. The farming community formed a growers association in 1996 (Oil Mallee Association, OMA) and became directly involved in the management of industry development. More than 12,000 ha of belts were established up to 2008 when the OMA published an industry development plan (OMA 2008). These plantings now form a considerable resource, not only of biomass, but also of potential information about the performance of mallee belts under a wide range of species, site and management input combinations. The majority have not been harvested since they were established. The earlyplantings have focussed attention onyield suppression effects on adjacent cropsand pastures as the mallee ages, which especially in the recent dry seasons is causing serious concern to growers.

The mallee production system concept involves regular harvesting of coppice regrowth. It was always anticipated that short cycle coppice harvests would limit the intensity of competition on adjacent crop or pasture. However, the opportunity to harvest has been delayed by the slow development of a large scale harvest capability, and this in turn has caused biomass supply coststo remain uncertain and inhibited commercial development (Enecon 2001, McCormack et al 2009, FFI CRC 2010). Research on the factors that determine mallee biomass productivity and the competition impact of narrow belt planting on adjacent crop and pasture has largely required the simulation of commercial harvest treatments.

The establishment of any large scale mallee biomass processing operation will need a plan for reliable delivery of biomass in sufficient quantities. Given the cost and difficulty of green biomass storage it will need to be supplied continuously. Hence the physiological needs of the mallee must be well enough understood to design farm and industry scale harvest regimes that will maintain predictable biomass yield and plant health while also permitting harvest of mature crops in any season. This regime must also manage the impact of belt competition with the adjacent crops and pastures, and be sustainable in the long term.

Wildy et al (2003) reviewed the literature of coppicing species, examined the coppice physiology of one of the major mallee species used in WA (*Eucalyptus kochii*subsp. *plenissima*), and reflected upon the management implications. They showed that harvest and subsequent coppicing in *E. kochii* subsp. *plenissima* at Kalannie (lat. 30S, long. 117E, 320 mm rainfall/year, 2200 mm pan evaporation/year) is associated with mobilisation of carbohydrate reserves from roots. Replenishment of these reserves after harvest takes 12 to 18 months. Harvest also causes a loss of fine roots and inhibited growth and secondary thickening in the root superstructure. These impacts may persist for 2.5 years before total root biomass is restored. Rebuilding fine root biomass proceeds in parallel with the regeneration of shoots. They found that spring-cut *E. kochii* subsp. *plenissima* restored its canopy more rapidly than autumn cuts, consistent with well established observations from the literature for other eucalypt species in Mediterranean climates. These results indicate that favourable yields will require harvest cycles greater than 3 years, perhaps with the need for attention to the season of harvest. Seasonal effects may be more important where the harvest frequency is pushing the 3 year limit.

To provide a broader understanding of harvest regimes CALM and the Department of Agriculture (DoA, now Department of Agriculture and Food WA, DAFWA) decided in 2005 to establish a series of experiments to examine the influence of season and frequency of harvest on the productivity of mallee belts and to concurrently measure the competition impact on adjacent crop or pasture. Supporting funds were provided by the Rural Industries R&D Corporation (RIRDC) and Avon Catchment Council (ACC). The Project commenced in 2006 with a first harvest at 19 sites selected from across the range of species and site conditions of the central wheatbelt region of WA (dispersed in the region between Narrogin to Kalannie, lat 30.0 to 33.6S, long 116.5 to 118.2E) including three sites at Esperance (lat 33.6S and long 121.8E). The Project included an interim assessment of the economic viability of mallee crops.

It was anticipated that coppice harvest cycles would vary from 3 to 7 years with longer cycles being necessary in the inland lower rainfall areas. Cycle length is controlled by the productivity of mallee at the particular location, the need for an adequate period for recovery after harvest and by the need to exceed a threshold yield for efficient harvest. The 5-year Project term funded by RIRDC and ACC concluded in 2010 when about half the sites had completed their first coppice harvest cycle.

It will be desirable for this Project to be continued for at least two coppice harvests, but ideally three, to clearly demonstrate whether the treatments generate consistent responses. Responses to treatments may be affected by age due to the progressive extension of root systems and the depletion of stored water. This may enhance yield possibly extending up to age 14 years since planting (Bartle et al 2011). Yield will also be affected by other biophysical factors, for example, rainfall amount and distribution will strongly influence yield and potentially enhance or disguise treatment responses.

In 2010 the Project won continuing funding through the Australian Government’s Second Generation Biofuels (Gen 2) R&D Program. To meet the Australian Government’s conditions the Project added investigation of nutrient loads in biomass to determine whether these might compromise the value of mallee biomass as an energy feedstock (Jenkins et al 1998, Grove et al 2007). This extension will carry the Project to 2012 after which further funds will be required. The first milestone report for the Gen 2 form of the Project is provided here (see Chapter 5) because some of the biomass yield data and biomass samples for nutrient content testing were collected during the term of the RIRDC stage of the Project.

This is the terminating Report of Project PRJ-000729 and presents data and analysis up to the end of 2010. It is divided into 4 main chapters as follows:

1. Chapter 3: Tree biomass(authors: Huxtable, Peck, Bartle and Sudmeyer)

2. Chapter 4: Competition zone effects (authors: Sudmeyer, Daniels, van Burgel, Jones, Peck and Huxtable)

3. Chapter 5: Biomass and nutrient export in harvested mallee systems (authors: Mendham, Bartle, Ogden and Peck)

4. Chapter 6: Economic analysis (Bartle, Abadi and Thomas)

Each chapter opens with an introduction and statement of objectives.

2 Objectives

This Project will investigate aspects of the management and productivity of integrated mallee/crop/pasture farming systems to enable the effects of competition between the mallee and agriculture components to be quantified and subject to economic analysis.

For belt plantings of three mallee species on a range of WA wheatbelt soils and rainfalls, this Project aims to:

1. Measure biomass growth of unharvested mallees and the coppice productivity of mallees subject to 4 harvest regimes and root pruning.
2. Determine the lateral extent of the competition zone adjacent to mallee belts and crop and pasture yield within the competition zone for the management regimes described in objective 1.
3. Use these data to assess the economic returns from integrated mallee/agriculture systems with various harvest and competition management regimes.
4. Develop robust guidelines for managing integrated mallee/agriculture systems to maximise economic returns.

This Project will test the hypothesis that management tools such as harvest regime and root pruning can be used to shift the balance of productivity between the crop and mallee components in integrated mallee/agriculture systems, and that by choice of management regime the complementarity between mallee and annual crop can be enhanced.

3 Tree biomass

Authors: Huxtable, D, Peck, A, Bartle, J. and Sudmeyer, R

3.1 Introduction

Mallee alley systems show promise as a method for commercial production of biomass feedstock for processing industries, whilst helping to protect agricultural land from secondary salinity and other forms of degradation.

The growth of mallee eucalypts and adjacent agricultural crops and pastures, planted in alley layouts with various harvest/management scenarios, was quantified at sites with differing climate and edaphic conditions across the Western Australian wheatbelt over a five year period.

The Project was jointly implemented by:

- the Department of Environment and Conservation (DEC) - responsible for project management and mallee growth measurements; and
- the Department of Agriculture and Food Western Australia (DAFWA) - responsible for crop and pasture measurements and site characterisation.

The Project received funding assistance from the Commonwealth Joint Venture Agroforestry Program (JVAP) and the Natural Heritage Trust (NHT). Ongoing funding from the Department of Resources, Energy and Tourism (DRET)enables the Project to continue research activities.

This chapter describes results from the mallee growth measurements component conducted by the DEC.

3.2 Methods

3.2.1 Location

Nineteen sites were selected to span a cross section of mallee species, soil types, landscape positions and climatic zones within the south west region of dryland farming (Table 3-1). This region experiences a Mediterranean climate with a seasonal drought from November to April, mean annual evaporation from 1500mm in the south to 2400mm in the north, mean annual rainfall of 550mm in the south west to 300mm in the north east (Figure 3-1). Conventional farming is dominated by annual rotations of cereal (wheat *Triticum aestivum*and barley *Hordeum vulgare*) or legume (blue lupin *Lupinus angustifolius*) crops. Cropping sequences are often inter-dispersed with improved annual legume (subterranean clover *Trifolium subterraneum*) and grass (annual ryegrass *Lolium rigidum*) pastures. For a detailed soil description of each site please see Appendix B.Site rainfall data were obtained fromSILO Data Drill in December 2010 (DataDrill 2010).

Table 3-1 Site location, rainfall (1970-2010), rainfall (2005-2010), evaporation, mallee species; *E. polybractea* (pb), *E. loxophleba* subsp. *lissophloia* (ll) or *E. kochii* subsp.*plenissima* (pl), year planted, number of mallee rows in belt and if planted on contour (–C), and width of alley between belts (expressed as m and multiples of belt height in 2006 and 2010 (2009 where marked with asterix).

Site	Nearest town-site	Lat	Long	Mean Annual Rainfall1970-2010 (mm)	Mean Annual Rainfall2005-2010 (mm)	Mean Annual Evaporation (mm)	Mallee Species	Planting Year	Age in 2006	No. rows	Alley width		
											(m)	H 2006	H 2010
1	Narrogin	-32.87	117.25	428	374	1653	pb	1996	10	2 row–C	70	12	10
2	Nomans Lake	-32.96	117.52	359	324	1630	ll	1997	9	2 row-C	20	5	5*
3	Wickepin	-32.85	117.59	349	315	1630	ll	2000	6	3 row	50	13	11
5	Buntine	-29.97	116.48	324	270	2342	ll	1998	8	4 row-C	>250	-	-
6	Kalannie	-30.29	117.43	301	272	2342	ll	1999	7	3 row	95	21	16
7	Burakin	-30.52	117.14	312	268	2279	ll	2000**	6	2 row	40	10	10*
8	Tincurrin	-32.98	117.74	364	321	1616	pb	1998	8	4 row-C	125-250	24+	20+
9	Arthur River	-33.48	117.00	442	416	1514	ll	1999	7	2 row	35	8	7
10	Harrismith	-32.76	117.84	334	315	1666	ll	1998	8	2 row	36	8	7
11	Koorda	-30.78	117.61	296	264	2261	pl	1999	7	2 row-C	30->250	17+	12+
12	Dumbleyung	-33.49	117.79	366	341	1579	ll	2000	6	6 row	55	17	14
13	Kulin	-32.67	118.24	323	309	1832	ll	1997	9	2 row	48	12	10
14	Wongan Hills	-31.00	116.92	335	303	2239	ll	2000**	6	4 row-C	40-120	14+	11+*
15	Kalannie	-30.21	117.36	319	284	2342	pl	1998	8	2 row	95	23	21*
16	Kalannie	-30.17	117.37	319	284	2342	pl	1994	12	2 row	95	34	28
17	Koorda	-30.60	117.39	295	263	2093	ll	1999^	7	2 row	50	13	10
18	Gibson	-33.62	121.78	539	568	1732	pb	2001	5	6 row-C	90-100	22	14
19	Gibson	-33.63	121.76	539	568	1732	pb	2001	5	6 row-C	120-140	34+	21+
20	Esperance	-33.52	122.15	458	452	1751	ll	2001	5	6 row	150-250	50+	31+

*** 2009 alley width**Planting date unconfirmed, therefore assumed. ^ Harvested in February 2002.NB: Site 7 not assessed for crop and pasture growth.**

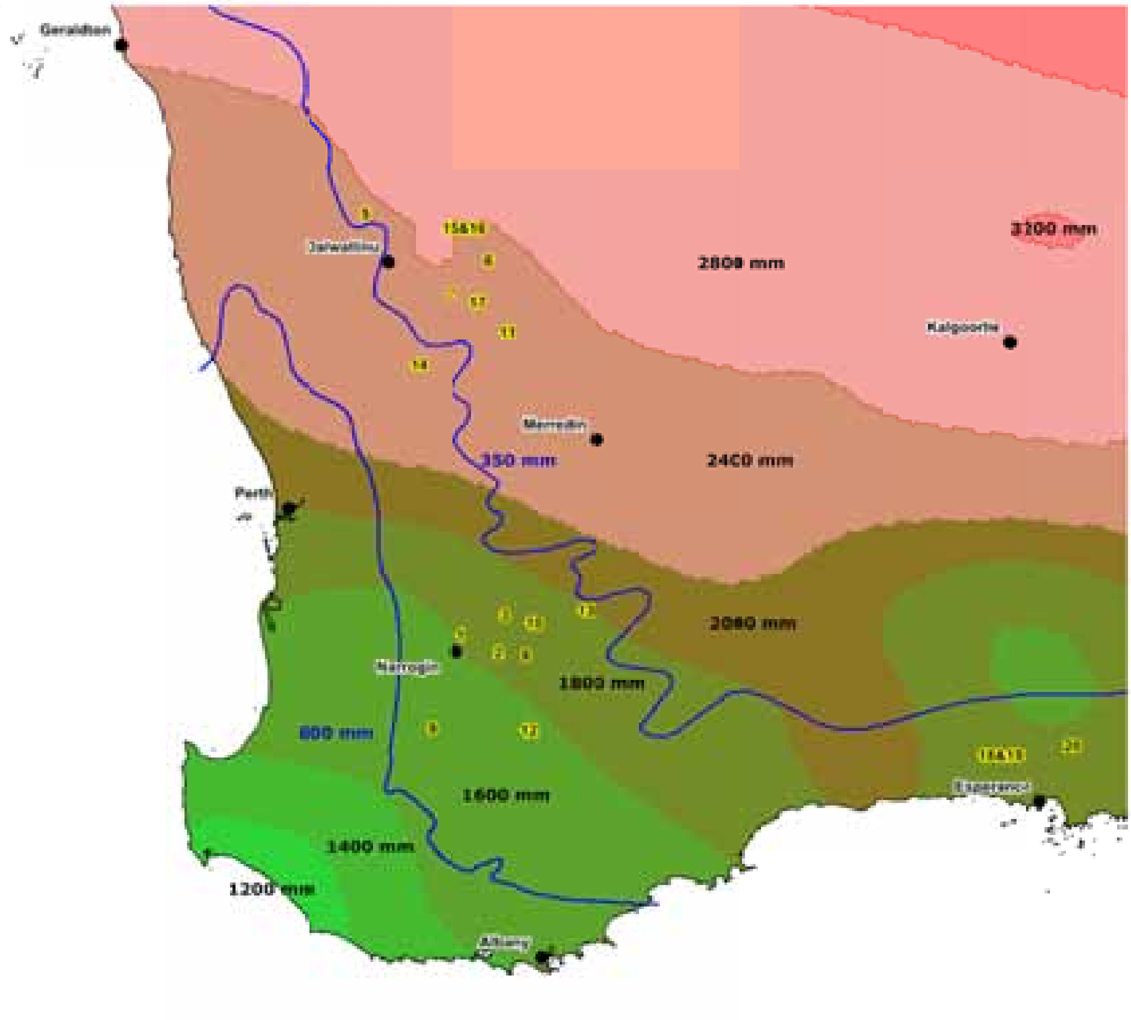

Figure 3-1 Location of the study sites, showing zones of potential evaporation and selected rainfall isohyets[1]

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[1] Data source Bureau of Meteorology (BOM).

Site selection was based on the following criteria:

- the trees were at least 5 years old;
- trees were planted in belt and alley layouts;
- tree growth and survival was representative of the better plantings in the area; and
- tree species were representative of those planted in the area.

Given this site selection process, the measured biomass yields (on average) were expected to be better than those across regional plantings established in the 1990s in Western Australia.

At site 17, a harvest operation had been undertaken by the landowner in February 2002. This site therefore had four year old coppice re-growth when sampled for this Project. All other sites were unharvested since establishment. Twelve sites were planted with *E. loxophleba* subsp. *lissophloia*, four sites with *E. polybractea* and three sites with *E. kochii* subsp. *plenissima*.

All sites were planted in belt configurations, consisting of 2, 3, 4 or 6 rows of trees planted within annual crop and pasture paddocks. Between row spacing was approximately 2m and within row spacing ranged from approximately 1.5m to 2.5m.

3.2.2 Experimental design

Each site included 18 plots (6 treatments x 3 replications) spanning one, two or three belts depending on planting layouts at the site; with the exception of site 7 which included only one set of autumn and spring harvest cycles (i.e. 4 treatments). Plots were 40 m or 45 m long, consisting of a 20 or 25 m measurement zone with 10 m buffer zones on either side (sites 15 to 20 have 25m plots, all others have 20 m plots). The plot length was selected to ensure that an adequate number of tree positions were included in each plot for biomass measurement purposes.

The following treatments were proposed at the outset of the Project:

1)Control (un-harvested mallees that are not root pruned)

2)3 year autumn harvest cycle

3)3 year spring harvest cycle

4)3 year spring harvest cycle, mallees root pruned

5)4 year autumn harvest cycle

6)4 year spring harvest cycle

For various reasons some sites were not harvested for a second time or the harvest interval/frequency differed from that planned. The main reason was the slow growth of the coppice. The implemented harvesting treatments are summarised inTable 3-2. Measurements ceased at sites 7 and 14 in 2009 due to poor growth, and at site 2 due to poor growth and the alleys being too narrow to measure an adequate spectrum of crop competition. Sheep grazed the newly coppicing mallee at some sites and the mallee plots were progressively fenced between 2006 and 2010.

Table 3-2 Year of second harvest and harvest interval for each site. Timing is for both spring and autumn harvests unless otherwise noted at sites 6 and 13.

Site	First harvest	Year mallee treatments were harvested for a second time (interval between harvests)	
	2006	2009	2010
1	X	X (3yr)	X(4yr)
2	X	No second harvest to date	
3	X	X (3yr)	X(4yr)
5	X		X(4yr)
6	X	X (3yr)	X(4yr) Autumn only
7	X	No second harvest to date	
8	X	X (3yr)	X(4yr)
9	X	X (3yr)	X(4yr)
10	X	No second harvest to date	
11	X	No second harvest to date	
12	X	No second harvest to date	
13	X	X (3yr)	X(4yr) Autumn only
14	X	No second harvest to date	
15	X	No second harvest to date	
16	X	X (3yr)	X(4yr)
17	X	X (3yr)	X(4yr)
18	X	X (3yr)	X(4yr)
19	X	X (3yr)	X(4yr)
20	X	No second harvest to date	

As a consequence of the variably imposed harvest treatments, the final set of treatments over the entirety of the Project sites included the following:

C	Trees unharvested (Control).
S3	Spring harvest 3 year interval
S4	Spring harvest 4 year interval
S5+	Spring harvest 5+ year interval
A3	Autumn harvest 3 year interval
A4	Autumn harvest 4 year interval
A5+	Autumn harvest 5+ year interval
RP3	Root pruned Spring harvest 3 year interval
RP5+	Root pruned Spring harvest 5+ year interval

3.2.3 Measurement of predictor variables

The autumn harvest and unharvested (Control) treatments were measured in March/April in each year of the Project, whilst the spring harvest treatments (including the RP treatments) were measured in September/October.

Stem diameters of previously unharvested mallees were measured at approximately 10 cm above ground level, which was high enough to avoid any lignotuberous swelling at the base of the trees where this occurred. All stems over 10 mm in diameter were measured. Generally two perpendicular measurements were taken on each stem using callipers. In plots with large trees (indicatively where stem diameter >100 mm) a diameter tape was used. These measurements were used to calculate the equivalent stem area of each tree, by summing the cross sectional stem areas of all stems (Equation 1). At all sites, the maximum height of plot trees (i.e. height of tallest stem) was also measured using a telescopic tree-measuring pole.

$$A_{equiv.} = \left(\frac{\pi . \sum_{i=1}^{n} D_{1i} . D_{2i}}{4} \right) = \left(\sum_{\iota = 1} A_{hi} \right) \qquad (1)$$

where:

$A_{equiv.}$ (cm^2) = equivalent cross sectional stem area at 10cm above ground level

D_{1i} *and* D_{2i} (cm) = perpendicular diameters of the *i*th stem at 10cm above ground level

$A_{hi}$$(cm^2)$ = cross-section area of the *i*th stem at 10cm above ground level

In coppicing mallee plots, the crown dimensions (height and 2 perpendicular widths at their widest extent) of each plant were generally measured and used to calculate the crown volume index (CVI) of each tree (Equation 2). At one site (site 17 at initial harvest in 2006) the number of coppicing stems per plant was sufficiently small to enable stem diameter measurements to be made as per the unharvested trees. CVI was used as an alternative to $A_{equiv.}$ in the measurement of unharvested trees at one site (Site 11), where small tree size and bushy form made stem cross sectional area measurements impractical.

$$CVI = Ht \times Width_{\_1} \times Width_{\_2} \tag{2}$$

where:

$CVI\ (m^3)$ = crown volume index of mallee canopy

Ht (m) = maximum height (bulk canopy) of mallee canopy

$Width_{\_1}$ and $Width_{\_2}$ (m) = perpendicular mallee canopy width dimensions (maximum extent of bulk canopy) measured parallel and perpendicular to the planting rows

3.2.4 Destructive biomass measurements

3.2.4.1 Sample tree selection

A stratified sampling system was used to select a representative sample of mallees for above ground biomass measurement at each site, in order to develop site level allometric equations for plot biomass determination. The sampling system was designed to optimise the prediction power of allometric models given the limited time and resources available for destructive measurements across the full suite of study sites.

Using the non-destructive mallee measurements, uncut mallees in the autumn harvest treatment plots were partitioned into 12 evenly spaced size classes based on $A_{equiv.}$. The size classes were uniquely determined at each site, based on the range between the smallest and largest mallees in the plots. In each of the smallest 3 size classes, one mallee was selected for destructive measurement. In each of the 4th to 6th smallest sized classes, up to three mallees were selected for destructive measurement. In each of the 2nd to 6th largest sized classes, up to six mallees were selected for destructive measurement. In the largest size class, which typically included less than three individuals for a given site (i.e.<2% of measured mallees), no mallees were selected for destructive measurement. The decision to exclude the largest mallees was due to the potential for one or two large trees (outliers) to bias the derived allometric relationships.

As an additional constraint for all size classes, if the number of mallees in a given equivalent stem area size class was greater than 10 then the mallees in that size class were also partitioned into 5 size classes based on height. The selection of mallees for destructive measurement was then made from the 2nd, 3rd and 4th height size classes only. This procedure was applied to avoid mallees which had abnormally damaged tops or were stunted.

Based on this stratification system, theoretically up to 42 mallees could be destructively sampled per site. Due to low numbers of mallees in the larger size classes, or extra sampling at some sites, the actual number of trees sampled per site ranged from to 23 to 50. Note that the selection of mallees within each size class was not done randomly. An iterative selection process was used starting in replicate 1 plots and then progressing through replicate 2 plots and replicate 3 plots respectively. For each replicate, mallees from autumn 3-year cycle plots were selected before mallees from autumn 4-year cycle plots. Once the requisite number of mallees for a given size class was selected then the selection process would terminate. As such, there was a bias for selection of mallees in replicate 1 plots. However, at most sites the number of mallees in each of the six largest equivalent stem area size classes was less than 7; therefore the potential for a replicate selection bias in these larger size classes was minimal.

Similar procedures were used to select a representative sample of coppicing mallees for above ground biomass determination in the autumn and spring harvest treatment plots, but using CVI as the selection parameter.

3.2.4.2 Measurement of total above ground biomass

Biomass sampling procedures were designed to be consistent with methods proposed by Snowdon et al. (2002). Manual harvesting consisted of removing mallees by chainsaw near ground level, to simulate a commercial harvesting operation. Mallees were weighed in an enclosed trailer fitted with a Ruddweigh 600mm loadbar system (precision +/- 0.1 kg). Mallees were either weighed whole, or in the case of large individuals broken into 2 to 5 sections for weighing. All mallees were weighed within 10 minutes of being felled in dry weather conditions.

The majority of biomass measurements used to develop site allometric equations for unharvested (Control) mallees were made in autumn 2006, with some additional measurements made in 2009 and 2010 to update the allometric models for the largest mallees at most sites. Some additional measurements were also taken in spring 2006; these were used for validation of allometric equations developed from the autumn data.

All coppice measurements for the development of allometric equations for coppicing mallees were taken in autumn and spring 2009 and 2010, using similar procedures to those described for uncut mallees. Estimates of coppice biomass of unharvested sites were made using ‘universal’ species regressions developed from destructive coppice data at the harvested sites.

3.2.4.3 Biomass partitioning and moisture content

At all sites except Site 14, six of the mallees selected for destructive measurement were chosen for biomass component determination. This included two mallees from ‘small’, ‘medium’ and ‘large’ size classes respectively at each site.

Component determination included measurement of the proportions of leaf, twig (branches <20mm diameter OB[2]), wood (from stem >20mm diameter OB) and bark (from stem >20mm) from the above ground mallee biomass. Stem sections above and below 20 mm diameter OB were separated, using callipers and cutting the stems with loppers. The >20mm diameter stem fraction from the whole mallees was weighed.

Sub samples were taken from the twig and leaf fraction by selecting one representative branch end (typically ≈1 kg green) and separating leaves and twigs for weighing. It was considered that the relatively small size of the trees (typically less than 6 m tall) and uniformity of the canopy in belt planting configurations negated any requirement for stratifying foliage sampling from the canopy. Three ≈20cm long billets of the stem >20mm OB component were then selected from the lower, middle and upper thirds of the stem respectively and the bark removed. These four fractions (leaf, twig, wood and bark) were weighed green in the field, then reweighed in the laboratory after oven drying at 70^0C to constant weight.

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[2] Outside bark.

Leaf litter was considered to be negligible based on a visual inspection of ground litter at all sites and was therefore not measured. Dead branches were similarly assessed to be negligible (consistently less than 0.5%) of the above ground biomass at all sites, and were included in the measure of total above ground green biomass as an undifferentiated component.

The Shapiro-Wilk test was used to test for normality. Tukey's test was used to compare means of biomass moisture content and biomass partitioning across sites, and between different coppice age classes.Statistical analyses were conducted using XLSTAT (Addinsoft 2011).

3.2.4.4 Total carbon analysis

A selection of oven dried biomass sub-samples, representing all of the biomass components, was used to determine component carbon content. The samples were re-dried at 40^0C and then milled to pass a 0.75mm screen. Carbon content was determined by combustion decomposition followed by infra red detection using a LECO SC444 carbon analyser.

The Shapiro-Wilk test was used to test for normality. Tukey's test was used to compare the carbon content of biomass fractions across sites. Statistical analyses were conducted using XLSTAT (Addinsoft 2011).

3.2.5 Allometric (prediction) equations

Allometric equations of the following form were developed for each site:

$$\ln Y = b_0 + b_1 \ln(X) + \ln\epsilon \quad (3)$$

where

Y (green kg) = standing tree biomass

X =the predictor variable (i.e. $A_{equiv.}$ or CVI)

b_0 and b_1 are parameters to be estimated

ϵ is the error term.

Equations of this form have been found to be appropriate in many studies of forestry allometrics (Specht & West 2003; Sochacki et al. 2007) and previous work on mallees undertaken by the DEC (unpublished data).

The log-transformation used in Equation (3) reduces heteroscedascity and facilitates fitting by linear regression. Outliers were removed by visual inspection of residual scatter plots. Correction factors for back transformation were determined using the ratio method of Snowden 1991. Across all sites only 17 data points were removedfor control trees, most of which were very small trees.17 points were also removed to develop site allometric equations for mallee coppice.

The data from all sites were also pooled for the development of universal allometric equations for each species.

Multiple parameter allometric models for previously uncut mallees were also tested incorporating various combinations of height, age and number of stems in addition to A_{equiv}. No significant improvement over single parameter equations was obtained, and therefore multiple parameter allometric models were not used in any further analysis.

The allometric equations developed for each site are included in Appendix A (Tables A-1 and A-2).

3.2.6 Multiple row biomass standardisation

Nine of the study sites included multiple row belts (i.e. >2 rows per belt). Interior row suppression has commonly been observed in mallee plantings, arising from the ability of exterior trees to access resources for growth in the adjacent alleys.

In order to compare results across all sites we decided to report data from outer rows only at these 9 sites. Thus site productivity results reflect the potential productivity of 2-row belt configurations. However yield differences between edge and interior rows are discussed in Section 3.4.4.

3.2.7 Biomass per hectare calculation

A 6m belt width was assumed for the calculation of mallee biomass per hectare. This width represents the strip of land between areas that are cropped or used to grow pasture, and therefore approximates the portion of agricultural land directly displaced by mallee belt establishment (Figure 3-2). The belt width typically exceeded the canopy width of the mallees at all sites.

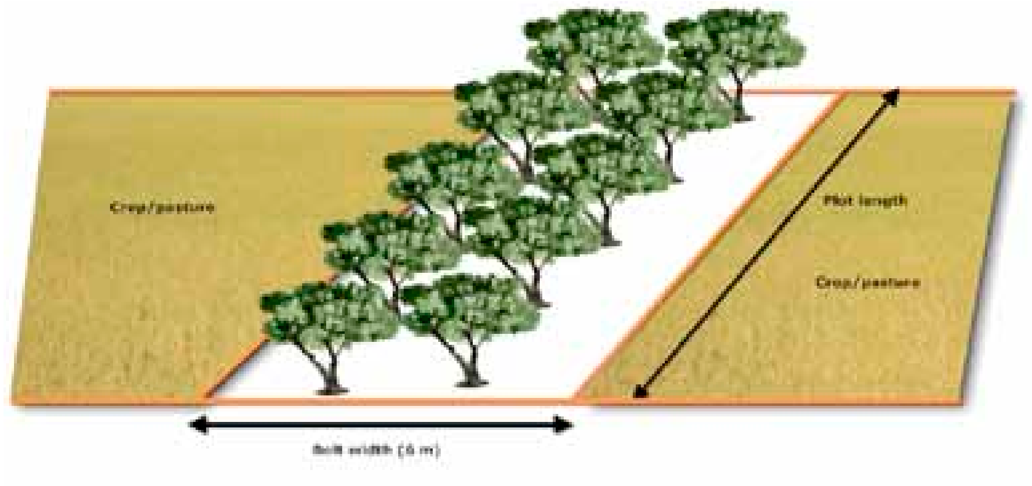

Figure 3-2 Belt dimensions used for biomass per hectare calculations. Plot area (m^2) = 6m x plot length (m)

3.3 Results

3.3.1 Standing biomass

There were large differences in standing biomass among sites (Table 3-3). Yields ranged from less than 20 green tonnes/ha to over 200 green tonnes/ha in unharvested (Control) treatments by 2010, and from 10 to over 100 green tonnes/ha in harvested (coppiced) treatments by age 4 (in 2010). The highest yields in unharvested treatments occurred at Site 1 (234 tonnes/ha in 2010) and Site 16 (167 green tonnes/ha in 2010). The highest yields in harvested treatments (age 4 coppice) occurred at Sites 1, 5, 8 and 18. Low yields at sites 7 and 12 were associated with secondary salinity, and poor growth was also observed at sites 11 and 14. Some plots at a number of sites also suffered browsing damage by sheep prior to being fenced off, most notably at sites 11 and 1.

Although standing biomass was correlated with tree age, large differences still occurred within even aged mallee cohorts across the sites; with unharvested plots at the most productive sites typically achieving approximately double the yield of the least productive sites (Figure 3-3). This trend was repeated and more strongly pronounced in 3 and 4 year old coppice in the harvested treatments (Figure 3-4).

Across all sites with 3 and 4 year harvest treatments imposed, the mean standing biomass of unharvested (Control) treatments approximately doubled from 60 to 120 green tonnes/ha in the period 2006 to 2010 (Figure 3-5). On average the coppice regrowth at these sites achieved yields of about 30 to 40 green tonnes/ha at age 3 and 40 to 60 tonnes/ha at age 4. Thus at many of these sites the 4 year old coppice had nearly reinstated the amount of standing biomass that existed at the commencement of the Project. For all treatments with a 3 year harvest cycle the mean standing biomass of the one year old coppice was greater in the second harvest rotation (in 2010) compared with the first harvest rotation (2007).

Sites where 5+ harvest treatments were imposed had lower mean standing biomass at the commencement of the Project (Figure 3-5), equating to approximately half the biomass of the sites where 3 and 4 year harvest treatments were imposed. On average the coppice regrowth at these sites achieved yields of approximately 20 green tonnes/ha at age 4, equating to approximately half of the standing biomass that existed at the commencement of the Project.

At the site level, considerable variation in standing biomass between plots was observed at the commencement of the Project in 2006 at all sites (Figure 3-6). This was putatively attributable to local scale edaphic and hydrological factors. These data indicate that at most sites the most productive plot had greater than double the yield of the least productive plot. This pattern was also commonly observed within treatments at each site. Sites with the greatest variation in standing biomass amongst plots included Sites 5, 6, 12 and 14. An example of this observation at some of the more productive sites (sites 1, 5 and 16) is provided in Figure3-7 (unharvested control treatment plots) and Figure 3-8(autumn 4-year coppice treatment plots). In 2010 the most productive plots in the unharvested (Control) treatments contained 2.0, 2.0 and 1.3 times the biomass of the least productive plots at sites 1, 5 and 16 respectively. The age 4 coppice in the most productive plots in autumn coppice treatments (treatment 5) contained 2.0, 3.4 and 2.2 times the biomass of the least productive plots at the same sites.

The large differences in biomass production within treatments within sites detracted from the development of broadly applicable growth curves (e.g. sigmoidal type) and the derivation of site index classes.

Table 3-3 Standing biomass of mallee treatments by site in the period 2006 to 2010. Shading indicates years mallees harvested.

Site	Year	crop/ pasture adjacent	Standing tree biomass (green tonnes/ha)										
			C	S3	S4	A3	A4	RP3	S5+(1)	S5+(2)	A5+(1)	A5+(2)	RP5+
1	2006	wheat	115.0	162.6	125.5	130.5	145.2	139.4					
	2007	pasture	148.5	1.0	0.7	11.8	13.7	1.2					
	2008	wheat	184.1	15.4	14.0	37.6	40.1	17.6					
	2009	pasture	215.3	50.6	41.3	79.2	78.5	49.2					
	2010	pasture	233.9	23.1	73.6	24.1	132.8	20.4					
2	2006	oats	57.7						69.8	71.4	54.2	59.3	64.7
	2007	pasture	63.4						4.6	2.8	3.6	3.6	1.8
	2008	oats	77.4						11.3	7.9	10.8	11.7	7.4
	2009		88.5								18.7	20.3	
	2010												
3	2006	barley	37.2	49.9	53.6	48.6	44.4	43.1					
	2007	pasture	45.9	1.9	1.6	4.6	4.2	1.6					
	2008	pasture	54.9	16.2	16.0	16.6	14.8	13.4					
	2009	pasture	63.5	24.8	27.7	30.8	24.4	23.6					
	2010	pasture	74.2	7.4	45.0	6.4	35.5	6.0					
5	2006	wheat	60.2		92.8		86.9	88.0	122.6		81.0		
	2007	wheat	73.9		0.3		1.2	0.3	0.3		1.3		
	2008	wheat	93.2		3.4		9.9	3.7	4.2		9.6		
	2009	wheat	97.4		9.8		21.3	10.1	11.7		23.0		
	2010	canola	115.8		33.2		73.0	27.3	31.8		65.8		
6	2006	pasture	56.8	48.1		47.7		57.7	38.6		58.7		
	2007	barley	73.4	0.0		2.7		1.3	1.6		2.6		
	2008	pasture	101.1	0.3		11.6		6.5	9.1		15.9		
	2009	wheat	121.3	1.6		17.8		17.7	20.2		23.3		
	2010	wheat	135.9	0.6		1.7		2.0	25.8		43.5		
7	2006		31.9						30.6		28.5		38.2
	2007		35.6						0.2		0.3		0.1
	2008		35.7						0.2		0.5		0.0
	2009		38.8								0.0		
	2010												
8	2006	wheat	78.2	83.6	112.6	83.4	84.3	114.8					
	2007	lupins	95.2	6.6	6.2	11.3	11.0	6.2					
	2008	wheat	124.4	24.6	29.0	22.2	21.2	30.5					
	2009	canola	132.0	38.8	48.4	50.5	48.3	44.2					
	2010	Wheat	146.4	10.7	72.6	13.5	66.6	11.9					
9	2006	pasture	61.0	62.6	70.9	59.6	51.2	67.9					
	2007	pasture	71.8	5.5	10.7	5.4	4.3	6.5					
	2008	pasture	88.5	21.3	28.4	19.3	16.1	20.3					
	2009	pasture	92.9	29.1	37.1	30.5	26.5	23.1					
	2010	pasture	107.3	10.1	52.0	7.4	42.0	6.4					
10	2006	oats	57.7						68.0	71.8	62.6	57.7	67.0
	2007	oats	71.4						2.0	2.1	2.6	2.7	1.9
	2008	pasture	84.5						12.2	12.0	10.9	10.6	11.0
	2009	pasture	95.2						17.5	16.4	21.3	22.6	15.3
	2010	pasture	112.9						33.2	30.4	30.4	29.6	28.7

Table 3.3 continued

Site	Year	crop/ pasture adjacent	Standing tree biomass (green tonnes/ha)										
			C	S3	S4	A3	A4	RP3	S5+(	S5+(	A5+(	A5+(	RP5+
11	2006	wheat	19.5						19.3	23.2	15.7	16.6	22.0
	2007	pasture	34.7						0.8	1.0	5.2	5.4	0.6
	2008	wheat	32.5						1.1	1.4	6.7	6.2	0.9
	2009	pasture	43.2						6.6	7.1	11.2	10.4	6.6
	2010	wheat	43.2						9.9	12.2	16.1	14.3	10.3
12	2006	pasture	31.4						42.3	33.5	32.2	22.2	38.3
	2007	pasture	34.1						3.7	2.6	3.7	3.3	2.6
	2008	oats	40.4						9.6	7.0	7.2	6.0	6.7
	2009	pasture	46.2						21.6	14.5	17.3	13.9	16.8
	2010	pasture	51.3						33.7	22.2	25.2	21.9	24.3
13	2006	wheat	58.4	60.9		51.2	59.3	56.9	70.0				
	2007	pasture	75.5	3.4		6.0	4.7	2.4	4.4				
	2008	wheat	86.1	9.6		11.8	11.4	8.2	11.6				
	2009	pasture	99.6	21.4		27.5	26.2	15.4	24.9				
	2010	wheat	112.5	2.7		3.2	30.0	2.0	31.7				
14	2006	wheat	25.0						24.3	23.4	22.1	10.1	23.3
	2007	pasture	30.6						0.6	0.4	0.8	0.3	1.2
	2008	pasture	37.5						0.8	0.6	4.7	1.7	0.9
	2009	wheat	41.9								5.2	1.9	
	2010												
15	2006	pasture	51.2						69.7	62.2	61.3	63.1	75.8
	2007	wheat	60.0						0.2	0.5	3.1	2.8	0.5
	2008	wheat	74.8						1.6	1.9	7.4	5.7	2.1
	2009	wheat	80.1						6.8	5.5	21.6	16.6	6.3
	2010	wheat	86.6						13.1	10.2	40.7	34.4	11.1
16	2006	wheat	90.6	114.2	111.2	105.8	127.5	113.7					
	2007	pasture	124.4	1.7	2.2	6.7	5.9	2.4					
	2008	wheat	143.7	12.8	19.0	30.6	26.9	17.3					
	2009		149.7	31.4	41.4	49.5	49.0	38.9					
	2010		166.8	10.3	51.8	9.2	63.0	14.2					
17	2006	pasture	28.1	34.3	49.1	38.1	31.8	39.0					
	2007	barley	42.4	2.6	3.4	2.6	3.1	2.1					
	2008	pasture	49.7	7.0	9.6	11.4	11.7	6.7					
	2009	canola	57.2	13.8	19.9	20.0	19.4	12.1					
	2010	barley	60.8	2.8	31.5	2.8	24.8	2.8					
18	2006	pasture	32.0	50.6	55.3	31.4	33.3	62.4					
	2007	pasture	50.9	7.0	7.9	8.7	14.9	7.9					
	2008		73.9	14.9	18.1	16.8	25.7	16.7					
	2009	canola	106.1	48.7	59.4	38.9	50.0	52.2					
	2010	wheat	102.7	10.0	72.4	7.4	70.6	11.8					
19	2006	canola	33.5	43.0	44.5	28.9	28.1	41.8					
	2007	wheat	46.1	9.0	10.2	10.0	11.7	8.8					
	2008	pasture	64.6	13.5	12.5	17.9	19.0	12.8					
	2009	wheat	96.1	43.7	42.6	37.0	35.0	45.3					
	2010	canola	107.6	6.7	45.6	5.9	42.9	7.5					
20	2006	wheat	21.2						23.4	24.1	17.9	18.0	20.3
	2007	barley	29.6						1.3	3.1	4.3	2.9	3.3
	2008	pasture	37.7						3.9	7.7	10.9	7.8	5.9
	2009	canola	46.0						12.3	19.6	23.0	15.0	15.7
	2010	wheat	49.0						16.6	25.3	30.8	20.5	19.5

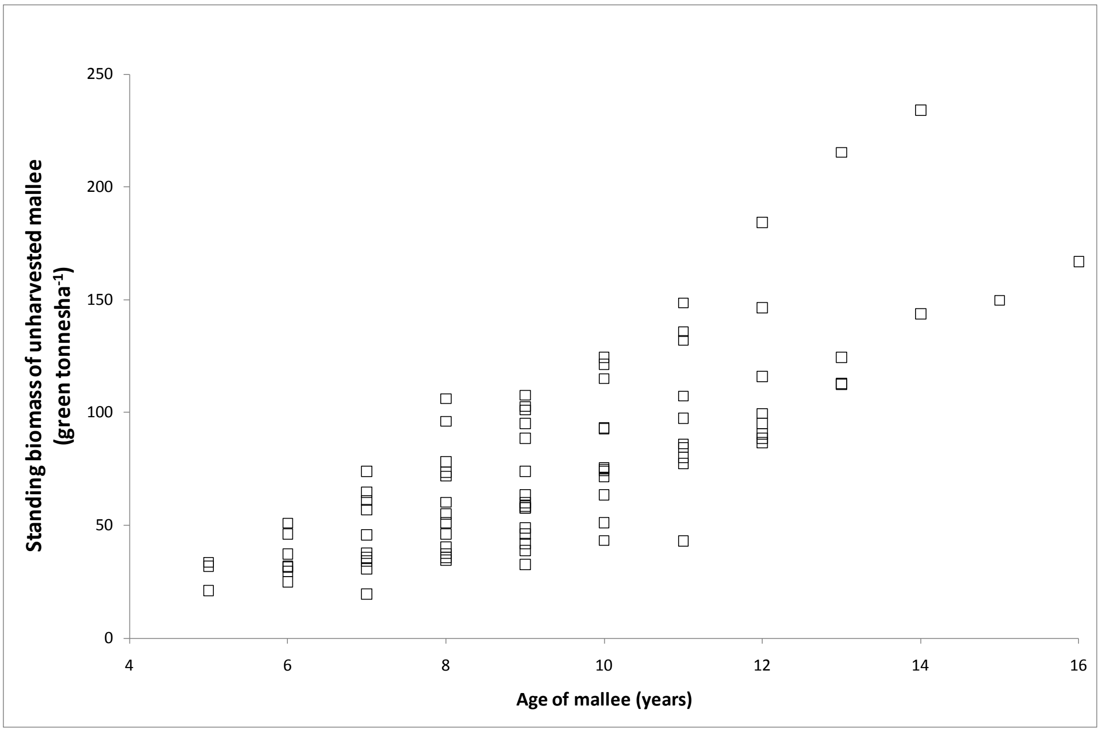

Figure 3-3 Standing biomass of unharvested (Control) treatments against mallee age at all sites[3] when measured in the period 2006 to 2010.

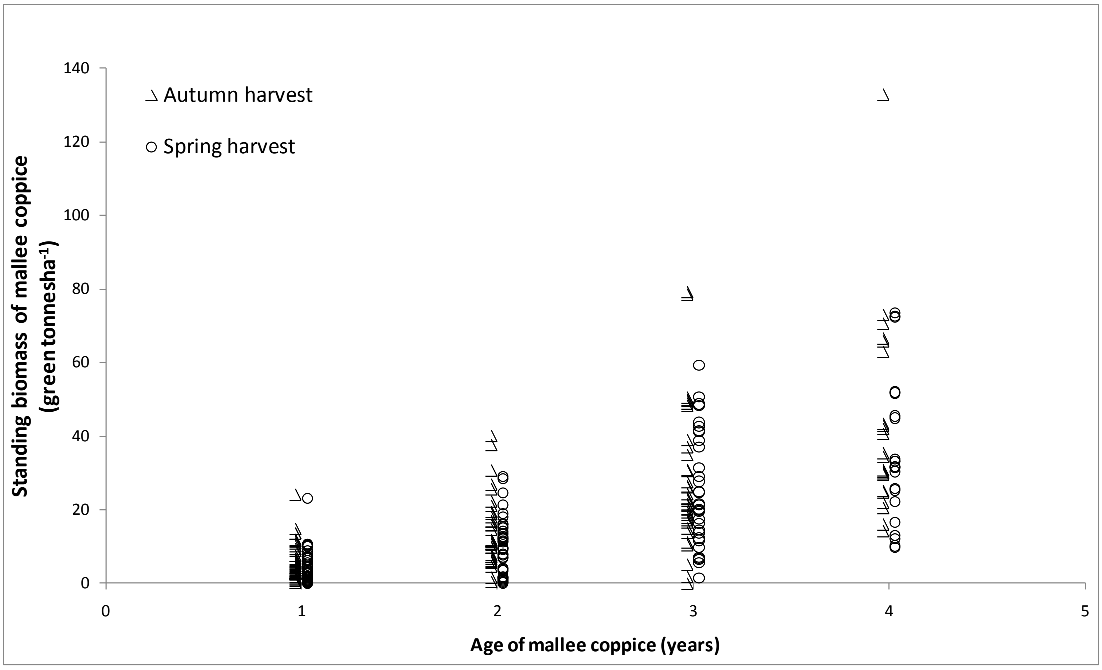

Figure 3-4 Standing biomass of harvested treatments against coppice age at all sites when measured in the period 2007 to 2010 (autumn and spring treatments offset in the figure)

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[3] Excluding site 17 which had been harvested in 2002.

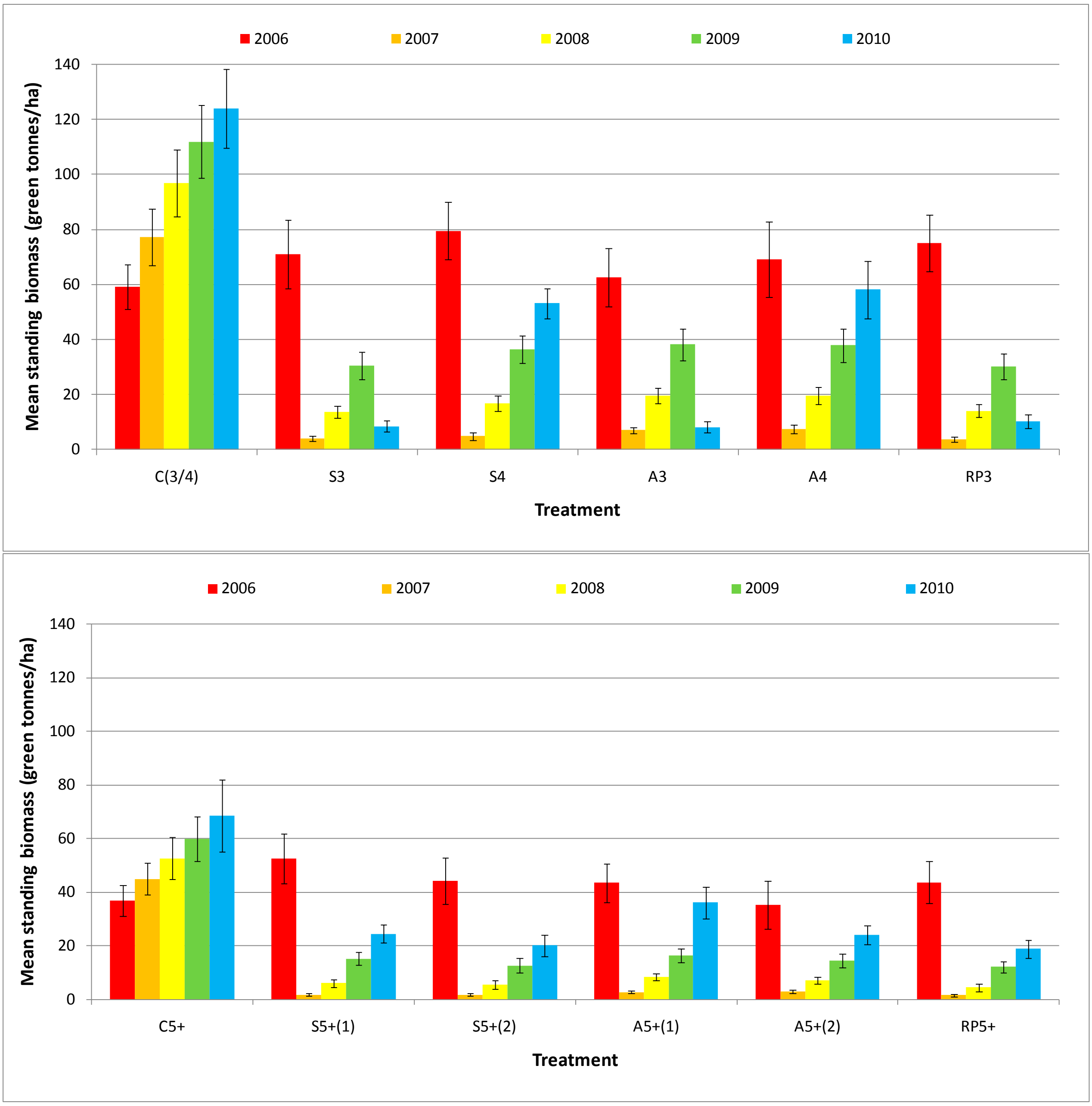

Figure 3-5 Mean standing biomass of mallee treatments across all sites between 2006 and 2010 (standard error bars shown). Approximately eleven sites with 3/4 treatments imposed, and eight sites with 5+ treatments imposed[4].

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[4] Refer to Table 3-3.

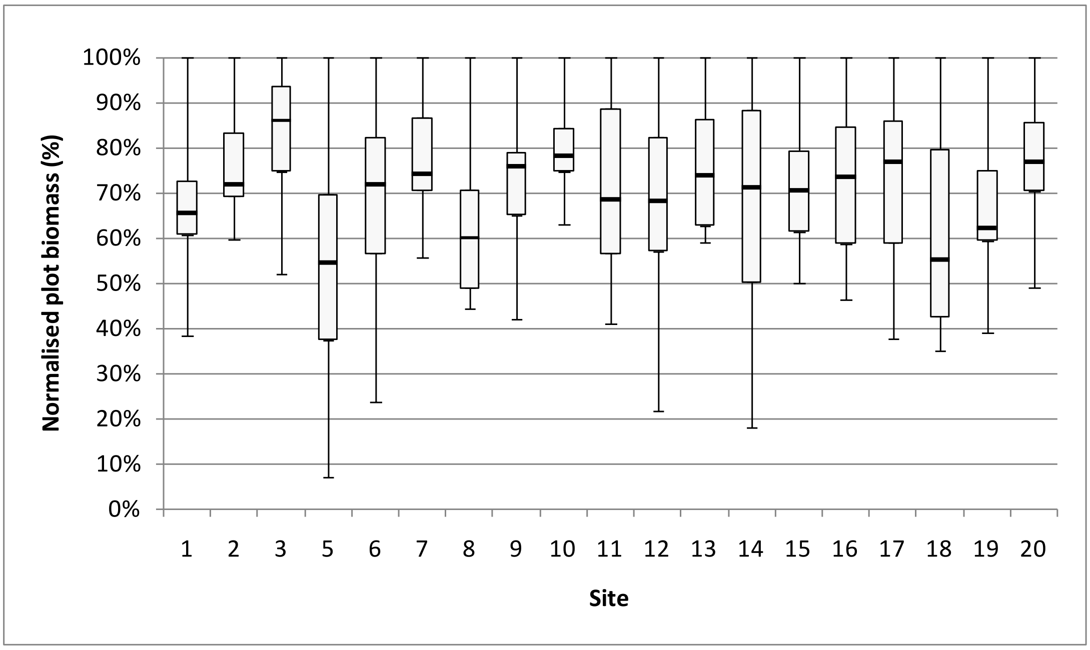

Figure 3-6 Variation in plot biomass at each site prior to harvesting in autumn 2006 (plot biomass expressed as a percentage of the plot with the highest biomass density (tonnes/ha) at each site; n = 18 at each site[5])

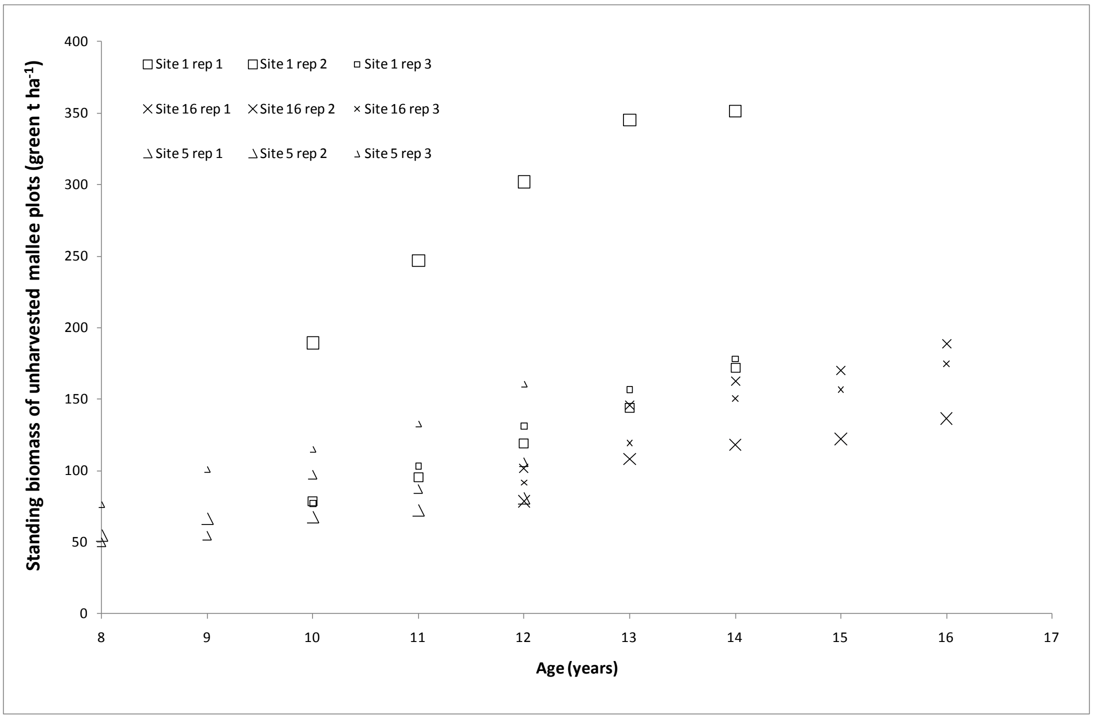

Figure 3-7 Standing biomass of unharvested (Control) plots against mallee age at sites 1, 5 and 16 when measured in the period 2006 to 2010

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[5] Except Site 7 which had 12 plots.

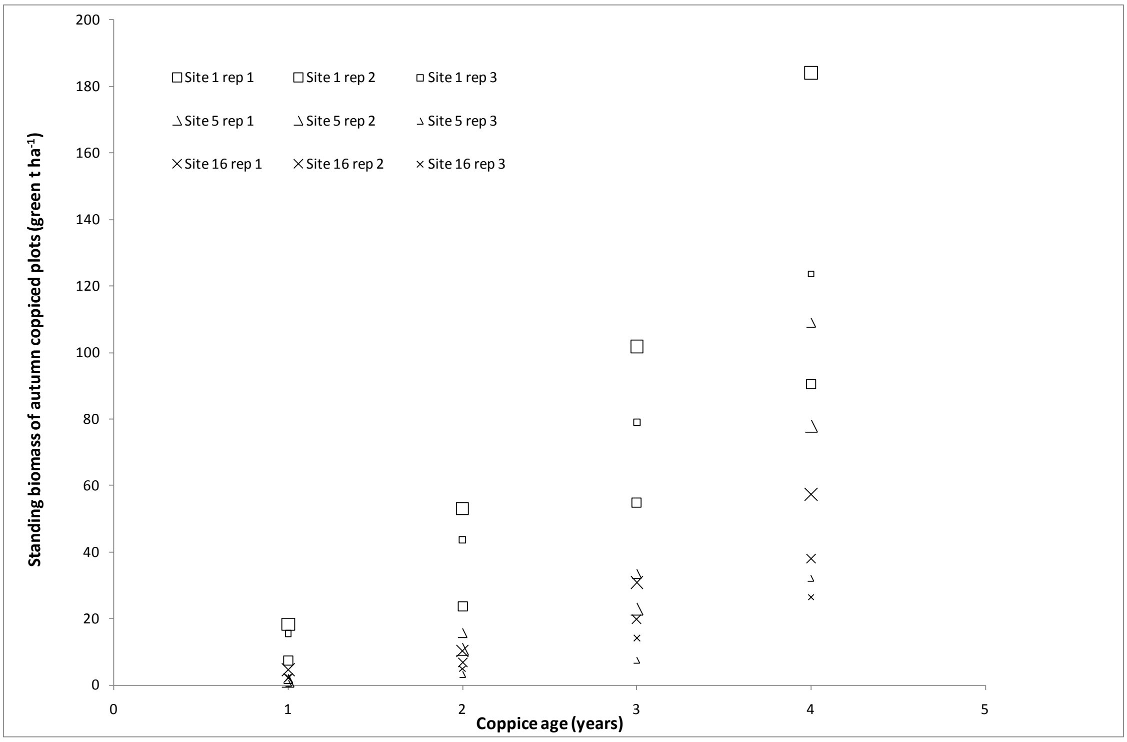


Figure 3-8 Standing biomass of autumn harvested plots (Treatment 5) against coppice age at sites 1, 5 and 16 when measured in the period 2007 to 2010

3.3.2 Mallee growth rates and patterns of growth

Annual biomass production varied markedly between sites (Table 3-4), ranging from zero to greater than 30 green tonnes/ha/year in unharvested (Control) treatments and zero to greater than 50 green tonnes/ha/year in harvested (coppiced) treatments. The largest annual biomass increments in unharvested treatments occurred at Site 1 (36 green tonnes/ha/year in 2007-2008) and in harvested treatments at Sites 1 and 5 (54 green tonnes/ha/year and 52 green tonnes/ha/year respectively in 2009-2010).

Across all sites with 3 and 4 year harvest treatments imposed, the mean annual biomass production of unharvested (Control) treatments typically ranged from about 10 to 20 green tonnes/ha/year in the period 2006 to 2010 (Figure 3-9). There was a general trend of declining growth rates in these treatments over the life of the Project. The growth rates of coppice between 3 and 4 years of age generally matched or exceeded that of the unharvested plots in the equivalent period.

In the unharvested (Control) treatments at sites where 5+ harvest treatments were imposed, annual biomass production rates were approximately half that of the sites with 3 and 4 year harvest treatments imposed (Figure 3-9). At these sites annual growth rates in the unharvested (Control) treatments remained relatively constant over the Project life. The growth rates of coppice between 3 and 4 years of age generally matched or exceeded that of the unharvested plots in the equivalent period, and were also about half of those observed at the sites with 3 and 4 year harvest treatments imposed.

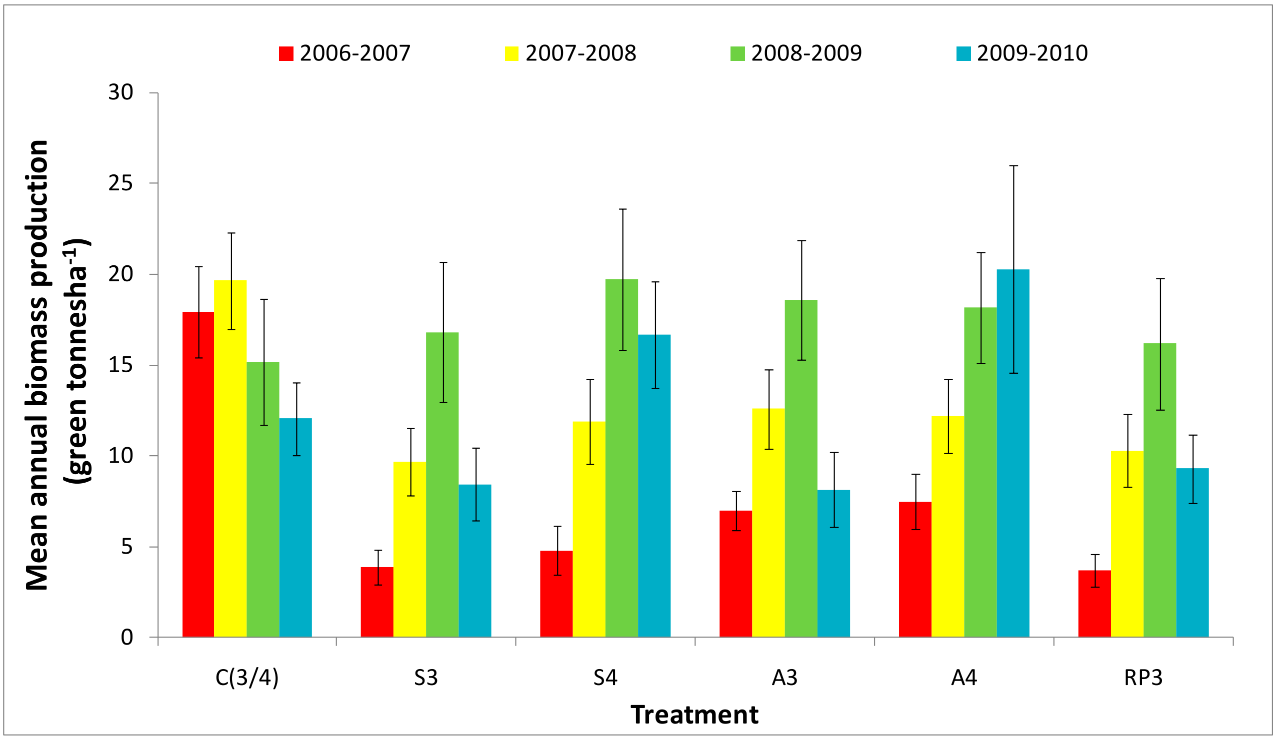
The overall patterns of growth varied substantially between sites, and in some cases within sites, which detracted from the identification of general trends in mallee growth behaviour. Examples of site variability and patterns of growth from selected sites are shown in Figure 3-10. At Site 1 the autumn coppice treatments were significantly more productive than the spring coppice treatments. Note that the spring coppice produced very little biomass in the first year, which was due to grazing damage by sheep. This effectively set back the coppice regrowth by 12 months. In the 3 year harvest treatments, the growth rate of the spring treatment matched that of the autumn treatment in 2010. At Site 5 very large differences in standing biomass across all treatments were evident at the commencement of the Project, reflecting the variable growing conditions at this site. All coppice treatments produced very little biomass in their first year of growth. Coppice growth rates were modest until 2010 when a large surge of growth was observed, particularly in the autumn harvest treatments. This was not reflected in the unharvested (Control) treatment at this site. At Site 18 the unharvested treatments tripled the amount of standing biomass in the period 2006 to 2009. However no growth (within error limits) occurred in 2009 to 2010, indicating a significant change in growing conditions occurred in this period. In contrast all of the harvested treatments displayed growth in the 2009 to 2010. A large growth surge was notable in mallee coppice between 2 and 3 years of age, which was especially pronounced in the spring harvest treatments. Note that at the commencement of the Project the standing biomass of the spring harvest treatments was somewhat greater than that of the autumn harvest and Control treatments at this site, despite the randomised distribution of all plots.

Table 3-4 Annual above ground biomass production of the mallee treatments by site in the period 2006 to 2010.

Site	Year	Annual biomass increment (green tonnes/ha/year)										
		C	S3	S4	A3	A4	RP3	S5+(1)	S5+(2)	A5+(1)	A5+(2)	RP5+
1	2006-2007	33.6	1.0	0.7	11.8	13.7	1.2					
	2007-2008	35.6	14.4	13.3	25.8	26.4	16.4					
	2008-2009	31.2	35.2	27.2	41.6	38.4	31.6					
	2009-2010	18.6	23.1	32.3	24.1	54.3	20.4					
2	2006-2007	5.7						4.6	2.8	3.6	3.6	1.8
	2007-2008	14.0						6.8	5.1	7.2	8.1	5.6
	2008-2009	11.2								7.9	8.6	
	2009-2010											
3	2006-2007	8.7	1.9	1.6	4.6	4.2	1.6					
	2007-2008	9.1	14.3	14.4	12.0	10.5	11.9					
	2008-2009	8.5	8.6	11.7	14.2	9.6	10.2					
	2009-2010	10.7	7.4	17.3	6.4	11.1	6.0					
5	2006-2007	13.7		0.3		1.2	0.3	0.3		1.3		
	2007-2008	19.3		3.1		8.7	3.4	3.9		8.3		
	2008-2009	4.2		6.4		11.4	6.3	7.6		13.4		
	2009-2010	18.4		23.4		51.7	17.3	20.1		42.8		
6	2006-2007	16.6	0.0		2.7		1.3	1.6		2.6		
	2007-2008	27.6	0.3		8.9		5.1	7.5		13.3		
	2008-2009	20.2	1.2		6.2		11.2	11.1		7.4		
	2009-2010	14.6	0.6		1.7		2.0	5.6		20.2		
7	2006-2007	3.7						0.2		0.3		0.1
	2007-2008	0.1						0.0		0.2		0.0
	2008-2009	3.1								-0.5		
	2009-2010											
8	2006-2007	17.1	6.6	6.2	11.3	11.0	6.2					
	2007-2008	29.1	18.0	22.8	10.9	10.2	24.3					
	2008-2009	7.6	14.1	19.4	28.3	27.1	13.7					
	2009-2010	14.4	10.7	24.2	13.5	18.3	11.9					
9	2006-2007	10.7	5.5	10.7	5.4	4.3	6.5					
	2007-2008	16.7	15.8	17.7	13.9	11.8	13.8					
	2008-2009	4.5	7.8	8.7	11.1	10.4	2.8					
	2009-2010	14.4	10.1	14.9	7.4	15.6	6.4					
10	2006-2007	13.8						2.0	2.1	2.6	2.7	1.9
	2007-2008	13.0						10.2	9.8	8.3	8.0	9.0
	2008-2009	10.7						5.3	4.4	10.5	11.9	4.4
	2009-2010	17.8						15.8	14.0	9.1	7.0	13.4

Table 3-4 continued

Site	Year	Annual biomass increment (green tonnes/ha/year)										
		C	S3	S4	A3	A4	RP3	S5+(1)	S5+(2)	A5+(1)	A5+(2)	RP5+
11	2006-2007	15.2						0.8	1.0	5.2	5.4	0.6
	2007-2008	-2.1						0.3	0.4	1.5	0.8	0.3
	2008-2009	10.7						5.5	5.7	4.5	4.3	5.6
	2009-2010	-0.1						3.3	5.1	4.9	3.8	3.7
12	2006-2007	2.7						3.7	2.6	3.7	3.3	2.6
	2007-2008	6.3						5.9	4.4	3.5	2.7	4.1
	2008-2009	5.8						12.0	7.4	10.0	7.9	10.1
	2009-2010	5.0						12.1	7.8	7.9	8.1	7.4
13	2006-2007	17.1	3.4		6.0	4.7	2.4	4.4				
	2007-2008	10.7	6.2		5.7	6.7	5.8	7.2				
	2008-2009	13.5	11.8		15.7	14.8	7.2	13.3				
	2009-2010	12.9	2.7		3.2	3.8	2.0	6.8				
14	2006-2007	5.6						0.6	0.4	0.8	0.3	1.2
	2007-2008	6.8						0.3	0.2	3.8	1.3	-0.3
	2008-2009	4.4								0.5	0.2	
	2009-2010											
15	2006-2007	8.9						0.2	0.5	3.1	2.8	0.5
	2007-2008	14.8						1.4	1.4	4.3	2.9	1.6
	2008-2009	5.2						5.1	3.7	14.2	10.9	4.1
	2009-2010	6.5						6.4	4.6	19.1	17.7	4.9
16	2006-2007	33.8	1.7	2.2	6.7	5.9	2.4					
	2007-2008	19.3	11.1	16.8	24.0	21.0	14.9					
	2008-2009	6.1	18.6	22.5	18.9	22.0	21.6					
	2009-2010	17.1	10.3	10.3	9.2	14.0	14.2					
17	2006-2007	14.3	2.6	3.4	2.6	3.1	2.1					
	2007-2008	7.3	4.4	6.2	8.7	8.6	4.6					
	2008-2009	7.6	6.8	10.3	8.7	7.7	5.3					
	2009-2010	3.6	2.8	11.6	2.8	5.4	2.8					
18	2006-2007	19.0	7.0	7.9	8.7	14.9	7.9					
	2007-2008	23.0	7.9	10.3	8.1	10.8	8.9					
	2008-2009	32.2	33.8	41.2	22.1	24.3	35.5					
	2009-2010	-3.4	10.0	13.1	7.4	20.7	11.8					
19	2006-2007	12.6	9.0	10.2	10.0	11.7	8.8					
	2007-2008	18.5	4.5	2.3	7.9	7.2	4.0					
	2008-2009	31.5	30.2	30.1	19.0	16.0	32.5					
	2009-2010	11.5	6.7	2.9	5.9	7.9	7.5					
20	2006-2007	8.4						1.3	3.1	4.3	2.9	3.3
	2007-2008	8.1						2.6	4.6	6.7	4.9	2.6
	2008-2009	8.3						8.4	11.9	12.1	7.2	9.8
	2009-2010	2.9						4.4	5.7	7.8	5.5	3.8



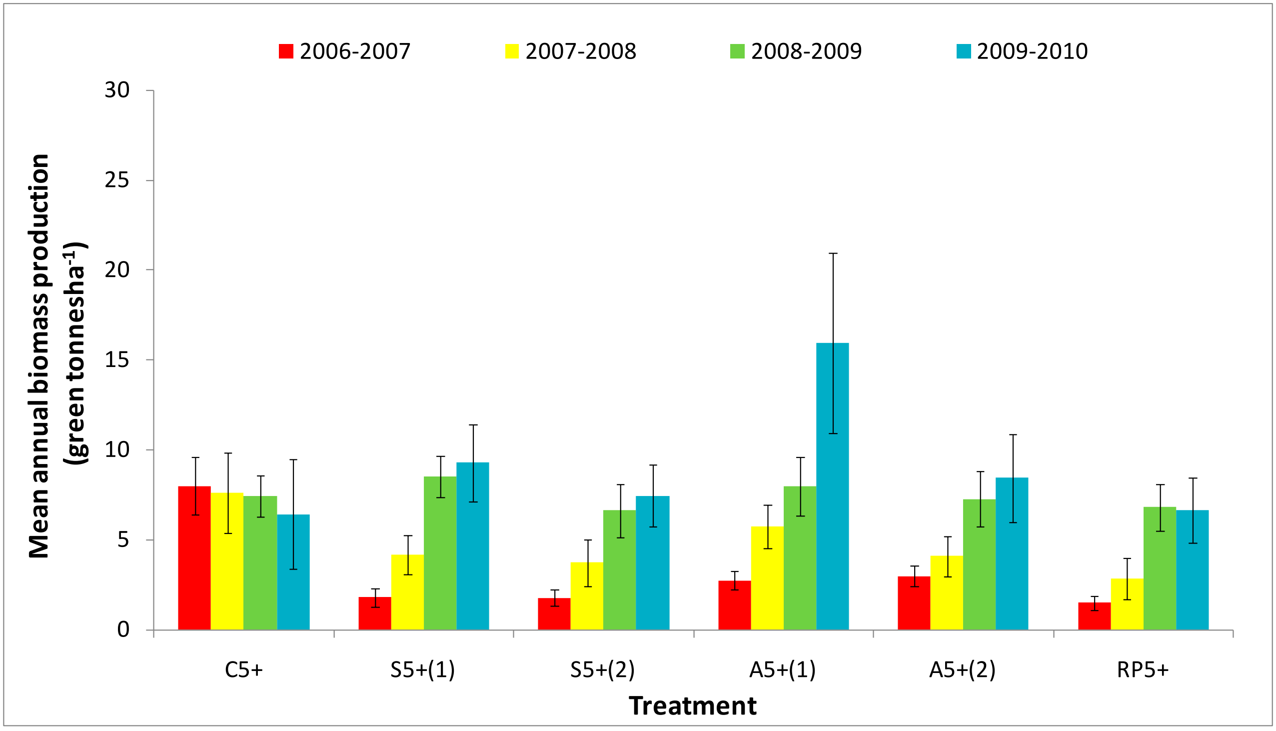


Figure 3-9 Mean annual increment of mallee treatments across all sites (standard error bars shown). Eleven sites with 3/4 treatments imposed, and eight sites with 5+ treatments imposed.

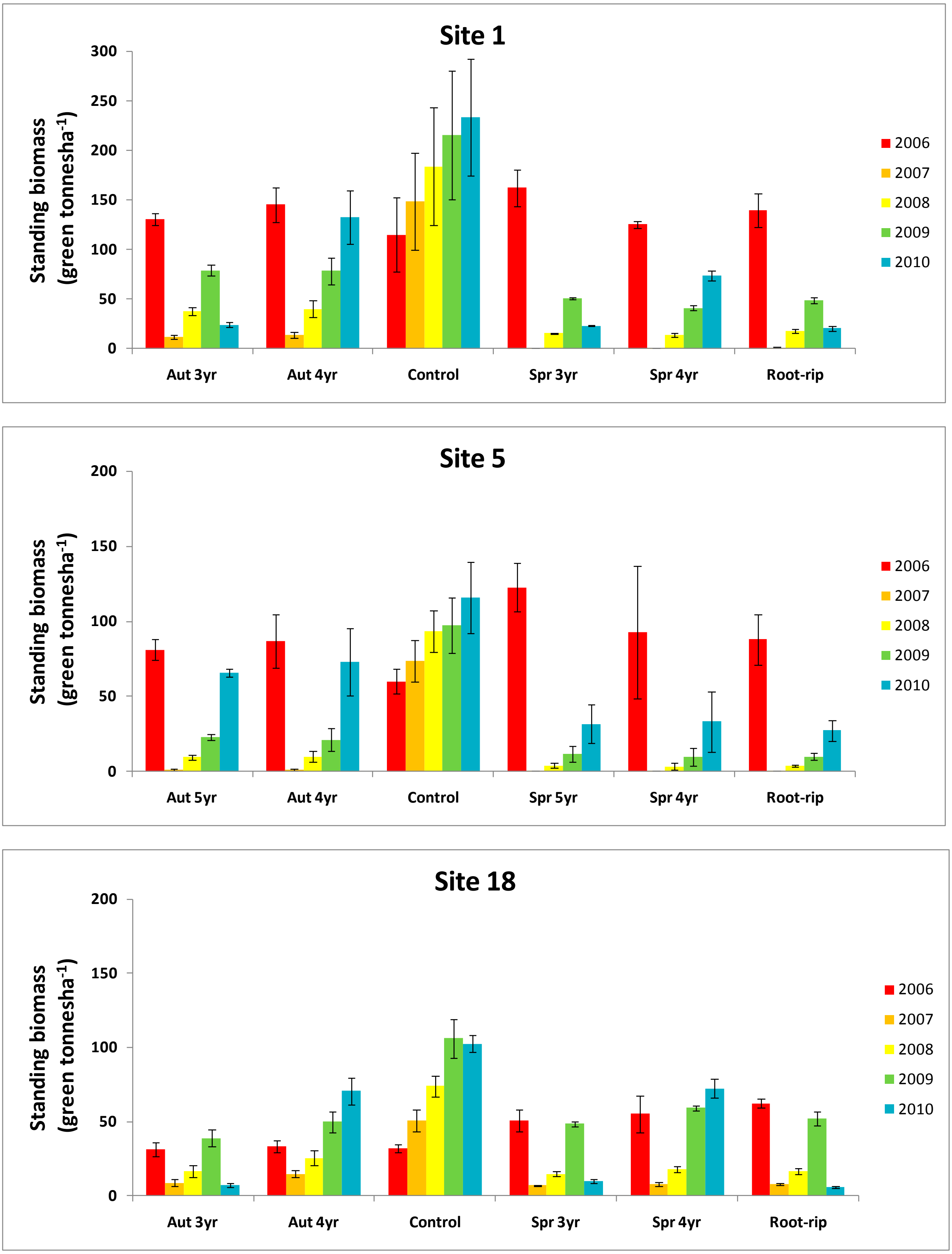


Figure 3-10 Standing biomass at sites 1, 5 and 18 between 2006 and 2010, showing patterns of growth in different treatments

3.3.3 Biomass partitioning and moisture content

3.3.3.1 Moisture content – unharvested mallee

The moisture content of mallee biomass destructively harvested in autumn 2006 varied between biomass components and also between sites (Table 3-5). For each of the wood, bark, twig and leaf components these differences were significant for some site combinations, but without consistent trends or differences between sites and species. The wood biomass at Site 8 had low mean moisture content (34%) relative to nine other sites; whilst wood moisture content for all other sites was not significantly different. Bark moisture content was more variable between sites; with the Esperance sites (18, 19 & 20) distinguished by relatively high bark moisture content (47 to 52%) and sites 15 and 16 near Kalannie by low bark moisture content (38 to 39%). Twig biomass was generally less variable between sites. At any given site the leaf biomass generally had higher moisture content than other biomass components. The Esperance sites were distinguished by relatively high leaf moisture content (51 to 54%), in addition to Site 8 (53%) and Site 2 (51%). The leaf component at Site 11 had low leaf moisture content (42%) in comparison with other sites.

The moisture content of biomass components, combined with biomass partitioning measurements, enabled the overall moisture content of the above ground biomass to be estimated at each site (using mass weighted biomass component means). The mean above ground biomass moisture content at most sites ranged between 41 and 44%. The Esperance sites were distinguished by relatively high above ground biomass moisture content (45.6% to 46.3%), whilst Site 11 was distinguished by relatively low above ground biomass moisture content (40.3%)

The limited number of samples measured in spring prevented a quantitative comparison of biomass moisture between the seasons, however inspection of the data indicated generally minor differences between autumn and spring 2006 at most sites where spring measurements were taken (sites 6, 8, 9, 15 and 17). Student’s t-tests indicated that significant reductions in moisture content between autumn and spring wood biomass components occurred at site 15, in bark components at sites 6 and 17, and in leaf components at site 15.

3.3.3.2 Moisture content – mallee coppice

The biomass moisture content of mallee coppice was only measured at a subset of sites, and included a more variable number of samples per site (i.e. one to six) as dictated by field work resources. This included measurements of both three and four year old coppice in autumn (Table 3-6) and spring (data not shown). A significant reduction in the moisture content of some biomass components between age 3 and age 4 was recorded at sites 9, 17 and 18 (n = 6 per site). A significant increase in leaf biomass moisture content was recorded at site 13. The limited number of samples measured in spring prevented a quantitative comparison between the seasons, however inspection of the data indicated similar trends to the autumn measurements dataset with no clear patterns of response.

In overall terms the coppice wood biomass consistently had a higher moisture content than the older mallee biomass that was harvested in 2006 (refer to Table 3-5). The coppice bark moisture content was variable in comparison with older mallee biomass, whereas the coppice twig and leaf moisture content was generally lower than the older mallee biomass.

There were differences in the moisture content of biomass components ofage 3 and 4 coppice respectively between sites, some of which were significant based on Tukey’s test(Table 3-6). The *Eucalyptus polybractea* coppice (sites 1, 8, 18 & 19) consistently had low wood moisture content relative to the other mallee species.

Table 3-5 Significant differences in the moisture content of unharvested mallee biomass components between sites at the commencement of the Project in autumn 2006 (Tukey's test, 95% confidence interval).

	Control moisture content (% and ANOVA grouping)				
Site	Wood	Bark	Twig	Leaf	Above ground biomass[6]
1	36.8 ab	47.0 bcd	43.2 abc	45.9 bcde	41.5 d
2	38.7 a	n/a	45.4 ab	50.8 abcd	44.1 abcd
3	39.5 a	42.0 defg	43.6 abc	47.0 abcde	43.3 abcd
5	40.3 a	44.1 cdef	43.4 abc	47.1 abcde	42.5 abcd
6	37.4 ab	43.9 cdef	45.1 ab	45.4 cde	41.7 bcd
7	36.9 ab	42.0 defg	42.8 abc	48.1 abcde	41.6 b
8	34.2 b	40.7 efg	44.9 ab	52.6 ab	42.8 abcd
9	39.4 a	42.6 defg	47.0 a	47.3 abcde	43.0 abcd
10	39.2 a	46.4 bcd	43.9 abc	45.1 de	42.8 abcd
11	36.9 ab	45.5 bcde	39.1 c	42.0 e	40.3 d
12	37.5 ab	38.8 g	42.9 abc	45.3 cde	41.7 cd
13	37.4 ab	44.0 cdef	44.3 abc	47.1 abcde	42.7 abcd
15	38.8 a	38.3 g	40.6 bc	46.1 bcde	39.6 d
16	38.0 a	39.3 fg	45.7 ab	48.6 abcde	42.2 bcd
17	40.2 a	47.7 abc	44.2 abc	46.0 bcde	43.6 abcd
18	37.3 ab	50.2 ab	43.0 abc	53.6 a	45.9 ab
19	36.8 ab	52.3 a	44.5 abc	52.2 abc	46.3 a
20	40.4 a	46.7 bcd	44.6 abc	50.8 abcd	45.6 abc
Species means					
E. polybractea	35.9	46.9	43.9	50.8	44.3
E. loxophleba subsp. *lissophloia*	38.6	43.7	44.3	47.0	43.1
E. kochii ssp *plenissima*	37.1	39.4	41.3	44.7	41.3
All species	37.8	43.6	43.7	47.3	43.0

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[6] Determined using mass weighted means of biomass components.

Table 3-6 Comparison of biomass moisture contentbetween sites for coppiced mallee at age 3 and age 4 respectively (Tukey's test, 95% confidence interval). Highlighted cells show a significant change between age 3 and age 4 for given sites (Students' t-test, p <0.05)

	Coppice moisture content (% and ANOVA grouping)									
	Age 3 coppice					Age 4 coppice				
Site	Wood	Bark	Twig	Leaf	Overall	Wood	Bark	Twig	Leaf	Overall
1	48.5 ab	55.1 a	43.2 ab	50.0 ab	47.9 a	44.8 cd	49.8 a	44.1 a	51.8 a	46.7 ab
3	52.7 ab	45.5 bcd	41.8 ab	44.1 c	44.5 bcd	50.0 ab	43.7 bc	40.3 ab	42.5 c	43.4bc
6						48.6 bcd	40.5 c	38.4 ab	43.5 c	42.4 c
8	46.9 b	43.9 cd	37.9 c	46.4 bc	42.6 d	46.2 bcd	44.7 bc	42.0 ab	46.7 abc	44.4 abc
9	51.1 ab	43.9 bcd	43.0 ab	47.3 bc	45.9 abc	48.9 bc	42.7 c	38.0 ab	42.6 c	42.2 c
13	51.5 ab	40.5 d	39.6 bc	43.5 c	43.0 cd	50.1 ab	41.7 c	40.1 ab	45.9 bc	44.4 abc
16	54.4 a	47.4 bc	41.7 ab	46.6 bc	45.4 abcd	54.3 a	47.5 ab	41.7 ab	47.6 abc	46.8 ab
17	52.8 ab	44.5 bcd	44.0 a	49.3 ab	47.9 a	47.8 bcd	42.4 c	41.7 ab	46.8 abc	47.9 a
18	47.3 b	50.4 ab	41.8 ab	52.0 a	46.5 ab	44.9 cd	43.5 bc	39.3 ab	49.3 ab	43.8 bc
19						44.7 d	42.6 c	37.8 b	45.7 bc	41.9 c
Min	**46.9**	**40.5**	**37.9**	**43.5**	**42.6**	**44.8**	**41.7**	**38.0**	**42.5**	**41.9**
Max	**54.4**	**55.1**	**44.0**	**52.0**	**47.9**	**54.3**	**49.8**	**44.1**	**51.8**	**47.9**
Mean	**50.6**	**46.4**	**41.6**	**47.4**	**45.5**	**48.4**	**44.5**	**40.9**	**46.7**	**44.4**

3.3.3.3 Biomass partitioning – unharvested mallee

E. loxophleba ssp *lissophloia* had significantly higher wood and bark proportions and lower leaf proportion than other mallee species (Table 3-7) despite lower total mean biomass. The only difference between partitioning of *E. polybractea* and *E. kochii* ssp *plenissima* is in the higher proportion of bark in the latter. The proportion of twig is the same for all species.

Table 3-7 Biomass partitioning of uncut trees by species.

Species (N)	Mean tree biomass (green kg)	Biomass fraction							
		Wood %	SE	Bark %	SE	Twig %	SE	Leaf %	SE
E.polybractea (27)	55.1	29.3	1.9	5.9	0.4	32.9	1.3	31.9	1.5
E.loxophleba lissophloia (82)	36.5	35.8	0.9	6.9	0.1	31.9	0.8	25.4	0.7
E.plenissima (24)	57.4	28.3	2.6	10.5	0.8	32.0	1.7	29.3	1.9
All species (133)	44.1	33.4	0.9	7.6	0.2	31.7	0.6	27.3	0.6

Biomass partitioning in the mallees destructively harvested in autumn 2006 varied substantially between sites (Table 3-8). For each of the wood, bark, twig and leaf components these differences were significant for some site combinations (Tukey's test; $p < 0.05$), but generally without consistent trends or differences between species. The differences can partially be explained by the different range of tree sizes occurring at different sites.

There was a high proportion of wood biomass at Site 5 (51%) relative to other sites. Other sites with a high proportion of wood biomass includedsites 1, 7, 9 and 16. With the exception of Site 7 (salt affected) these sites included the largest and oldest trees. Site 11 had a significantly low proportion of wood (13%) compared with all other sites. Other sites with relatively little wood partitioning included sites 18, 19 and 20; which comprised the youngest mallee plantings.

Bark partitioning was relatively similar across all sites with the exception of sites 15 and 16 (greater bark proportion) and sites 18 and 19 (lower bark proportion). These differences were significant for some site combinations. The data may reflect species differences in bark partitioning (i.e. greater bark in *E. kochii* subsp. *plenissima*), however additional measurements across a greater range of sites and mallee age classes are required to elucidate this.

Sites 1, 5, 6, 7 and 16 had significantly less twig partitioning compared with the majority of other sites. This finding wasrelated to the relatively high proportion of wood in the above ground biomass at these sites. Conversely Site 11 had the highest proportion of twig biomass, which was significantly greater than these aforementioned sites.

Sites with the highest proportion of leaf biomass included sites 11, 18, 19 and 20; all of which included relatively young and/or small mallees. In contrast sites where the mallees had a relatively low proportion of leaf biomass (sites 2, 5, 9and 16) included a mixture of mallee age classes and sizes.

The limited number of samples measured in spring prevented a quantitative comparison of biomass partitioning between the seasons, however inspection of the data indicated generally minor differences between autumn and spring 2006 at sites where spring measurements were taken (sites 6, 8, 9, 15 and 17). Student's t-tests indicated that significant differences in bark biomass partitioning between mallees harvested in autumn and spring occurred at Site 6, in twig biomass partitioning at Site 9, and in leaf biomass partitioning at Site 15. Given the small sample sizes (n=6) these findings may be an artefact of differences in the size of individual mallees sampled in autumn and spring respectively.

Relationships between biomass partitioning and mallee above ground biomass were investigated (Figure 3-11). Wood biomass increased non-linearly with above ground biomass, and consistently exceeded 25% for mallees with total above ground biomass greater than 30 kg (green). Data were limited for mallees with above ground biomass greater than 100 kg (green), however the wood proportion appeared to level off between 40% and 60% in the largest size classes. The bark biomass proportion was more variable across size classes and ranged from 4 to 16%. The data indicated that *E. kochii* subsp. *plenissima*biomass may be characterised by a greater bark proportion than the other species. Twig biomass proportion also varied substantially across a range of size classes, with a slight negative correlation with mallee above ground biomass apparent. Leaf biomass generally declined with mallee size, and for mallees in the larger size classes appeared to level off between 15% and 25%.

Table 3-8 Significant differences in above ground biomass partitioning between sites at the commencement of the Project in autumn 2006 (Tukey's test, 95% confidence interval).

Site	Green biomass partitioning (% and ANOVA grouping)			
	Wood	Bark	Twig	Leaf
1	41.1 ab	7.9 bc	26.1 bc	24.9 defg
2	36.6 bcd	7.3 cd	33.6 abc	22.4 efg
3	28.5 cdef	6.0 cd	37.7 ab	27.8 def
5	50.9 a	6.7 cd	25.4 c	17.0 g
6	37.9 bcd	6.8 cd	25.9 bc	29.4 bcde
7	41.2 ab	7.4 cd	26.4 bc	24.9 defg
8	33.6 bcde	6.1 cd	33.6 abc	26.7 def
9	39.3 abc	7.6 cd	32.4 abc	20.7 efg
10	32.5 bcde	7.0 cd	36.4 abc	24.1 defg
11	12.9 g	6.1 cd	40.8 a	40.3 a
12	29.9 bcdef	6.6 cd	34.4 abc	29.1 bcdef
13	32.4 bcde	7.3 cd	34.2 abc	26.2 defg
15	31.5 bcde	10.9 b	29.7 abc	27.9 cdef
16	40.6 ab	14.4 a	25.4 c	19.6 fg
17	36.7 bcd	6.9 cd	30.8 abc	25.6 defg
18	23.0 efg	5.0 cd	34.5 abc	37.5 abc
19	19.6 fg	4.8 d	37.3 abc	38.3 ab
20	26.8 def	6.2 cd	34.4 abc	32.7 abcd

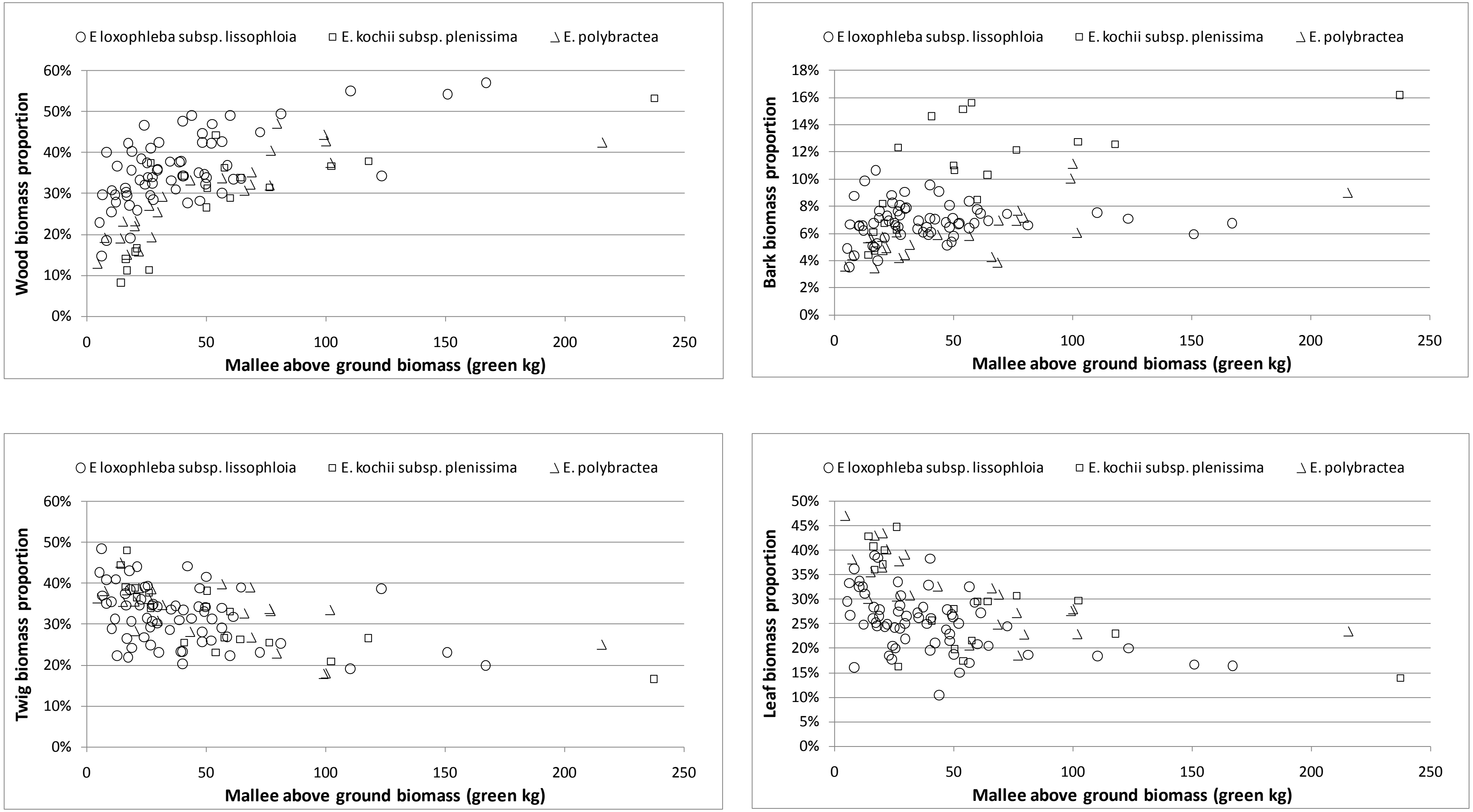

Figure 3-11 Relationships between biomass components (wood, bark, twig and leaf) and mallee above ground biomass (green weight basis) in unharvested(Control) treatments

Quantitative relationships between above ground biomass and biomass components were developed using linear regression techniques (Table 3-9). Analysis of residuals indicated that square root transformations improved the species regression models, and were preferable to log transformations. For all species, in general the proportion of wood was positively correlated with above ground biomass, and leaf and twig proportions were negatively correlated with above ground biomass. The bark proportion was positively correlated with above ground biomass in the case of *E. kochii* subsp. *plenissima* and *E. polybractea*, but there was no relationship in *E. loxophleba* subsp. *lissophloia*. To further investigate this finding the ratio of bark to wood from the *E. loxophleba* subsp. *lissophloia* was determined and contrasted across sites and mallee size classes. There was a weak negative correlation between mallee above ground biomass and the bark to wood ratio for mallees with above ground biomass of less than 100 kg (Figure 3-12). There was no significant difference in the bark to wood ratio between sites, with the exception of Site 5 (significantly lower bark to wood ratio) and Site 20 (significantly higher bark to wood ratio.

Table 3-9 Regression coefficients for linear regression models relating biomass partitioning with total above ground biomassfor unharvested mallee.Regression models of the form $\sqrt{Y}= a\times \sqrt{X}+ b$, where X is total above ground biomass (green kg)[7]

Species	Size range (green kg above ground biomass *X*)	Biomass fraction oftotal above ground biomass (*Y*)	n[8]	a	b	r^2
E. loxophleba subsp. *lissophloia*	5 to 100	Wood	58	0.0212	0.4738	0.50
		Bark	57	0.0007	0.2569	0.01
		Twig	60	-0.016	0.6554	0.33
		Leaf	54	-0.0146	0.589	0.46
E. kochii subsp. *plenissima*	10 to 100	Wood	15	0.0472	0.182	0.72
		Bark	16	0.0194	0.1846	0.49
		Twig	16	-0.0258	0.7398	0.66
		Leaf	15	-0.0234	0.7093	0.44
E. polybractea	5 to 100	Wood	23	0.0345	0.3081	0.84
		Bark	21	0.0094	0.1781	0.52
		Twig	23	-0.0155	0.6723	0.37
		Leaf	20	-0.021	0.7099	0.75

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[7] The ratio method of Snowden (1991) was used to test for bias in back transformation of the square root transform. Correction factors were consistently within 1 to 2% of unity and therefore omitted.

[8] Number of observations included in the regression model.

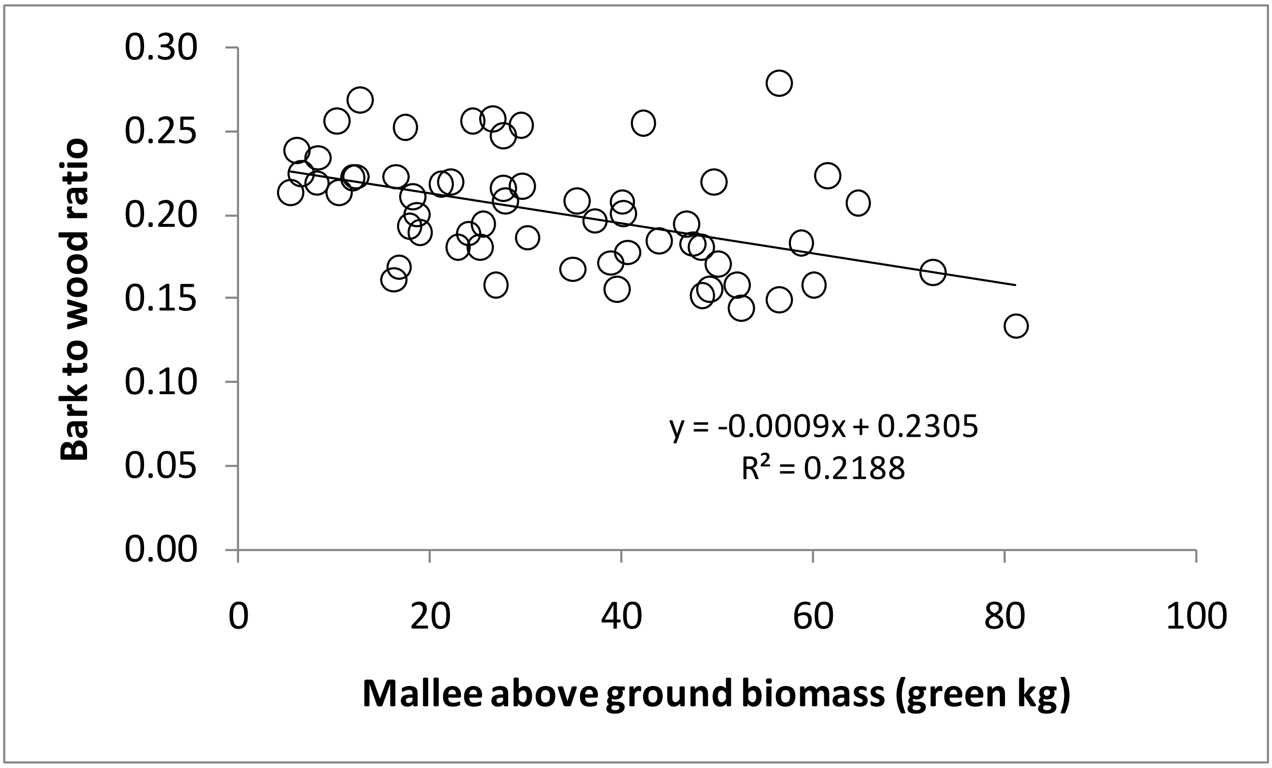

Figure 3-12 **Relationship between bark to wood ratio and above ground biomass in *E. loxophleba* subsp. *lissophloia* unharvested (Control) treatments (n = 60)**

3.3.3.4 Biomass partitioning – mallee coppice

Biomass partitioning in coppiced treatments varied substantially between sites. For each of the wood, bark, twig and leaf components these differences were significant for some site combinations (Tukey's test; $p < 0.05$), but generally without consistent trends or differences between species. The differences can partially be explained by the different range of mallee sizes occurring at different sites.

The wood biomass proportion of above ground biomass ranged between 10% and 27% for age 3 coppice and 18% to 32% for age 4 coppice (Tables 3-10 and 3-11). Differences in wood proportion between sites were generally not significant. Between age 3 and 4 the wood proportion increased significantly at some (but not all) sites.

Bark and twig partitioning ranged between 2% and 5% and 29% to 45% respectively for age 3 coppice, and 4% to 7% and 35% to 46% respectively for age 4 coppice (Tables 3-10 and 3-11). Differences between sites were generally not significant.

Leaf partitioning ranged between 32% and 47% for age 3 coppice, with some significant differences between sites. In the age 4 coppice leaf partitioning ranged between 27% and 43% with less pronounced site differences. Site 13 was notable in having a relatively high proportion of leaf biomass at age 4 (43%) compared with other sites.

The limited number of samples measured in spring prevented a quantitative comparison of biomass partitioning between the seasons, however inspection of the data indicated generally minor differences between autumn and spring 2006 at sites where spring measurements were taken.

Relationships between biomass partitioning and coppice above ground biomass exhibited broadly similar patterns to the unharvested mallees (Figure 3-13); however for plants with equivalent above ground biomass the proportion of wood in mallee coppice (10% to 35%) was generally less than in unharvested mallee (20% to 50%). Conversely twig partitioning was greater in the mallee coppice. Leaf partitioning appeared to be reasonably similar for mallee coppice and unharvested mallee, with some indication of a slightly greater leaf proportion in mallee coppice in the 50 to 100 kg (green) above ground biomass range.

Quantitative relationships between above ground biomass and biomass components for mallee coppice (age 3 and 4) were developed using linear regression techniques(Table 3-12). Analysis of residuals indicated that square root transformations improved the species linear regression models, and were preferable to log transformations. For all species, in general the proportion of wood was positively correlated with above ground biomass, and leaf and twig proportions were negatively correlated with above ground biomass. The coefficients of determination (r^2 values) for the biomass partitioning relationships for mallee coppice generally indicated a lower goodness of fit in comparison with the unharvested mallees. This may be explainable by the wider range of growth forms exhibited by mallee coppice (i.e. from few to many stems across a range of stem size classes). There was a noticeable lack of correlation between above ground biomass and leaf biomass for *E. loxophleba* subsp. *lissophloia* and *E. polybractea* across the full range of measured sizes classes. Inspection of the pooled dataset suggested that differences in leaf partitioning between sites may have contributed to this result, however this was not quantitatively assessed.

Table 3-10 **Green biomass partitioning of three and four year old mallee coppice treatments (mean of 6 mallees per site[9]). Highlighted cells show a significant change between age 3 and age 4 (Student's t-test, $p < 0.05$)**

Site	Species	Wood (%)		Bark (%)		Twig (%)		Leaf (%)	
		Age 3	Age 4	Age 3	Age 4	Age 3	Age 4	Age 3	Age 4
1	*E. polybractea*	27	32	5	5	29	35	40	28
3	*E. loxophleba* subsp. *lissophloia*	15	22	3	5	43	39	38	34
8	E. *polybractea*	10	21	2	4	45	46	44	29
9	*E. loxophleba* subsp. *lissophloia*	19	24	3	5	42	42	36	29
13	*E. loxophleba* subsp. *lissophloia*	13	18	3	4	37	35	47	43
16	*E. kochii* subsp. *plenissima*	12	22	3	7	42	38	42	33
17	*E. loxophleba* subsp. *lissophloia*	20	25	5	4	36	40	39	31
18	*E. polybractea*	21	28	4	5	44	38	32	27
Min		**10**	**18**	**2**	**4**	**29**	**35**	**32**	**27**
Max		**27**	**32**	**5**	**7**	**45**	**46**	**47**	**43**
Mean		**17**	**24**	**4**	**5**	**40**	**39**	**40**	**32**

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[9] With the exception of site 18 (age 3) which included four samples only, and sites 1 and 16 (age 4) which included five samples only.

Table 3-11 Significant differences in above ground biomass partitioning between sites for coppiced mallee wood and leaf components (Tukey's test,95% confidence interval).

	Age 3 coppice				Age 4 coppice			
Site	Wood %	Bark %	Twig %	Leaf %	Wood %	Bark %	Twig %	Leaf %
1	26.8 a	4.8 a	28.9 b	39.5 abc	32.3 a	5.0 ab	35.2 b	27.6 b
3	15.4 b	3.4 ab	43.2 a	37.9 bc	22.3 ab	4.5 ab	39.4 ab	33.7 ab
6	19.7 ab	4.6 a	36.2 ab	39.5 abc	19.9 ab	4.1 b	41.2 ab	34.8 ab
8	09.8 b	1.9 b	44.6 a	43.6 ab	20.9 ab	3.9 b	46.0 a	29.2 b
9	18.7 ab	3.4 ab	42.2 a	35.7 bc	23.9 ab	5.0 ab	41.9 ab	29.2 b
13	12.7 b	3.0 ab	36.8 ab	47.4 a	17.9 b	3.8 b	35.4 b	42.9 a
16	12.4 b	3.2 ab	42.4 a	42.0 ab	22.2 ab	7.1 a	38.2 ab	32.5 ab
17	20.5 ab	4.7 a	35.8 ab	39.0 abc	24.6 ab	4.4 b	39.7 ab	31.3 b
18	20.6 ab	3.8 ab	44.1 a	31.6 c	28.3 ab	5.0 ab	39.7 ab	27.1 b

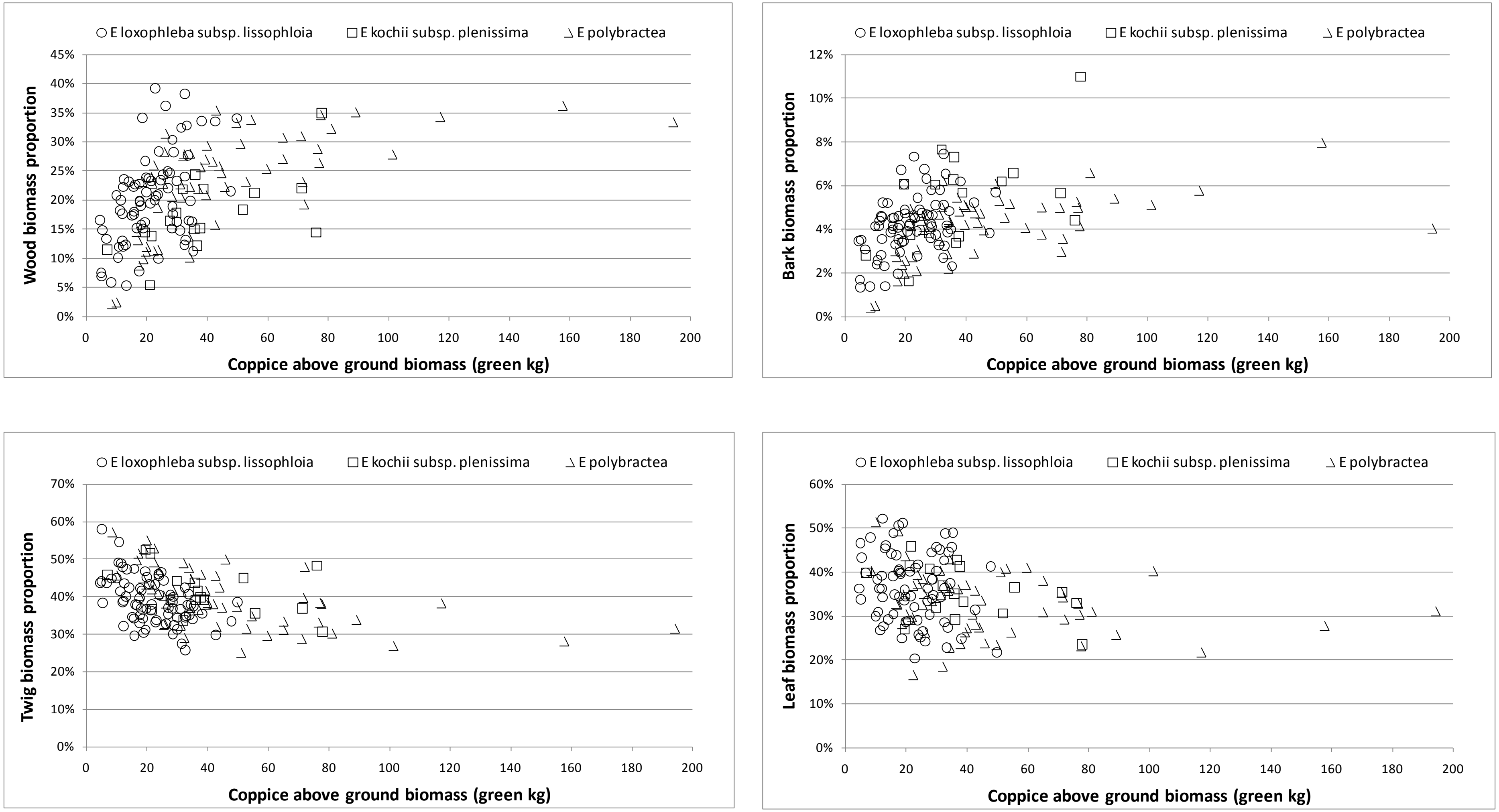

Figure 3-13 Relationships between biomass components (wood, bark, twig and leaf) and mallee coppice (combined age 3 and 4) above ground biomass (green weight basis)

Table 3-12 Regression coefficients for linear regression models relating biomass partitioning with total above ground biomass for 3 and 4 year old mallee coppice. Regression models of the form $\sqrt{Y} = a \times \sqrt{X} + b$, where X is total above ground biomass (green kg)[10]

Species	Size range (green kg above ground biomass X)	Biomass fraction oftotal above ground biomass (Y)	n[11]	a	b	r^2
E. loxophleba subsp. *lissophloia*	5 to 50	Wood	64	0.0393	0.2697	0.41
		Bark	64	0.0095	0.162	0.19
		Twig	68	-0.0182	0.7082	0.24
		Leaf	74	-0.0102	0.6497	0.03
E. kochii subsp. *plenissima*	5 to 80	Wood	16	0.0231	0.282	0.35
		Bark	16	0.0159	0.131	0.29
		Twig	16	-0.0183	0.7471	0.37
		Leaf	16	-0.0181	0.7113	0.36
E. polybractea	10 to 100	Wood	51	0.0253	0.326	0.35
		Bark	48	0.0079	0.1562	0.32
		Twig	51	-0.0205	0.7609	0.39
		Leaf	20	-0.0077	0.6197	0.07

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[10] The ratio method of Snowden (1991) was used to test for bias in back transformation of the square root transform. Correction factors were consistently within 1 to 2% of unity and therefore omitted.

[11] Number of observations included in the regression model.

3.3.4 Growth of interior vs edge rows.

Sites that contained multiple (> 2 row) row belts are described in Table 3-13. At all of these sites the yield of the internal rows was generally less than the edge rows (Table 3-14 and Figure 3-14).

In unharvested treatments the biomass yield of interior rows progressively decreased in comparison with edge rows over the period 2006 to 2010 (Figure 3-14). In 2006 across all sites the interior row biomass was on average about 75% of the edge row. By 2010this proportion has decreased to about 60% of the edge row.Examination of data from individual sites revealed different patterns of change between 2006 and 2010 (Figure 3-15). Sites 3, 6, 8, 18 were characterised by strongly declining interior row yield relative to the edge rows over this period. Sites 12, 19 and 20 exhibited a less pronounced decline with some trend reversals between years.

In coppiced treatments, interiorrow biomass yield was on average about 70% to 80% of edge rows from age 1 to 4 (Figure 3-14). Examination of data from individual sites revealed different patterns of change between 2007 and 2010 (Figure 3-16). Sites 6 and 8 exhibited a pattern of strongly declining interior row yield relative to the edge rows over this period. By 2010 the internal row yields at these sites were less than 50% of the edge row yield. At sites 3, 18 and 19 interior row yields were less than edge rows (in the order of 60% to 80% of edge rows) without a clear increasing or declining trend. At sites 12 and 20 internal row yield was comparable to the edge rows.

The overall data suggests a negative correlation between edge row biomass (tonnes/ha) and internal row yield as a proportion of edge row yield, however this was not quantitatively assessed and is subject to individual site effects.

Table 3-13 Sites with multiple row belts

Site	Number of rows	Year of establishment	Species
3	3	2000	*E. loxophleba* subsp. *lissophloia*
5	4	1998	*E. loxophleba* subsp. *lissophloia*
6	3	1999	*E. loxophleba* subsp. *lissophloia*
8	4	1998	*E. polybractea*
12	6	2000	*E. loxophleba* subsp. *lissophloia*
18	6	2001	*E. polybractea*
19	6	2001	*E. polybractea*
20	6	2001	*E. loxophleba* subsp. *lissophloia*

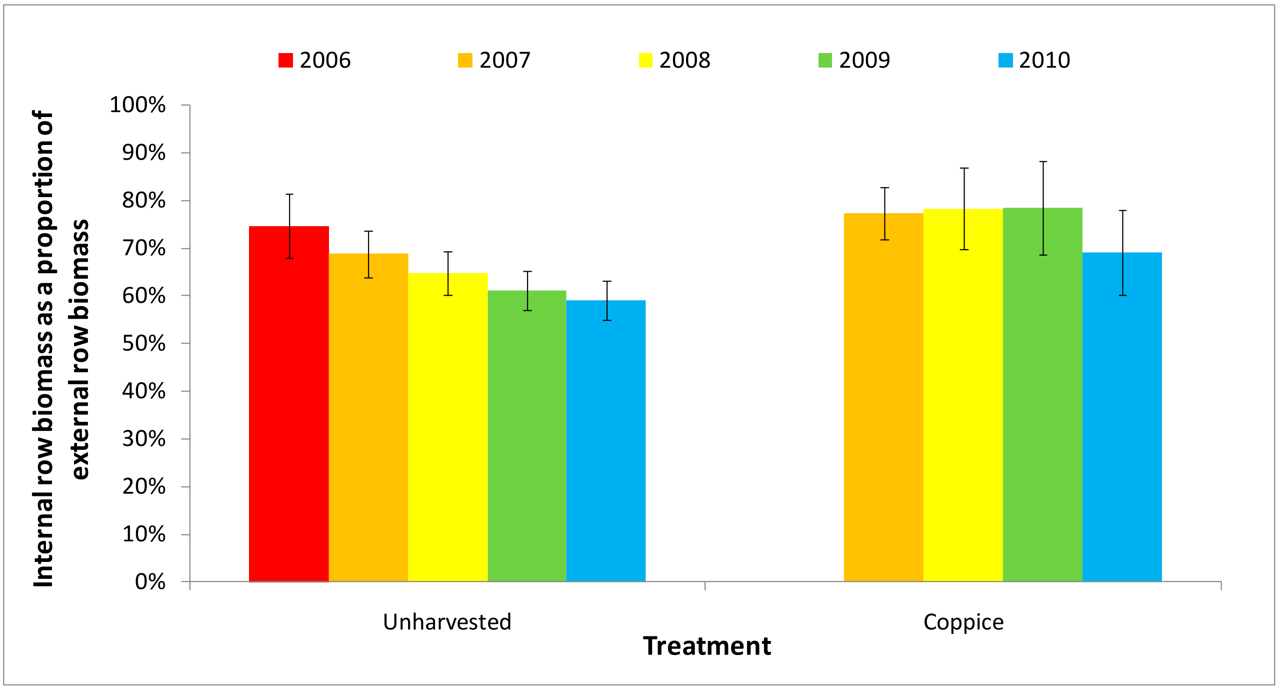

Figure 3-14Internal row biomass as a proportion of edge row biomass (mean of sites 3, 6, 8, 12, 18, 19 and 20; standard error bars shown)

Table 3-14 Standing biomass of edge and internal trees at sites with multiple row belts in the period 2006 to 2010

Site	Year	Annual biomass increment (green tonnes/ha/year)			
		unharvested mallee (Control)		4 year old coppice (Autumn harvest)	
		edge trees	internal trees	edgetrees	internal trees
3	2006	37.2	32.6		
	2007	45.9	35.4	4.2	2.6
	2008	54.9	40.1	14.8	9.3
	2009	63.5	43.3	24.4	15.8
	2010	74.2	50.6	35.5	20.5
5	2006	60.2	60.6		
	2007	73.9	76.7	1.2	1.0
	2008	84.1	90.0	9.9	7.9
	2009	97.4	98.5	21.3	16.2
	2010	115.8	120.8	73.0	45.7
6	2006	56.8	38.5		
	2007	73.4	47.9	2.6	1.8
	2008	101.1	62.4	15.9	9.9
	2009	121.3	65.9	23.3	13.6
	2010	135.9	67.1	43.5	18.8
8	2006	78.2	58.9		
	2007	98.7	65.1	11.0	7.1
	2008	119.4	72.1	21.2	12.7
	2009	132.0	76.4	48.3	22.6
	2010	147.3	76.5	66.6	29.9
12	2006	31.4	14.9		
	2007	34.1	17.6	3.3	2.9
	2008	40.4	18.8	6.0	5.6
	2009	46.2	20.1	13.9	14.6
	2010	51.3	23.4	21.9	19.7
18	2006	32.0	33.4		
	2007	50.9	47.6	14.9	11.3
	2008	73.9	63.0	25.7	16.7
	2009	99.5	76.5	50.0	36.8
	2010	112.5	84.9	70.6	44.8
19	2006	33.5	23.3		
	2007	46.1	28.3	11.7	9.7
	2008	64.6	43.4	19.0	15.7
	2009	96.1	61.5	35.0	27.7
	2010	110.1	71.7	42.9	33.5
20	2006	21.2	14.8		
	2007	29.6	19.7	2.9	2.9
	2008	37.7	22.4	7.8	9.5
	2009	46.0	29.0	15.0	18.1
	2010	49.0	28.3	20.5	21.9

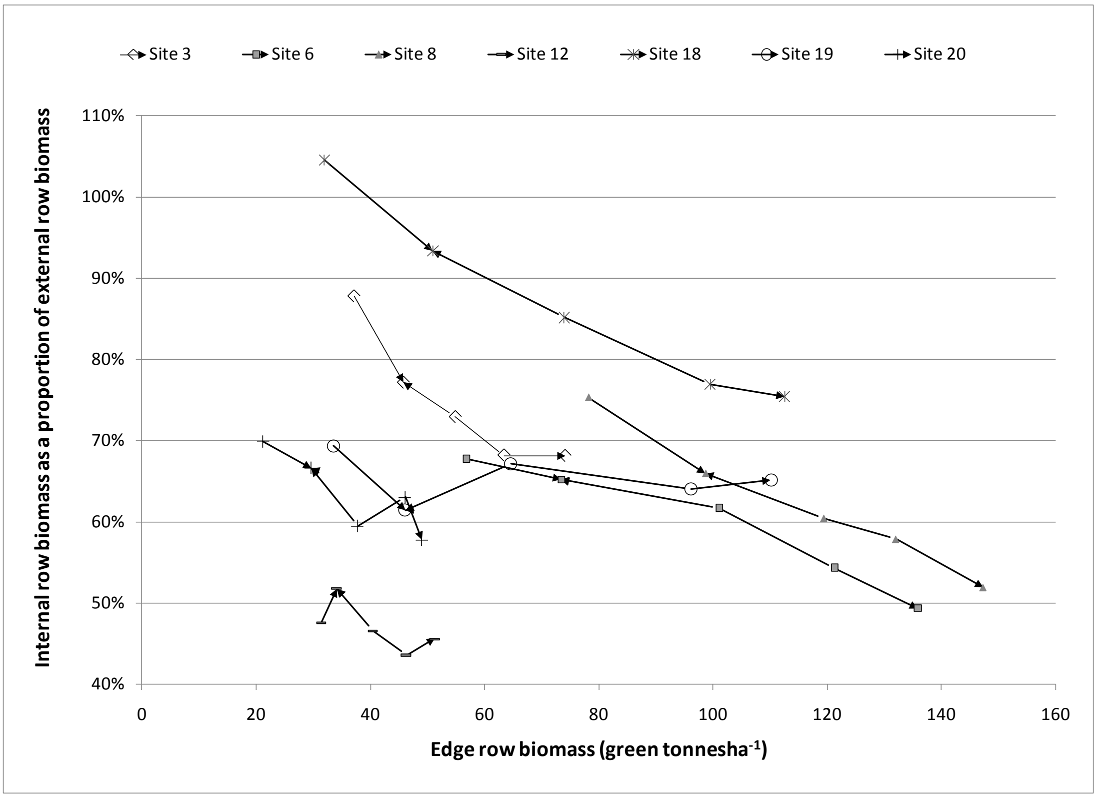

Figure 3-15 Time series change (2006-2010) in internal row biomass as a proportion of edge row biomass in unharvested (Control) treatments

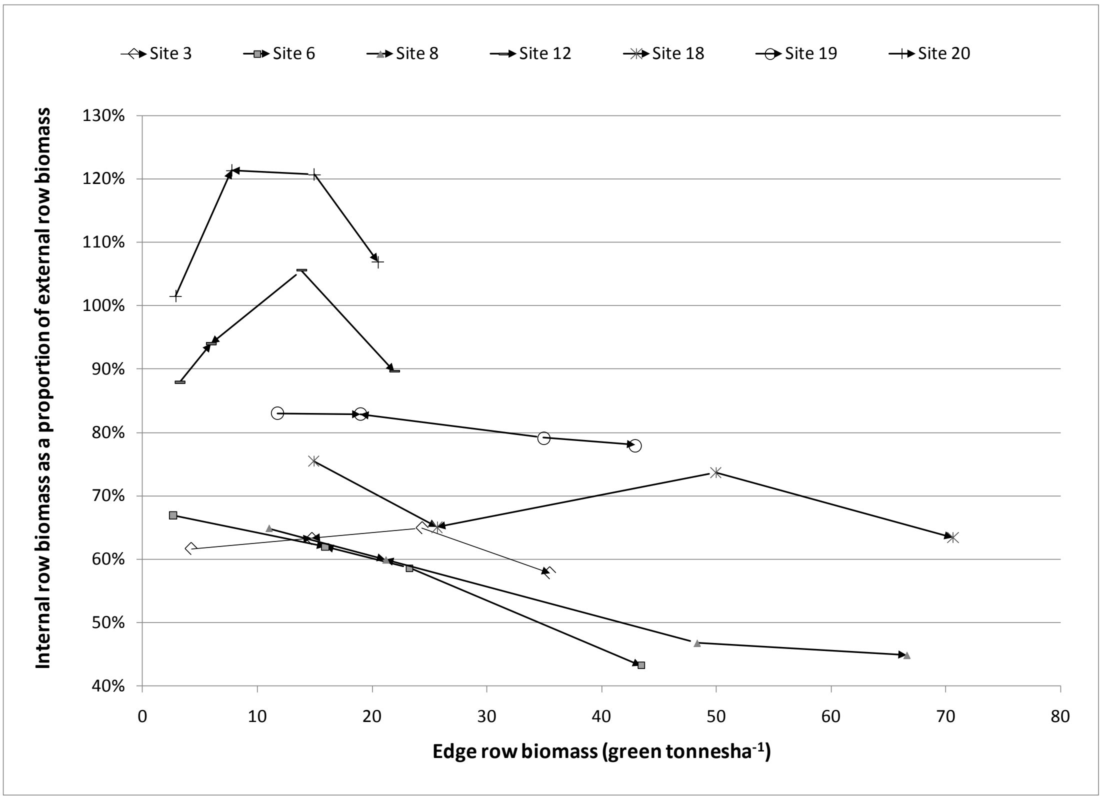

Figure 3-16 Time series change (2007-2010) in internal row biomass as a proportion of edge row biomass in autumn 4 year coppice treatments

3.3.5 Mortality

Mallee mortality ranged from 0 to 84% after the initial spring harvest, with an average of 11% (Table 3-15). Overall, eight percent of all tree stumps failed to coppice from this harvest. After the first autumn harvest mortality ranged from 0 to 25%, with an average of 5%. Overall, four percent of all mallee stumps failed to coppice from this harvest.

Tree mortality was substantially reduced after the first coppice cycle. For example less than 0.5% of live stumps failed to produce coppice after the second (2009) harvest.

The data supports the assertion that mortality in the belt establishment phase (Table A-4) is generally much greater than mortality from harvest. At the outset of the Project in autumn 2006, 19% of tree positions were empty, absent or included dead mallees. This could be explained by planting error or mortality following establishment.

Table 3-15 Tree mortality post harvest.

	Spring harvest mortality (%)		Autumn harvest mortality (%)	
Site	2006 harvest	2009 harvest	2006 harvest	2009 harvest
1	5.5	0.0	0.0	0.0
2	0.6	n/a	1.9	n/a
3	0.6	0.0	0.6	0.6
5	5.6	n/a	2.3	n
6	47.9	1.5	17.5	3.3
7	84.0	n/a	25.4	n/a
8	2.6	0.0	3.1	0.0
9	0.4	0.4	1.8	0.5
10	2.2	n/a	0.4	n/a
11	8.5	n/a	0.0	n/a
12	1.0	n/a	3.0	n/a
13	1.5	1.5	1.5	0.7
14	22.6	n/a	9.7	n/a
15	15.5	n/a	0.6	n/a
16	0.4	0.0	3.5	0.4
17	1.5	2.0	8.2	2.1
18	0.8	0.0	0.8	0.0
19	0.5	0.0	0.8	0.4
20	2.0	n/a	8.3	n/a
Mean	**11**	**0.5**	**5.0**	**0.7**
Median	**2.0**	**0.0**	**1.9**	**0.5**
Min	**0.0**	**0.0**	**0.0**	**0.0**
Max	**84.0**	**2.0**	**25.0**	**3.3**
Overall survival	**92.0**	**99.8**	**96.0**	**99.6**

Note: post-2006 harvest measured in 2008, post-2009 harvest measured in 2010

3.3.6 Carbon and ash content

A selection of oven dried biomass samples were used for measurements of total carbon and ash[12] content in the mallee biomass. This included six samplesfor each biomass component (wood, bark, twig and leaf) from sites 8, 9, 15 and 17, andthree samples for each biomass component from site 10. Each sample was taken from a different mallee.

For each biomass component the carbon content was similar across sites and species (Table 3-16). The carbon content of different biomass components was: leaf (54% to 58%), twig (50%), wood (49% to 50%) and bark (46% to 49%). The leaf component had significantly more carbon than other components (Tukey's test; $p < 0.05$).

The ash content was more variable between sites and biomass components (Table 3-16) summarised as: bark (5.4% to 8.4%), leaf (4.1% to 4.7%), twig (2.4% to 2.7%) and wood (0.3% to 0.8%). The bark and leaf componentsgenerally had significantly more ash than the twig and wood components (Tukey's test; $p < 0.05$).

Table 3-16 Total carbon and ash content by biomass component (as a percentage of dry biomass)

Site	Biomass component	Carbon and ash content (% and Anova grouping)	
		Carbon	Ash
8	Wood	49.8 c	0.3 e
9	Wood	49.4 cd	0.7 e
10	Wood	49.2 cd	0.6 e
16	Wood	49.4 cd	0.8 e
17	Wood	49.2 cd	0.7 e
8	Bark	47.1 d	5.5 bc
9	Bark	46.7 d	8.4 a
10	Bark	46.3 d	7.4 ab
16	Bark	49.1 cd	4.1 cd
17	Bark	48.3 cd	5.4 bc
8	Twig	50.3 c	2.4 de
9	Twig	50.4 c	2.7 de
10	Twig	49.6 cd	2.4 de
16	Twig	50.3 c	2.4 de
17	Twig	50.1 c	2.6 de
8	Leaf	55.9 ab	4.1 cd
9	Leaf	56.3 ab	4.7 bcd
10	Leaf	57.7 a	4.4 bcd
16	Leaf	54.0 b	4.2 cd
17	Leaf	56.1 ab	4.4 bcd

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[12] Non-volatile inorganic matter.

3.4 Discussion

3.4.1 General findings

An overriding finding from this study was the high spatial and temporal variability in mallee yields and patterns of growth in belt planting layouts. This presents challenges for designing mallee yield experiments (requirement for large plot sizes and replications) and for reliably estimating paddock scale yields from point measurements.

Yield differences of 50% or more over relatively short belt distances (i.e. tens of meters) were observed at all study sites (Figure 3-4). These observations are consistent with other published studies. Pracilio et al. (2006) used tree height as a proxy for *E. polybractea*2-row belt yields in an investigation of the effect of soil profile factors on productivity near Kalannie. The biomass of the 9-year old mallees ranged from 57 to 178 green tonnes/ha (and tree-height from 4.3 to 7.3 m) within the sandplain landform at this location. Their study site was immediately adjacent to Site 15 used in this study. Carter & White (2009)measured a 6-fold difference in the yields of 6-year old *E. kochii* subsp. *borealis* in a belt planting near Coorow. At this site the yield difference was explained by differences in groundwater availability along the belt, as dictated by groundwater depth and the presence of a silcrete hardpan.

The range of mallee productivity (green above ground biomass) measured in this study was comparable with reported values at other sites in the Wheatbelt Region of south western Australia (Table 3-17). The coppice productivity measured at Site 1 in this study (age 3: 17-26 green tonnes/ha/year; and age 4: 18-33 green tonnes/ha/year) was exceptional and significantly exceeded the next most productive site.

3.4.2 Factors affecting productivity

Mallee yields were positively correlated with age (Figures 3-3 & 3-4); however given the variability in yields within and between sites age was a relatively poor predictor of mallee productivity. This finding was reinforced by the high level of time series variability in growth rates observed at many sites.

Other factors potentially affecting mallee productivity include climate and edaphic factors, herbivory and inherent species differences.

3.4.2.1 Climate

Climate variables such as solar radiation, rainfall, temperature and evaporation can have a major influence on the productivity of farmland revegetation (Harper et al. 2008). Water availability, as influenced by rainfall, is generally the most limiting climate factor affecting tree growth in the Wheatbelt Region.

Interpolated monthly rainfall datasets (DataDrill 2010) were generated for each site and tested for relationships with mallee productivity. To buffer against the high spatial and temporal variability in measured yields, empirical mallee rainfall water use efficiency (WUE) values were derived for each plot at each site over the Project life (2006 to 2010).

$$\text{Mallee WUE}=\frac{\text{Standing biomass at Ti}-\text{Standing biomass at T0}}{1000\times\text{Rainfall reecived in period Ti to T0}}$$

Table 3-17 Reported mallee yields in belt plantings on farmland in Western Australia[13]

Source	**Species**	**Location** (nearest town)	**Age**	**Unharvested or coppice**	**Annualised yield**[14] **(green tonne ha^{-1} year^{-1}**
Brooksbank et al. (2011)	*E. polybractea*	Gibson	7	unharvested	3 - 7
		Goodlands	13		9 - 23
Carter & White (2009)	*Eucalyptus kochii* subsp. *borealis*	Coorow	6	unharvested	2 - 11
Grove et al. (2007)	*E. polybractea*	Narrogin	5	unharvested	5
	E. loxophleba subsp. *lissophloia*	Narrogin	4		3
	E. loxophleba subsp. *lissophloia*	Kalannie	5		1
	E. kochii subsp. *plenissima*	Kalannie	3		1 - 2
Liew (2009)	*E. polybractea*	Tincurrin	4	unharvested	1 - 4
			9	unharvested	4 - 9
			11	unharvested	4
			14	unharvested	5
			4	coppice	6
			9	coppice	10
Pracilio et al. (2006)	*E. polybractea*	Kalannie	10	unharvested	2 to 17
Sudmeyer & Daniels (2010)	*E. polybractea*	Gibson	5½	unharvested	9
Wildy et al. (2003) and (2004a, b)	*E. kochii* subsp. *plenissima*	Goodlands	6	unharvested	≤8
			1	coppice	2 - 6
			2	coppice	7 - 10
This study[15]	*E. loxophleba* subsp. *lissophloia*	Various	5 to 13	unharvested	4 - 12
			3	coppice	5 - 10
			4	coppice	8 - 13
	E. kochii subsp. *plenissima*	Goodlands & Koorda	7 to 16	unharvested	3 - 10
		Goodlands	3	coppice	11 - 17
			4	coppice	13 - 16

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[13] Adjusted for moisture content where required

[14] Mean annual increment since establishment unless age interval specified

[15] Excluding sites where productivity was compromised by grazing damage or visually obvious salinity

Source	**Species**	**Location** (nearest town)	**Age**	**Unharvested or coppice**	**Annualised yield[14] (green tonne ha^{-1} year^{-1}**
	E. polybractea	Various	5 to 14	unharvested	6 - 17
			3	coppice	12 - 27
			4	coppice	11 - 33

where:

WUE (green kg/ha/mm) =	the quantity of above ground biomass accumulated per unit of rainfall in the period of interest

Standing biomass (green tonnes/ha) = the quantity of above ground biomass in the plot

T0 (month) = the time at the beginning of the period of interest

Ti (month) = the time at the end of the period of interest

Rainfall (mm) = the rainfall received at the site in the period of interest

The period Ti-T0 equated to four years (April to April for autumn treatments and October to October for spring treatments).This included mallees between 5 and 16 years of age in unharvested treatments, and coppice up to age 4 in harvested treatments.

Excluding the worst performing treatments, mallee WUE ranged from approximately 20 to 100 green kg/ha/mm in unharvested (Control) plots and 10 to 80 green kg/ha/mm in coppice plots.At sites where 3 and 4 year harvest treatments were imposed, the median WUE was 40 greenkg/ha/mm in unharvested (Control) plots and 29 to 34 green kg/ha/mm in coppiced plots(Figure3-17). At sites where 5+ harvest treatments were imposed, the median WUE was 27 green kgha^{-1}mm^{-1}in unharvested (Control) plots and 17 to 23 green kg/ha/mm in coppiced plots (Figure3-18).

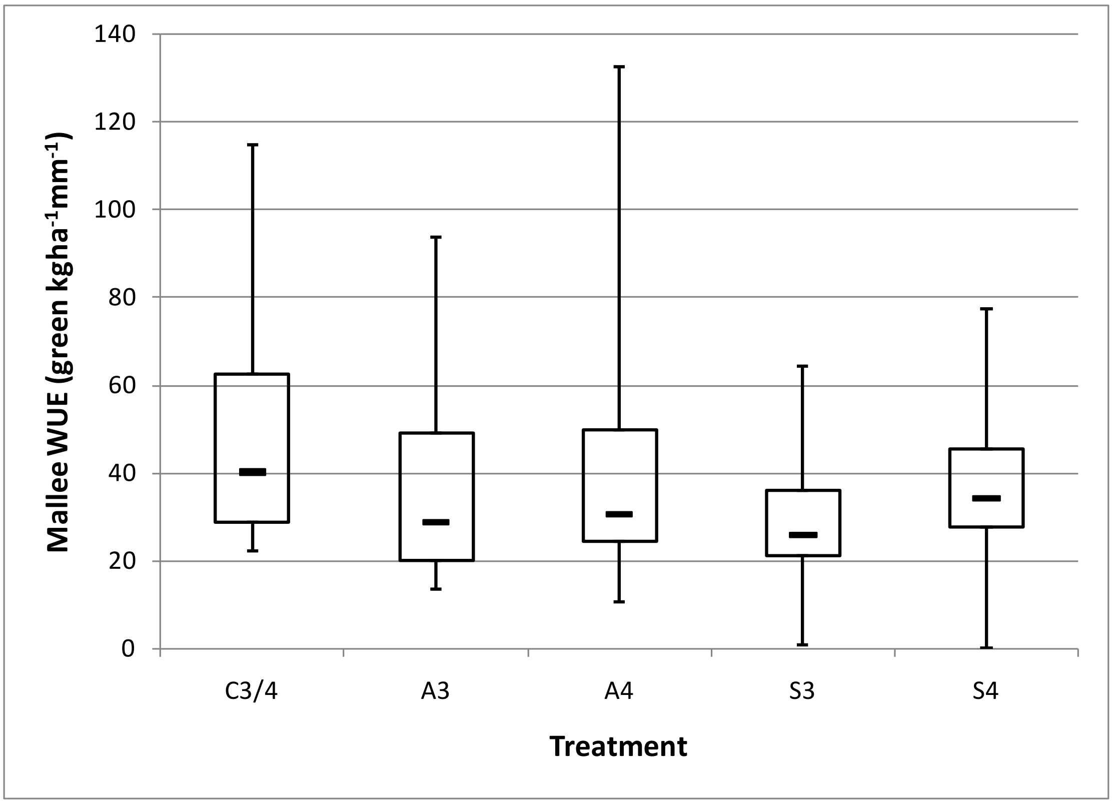

Figure 3-17 Variation in plot WUE for sites with 3/4 treatments imposed.

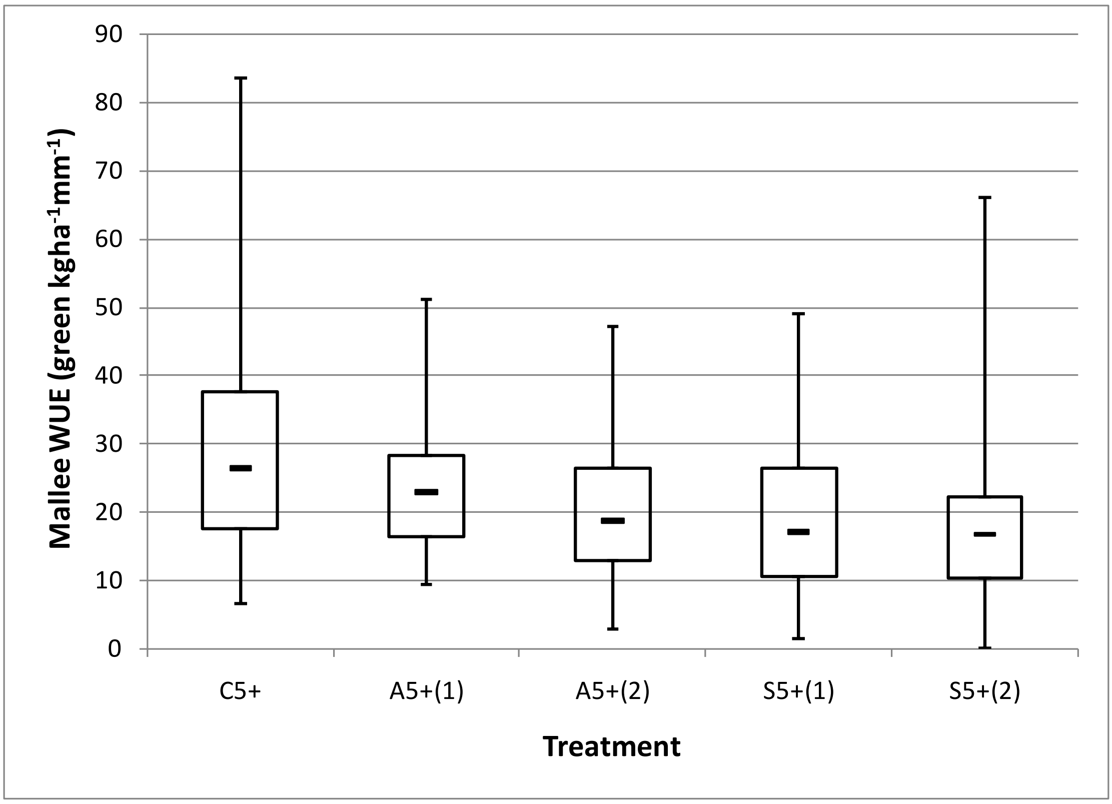

Figure 3-18 Variation in plot WUE for sites with 5+ treatments imposed.

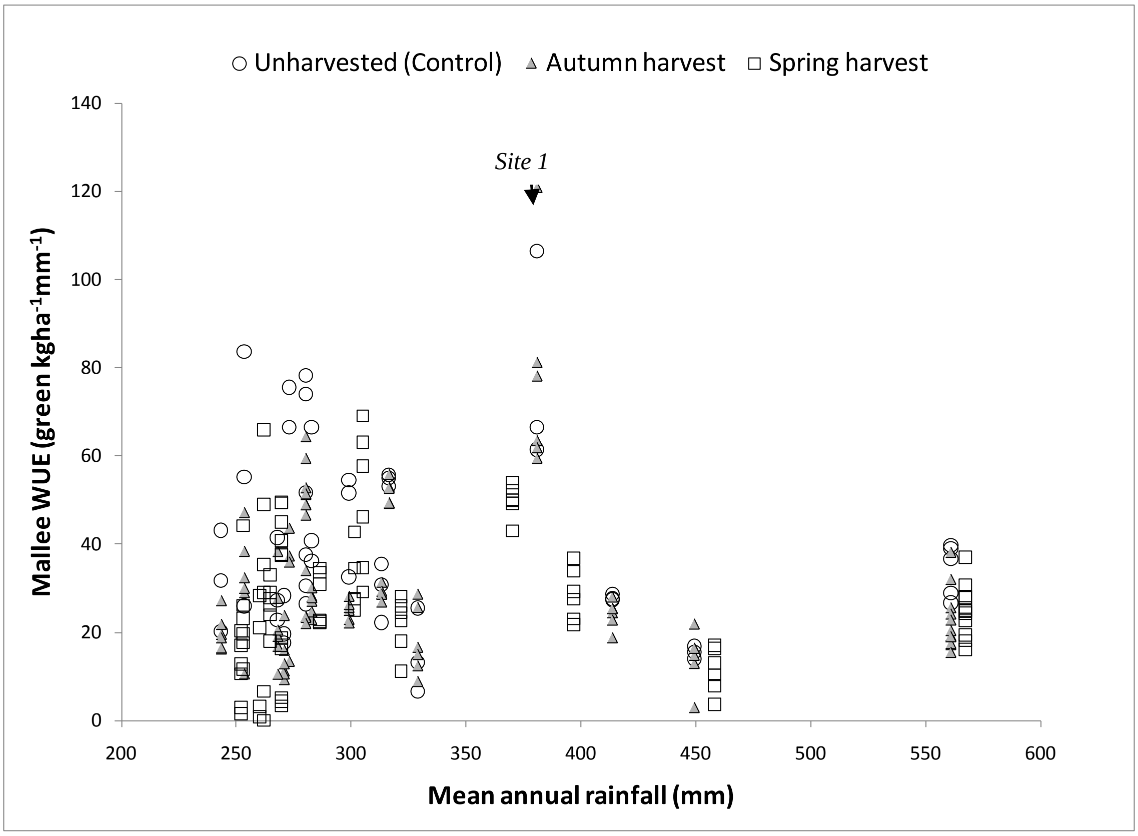

Figure 3-19 Mallee WUE against mean annual rainfall for the equivalent growing period (2006 to 2010) (all treatments)

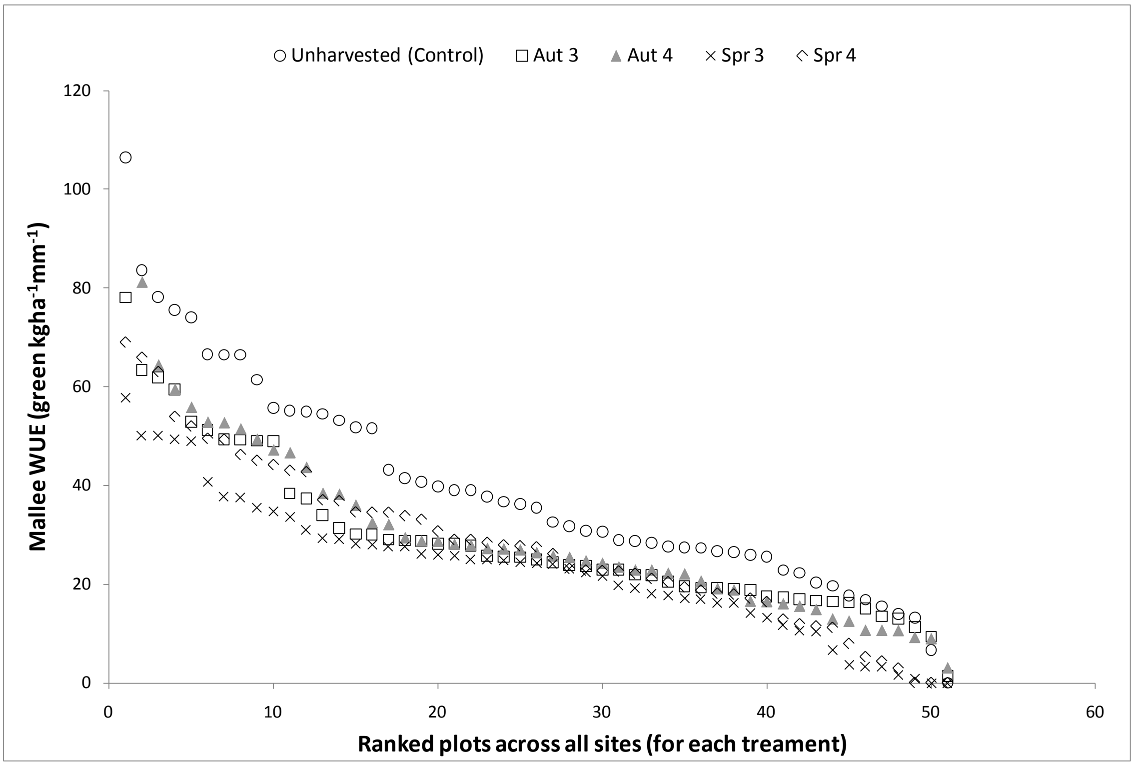

Figure 3-20 Mallee WUE ranked by plot for each treatment

Mallee WUE appeared to be poorly correlated with mean annual rainfall for unharvested and coppice treatmentson visual inspection (Figure 3-19). To investigate this further the WUE values were ranked separately for each treatment (Figure 3-20). A disparity was observed for the top 16 ranked plots and the bottom 11 ranked plots respectively, based on inflection points in the treatments rankings. Across all treatments site 1, 8 and 15 were consistently in the top rankings, whilst sites 2, 11 and 20 were consistently in the bottom rankings. The autumn coppice plots at site 12 were also in the bottom rankings, as were the spring coppice plots at site 16 for these respective treatments. These findings are suggestive of the overriding importance of site factors over climate factors with respect to mallee productivity.

Non-parametric Spearman's rank coefficients relating mallee productivity with rainfall over the same period were compared with thelinear Pearson's product-moment (r)coefficients for the unharvested (Control), autumn 4-year coppice and spring 4-year coppice mallee WUE datasets respectively (Table 3-18).Correlations were relatively poor in all cases, however the improved Spearman's coefficients for coppice treatments suggested that higher rainfall is associated with higher productivity in these treatments based on non-linear monotonic relationships.

Table 3-18 Correlation between rainfall and plot biomass production (2006 to 2010) in mallee treatments

Treatment[16]	**Spearman's rank coefficient**	**Pearson product-moment correlation coefficient (r)**	**r^2**
unharvested (Control)	0.32	0.32	0.102
autumn 4-year coppice	0.47	0.31	0.098
Spring 4-year coppice	0.55	0.46	0.207

Based on the assumption that the median mallee WUE is representative of predominantly rain-fed growing conditions, it is postulated that the high productivity sites in this study (notably sites 1, 8, 15 and portion of site 5) were able to access significant alternative water sources during the period of the study. This could include deep stored soil water reserves beneath the rows and in the adjacent alleys, lateral flow of surface or shallow subsurface water and/or permanent deep groundwater. These sources have been implicated in contributing to high mallee yields in other reported studies (Carter & White 2009; Pracilio et al. 2006; Wildy et al. 2004a, Brooksbank et al 2011).

For empirical purposes, it is tentatively proposed that mallee WUE can be expected to lie within the range of 20 to 40 green kg/ha/mm under predominantly rain-fed growing conditions in the Wheatbelt region for unharvested mallees between 5 and 16 years of age and mallee coppice between 3 and 4 years of age. These growing conditions can be expected when the stored soil water surplus developed under agricultural land use has been largely depleted. This WUE range is consistent with the findings of Wildy et al. (2004b)

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[16] Plots from all sites excluding sites 7 and 14, and site 6 replicate 2.

whoinvestigated mallee water use budgets in 2-row belt plantings. Theempirical mallee WUE at their studysite over a 22 month growing period was[17]:

- 84 green kg/ha/mm (unharvested age 5.3 to 7.2 increment) where a perched watertable was accessible (Wildy et al. site 3)
- 56 green kg/ha/mm (unharvested age 5.3 to 7.2 increment) where groundwater was not accessible, but with significant soil water depletion (accounting for approximately 50% of mallee water use) beneath the adjacent alley (Wildy et al. site 1)
- 50 green kg/ha/mm (22 month old coppice) where a perched watertable was accessible (Wildy et al. site 3), and
- 33 green kg/ha/mm (unharvested age 5 to 7 increment) where groundwater was not accessible, and where some soil water depletion (accounting for approximately 14% of mallee water use) beneath the adjacent alley (Wildy et al. site 1).

The WUE range is also consistent with the findings of Carter and White (2009) who measured biomass yields in an unharvested 2-row belt planting of*E. kochii* ssp. *borealis* near Coorow (between the ages3½ and 6½ years old). The belts at this site spanned a gradient of groundwater accessibility, as dictated by the depth to watertable and the presence of root impeding hardpan layers. Over the 3 year period of growth measurements the empirical mallee WUE was[18]:

- 47 green kg/ha/mm where accessible groundwater at 2 m depth
- 44 green kg/ha/mm where accessible groundwater at 3 m depth
- 34 green kg/ha/mm where accessible groundwater at 4 m depth
- 19 green kg/ha/mm where accessible groundwater at 5 m depth and probably inaccessible, and
- 21 green kg/ha/mm where groundwater was deep and not accessible

There are few other data in the published literature where empirical mallee WUE, or the time series biomass measurements underpinning its derivation, have been reported.

It is concluded that mallee WUE values exceeding about 40 green kg/ha/mm (over periods of several years) could potentially indicate that significant additional sources of water besides rainfall are available for mallee growth, and that values below about 20 green kg/ha/mm may indicate significant site constraints. With further development and validation, the use of mallee WUE valuescould usefully contribute to procedures for characterising the potential and performance of mallee planting sites. This is particularly the case where opportunities exist to augment an existing resource with additional plantings at a district scale.

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[17] Derived WUE values using an above ground biomass moisture content of 43% and assuming each mallee occupied an area of 1.77 m x 3 m within the 6m wide belt.

[18] Derived WUE values based on Carter 2009 unpublished data, using above ground biomass moisture content of 43% and assuming each measurement plot occupied an area of 0.0072 ha (12 m long x 6m wide belt sections).

3.4.2.2 Edaphic factors

Correlations between edaphic variables and mallee productivity (2006 to 2010 growth increment) were investigated using all sub-sets multiple regression, using the soil profile data collected by the Department of Agriculture and Food (refer to Ch 4 Section 4.2.3).

Variables that were significantly correlated ($P<0.05$) for each of the unharvested (Control), 4-year autumn coppice and 4-year spring coppice treatments are presented inTable 3-19. Correlations were relatively poor for all variables. The aggregated variables CL1 and CL3 (defined as the minimum of either depth to: water table, bedrock, hardpan or ECe ≥ 8 dSm^{-1}or ECe ≥ 16 dSm^{-1}respectively) exhibited the best correlations across all treatments ($r^2 \approx 0.2$ to 0.4).

Given the high variability in yields within sites, the soil profile characterisation at each site may not have had sufficient resolution to elucidate the key edaphic factors. Despite this the results suggest that plant available soil profile depth is likely to have a prominent role in influencing mallee yields. The importance of soil profile depth in mediating plantation performance is well understood for other plantation species such as *Eucalyptus globulus*in rainfall limited environments (see for example Harper et al. 2009; White et al. 2009).

The spatial variability in mallee yields observed in this study presents challenges for developing practically useful site assessment methods for designing new plantings. Traditional ground based survey methods (including soil profile descriptions) are unlikely to be cost effective for dispersed belt plantings. Future site assessment methods are likely to require the use of broad scale remote sensing technologies, targeting profile depth and possibly inferring site qualities from time series changes in surface cover (e.g. crops, pastures, remnant and planted vegetation) using satellite imagery. The National Water Commission *Atlas of groundwater-dependent ecosystems*project provides an example of where novel satellite data interrogation methods (applied to historical imagery) are providing new insights into vegetation behaviour and water use at multiple spatial scales.

Table 3-19 Correlation between edaphic variables and plot biomass production (2006 to 2010) in mallee treatments (r^2 values; $P<0.05$; positive correlations unless specified)

	Treatments		
Edaphic variables	**unharvested (Control)**	**autumn 4-year coppice**	**Spring 4-year coppice**
CL1 = the minimum of either depth to: water table, bedrock, hardpan or ECe ≥ 8 dSm^{-1}	0.175	0.420	0.312
CL2 = the minimum of either depth to: water table, bedrock, hardpan, pH(CaCl2) ≤ 4.5 or ECe ≥ 8 dSm^{-1}	0.247	0.287	0.236
CL3 = the minimum of either depth to; water table, bedrock, hardpan or ECe ≥ 16 dSm^{-1}	0.222	0.392	0.358
Colwell-P	0.204	0.172	
Colwell-K			0.091 (-ve)

Edaphic variables	**Treatments** **unharvested (Control)**	**autumn 4-year coppice**	**Spring 4-year coppice**
Sulphur	0.083		
Organic-C[19]	0.185		0.102

3.4.2.3 Herbivory

Results from this study indicate that short term sheep grazing can severely impact coppice regrowth in the first 2 years following harvest. Heavy grazing after the spring 2006 harvest at Site 1 and replicate 1 of Site 11 greatly suppressed coppice growth. At Site 1 the tree growth improved markedly in subsequent years, but at Site 11 the spring coppice growth is still significantly poorer than that of the unaffected replicates. Care is required for the integration of mallee production systems with grazing enterprises, and livestock should be kept out of paddocks in at least the first year after mallee harvest.

Spring beetle (*Liparetrus* spp.) herbivory also affected tree growth at many sites, especially at site in the north-east Wheatbelt region. The beetles can severely damage leaves and showed a preference for soft young growth, which appeared to impact productivity temporarily. Since insecticidal control is problematic and costly further research into optimising the timing of harvest to avoid spring beetle damage to young coppice is recommended.

Parrot damage was noticed at some sites, particularly sites with older stands of remnant vegetation nearby (such as sites 2, 9 and 10). The ‘Twenty-eight’ (*Barnardius zonarius*) was the primary species implicated in damaging mallees of all ages by ringbarking the stems. Where ringbarking occurs the stems tend to die back leading to a sprawling growth form. Severe ringbarking can significantly affect mallee productivity since it leads to twiggy, leafy growth over woody growth. There are few practical management options available for mitigating against parrot strike, except for selecting sites without large adjacent stands of remnant vegetation.

3.4.2.4 Tree species

The wide variation of productivity between and within sites prevented a meaningful comparison of mallee species performance. The findings of this study highlight the importance of using well designed species trials, which take into account local scale site variability, for elucidating differences in species biomass production and biomass partitioning.

3.4.3 Biomass partitioning and moisture content

Biomass partitioning information is important for two key reasons:

- biomass moisture content and the relative proportions of biomass components (wood, bark, leaf and twig) can affect the utility of the biomass for product manufacturing. Biomass partitioning will therefore influence the value of the harvested biomass, and

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[19] Organic-C was strongly correlated with Colwell-P ($r^2 = 0.71$).

- patterns of biomass partitioning can potentially provide insights into site attributes affecting mallee productivity.

For a given yield of above ground biomass, this study found that coppice biomass has a lower proportion of wood than unharvested mallees and a higher proportion of leaf (Tables 3-7 and 3-10).The results indicate this is due to the multi-stemmed habit of mallee coppice relative to the unharvested mallees. Twig and bark proportions have been shown to vary little between coppice and uncut trees. It follows that if wood is the desired product (e.g. as a wood pellet feedstock), then longer harvest cycles may be adopted. If leaf is sought (e.g. for cineole extraction) then shorter harvest cycles are more suitable.

The Narrogin IWP feasibility study assumed that delivered biomass based on short cycle coppice would include 50% wood, 15% twig and bark, and 35% leaf (Enecon 2001), based on an initial harvest at age 5 and subsequent harvest on a 3 year cycle. The findings of this study suggest that the wood and leaf proportions used in the Narrogin IWP feasibility were overestimated, with twig and bark underestimated. The twig and bark fractions in this study are approximately 35-45% of biomass for both coppice and uncut trees, with wood around 30-35% (uncut) and 20% (coppice) and leaf 25-30% (uncut) and 35-40% (coppice) of green biomass.

Carter & White 2009 observed a pronounced decline in leaf area index with decreasing availability of groundwater in a belt planting of *E. kochii* subsp. *borealis* at Coorow.

3.4.4 Growth of interior vs edge rows.

Plantation trees on compartment edges are generally more productive than those within plantation blocks (Ritson 2004). This ‘edge effect’ is commonly observed and accepted, however there are few reported instances where it has been quantified in mallee plantings. Maximising the beneficial aspects of the ‘edge effect’ for yield optimisation is a key design objective for dispersed mallee belts.

Bartle et al. 2011 reported edge rows producing double the biomass of interior rows in 8-row belts of *E. polybractea* (age 8) at Gibson. At this site there was little difference in the productivity of edge and interior rows until age 4, however a differential in productivity progressively developed over the subsequent four years. The transition from edge to interior row yields was pronounced; with all rows except the single outer rows exhibiting a similar extent of reduced yield.

In this study edge rows were also significantly more productive than interior rows in unharvested (Control) and coppice treatmentsat the 8 sites with multiple row belt configurations (Table 3-13).

Since a focus of the Project was on the performance of two-row belts, the two-row equivalent of multiple-row belt yield was estimated to be the outer-row yield (or double the single measured outer row yield) expressed on the basis of the standard 6m wide two-row belt.The soundness of this estimate depends on the relative competition imposed by a companion single row or one or more inner rows. The inner rows would appear likely to provide a greater intensity of competition on the outer row and so the corrected two-row data for the 8 sites with multiple-row belts is likely to be conservative.

In the course of the analysis presented in Chapter 4 it became apparent that the competition imposed by mallee belts on the adjacent annual crop/pasture agriculture was larger than anticipated. In Chapter 6 it is proposed that given the large competition penalty carried by the outer row, the inter-row area of the two-row belt could be expanded to provide lower opportunity cost land, and that this may be a more economic option to increase biomass production than additional two-row belts. A method to derive an index of inter-row area biomass productivity (the ‘yield conversion factor’, YCF) was developed. This method uses the coppice yield ratio of inner and outer row yields from Table 3-14.

This continuing evolution towards optimal use of mallee belts highlights the need to continue the R&D presented in the report.

3.4.5 Mortality

The ability of mallee to regenerate the canopy after removal by harvesting or other means is a feature of this Eucalypt growth form. The low rates of mortality following harvest observed in this study were consistent with other reported observations (Table 3-20).

Table 3-20 Reported mortality rates following harvesting for farm grown mallee

Source	**Species**	**Location**	**Treatment**	**Reported mortality**
Wildy et al. (2003)	*E. kochii* subsp. *plenissima*	Goodlands	Harvested once at age 5	2% and 0.5% for February and October harvests respectively
Milthorpe et al. (1998)	*E. polybractea* *E. kochii*	Condobolin	Harvested at age 1 and then annually for the following 4 years.	1% for the duration of the experiment
Milthorpe et al. (1994)	*E. polybractea*	Condobolin	Harvested at age 1 and then annually for the following 4 years.	A few %; sporadic and comprised mainly of small (runt) plants
Eastham et al. (1993)	*E. kochii* subsp.*plenissima* *E. kochii* subsp. *borealis* *E. angustissima*	Wongan Hills	Harvested at age 3 and age 5	A few %
This study	*E. loxophleba* subsp. *lissophloia* *E. kochii* subsp. *plenissima* *E. polybractea*		Harvested at age 5 to 12. Repeat harvested 3 and 4 years later	median ≤2% high mortality at a few siteslinked to site constraints (e.g. salinity)

3.4.6 Carbon and ash content

The biomass carbon and ash contents measured in this study were comparable with other reported values form Western Australian sites (Table 3-21). Note that Olsen et al. 2004 reported the results of combustion tests of samples from *E. kochii* subsp. *plenissima* and

E. loxophleba subsp. *loxophleba*. For each species, the sample included a mixture of 1/3 wood, 1/3 leaf and 1/3 twig and bark; in order to represent whole tree biomass.

Table 3-21 Reported mallee biomass carbon and ash content (dry basis)

Source	**Species**	**Carbon %**	**Ash %**
Abdullah et al. 2010	*E polybractea*	wood 49.1 bark 43.1 leaf 54.3	wood 0.6 bark 7.1 leaf 4.1
Olsen et al. 2004	*E. loxophleba* subsp. *loxophleba* whole tree mixture (sample B136)	48.8	3.0
	E. kochii subsp. *plenissima* whole tree mixture (sample B143)	50.2	2.2
This study	*E. loxophleba* subsp. *loxophleba* *E. kochii* subsp. *plenissima* *E polybractea*	wood (49-50) bark (46-49) twig (50) leaf (54-58)	wood (0.3-0.8) bark (5.4-8.4) twig (2.4-2.7) leaf (4.1-4.7)

4 Tree and crop competition effects

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4.1 Introduction

New industries based on production of biomass from belts of mallees integrated into dryland cropping systems hold considerable promise for ameliorating some of the environmental concerns associated with conventional farming systems and for providing farmers with new income sources derived from biofuels, bio-feedstocks and carbon sequestration (e.g. URS 2009; Bartle and Abadi 2010, Chapter 5 this report).This research project and other work (Cooper et al. 2005; URS 2009; Bartle and Abadi 2010; Chapter 3 this report) has shown that the best mallee growth is achieved when mallees are planted as two row belts in alley systems.Growing the mallees in this way maximises the mallee/agriculture interface and the ability of the mallees to capture resources from the competition zone alongside the belts.

Research in temperate southern Australia has shown that windspeed reductions and associated micrometeorological changes within 10-20 times the height (H) of a windbreak can improve agricultural production.Offsetting this is generally reduced agricultural yield in the 2-3 H wide competition zone adjacent to the trees (George-Jaeggli et al. 1998; Sudmeyer et al. 2002a; Sudmeyer et al. 2002b; Unkovich et al. 2003; Oliver et al. 2005; Bennell and Verbyla 2008).Yield reductions in the competition zone can have a significant impact on the economics of these systems (Jones and Sudmeyer 2002; Sudmeyer and Flugge 2005).While this is relatively well understood and accepted for windbreak systems, there is relatively little information relating to agricultural production in the competition zone of mallee agroforestry systems. The authors know of only two published studies that provide information on how harvesting mallees affects agricultural productivity in the competition zone (Sudmeyer 2001; Sudmeyer and Flugge 2005). This lack of information is a constraint to the development of a mallee based biomass production industry (Pannell 2001).

More information relating to agricultural productivity in the competition zone of harvested mallees is needed to fully understand the economics of mallee agroforestry systems and set appropriate biomass pricing benchmarks.Accordingly, the aim of this study was to quantify and understand the productivity of agricultural crops and pastures growing in the competition zone adjacent to mallee belts with various harvest/management scenarios at sites with differing climate and edaphic conditions.

4.2 Methods

4.2.1 Sites

The sites and there selection are described in Section 3.2.1.Crop and pasture measurements were not made at Site 7 as the volunteer saltland pasture was considered too poor to warrant assessment.

4.2.2 Treatments

The treatments applied to the mallee belts related to timing of harvest (autumn or spring), harvest interval (3, 4 and 5+ years) and harvest and root pruning. The control was unharvested mallees. In 2006, two autumn and two spring harvest treatment plots were established at each site. Initially the harvest intervals were planned to be three and four years at all sites but this interval had to be increased at sites with slower coppice growth rates. Consequently the harvest interval was four years at Site 5 and greater than five years at Sites 2, 10-12, 14, 16 and 20. The root pruning treatment applied at each site was to spring harvested mallees with the shortest interval between harvests. The treatments are listed below:

C	Trees unharvested (Control).
S3	Spring harvest 3 year interval
S4	Spring harvest 4 year interval
S5+	Spring harvest 5+ year interval
A3	Autumn harvest 3 year interval
A4	Autumn harvest 4 year interval
A5+	Autumn harvest 5+ year interval
RP3	Root pruned Spring harvest 3 year interval
RP5+	Root pruned Spring harvest 5+ year interval

From 2006 to 2008 agricultural productivity was measured on four treatments at each site replicated three times in a randomised block design. The treatment sets were {C, S3, A3, RP3} or {C, S5+, A5+, RP5+} although to year three of the trial both treatment sets were practically equivalent. In 2009 and 2010, treatments S4 and A4 were added at the sites with treatment set {C, S3, A3, RP3}, making six treatments at these sites.

Each treatment was applied along either 40 m (Sites 1-14) or 45 m (Sites 15-20) of mallee belt and plots extended 30 m into the agricultural area adjacent to the belts (or to the centre of the alley at Sites 2, 9 and 10) to form a rectangular treatment plot. Treatment buffers were 10 m wide with measurement plots either 20 m long (Sites 1-14) or 25 m (Sites 15-20).

At Sites 6, 10, 14 and 15 some of the treatment replicates showed poor mallee survival or growth after being harvested in 2006 (see Section 3), consequently coppice growth was considered less than would be acceptable in a commercial enterprise and mallee/crop competition was minimal. Therefore, data from the following treatment replicates were removed from the subsequent analysis of mallee/crop competition; Site 6 - all replicates of S3 and one replicate each of A3, A4, S4 and RP3; Site 10 - one replicate of S5+; Site 14 - one replicate of A3 and two replicates each of S3 and RP3; and Site 16 – one replicate each of S5+ and RP5+. All measurements at Sites 2 and 14 were discontinued in 2009 and 2010 respectively due to poor mallee growth.

Mallees were harvested by chainsawing stems at ground level, removing all of the above ground biomass and allowing the mallees to coppice from the stump. Sheep grazed coppicing mallees at some sites so the tree lines were progressively fenced between 2006 and 2009.

Root pruning to sever lateral mallee roots between 2 and 5 m from the belts was done on a two year interval at each site commencing in 2006 (2007 for Site 9). In 2006 farmers used their own rippers and ripping depth ranged between 30 and 70 cm (depending on the machine and clay depth) with time of root pruning ranging between spring and autumn depending on individual farm operations. In autumn 2008 a trailed ripper was used at all sites to achieve a uniform ripping depth of 60 cm, 2.5 m from the belts. In autumn 2010 a three point linkage mounted ripper was used 2.5 m from the belts at all sites, with ripping depth ranging between 30 and 60 cm depending on clay depth. Other studies (Sudmeyer et al. 2004; Sudmeyer & Flugge 2005) suggest that ripping would have cut most of the lateral roots where the subsoil clay was within 50 cm of the soil surface. However, lateral roots would have remained uncut below the depth of the ripper at sites with deep sands.

The benefits of root pruning were appreciated and adopted by many farmers during the trial causing some problems to the project. Part of Site 2 was root pruned to a depth of 20 cm in 2007 and all of Site 17 was root pruned to a depth of 20 cm in 2008 and 2009 using an agro-plough. In 2009 Site 18 was root pruned to a depth of 25 cm using a single ripper and Site 16 was root pruned to 65 cm 2 and 4 m from the trees. The depth of pruning at Sites 2, 17, 18 and 19 was not considered deep enough to sever all lateral tree roots so measurements were continued. The depth of pruning at Site 16 was considered deep enough to significantly affect mallee/crop competition and measurements were discontinued.

4.2.3 Site characterisation

4.2.3.1 Climate

Annual rainfall (P) (Table 4-1) and potential evaporation (E) and growing season rainfall (GSP) and evaporation (GSE) data were obtained from the “Data Drill” (DataDrill 2010), with growing season defined as the period from April 1 to October 31 each year. Annual and growing season climate moisture index (CMI and GSCMI respectively) were calculated as (P/E – 1) or (GSP/GSE – 1) respectively (Thornthwaite 1948).

4.2.3.2 Soil

The soil at each site was classified according to the Australian Soil Classification (Table B.3 Appendix B) (Isbell 1996).

Soil cores were collected 20 m from the mallee belts in the centre of each control plot at each site. Sites 1, 2, 3, 8, 10 and 13 were sampled in 2008, Sites 5, 6, 7, 11, 14, 15, 16 and 17 in 2009 and Sites 9, 12, 18, 19 and 20 in 2010. Cores were collected using an EVH Rhino 2100 drill rig. The cores were 44 mm in diameter and were collected to a maximum depth of 10 m or where bedrock, groundwater or a hardpan too hard to drill through (e.g. silcrete or ferricrete) was intersected. Where free water was detected in the core, the core hole was left open for 1-2 hours after drilling to allow a better measurement of water table depth. On a few occasions holes collapsed and it was not possible to re-measure watertable depth. This method may have overestimated watertable depth where the saturated layer conductivity was low. Cores were sampled according to visually identifiable horizons and where the horizon thickness exceeded 75 cm into 75 cm long samples. Each sample was dried at 110 ^{o}C in 2008 and 2009 and at 45 ^{o}C in 2010, the coarse (>2 mm diameter) fraction was determined and the <2 mm diameter fraction analysed by CSBP Soil and Plant Analysis Laboratory. Results from these analyses are given in Appendix B.

The amount of each nutrient stored in the soil profile between the surface and 50 cm depth was estimated using representative bulk densities for the various soil horizons (loam = 1.75, sand = 1.55, clay = 1.85) and expressed as g/m^2. Mallee rooting depth was estimated using three sets of criteria; CL1 = the minimum of either depth to: water table, bedrock, hardpan or ECe ≥ 8 dSm^{-1}; CL2 = the minimum of either depth to: water table, bedrock, hardpan, pH($CaCl_2$) ≤ 4.5 or ECe ≥ 8 dSm^{-1}; CL3 = the minimum of either depth to; water table, bedrock, hardpan or ECe ≥ 16 dSm^{-1}. The pH and salinity limits are based on the standards outlined in Tables B-1 and B-2 respectively in Appendix B.

4.2.4 Crop and Pasture growth

Crop and pasture growth was measured between 2006 and 2010, although not all sites or treatments were measured each year due to dry conditions, agronomic manipulations or other reasons.

Crop and pasture growth was determined from measurement plots running parallel to, and 2, 4, 6, 8, 12, 16, 20, 24 and 30 m from, the belt in each treatment plot.Measurements at 30 m were only made at sites with taller belts (Sites 1, 5, 6, 8 and 15).Narrow alleys at Sites 2, 9 and 10 (Table 3-1) meant the maximum distance from the belts was 10, 16 and 18 m respectively.

Crop grain yield was measured by machine harvesting plots 1.7 or 1.8 m wide and either 20 or 25 m long (same length as the measurement plots described previously).At Sites 18, 19 and 20, canola yield was determined from hand-harvested samples taken just prior to the crop being swathed.In the case of hand-harvests, total above-ground green biomass was determined from five 0.5 m^2 quadrats cut at each distance and weighed in the field.At each site, samples from each distance in the three replicates of treatment C were subsequently dried at 70 ^{o}C and the grain weight and harvest index determined.The harvest index at each site was used to estimate grain weight using the green above-ground biomass data determined in the field.

Pasture above-ground biomass was determined once in September each year using the calibrated visual assessment technique of Campbell and Arnold (1973).Assessments were made at 20 points at each measurement distance (10 assessments x two persons) and average above-ground biomass determined for the plot at each distance in each treatment replicate.

While the lateral extent of tree/crop competition varied among treatments, years and sites, measurement distances ≥ 20 m from unharvested belts ranged between 2.8 and 13.5 H and averaged 5.5 H.Therefore this study assumed crop and pasture ≥ 20 m from the belts was unaffected by competition.

Sudmeyer et al. (2002a) showed that where crops were unaffected by sand blasting, crop yield ≥ 20 H from windbreaks was largely unaffected by shelter and could be regarded as open yield.They also found that yields at distances between 4 and 20 H were not significantly different from open yield.Measured mallee heights and crop yield data from Sudmeyer et al. (2002a) were used to estimate yields at 20, 24 and 30 m relative to open conditions for each site and year (excepting sites 2, 9 and 10 where the centre of the alleys was < 20 m from the belt).This analysis suggests that average yield 20-30 m from unharvested belts would have ranged between 90 and 104 % of open yield and averaged 99 %.Where belts had been harvested shelter would have been reduced and it could be assumed that average yield at 20-30 m was closer to open yield.

Consequently open yields in this study were assumed to be equal to the average yield ≥ 20 m from the belts for all treatments.The exception to this was for Sites 2, 9 and 10 where open yield was assumed to be at the centre of the alleys and the competition zone was calculated for 2-10, 2-16 and 2-20 m respectively.

For the purposes of comparing the magnitude of mallee/crop competition among sites and years, crop or pasture yield at each measurement distance within the competition zone was normalised by expressing it relative to mean open yield for that particular treatment plot.As belt width is currently taken to include 2 m of uncropped land on either side of the belt, the mean yield within the competition zone was then calculated for the area 2-20 m from the belts.Where the uncropped distance next to the trees was more than 2 m wide, yield from 2 m to the edge crop was assumed to zero when calculating mean yield between 2 and 20 m.

The actual lateral extent of mallee agriculture competition in each treatment was estimated by consecutively comparing yield data at each measurement distance with yield at distances further from the belt.Competition extent was taken to be where yield exceeded 80% of the average yield measured at all points further from the belt.Competition extent was not estimated for Sites 2, 9 and 10.

4.2.5 Statistical analysis

Statistical analysis was only done using data from sites where the alley width exceeded 48 m, so data from Sites 2, 9 and 10 were excluded.

Mean competition zone yield for the various harvest and root pruning treatments were compared for each site and year using analysis of variance. This analysis identified data from particular sites and years with high variability, if this variability was considered to be caused by agronomic or seasonal factors rather than treatment effects these data were omitted from the subsequent analyses.

Analysis of variance was also used to do combined analyses across sites for each year. Treatment by site interactions were also assessed at this time. Only sites with the same treatments were compared for each year i.e. sites 1, 3-8, 13, 15 and 17-19 (treatments C, S3, S4, A3, A4, and RP3) and Sites 11, 12, 14, 16 and 20 (treatments C, S5+, A5+ and RP5+).

The correlation between edaphic and climatic conditions and the extent and magnitude of competition adjacent to harvested and unharvested mallees were investigated using all sub-sets multiple regression. Two analyses were conducted:

1. The first used site averages for each year with the following variables (terms) tested; CMI, P (mm), GCMI, GSP, crop or pasture (C or P), CL1 (m), CL2, CL3, m), depth to clay subsoil (m), mallee belt mean annual above ground biomass increment (MAI, green t/ha/yr), mallee belt biomass (green t/ha), mallee leaf biomass (dry t/ha), mallee age (years) and mallee height (m).
2. The second analysis only used data from the control treatment. Data from each site were averaged across all of the years that pasture or crop were measured at each site In addition to testing the variables described above, the following variables were also tested; the percentage of years the site was in crop, N present as ammonium, N present as nitrate, organic carbon, available sulphur, Colwell-P and Colwell-K, with soil nutrients expressed as the amount present in the top 50 cm of the soil profile (g/m^2).

Optimal models were selected on the basis of providing the greatest explanatory power with the least variables and all of the variables being significant (P<0.05).

4.2.6 Economic analysis

The gross margin (GM) or annualised return ($\$ha^{-1}$) from crops and pastures growing adjacent to the mallee belts was estimated for each distance that measurements were made using treatment averages for each site and year.These values were used to calculate the zero GM distance (where costs of production were equal to returns).

The spatially complex crop/pasture yield and GM responses in the competition zone were simplified to a binary function, i.e. an area next to the belt where GM was effectively zero (the opportunity cost distance) and the remaining area where GM was equivalent to open values.This approach has also been taken with crop yields and drainage below the root zone (Lefroy et al. 2001 Knight et al.2002, Ellis et al. 2005; Oliver et al. 2005, Robinson et al. 2006, Crosbie et al. 2008).The opportunity cost distance is the width of the area next to the belt over which agricultural income was effectively forgone.Opportunity cost distance was calculated as:

$$\text{opportunity cost distance} = [22(\text{open GM}) - (\sum GM_{0\text{-}22\ m})]/\text{open GM} \qquad \text{Eq. 1}$$

Where open GM is the mean gross margin for each particular treatment replicate at distances ≥ 20 m from the belt ($\$m^{-2}$) and $\sum GM_{0\text{-}22\ m}$ is the cumulative GM in a 1 m wide transect stretching from the belt out to a distance of 22 m (the midpoint between the 20 m and 24 m measurements.A positive result indicated a net increase in returns from the competition zone, while a negative result indicated a loss with the amount expressed as the width (m) of the strip alongside one side of the belt that is effectively gained or lost to agricultural production.

It was not possible to calculate opportunity cost distance when open GM was negative.To be able to include data from those years in the analysis, average opportunity cost distance was calculated for each using site Eq. 1 where open GM and $\sum GM_{0\text{-}22\ m}$ were the sum for all of the years that data were available at that site.These data were used in turn to calculate the average for each treatment across all sites

Grain prices were taken from Co-operative Bulk Handling and Emerald quoted prices, cash prices (personal communication from local farmers) and ABARE’s index of prices received (ABARE 2009; ABARE-BRS 2010) and were at the ‘farm gate’ i.e. after transport costs and fees.Wheat prices were for APW grade equivalent (Australian Wheat Board), barley price was the average of feed and malt grades.Costs of production were based on unpublished Department of Agriculture and Food Western Australia (DAFWA) gross margins (DAFWA 2005)and farm survey data, information published in the Farm Budget Guides for 2006-2010 (Farm Weekly, 2006; 2007; 2008; 2009; 2010) and ABARE’s index of prices paid (ABARE-BRS 2010).Sheep income was derived from average productivity of wool and sheep enterprises for the various regions as given in Bankwest (2006; 2008) and updated according to the indexes of prices paid and received (ABARE-BRS 2010).The cost of root pruning was assumed to be $15 /km for each side of the belt (Sudmeyer and Flugge 2005) and was indexed according to ABARE’s index of prices paid (ABARE-BRS 2010).

It should be noted that this analysis gives an indication of gross margins based on district averages each year rather than site specific values.

4.3 Results

4.3.1 Crop and pasture growth

Typically crop and pasture yields were least nearest the belts and increased with distance from the belts (e.g. Figure 4-1a).There was considerable variation in competition extent among sites, years and treatments (Table 4-1), with competition extent ranging from a minimum of 2.9 m for treatment S5+ at Site 14 in 2007 to a maximum of 21 m for treatment C at Site 8 in 2006.

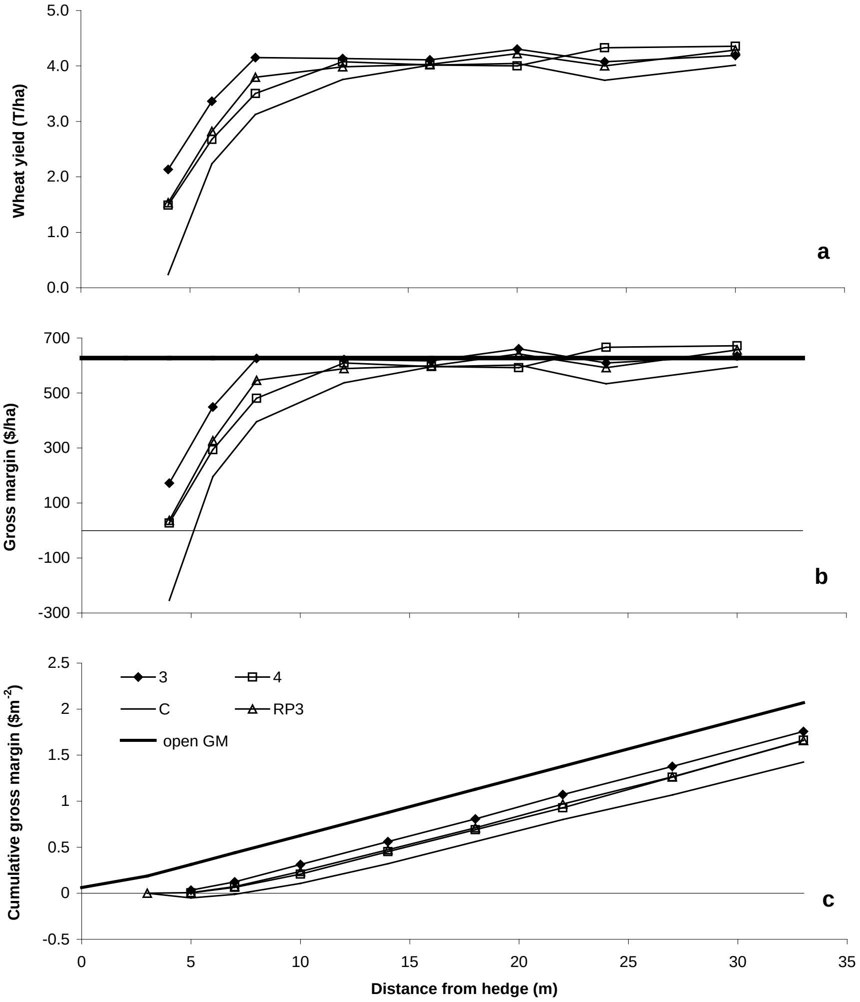

Figure 4-1 Wheat yield (a), gross margin (b) and cumulative gross margin (c) at various distances from mallee belts that were either; unharvested (C), harvested on a three year interval (3; mean of data from treatments S3 and A3), harvested on a four year interval (4; mean of data from treatments S4 and A4) or harvested on a 3 year interval and root pruned biennially (RP3).Cumulative GM is calculated from the edge of the trees (0 m) to midway between measurement points. Data from Site 19 in 2009.

Table 4-1 Crop or pasture grown each year and competition extent.Where measurements not taken the reason is indicated; dry conditions (D), poor weed control (W), poor mallee growth (C) or other reasons (O). Shading indicates the years mallees were harvested. Also shown is significance of differences between treatments and least significant differences at *P*<0.01 (LSD). *P* <0.05 shown in bold text.

Site	Year	crop/ pasture	Competition extent (m)									*P*	LSD
			C	S3	S4	A3	A4	RP3	S5+	A5+	RP5+		
1	2006	wheat	11.9	14.0	-	9.6	-	12.3				0.310	5.0
	2007	pasture	10.0	6.6	-	5.2	-	4.6				0.189	5.5
	2008	wheat	6.7	4.7	-	7.0	-	4.8				0.184	2.8
	2009	pasture	8.8	6.5	10.2	6.1	5.4	5.7				0.329	5.2
	2010	pasture	10.2	4.5	6.1	4.0	6.3	4.0				**0.001**	2.2
3	2006	barley	7.3	6.2	-	6.3		7.2				0.479	2.0
	2007	pasture	8.2	4.0	-	7.9	-	7.1				0.083	3.5
	2008	pasture	5.2	4.4	-	5.5	-	4.6				0.611	2.0
	2009	pasture	8.8	6.5	10.2	6.1	5.4	5.7				0.329	5.2
	2010	pasture	6.2	7.6	9.5	4.5	6.7	4.0				0.087	5.0
5	2006	wheat	13.7	18.7	-	16.6	-	18.5				0.193	5.4
	2007	wheat	19.1	5.0	-	17.3	-	9.2				**0.017**	7.9
	2008	wheat	12.2	4.0	-	4.0	-	4.0				0.225	10.0
	2009	wheat	12.9	-	6.4	-	8.0	-				**0.031**	4.0
	2010	canola	20.3	-	O	-	O	-				-	-
6	2006	pasture	D	C	-	D	-	D				-	-
	2007	barley	17.3	C	-	6.6	-	7.5				**0.032**	7.3
	2008	pasture	11.3	C	-	5.7	-	10.7				0.447	16.7
	2009	wheat	12.0	C	9.7	5.3	7.1	5.8				**0.001**	1.5
	2010	wheat	D	C	D	D	D	D				-	-
8	2006	wheat	21.0	15.1	-	14.5	-	13.9				0.533	13.9
	2007	lupins	10.1	5.7	-	5.3	-	6.8				**0.042**	3.3
	2008	wheat	O	O	2	O	-	O				-	-
	2009	canola	14.7	15.7	15.4	13.3	14.1	9.7				0.376	6.3
	2010	wheat	17.8	15.7	18.4	13.3	12.0	13.2				**0.071**	4.9
11	2006	wheat	7.5						6.3	6.8	6.6	0.129	1.1
	2007	pasture	7.5						7.3	7.8	7.7	0.999	9.9
	2008	wheat	W						W	W	W	-	-
	2009	pasture	W						W	W	W	-	-
	2010	wheat	12.1						O	O	O	-	-
12	2006	pasture	4.3						8.3	10.2	8.4	**0.003**	2.4
	2007	pasture	11.3						6.9	7.1	9.7	0.365	6.2
	2008	oats	9.5						9.7	7.9	6.7	0.402	4.5
	2009	pasture	10.4						9.7	11.2	7.4	0.377	5.2
	2010	pasture	12.9						14.9	13.9	13.8	0.780	4.4

Site	Year	crop/ pasture	Competition extent (m)									*P*	LSD
			C	S3	S4	A3	A4	RP3	S5+	A5+	RP5+		
13	2006	wheat	17.8	15.8	-	10.1	-	11.8				0.086	6.5
	2007	pasture	6.9	5.2	-	8.9	-	4.0				0.177	4.9
	2008	wheat	12.7	12.1	-	10.3	-	9.2				0.594	6.4
	2009	pasture	8.7	6.4	6.0	5.0	7.3	4.0				**0.002**	1.8
	2010	wheat	D	D	D	D	D	D				-	-
14	2006	wheat	4.0						4.0	4.0	4.0	0.441	-
	2007	pasture	4.9						2.9	3.6	4.2	0.564	1.8
	2008	pasture	5.1						4.3	5.5	5.5	0.434	6.6
	2009	wheat	6.6						4.0	5.3	4.0	0.170	3.1
15	2006	pasture	9.5						11.7	11.5	14.1	0.575	8.6
	2007	wheat	13.4						6.7	8.8	6.7	**0.021**	3.7
	2008	wheat	14.8						4.0	8.7	4.0	**0.004**	4.6
	2009	wheat	11.9						4.0	5.8	4.0	**0.002**	2.8
	2010	wheat	19.6						O	O	O	-	-
16	2006	wheat	13.6	14.9		9.3		11.3				0.137	5.4
	2007	pasture	15.8	4.9		4.0		7.4				**0.020**	6.9
	2008	wheat	14.9	7.6		8.6		7.8				**<0.001**	1.2
17	2006	pasture	12.9	10.9	-	5.0	-	11.1				0.172	7.9
	2007	barley	D	D	-	D	-	D				-	-
	2008	pasture	15.2	7.9	-	6.4	-	6.1				0.054	7.0
	2009	canola		O	-	O	-	O				-	-
	2010	barley	19.0	O	O	O	O	O				-	-
18	2006	pasture	4.0	4.0	-	4.0	-	4.0				0.441	-0
	2007	pasture	6.9	5.0	-	4.4	-	11.2				0.138	6.4
	2009	canola	13.3	8.5	12.0	11.2	14.9	11.5				0.637	5.4
	2010	wheat	8.9	5.8	7.8	5.7	5.6	4.6				**0.036**	2.7
19	2006	canola	7.1	5.3	-	4.0	-	5.7				0.328	3.6
	2007	wheat	6.7	4.0	-	4.0	-	4.0				0.079	2.4
	2008	pasture	8.3	6.3	-	5.6	-	6.7				0.191	2.6
	2009	wheat	8.2	6.3	7.4	4.8	7.5	6.9				**0.024**	**1.8**
	2010	canola	9.4	4.4	6.3	4.2	4.0	4.5				**0.003**	2.5
20	2006	wheat	8.2						6.9	5.8	6.2	0.196	2.5
	2007	barley	8.1						7.5	6.2	6.2	0.329	2.8
	2008	pasture	12.2						8.6	8.5	5.0	0.438	9.8
	2009	canola	10.7						9.0	10.7	9.5	0.196	2.1
	2010	wheat	11.2						9.8	12.0	10.0	**0.009**	1.1

Mean competition extent differed significantly among treatments at one, five, two, five and five sites in years 2006-2010 respectively, with a general trend of greater competition extent in treatment C compared to other treatments and the extent for other treatments varying among sites and years (Table 4-1).

Table 4-2 Crop or pasture grown each year and yield in competition zone 2-20 m (except where noted) expressed as % of open yield.Only Sites/years when data collected are shown. Shading indicates years mallees harvested. Site/years marked with asterisk showed high variability due to agronomic or climatic factors. Also shown is significance of differences between treatments and least significant differences at P<0.01 (LSD). P <0.05 shown in bold text.

Site	Year	crop/ pasture	Yield from 2 m to 20 m$^{\#}$ (% open)									*P*	LSD
			C	**S3**	**S4**	**A3**	**A4**	**RP3**	**S5+**	**A5+**	**RP5+**		
1	2006	wheat	58	55	-	77	-	61				0.096	18
	2007	pasture	75	89	-	90	-	100				0.136	22
	2008	wheat	91	84	-	84	-	89				0.744	18
	2009	pasture	73	80	75	93	88	93				0.178	20
	2010	pasture	71	97	90	106	88	100				**0.003**	14
2	2007	pasture	52						85	62	60	-	-
	2008	oats	48						65	53	91	-	-
3	2006	barley	79	81	-	85	-	77				0.547	14
	2007	pasture	82	97	-	90	-	81				0.170	16
	2008	pasture	84	93	-	87	-	85				0.194	10
	2009	pasture	92	89	93	92	88	91				0.939	13
	2010	pasture	95	99	70	103	79	100				**0.042**	23
5	2006	wheat	44	29	-	48	-	31				0.051	15
	2007	wheat	26	75	-	50	-	66				**0.004**	18
	2008	wheat	83	128	-	114	-	109				0.069	32
	2009	wheat	57	-	82	-	76	-				0.086	20
	2010	canola	20	-	-	-	-	-				-	-
6	2007	barley	42	-	-	89	-	75				0.073	41
	2008*	pasture	60	-	-	97	-	77				0.428	98
	2009	wheat	56	-	76	102	85	86				**0.005**	15
8	2006	wheat	36	47	-	69	-	51				0.183	31
	2007	lupins	69	78	-	92	-	78				0.231	23
	2009	canola	49	58	48	65	52	48				0.816	31
	2010	Wheat	39	46	30	59	65	60				**0.036**	23
9	2006	pasture	56	64	-	88	-	-				-	-
	2007	pasture	80	83	-	84	-	89				-	-
	2008	pasture	92	93	-	83	-	98				-	-
	2009	pasture	90	101	100	98	91	92				-	-
	2010	pasture	55	68	73	75	86	87				-	-
10	2006	oats	61						58	123	64	**0.001**	24
	2007	oats	64						90	86	105	**0.004**	15
	2008	pasture	59						84	80	88	**0.047**	20
	2009	pasture	54						64	69	69	**0.050**	11
11	2006	wheat	79						86	80	86	**0.199**	9
	2007	pasture	83						88	87	89	**0.974**	33
	2010	wheat	49						-	-	-	-	-

Site	Year	crop/ pasture	Yield from 2 m to 20 m# (% open)									*P*	LSD
			C	S3	S4	A3	A4	RP3	S5+	A5+	RP5+		
12	2006	pasture	78						67	93	81	**0.014**	14
	2007	pasture	73						78	77	77	0.912	18
	2008	oats	69						78	84	92	0.147	21
	2009	pasture	72						77	58	73	0.318	25
	2010	pasture	61						52	58	61	0.664	19
13	2006	wheat	35	40	-	69	-	55				**0.021**	21
	2007*	pasture	71	97	-	98	-	102				0.478	50
	2008	wheat	56	65	-	67	-	75				0.381	24
	2009*	pasture	70	124	93	114	106	150				**0.022**	41
14	2006	wheat	93						89	105	96	0.219	18
	2007	pasture	95						109	79	79	**0.016**	14
	2008*	pasture	107						88	106	109	0.846	84
	2009*	wheat	90						105	93	89	**0.035**	6
15	2006	pasture	79						54	60	46	0.131	29
	2007	wheat	31						79	76	73		
	2008	wheat	51						88	82	88	**0.006**	15
	2009	wheat	64						102	82	109	**0.001**	12
	2010	wheat	29						-	-	-	-	-
16	2006	wheat	52	46		65		54				**0.035**	11
	2007	pasture	35	71		73		72				**0.005**	20
	2008	wheat	50	82		65		69				**0.028**	19
17	2006*	pasture	66	71	-	209	-	66				**0.013**	83
	2008	pasture	54	68	-	79	-	77				**0.002**	9
	2010	barley	16	-	-	-	-	-				-	-
18	2006	pasture	89	94	-	90	-	85				0.213	9
	2007	pasture	81	80	-	87	-	67				0.192	19
	2008	pasture	81	87	-	86	-	88				0.518	11
	2009	canola	61	64	68	68	55	64				0.444	12
	2010	wheat	74	79	77	80	78	91				0.104	11
19	2006	canola	80	96	-	92	-	87				**0.007**	7
	2007	wheat	90	92	-	88	-	88				0.941	21
	2008	pasture	78	95	-	88	-	85				0.119	14
	2009	wheat	76	85	77	88	79	81				0.061	10
	2010*	canola	84	107	88	84	102	101				0.742	44
20	2006	wheat	77						82	86	85	0.743	20
	2007	barley	82						81	85	88	0.728	16
	2008	pasture	56						85	72	86	**0.030**	20
	2009	canola	70						76	73	73	0.812	14
	2010	wheat	69						78	65	77	**0.011**	7

#Yield is for 2-10 m with open yield assumed at 10 m at Site 2, 2-16 m with open yield assumed at 16 m at Site 9 and 2-20 m with open yield assumed at 18 m at Site 10.

There was also considerable variation in competition magnitude (Table 4-2) with yield in the competition zone ranging from a minimum of 20% of open for treatment C at Site 5 in 2010 to a maximum of 128% for treatment S3 at Site 5 in 2008 (not including data from sites with high variability).Differences in competition zone yield for the various treatments were significant at seven, four, five, five and five sites in years 2006-2010 respectively, with a general trend of less yield in treatment C compared to other treatments and the magnitude of differences varying among sites and years.There was high variance in competition zone yield at seven site/years (Table 4-2).Five of these sites had very patchy pasture growth due to dry conditions, one had poor wheat growth also due to dry conditions and one had canola with irregular weed control.As the variability couldn’t be attributed solely to treatment effects data from these sites were omitted from further analysis.

By averaging treatment responses across sites each year, some broad trends in competition response became clearer.In the year mallees were harvested (either for the first or second time), competition extent (Figure 4-2 c and d) and magnitude (Figure 4-2 a and b) were only significantly decreased relative to the control treatment if the mallees were harvested in autumn.Competition was not significantly decreased by spring harvest.Competition magnitude and extent subsequently decreased compared to the control, during the first and second years after mallee harvest for both autumn and spring harvest treatments.By three years after harvest, competition extent and magnitude was still less than for the control but only significantly for treatments S5+ and RP5+. Four years after harvest, competition extent and magnitude were similar for control and harvested mallees.Root pruning harvested mallees did not significantly reduce competition extent and magnitude compared to just harvesting at the same interval and season.

Competition extent and magnitude averaged over the five measurement years were relatively similar among harvested treatments (Table 4-3).Compared to unharvested mallees, yield in the competition zone of harvested mallees was increased by 11-16%, 8-12% and 7-11% for 3, 4 and 5+ year harvest intervals respectively and competition extent was reduced by 2.9-3.7 m, 2.5-3.3 m and 1.6-2.1 m respectively.

Table 4-3 Mean yield in the competition zone and competition extent over five years of measurement. Control (C) shows values at sites with 3-4 year harvest interval and 5+ yr harvest interval respectively.

	Harvest interval								
	C	3 yr			4 yr		5+ yr		
		S3	A3	RP3	S4	A4	S5+	A5+	RP5+
Mean yield (% open)	63 & 67	74	79	75	71	75	77	73	78
Extent (m)	11.7 & 10.8	8.7	8.0	8.1	9.2	8.4	8.8	9.2	8.4

Site and site by treatment interactions were significant factors in determining both yield in the competition zone and the lateral extent of competition.All subset regression analysis showed that competition magnitude and extent adjacent to harvested mallees were most strongly correlated to harvested mallee biomass and increased with increasing mallee biomass and height, decreased with increasing rainfall and were greater for crop compared to pasture (Table 4-4).While the resultant linear equations were statistically significant they explained less than 30% of the variability in competition extent or magnitude.

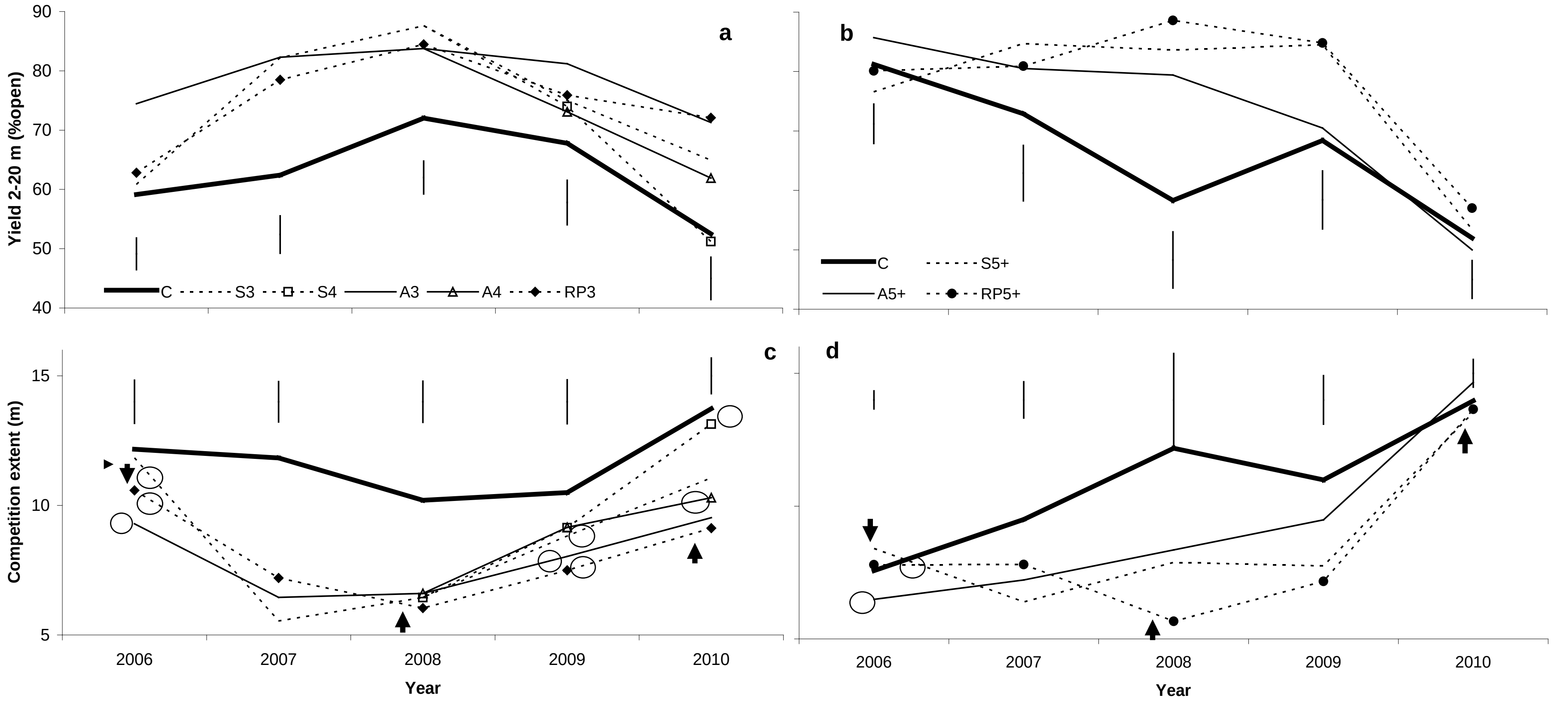

Figure 4-2 Mean yield in the competition zone (2-20 m) of unharvested mallee belts (C) or mallees harvested on 3 or 4 (a) or 5+ (b) year intervals in either spring (S) or autumn (A) and the lateral extent of competition from unharvested mallee belts (C) or mallees harvested on 3 or 4 (c) and 5+ year (d) intervals in either spring (S) or autumn (A).Open circles show when treatments were harvested, arrows when they were root pruned and vertical bars show LSD (*P*<0.05).

Table 4-4 Coefficients for the 1-3 variable models that best explain competition extent and magnitude (% open) adjacent to harvested mallee belts.

	Const.	Explanatory variable parameter (t probability of parameter in brackets)				r^2
		Mallee biomass (t/ha)	Growing Season Rainfall (mm)	Crop/Pasture (Crop=0, Pasture=1)	Mallee height (m).	
% open	84.3	-0.273 (<0.001)				0.21
	71.2	-0.253 (<0.001)	0.056 (<0.001)			0.27
	69.5	-0.241(<0.001)	0.052 (<0.001)	5.660 (0.011)		0.29
extent	6.827	0.056 (<0.001)				0.19
	10.0	0.052 (<0.001)	-0.014 (<0.001)			0.27
	10.5		-0.015 (<0.001)	-1.604 (<0.001)	0.906 (<0.001)	0.30

For unharvested mallees, competition magnitude and extent were most strongly correlated with mallee age and increased with increasing mallee age, MAI+biomass and height and decreased with increasing rainfall (Table 4-5).The resultant linear equations were statistically significant but explained less than 50% of the variability in competition extent and magnitude.

Table 4-5 Regression coefficients for the 1-4 variable models that best explain competition extent and magnitude (% open) adjacent to unharvested mallee belts based on a dataset of site means for each year.

	Constant	Explanatory variable parameter (t probability of parameter in brackets)					r^2
		Mallee age (years)	Growing Season Rainfall (mm)	Mallee height (m)	Mallee MAI (t/ha/yr)	Mallee above ground biomass (t/ha)	
% open	104.34	-4.350 (<0.001)					0.22
	78.0	-3.871 (<0.001)	0.102 (<0.001)				0.35
	78.7	-2.690 (0.028)	0.132 (<0.001)	-3.990 (0.107)			0.37
	137.5	-9.570 (<0.001)	0.123 (<0.001)		-9.290 (0.002)	0.810 (0.004)	0.44
extent	2.48	0.965 (<0.001)					0.25
	7.72	0.871 (<0.001)	-0.020 (0.001)				0.37
	7.55	0.598 (0.019)	-0.027 (<0.001)	0.924 (0.072)			0.39
	-5.16	2.115 (<0.001)	-0.024 (<0.001)		1.973 (0.002)	-0.174 (0.003)	0.46

Soil cores taken 20 m from the mallee belt of each replicate of treatment C at each site provided data which further defined the edaphic conditions.These soil core data were assumed to be representative of each site across all of the measurement years (Appendix B).Analysis showed mean competition extent and magnitude (across all years) increased with mallee age and $P_{Colwell}$ in the soil (Table 4-6).

While competition extent tended to increase with mallee height, the relationship was weak with competition extent generally remaining above 6 m even for harvested mallees (Figure 4-2).Consequently the proportion of the sheltered zone occupied by the competition zone increased as mallee height decreased.For unharvested mallees competition extent expressed as a multiple of their height (H) ranged between 1.0 and 5.7 H with a mean of 2.6 H.

Table 4-6 Regression coefficients for the 1 and 2 variable models that best explain competition extent and magnitude (% open) adjacent to unharvested mallee belts based on a dataset of site means averaged across years

	Constant	Explanatory variable parameter (t probability of parameter in brackets)		r^2
		Mallee age (yrs)	$P_{Colwell}$ (g/m^2)	
% open	120.2	-6.28 (0.009)		0.38
	148.2	-7.03 (<0.001)	-3.04 (0.004)	0.67
extent	-0.54	1.334 (0.01)		0.37
	-6.91	1.504 (<0.001)	0.692 (0.002)	0.71

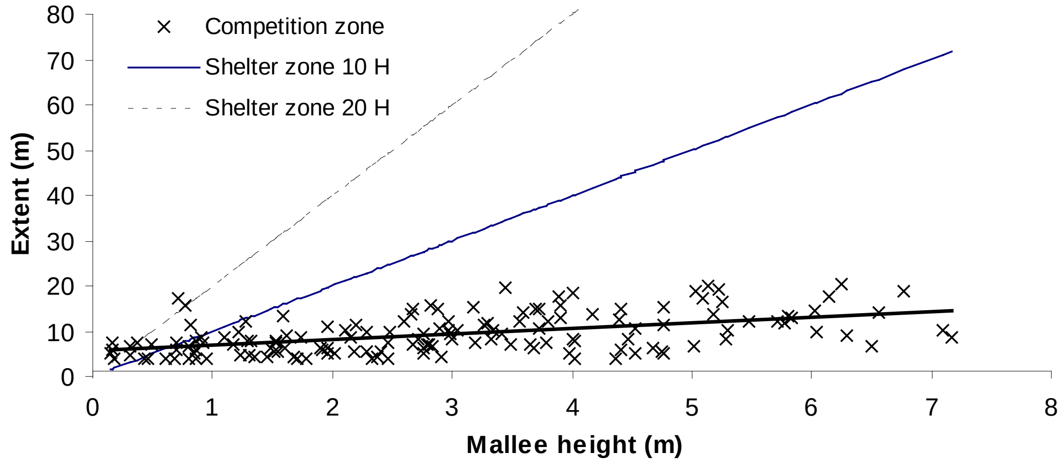

Figure 4-3 Lateral extent of competition zone and sheltered zones, to 10 and 20 times belt height (H), for harvested and unharvested mallees of differing height. Also shown is the line that best describes the relationship between tree height and competition extent (competition extent (m) = 1.2164 x tree height (m) + 5.6761, r^2=0.25).

4.3.2 Economic analysis

District average values for input costs and crop and sheep returns together with measured productivity data suggest open GM was less than zero for 11 of the 75 field years for which data were collected (Table 4-7).This is in addition to the 6 field years when data was not collected because the crop or pasture was considered too drought affected to warrant measurement (Table 4-1).GM was generally least near the belts and increased with distance to reach open values outside the extent of competition (e.g. Figure 4-1b).

Table 4-7 Zero GM distance for crop and pasture adjacent to mallee belt rows, open gross margin (open GM) and width of uncropped area alongside belt rows.

Site	Year	crop/ pasture	zero GMdistance (m)									Open GM	Uncrop dist.
			C	S3	S4	A3	A4	RP3	S5+	A5+	RP5+	($ha^{-1})	(m)
1	2006	wheat	10.4	10.8		5.3		10.1				147	2
	2007	pasture	7.4	7.1		3.2		2.0				66	-
	2008	wheat	4.9	4.0		4.8		4.0				235	2
	2009	pasture	6.7	4.7	6.5	2.6	4.3	4.2				113	-
	2010	pasture	7.4	2.0	4.0	2.0	2.2	2.3				130	-
2	2007	pasture	7.3						6.4	6.4	5.7	-	-
	2008	oats	-						-	-	-	-	4
3	2006	barley	3.3	3.1		2.4		4.2				476	2
	2007	pasture	6.7	13.0		7.6		5.3				27	-
	2008	pasture	5.2	5.5		6.3		5.4				27	-
	2009	pasture	4.0	2.9	3.0	2.3	3.7	2.9				60	-
	2010	pasture	5.2	3.3	3.8	2.0	4.4	2.9				69	-
5	2006	wheat	8.9	12.2		9.9		11.9				128	3-4
	2007	wheat	17.2	3.5		13.8		8.3				120	3
	2008	wheat	4.0	4.0		4.0		4.0				388	1-4
	2009	wheat	8.7	4.0		5.1		4.5				163	1-4
	2010	canola	16.5									208	2.5
6	2007	barley	9.6			4.0		4.0				505	4
	2009	wheat	9.4		6.7	2.8	5.4	3.5				177	1-2
8	2006	wheat	-	-		-		-				-41	3-5
	2007	lupins	5.6	4.0		4.0		4.7				416	5
	2009	canola	-	-		-		-				-9	2-5
	2010	wheat	-	-		-		-				-66	2-5.5
9	2006	pasture	7.5	8.8		3.9						-	-
	2007	pasture	6.5	5.6		5.6		6.3				-	-
	2008	pasture	2.7	2.8		3.5		2.2				-	-
	2009	pasture	2.5	2.0	2.0	2.0	2.2	2.3				-	-
	2010	pasture	2.0	2.0	2.0	2.0	2.0	2.0				-	-
10	2006	oats	-						-	-	-	-	2-3
	2007	oats	10.3						3.5	6.4	2.1	-	2
	2008	pasture	10.5						5.8	7.4	7.6	-	-
	2009	pasture	10.1						7.8	6.7	7.8	-	-
11	2006	wheat	5.4						4.8	4.9	4.6	183	4
	2007	pasture	-						-	-	-	-2	-
	2010	wheat	12.6									46	3

Site	Year	crop/ pasture	zero GMdistance (m)									Open GM	Uncrop dist.
			C	S3	S4	A3	A4	RP3	S5+	A5+	RP5+	($\$ha^{-1}$)	(m)
12	2006	pasture	6.9						7.7	3.4	7.3	95	-
	2007	pasture	7.7						6.8	6.7	6.3	81	-
	2008	oats	-						-	-	-	-105	
	2009	pasture	6.3						5.5	5.3	2.0	166	-
	2010	pasture	11.0						11.5	7.8	8.6	181	-
13	2006	wheat	-	-		-		-				-60	5-6
	2008	wheat	6.5	4.0		5.3		4.0				552	3-6
14	2006	wheat	5.4						5.5	4.8	6.0	13	2
	2007	pasture	2.7						2.0	2.0	2.0	74	-
15	2006	pasture	-						-	-	-	3	-
	2007	wheat	13.8						10.2	9.4	4.0	174	4
	2008	wheat	4.2						2.0	2.0	2.0	812	2.5 - 9
	2009	wheat	8.3						4.0	4.0	4.0	194	2.5- 6
	2010	wheat	18.1									78	
16	2006	wheat	-	-		-		-				-71	6
	2007	pasture	-	-		-		-				-2	-
	2008	wheat	9.5	8.0		8.0		8.0				242	3 - 6.5
17	2008	pasture	-						-	-	-	-1	-
	2010	barley	-						-	-	-	-183	2.5-3.5
18	2006	pasture	2.8	3.0		3.0		3.1				86	-
	2007	pasture	5.3	3.3		2.1		3.8				90	-
	2008	pasture	5.2	3.3		3.8		3.4				100	-
	2009	canola	10.8	7.2	8.3	7.3	9.8	8.9				303	4-4.5
	2010	wheat	4.8	4.7	4.8	4.3	4.6	4.0				677	3-4
19	2006	canola	3.1	3.5		2.0		2.9				535	2
	2007	wheat	2.8	2.4		2.4		2.0				1478	4
	2008	pasture	5.3	3.3		2.1		3.9				100	-
	2009	wheat	5.1	4.1	4.0	4.0	4.0	4.0				627	4.5
20	2006	wheat	7.0						6.6	4.0	5.3	234	4-8
	2007	barley	4.0						4.0	4.0	4.0	514	5
	2008	pasture	10.0						5.6	6.0	4.2	74	-
	2009	canola	5.4						4.9	6.7	5.9	395	2.5-3
	2010	wheat	4.0						4.0	4.3	4.0	811	2.5-4

The distance from the belt at which the cost of crop or pasture production was equal to the returns received (zero GM) ranged from 2 to 18 m (Table 4-7).The mean zero GM distance was 7.2 m for unharvested mallees and ranged between 4.4 and 5.5 m for the harvested mallees (Table 4-8).Annual mean zero GM distance was similar for harvested and unharvested mallees in the year the mallees were first harvested, then declined relative to unharvested mallees and remained less for at least four years (Figure 4-5 d).Increased frequency of harvest reduced zero GM distance relative to unharvested treatments.Root pruning mallees had little effect on mean zero GM distance.

The opportunity cost distance ranged between +1 and 44 m for unharvested mallees and +5 and 33 m for harvested mallees (where + indicates a benefit or effective increase in GM within 22 m of the belt) (Table 4-9).Treatment means of opportunity cost distance showed similar trends over time to zero GM distance (Figure 4-5a and c).The mean opportunity cost distance was 14 m for unharvested mallees and ranged between 8.4 and 9.2 m for the harvested mallees (Table 4-8).Root pruning mallees had little effect on mean zero GM distance for 3 and 4 year harvest intervals but decreased it by 1 m for the 5+ year harvest interval.

Table 4-8 Mean opportunity cost and zero GM distances over five years of measurement for unharvested mallees (C) and mallees harvested on 3, 5 and 5+ year intervals with (+RP) and without (-RP) root pruning.GM adjacent to mallees harvested on a 4 year interval was assumed to be the same as adjacent to mallees harvested in a 3 year interval for the first 3 years after harvest.Values are means of harvest interval treatments taken across all sites and seasons of harvest and don't include data from years when open GM < 0 $\$ha^{-1}$.

	C	Harvest interval				
		3 yr		4 yr	5 yr	
		-RP	+RP	-RP	-RP	+RP
Opportunity cost distance (m) (open GM >0 $\$ha^{-1}$)	14.0	8.4	8.6	9.2	8.9	8.0
Zero GM distance (m)	7.2	4.6	4.5	4.5	5.5	4.9

The means in Table 4-8 were calculated using values obtained when open GM >0 $\$ha^{-1}$ (Table 4-9), data for years when open GM < 0 $\$ha^{-1}$ could be included in the analysis by calculating the total GM across all measurement years for each site.This analysis did not markedly alter the mean opportunity cost distance except for mallees harvested on a 3 year interval where is was 2.3 m wider at 10.7 m and mallees harvested on a 5 + year interval where it was 1.8 m narrower at 7.1 m.

Table 4-9 Opportunity cost distance for crops and pastures adjacent to mallee belt rows in years when open GM is greater than break even.

Site	Year	crop/pasture	Opportunity cost distance (m)								
			C	S3	S4	A3	A4	RP3	S5+	A5+	RP5+
1	2006	wheat	22.4	19.8		10.3		19.3			
	2007	pasture	14.9	13.6		7.6		-1.3			
	2008	wheat	4.1	8.3		6.8		5.7			
	2009	pasture	12.3	11.6	12.3	6.5	8.0	4.7			
	2010	pasture	12.7	3.2	5.9	-0.4	7.2	2.3			
3	2006	barley	7.5	7.0		6.2		8.0			
	2007	pasture	13.7	32.9		14.4		12.4			
	2008	pasture	12.9	11.4		12.9		15.8			
	2009	pasture	5.7	7.1	4.6	5.4	8.0	5.5			
	2010	pasture	4.7	2.5	12.0	-0.3	11.2	3.0			
5	2006	wheat	18.6	23.1		19.2		24.3			
	2007	wheat	38.2	15.1		24.5		19.0			
	2008	wheat	5.8	-4.4		-2.5		-0.2			
	2009	wheat	17.7	8.0		11.4		9.8			
	2010	canola	27.4								
6	2007	barley	16.5			4.8		8.1			
	2009	wheat	16.9		12.1	1.2	9.1	6.9			
8	2007	lupins	9.4	7.4		3.2		3.4			
11	2006	wheat	7.3						4.1	7.1	5.0
	2010	wheat	43.4								
12	2006	pasture	12.8						16.5	5.9	12.7
	2007	pasture	21.0						17.0	15.1	13.9
	2009	pasture	12.0						10.0	10.4	9.0
	2010	pasture	21.9						22.6	16.0	14.8
13	2008	wheat	13.1	10.9		10.4		7.7			
14	2006	wheat	14.3						8.1	27.7	
	2007	pasture	4.4						-3.4	10.1	10.1
15	2007	wheat	23.0						12.7	3.9	10.1
	2008	wheat	9.9						2.8	4.2	3.6
	2009	wheat	13.1						0.4	7.3	-2.0
	2010	wheat	43.5								
16	2008	wheat	14.2	3.2		9.3		8.1			
18	2006	pasture	5.7	4.3		5.5		7.5			
	2007	pasture	9.4	9.5		6.3		13.3			
	2008	pasture	8.7	6.8		7.0		7.4			
	2009	canola	17.8	15.3	13.0	13.0	16.8	15.8			
	2010	wheat	8.1	6.6	7.1	6.6	6.8	4.1			
19	2006	canola	7.6	3.2		4.7		5.3			
	2007	wheat	4.6	3.7		4.5		4.6			
	2008	pasture	9.4	9.5		6.3		13.7			
	2009	wheat	8.1	5.4	8.0	4.8	7.2	6.6			
20	2006	wheat	9.9						7.1	5.9	6.5
	2007	barley	-0.7						-1.4	-6.8	1.0
	2008	pasture	22.3						11.7	15.5	9.4
	2009	canola	10.3						9.4	9.9	9.9
	2010	wheat	9.0						6.9	9.9	7.3

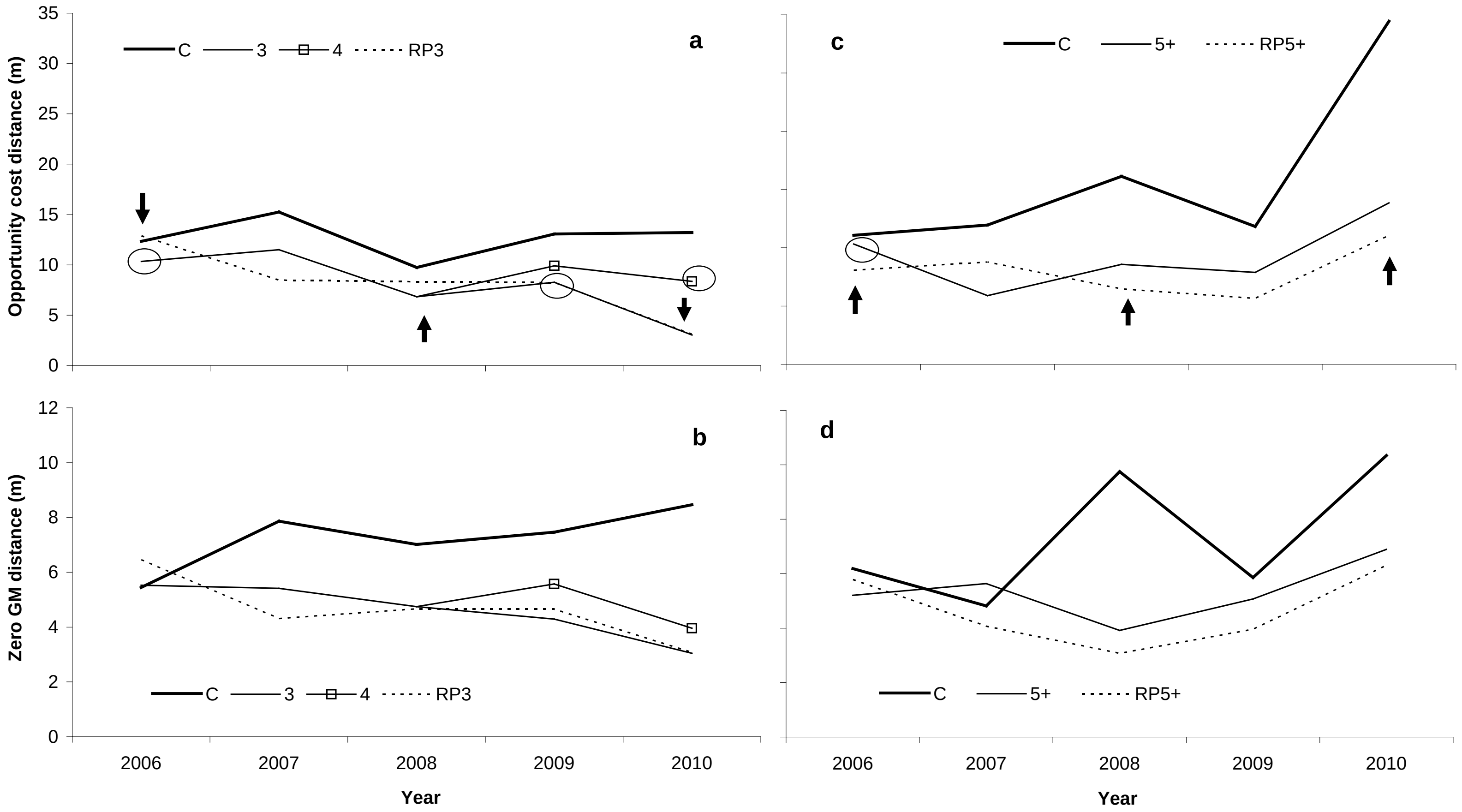

Figure 4-4 Mean opportunity cost distance for crops and pasture adjacent to mallee belts at sites that were unharvested (C), or harvested on a 3 or 4 year interval (a) or (b) 5+ year interval or harvested on 3 or 5 year intervals and root pruned biannually (RP3 and RP5 respectively) and mean zero GM distance at the same sites (b and d). Open circles show when treatments were harvested, arrows when they were root pruned.Note: only treatment C was measured at Sites 5, 11 and 15 in 2010.

The opportunity cost distances shown in Table 4-9 were calculated using measured data which included a range of uncropped distances next to the trees.The width of this area varied among sites and years with a maximum distance of 9 m (Site 16), but averaged 3.6 m across all sites and years (Table 4-8).Figure 4-6 shows that for a site and year with a wide zero GM distance (e.g. Treatment C at Site 5 in 2007) it is possible to reduce the opportunity cost distances from 36 m to 19 m by leaving an 18 m wide uncropped strip alongside the belt.However, for a site with relatively small zero GM distances (e.g. for harvested mallees at Site 5 in 2007 or harvested and unharvested mallees at Site 19 in 2009) there is no advantage to leaving an unharvested strip wider than 5 m.Figure 4-7 shows that while the costs of inputs and prices received for agricultural products doesn't alter the optimum uncropped distance in a particular year they do affect the opportunity cost distance.Opportunity cost distance generally increases with increasing input prices and declines with increasing prices paid for commodities.

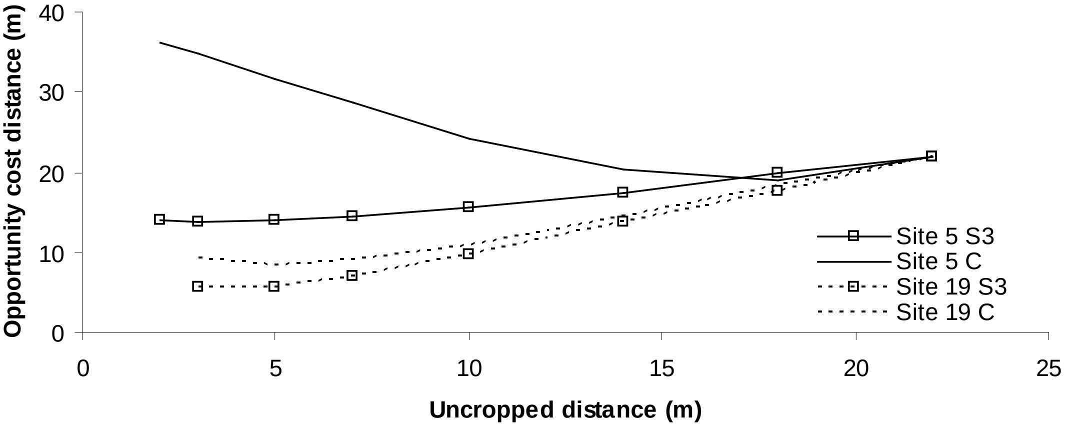

Figure 4-5 **Change in opportunity cost distance with distance uncropped next to belts. Calculated using data from Sites 5 (2007) and 19 (2009) and for unharvested mallees (C) and mallees spring harvested on a three year interval (S3).**

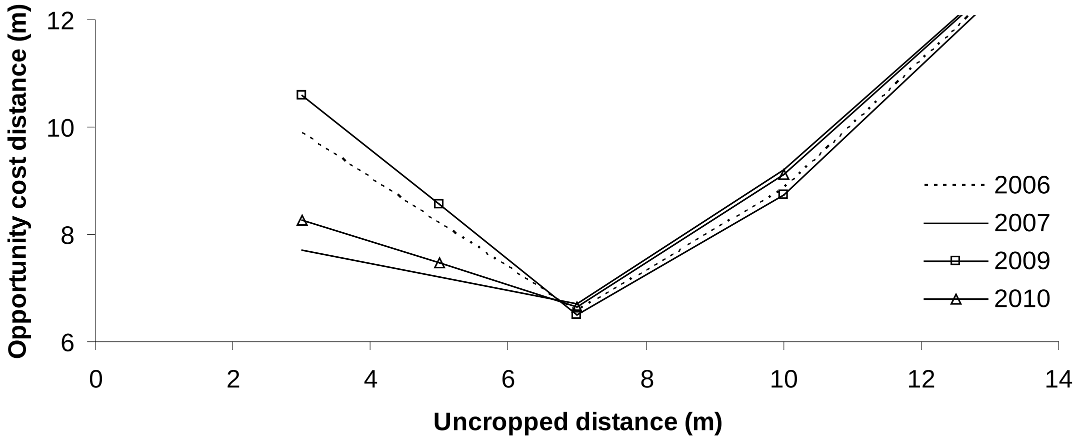

Figure 4-6 **Change in opportunity cost distance with distance uncropped next to unharvested mallees and various open GMs. Calculated using data from Site 20 (2006) and input costs and wheat prices for 2006 (230 $ha^{-1} and 182 $t^{-1} respectively), 2007 (280 $ha^{-1} and 368 $t^{-1} respectively), 2009 (308 $ha^{-1} and 225 $t^{-1} respectively) and 2010 (270 $ha^{-1} and 290 $t^{-1} respectively).**

4.4 Discussion

Competition extent and magnitude varied widely among sites and years but for unharvested mallee belts were broadly similar to what has been reported for various tree systems in southern Australia.Harvesting mallee belts reduced competition for up to three years.Root pruning harvested mallees had little effect on yield but a greater effect on gross margin.These findings along with some of the economic implications are discussed below.

For unharvested mallees the average extent of competition was 11.1 m or 2.6 times mallee height (H).This is within the range of reported competition extent for mallees (8-10 m or 2-5 H (Sudmeyer and Flugge 2005; Sudmeyer and Daniels, 2010)) and for various exotic and native tree species at other sites in southern Australia (Table 4-10; Bird et al. 2002; Woodall and Ward 2002; Unkovich et al, 2003; Sudmeyer and Flugge 2005; Sudmeyer and Daniels 2010) and temperate areas elsewhere in the world (e.g. Brandle et al. 2009).It is also within the measured root extent of mallees (10-15 m or 5H (Sudmeyer et al, 2004)) or extent inferred from reduced soil water content (6-20 m or1.9-6 H (Robinson et al. 2006; Brooksbank et al 2011)).

For unharvested mallees the average crop and pasture yield reduction was 35% within 20 m and 52 % within the area identified as suffering competition.This is generally greater than reported for non mallee species (Table 4-10; Bird et al. 2002; Woodall and Ward 2002; Unkovich et al, 2003), but similar to the 43 % (0.5-2 H) to 50% (0.5-4 H) reported by Sudmeyer and Flugge (2005) and Sudmeyer and Daniels (2010) respectively for other mallee alley systems.Some of the difference in magnitude can be explained by the area over which competition was estimated.In this study and those of Sudmeyer and Flugge (2005) and Sudmeyer and Daniels (2010) it was calculated as the average of crop or pasture yield starting 2 m (average 0.5 H) from the mallees out to the extent competition was identified.This will tend to give greater competition magnitude than indicated in studies where the first measurement is further from the trees e.g. 1 H in Sudmeyer et al. (2002a) or Bennell & Verbyla (2008).

Table 4-10 The extent of the competition and sheltered zones and the magnitude of crop yield changes within those zones for this and other windbreak studies in temperate southern Australia. N indicates the number of measurement field years. Note the magnitude of competition is calculated only within the area of competition extent.

Source	State	N	Competition zone		Sheltered zone		1-20 H
			Extent (H)	Δ yield (% open)	Extent (H)	Δ yield (% open)	Δ yield % open
Bennell & Verbyla 2008	SA crop	32	2.1	-19	10	7	2
Oliver *et al* 2005	WA crop	24	2.6		8		-7
Sudmeyer *et al.* 2002a	WA crop +we*	64	3.9	-21	20	4	-0.7
	WA crop –we*	58	3.9	-27		2	-4
This study		57	2.6	-52			

* +we is average including sites with wind erosion, -we is average for sites without wind erosion.

Harvesting the mallees generally reduced both the extent and magnitude of competition for two to three years.By four years after harvest, competition was similar for harvested and unharvested mallees.Compared to unharvested mallees harvesting mallees on 3, 4 and 5+ year intervals increased average crop and pasture yield by 14%, 10% and 9% respectively over the five year period of the trial.

Season of harvest influenced competition response probably as a result of both immediate reductions in mallee water use and in differences in coppice growth rates.Competition was only reduced in the year mallees were harvested when harvest was prior to the onset of growing season rainfall (autumn harvest) with spring harvest having little effect.This difference was evident for both the first and second harvest and was particularly marked for the second harvest of the four year rotation.This and other studies have highlighted the importance of water availability in terms of growing season rainfall in determining competition magnitude and extent.Autumn harvest stops mallee water use at a time when rainfall exceeds potential evaporation, allowing a reduction of soil water deficit in the early part of the growing season.This would allow the partitioning of more water to crops or pasture.In contrast, when mallees are harvested in spring, crop or pasture has established and largely completed vegetative growth phases under conditions of high soil water deficit.In addition mallee water use ceases as rainfall is declining and potential evaporation is increasing, reducing the opportunity of increasing stored soil water.

There was also a general trend for greater coppice regrowth from autumn harvested mallees compared to spring harvested mallees for both the first and subsequent harvests (see Section 3).At the sites with 5+ year rotation lengths this resulted in greater competition extent and magnitude next to autumn harvested mallees two and three years after harvest compared to spring harvested mallees (Figure 4-2 b and d).At sites with three and four year harvest intervals the water saving benefits of autumn harvest offset any additional competitiveness afforded by greater coppice growth.

In a commercial mallee biomass production system it is likely that harvesting would operate year round.If there is flexibility in scheduling mallee harvest operations farmer’s may benefit financially ifmallees are harvested in the 4-5 month period before the start of the growing season in years the alleys were to be cropped (high input costs) with later harvests scheduled for alleys with pasture (lower input costs).Consultation between mallee harvesters and farmers with livestock will also be essential to control grazing of coppice in the first 1 or 2 years after harvest.In terms of estimating competition effects on agricultural economics, it is suggested that the averages of autumn and spring harvest values are used until better values can be derived when commercial harvesting commences.

For unharvested mallees 46% of the variability in extent and 44 % of the variability in magnitude could be explained by positive correlations with mallee age, height or biomass and negative correlation with growing season rainfall, confirming trends observed in other studies (Sudmeyer et al. 2002a; Unkovich et al. 2003;Oliver et al. 2005).Mallee age, height, growth rate (MAI) and biomass were all positively correlated (data not presented) and were somewhat interchangeable as explanatory variables for competition magnitude and extent adjacent to both harvested and unharvested mallees.For harvested mallees, age was not a significant factor, but both competition magnitude and extent were greater for crops compared to pastures.The variable response of different crops types to shelter provided by tree windbreaks has been widely reported (Sudmeyer et al. 2002a; Bennell & Verbyla 2008; Brandle et al. 2009), but the response of various crops and pastures to competition is less well reported (Sanford and Sudmeyer 2007; Sudmeyer and Speijers 2007).On a site average basis, competition magnitude and extent were also positively correlated with plant available potassium ($P_{Colwell}$) content in the top 50 cm of the soil profile.This is attributed to a positive correlation between $P_{Colwell}$ content and tree growth (see Section 3), and the correlation between $P_{Colwell}$ content and soil characteristics such as depth to clay and the content of other nutrients (Appendix B).

Root pruning spring harvested mallees did not consistently improve crop or pasture yields in the competition zone and while mean competition extent and magnitude from 2008 to 2010 were generally less, differences were never statistically significant.This result differs from that of Sudmeyer and Flugge (2005) who reported competition losses declining from 50% to 37% when harvested mallees were root pruned.Sudmeyer and Flugge (2005) also reported a significant decline in the growth rate of root pruned mallees.In this trial differences in growth between root pruned and non-root pruned spring harvested mallees were never statistically significant.Though there was a general trend for less growth of root pruned belts at sites with 5+ year harvest intervals, and by 4 years after harvest root pruned belts had 14% less standing biomass than non-pruned belts.

The economic consequences of mallee/crop competition in terms of agricultural production forgone were significant.While there was considerable variability among sites and years, the average opportunity cost distance, the width of the belt of land from which agricultural production is effectively forgone, was 14 m on each side of unharvested mallee belts.This included an average uncropped distance of 3.6 m and amounted to about 39% of mean alley width.This distance is considerably greater than the 2 m on either side of mallee plantings that is commonly assumed to be left uncropped and could have a significant impact on the economics of carbon sequestration schemes utilising dispersed belts of mallees.While trends in opportunity cost distance over time were broadly similar to trends in crop yield in the competition zone of both harvested and unharvested mallees, harvesting and root pruning the mallees had more impact on GM than on yield.Over five years the opportunity cost distance was reduced to 8, 9 and 9 m adjacent to mallees harvested on 3, 4 and 5+ year intervals respectively (mean of both season of harvest treatments and all available sites) and to 7 and 8 m for root pruned mallees harvested on 3 or 5+ year interval respectively.

Tree/crop competition and associated lost agricultural income can be a significant factor in farmers' perceptions and decisions regarding agroforestry systems (Ong et al. 2002; Pannell 2001; Brandle et al. 2009).Clearly, the opportunity cost of competition adjacent to mallee belts can be significant in terms of forgone agricultural production.For mallee agroforestry systems to be acceptable to farmers these costs will have to be offset through direct returns for harvested biomass and sequestered carbon or indirect benefits such as shelter or environmental amelioration.In all cases mallee agroforestry systems will be more acceptable to land managers if competition can be minimised.

The potential for direct returns from the mallees is discussed in detail in Chapter 6.The value of environmental services is often difficult to quantify, and there are currently no mechanisms for farmers to receive payment for these services.Though this may change, for example; Garnaut (2011) suggested that some mechanism for paying for environmental services should be built into any future carbon farming legislation.Bennett et al. (2011) have made a detailed analysis of the hydrological impacts of mallee agroforestry in terms of ameliorating salinisation in Western Australia, and suggest that wide-space mallee belts will not significantly reduce the area affected by secondary salinity.

Some estimate of the value of shelter for crops can be made using our yield and gross margin data for unharvested mallees and published values of crop yield increases in the sheltered zone of tree windbreaks (Table 4-11).This analysis suggests that any additional returns in the sheltered zone would only offset competition losses at one site in one year and only if a 4% yield increase was achieved over a 20 H wide sheltered zone (Table 4-11).For the actual alley configurations measured in this study the mean opportunity cost distance would only have been reduced by 1 m at the highest levels of shelter.If the alleys were all assumed to be 25 H wide (this maximises the ratio of sheltered zone to competition zone) then mean opportunity cost distance would have been reduced by 3 m.The shelter value of harvested mallees will be considerably less than indicated for unharvested mallees as the competition zone occupies a much greater proportion of the sheltered 20 H lee compared to taller trees (Figure 4-4).

Table 4-11 **Opportunity cost distances (total for both sides of the alley) calculated using competition zone data from this study and published values of yield increase in the sheltered zone of windbreaks. Calculated for actual alley widths and 25 H wide alleys.**

Site	year	Alley		Opportunity cost distance (m)							
				Actual alley width				Standard 25 H wide alley			
		m	H	0%	7% to 10 H	2% to 20 H	4% to 20 H	alley width (m)	0%	2% to 20 H	4% to 20 H
1	2006	70	12	44	43	43	43	144	44	39	34
1	2008	70	11	10	9	10	9	162	10	5	0
3	2006	50	13	11	11	11	11	95	11	10	9
5	2006	>250						129	49	46	43
5	2007	>250						130	70	67	63
5	2008	>250						137	11	10	10
5	2009	>250						146	33	33	32
5	2010	>250						156	52	51	50
6	2007	95	19	45	44	45	44	127	45	44	42
6	2009	95	17	33	33	33	33	143	33	33	32
8	2007	125	24	19	18	18	18	133	19	18	18
13	2008	48	11	19	19	19	19	110	19	18	16
14	2006	60	21	26	25	21	15	73	26	23	20
15	2007	95	35	44	43	43	43	69	44	44	44
15	2008	95	33	42	42	41	41	72	42	42	42
15	2009	95	29	39	39	37	36	83	39	38	37
15	2010	95	28	101	100	98	96	86	101	99	98
15	2008	95	22	29	28	28	28	110	29	28	28
18	2009	90	15	47	43	46	45	145	47	43	39
18	2010	90	14	16	16	16	16	157	16	16	15
19	2006	120	34	26	26	25	24	87	26	26	25
19	2007	120	29	21	20	20	19	102	21	20	19
19	2009	120	23	17	16	16	16	132	17	16	16
20	2006	150	50	31	31	29	28	75	31	30	30
20	2007	150	44	11	11	10	9	85	11	10	10
20	2009	150	33	33	32	31	29	113	33	31	30
20	2010	150	31	30	29	28	27	119	30	29	27
max		150	50	101	100	98	96	162	101	99	98
min		48	11	10	9	10	9	69	10	5	0
mean		101	25	31	31	31	30	116	34	32	31

It is likely that the opportunity cost of competition adjacent to unharvested mallees could be significantly reduced by root pruning.Figure 4-5 shows that root pruning harvested mallees achieved greatest reduction in opportunity cost distance compared to unharvested mallees four years after harvest.Further measurements are needed to investigate whether root pruning is more effective in reducing competition in longer harvest cycles. While root pruning has been shown to be effective in reducing competition adjacent to a range of tree species (Sudmeyer et al. 2002b; Woodall and Ward 2002; Sudmeyer and Flugge 2005) there are no reported data for unharvested mallee belts.Given the lack of this information and differences in the magnitudes of competition and coppice growth reductions reported in this study and that of Sudmeyer and Flugge (2005), further work is required to quantify the effect of root pruning on mallee competition and mallee growth for both harvested and unharvested mallees.

There is also some scope for reducing the opportunity cost distance by using variable rate technologies to reduce the amount of agricultural inputs such as fertilisers, herbicides and pesticides applied to the competition zone, particularly in years when the costs of inputs rise,prices for products fall or in dry years (Figure 4-7).Further work is required to quantify the economics of doing this and to investigate whether reducing the application of fertilisers would affect mallee growth.

A simpler approach would be to increase the width of the uncropped area immediately adjacent to the belt.This distance was quite variable in this study and ranged from less than 2 m to 9 m, with an average of 3.6 m across all sites and years (Table 4-8).The distance tended to be most variable where mallee belts had been planted on the contour and was greatest for sites where the size of farm machinery had changed since the belts were established so the alley was no longer an even multiple of machinery width.As costs exceed returns inside the zero GM distance, there is a good case for increasing the uncropped distance to 7 m next to unharvested mallees and 4-5 m next to harvested mallees (Table 4-11).These wider alley margins would still require management to ensure they didn’t become reservoirs for pest and diseases or the source of herbicide resistance from poorly controlled weeds (GRDC 2011).

4.5 Conclusions / Implications

Mallee/crop competition was highly variable across sites and years but on average competition extends 11-12 m or 2.6 times the height of unharvested mallee belts.Within this zone agricultural yield was reduced by 52 %.These values are similar to those reported for taller tree species.Harvesting mallees reduced competition for three years after harvest.Over the five years of this trial, harvesting mallees on 3, 4 and 5+ year intervals increased yields in the competition zone by 14 %, 10 % and 9 % respectively.This reduced the area of land over which agricultural income was forgone by 40 %, 34 % and 36 % respectively.

Competition increased with mallee age, height and biomass and was greater in low rainfall years and areas.These trends have been reported for other tree species.

Season of harvest influenced both the extent and magnitude of competition but it is unclear if farmers will have control over when mallees are harvested.However some consultation will be necessary to ensure that coppicing mallees are not damaged by grazing stock.

Root pruning harvested mallees resulted in only small increases in agricultural yield and only reduced the area of land over which agricultural income was forgone for the 5 + year mallee harvest interval.Further work is required to quantify the benefits (in terms of increased agricultural production) and costs (in terms of reduced mallee growth) of root pruning over longer harvest intervals and for unharvested mallees.

The economic cost of competition was equivalent to forgoing agricultural production for 14 m on either side of unharvested mallee belts, or about 39% of alley width.Harvesting the mallees reduced this distance to 8-9 m.Farmers should be aware of the financial impact of competition when making decisions about large scale mallee planting.

The opportunity cost of mallee/crop competition may be reduced by root pruning unharvested and long harvest interval mallees, increasing the uncropped distance next to the belts, reducing the rates of agricultural inputs in the competition zone and ensuring that alley widths are at least 25 times the height of the mature trees.

Mallee agroforestry systems that are regularly harvested for biomass or left unharvested as carbon sinks must fully account for forgone agricultural production in the competition zone of the mallees if they are to be widely adopted.

5 Biomass and nutrient export in harvested mallee systems

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5.1 Introduction

The aim of this section is to explore the impact of mallee harvesting on nutrient export under different harvest regimes, and to understand the impacts of site and harvest regime on the potential for sites to remain productive into the future. It is imperative to ensure that site productivity can be maintained for the foreseeable future to ensure that an industry based on mallees can be profitable and justifies the significant investment in development of the required harvesting and processing infrastructure.

5.2 Methods

5.2.1 Sites

Material was sampled from 10 sites in Western Australia for assessment of biomass and nutrient export rates under different harvest regimes (Sites 1, 3, 6, 8, 9, 13, 16, 17, 18 and 19). The sites that were used in this study are shown in Figure5-1, as marked with an *. They represent a representative cross-section of the typical climates and soils in the mallee-growing region of Western Australia. Treatment responses at all of these sites have been intensively monitored, and we have utilised the productivity information from control stands (uncut) and from coppice stands grown for a short cycle (3 years) and a medium cycle (4 years) after cutting to calculate the export of biomass and nutrients from typical mallee sites.

5.2.2 Tree harvest and sub-sampling

At each site, between 5 and 9 coppice trees were selected for sampling. These trees covered the range of coppice treatments (including harvested in autumn or spring, and harvested at a 3 or 4 year interval). Across the 10 sites, a total of 70 trees were assessed. The harvest trees were measured *in situ* and then cut at the base, and divided in the field into 4 fractions – wood (>20mm), bark, twigs (<20mm) and leaves. Each of the fractions was subsampled, weighed green and transported to the laboratory. The subsamples were dried to constant weight at 65°C, and the dry weight recorded. The subsamples were chemically analysed for their nutrient concentrations, including the macronutrient nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), sulphur (S) and the micronutrients boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn).

5.2.3 Development and application of allometric regressions

The nutrient content of each of the biomass components was calculated by multiplying the nutrient concentrations by the component dry weights, and allometric regressions were developed between canopy cubic volume and biomass and nutrient content on a tree basis. Whilst individual stem measures often provide for greater accuracy in these types of allometric regressions (Grove et al. 2007), the sheer number of stems in regrowing coppice makes individual stem measures impractical. Canopy volume is a good surrogate in coppice situations, with canopy volume typically explaining 70-90% of the variation in tree biomass and nutrient content.

The effects of site, species, harvest season and age of material were explored in these relationships. The effects of harvest season were not generally significant, whilst the other factors had varying significance in the resulting regressions, which are detailed below. For the purposes of exploring nutrient export at the 10 focus sites, site-specific regressions were used, but these are not likely to be widely applicable, so the species-specific regressions are presented for more general application.

The newly developed allometric regressions were applied to the measured coppice regrowth at each of the 10 focus sites, and allometric relationships for seedling/control material were taken from Grove et al. (2007).

5.3 Results and Discussion

5.3.1 Biomass and nutrients in control/seedling plots

The predicted biomass in the seedling-grown trees across the sites prior to installation of the experiments is shown in Figure 5-1. It is worth noting that typical wheat yields in this region are 3-4 t/ha/y in the higher rainfall regions, and 1-2 t/ha/y in the lower rainfall regions demonstrating that mallees are efficient producers of biomass, and this is likely to be due to their ability to access deeper stored soil water, and because they can grow year-round and make the most of rainfall at any time of year.

As well as assessing biomass in the seedling/uncut crop, we also used the results of Grove et al. to calculate the nutrient uptake rates across the 18 sites (Table 5-1). Site 11 was not included in this analysis due to difficulties translating the CVI measurements into biomass using Grove et al's methods. The trees on average took up around 23 kg of N/ha/y, 1.5 kg P/ha/y, 10.3 kg K/ha/y and appreciable quantities of macro-nutrient cations.

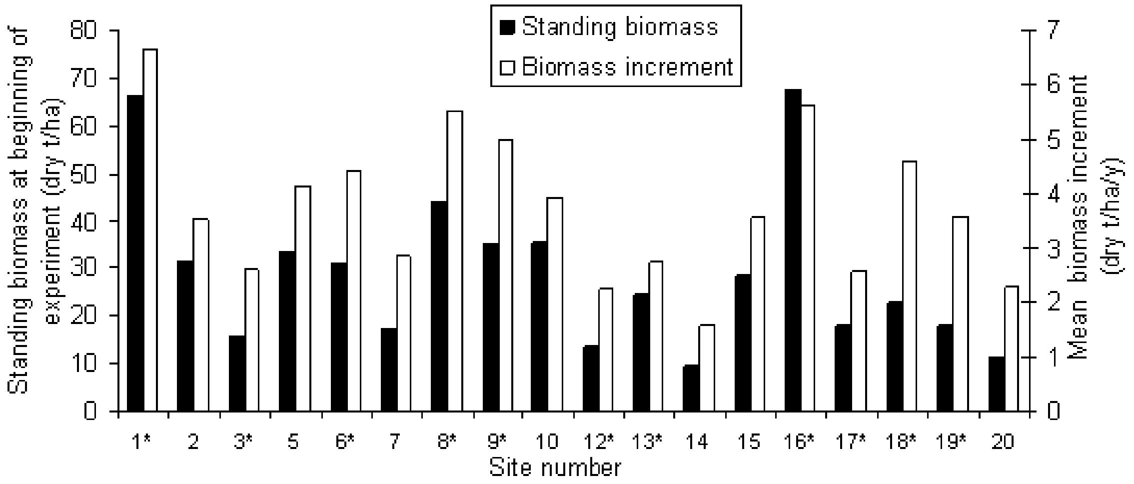


Figure 5-1 Standing biomass and biomass increment in the initial crop prior to first harvest. Note that sites marked with a '*' were focussed on for the full nutrient export analysis.

Table 5-1 Average annual nutrient uptake (kg/ha belt area) by the first rotation/seedling crop

Nutrient	Mean annual uptake (SEM)
Biomass (dry t/ha)	3.75 (0.23)
Nitrogen (kg/ha)	22.8 (1.1)
Phosphorus (kg/ha)	1.53 (0.08)
Calcium (kg/ha)	38.3 (2.3)
Magnesium (kg/ha)	3.87 (0.27)
Potassium (kg/ha)	10.3 (0.6)

5.3.2 Nutrient concentrations in coppice material

The concentration of nutrients was significantly different between fractions for all of the nutrients that were assessed (Table 5-2), thus highlighting the need to account for the fractions separately. Species also had a significant effect for P, Ca, Mg and S, and there was a significant interaction between plant fraction and species for Ca, Mg and S.

The actively growing leaf and twig fractions had higher concentrations of N, P, and S, whilst the bark had significantly higher calcium concentration than the other fractions (Table 5-3). The wood generally had lower concentrations of all nutrients. The significant interaction between species and plant fraction for Mg ($P<0.001$) was probably because *E.polybractea* had a higher Mg content in its bark than the other species, whilst the interaction with S ($P<0.001$) was because *E.kochii* had higher S levels in bark and wood compared to the other species.

It is interesting to note that foliar N and P concentrations reported here are lower than has been found to be adequate for good growth in other eucalypt species (Dell et al. 2002), but it needs to be recognised that this may be partly because the leaves analysed here were representative of the whole tree, rather than the first expanded leaves taken from the top third of the canopy that is recommended for sampling for nutrient analysis. It also needs to be noted that eucalypts tend to regulate leaf area to adjust for N and P concentration because these nutrients are readily re-translocated throughout the plant to the sites where they can be most efficiently utilised, so foliar N and P can be an insensitive indicator of plant status. However, these lower levels suggest that these nutrients need to be monitored over the longer term to ensure that N and P do not become limiting to productivity.

There were no species or interaction effects on the micronutrients (Table 5-2), so the fraction averages are shown in Table 5-4. The results mirror those for the macronutrients, with the highest concentrations in the leaf material and lowest concentrations in the wood material, except that bark had the highest manganese concentrations. Both Ca and Mn tend to be taken up with mass flow of water to the roots, and are not (or not readily for Mn) retranslocated through the phloem, so they accumulate in the bark and older leaves. The average foliar concentrations of the micronutrients were all within the range suggested to be adequate for other eucalypt species in by Dell et al. (2002).

Table 5-2 Significance of species and plant fraction on nutrient concentration (*=P<0.001, **=P<0.01, *=P<0.05).**

Nutrient	Plant fraction	Species	Interaction
Nitrogen	***	ns	ns
Phosphorus	***	*	ns
Potassium	***	ns	ns
Calcium	***	**	*
Magnesium	***	***	***
Sulphur	***	**	***
Boron	***	ns	ns
Copper	***	ns	ns
Iron	***	ns	ns
Manganese	***	ns	ns
Zinc	***	ns	ns

Table 5-3 Macronutrient concentration (%) by species and plant component (SEM in parentheses)

Nutrient	Species	Leaf	Twig	Bark	Wood
Nitrogen					
	E. kochii	1.32 (0.08)	0.47 (0.01)	0.38 (0.02)	0.24 (0.01)
	E. lox. liss	1.55 (0.05)	0.60 (0.11)	0.42 (0.01)	0.25 (0.01)
	E. polybractea	1.57 (0.05)	0.44 (0.02)	0.43 (0.01)	0.20 (0.01)
Phosphorus					
	E. kochii	0.080 (0.007)	0.065 (0.008)	0.027 (0.002)	0.030 (0.004)
	E. lox. liss	0.096 (0.005)	0.085 (0.006)	0.038 (0.002)	0.031 (0.002)
	E. polybractea	0.099 (0.006)	0.065 (0.006)	0.032 (0.001)	0.023 (0.001)
Calcium					
	E. kochii	0.56 (0.05)	0.55 (0.13)	1.07 (0.18)	0.11 (0.02)
	E. lox. liss	0.63 (0.04)	0.72 (0.06)	1.89 (0.09)	0.21 (0.02)
	E. polybractea	0.73 (0.06)	0.72 (0.05)	1.66 (0.13)	0.10 (0.00)
Magnesium					
	E. kochii	0.13 (0.02)	0.09 (0.02)	0.14 (0.01)	0.05 (0.01)
	E. lox. liss	0.13 (0.01)	0.08 (0.01)	0.11 (0.01)	0.05 (0.00)
	E. polybractea	0.15 (0.01)	0.11 (0.01)	0.22 (0.01)	0.04 (0.00)
Potassium					
	E. kochii	0.62 (0.10)	0.34 (0.06)	0.42 (0.07)	0.12 (0.01)
	E. lox. liss	0.57 (0.03)	0.39 (0.03)	0.22 (0.01)	0.09 (0.00)
	E. polybractea	0.54 (0.03)	0.39 (0.05)	0.27 (0.02)	0.09 (0.01)
Sulphur					
	E. kochii	0.110 (0.007)	0.035 (0.003)	0.065 (0.006)	0.030 (0.003)
	E. lox. liss	0.108 (0.003)	0.039 (0.002)	0.031 (0.001)	0.022 (0.001)
	E. polybractea	0.111 (0.004)	0.041 (0.003)	0.037 (0.002)	0.021 (0.001)

Table 5-4 Micronutrient concentration (mg/kg). SEM is in parentheses.

Fraction	Boron	Copper	Iron	Manganese	Zinc
Leaf	93.4 (6.4)	4.85 (0.31)	106.1 (4.4)	194.8 (19.7)	14.64 (0.64)
Twig	13.0 (0.5)	5.38 (0.35)	40.5 (3.3)	156.0 (18.6)	13.15 (0.72)
Bark	14.7 (0.4)	4.10 (0.26)	51.2 (5.1)	284.6 (28.1)	10.43 (0.40)
Wood	3.1 (0.1)	3.08 (0.19)	12.2 (2.0)	111.8 (15.9)	6.65 (0.36)

5.3.3 Changes in proportions of biomass fractions with age

Some biomass fractions have higher nutrient contents than others, and the proportions of these fractions change over time, so the value of the material, both as a feedstock in a processing plant, and for the site, is likely to change over time. For example, the leaf fraction tends to have the highest nutrient concentrations, so removing more leaf material will deplete the site faster than removing woody material. The proportions of these fractions also change as the trees get bigger (Figure5-2), with the proportion of woody material increasing with tree size. In smaller trees, the wood fraction was only around 10% of the total above-ground biomass, but this increased to around 40% in the largest trees in our sample. Conversely, the leaf and twig fractions each represented about 40% of the above-ground biomass in the smaller trees, but their relative proportions had declined to around 30% in the larger trees in our sample. The proportion of bark remained relatively stable at around 5%. Whilst it is important to maintain the nutrient capital at these sites, it also needs to be recognised that the fractions with higher nutrient concentrations are also likely to cause more problems in processing of the material. Thus, a longer rotation is likely to provide a better quality material for processing as it will contain a greater proportion of the lower-nutrient concentration wood fraction.

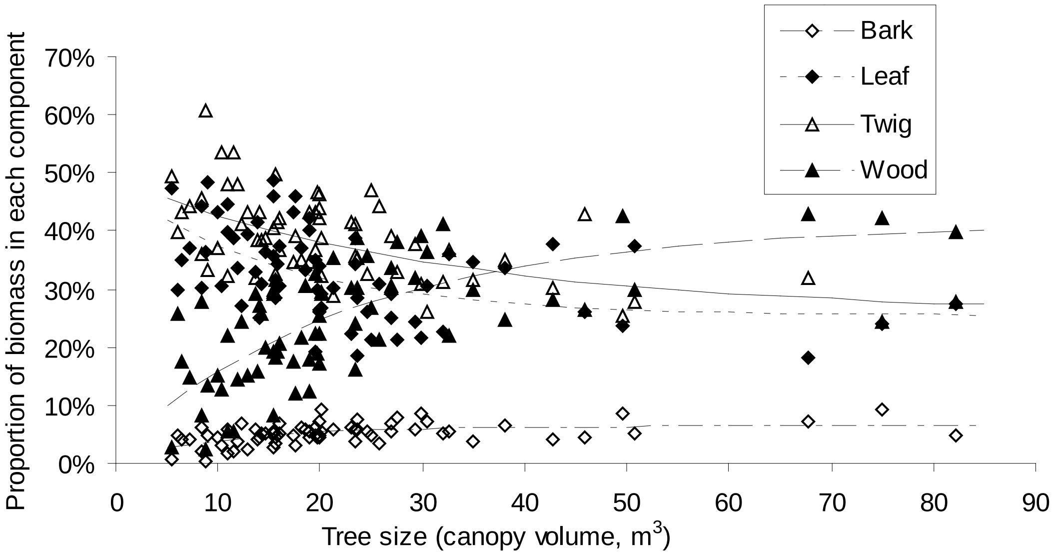


Figure 5-2 Proportion of biomass in each of the components of coppice regrowth. Regression lines shown are averaged across the species, but there were minor species differences significant for the leaf and wood components

5.3.4 Export of nutrients from coppice crops

The export of macronutrients (Figure 5-3) from 2 contrasting sites (Site 1 and Site 16) shows that the relative proportions of the nutrients exported don't change markedly from site to site, and that it is closely related to the biomass production. It also shows that export rates can be quite high at productive sites, with over 400 kg of N in the above-ground biomass at Alexanders after 4 years. The calculated average annual export of biomass and nutrients in the coppice crop (Table 5-5) shows that the coppice crop has relatively higher export rates than the seedling crop (cf Table 5-4) for most nutrients, with the exception of Ca. The 4-year harvest resulted in an increase of about 27% in the annual biomass production (i.e. a 69% increase in absolute biomass from year 3 to year 4), but only a 7-10% increase in nitrogen and potassium export, due to the increased proportion of the lower-nutrient-concentration wood fraction. However, uptake of some nutrients like Ca, Mg, B and Mn increased proportionally more than the biomass, probably reflecting an increase in the proportion of bark. The export rates per unit of biomass (Table 5-6) elucidate these trends, with the concentration of N and K declining but concentrations of Ca, B and Mn are increasing between the 3 and 4 year harvests.

The export of nutrients from a typical wheat crop (1 t/ha, wheat+straw) are reported to be around 25 kg/ha N, 3 kg P, 14 kg /ha K, 3.5 kg/ha S, 1.7 kg/ha Mg, and 1.3 kg/ha Ca (Gartrell &Bolland, 2000), suggesting that mallees are likely to require a similar level of replacement of N, P and K as adjacent agriculture. However, Ca and Mg are exported in woody crops in relatively larger quantities than from agricultural crops, so this situation will need to be monitored to ensure that significant depletion and productivity decline does not occur due to cation removal. Cation deficiency is unlikely to be a serious factor in the short term because the high levels of Ca uptake are likely to be a function of high availability in the soil rather than physiological requirement. This is because Ca is absorbed with mass flow of water, and cannot be easily retranslocated by the trees. Calcium is a physiological requirement for plant function as it is essential for maintaining cell membrane integrity, but it is required at much lower concentrations than found in our study (typically < 1 mg/kg, Dell et al. 2002).

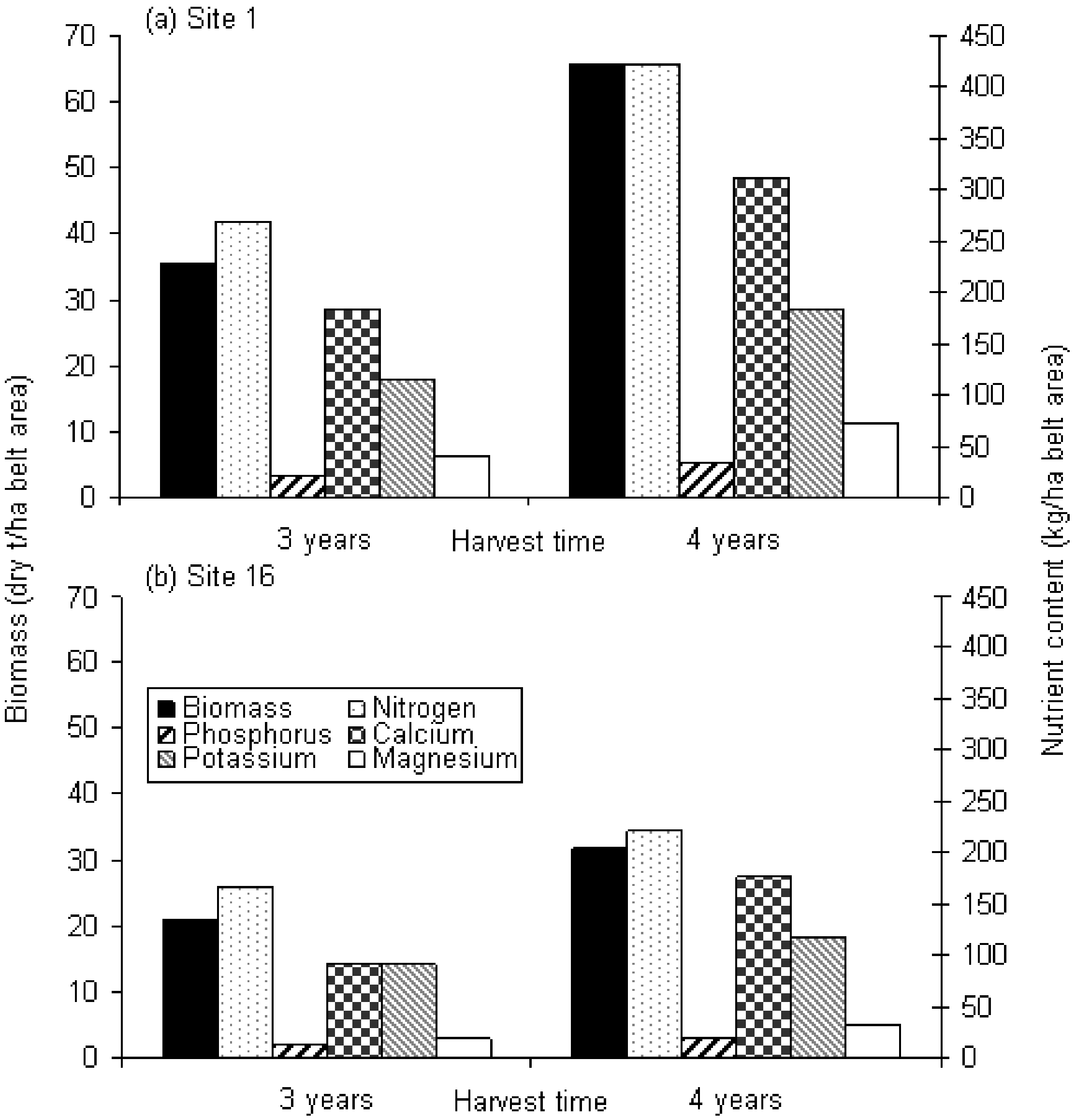


Figure 5-3 Biomass and macronutrient export at different coppice harvests (3 or 4 years) at 2 key sites – Site 1 (a) and Site 16 (b).

Table 5-5 Annual biomass and nutrient export across the 10 focus sites for nutrients under 3 and 4 year harvest regimes. The range in export rates is shown in parentheses.

	3 year harvest	4 year harvest
Biomass (t/ha/y)	5.89 (1.54-11.79)	7.48 (4.07-16.39)
Macronutrients (kg/ha/y)		
Nitrogen	46.7 (11.7-89.7)	50.1 (24.3-105.5)
Phosphorus	3.85 (1.33-6.88)	4.73 (2.74-8.67)
Calcium	32.2 (10.9-61.1)	46.6 (29.8-80.2)
Magnesium	5.78 (1.53-13.54)	7.58 (3.94-18.35)
Potassium	20.7 (6.6-38.5)	22.8 (13.3-45.6)
Sulphur	3.34 (0.95-6.66)	4.16 (2.36-8.43)
Micronutrients (kg/ha/y)		
Boron	0.23 (0.04-0.60)	0.37 (0.12-0.94)
Copper	0.03 (0.01-0.06)	0.03 (0.02-0.07)
Iron	0.32 (0.11-0.68)	0.38 (0.19-0.75)
Manganese	0.66 (0.30-0.94)	0.97 (0.48-1.27)
Zinc	0.07 (0.02-0.11)	0.08 (0.04-0.14)

Table 5-6 Nutrient export rates per unit of biomass under the 3 and 4 year harvest regimes

	3 year harvest	4 year harvest
Macronutrients (mg/g)		
Nitrogen	7.93 (7.06-10.61)	6.84 (5.38-9.38)
Phosphorus	0.67 (0.52-0.86)	0.65 (0.51-0.88)
Calcium	5.63 (4.35-7.09)	6.53 (4.75-8.72)
Magnesium	0.96 (0.84-1.15)	0.98 (0.81-1.12)
Potassium	3.63 (2.78-4.63)	3.13 (2.70-4.05)
Sulphur	0.57 (0.51-0.67)	0.56 (0.49-0.65)
Micronutrients (mg/kg)		
Boron	39.5 (20.4-105.9)	55.1 (28.4-174.5)
Copper	4.39 (3.57-5.09)	4.23 (3.26-5.15)
Iron	55.4 (38.3-74.2)	51.8 (39.5-78.0)
Manganese	129 (76-205)	156 (44-274)
Zinc	11.2 (9.3-15.5)	11.1 (8.5-12.5)

Species-specific parameters to allow for calculation of individual nutrient content of coppice trees are shown in Table 5-7. The slope factor was not significantly different between the species, but there was a significant effect of species on the constant parameter.

Table 5-7 Parameters to calculate above-ground nutrient content (kg/tree) of the different mallee species from the canopy cubic volume, where content = $e^{(a.\ln(\text{canopy cubic volume}) + b)}$

Nutrient	Slope (a)	Constant (b) for each species		
		E.kochii	*E.lox.liss.*	*E.polybractea*
Nitrogen	0.87	-4.91	-5.10	-4.83
Phosphorus	0.93	-6.71	-7.19	-6.78
Calcium	0.90	-7.07	-7.33	-7.19
Magnesium	0.80	-4.92	-5.43	-5.19
Potassium	0.84	-5.30	-5.78	-5.58
Sulphur	0.89	-7.02	-7.52	-7.25
Boron	0.88	-4.54	-4.86	-4.68
Copper	0.65	-9.09	-9.74	-9.33
Iron	0.98	-12.16	-12.66	-12.45
Manganese	0.74	-8.93	-9.46	-9.17
Zinc	0.77	-8.30	-8.50	-8.57

5.3.5 Below-ground

The majority of this section has focussed on the above-ground material because this is the fraction that will be regularly harvested and removed from the site. It is also worth noting that mallees develop a large root system, which will also sequester carbon and nutrients in the below-ground biomass. Measurement of mallee root systems (Brooksbank &Goodwin, 2011) have shown that root biomass is typically around 30-60% of the above-ground biomass, and much of this is in the fine roots (Wildy et al. 2003). Fine roots typically senesce dramatically at harvest (Wildy &Pate, 2004a and Wildy et al. 2003), thus the nutrients will be released back into the soil as the roots decompose.

5.3.6 Conclusions and management implications

We have demonstrated that the mallee system is likely to result in significant export of nutrient capital from the sites, but that the magnitude of nutrient export is similar to the rates that typically occur with removal of agricultural produce, even though significantly more biomass is likely to be removed from the site in the mallee system. To ensure sustained production in the longer term, it will be necessary to at least replace the key nutrients of nitrogen, phosphorus and potassium. To ensure that this happens, it will be important for growers to recognise the nutrient depletion caused by mallees and re-apply sufficient nutrients to account for this. Our data does indicate that Ca and Mg export is likely to be markedly higher in harvested mallee crops than occurs in agricultural produce, suggesting that we may need to monitor this situation. However, much of the cation export is likely to be due to greater availability of cations at depth, and uptake is a result of luxury consumption rather than physiological requirement, and once these stocks are exhausted, growers will need to look at replacing these nutrients as well. Mallees are likely to have more buffering because they can explore deeper in the soil profile than agricultural crops, and they can utilise nutrients (and water) from the alley zone. The processing technology also potentially allows for return of at least some of the nutrients in the ash or biochar byproduct. However the processing may lead to loss or volatilization of key elements such as nitrogen and sulphur, thus these will need replacing from other sources. Legume cropping in the alley is a prospective option for replenishment of N, but would need to be practiced regularly (every 2-3 years) to achieve allow sufficient N fixation to account for N losses in biomass. Micronutrients are also removed in the biomass, but in much smaller total quantities. It will be important to ensure that mallee productivity does not become limited by micronutrient deficiency, but this is likely to vary with site, and visual symptoms are often the best management tool to identify and address micronutrient deficiency (Dell et al. 2002).

6 Economic analysis

Authors: Bartle,J, Abadi, A. and Thomas, Q.

6.1 Introduction

This chapter aims to use the data generated in the Project to examine the potential for mallee biomass production to become a commercially viable activity on wheat/sheep farms in Western Australia.It will focus in particular on analysis of the economic importance of the factors investigated in this Project, i.e. harvest regimes, root pruning and the impact of competition on adjacent crop and pasture by mallee belt systems.

A spread sheet model was developed to contrast the annual average farm operating surplus (i.e. gross revenue less operational costs) under conventional agriculture with the annualised net present value of mallee belts.It does this by showing the mallee performance settings required to break-even with conventional agriculture.The area of farmland over which the mallee enterprise must break-even includes that on which the trees stand, as well as an area equivalent to that lost to adjacent agriculture through competition by lateral roots from the mallee belt.The analysis is located in the central and southern wheatbelt region where rainfall ranges from 300 to 700mm/year.The biomass is notionally supplied to power stations for electricity generation.The analysis accounts for revenues from biomass sales, renewable energy certificates (RECs, Office of the Renewable Energy Regulator, 2011) and the proposed Carbon Farming Initiative (DCCEE, 2010; Parliament of the Commonwealth of Australia, 2011).

6.2 Methods

6.2.1 Conventional agriculture comparator

The mallee yield data available from this Project extends across a wide geographic range of the central/southern wheatbelt of south-west Western Australia.The productivity of conventional agriculture varies greatly across this range and is closely related to rainfall.The analysis of mallee performance was therefore conducted within four rainfall zones based on averages over the past 30 years (DEC GIS) as follows:

- Zone 1: 300 to 400 mm rainfall per year (350 mm rainfall), e.g. Lake Grace, Merredin, Kalannie
- Zone 2: 401 to 500 mm rainfall per year (450 mm rainfall), e.g. Katanning, Narrogin, Northam
- Zone 3: 501 to 600 mm rainfall per year (550 mm rainfall), e.g. Frankland, Williams, Wandering
- Zone 4: 601 to 700 mm rainfall per year (650 mm rainfall), e.g. Rocky Gully, Boyup Brook, Boddington.

Bankwest Benchmarks (Planfarm, 2009) were used to derive the average farm operating surplus for each of these zones.The regional boundaries used for the Bankwest Benchmarks do not align neatly with rainfall zones.A representative rainfall was therefore nominated for the operating surplus for each of the relevant Bankwest regions and scaled to the median of each rainfall zone.Each annual benchmark from 1985 to 2009 was corrected for inflation using the historical inflation rate.The averages are presented in Table 6-1.

Table 6-1 Average present value Bankwest Benchmark operating surplus for the period 1985 to 2009 interpolated across rainfall zones.

Rainfall zone	1	2	3	4
Rainfall median in mm/year	350	450	550	650
Operating surplus in $/ha/year	$100	$121	$126	$131

6.2.2 Mallee yield inputs

Above-ground mallee yield inputs to the model were derived mainly from the data from this Project(see Chapter 3), but also calibrated with other published data (OMA/URS 2008, Bartle et al. 2011) and other unpublished data.Below-ground biomass data came from Brooksbank and Goodwin (2011) and Peter Ritson (pers comm).

All mallee yield inputs were standardised to represent widely separated (>50 m) two-row belts where the spacing between the two planting rows is 2 m and the spacing between trees within the rows is 2 m (see 3.2.6). Where yield data were taken from multiple row belts the yield of the outside rows were taken as the best estimate of two-row belt yield. A 2 m wide buffer is allocated either side (also called the exclusion zone (EZ) from the perspective of the adjacent crop/pasture) to give a belt 6m wide. Yields are averaged across all species and experiment sites. The number of Project experiment sites used to derive these yields was 15, with 11 for 350 mm rainfall, 3 for 450 mm rainfall, 1 for 550 mm rainfall and nil for 650 mm rainfall. Data from 3 of the original 18 sites were excluded, but only because a case could be made that poor mallee performance at these sites could have been anticipated based on present knowledge.

The Project data showed considerable variability in growth between and within sites (see Section 3.3). This partly obscured observation of treatment responses to season of harvest and root pruning but there was a clear positive response to the longer harvest cycle treatment. The estimates presented here combine these responses into generic estimates of yield potential.

Model input estimates of first harvest yield are provided in Table 6-2 and are derived largely from the data in Table 3-3.These data show that mallee belts in higher rainfall zones reach harvestable yield (~60 green tonnes/ha of two row belt) earlier than lower rainfall zones.Note that there were no data for the 650 mm median rainfall zone and the estimates were derived by extrapolation.

Table 6-2 Age and yield of first harvest in of two-row mallee belts in green tonnes/ha across rainfall zones

Rainfall zone mm/year	350	450	550	650
First harvest age	8	7	6	5
First harvest yield	60	60	60	60

Model input estimates for mallee coppice growth cycles over time are provided in Table 6-3 and are based largely on the data presented in Table 3-3.Note that the efficient harvest threshold of 60 green tonnes/ha is reached sooner in higher rainfall zones.

Table 6-3 Inferred above-ground cumulative coppice growth over time for two-row mallee belts in green tonnes/ha across rainfall zones

Coppice age in years	350mm	450mm	550mm	650mm
1	4	7	10	15
2	12	20	25	30
3	25	40	50	60
4	35	60	70	80
5	50	80	90	100
6	55	90	100	110

Mallee coppice yield estimates expressed in green tonnes/ha/year are provided in Table 6-4.

Table 6-4 Inferred mean annual above-ground coppice increments over time for two-row mallee belts in green tonnes/ha across rainfall zones

Coppice age in years	350mm	450mm	550mm	650mm
1	4.0	7.0	10.0	15.0
2	6.0	10.0	12.5	15.0
3	8.3	13.3	16.7	20.0
4	8.8	15.0	17.5	20.0
5	10.0	16.0	18.0	20.0
6	9.2	15.0	16.7	18.3

Below-ground biomass is assumed to grow at a rate of 50% of above-ground biomass up to the age of first harvest (Brooksbank and Goodwin 2011). The impact of harvest causes fine root loss and slowed structural root growth (Wildy et al 2003) resulting in a rapid loss of about 20% of below-ground biomass.This takes about 2 years to be restored to the pre-harvest level. Below-ground growth then slows to a rate of 7% per year until the next harvest. Over the long term, coppice crops are assumed to continue their rapid rebuilding of below-ground biomass after harvest, but to slow their subsequent growth of below-ground biomass from 7% per year to 0% after 50 years.

6.2.3 Mallee establishment and supply chain costs

Initial establishment of mallee in two-row belts is estimated to cost $1000/ha.

The costs of the supply chain from harvest of the standing crop to delivery to a central processing plant, assume a mature system, when development costs have been covered and efficient large scale services are available.The supply chain costs are estimated to be $28/green tonne for harvest and on-farm haulage, $10/green tonne for road transport and $6/ green tonne for administration costs.These systems and their operating costs are under active development (McCormack et al 2009, Yu et al 2009).The FFI CRC (2010) provides an indication of current costs using improvised supply chain elements and how this is expected to decline with large scale development.It is projected that large scale harvest machines now under development will cut a single row at a time, have a maximum ground speed of 3 km/hr and a throughput capacity exceeding 60 green tonnes/hour.Hence a yield of 60 green tonnes/ha for a 6 m wide two-row belt (i.e. 20 green tonnes/km on each row) is required to achieve an economically efficient harvest operation.Where yields below this level are harvested the costs will be higher than the base-case supply chain harvesting cost of $28/green tonne, but no correction to model inputs are made for this in later analysis where marginal yields may sometimes be included in sets of model outputs.

Mallee belts do not require much management input but an annual on-farm crop tending cost of $5/ha for occasional miscellaneous jobs is included.Root pruning may prove useful in controlling root competition.Ripping to 0.6m costs $15/km or $50/ha.

6.2.4 Accounting for the competition impact

Chapter 4 has shown that competition imposed by mallee belts on adjacent crop or pasture can have a larger opportunity cost than that of the belt itself.It is therefore an important input to the model.

The competition zone can be divided into segments as shown in Figure 6-1, each of which requires separate treatment in the analysis.The exclusion zone (EZ) is the 2m buffer that abuts the tree planted row and which is too close to be included in the conventional farm activities in the alley (i.e. the alley is the open paddock area between belts).This EZ is dealt with as part of the belt area.

The no-cropping zone (NCZ) is a variable distance from the EZ defined as the area where the marginal cost of competition exceeds the marginal return from the crop, i.e. where competition is strong enough to reduce crop yield below the level where it can cover cropping costs.This zone varies in width with factors affecting competition (e.g. varying intensity of root competition across the harvest cycle), and crops costs and returns.Hence it requires a separate step in the analysis.

For this analysis the competition zone is defined as the area where crop can be grown profitably but where it will still have its yield reduced over what is possible in the open paddock.Note that this definition is specific to this analysis - more generally in this Report and elsewhere the competition zone includes all the competition components (EC, NCZ and competition zone as defined here).In Figure 6.1 open paddock begins where loss from competition fades out.In reality, a sheltered zone occurs between the competition and open paddock zones, where yield may be enhanced by the protection from wind provided by the tree belt.The shelter zone may extend out to 20 times the height of the trees (Sudmeyer et al 2002a).The existence of a shelter zone imposed a compromise on data collection in this Project, i.e. it was not practical or realistic to take yield measurements at >20 tree heights from the belt.Instead open-paddock measurements were taken in the 20-30 m range where it was possible that enhanced yield occurred.As explained in Chapter 4, this compromise is not considered to have significantly over-estimated the impact of competition.

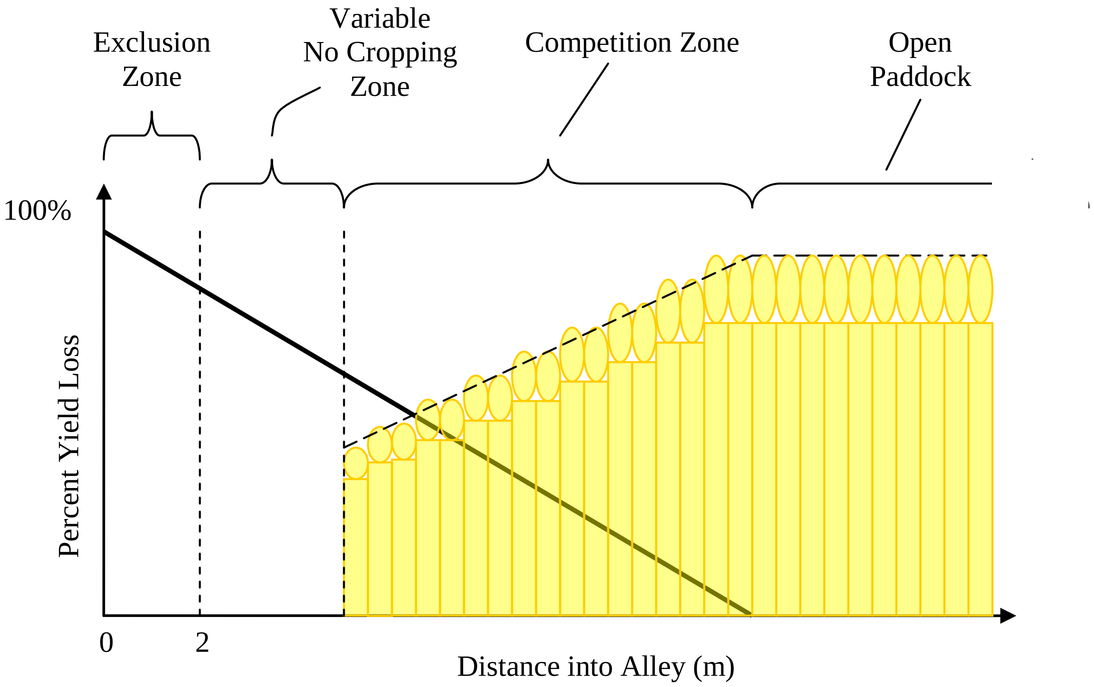


Figure 6-1 **Shows the decline in competition impact with increasing distance from the base of the trees out into the alley, and segments across this gradient, each of which is separately dealt with in the model.**

Competition is measured as a percentage loss of open paddock yield and follows the general form presented in Figure 6-2.The intensity of competition and its extent (distance to open paddock) are the factors that determine the total yield loss.Intensity plotted against distance into the alley gives a monotonically decreasing yield loss relationship where the area under the curve will be proportional to the total yield loss.

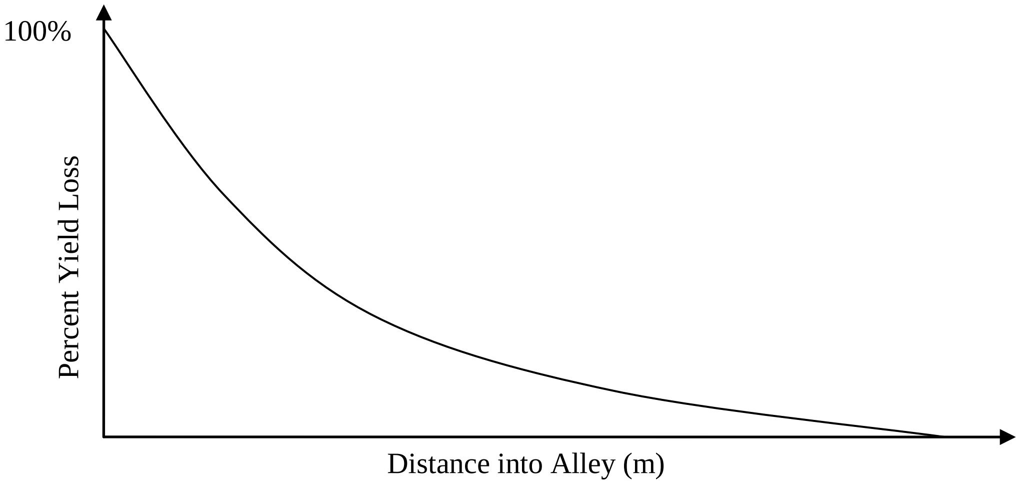


Figure 6-2 **General form of the yield loss curve across the competition zone**

The yield loss curve is modelled as a linear function as shown in Figure 6-3. This simplification is justified in the absence of enough data for sharp characterisation of the curve. It will slightly over-estimate the competition impact. The linear model is fully specified by its end points, i.e. the maximal intensity at the belt and the distance into the alley required to reach open paddock yield. These end points are manipulated to achieve a close calibration with results provided in Chapter 4.

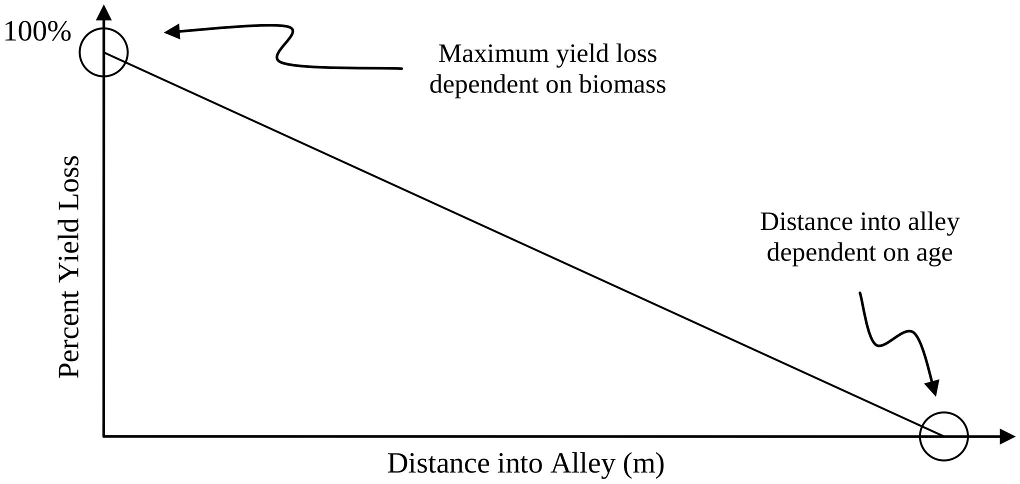


Figure 6-3 Linear competition decay model where end points are functions dependent on standing biomass and age respectively.

It is assumed that open paddock distance is a function of the age of the belt with the extent increasing to a plateau over time.The extent of competition reflects root penetration into the alley and this reaches a maximum over time.Although the mallee belt is coppiced regularly, the root system remains largely in place and so extent will not change greatly after harvest.

The intensity of competition reflects the competition for resources, especially water, by the belt and is at a maximum closest to the belt.The demand for water is related to standing biomass which is related to time since harvest.Therefore competition intensity is modelled as a function of time since harvest.

The yield loss curve is used to calculate the competition cost (expressed as an area) per hectare of belt as shown in Figure 6-4.The yield losses will only be incurred where the crop is grown, i.e. there is no crop competition loss in the EZ or the NCZ as shown in Figure 6-1.However, unlike the belt area and the NCZ, the competition zone loss cannot be estimated from the opportunity cost of land, but instead needs to be estimated from the actual income loss due to lower yield. This is done by estimating the income that would have been achieved in the alley and using this to calculate the loss incurred.The income is calculated by using the estimated gross-margin along with an estimate of the cost-income ratio for farms in each rainfall zone.The income loss is expressed on an area basis per hectare of belt area.

The higher intensity of competition closer to the belt, and its variation with time since harvest, gives a variable width to the NCZ.The model optimises NCZ width by calculating the point at which cropping becomes profitable for each cropping year.

The pasture phase of the agricultural rotation in the alley incurs the same competition extent and intensity as the crop phase.However, pasture does not have the high operational costs of a crop because it re-establishes voluntarily.Hence it does not require the equivalent of a NCZ but instead incurs a reduction of yield across the full extent of the competition zone.Pasture operational costs are assumed to decline with the declining importance of grazing from the 650 mm rainfall zone where a cost of $50/ha is imposed, $30 in 550 mm, $10 in 450 mm and nil in 350 mm rainfall.These are incorporated into the analysis as an addition to the operating surplus across the competition zone.

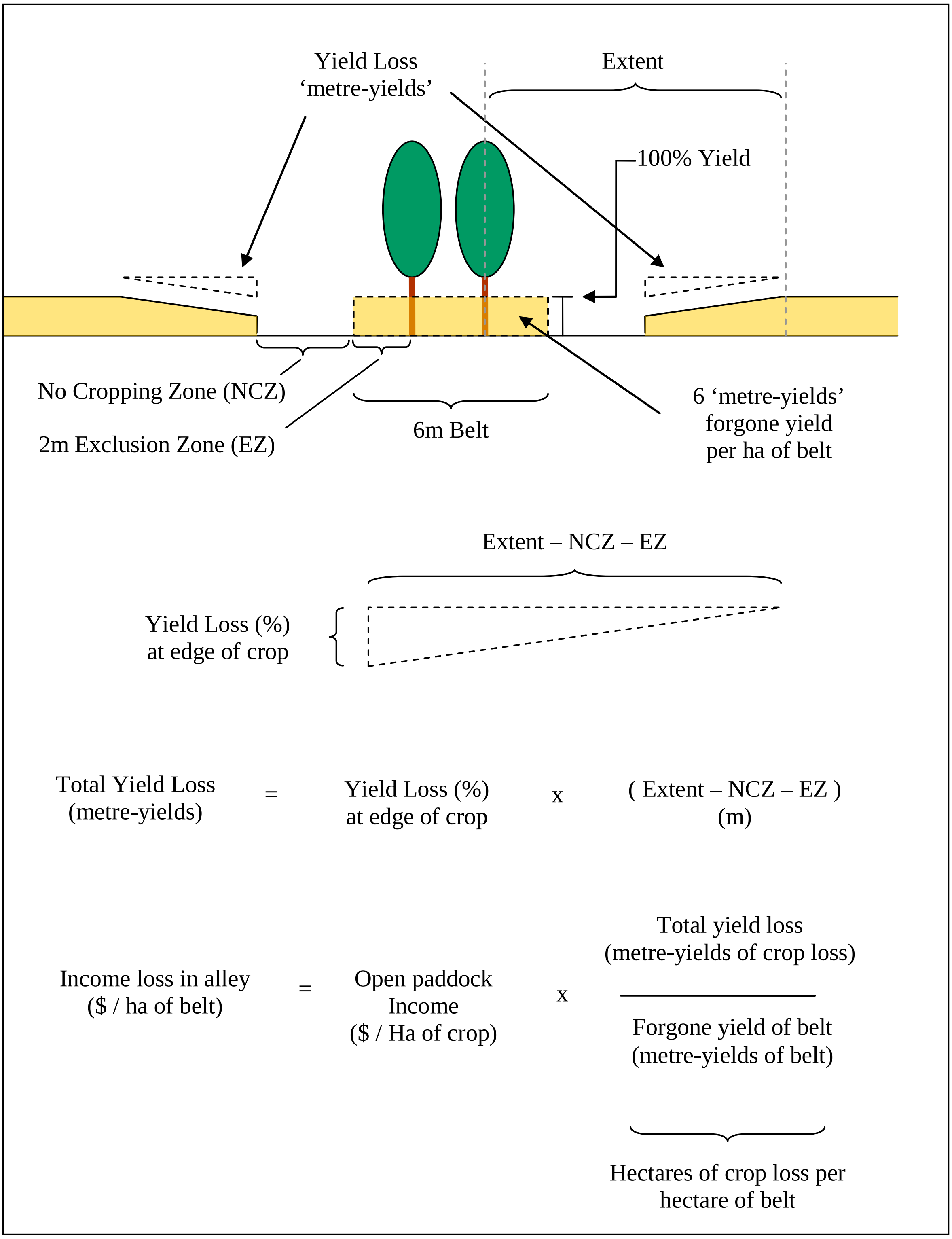


Figure 6-4 Schematic and calculation of crop competition zone income loss expressed as area of loss per ha of belt area

Given the up-front costs of cropping and heavy cost of imposing a NCZ, the model assumes the farmer will choose to grow crops in the first few years after a mallee harvest (when the competition intensity is lower, and the NCZ narrower) and switch to pasture in the years leading up to the next harvest (as competition intensity reaches its maximum).The timing of this switch would also be influenced by the respective market conditions for crops and grazing.The model bases the timing of the switch on the regional cropping proportions given in Table 6-5 to segregate crop and pasture phases over the harvest cycle.

Table 6-5 Variation in farm crop proportion across rainfall zones in %

Rainfall zone	350 mm	450 mm	550 mm	650 mm
Crop proportion	70	60	50	40

6.2.5 Revenues from biomass and carbon

The break-even model calculates a delivered cost of biomass from the perspective of an electricity generator.It constructs a matrix of the parameters required to calculate biomass price by time (projected for up to 50 years).It integrates the costs and revenues of electricity generation, including current and likely future carbon related obligations, to derive projections of biomass price over time.Key variables with current value estimates are listed in Table 6-6.These parameters can be varied to test sensitivity.

Table 6-6 Key parameters for the calculation of the biomass value

Parameter	Units	Value
Effective energy generated from biomass	MWh/gt	0.92
Effective energy generated from coal (from Collie WA)	MWh/t	1.83
Emissions per tonne of coal	t of CO2-e/t	1
Emissions per tonne of biomass	t of CO2-e/t	0
Emissions displaced per tonne of biomass	t of CO2-e/t	0.50
Generator operating costs (excluding feedstock)	$/MWh	40
Generator risk and profit margin	%	20%
Initial carbon price	$/t	$25
Carbon price escalator	per annum	3%
Fossil fuel price escalator to account for scarcity (excluding carbon price escalation)	per annum	1%
Initial electricity price	$/MWh	60
Period of REC price escalation	Years	10
REC price escalation	%	3%
REC initial price	$/MWh	40

The calculation of biomass price starts with the initial electricity price.To this is added the initial RECs price, and revenue for other avoided carbon emissions, to give a first year value of bio-electricity to the generator.Estimates of the generators operational costs and profit margin are deducted to give a biomass buyers' price for the first year of $54. This price increases over time according to the price escalation estimates of carbon, electricity and RECs to reach $94 over a 30 year period.This method delivers a biomass buyers' view of the value of biomass.In particular, RECs are the property of the electricity generator.Hence the biomass price built into this analysis will only be representative of what a biomass grower might receive if, in a mature market with strong competition for biomass, the value of RECs flows downward to stimulate supply.

The CFI is proposed to provide revenue calculated from a rolling average estimate of changes in carbon storage over the long term (DCCEE 2010).For a harvested mallee crop revenues would accumulate to first harvest. Harvest removes all of the above ground biomass, plus some below-ground biomass is lost, and these change the cumulative storage of carbon.The first coppice crop would replenish the stored carbon removed by harvest and also add a little more below ground biomass.This cycle in carbon stocks would be dealt with as a rolling average of the cycle of gain and loss in carbon storage.Most of this would accrue as annual payments in the first several years after which the on-going increase, mainly in slowly increasing below ground biomass, would be minimal.

6.2.6 Cash flow analysis

The model specifies the biomass grown for each rainfall zone and each harvest cycle, calculates the CFI increments and stocks of sequestered carbon, and assembles the cash flow of costs and revenues projected over the chosen period.The period is adjusted to include only whole coppice cycles so that costs are not counted without revenue.The net present value (NPV) is calculated using a chosen period and discount rate.The flows of revenues and costs for separate parameters are displayed.Their NPV is also displayed to reveal, for example, the breakdown of opportunity cost into belt, NCZ and competition zones.

6.2.7 Break even analysis

The break-even analysis uses the *Excel* goal seeking facility to compute multipliers for biomass yield and price that would be required for the mallee enterprise (including all competition costs) to generate the same operating surplus as the foregone agricultural enterprise would have generated from that area.This enables simple comparisons of changes that would be required in the two key mallee performance parameters to break-even with conventional agriculture.**Note that a multiplier <1 means that mallee yield or price exceeds by that factor the level required to break-even, and a multiplier >1 means that yield or price needs to be increased by that factor to break-even.**

6.2.8 Sensitivity to key parameters

The model has been configured so that all parameters that may vary can be tested for the sensitivity to such variation on model predictions.This can be conducted over all rainfall zones and harvest cycles to generate tables and charts of the multipliers required for the mallee and conventional agricultural enterprises to break-even.

6.2.9 Summary of model input parameters

A summary of major model input parameters is given in Table 6-7.These are the current best estimates of inputs and are used to generate a base-case scenario to provide a comparator for sensitivity analysis.

Table 6-7 Summary of major model input parameters, sources and values used in the base-case

Model input parameter	Input data
Conventional agriculture operating surplus	See Table 6-1
Mallee field establishment	$1,000/ha
Mallee belt dimensions (2-rows, 2 m apart with 2 m EZ = 6m wide)	0.6 ha/km
Mallee on-going management	$5/ha/year
Mallee yields	See Tables 6-2 and 6-3
Competition zone dimensions and impacts	Figure 6-4, Chapter 4
Biomass supply chain (harvest and transport services)	$44/green tonne
Cash flow period (adjusted for complete harvest cycles)	~50 years
Project discount rate	7%
Carbon price at year 1	$25/tonne CO2-e
Carbon price escalator	3%
Renewable Energy Certificates price at year 1	$40/MWh
Renewable Energy Certificates price escalator	3%/year
Renewable Energy Certificates applicable period for price escalation	10 years

6.3 Results

6.3.1 Base-case results

The model uses experimental data (from Chapters 3 and 4), and other best estimates, as inputs to a base-case scenario to demonstrate the economic performance of mallee systems, and to test the sensitivity of changes to key inputs.Consistent with the objectives of the Project, there is a focus on the sensitivity of harvest regimes, biomass productivity and the mallee belt competition imposed on adjacent agriculture.Model inputs are presented in detail in the Methods section and the base-case settings for key variables are listed in Table 6-7.Model outputs are in the form of a multiplier for either yield or price that would be required for the mallee enterprise to break-even with the conventional agriculture displaced by the area of the mallee belt and its competition zone.

The base-case results are given in Tables 6-8 and 6-9.Table 6-8 shows that the 650 and 550 mm rainfall zones have multipliers that are <1 for all harvest frequencies, indicating that better than break-even yields could be achieved.For optimum frequencies in these rainfall zones mallees exceed break-even performance by 25% in 650 and 15% in 550 mm rainfall zones.For the 450 mm zone better than break-even yields only occur for the 5 year harvest frequency.For 350 mm rainfall the multipliers all fall well short of break-even yield (i.e. all multipliers >1) with the short fall the least for the 5 year harvest cycle at 27%.

Table 6-8 Multipliers required for break-even yield under base-case inputs

Harvest frequency (years)	350 mm	450 mm	550 mm	650 mm
3	1.45	1.09	0.89	0.75
4	1.39	1.00	0.85	0.75
5	1.27	0.96	0.85	0.76
6	1.34	1.00	0.90	0.83

Note: shaded cells indicate multipliers <1 where performance is better than break-even.

Table 6-9 shows that 450, 550 and 650 mm rainfall zones can all exceed the break-even price for appropriate harvest cycles, but the 350 mm zone falls short by about 12%.

Table 6-9 Multipliers required for break-even biomass price under base-case inputs

Harvest frequency (years)	350 mm	450 mm	550 mm	650 mm
3	1.19	1.04	0.95	0.89
4	1.17	1.00	0.94	0.89
5	1.12	0.98	0.93	0.89
6	1.15	1.00	0.96	0.92

The base-case Net Present Value (NPV) for a 5 year harvest cycle in the 450 mm zone over the 50 year cash flow period is $1070.Tables 6-10 and 6-11 give a breakdown of the NPV of costs and revenues respectively.The proportion of each cost and revenue component for this cycle and rainfall zone is comparable to others.

Table 6-10 % share of NPV base-case costs/ha by components for the 5 year harvest frequency in the 550 mm rainfall zone

Cost component	% share of total NPV
Mallee biomass production costs on-farm	7
Supply chain (harvest to delivery) costs	53
Opportunity cost of land occupied by mallee belt	12
Opportunity cost of the no crop zone (NCZ)	11
Opportunity cost of crop land equivalent lost to competition	5
Opportunity cost of pasture land equivalent lost to competition	11

Table 6-11 **% share of NPV base-case revenue by each revenue component for the 5 year harvest frequency in the 550 mm rainfall zone**

Revenue component	% share of total NPV
Biomass sales	88
Carbon farming initiative payments for carbon sequestered	12

No revenue from RECs is listed in Table 6-11 because it is incorporated into the biomass price.However, RECs revenue makes up about one third of biomass revenue for the 5 year cycle in the 550 mm rainfall zone.

The base-case variation in the NPV of costs over the range of harvest frequencies for 550 mm rainfall zone is given in Table 6-12.As indicated in Table 6-10 the major cost item is the supply chain.This cost declines with less frequent harvest but this gain is partially offset by greater competition zone costs.The accuracy of these outputs is reduced by the variation in the proportion of the 50 year period that is occupied by completed harvest cycles (ranging from 46 to 50 years or 8 to 15 harvests), and by the absence of any correction in the model for likely increase in harvest efficiency from the greater biomass load on offer under less frequent harvest.

Tables 6-10 and 6-12 indicate the size of the land opportunity cost - totalling 39% of costs in terms of Net Present Value (NPV), and second only to supply chain costs. It is useful to express this cost in the form of a ratio of opportunity cost of competition and the opportunity cost of the belt area. This ranges from 2.2 to 2.4 for the 550 mm rainfall zone across the range of harvest frequencies, with more frequent harvests (with weaker competition) at the low end of the range. However, the frequency of harvest is not a sufficient treatment to greatly reduce this cost.

Table 6-12 **Impact of harvest frequency on NPV of base-case costs/ha for the 550 mm rainfall zone over ~ 50 year period**

Harvest frequency in years	3	4	5	6
Biomass production costs in $	1,074	1,074	1,073	1,074
Supply chain costs in $	7,893	8,026	7,876	7,273
Opportunity cost of the belt area in $	1,735	1,744	1,725	1,735
Total opportunity cost in competition zone in $	3,787	3,995	4,087	4,237
Total costs in $	14,489	14,840	14,762	14,319
Opportunity cost ratio: competition area/belt area	2.2	2.3	2.4	2.4
Period of cash flow in years	48	50	46	48
Number of harvests	15	12	9	8
Green tonnes/ha harvested over ~50 year period	760	830	780	760
Biomass taken per harvest in green tonnes/ha	51	69	87	95
Opportunity costs as % of total costs	38	39	39	42

Table 6-13 presents base-case variation in the NPV of revenues over the range of harvest frequencies for the 550 mm rainfall zone.As indicated in Table 6-11 the major revenue item is from sale of biomass for processing and this incorporates RECs revenue as part of the biomass price.

Table 6-13 Impact of harvest frequency on NPV of revenues/ha for the 550 mm rainfall zone (NPV is flow of revenues over ~ 50 year period discounted to present value at 7%)

Harvest frequency in years	3	4	5	6
Biomass sales revenue in $	13,812	14,166	13,920	12,881
CFI revenue in $	1,402	1,699	1,912	2,092
Total revenues in $	15,214	15,865	15,832	14,973
NPV of cash flow in $	725	1,026	1,070	655

6.3.2 Sensitivity tests of major inputs

6.3.2.1 Biomass yield

The sensitivity to yield change was tested by looking at change due to plus and minus 10% and 20% variations in coppice yields as compared to the base case yield.These data are presented in Tables 6-14 and 6-15 for the 550 mm rainfall zone across 4 harvest cycles in the form of changes to yield and price multipliers compared to the base case.

Table 6-14 Change in yield multipliers for the 550 mm rainfall zone across 4 harvest cycle lengths where yield varies by +/- 10 and 20%

Yield variation %	+20	+10	Base-case	-10	-20
3 year cycle	0.76	0.82	0.89	0.97	1.06
4 year cycle	0.73	0.79	0.85	0.93	1.02
5 year cycle	0.73	0.78	0.85	0.93	1.02
6 year cycle	0.78	0.84	0.90	0.98	1.08

Table 6-15 Change in price multipliers for the 550 mm rainfall zone across 4 harvest cycle lengths where biomass yield varies by +/- 10 and 20%

Yield variation %	+20	+10	Base case	-10	-20
3 year cycle	0.90	0.92	0.95	0.99	1.03
4 year cycle	0.88	0.91	0.94	0.97	1.01
5 year cycle	0.88	0.90	0.93	0.97	1.01
6 year cycle	0.90	0.92	0.96	0.99	1.04

Improvement in performance may be more important in the 350 mm rainfall zone where yield and price multipliers are well above break-even level.Table 6-16 shows the sensitivity of the yield and price multipliers to improved yield across harvest frequency.An improvement in yield of 40% is required to break-even.

Table 6-16 % increase in yield and price multipliers required for the 350 mm rainfall zone to approach break-even for 4 harvest frequencies

	Yield multipliers			Price multipliers		
Yield variation %	Base case	+20	+40	Base case	+20	+40
3 year cycle	1.45	1.27	1.13	1.19	1.12	1.06
4 year cycle	1.39	1.22	1.09	1.17	1.10	1.04
5 year cycle	1.27	1.11	0.98	1.12	1.05	0.99
6 year cycle	1.34	1.17	1.04	1.15	1.08	1.02

6.3.2.2 Cash flow period

The period of the cash flow analysis for the base case is the largest number of complete harvest cycles for that harvest frequency within a 50 year period.The sensitivity of the yield break-even multipliers to the cash flow period for the 5 year harvest cycle across rainfall zones are given in Figure 6-5.The sensitivity of the price break-even multipliers to the cash flow period is comparable.Little variation in sensitivity occurs across harvest cycles within rainfall zones.

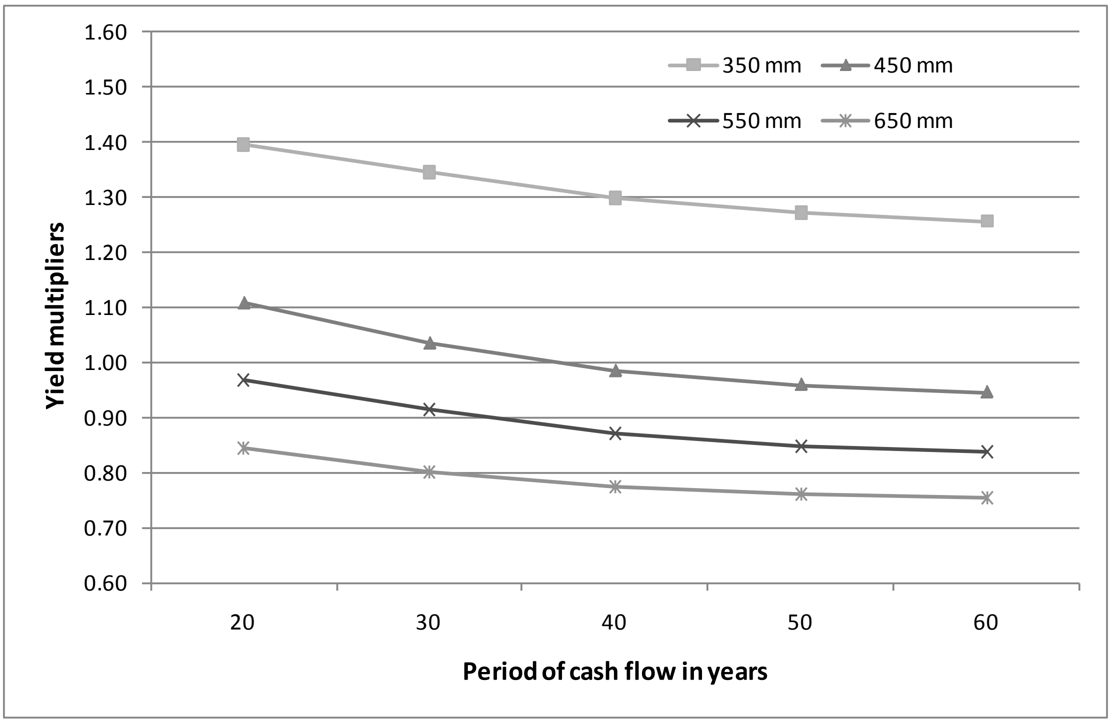


Figure 6-5 Sensitivity of break-even yield multiplier to cash flow period for the 5 year harvest cycle across the four rainfall zones

6.3.2.3 Discount rate

The base-case scenario uses a discount rate of 7%.The sensitivity to the yield break-even multipliers to the discount rate is presented in the same way as for cash flow period in Figure 6-6.These sensitivities are reflected in the price multipliers.Little variation was observed in the yield multipliers between harvest cycles within any rainfall zone.

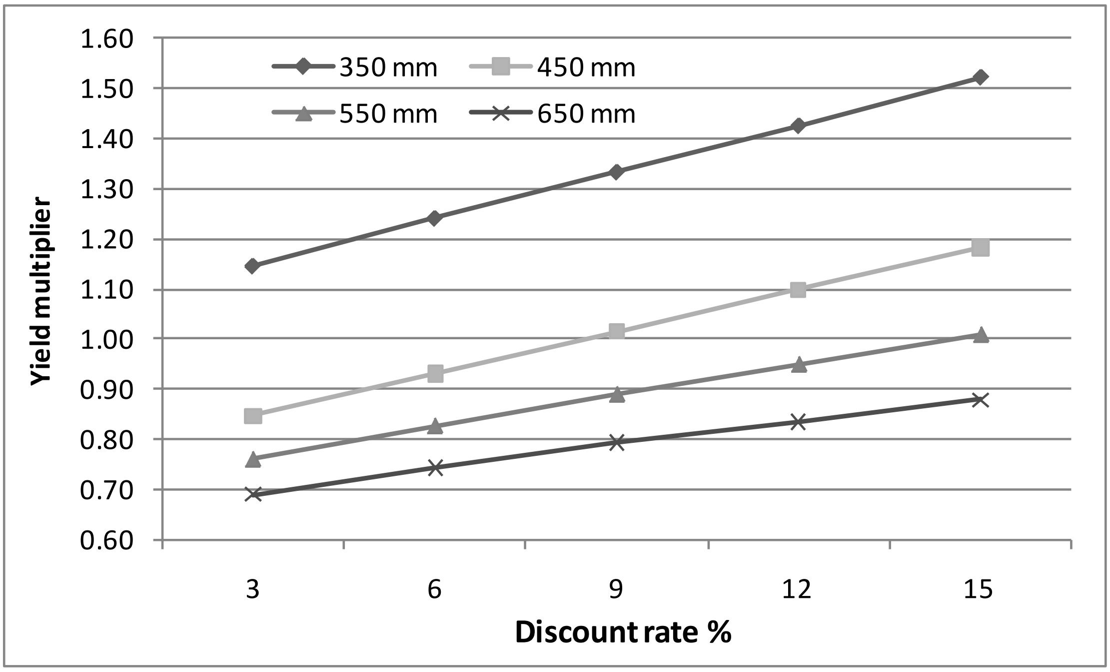


Figure 6-6 **Sensitivity of break-even yield multiplier to discount rate (%) for a five year harvest cycle over the range of rainfall zones**

6.3.2.4 Initial carbon price

The initial carbon price used in the base case is $25/tonne CO2-e.This escalates at 3%/year.Figure 6-7 shows the sensitivity of the yield multipliers to different levels of initial carbon price but with the same rate of escalation.The price multipliers reflect the same degree of sensitivity and little variation was observed between harvest frequencies within any rainfall zone.

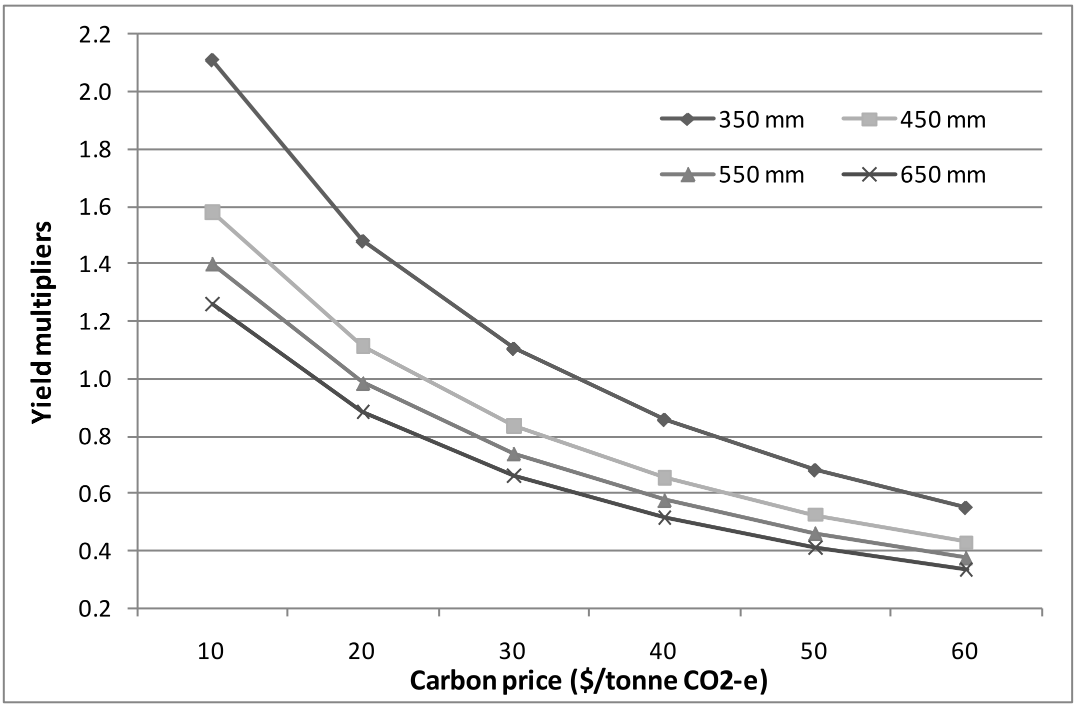


Figure 6-7 Sensitivity of break-even yield multiplier to start-up carbon price for the five year harvest cycle over the range of rainfall zones

6.3.2.5 Carbon price escalation

The base-case scenario assumes a steady escalation of the initial carbon price of 3% per year.Figure 6-8 shows the sensitivity of yield multipliers to lower and higher rates of escalation in carbon price for the 5 year cycle across rainfall zones using the base-case starting price of $25/tonne CO2-e.

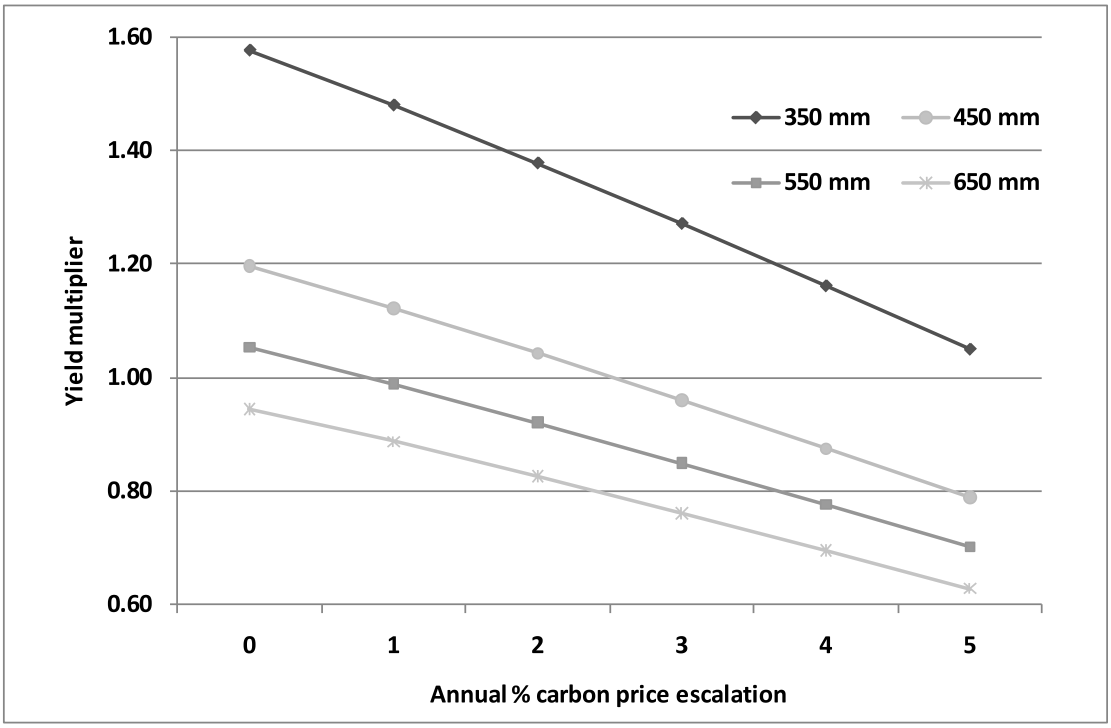


Figure 6-8 Sensitivity of break-even yield multiplier to carbon price escalation for a 5 year harvest frequency across rainfall zones

6.3.2.6 Carbon price and escalation combined

The Australian Government proposes to introduce a carbon tax in July 2012 which will be converted to a fully flexible cap-and-trade emissions trading mechanism by July 2015 (Australian Government 2011).The tax will commence at $23 tonne CO2-e and rise by 2.5% in real terms each year until the commencement of the cap-and-trade market.The cap will have the long term aim of reducing net greenhouse gas emissions to 80% below the levels of 2000 by 2050.

This test contrasts a no-carbon price scenario with the initial settings of the proposed carbon tax extended over the long term (rather than estimate the outcome of the cap and trade mechanism) and with the settings proposed by Garnaut (2011). The results are presented in Table 6-17.

Table 6-17 Break-even multipliers for a harvest frequency of 5 years across all rainfall zones under a range of carbon scenarios

Scenario	Multiplier	350 mm	450 mm	550 mm	650 mm
No carbon price	Yield	3.40	2.52	2.26	2.04
	Price	1.68	1.43	1.35	1.29
Carbon tax scenario - initial carbon price $23, escalation 2.5%.	Yield	1.40	1.06	0.94	0.84
	Price	1.17	1.03	0.97	0.93
Garnaut scenario - initial carbon price $26, escalation 4%	Yield	1.13	0.85	0.75	0.67
	Price	1.06	0.93	0.88	0.85

6.3.2.7 Establishment costs

There has been a recent history of major public investment in farmland revegetation to gain public-good benefits in the form of more sustainable agriculture and downstream environmental benefits (Sparks et al 2006, Wallace 2010).If establishment costs were met from the public purse, and all the other base-case parameters applied, then the yield and cost multipliers given in Table 6-18 would be achieved.

Table 6-18 Base-case break-even multipliers for yield and price for a harvest frequency of 5 years across all rainfall zones if establishment costs are not incurred.

Scenario	Multiplier	350 mm	450 mm	550 mm	650 mm
No establishment cost	Yield	1.03	0.80	0.71	0.64
	Price	1.01	0.91	0.87	0.84

6.3.2.8 RECs benefits

RECs strongly stimulate biomass demand for electricity generation but may have limited duration, pending development of other incentives for reducing greenhouse gas emissions.The base-case assumes an opening RECs price of $40/tonne CO2-e, an escalation in price of 3% per year and a term of 10 years.The scenarios in Table 6-19 were tested for their impact on yield and price multipliers for the five year harvest frequency across all rainfall zones.

Table 6-19 Base-case break-even multipliers for yield and price for a harvest frequency of 5 years across all rainfall zones for various RECs scenarios.

Scenario	Multiplier	350 mm	450 mm	550 mm	650 mm
No RECs.	Yield	No model solution			
	Price	1.93	1.72	1.65	1.59
Initial RECs price $20, no escalation	Yield	3.19	2.38	2.14	1.94
	Price	1.51	1.34	1.28	1.23
Initial RECs price $40, no escalation	Yield	1.66	1.25	1.10	0.99
	Price	1.24	1.10	1.04	1.00
Initial RECs price $40, escalation 1.5%	Yield	1.45	1.09	0.97	0.87
	Price	1.18	1.04	0.99	0.95

6.3.2.9 Summary of major sensitivities

Table 6-20 tabulates some major sensitivities tested above for ready comparison between single factor variations from the base case.

Table 6-20 Break-even multipliers for yield for a harvest frequency of 5 years across all rainfall zones for a range of single factor variations from the base-case.

Scenario	350 mm	450 mm	550 mm	650 mm
Base case	1.27	0.96	0.85	0.76
No carbon price	3.40	2.52	2.26	2.04
Proposed carbon tax extended to full term	1.40	1.06	0.94	0.84
No establishment cost	1.03	0.80	0.71	0.64

6.4 Discussion

This chapter examines results of the Project using a model designed to compare the economic performance of mallee belts and conventional agriculture.It deals in turn with harvest regimes (i.e. season and frequency of harvest), the competition imposed by harvested belts of mallee on the adjacent agriculture, and root pruning to manage competition.It then presents a generic assessment of mallee belt economics especially with respect to the fast evolving issues related to climate change.

6.4.1 6.4.1 Season of harvest

No significant difference was observed to contrasting seasons of harvest (i.e. spring and autumn) for aggregated yield data (Figures 3-4 and 3-5), although differences in favour of both spring and autumn were common at the site level (Appendix A2).The literature indicates that in Mediterranean climate regions mallee regeneration after spring removal of above ground biomass occurs more rapidly than for autumn (Wildy and Pate 2002, Wildy et al 2003).Indeed Noble (1989) and Milthorpe et al (1994) found that autumn harvests can cause high mortality.This was not observed in mortality data following harvest in this Project (Table 3-15).An explanation for the lack of a consistent separation in yield performance for the contrasting seasons of harvest in this Project may be the spread of harvest times in each season (due to work load) and the timing of autumn rainfall affecting water availability.Chapter 4 (section 4.4) discusses these factors in relation to their impact in the competition zone.No variation of mallee yield in relation to season was included in the yield input to the model.

The season of harvest remains a potentially important issue, especially in combination with high frequency of harvest, where plant health and longer term productivity may be compromised (Wildy et al 2003).

6.4.2 6.4.2 Frequency of harvest

There are two aspects of growth response to less frequent harvest that are of particular importance from the economics perspective:

1. How quickly does coppice growth rate decline over time?
2. Less frequent harvest means more biomass available per harvest.

The first concerns the coppice growth response curve. The economically desirable time for coppice harvest will be when coppice growth starts to slow or, more precisely,when the value of the marginal growth increment falls below the marginal costs of maintaining the stand. Slowing growth rate also indicates a biologically suitable time to harvest – the new canopy will have had time to restore the root system that was depleted in the early regeneration phase (Wildy et al 2003). Chapters 3 and 9 (Appendices A-1 and A-2) demonstrate substantial regional and local variation in growth curves reflecting the particular species, climatic and edaphic conditions at each site. A much larger body of data will be required to understand species and site attributes well enough to predict appropriate harvest frequencies and biomass yields.

The timing of the two harvests applied to each experiment aimed to take the first harvest shortly before peak growth rate and the second after growth had slowed, with a 1 or 2 year interval in between.This objective was generally achieved as indicated for aggregated data in Figure 3-9 (for 3 and 4 year harvest cycles).The economic importance of choosing a near-optimum harvest frequency is evident in the yield input data for the base-case (Table 6-3) where growth rate for all rainfall zones declines by coppice age 6, and this is reflected in an increase in the yield multiplier trend (Table 6-8).

The second aspect of the growth response to lower harvest frequency is the obvious one - the extra period of growth will generate more biomass (see Figure 3-8).From the economic perspective more biomass/ha may lift the crop into the efficient operating range for the harvester (>60 green tonnes/ha or >20 green tonnes/row km).There may also be an upper limit (in terms of biomass/km or stem diameter) but competition costs escalate and biomass growth rate declines with older coppice, so long cycles are unlikely to be feasible.Other relevant factors are: less frequent harvest should incur less operating cost/tonne biomass; and more frequent harvest brings biomass revenues forward and this improves cash flow.

The interplay of these factors is evident in Tables 6-8, 6-9 and 6-12.Tables 6-8 and 6-9 give the base-case yield and price multipliers.For each rainfall zone the multipliers show an optimum harvest frequency, due to the balance struck between the dominant opposing costs, i.e. less frequent harvest (reducing costs) and competition (increasing costs).Table 6-12 shows the dominance of supply chain and competition costs.It also shows that halving the frequency of harvest (from 3 to 6 years) nearly doubles the biomass per harvest.This reveals a deficiency in our analysis, i.e. the model pools all supply chain costs (capital and operating), and makes no adjustment for likely improved harvest efficiency with a heavier crop.Hence the 6 year coppice yield in the 350 mm rainfall zone of 55 tonnes/ha (16.5 tonnes/km single row), in spite of being less than the expected efficient operating range for the harvester, is given the same supply chain cost per tonne.McCormack et al (2009) provide some estimates of how harvests costs might vary with biomass yield.The supply chain incurs more than 50% of costs (Table 6-10) so there is considerable motivation for further investigation of how frequency of harvest and biomass yield can be managed to improve harvester efficiency and reduce supply chain costs.

6.4.3 6.4.3 Competition zone costs

The competition results (Chapter 4, Section 4.2.4) are perhaps the most important output from this Project.They show the competition impacts observed by Sudmeyer and Flugge (2005) for unharvested mallee belts in the Esperance region are broadly similar to those for harvested belts in the wider wheatbelt of WA.These results contrast sharply with previous qualitative estimates of the competition impacts of regularly harvested mallee belts, for example, Bartle and Abadi (2009) estimated the ratio of competition zone loss to belt area loss at 0.8, i.e. a 6 m belt will impose competition on each side equivalent to another 4.8 m to give a total width of 10.8 m effectively removed from conventional agricultural production.This Projectshows competition to belt ratios up to 2.4 (Chapter 4 and Tables 6-12, 6-10) nearly doubling displaced agricultural production to 20.4 m.The effective (or equivalent) land area occupied by the belt incurs an opportunity cost that over many harvest cycle contributes 39% of total costs, consisting of 12% for the belt itself, 16% for loss due to competition with crop and 11% due to competition with pasture.

A hypothesis of this Projectwas that regular harvest would provide a sufficient means to minimise competition with adjacent crop or pasture.Although the data show high variability, significant differences were found between treatments in competition zone crop yield (i.e. % of open paddock yield across a 2-20 m distance from the tree line).These data are presented for each site and treatment in Table 4-2, for mean yields over time for all treatments in Figure 4-2 and integrated over time in Table 4-3.This shows the benefit of harvest on competition zone yield peaks at 20% (i.e. increasing from ~60 to ~80% of open paddock yield over the 2 to 20 m range of the competition zone) in the second year after harvest then declines back to the unharvested yield by year four, to give a whole cycle benefit of 9 to 14% for 3 to 5 year cycles.This is reflected in an increase of NPV of costs from 38% to 42% across the range of harvest frequencies from 3 years to 6 years (Table 6-12).

More regular harvest (i.e. <3 year cycles) might incur less competition loss but will encroach on the root system recovery period (>2 years after harvest) and risks progressively reducing plant vigour and health (Wildy 2003). Furthermore, biomass yields in this age range are low and would increase harvest costs.Hence we conclude that while regular harvest has a moderating impact on competition it cannot greatly reduce the cost.Other options that might be available to improve the economics of belt systems are explored in the next two sections.

6.4.4 6.4.4 Wider belts

Given the unavoidable opportunity cost of competition incurred by narrow two-row belts, could adding inter-row space provide land at lower opportunity cost?This is a complex question but one for which the results of this Project help provide a preliminary answer.

Narrow two-row belts were strongly promoted in recent years to counter the widespread observation that belts with 3 or more rows display strong suppression of inner-row growth.Inner-row suppression is undesirable because it indicates poor value accruing from the inner-row investment and, with larger trees in the outer-rows, creates two tree size classes that may compromise harvest efficiency.These factors, combined with the potential to reduce competition loss by shorter harvest cycles, were seen to strongly favour the fast uniform growth of narrow two-row belts.However, it was always clear that experimental evidence would be required to help understand the balance of belt width, number of rows per belt, harvest efficiency and competition and hence this Project was initiated in 2005.

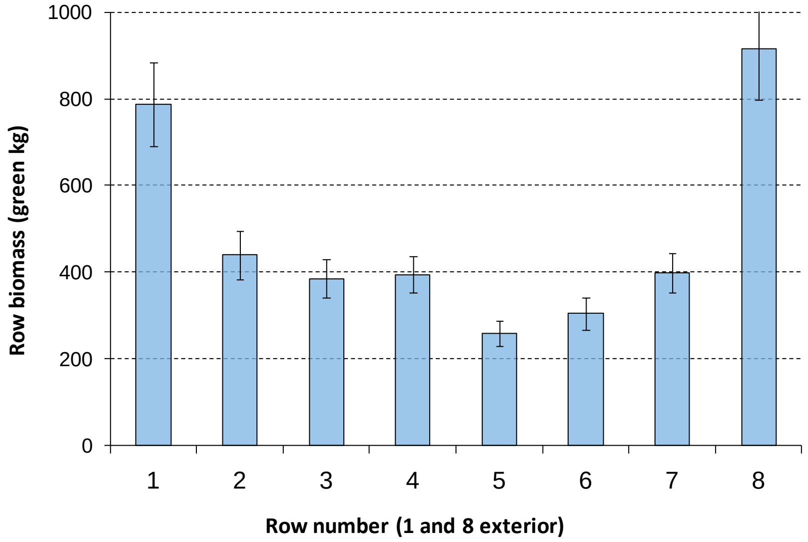


Figure 6-9 Transverse section of an eight-row mallee belt showing standing biomass (kg per plot) for each row at age eight with 2m spacing between rows at Gibson WA. From Bartle et al 2011.

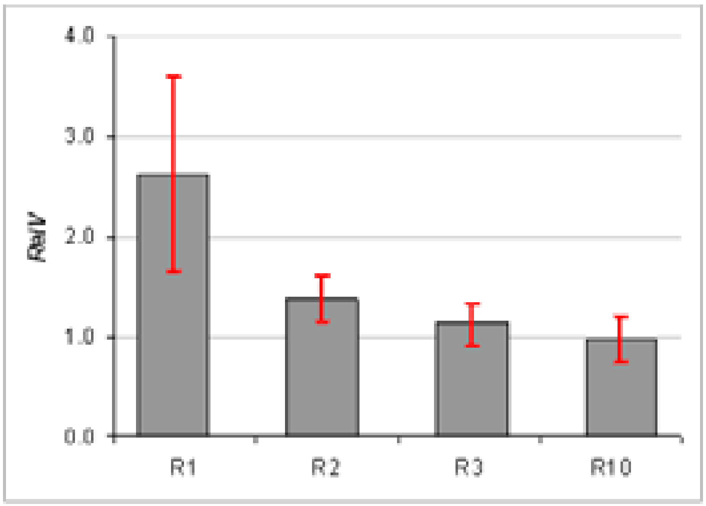


Figure 6-10 Decline in stem-wood volume for *Pinus pinaster* across row number from R1 (perimeter row) to R10 (internal row).From Ritson (2004).

Inner row suppression (and its complement, enhanced growth of edge rows) is widely observed in tree crops (Figures 6-9 and 6-10).Inner and outer row data from this Project are presented in Table 3-14.Six of the Project sites have belts with >2 rows on a regular 2 m row spacing, for which inner and outer row yield data are available (sites 5 and 8 in Table 3-14 are excluded due toirregular spacing).These data show the ratio of inner/outer row coppice yield is ~0.75 (when yield is related to row area as specified by the belt geometry) and does not vary significantly between years over the 4 year harvest cycle (Figures 3-14 and 3-16).If we assume that the ratio is a stable attribute of the <6 row planting configuration it can be used predictively, i.e. an inner-row occupying a 2 m space grows 0.75 of the yield of an outer-row, or the inverse, an outer row of a belt with 2 m spacing between rows has an outer/inner row ratio of 1.33 .This relationship can be used to define a ‘yield conversion factor’ (YCF), i.e. the inter-row space required to grow one outer-row yield equivalent.For a 2 m spacing YCF = 2 * outer/inner ratio, or 2 * 1.33 = 2.66 m.This result indicates that YCF inputs of 4, 6 and 8 m used for sensitivity testing are conservative.

The break-even model was adapted to provide a preliminary test of the economics of wider belts.The base-case two-row belt (with an inter-row space of 2 m) is used as the comparator.The following assumptions were made:

1. The base-case two-row yield estimates used in this analysis are derived in about equal parts from multiple row belts (where double the outer-row yield was taken as the best estimate for two-row yield) and from two-row belts (see 6.2.2).Although the outer-row can strongly suppress inner-rows, competition to some degree will also work in reverse, i.e. the inner-rows will compete with and reduce the yield of the outer-rows.Hence the outer-row yield being used here is partly the consequence of competition either from inner rows or from a companion outer-row.It is not clear how this influences the YCF.For example, the assumption that double the outer row yield is the best estimate of two-row belt yield appears to be an under-estimate, given the

high YCF derived above. This indicates the need for further experimentation to better quantify the YCF.

2. It is assumed that competition zone extent and intensity remain unchanged for the various internal belt spacings used in these analyses.
3. Additional inner-rows can be planted on the same 2 m inter-row spacing as the base-case two-row belt.Alternatively, to account for likely capacity of the outer-rows to be able to fully capture the biomass production potential of a wider inter-row spacing, unplanted inter-row widths up to 12 m are also tested.The likelihood of the two outer-rows being able to consume the resources available from a wider unplanted inter-row space is supported by several observations indicating high water extraction and consumption by mallee belts (Robinson et al 2005, Sudmeyer and Goodreid 2006, Carter and White 2009).Avoiding inner rows saves expenditure on planting and eliminates the potential difficulty of two size classes at harvest.It also adds biomass yield to the outer-rows and opens scope to reduce harvest frequency, competition loss and cost.

Figure 6-11 shows the modelled results for yield multipliers for YCF of 4 m for all rainfall zones, a five year harvest frequency and two-row belts widths of 8, 12 and 16 m (corresponding to inter-row spacings of 4, 8 and 12 m respectively).

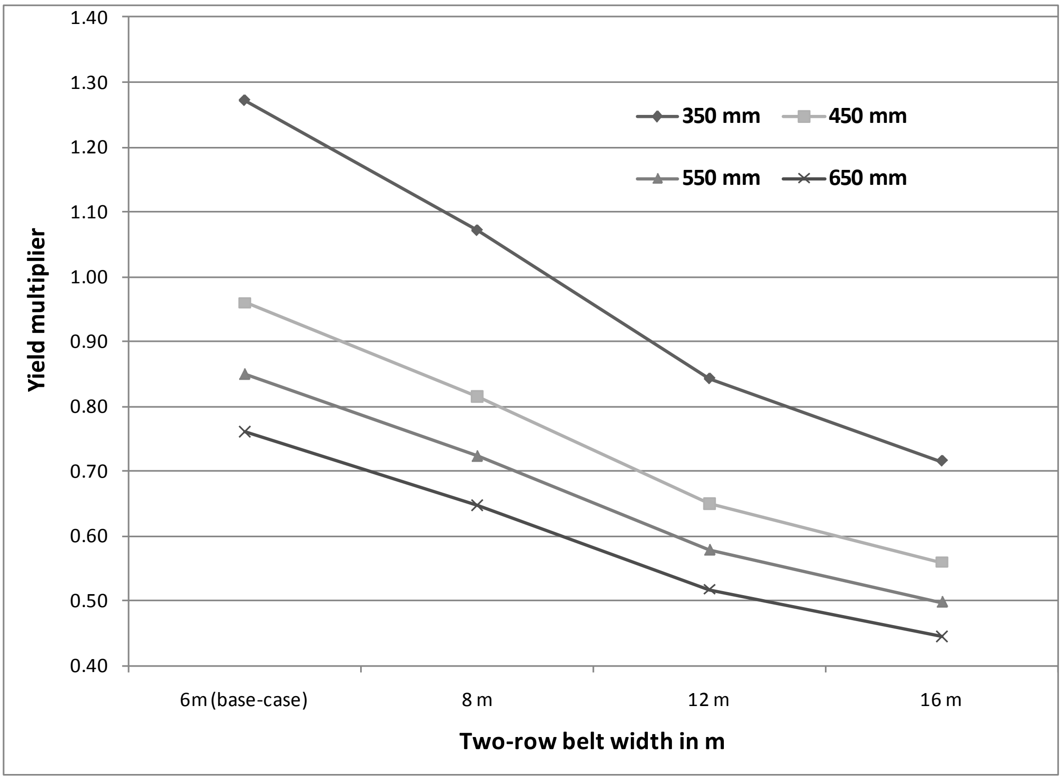


Figure 6-11 Yield multipliers for a five year harvest frequency for a range of two-row belts widths and a YCF= 4 across all rainfall zones, in contrast to the base-case.

The model shows substantial gains in break-even multipliers for wider belts compared to the base-case. Figure 6-11 shows that break-even could be achieved in the 350 mm rainfall zone for a two row belt width of about 9 m (inter-row spacing 5m), whereas the base-case is 27% below break-even.These yield gains are also reflected in price break-even multipliers, e.g. a 12 m wide two-row belt with YCF of 4m in 450 mm rainfall to 650 mm rainfall zones are up to 20% better than break-even.

If a single inner row is included in the widened inter-row space a decline of 5 to 7% in yield multipliers is incurred, reflecting the increased cost of establishment, but not taking account of any reduction in harvest frequency and increase in competition loss.

Sensitivity of yield multipliers to YCF is shown in Figure 6-12. It shows that even at the highest tested level of YCF (8 m of extra inter-row interval to gain one outer-row yield equivalent) the break-even yield multipliers are less than the base-case.The 350 mm rainfall zone does not achieve yield break-even under the base-case but it does for either a 12 m wide two-row belt (with 8 m inter-row space) when YCF is less than 6, or a 10 m wide belt (with 6 m inter-row space) with YCF of 4. This opens the prospect of commercially viable mallee production across the whole WA wheatbelt region.

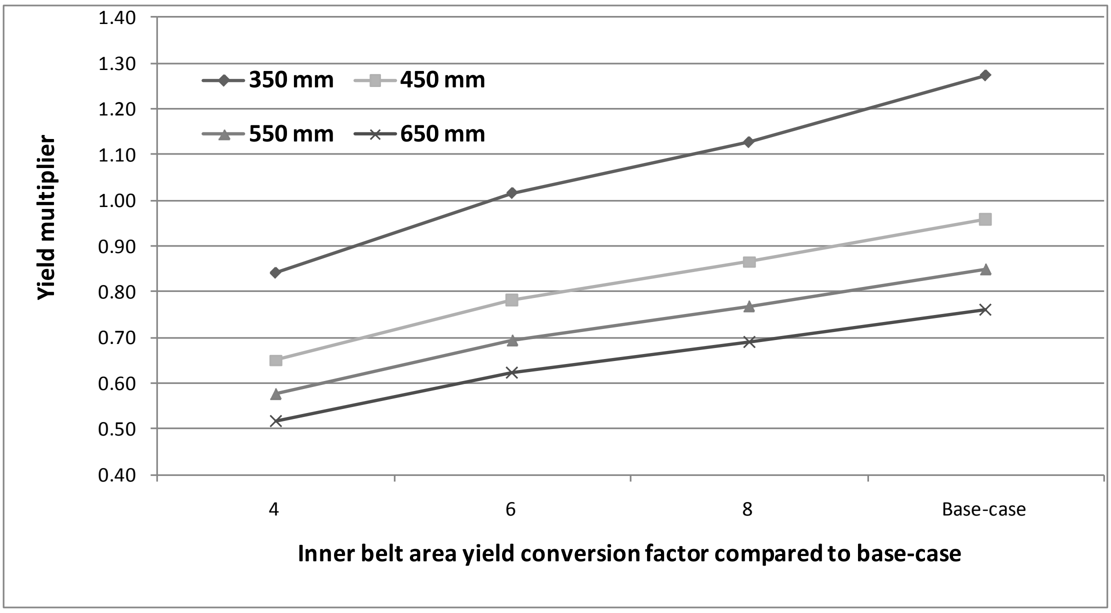


Figure 6-12 Yield multipliers for a five year harvest frequency, 12 m, two-row belt for all rainfall zones and for YCF ranging from 4 to 8, in contrast to the base-case.

The number of rows in a belt is important from the perspective of harvest operating costs.If the two rows of a wider belt are able to fully capture the yield potential of the inter-row width, and this avoids the need for an additional row, then omitting the extra row will decrease row length by 33% and the same yield will be distributed over 67% of the distance. Comparing a 2 row 12 m wide belt (with a single inter-row space of 8 m) with a 3 row 12 m wide belt (two inter-row spaces of 4 m), in the 450 mm rainfall zone with YCF of 4 and harvest cycle 5 years, means the 2 row belt will have an average harvest of 41 tonnes of biomass/km of row in contrast to the 3 row belt having 27 tonnes/km. This may increase harvest efficiency and be reflected in lower costs. Alternatively, the extra biomass production potential may be better utilised by increasing harvest frequency and reducing competition loss. The capacity to make such adjustments is not included in the current version of the model.

6.4.5 6.4.5 Other competition zone management options

Chapter 4 presents data to show that root pruning on a two year interval did not significantly increase competition zone yield above that gained as a consequence of harvest (see Figure 4-2).Hence root pruning was not incorporated into opportunity cost inputs to the model.In contrast to this finding, Sudmeyer and Flugge (2005) reported significant improvement in competition zone yield as well as a later reduction in mallee yield.In Chapter 4 the likely increase in effectiveness of detecting root pruning response, if analysed in terms of impact on gross margins, is discussed (see section 4.4).It can be concluded that there is a case for further investigation of root pruning.

The extent and magnitude of competition adjacent to mallee belts varied greatly between sites (Chapter 4 and Tables 4-1 to 4-4).Much of the variation is due to factors that are not easily managed or avoided in established stands.However, for new plantings site selection can avoid sites likely to display high competition impact.For example, relatively shallow duplex soil profiles, especially where root penetrability of the subsoil clay is poor, can confine lateral mallee roots to shallow depth and enhance competition extent and magnitude.Such sites and others with related deficiencies like shallow saline groundwater, shallow basement rock or difficult-to-penetrate hardpan can be avoided in site selection (Bartle et al 2011).In many areas there is already substantial largely practical knowledge available to guide site selection.

The economic impact of competition can be reduced if the higher input cost cropping phase of the agricultural rotation is conducted during the lower competition intensity period following mallee harvest, and the lower input cost pasture phase is conducted during the lead up to the next harvest.This tactic was considered self evident and likely to be readily adopted by growers.It was incorporated into the model but its advantage was not quantified.

It was shown in Chapter 4 (Table 4-4 and 4-5) that competition magnitude and extent is negatively correlated with rainfall.It follows that competition cost could be reduced by favouring higher rainfall areas for new plantings.Alternatively, mallee belt systems designed to passively or actively capture additional water, as discussed by Bartle et al 2011, may also exhibit reduced competition.In its present stage of development the model was not able to test these scenarios.

Another competition management option that has not been widely canvassed is to design planting layouts so that the competition zone occupies non-arable land.Such land might include farm tracks, fence lines, laneways, firebreaks, banks and drains, all linear features well suited to being aligned with long narrow belts.There may be useful complementary benefits, e.g. the competition zone is dry and unproductive and may provide an attractive surface for tracks and firebreaks.Consider a low relief, fully cleared, square farm of 3600 ha (6 x 6 km) and 9 paddocks of 400 ha (2 x 2 km), with tracks on one side of all fence lines to give 48 km x 7.5 m wide non arable land, plus another 24 km of firebreaks 5 m wide.This totals 48 ha (1.3% of the farm) of non-arable (and low grazing value) land potentially available to be used as competition zone. The total land opportunity cost for a 10% planting (i.e. 360 ha including competition zone on a 2 to 1 ratio with the belt area) would be reduced by 13.3%, or the competition zone cost imposed by the 120 ha of belt area would be reduced by 20%.

6.4.6 Mallee belt economics and climate change

The base-case scenario shows that mallee belts in the south west of Western Australia range from about 30% better yield than break-even with conventional agriculture in the 650 mm/year rainfall zone, down to some 30% poorer in the 350 mm/year rainfall.The transition to below break-even (i.e. multiplier >1) occurs around the 400mm/year rainfall isohyet and coincides with a steepening rate of decline of coppice yield in relation to rainfall (Table 6-3).Hence improvement in mallee belt performance becomes increasingly difficult to achieve with the transition into 350 mm rainfall zone.

The sensitivity of the base-case to variation in yield for the 3 to 6 year harvest frequencies for the 550 mm rainfall zone is given in Table 6-14.This shows that the 4 and 5 year cycles will break-even 15% below their expected yield of 18 green tonnes/ha/year.Yield variation in terms of the break-even biomass price (Table 6-15) is 6-7% below the expected yield and a 20% yield shortfall in yield would still nearly break-even.Hence the 550 mm rainfall zone yields look quite promising.This contrasts with the 350 mm rainfall zone where the 5 year cycle base-case yield estimate (10 tonnes/ha/year) is 27% below break-even yield and 12% below break-even price (Table 6-16).If yield increase is the only option for improvement it would need to increase by 40%.This appears to be a challenge.However, there is substantial local variation in yield (see Table 3-3).Of the 12 sites in this zone 3 have at least one treatment average that exceeds the 40% yield target.Hence yield may be improved by better site selection although this is likely to constrain potential area available.Another option is to improve design of belt layout to achieve better passive and potentially active capture of extra water (Carter and White 2009, Bartle and Abadi 2010, Bartle et al 2011).Future Farm Industries CRC and CSIRO Ecosystems Science have recently commenced a project to explore water capture potential and quantify the yield response by mallee to extra water supply.

The duration of the cash flow period and discount rate are both sensitive determinants of the yield and price multipliers (Figures 6-5 and 6-6).However the longer project periods and lower discount rates that give the best yield and price multipliers may not readily attract commercial investment, at least not with the level of uncertainty and risk that remains in mallee development.The potential public-good outcomes of mallee development (Chapter 1) remain a major motivation for continuing public investment (Sparks et al 2006, Wallace et al 2010).This requires sound technical and economic information to guide that investment, as well as more public investment in R&D and industry start-up. One such public investment might be to steer early adoption of mallee cropping into localities where greater public good outcomes might be achieved.This is the context of the results presented in Table 6-18.Could direct public investment in off-setting establishment costs (i.e. about $1,000/ha of planting) for key biodiversity conservation assets located in the 350 mm rainfall zone be effective? Although such an investment would substantially reduce the shortfall in the multipliers, i.e. yield: 1.27 to 1.11, and price: 1.12 to 1.05, it does not alone reach break-even.

The base-case scenario incorporates existing and likely future inducements that aim to stimulate development of renewable energy, carbon sequestration, and activities that will reduce carbon emissions mediated through market pricing or tax processes (Australian Government 2011, Garnaut 2011).Sensitivity tests were conducted on carbon, carbon price escalation over time, and for the two combined.

This shows that biomass price multipliers reach break-even for the 650 mm rainfall zone at a carbon starting price of $16/tonne CO2-e, for the 550 mm rainfall zone at $20, for the 450 mm rainfall zone at $26 and the 350 mm rainfall zone at $37.Note that the base-case used a carbon starting price of $25/ tonne CO2-e, which is around the mooted opening price, putting the wetter three zones within range.No carbon price escalation is required to maintain the yield and price multipliers for the 650 mm rainfall zone.But the 550 mm rainfall zone requires a carbon price escalation of 1%/year to remain better than break-even, the 450 mm rainfall zone requires about 4% but the 350 mm rainfall zone is outside the tested maximum of 5%.

Results for combinations of both carbon price and annual percentage escalation are presented in Table 6-17.With no carbon price none of the rainfall zones could break-even.Only the 650 mm rainfall zone qualifies at $20 and 2%, but for the carbon tax and Garnaut scenarios of $26 and 4%, all zones except the 350 mm rainfall zone would be close to or do better than break-even.A strong carbon pricing outcome from the present political process is essential if the mallee industry is to develop strongly.

RECs are a current revenue source for generators of renewable electricity but they will only be available until 2020 (Garnaut 2011).Table 6-19 provides results for various RECs scenarios.Although the model was not designed to resolve a zero input for estimation of the yield multiplier, it can compute the price break-even multiplier which shows that zero RECs revenues would mean no break-even with agriculture could be achieved for any rainfall zone.The 650 mm rainfall zone can reach break-even with a RECs price of $40 without any escalation over time, while $40 plus an annual escalation of 1.5% is required for the 550 mm zone to break-even, and the 450 mm zone breaks-even in the base case of $40 plus an annual escalation rate of 3%.These results pose an obvious question – to what degree might a higher carbon price off-set the loss of RECs revenues?A carbon price range of $55-60 would progressively achieve break-even for 650, 550 and then 450 mm rainfall zones, but not the 350 zone.At a carbon price of $60/tonne CO2-e and an annual escalation of 3%, the landed biomass price opens at $39/green tonne and increases to $89 over 30 years.

The CFI is another important source of revenue (Parliament of the Commonwealth of Australia, 2011).Given that it is a payment for the value of carbon sequestered in a permanent mallee crop it will be an additional source of revenue to that arising from other sources including a carbon tax.The mallee stand quickly reaches its long term average above and below ground biomass storage and so its revenue comes early.When expressed as a proportion of the NPV of revenues for the base case (450 mm rainfall, 5 year cycle) it is about 12% of revenue (Table 6-11).This is equivalent to about $2.50/green tonne of biomass.CFI is a useful but not critical addition to the revenue stream, compared to RECs (32% of revenue) and biomass sales incorporating the carbon price impact (56% of revenue).

6.5 Conclusions from economic analysis

This Project has shown that the lateral extent and intensity of competition on crops and pasture adjacent to mallee belts is larger and less amenable to control by regular harvest than previously anticipated.These two factors increase the opportunity cost of land for the standard narrow two-row belt to some 39% of all costs.The economic analysis using the new yield and competition results from this Project along with a base-case set of costs and revenues appropriate to electricity generation shows that narrow two-row mallee belts will only break-even with conventional agricultural activities in the wetter parts of the WA wheatbelt, i.e. more than 450 mm rainfall per year.

The base-case assumptions include revenue estimates from the existing Renewable Energy Target (RECs) and the foreshadowed Carbon Farming Initiative and carbon tax.A carbon tax of about the value assumed in this analysis has been announced but not yet legislated.It is clear that mallee biomass production and processing will require strong carbon price settings to achieve economic viability and rapid, early development.

It is also desirable to counter uncertainty and facilitate rapid adoption by improving the economic case for mallee belts through better design and management.

This analysis showed that a strong improvement in profitability might be achieved by widening the inter-row space of the standard two-row belt (currently 2 m) out to 8 m or more.This provides more production area without the penalty of the large opportunity cost of the competition zone that the outer row incurs. In this way the large competition cost can be spread over a wider belt and a larger volume of biomass.With this innovation it was shown that profitable mallee belt production could be undertaken in the low-rainfall eastern wheatbelt while for higher rainfall areas increases in the margins on break-even yields (up to 45%) and biomass selling price (up to 20%) could be achieved.

The economic implications for mallee belts from this innovation are substantial.Hence it is urgent that the performance of new belt designs be subject to field experimentation to test the assumptions used in this analysis.The key objectives of such work would be:

1. Measure the variation in yield for two row belts over the inter-row width range of 2-16 m.
2. Determine the inter-row width where the introduction of a third row would become profitable.

3. Examine the variation in extent and intensity of competition on adjacent crop/pasture with variation in belt spacing and row number, including observation of grazing value of the inter-row space in wider belts.
4. Provide sufficient data to develop and calibrate growth models that can predict yield for any belt spacing configuration.

It is also imperative that the series of harvest regime and competition impact experiments be continued.These experiments have generated the knowledge that has led to the major change of design in mallee belts now being considered.They will also enable the longer term cumulative effects of frequency of harvest to be followed.It would be desirable to add to the number of these experiments to increase the sample size and improve the site coverage into the >550 mm rainfall zone.

Effective economic assessment of these data would require updates in supply chain analysis to better define how harvester efficiency and cost varies with length of row and yield per km.This would also require better definition of growth over time to guide harvest timing.Modifications could be built into the existing break-even model to allow harvest cost to vary with the yield changes related to specified spacing configurations and the timing of harvest.

7 Implications

The Project has substantially improved the understanding and knowledge-base to support a potential future mallee biomass industry, specifically it:

1. Generated and analysed a substantial body of biomass growth data for unharvested and coppiced mallee belts subject to 4 harvest regimes and root pruning.
2. Defined the lateral extent and intensity of competition imposed by mallee belts on adjacent annual crop/pasture subject to the 4 harvest regimes and root pruning.
3. Used these data to assess the economic returns from integrated mallee/agriculture systems with various harvest and competition management regimes.
4. Indicated modifications to the commonly used pre-commercial designs of integrated mallee/agriculture systems to maximise potential economic returns.

Chapter 3 provides the most comprehensive available datasets for mallee growth in narrow belts (coppice and unharvested controls) over time and across the WA wheatbelt rainfall range, along with partitioning into biomass components and moisture content.

Substantial variation was observed in mallee biomass yield within and between sites - typical productivity was in the range of 10-20 green tonnes/ha/year. Growth was positively correlated with rainfall, rooting depth and soil fertility. Water is recognised as the major limiting resource for perennial plant growth in the WA wheatbelt environment where evaporation exceeds rainfall by a factor ranging from 3 to 7. Yield variation was analysed by deriving a water use efficiency parameter (WUE in green kg biomass/ha/mm rainfall) for each plot level observation of yield. By comparison with other more detailed investigations of WUE it was found that the range of WUE observed in this Project indicated segregation into:

- high performance where WUE >40 kg biomass/ha/mm rainfall and plots were likely to be accessing other sources of water in addition to rainfall
- median performance where WUE ranged from 20-40 kg biomass/ha/mm rainfall and growth appeared to be based on rainfall alone
- low performance where WUE <20 kg biomass/ha/mm rainfall where site constraints prevented full utilisation of rainfall.

Plots from the same experiment site were clustered close enough to indicate that this is a paddock-scale phenomenon not just a local effect.

These results provide a useful addition to the growing body of information about site selection and water management for mallee biomass production. Narrow belt planting of mallee is favoured because it opens potential to capture extra resources, especially targeting surplus water from adjacent areas under annual plant agriculture. Future site selection and design of planting configuration will require better knowledge of paddock-scale hydrology as well as other conventional site and profile attributes to achieve best yields.

Conventional ground-based site assessment is unlikely to be cost effective for dispersed belt plantings. Remote sensed spatial data management techniques will become necessary. Initial work in this area has commenced but much remains to be done. The National Water Commission *Atlas of groundwater-dependent ecosystems* Project provides an example where novel satellite data interrogation methods (applied to historical time-series imagery) are providing new insights into vegetation behaviour and water use at multiple spatial scales. The use of spatial analysis for site selection and design of planting configuration will also be required to integrate with the planning and management of precision farming techniques.

Chapter 4 assessed the lateral extent and intensity of competition on crops and pasture adjacent to mallee belts for the equivalent of over 75 field-years (i.e. ~20 sites by 2-5 measurement years). It showed that competition increased with mallee age and biomass, and decreased with growing season rainfall. No correlation was found between competition and depth to clay subsoil. The opportunity cost of competition was equivalent to removing 8-9 m of land from agricultural production on either side of harvested belts, but 14 m from unharvested belts.

Economic analysis suggested that increasing the width of the uncropped area next to mallee belts and decreasing input costs in the competition zone could lessen the cost of competition. Root pruning was not effective in reducing competition for mallees harvested on a 3-4 yr interval but may be effective for longer harvest intervals.

Chapter 5 showed that a similar amount of nutrients are removed with harvested mallee biomass as are removed with annual cropping. Although the deep root systems of mallee can tap nutrient storage, additional nutrient sources will eventually have to be provided if mallee growth is to be sustained in the long term.

Chapter 6 showed for the mallee biomass yields and competition losses measured in this Project, along with a representative set of base-case costs and revenues, narrow two-row mallee belts are more profitable than conventional agricultural activities in the wetter parts of the WA wheatbelt, i.e. greater than 450 mm rainfall per year. The opportunity cost of land for the standard 6 m wide two-row belt accounted for some 39% of all costs for delivered chipped biomass. It is important to note that these calculations include revenues from the existing Renewable Energy Target (RECs) and the foreshadowed Carbon Farming Initiative and carbon tax, with a price of carbon at around $25/tonne CO2-e.

The analysis showed that mallees might also improve the profitability of farm enterprises in lower rainfall areas of the WA wheatbelt, but that this would require a modified belt configuration. Widening the inter-row spacing of the standard two-row belt provides additional mallee production area, unencumbered by competition zone costs. This effectively reduces the proportion of the area in the competition zone compared to the land occupied by the mallee belt. In this way the competition cost can be spread over a wider belt and a larger volume of biomass. The estimates of yield from the inter-row space were taken from Project sites with multiple row belts. Sensitivity tests indicated, mallees could potentially increase the profitability of agricultural enterprises in the 300 to 400 mm rainfall zone. The same logic also applies in the higher rainfall areas, where wider belts could further improve the profitability of mallee systems. Yields up to 45% better than break-even, or biomass selling price up to 20% better than break-even, may be possible. Thus there may be a substantial margin for profit in the higher rainfall zones that could facilitate rapid adoption by growers.

Whilst wider spaced 2-row belts have significant potential, there is an urgent need to empirically test the assumptions made in the modelling. The key objectives of such work would be to:

1. Locate existing plantings that may be suitable for early indication of likely performance of two row belts with a wide inter-row space.
2. Establish new experiments to provide hard data on the variation in yield for two row belts over the inter-row width range of 2 – 16 m.
3. Determine the inter-row width where the introduction of a third row would become profitable.
4. Examine the variation in extent and intensity of competition on adjacent crop/pasture with variation in belt spacing and row number and better definition of the efficacy of root pruning.

5. Provide sufficient data to develop and calibrate growth models to predict yield for any belt spacing configuration.
6. Explore the productivity and profitability of mallee systems in the >550 mm rainfall regions (i.e. the ‘wool’ belt of WA), where there are few data available.

To complement this work the series of harvest regime and competition impact experiments that were the basis of this Project should be continued for a total of 3 coppice harvest cycles. The first cycle is not yet complete. This will enable the longer term cumulative effects of season and frequency of harvest to be followed. It would be desirable to strategically add to the number of these experiments to increase sample size and extend the range of sites into the higher rainfall areas. These experiments will also provide the earliest opportunity to detect the run-down in stored nutrients anticipated in Chapter 5 to be a medium term issue.

Wider belts (plus their competition zone) indicate that mallee occupancy of up to 20% of suitable sites/paddocks may prove to be commercially viable. Farmers may seek to offset a decrease in cereal cropping area within any one paddock, with a larger proportion of crop in the whole farm rotation in order to maintain the size of the cropping program. This would in turn require adjustment in the farm grazing enterprise. Issues like these will need to be examined using a whole-farm optimisation model like MIDAS.

Chapter 6 showed several examples of where a better understanding of how harvester efficiency varies with yield density (biomass yield per km) is required. This would enable belt design (row number and spacing), harvest frequency, competition intensity and cost to be optimised. It would also require better definition of growth over time to guide harvest scheduling.

This Project predicts that with favourable carbon price settings integrated mallee biomass production in the WA wheatbelt could improve the profitability of farm businesses. However, mallee belts also bring opportunity for collateral benefits. At the farm level, these benefits may include salinity abatement, crop and stock shelter, erosion control, aesthetics, habitat for native biodiversity and farm business diversification. In addition there are related off-farm public-good outcomes. It is difficult to quantify these benefits in economic terms. But if they come without cost, then any benefit, no matter how small or intangible, has a positive value. Hence farmers’ perception of the collateral benefits of integration of mallee into their farming practice may strongly influence adoption.

8 Recommendations

8.1 Recommendations for future R&D.

1. Undertake field investigation of suitable existing plantings, and establish new experiments, to assess the effects of wider belt configuration on mallee yield, competition zone impact and economics.
2. Maintain the existing harvest regime and competition zone experiments to document the cumulative effects of treatments on yield and nutrient removal over 3 coppice harvest cycles.
3. Extend harvest regime and competition zone experiments into higher rainfall zones, where economic analysis indicatesgood potential but where data are scarce.
4. Undertake MIDAS modelling to examine whole farm optimisation of the proportions of mallee, annual crop and pasture in integrated farming systems.
5. Determine the variation in the cost of harvest and supply chain operation over a wide range of yield densities (biomass/km of row) and apply this to optimisation of belt design and harvest scheduling.
6. Develop site assessment techniques for integrated mallee belt design with potential for interception of local run-off.This will require remote sensed data for spatial analysis, surface water management, farm planning and compatibility with precision farming practices.
7. The emergence of large scale commercial mallee biomass industries will open an important opportunity to capture collateral benefits of extensive tree planting without cost. This will provide impetus to improve the economic and environmental performance of wheatbelt agriculture. To capture this potential, and to document the relevant antagonisms and synergies within agricultural systems, it is recommended that the Future Farm Industries Cooperative Research Centre method of system benefits analysis be further developed.

8.2 Recommendations for growers.

During the pre-commercial phase of mallee planting (1994 to the present) a wide range of establishment and management practices have been used.Over this period there was continuous testing, observation and modification of practice.This phase of development is reviewed by OMA (2008).More recent conceptual and practical development of a mallee harvester and supply chain, the history of observation of mallee growth and interaction with other farming practice and the results of this research have led to a new synthesis. This synthesis anticipates the prospect of large scale commercial planting of mallee being undertaken on a project by project basis as new processing operations are established. These recommendations focus on the contribution to potential commercial practice arising from the research undertaken during this Project.

In order to achieve economic performance for large scale integrated mallee planting it is recommended that account be taken of the following generic design and management indications flowing from this Project:

8.2.1 Harvest frequency and season

1. No adverse outcome from season of harvest was observed - this is positive given that commercial harvest will need to be active all year round.
2. The anticipated frequency of harvest may be reduced if wider two-row belts are adopted.Wider two-row belts will have faster growth rates and this may enable more frequent harvest.It may also provide the option to take greater harvest volumes and thereby reduce harvest cost.More frequent harvest has the added advantage of reducing competition.

8.2.2 Crop and pasture competition

1. Growers should plan on a variable ‘no-crop-zone’ adjacent to belts because the impact of competition means that the variable costs of crop establishment may not be recovered.The width of this zone will vary with natural site factors, but it will also vary across the harvest cycle giving a no-crop-zone ranging from 4 to 10 m (each side).
2. There may be some benefit in root pruning but this requires further R&D.
3. Crops should be preferentially grown in the 3 years after mallee harvest when the intensity of competition will be lowest and the no-crop-zone the narrowest.The pasture phase of the agricultural rotation should be timed for the lead-up to mallee harvest.This also means that mallee harvest can be done during the pasture phase with less complication.

8.2.3 Belt planting configuration

1. This Project indicates that wide spaced two-row belts may be the most profitable planting configuration.Such belts should be less 12 m wide but only have two-rows, i.e. have an inter-row space of up to 8m.In addition to a likely increase in profitability there are several other benefits from such wide spaced two-row belts: removing inner rows eliminates risk of inner-row suppression and extra harvest cost; they grow faster and this may reduce harvest cost; more frequent harvest may be possible with reduced competition costs; the inter-row space may provide a useful path for harvest equipment.
2. For any belt the minimum spacing between rows should be 3 m to allow access for the harvest equipment now under development.

8.2.4 Site selection

1. This Project indicates considerable scope for improved site assessment.Conventional techniques will not be adequate for some aspects of site selection and other site related objectives like design for interception of local run-off and compatibility with precision farming practice.This will require remote sensed data and spatial analysis techniques to be developed.

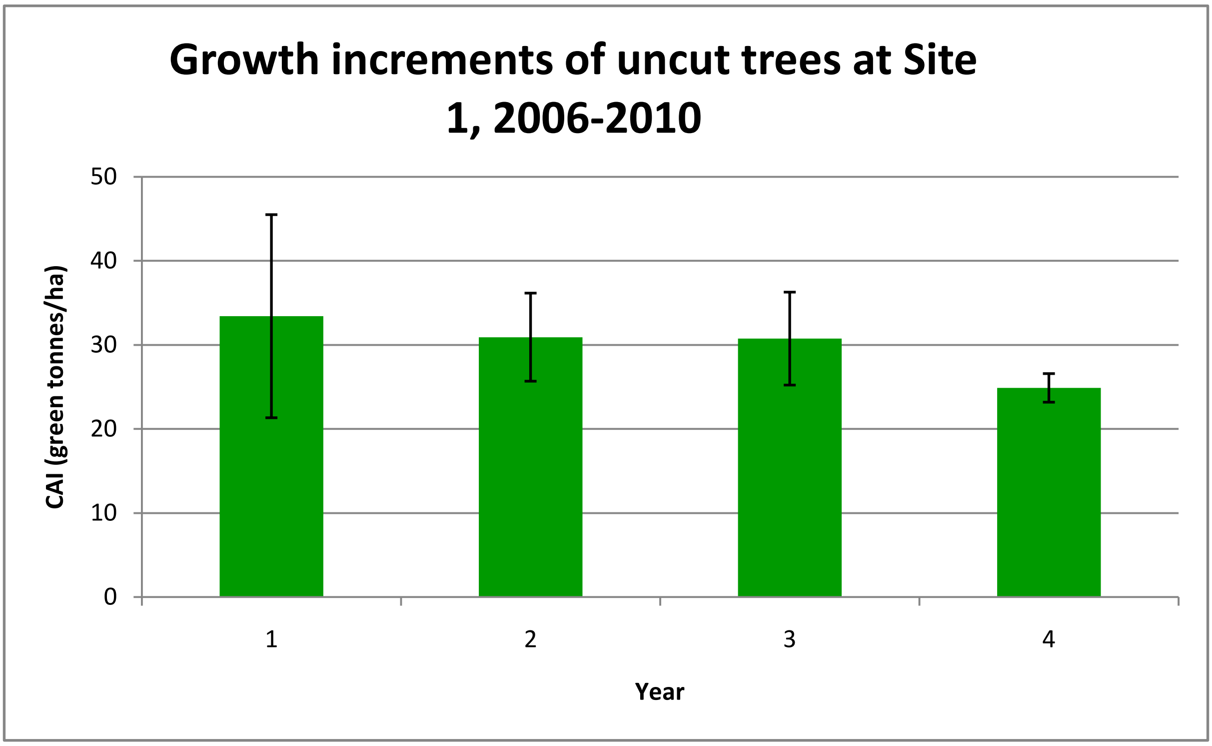
8.2.5 Other recommendations

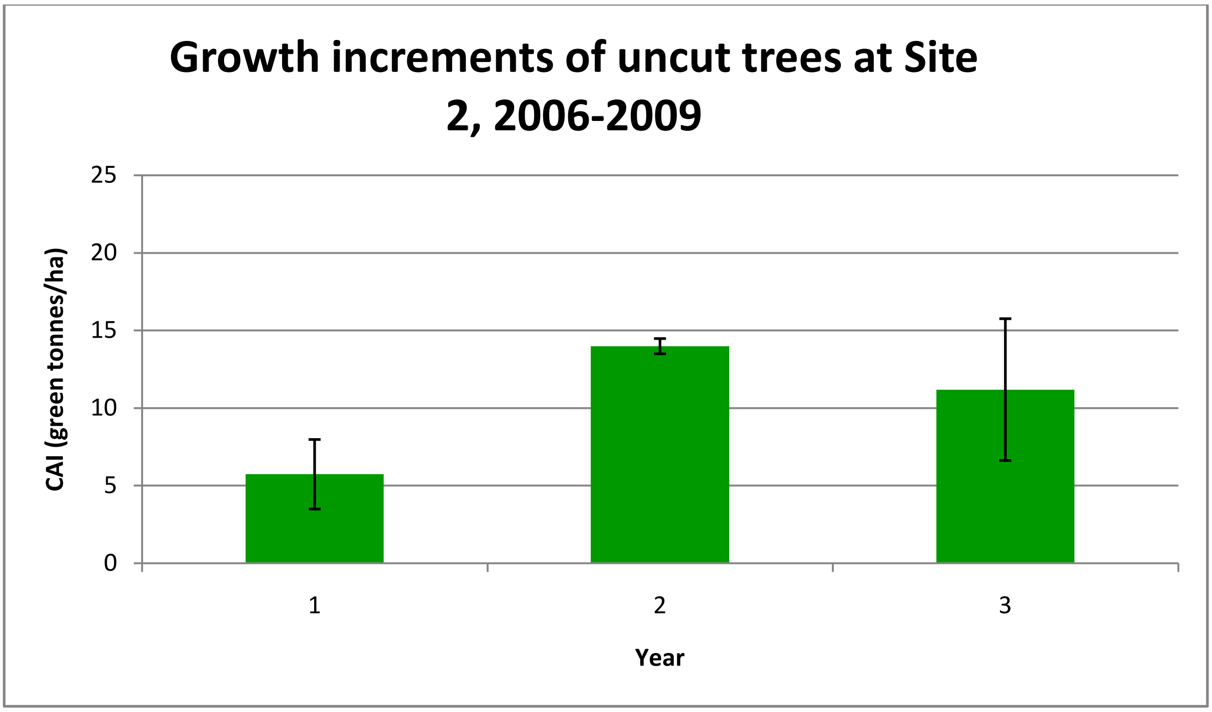
1. There is a grazing risk period in the early coppice stage.This will require stock management for periods in the first year following tree harvest.

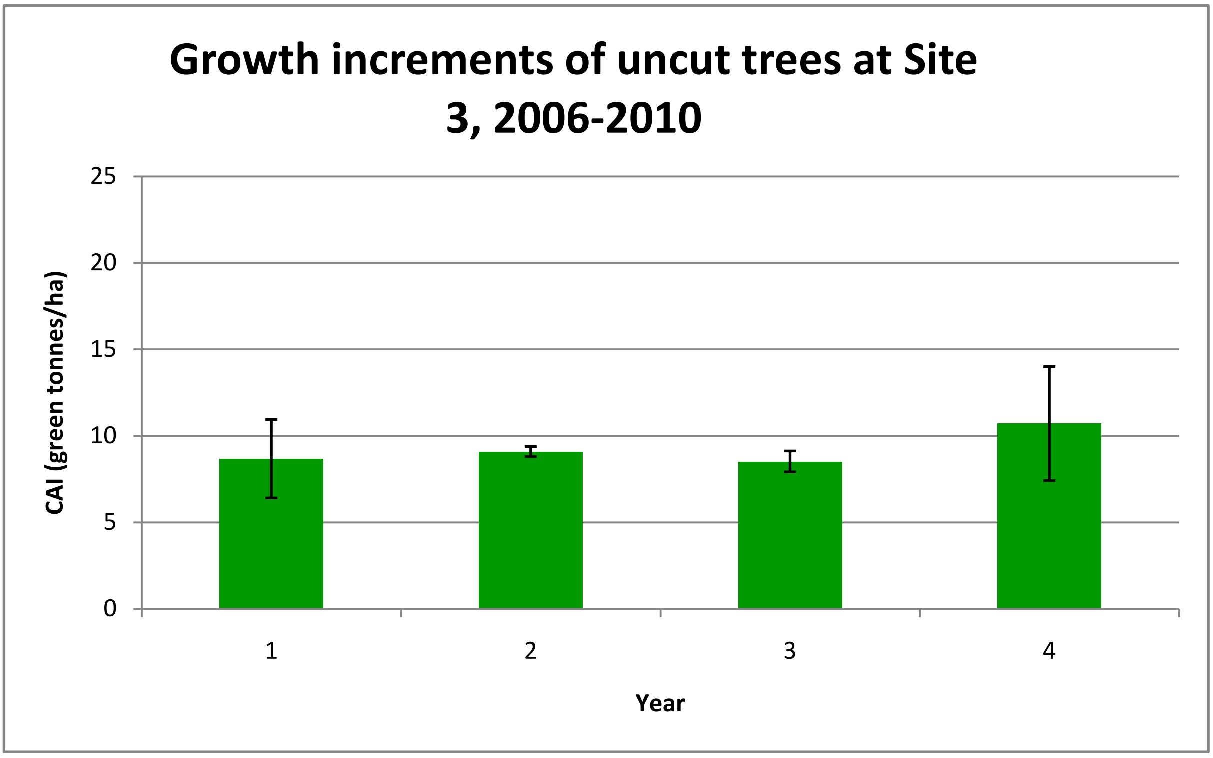
9 Appendices

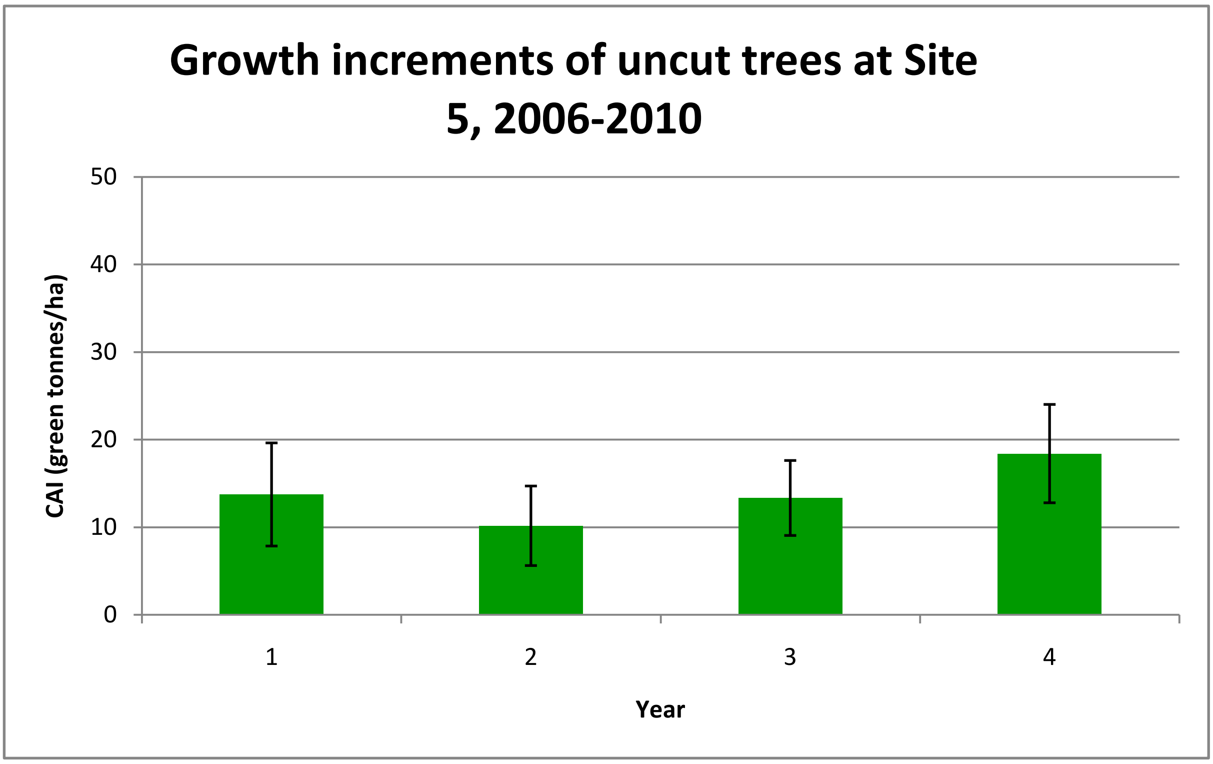
9.1 Appendix A Biomass charts of all sites.

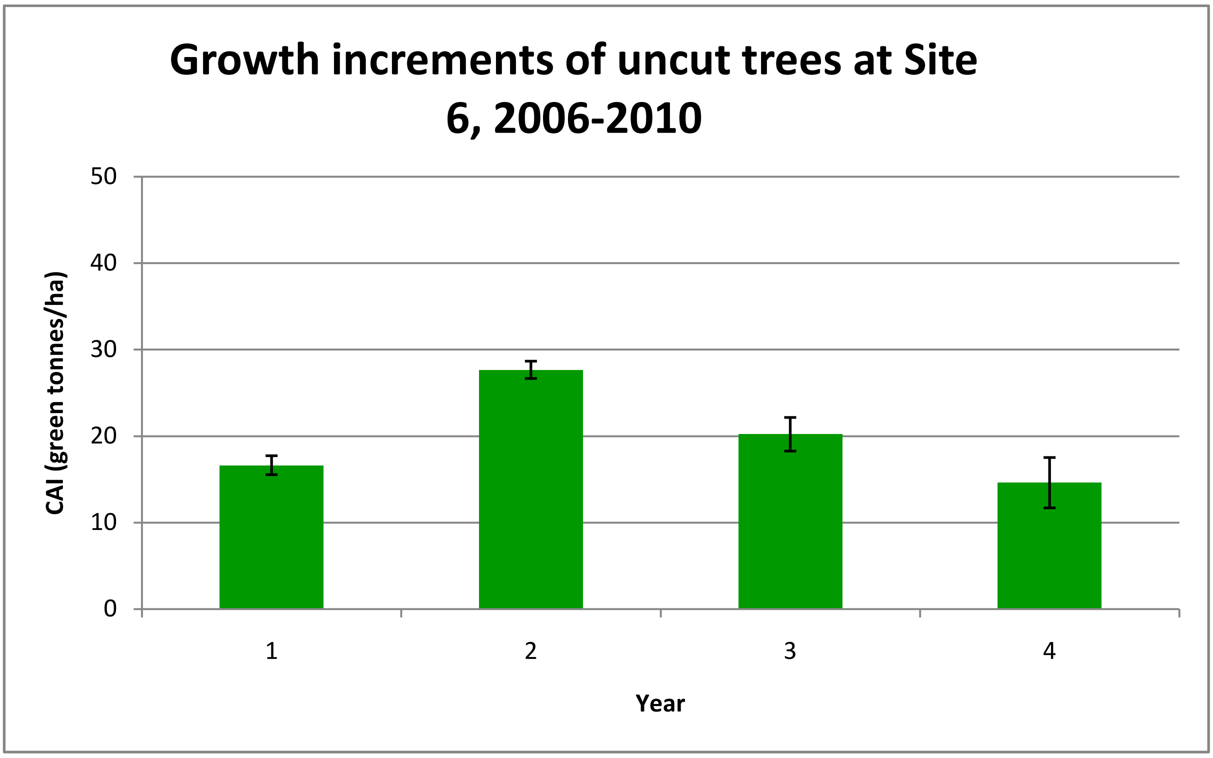
9.1.1 A-1 Control (uncut) tree biomass charts of all sites with standard errors, 2006-2010 (unless otherwise stated).

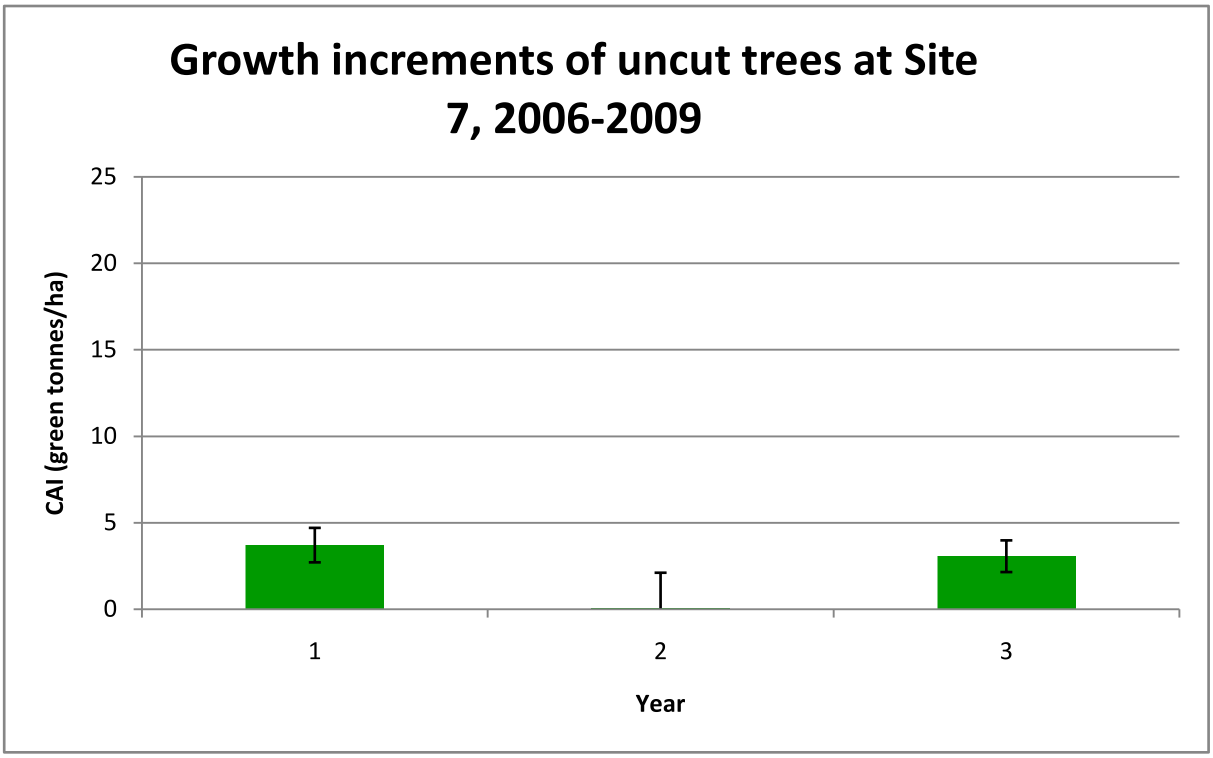


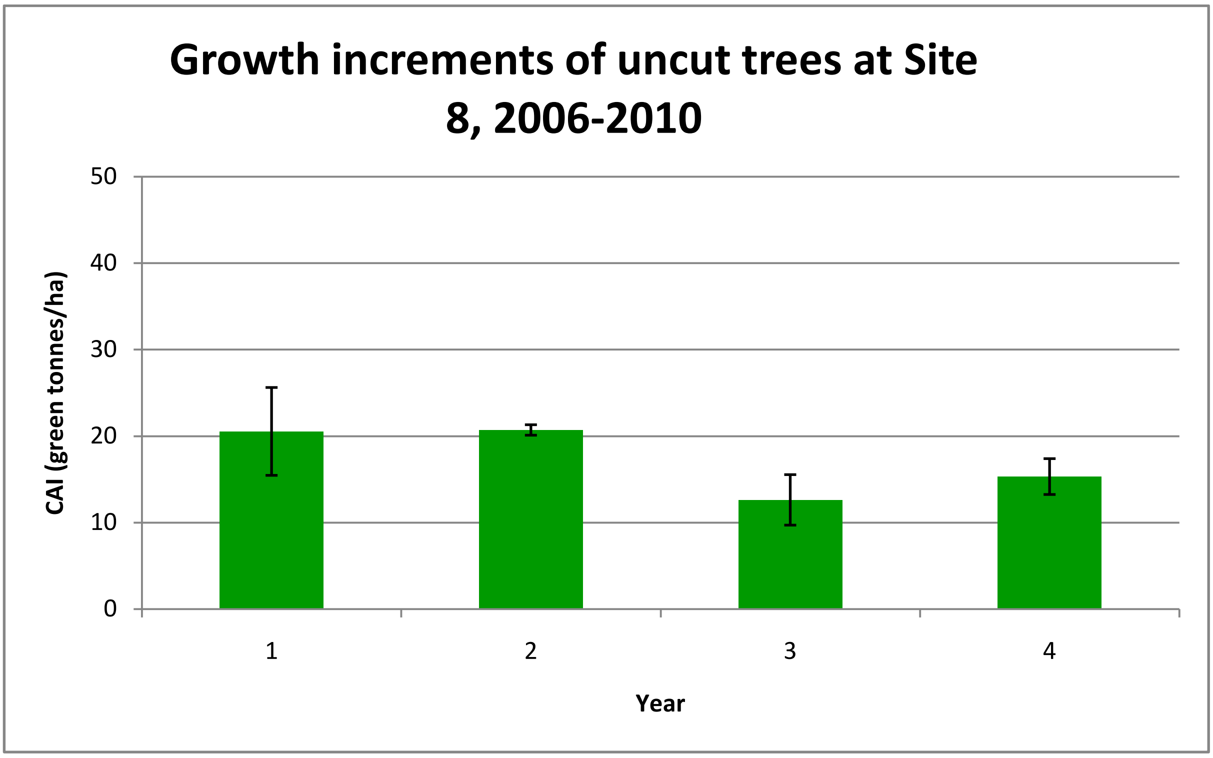


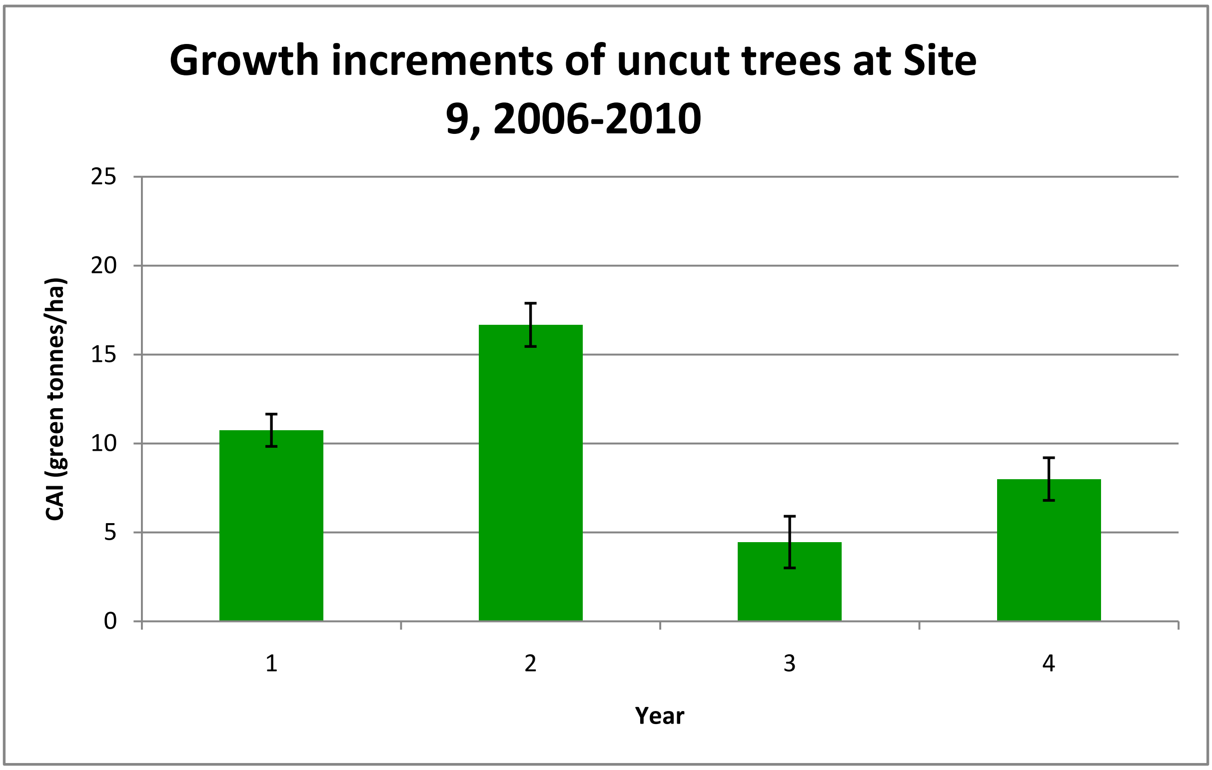

Growth increments of uncut trees at Site 3, 2006-2010
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
4
Year

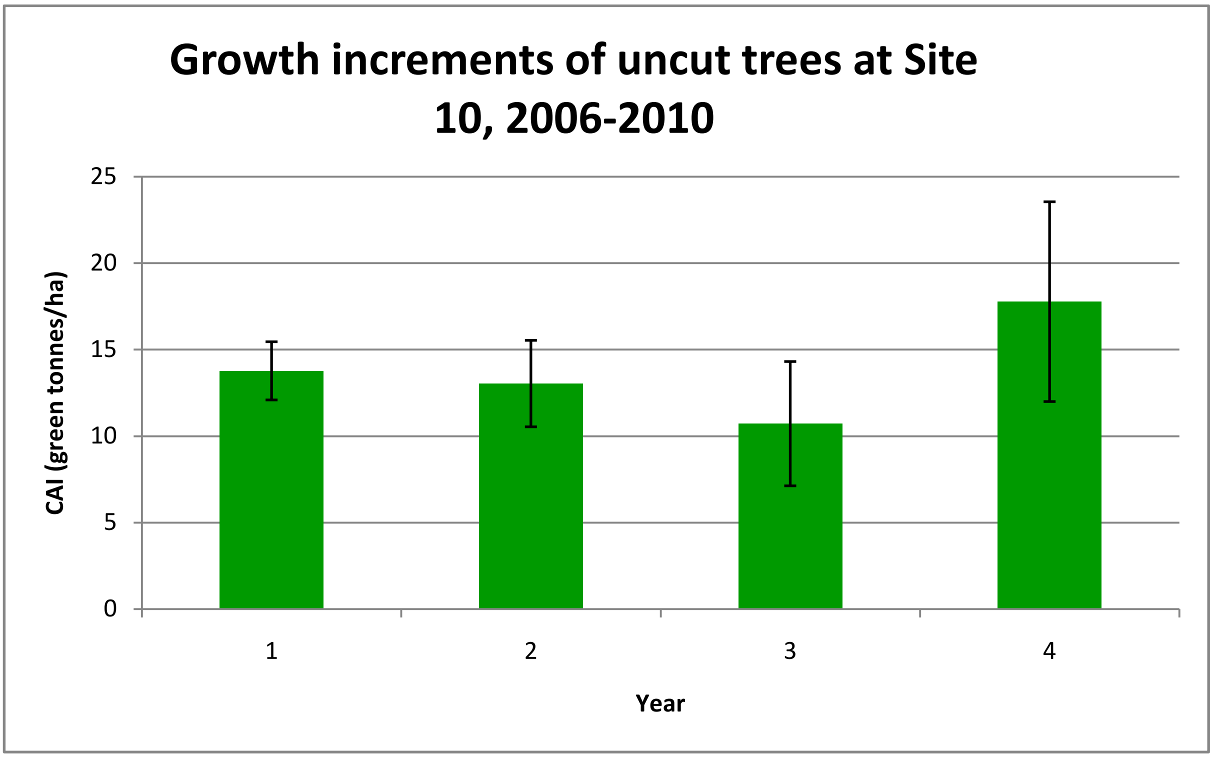

Growth increments of uncut trees at Site 5, 2006-2010
CAI (green tonnes/ha)
50
40
30
20
10
0
1
2
3
4
Year

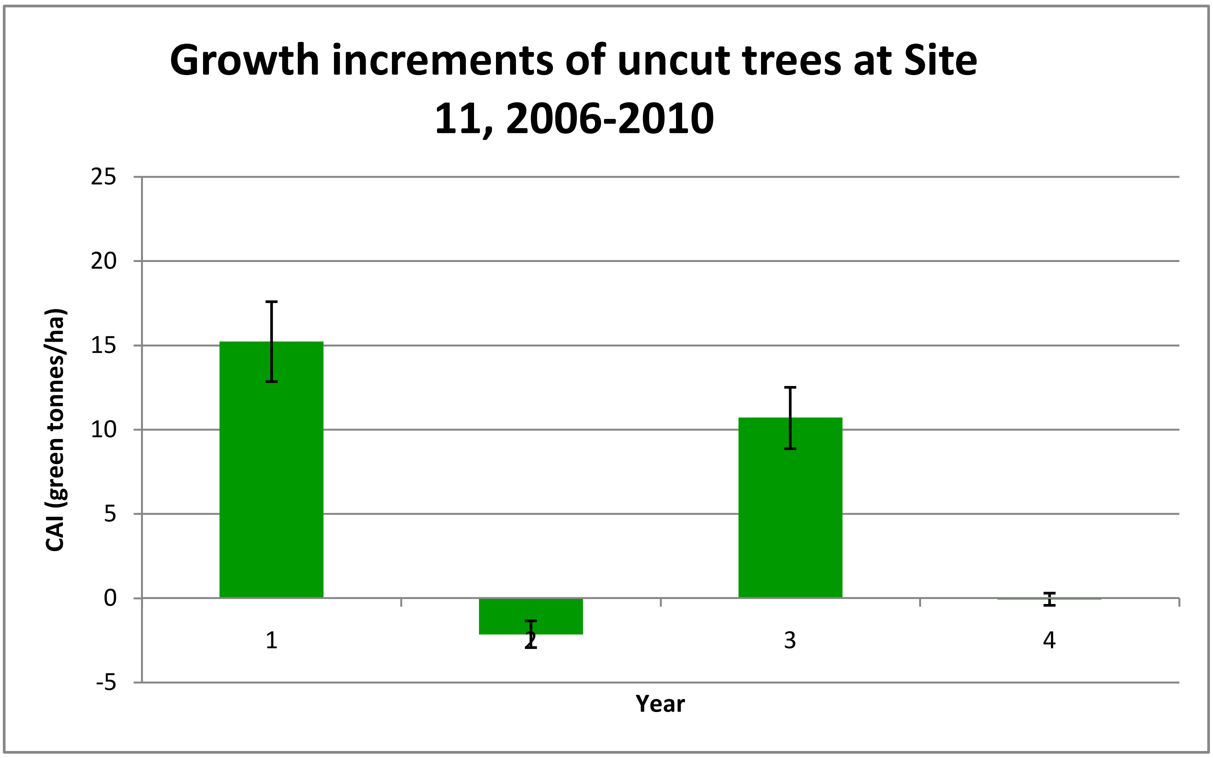

Growth increments of uncut trees at Site 6, 2006-2010
CAI (green tonnes/ha)
50
40
30
20
10
0
1
2
3
4
Year

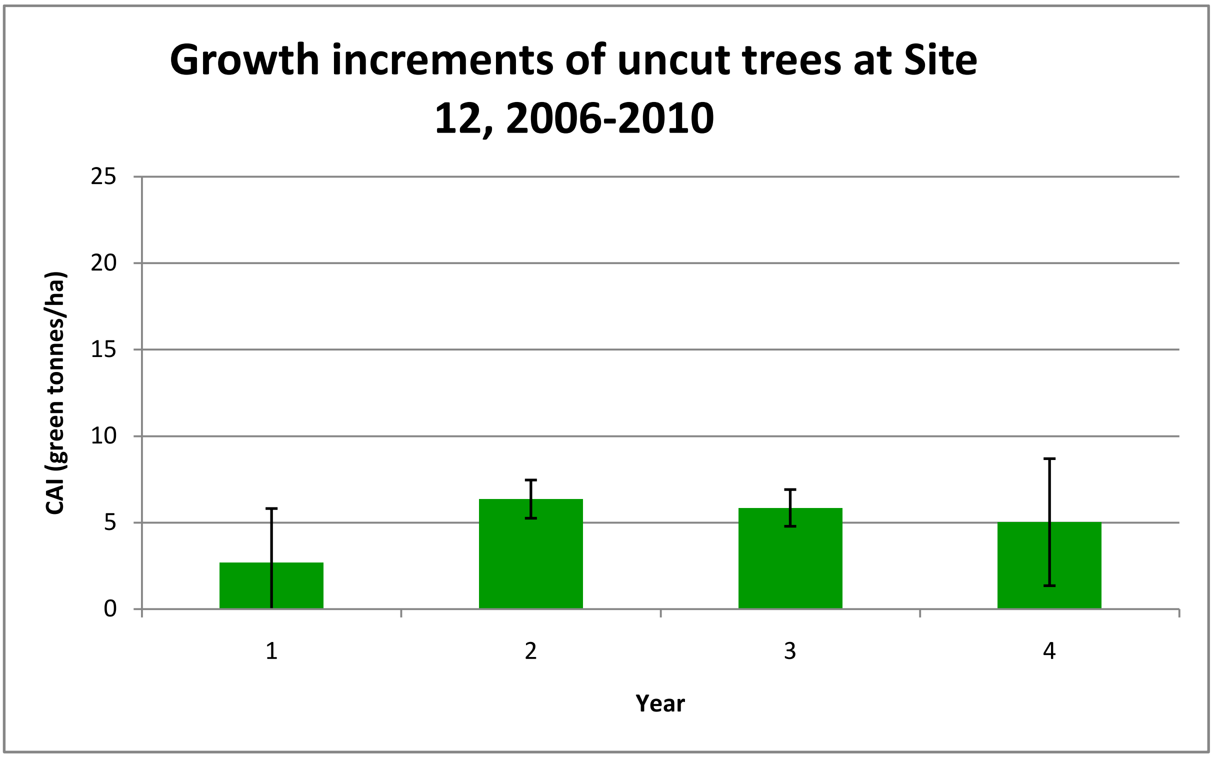

Growth increments of uncut trees at Site 7, 2006-2009
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
Year

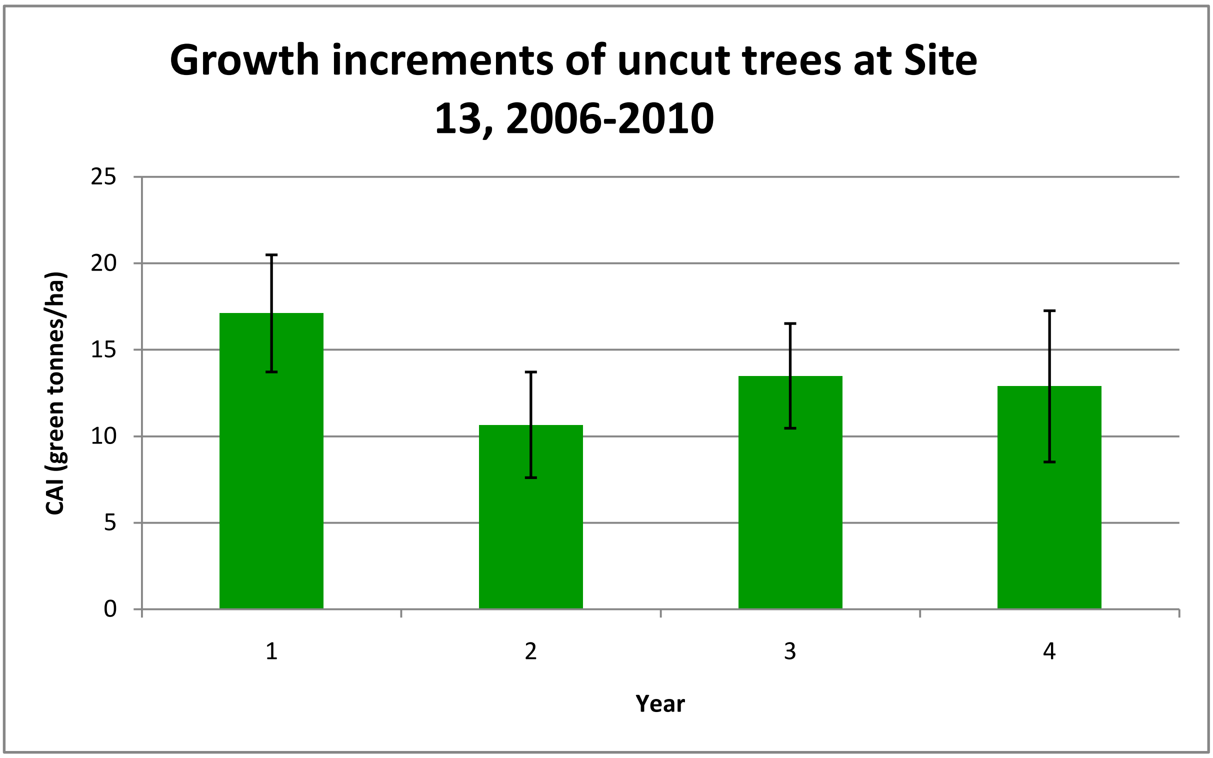

Growth increments of uncut trees at Site 8, 2006-2010
CAI (green tonnes/ha)
0
10
20
30
40
50
1
2
3
4
Year

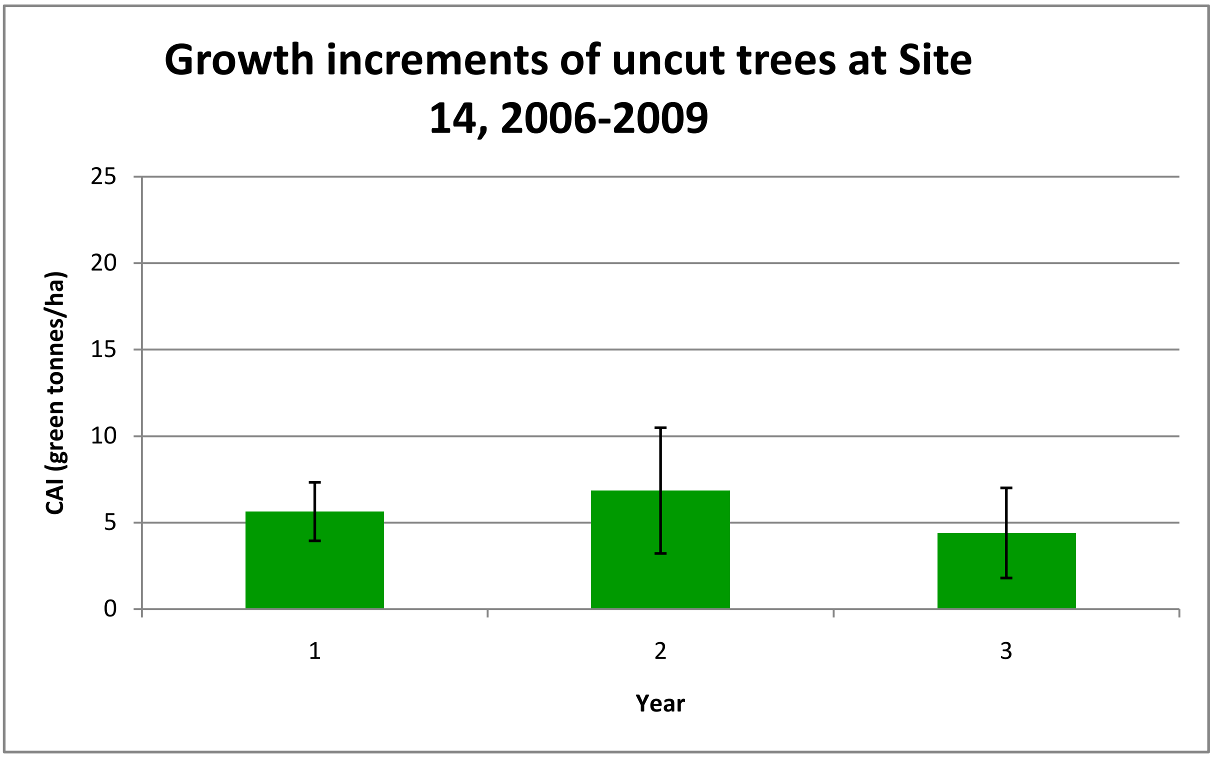

Growth increments of uncut trees at Site 9, 2006-2010
CAI (green tonnes/ha)
0
5
10
15
20
25
1
2
3
4
Year

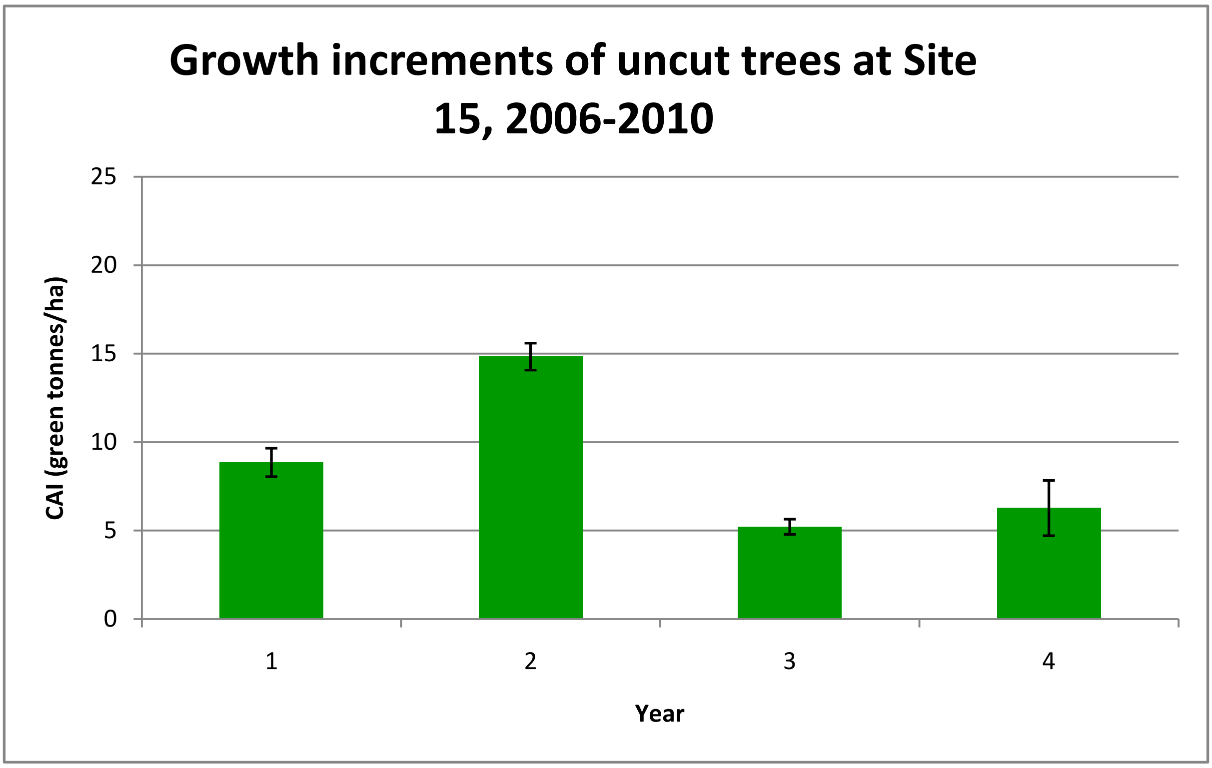

Growth increments of uncut trees at Site 10, 2006-2010
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
4
Year

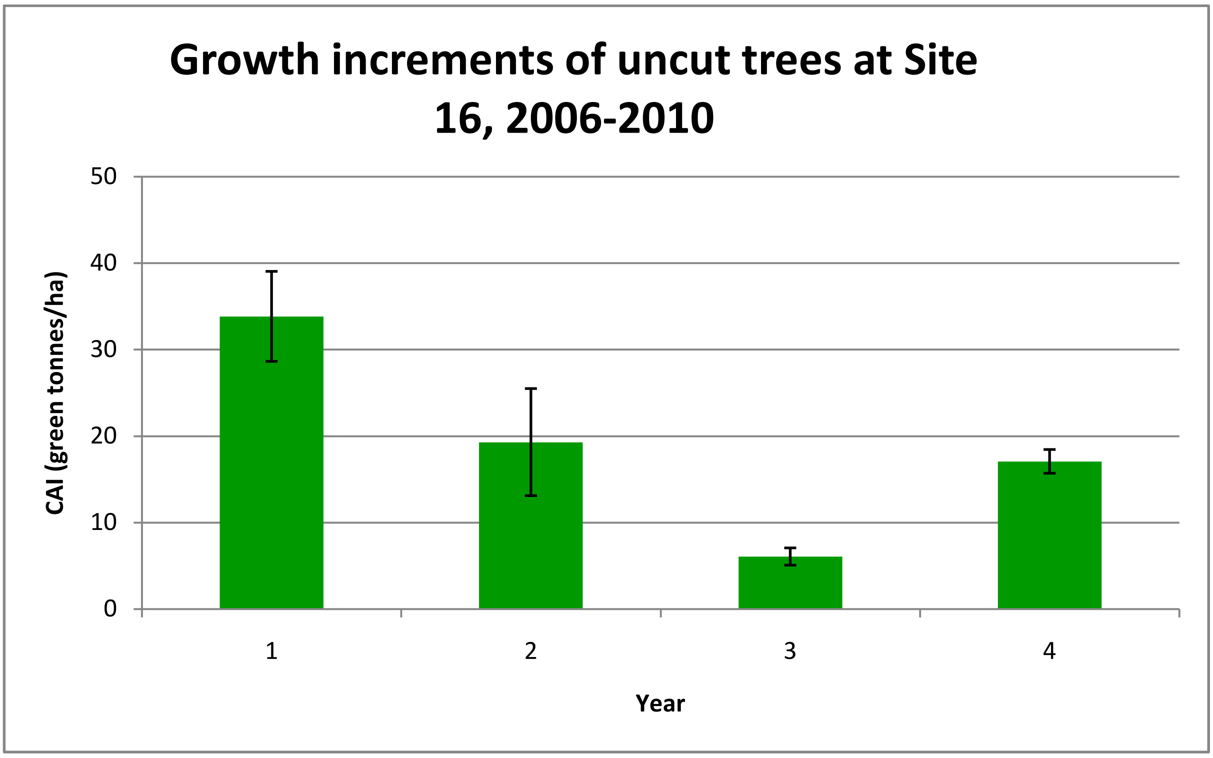

Growth increments of uncut trees at Site 11, 2006-2010
CAI (green tonnes/ha)
25
20
15
10
5
0
-5
1
2
3
4
Year

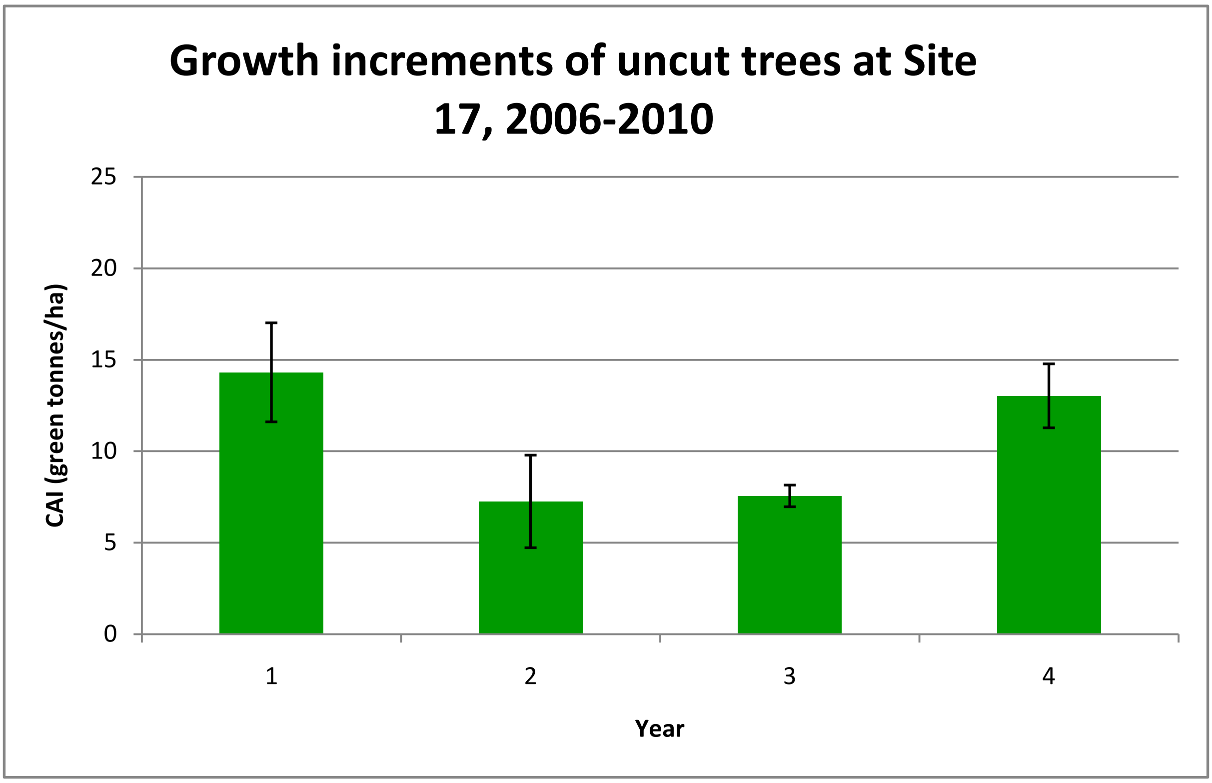

Growth increments of uncut trees at Site 12, 2006-2010
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
4
Year

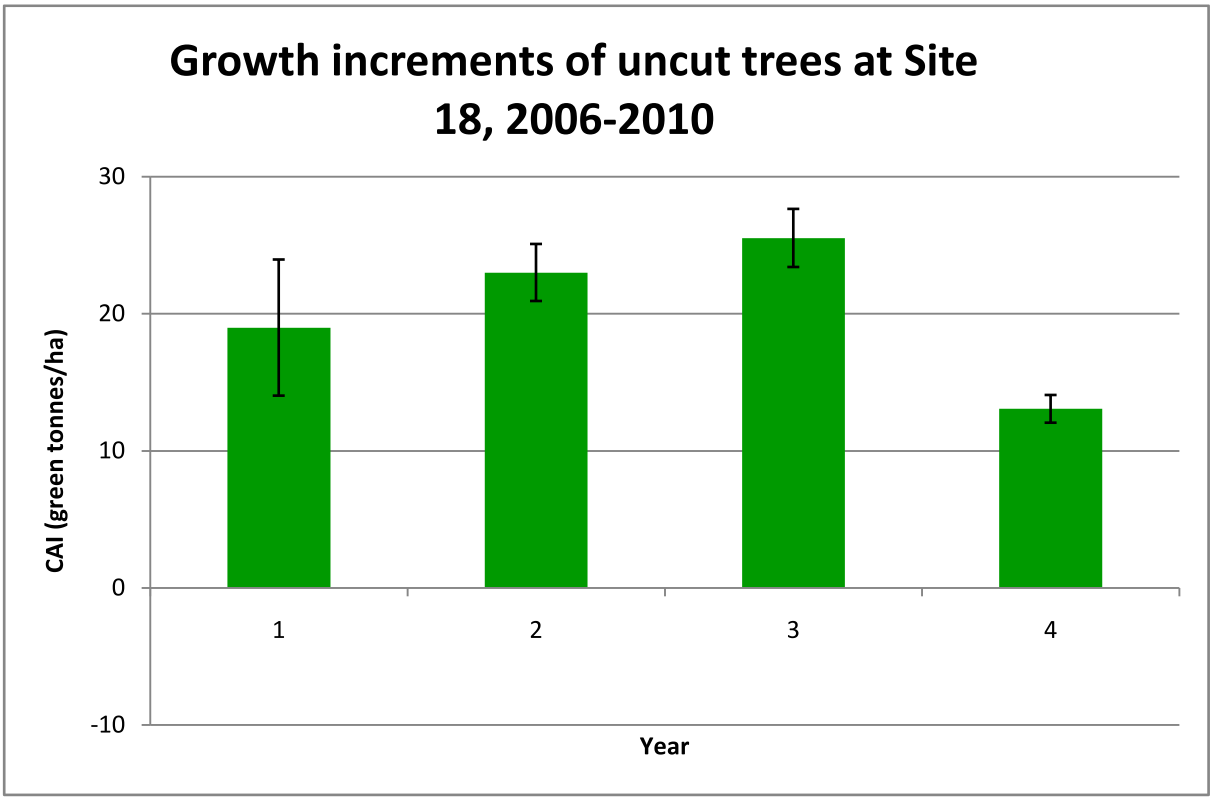

Growth increments of uncut trees at Site 13, 2006-2010
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
4
Year

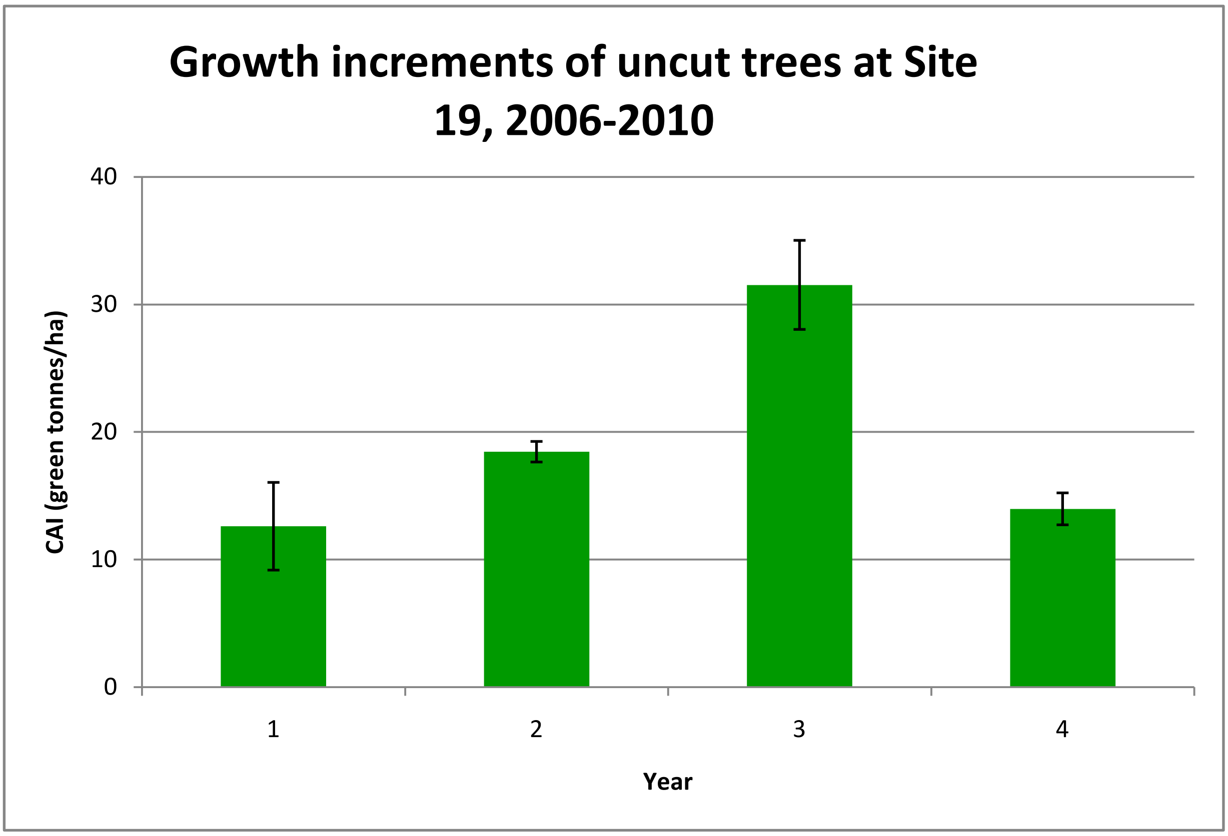

Growth increments of uncut trees at Site 14, 2006-2009
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
Year


Growth increments of uncut trees at Site 15, 2006-2010
CAI (green tonnes/ha)
25
20
15
10
5
0
1
2
3
4
Year


Growth increments of uncut trees at Site 16, 2006-2010
CAI (green tonnes/ha)
0
10
20
30
40
50
1
2
3
4
Year


Growth increments of uncut trees at Site 17, 2006-2010
CAI (green tonnes/ha)
0
5
10
15
20
25
1
2
3
4
Year


Growth increments of uncut trees at Site 18, 2006-2010
CAI (green tonnes/ha)
30
20
10
0
-10
1
2
3
4
Year


Growth increments of uncut trees at Site 19, 2006-2010
CAI (green tonnes/ha)
40
30
20
10
0
1
2
3
4
Year

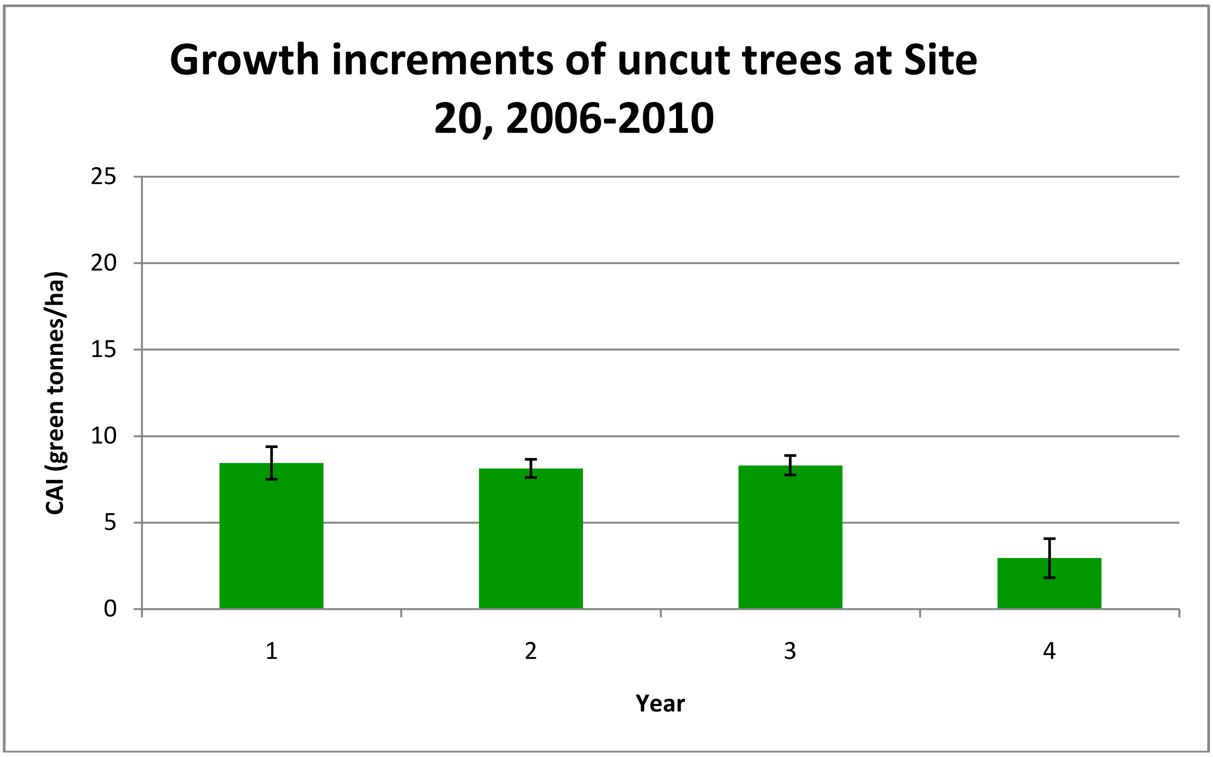
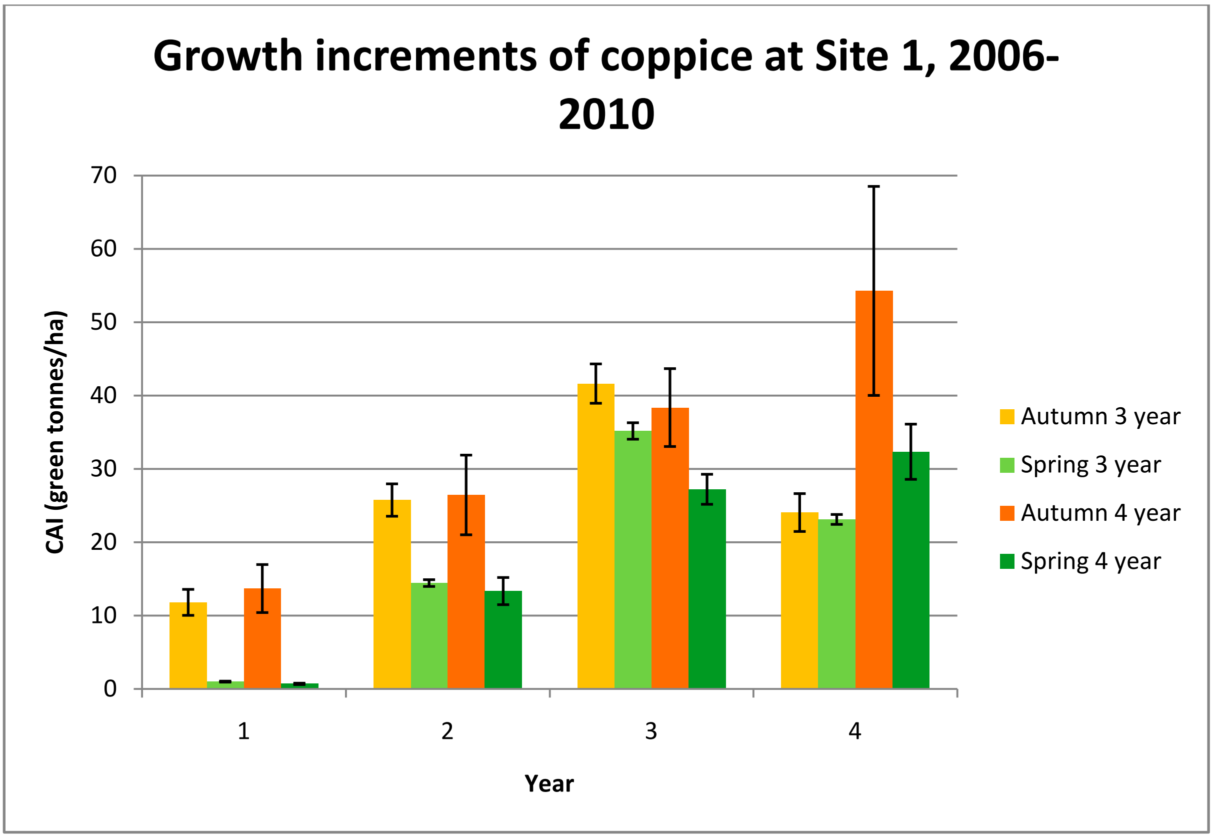
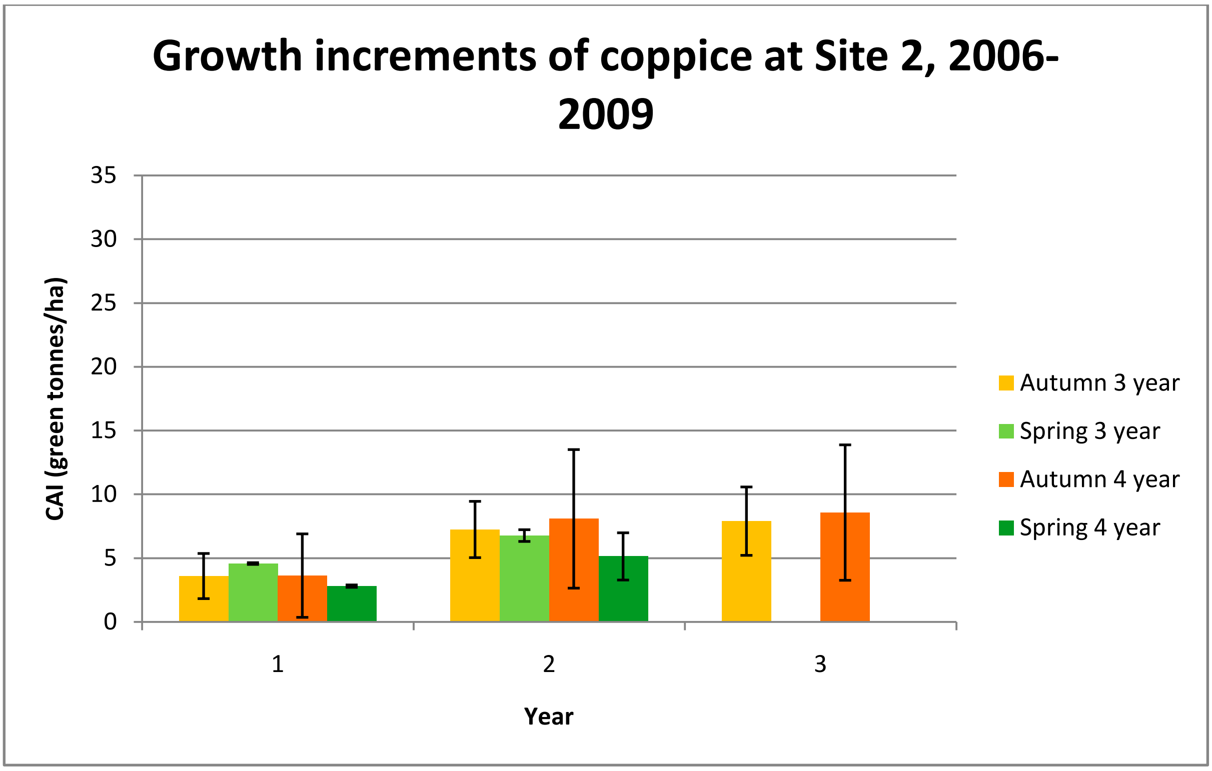

Growth increments of uncut trees at Site 20, 2006-2010
CAI (green tonnes/ha)
0
5
10
15
20
25
1
2
3
4
Year

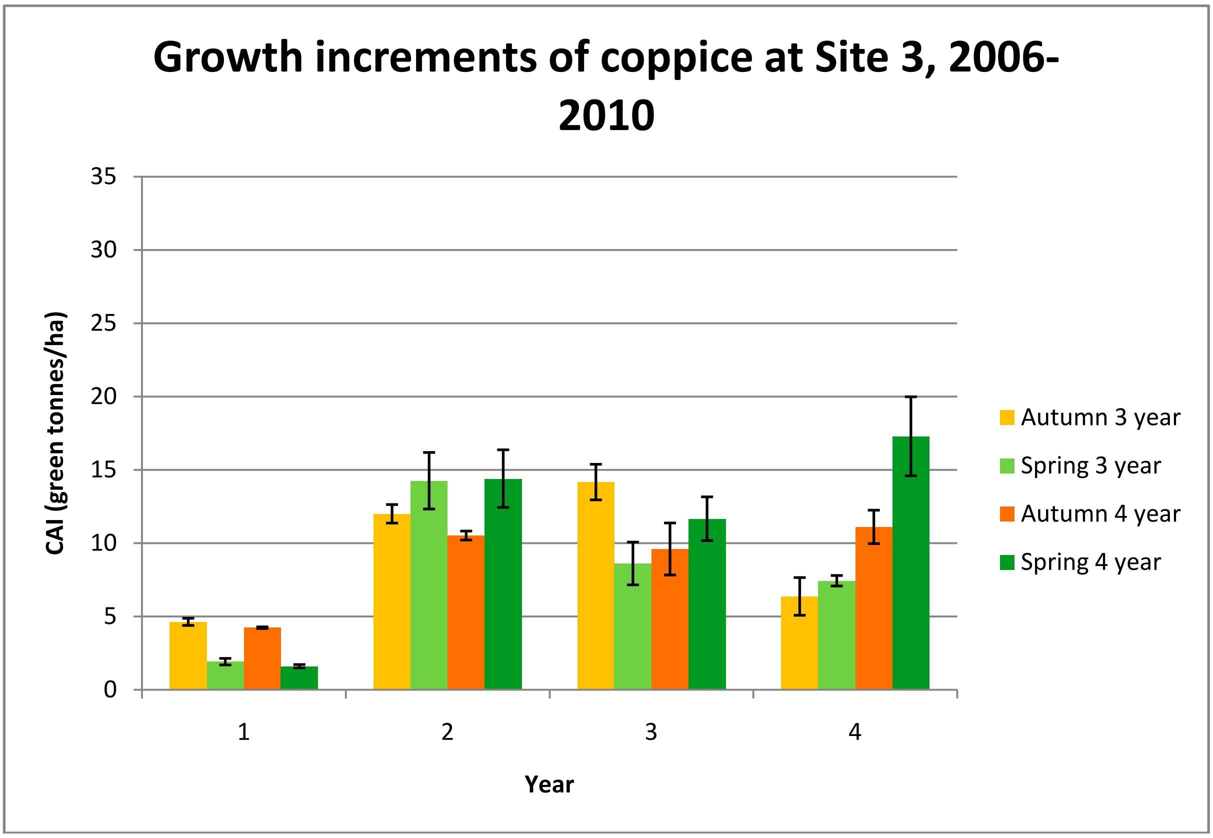
Table A-1 Regression parameters for control trees (indicates that the universal species regression was used).**

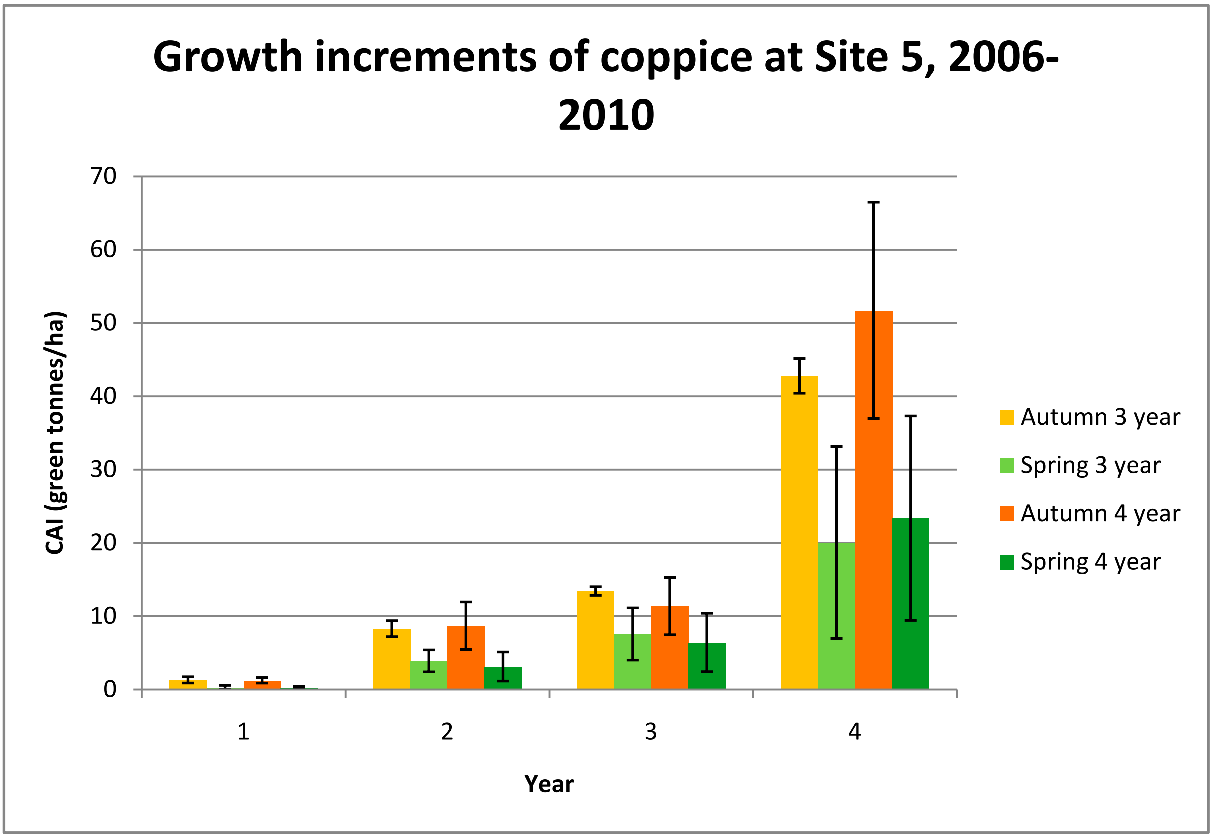
Species	Site	n	log transform	slope	intercept	r^2	min ln(SBA) or SBA (cm^2)	max ln(SBA) or SBA (cm^2)
E. polybractea	1	39	y	1.154099	-1.25032	0.92	3.57	6.86
	8	799	y	1.259897	-1.94652	0.86	1.24	6.06
	18 19	203	y	1.273282	-2.11485	0.95	1.29	5.66
E. kochii ssp *plenissima*	11	46	y	0.918179	1.06598	0.92	-0.38	3.43
	15	34	y	0.950342	-0.63104	0.83	3.51	5.94
	16	123	y	1.260269	-2.08186	0.94	0.76	6.20
E. loxophleba ssp *lissophloia*	2	39	y	1.445219	-2.80678	0.90	2.86	5.13
	3	48	n	0.638151	-2.21417	0.92	4.91	153.94
	5	35	y	1.172572	-1.22851	0.97	2.67	6.02
	6**	482	y	1.23248	-1.67068	0.92	1.34	6.02
	7	22	n	0.602146	-3.14402	0.97	10.45	89.85
	9	36	n	0.641247	-8.11755	0.93	19.15	292.18
	10	61	n	1.13931	-1.29696	0.96	2.6	5.69
	12	61	y	1.288563	-1.95136	0.91	1.51	5.14
	13	55	y	1.234035	-1.49886	0.85	2.77	5.75
	14	47	n	0.586144	-3.85847	0.95	6.61	113.89
	17	43	y	1.154395	-1.48631	0.98	1.59	5.78
	20	75	y	1.151169	-1.50922	0.90	1.34	5.11

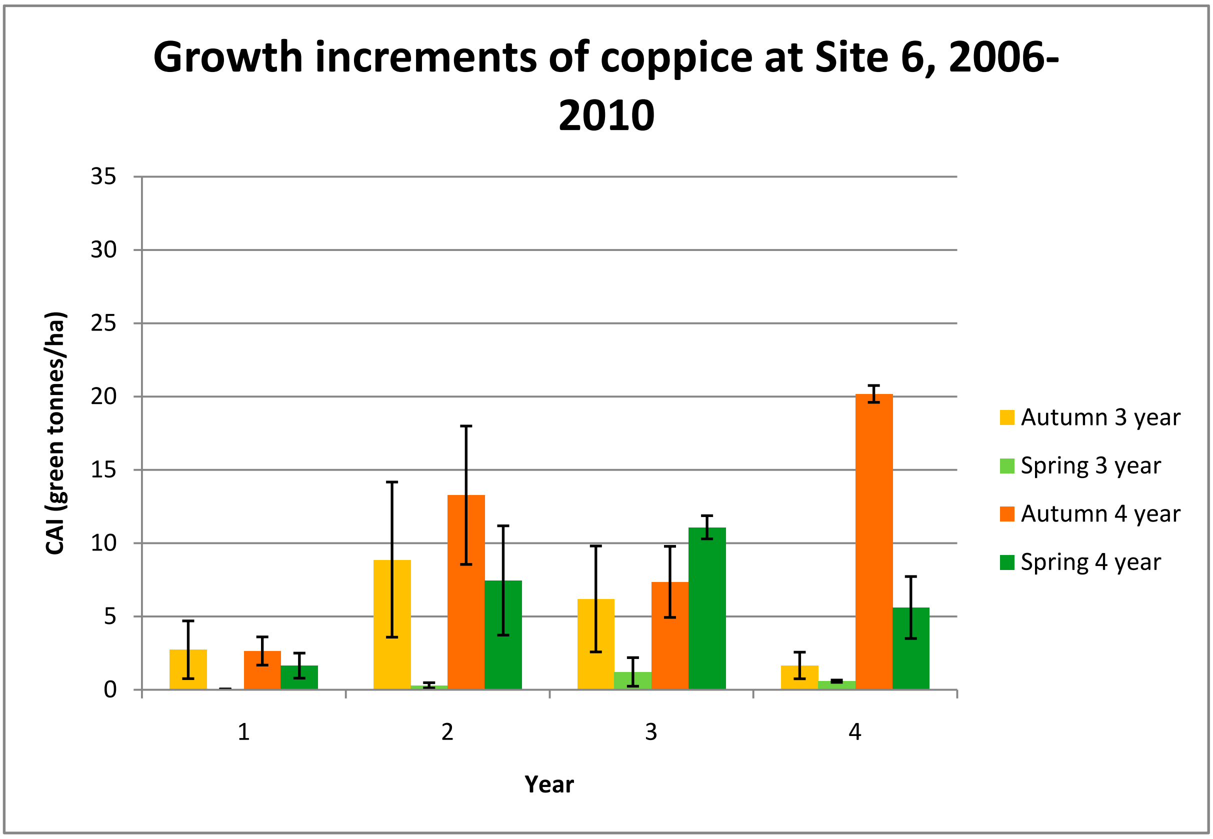
9.1.2 A-2 Coppice biomass charts of all sites with standard errors, 2006-2010 (unless otherwise stated).

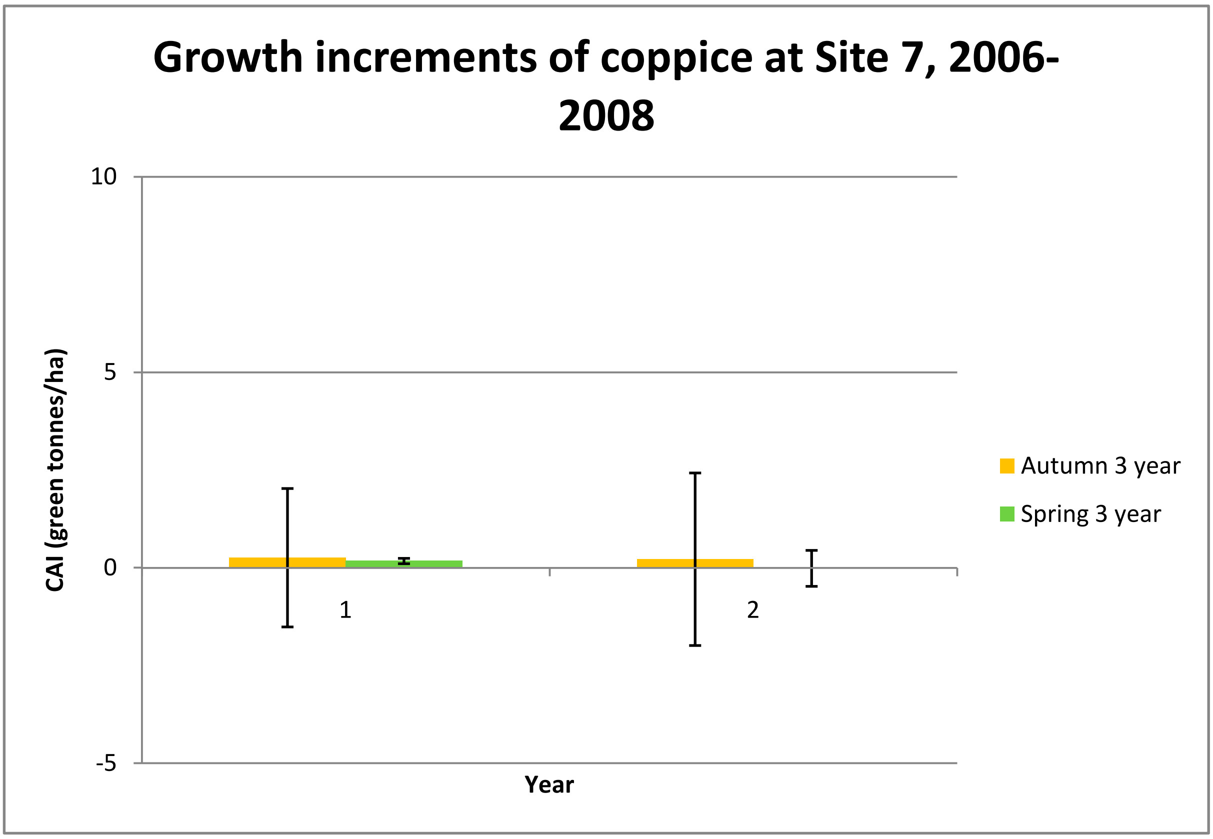


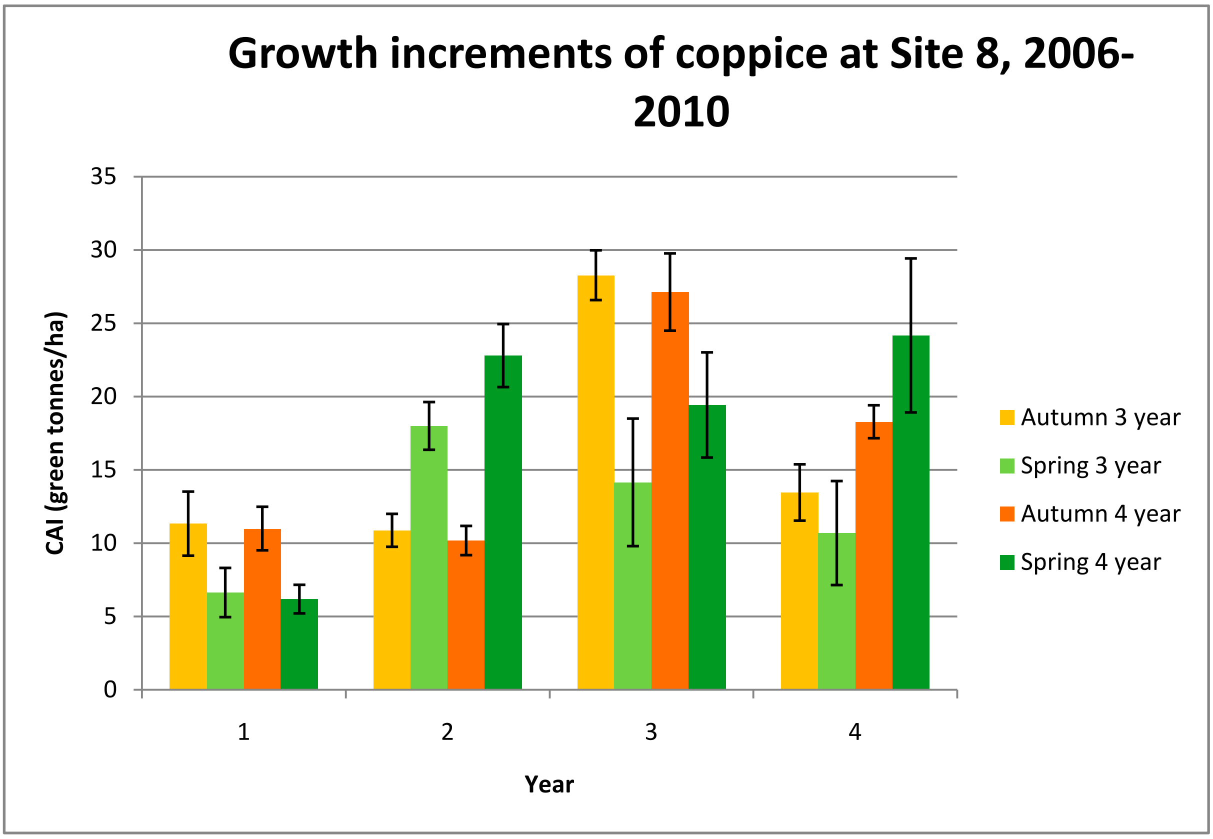


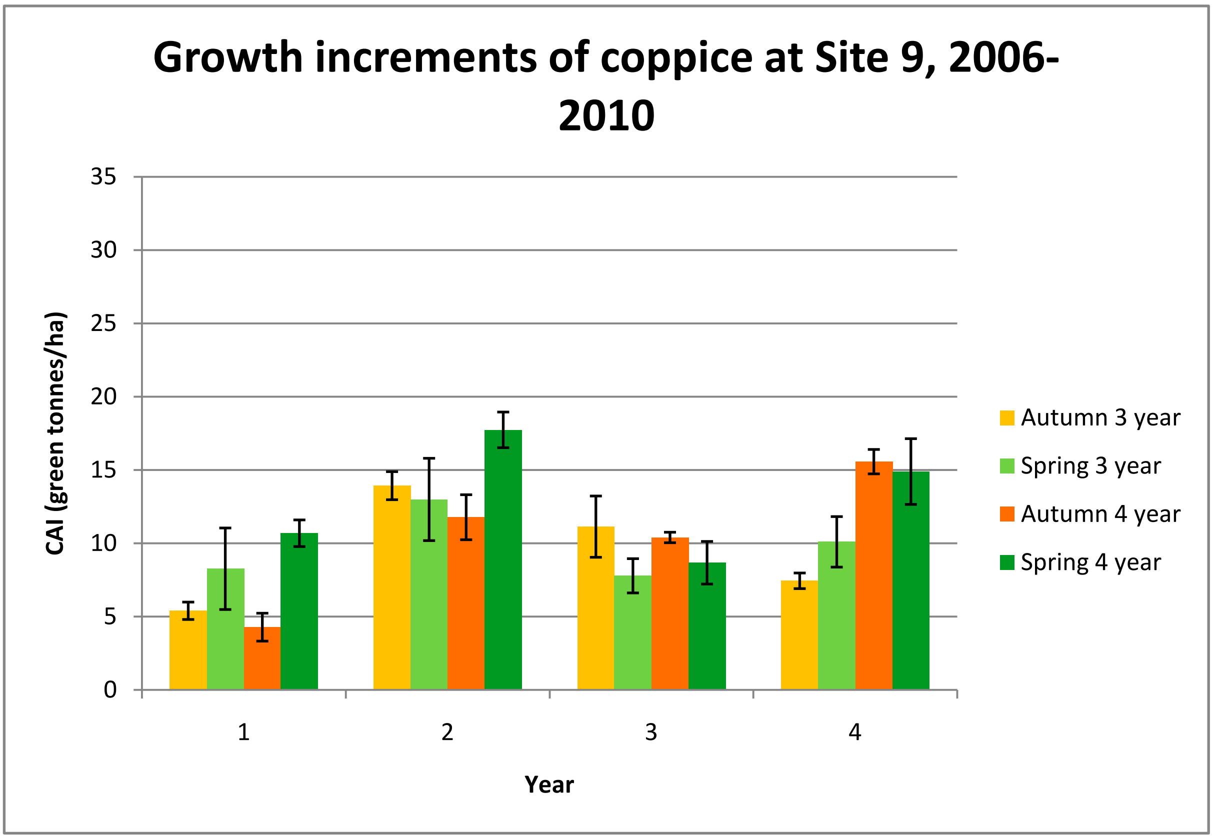

Growth increments of coppice at Site 3, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

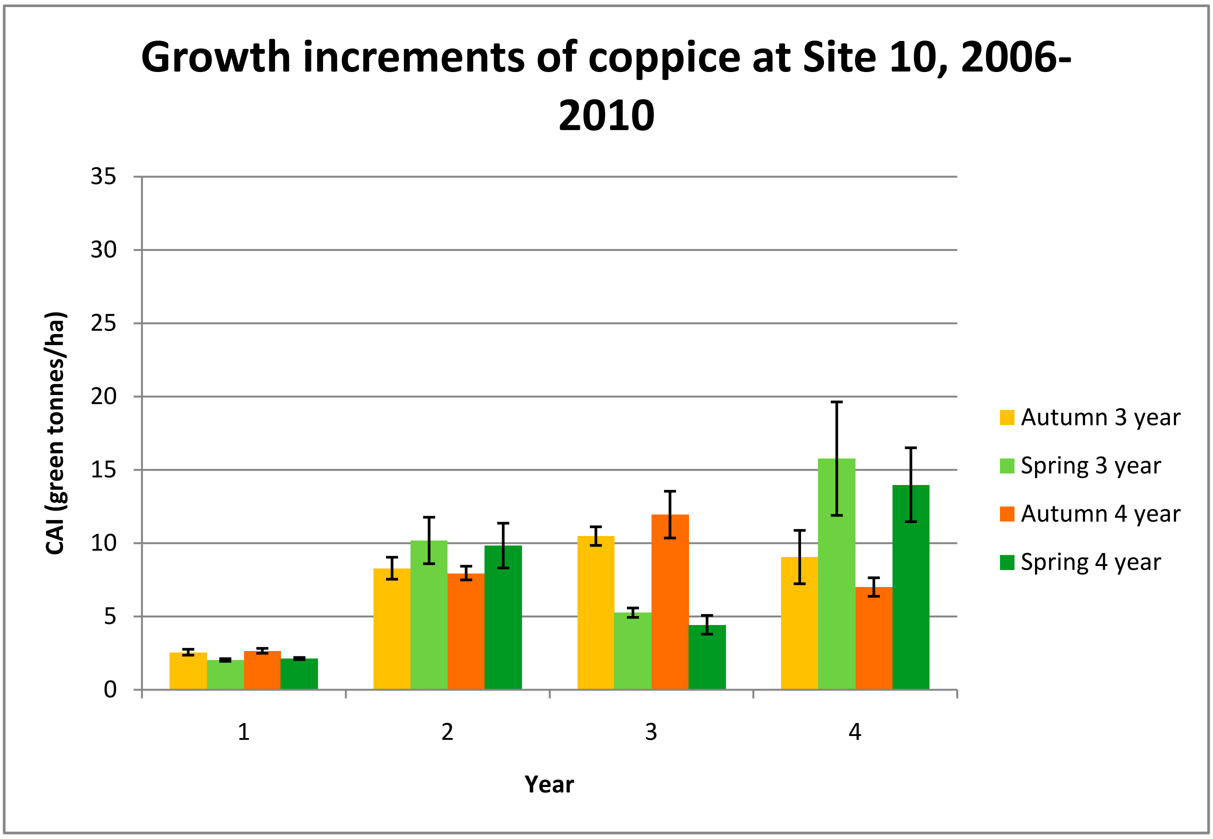

Growth increments of coppice at Site 5, 2006-2010
CAI (green tonnes/ha)
70
60
50
40
30
20
10
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

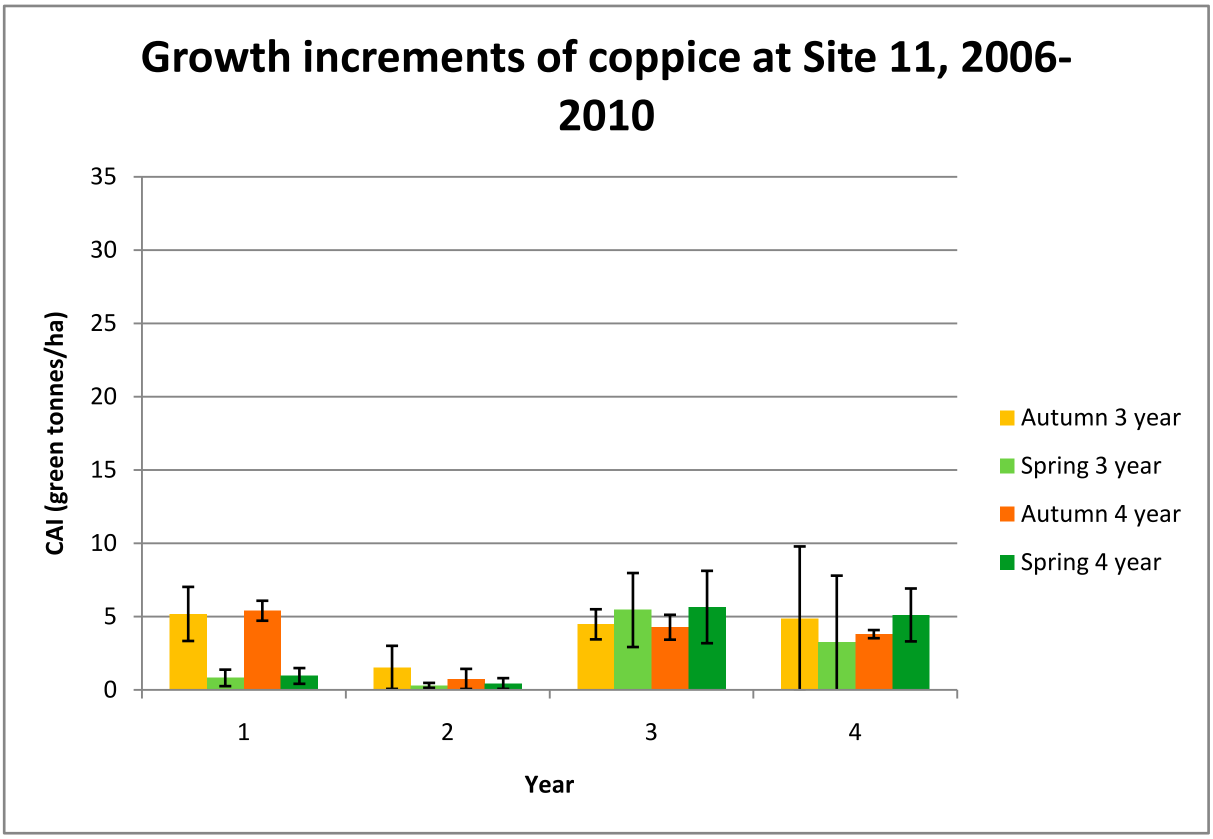

Growth increments of coppice at Site 6, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

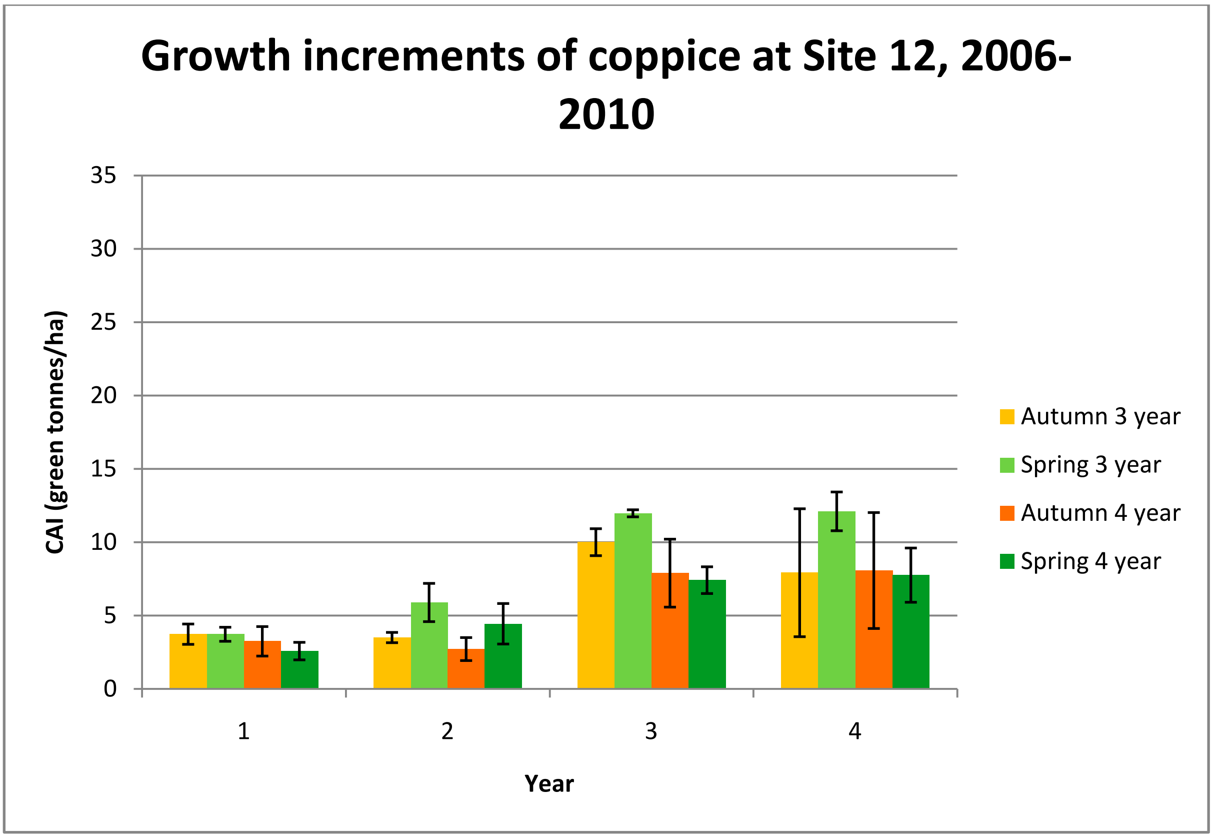

Growth increments of coppice at Site 7, 2006-2008
CAI (green tonnes/ha)
10
5
0
-5
1
2
Year
Autumn 3 year
Spring 3 year

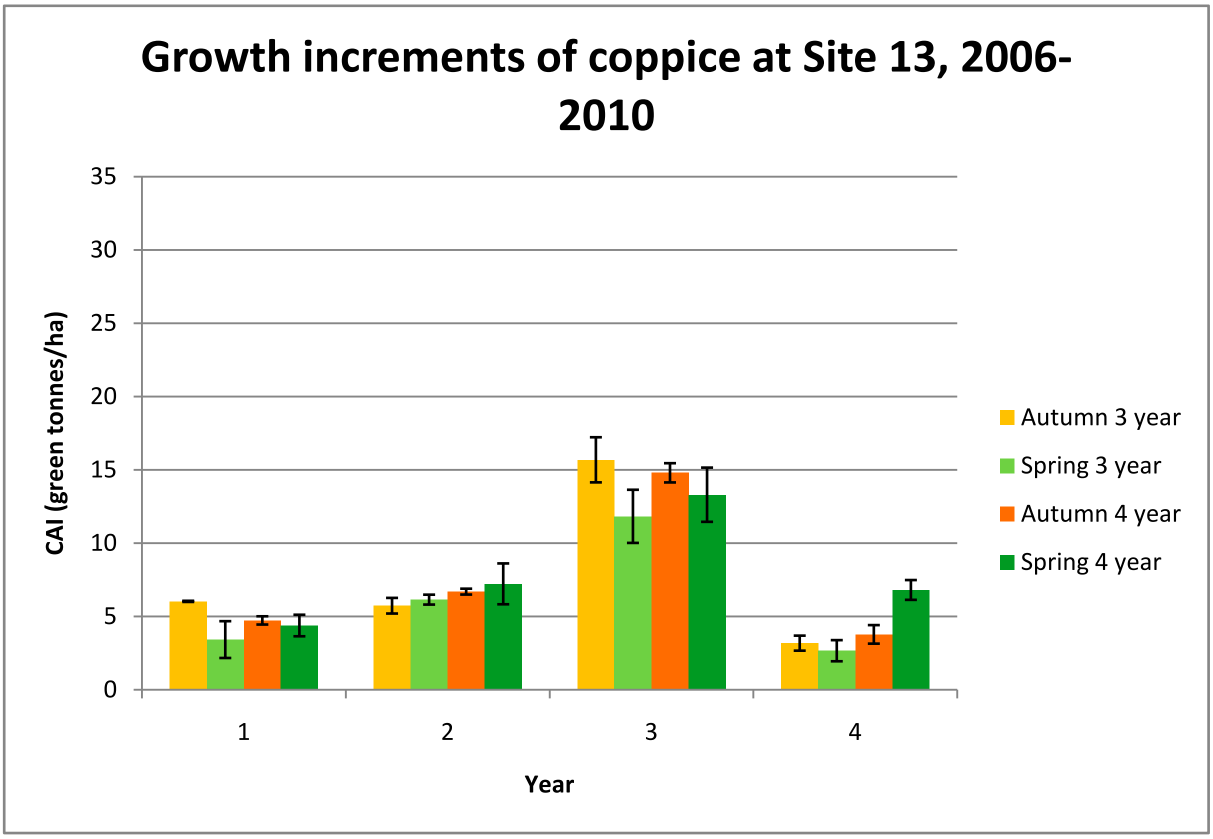

Growth increments of coppice at Site 8, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

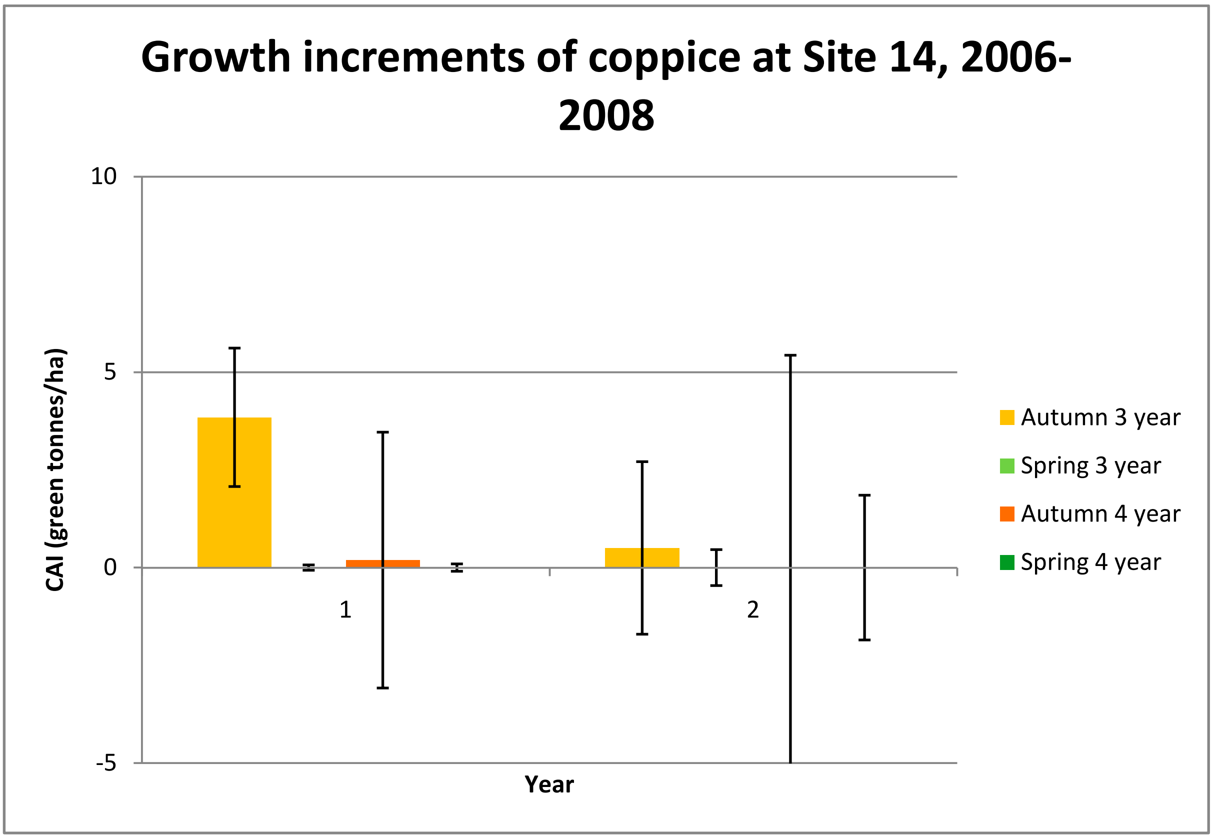

Growth increments of coppice at Site 9, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

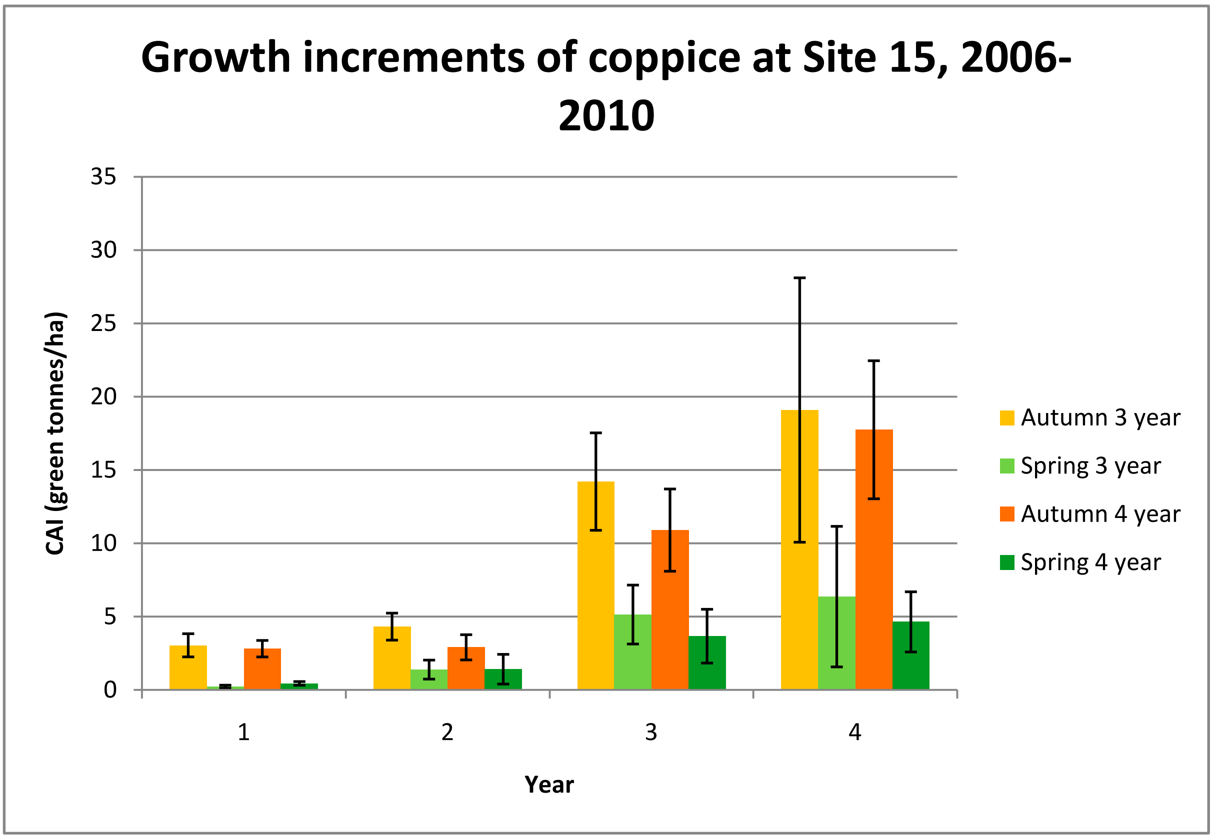

Growth increments of coppice at Site 10, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

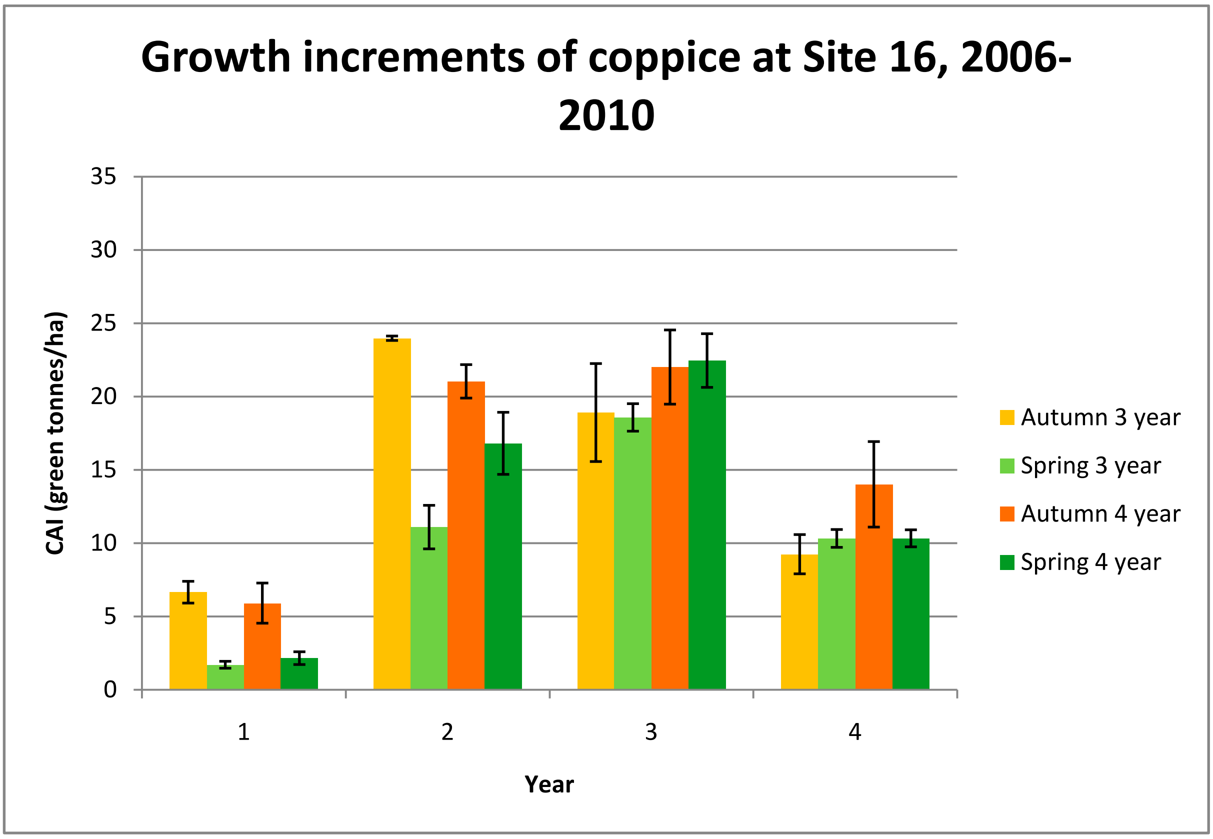

Growth increments of coppice at Site 11, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

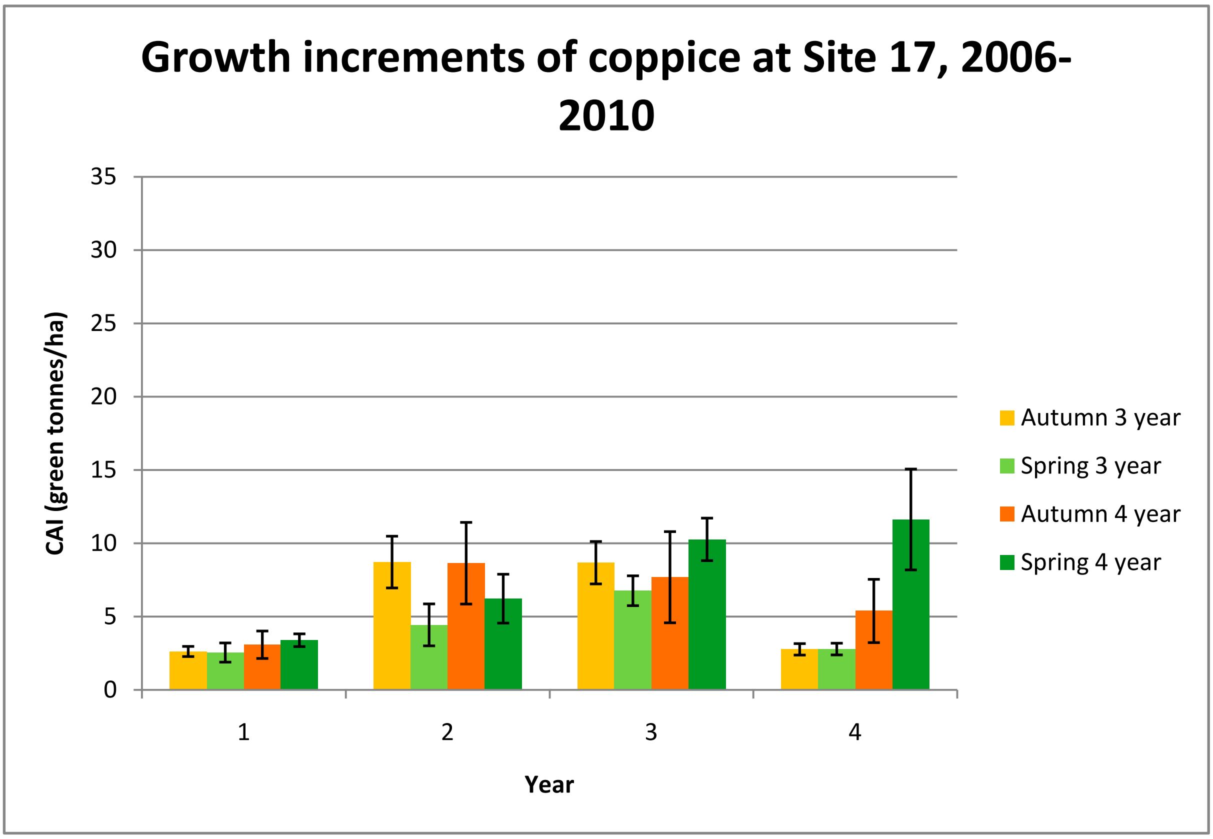

Growth increments of coppice at Site 12, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

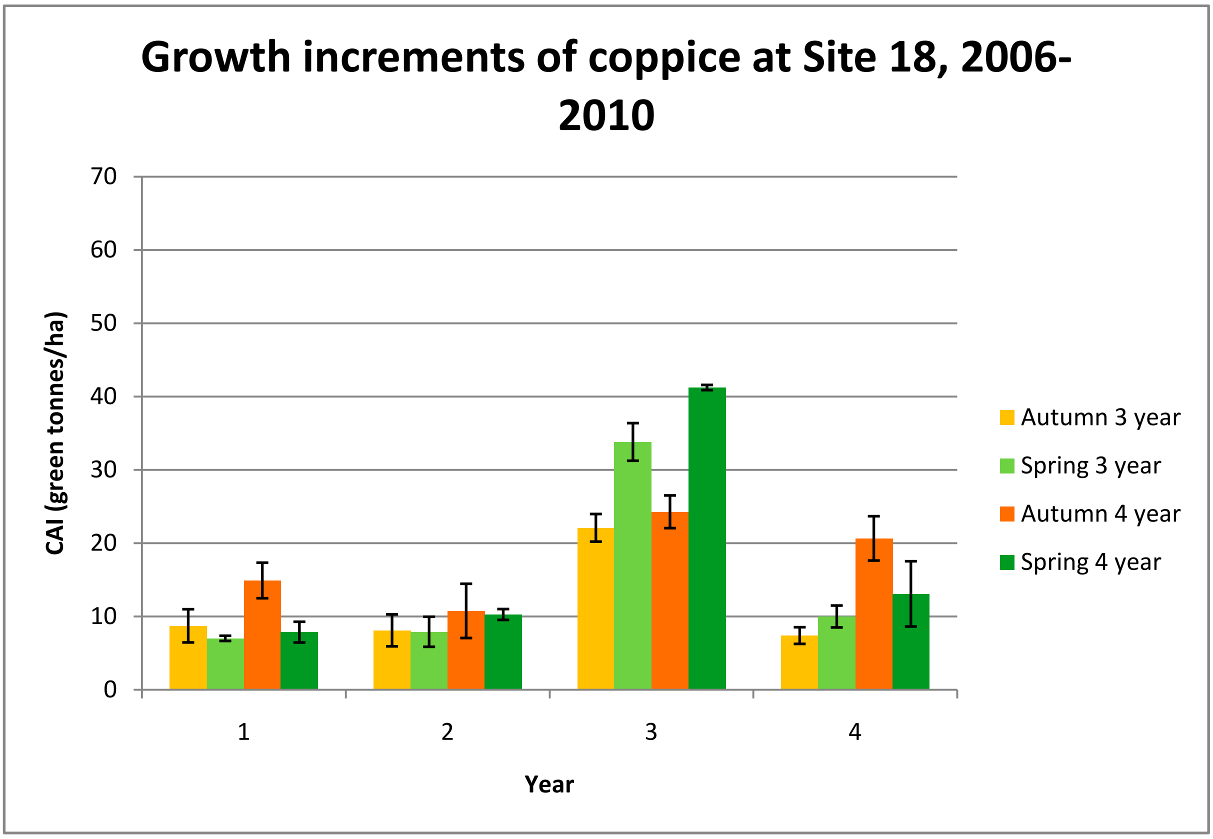

Growth increments of coppice at Site 13, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

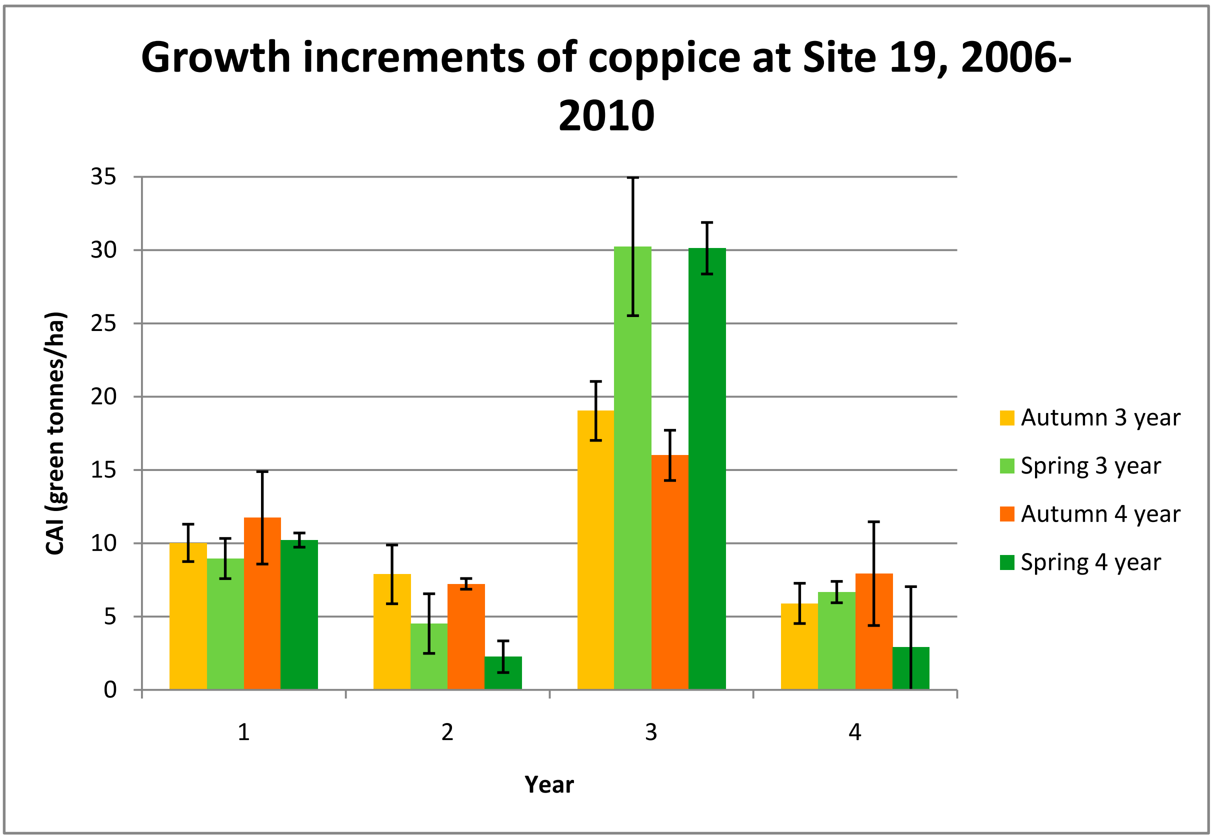

Growth increments of coppice at Site 14, 2006-2008
CAI (green tonnes/ha)
10
5
0
-5
1
2
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year


Growth increments of coppice at Site 15, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year


Growth increments of coppice at Site 16, 2006-2010
CAI (green tonnes/ha)
0
5
10
15
20
25
30
35
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year


Growth increments of coppice at Site 17, 2006-2010
CAI (green tonnes/ha)
0
5
10
15
20
25
30
35
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year


Growth increments of coppice at Site 18, 2006-2010
CAI (green tonnes/ha)
70
60
50
40
30
20
10
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year


Growth increments of coppice at Site 19, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

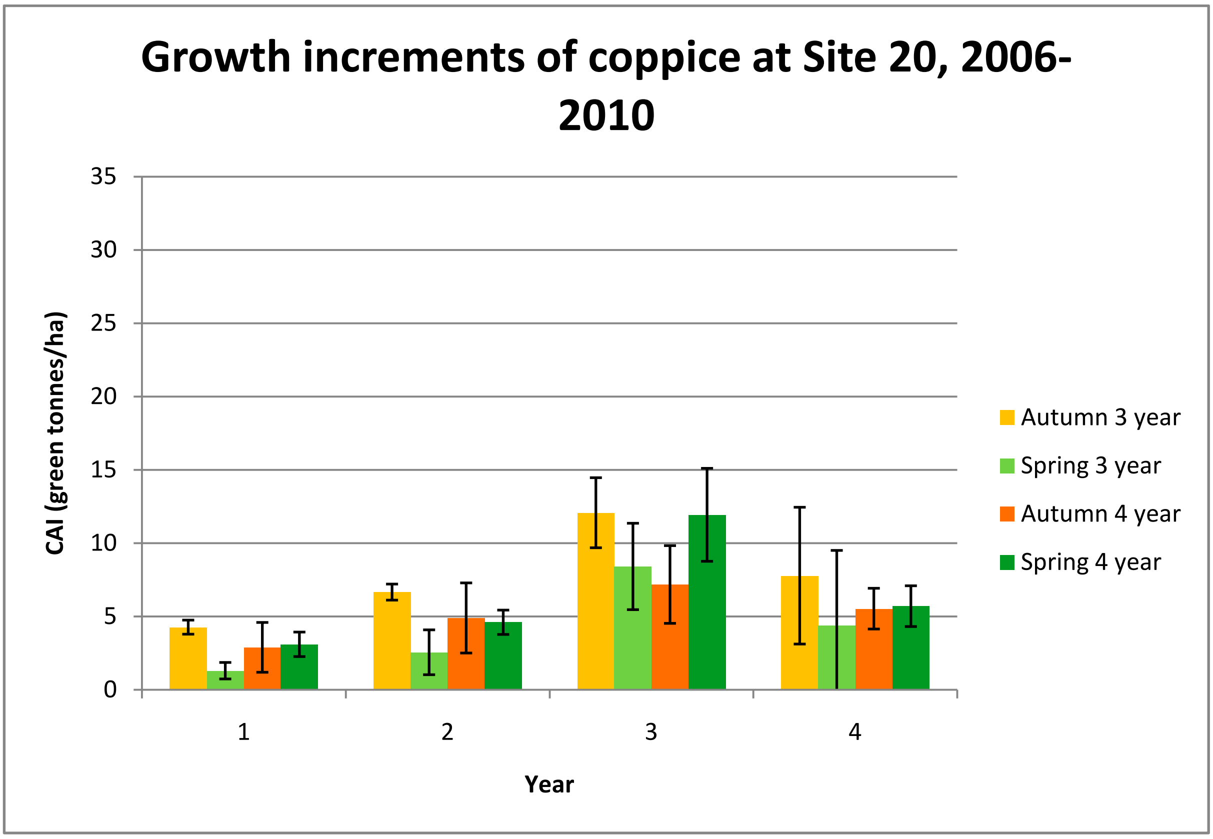

Growth increments of coppice at Site 20, 2006-2010
CAI (green tonnes/ha)
35
30
25
20
15
10
5
0
1
2
3
4
Year
Autumn 3 year
Spring 3 year
Autumn 4 year
Spring 4 year

Table A-2 Regression parameters for coppice (* denotes that the regression from site 16 was used, ** denotes that the universal species regression was used)

Species	Site	n	log transform	slope	intercept	r^2	min ln(CVI) (m^3)	max ln(CVI) (m^3)
E. polybractea	1	77	y	1.096533	0.120266	0.92	0.73	4.54
	8	90	y	1.070413	0.229971	0.87	0.88	3.85
	18	195	y	1.086421	0.183664	0.91	-0.38	4.59
	19							
E. kochii ssp *plenissima*	11*	84	y	1.000084	0.651208	0.91	0.38	4.00
	15*							
	16							
E. loxophleba ssp *lissophloia*	2**	454	y	1.085382	-0.09814	0.87	-0.67	4.11
	3	114	y	1.047679	-0.00071	0.86	0.32	3.76
	5	50	y	1.05317	0.045162	0.74	1.59	4.11
	6	61	y	1.206196	-0.58001	0.89	0.68	3.62
	7**	454	y	1.085382	-0.09814	0.87	-0.67	4.11
	9	93	y	1.118456	-0.21731	0.93	-0.67	3.75
	10**	454	y	1.085382	-0.09814	0.87	-0.67	4.11
	12**	454	y	1.085382	-0.09814	0.87	-0.67	4.11
	13	75	y	1.108365	0.012501	0.94	0.44	3.40
	14**	454	y	1.085382	-0.09814	0.87	-0.67	4.11
	17	97	y	1.115923	-0.26757	0.89	0.37	3.79
	20**	454	y	1.085382	-0.09814	0.87	-0.67	4.11

Table A-3 **Relative difference in standing biomass within treatment replicates at each site in autumn 2006 (prior to harvesting treatments being imposed)**

Site	Biomass of the least productive plot relative to the most productive plot for each treatment										
	C	**S3**	**S4**	**A3**	**A4**	**RP3**	**S5+(1)**	**S5+(2)**	**A5+(1)**	**A5+(2)**	**RP5+**
1	189.4	199.4	131.9	141.8	178.1	172.5					
1	77.0	143.0	120.3	121.5	121.2	115.9					
1	41%	72%	91%	86%	68%	67%					
2	58.1						73.0	82.1	56.8	61.7	68.6
2	57.2						67.0	55.6	49.2	56.1	57.8
2	98%						92%	68%	87%	91%	84%
3	45.3	52.9	55.2	54.3	49.4	47.3					
3	28.8	47.6	52.3	41.9	36.4	41.0					
3	64%	90%	95%	77%	74%	87%					
5	76.1		162.1		115.5	116.6	149.3		88.1		
5	49.8		11.4		53.8	58.7	92.9		67.4		
5	65%		7%		47%	50%	62%		76%		
6	60.0	74.1		63.2		76.0	55.4		68.8		
6	53.7	24.3		30.6		25.0	18.2		48.1		
6	90%	33%		48%		33%	33%		70%		
7	34.7						39.7	0.0	30.1	0.0	41.2
7	30.1						22.9	0.0	26.7	0.0	34.4
7	87%						58%		89%		84%
8	84.4	106.6	126.3	109.3	94.1	148.4					
8	65.9	68.9	90.5	69.0	70.8	96.0					
8	78%	65%	72%	63%	75%	65%					
9	66.9	75.2	85.1	67.3	66.9	73.8					
9	51.8	54.5	59.6	48.3	35.9	64.8					
9	77%	73%	70%	72%	54%	88%					
10	62.6						73.0	81.2	64.9	62.0	70.7
10	51.3						60.7	64.6	61.0	54.0	65.1
10	82%						83%	80%	94%	87%	92%
11	24.5						25.7	27.3	21.0	23.3	26.1
11	14.0						15.9	16.0	12.0	11.2	17.6
11	57%						62%	59%	57%	48%	67%

Site	Biomass of the least productive plot relative to the most productive plot for each treatment										
	C	S3	S4	A3	A4	RP3	S5+(1)	S5+(2)	A5+(1)	A5+(2)	RP5+
12	42.3						49.6	43.5	37.5	37.5	41.6
12	23.1						32.9	27.6	28.2	10.8	34.8
12	55%						66%	63%	75%	29%	84%
13	78.8	69.0	74.5	57.4	64.6	72.4					
13	47.3	51.3	63.3	48.0	54.3	46.4					
13	60%	74%	85%	84%	84%	64%					
14	27.9						30.0	26.4	28.8	16.3	32.4
14	22.9						13.4	20.4	16.3	5.8	7.7
14	82%						45%	77%	57%	36%	24%
15	64.1						75.8	69.9	88.0	85.9	81.9
15	41.0						65.3	54.1	44.2	51.7	69.1
15	64%						86%	77%	50%	60%	84%
16	101.4	125.3	121.8	147.4	153.3	128.7					
16	78.6	96.9	104.9	77.0	109.7	93.3					
16	78%	77%	86%	52%	72%	72%					
17	41.9	37.6	50.2	40.0	41.6	45.5					
17	19.0	29.8	48.2	34.9	24.2	28.1					
17	45%	79%	96%	87%	58%	62%					
18	36.3	65.7	74.3	41.4	40.8	67.4					
18	27.8	42.3	31.9	26.2	26.5	57.3					
18	76%	64%	43%	63%	65%	85%					
19	34.5	52.3	46.1	34.6	33.9	55.4					
19	32.9	36.3	42.0	22.7	21.7	33.4					
19	95%	70%	91%	65%	64%	60%					
20	22.1						26.9	26.3	20.3	23.0	22.9
20	20.6						18.5	21.8	13.2	13.9	18.9
20	93%						69%	83%	65%	60%	83%

🟥 less than 50%

🟦 50% to 75%

Table A-4 Tree establishment/survival post planting

Site	Establishment/planting survival* (%)
1	77
2	86
3	86
5	63
6	78
7	71
8	90
9	90
10	93
11	90
12	84
13	81
14	77
15	62
16	85
17	75
18	88
19	85
20	84
Mean	**81**
Min	**62**
Max	**93**
Overall survival*	**76**

*Tree survival calculated by summing dead trees and vacant tree positions in 2006, divided by total number of tree positions in the plot.

9.2 Appendix B Soil descriptions

Table B-1 Salinity intensity classifications. These limits are for surface soils and have been adopted by the National Coordination Committee for Salinity Information (John Simons pers com 2010).

Class	ECe dS/m	Effect on plants
Non-saline	<2	None
Slightly saline	2-4	Decreased growth in sensitive crops and deep rooted horticultural species
Moderately saline	4-8	Decreased growth in most crops and dieback in most trees
Highly saline	8-16	Too salty for most crops halophytes dominate, trees dead or dying
Severely saline	16-32	Halophytes dominate though growth decreased, only salt tolerant trees survive (e.g. Melaleuca)
Extremely saline	>32	Bares scalds, samphire

Table B-2 Soil pH classifications. Source: Peverill KI, Sparrow LA, Reuter DJ (1999).

Class	pH (water)	Comment
Very strongly acid	<4.5	Most nutrients and trace elements largely unavailable, possibility of Al toxicity
Strongly acid	4.5-5.3	Nutrient and trace elements are limited
Moderately acid	5.3-5.8	pH critical to plant growth acid-tolerant cultivars needed
Slightly acid	5.8-7.0	Soils likely to be most productive
Slightly alkaline	7.0-8.0	Micronutrient deficiencies may occur
Moderately-very strongly alkaline	>8.0	Only alkaline tolerant plants will thrive trace element deficiencies likely

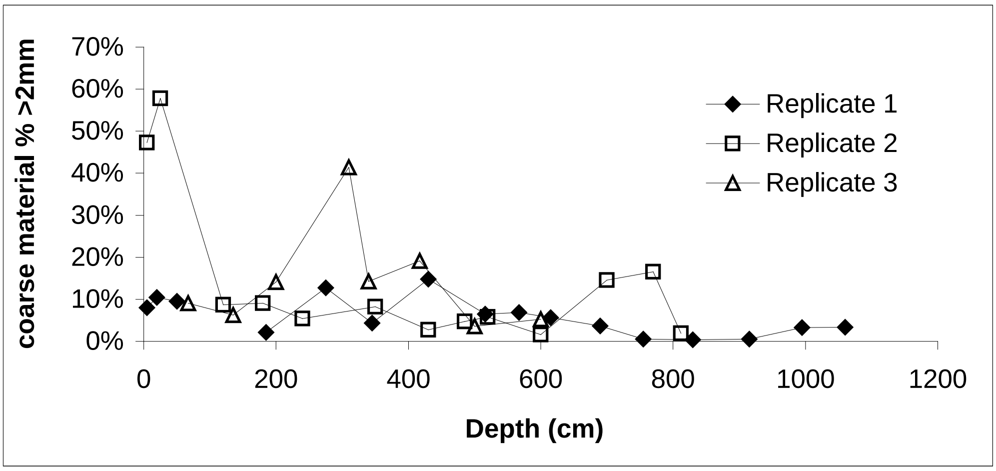
Table B-3 Soils identified at each site and named according to the Australian Soil Classification (Isbell 1996)

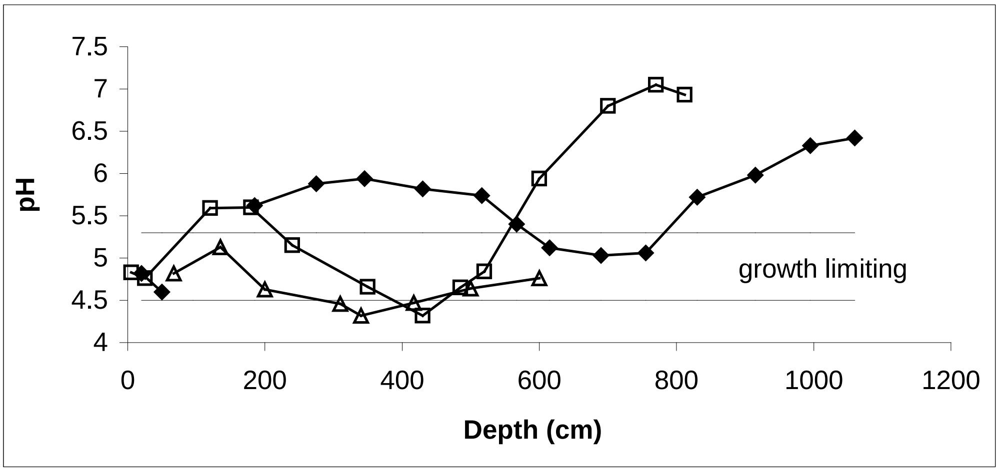
Site	**Australian Soil Classification**
1	brown Tenosol; brown Chromosol
2	yellow Chromosol
3	brown Kandosol
5	ferric subnatric yellow Sodosol; haplic mesotrophic yellow Kandosol; basic arenic yellow-orthic Tenosol
6	acidic-mottled mesotrophic red Kandosol; sodic hypercalcic red Kandosol; mesotrophic subnatric red Sodosol; supracalcic subnatric red Sodosol
7	mesotrophic mottled-subnatric red Sodosol; mesotrophic mottled-subnatric yellow Sodosol; bleached tenosolic salic Hydrosol
8	yellow Chromosol; grey Chromosol; brown Kandosol
9	yellow Chromosol, brown Chromosol
10	grey Chromosol; brown Chromosol
11	eutrophic, mottled-hypernatric brown Sodosol
12	red Chromosol
13	red Tenosol
14	mesotrophic petroferric grey Sodosol; ferric mottled-subnatric yellow Sodosol
15	hypercalcic subnatric red Sodosol; sodic Supracalcic red Kandosol
16	acidic regolithic brown-orthic Tenosol; acidic-mottled mesotrophic brown Kandosol
17	mottled-sodic eutrophic brown Dermosol
18	ferric-sodic mesotrophic brown Sodosol; ferric mottled-mesonatric brown Sodosol; bleached-ferric mesotrophic brown Sodosol; ferric mottled-subnatric brown Sodosol
19	ferric-sodic mesotrophic brown Chromosol
20	Mesotrophic petrocalcic brown Sodosol; vertic pedal hypercalcic Calcarosol; supracalcic petrocalcic brown Sodosol; ferric, sesquic aeric Podosol

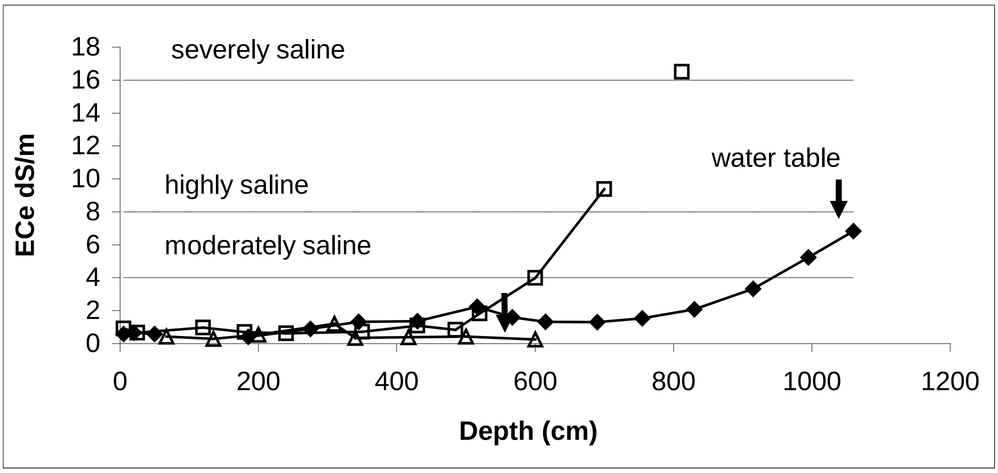
9.2.1 B-1 Drilling results listed by site

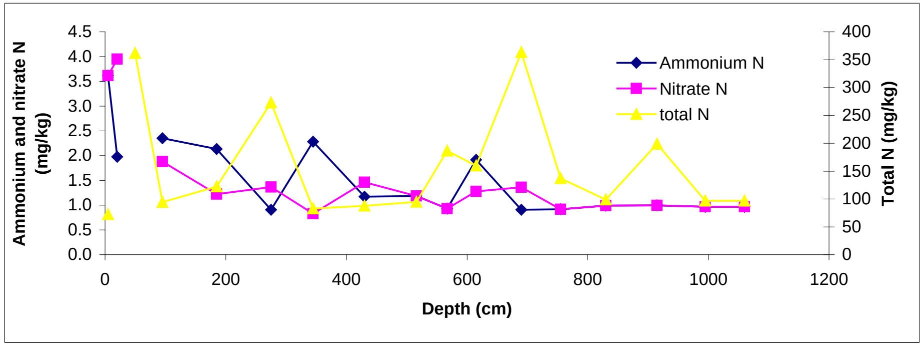
Site 1 Drill log

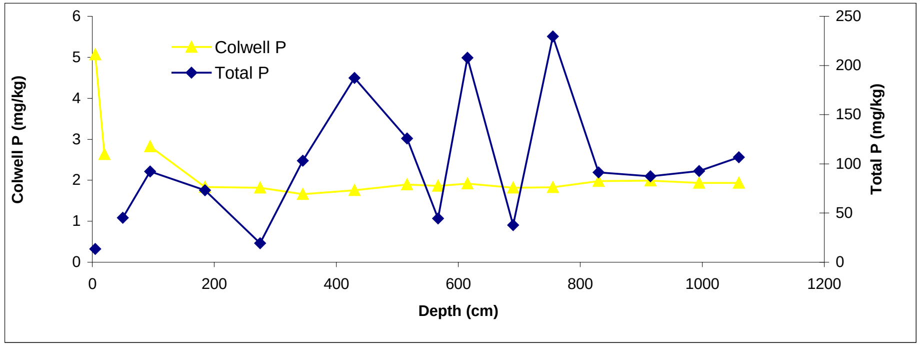
Rep	Depth (cm)	Description
1	0-10	sandy loam topsoil
	10-30	sand
	30-60	sandyclay
	60-150	orange clay
	150-225	orange mottled clay
	2250-450	pink clay silcrete at 300
	450-1040	pale yellow/white clay irregular quartz bands
	1040-1080	very sandy and saturated
		free water at 1040
2	0-10	gravelly sand topsoil
	10-40	gravelly sand
	40-100	orange clay
	100-300	orange clay & red mottles
	300-500	paler yellow mottled clay
	500-800	pale yellow/white clay irregular quartz bands relic roots at 700
	800-825	brown mica clay
		free water at 500
3	0-60	gravelly sand
	60-320	orange mottled clay
	320-375	paler yellow mottled clay much coarse quartz
	375-450	320-400 sandy clay & soft segregation- red
	450-620	pale yellow/white clay irregular quartz bands
		free water at 700

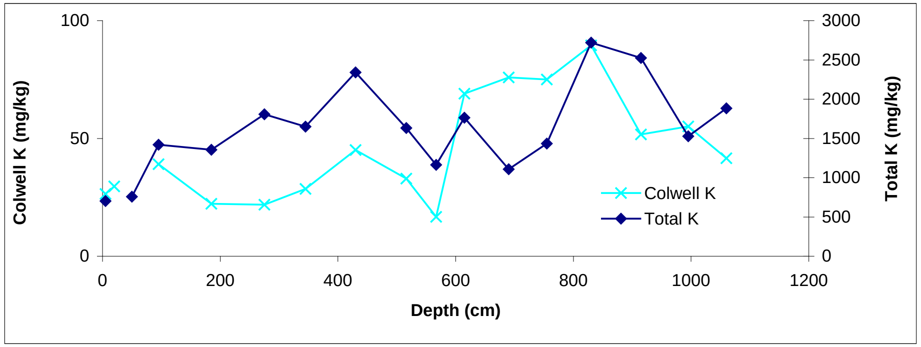

coarse material % >2mm
70%
60%
50%
40%
30%
20%
10%
0%
0
200
400
600
800
1000
1200
Depth (cm)
Replicate 1
Replicate 2
Replicate 3

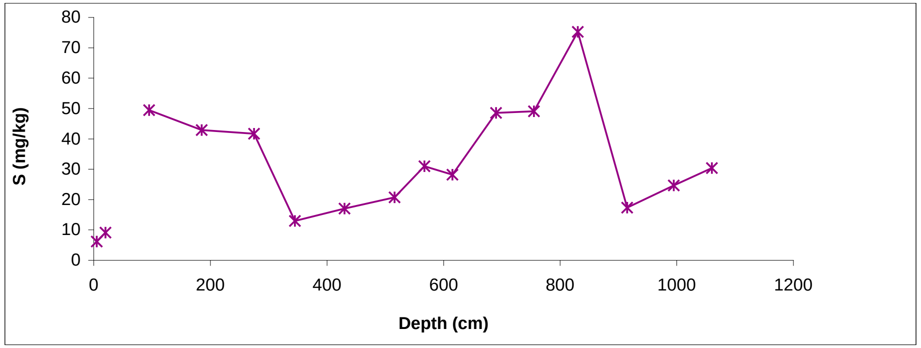

pH
7.5
7
6.5
6
5.5
5
4.5
4
0
200
400
600
800
1000
1200
Depth (cm)
growth limiting

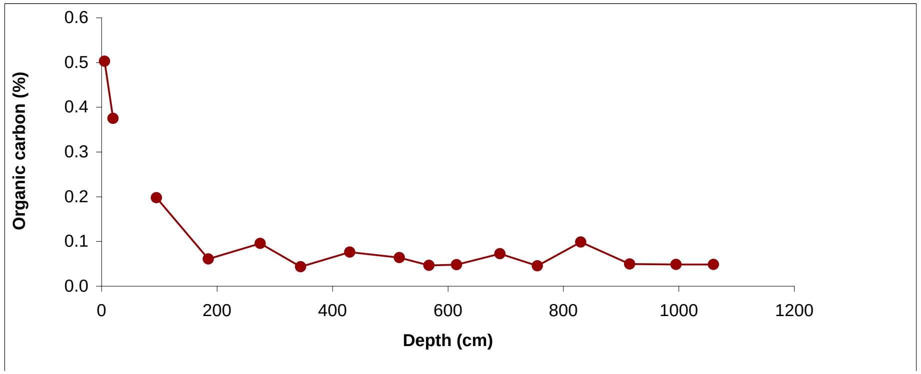

ECe dS/m
18
16
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
Depth (cm)
severely saline
highly saline
moderately saline
water table


Ammonium and nitrate N (mg/kg)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Total N (mg/kg)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
Depth (cm)
Ammonium N
Nitrate N
total N


Colwell P (mg/kg)
6
5
4
3
2
1
0
Total P (mg/kg)
250
200
150
100
50
0
0
200
400
600
800
1000
1200
Depth (cm)
Colwell P
Total P

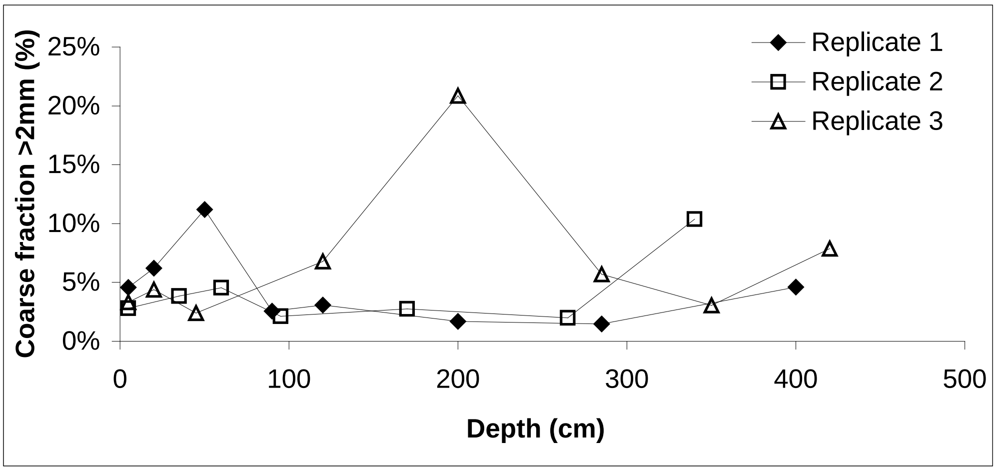

Colwell K (mg/kg)
100
50
0
Total K (mg/kg)
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Depth (cm)
Colwell K
Total K

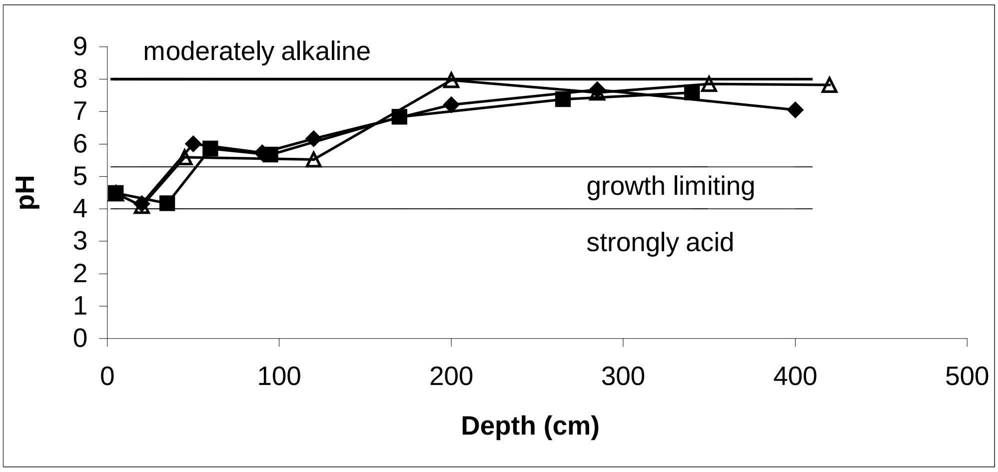

S (mg/kg)
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
Depth (cm)

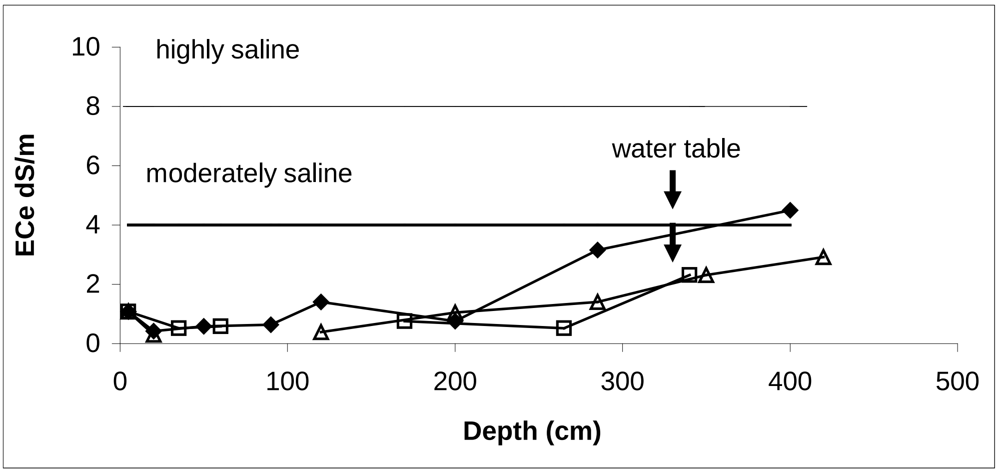

Organic carbon (%)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
200
400
600
800
1000
1200
Depth (cm)

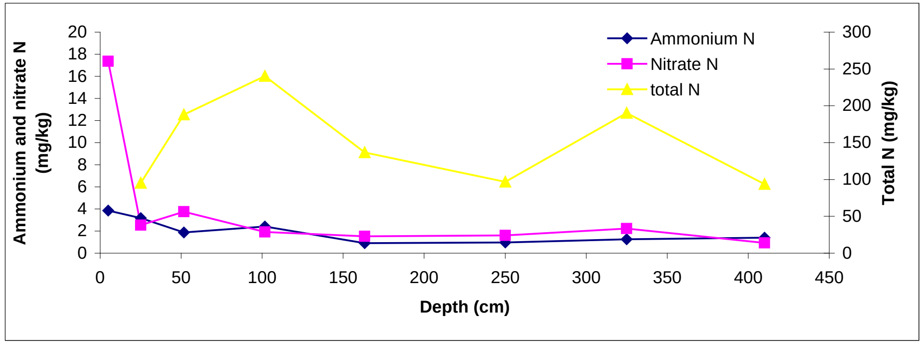
Site 2 Drill log

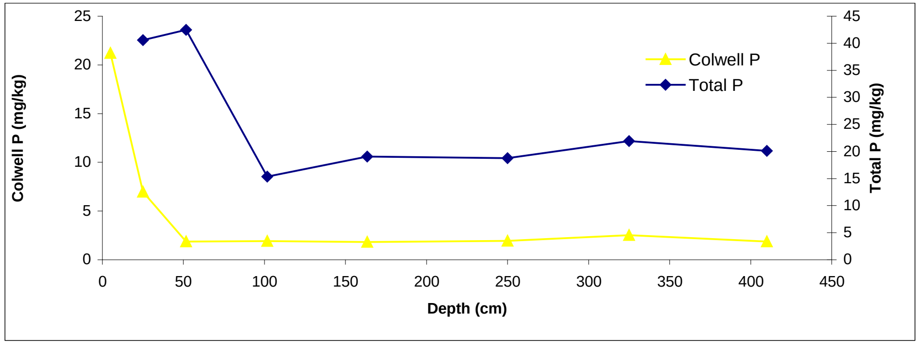
Rep	Depth (cm)	Description
1	0-10	topsoil
	10-30	sand
	30-380	orange mottled clay
	380-420	orange clay grey mottles
		saturated at 400
2	0-10	topsoil
	10-40	sand
	40-330	orange mottled clay
	330-350	orange clay grey mottles
		saturated at 360
3	0-10	topsoil
	10-35	sand
	40-320	orange mottled clay
	320-440	sandy clay & soft segregations- red

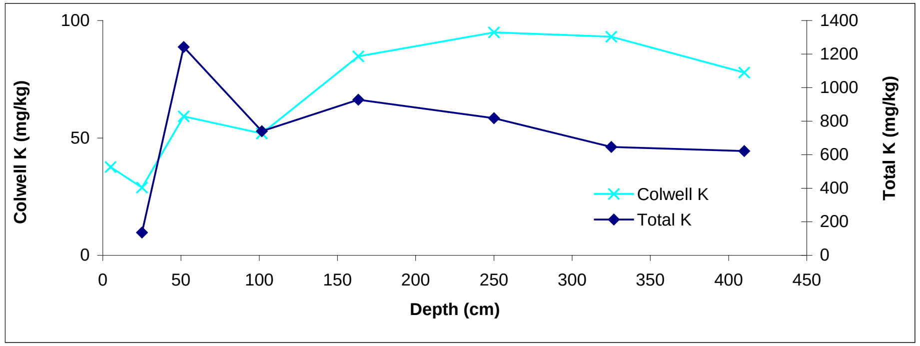

Coarse fraction >2mm (%)
25%
20%
15%
10%
5%
0%
0
100
200
300
400
500
Depth (cm)
Replicate 1
Replicate 2
Replicate 3

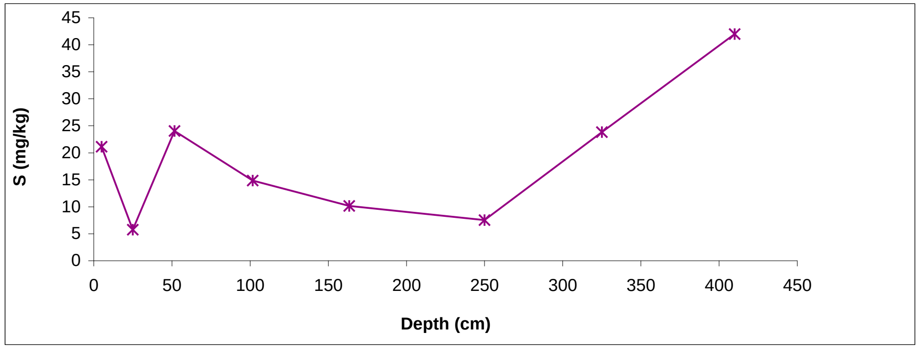

pH
9
8
7
6
5
4
3
2
1
0
moderately alkaline
growth limiting
strongly acid
0
100
200
300
400
500
Depth (cm)

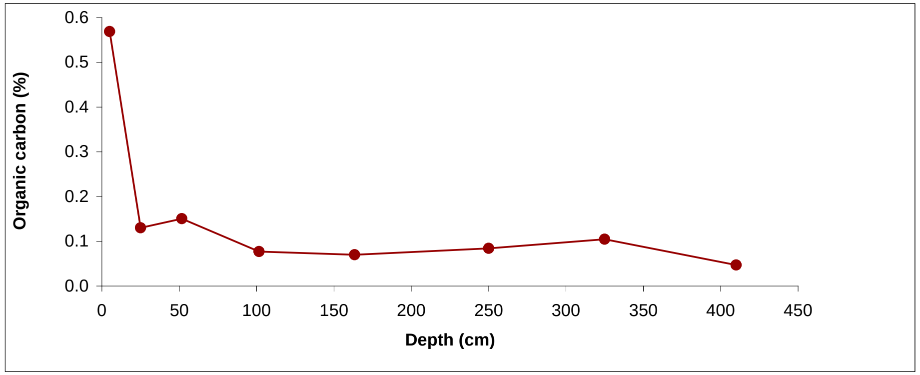

ECe dS/m
10
8
6
4
2
0
highly saline
moderately saline
water table
0
100
200
300
400
500
Depth (cm)


Ammonium and nitrate N (mg/kg)
Total N (mg/kg)
Depth (cm)
Ammonium N
Nitrate N
total N
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300
0
50
100
150
200
250
300
350
400
450


Colwell P (mg/kg)
Total P (mg/kg)
Depth (cm)
Colwell P
Total P
0
5
10
15
20
25
0
5
10
15
20
25
30
35
40
45
0
50
100
150
200
250
300
350
400
450

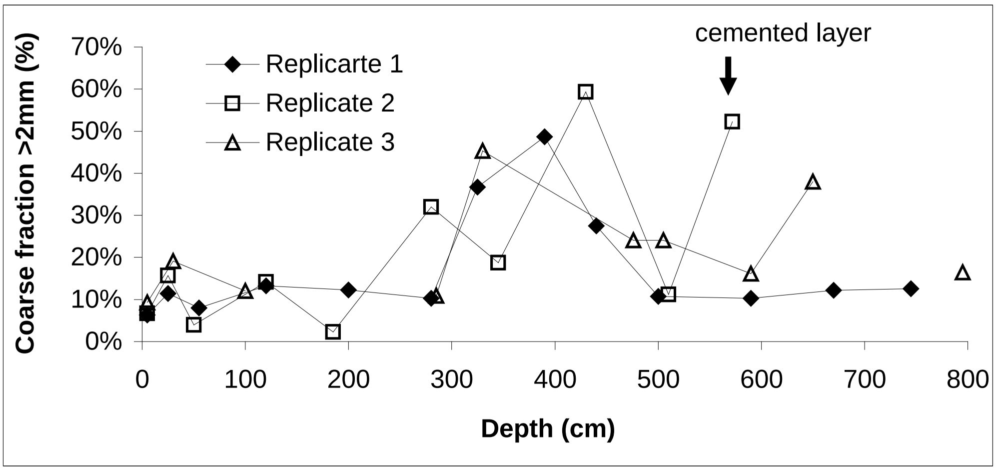

Colwell K (mg/kg)
Total K (mg/kg)
Depth (cm)
Colwell K
Total K
0
50
100
0
200
400
600
800
1000
1200
1400
0
50
100
150
200
250
300
350
400
450

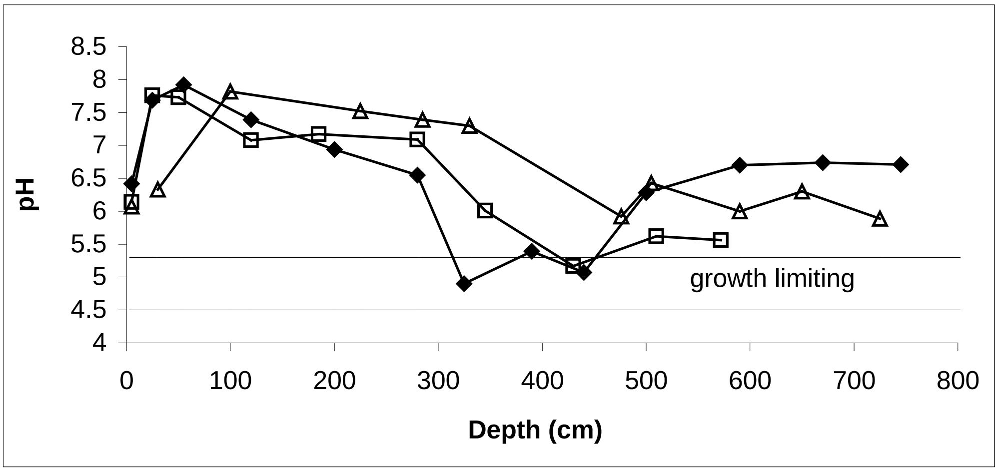

S (mg/kg)
Depth (cm)
0
5
10
15
20
25
30
35
40
45
0
50
100
150
200
250
300
350
400
450

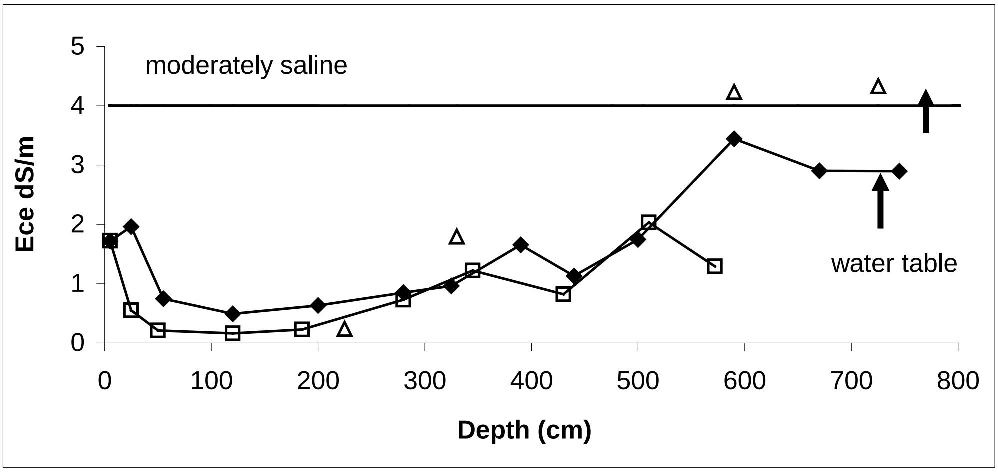

Organic carbon (%)
Depth (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200
250
300
350
400
450

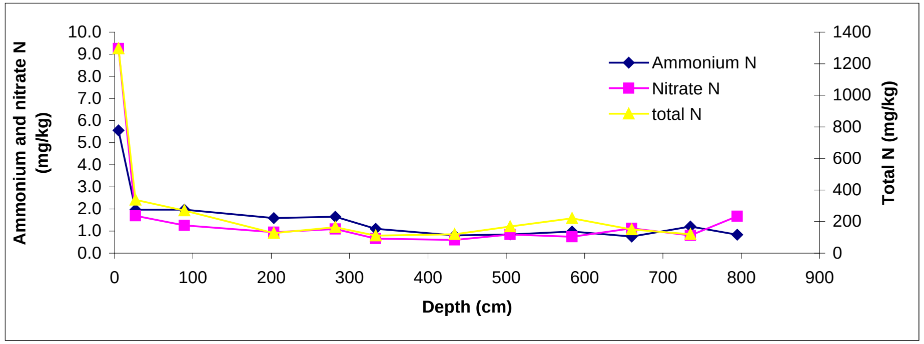
Site 3 Drill log

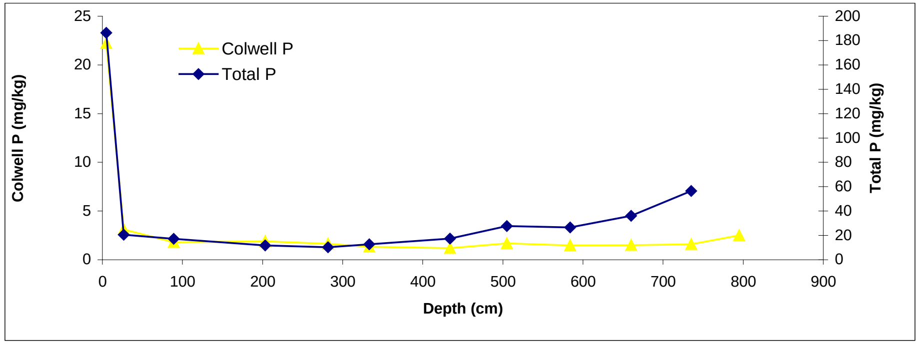
Rep	Depth (cm)	Description
1	0-10	sandy loam topsoil
	10-300	orange mottled clay relic roots at 340
	300-340	transition to white clay @ 340 old roots
	420-460	crumbly white clay occ. Red mottles
	480-760	pallid zone clay occasional red band and coarse quartz
		saturated at 760
2	0-6	sandy loam topsoil
	10-300	orange mottled clay
	300-340	transition to white clay @ 340 old roots
	420-460	crumbly white clay occ. Red mottles
	490-530	old root material
	560-585	large chunks of calcrete
3	0-10	sandy loam topsoil
	15-120	orange mottled clay
	210-300	grey/orange clay. Some soft red segregation
	300-815	pallid zone clay occasional red band and coarse quartz
		saturated at 800

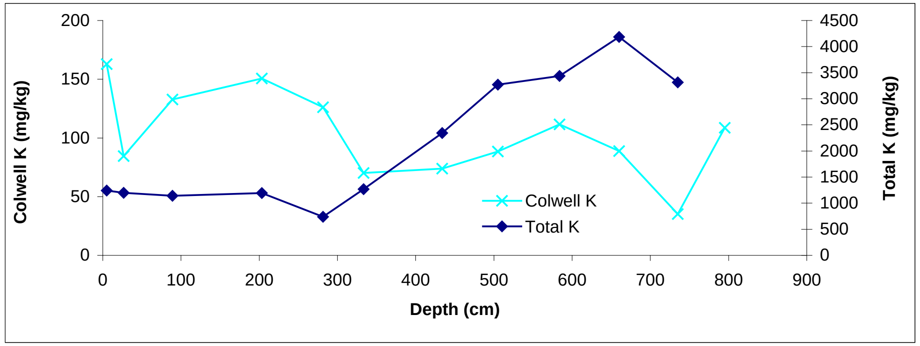

Coarse fraction >2mm (%)
70%
60%
50%
40%
30%
20%
10%
0%
Replicarte 1
Replicate 2
Replicate 3
cemented layer
0
100
200
300
400
500
600
700
800
Depth (cm)

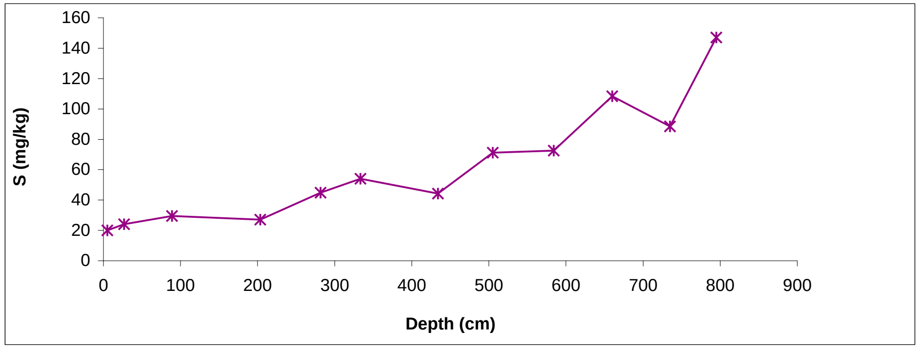

pH
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
growth limiting
0
100
200
300
400
500
600
700
800
Depth (cm)

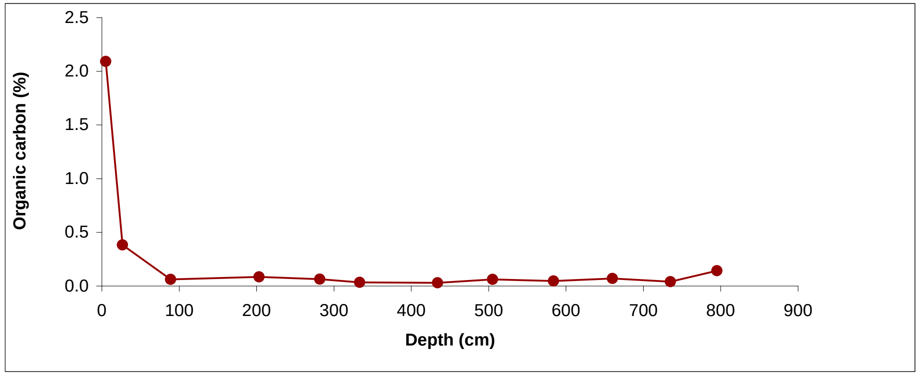

Ece dS/m
5
4
3
2
1
0
moderately saline
water table
0
100
200
300
400
500
600
700
800
Depth (cm)


Ammonium and nitrate N (mg/kg)
Total N (mg/kg)
Depth (cm)
Ammonium N
Nitrate N
total N
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900


Colwell P (mg/kg)
Total P (mg/kg)
Depth (cm)
Colwell P
Total P
25
20
15
10
5
0
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900

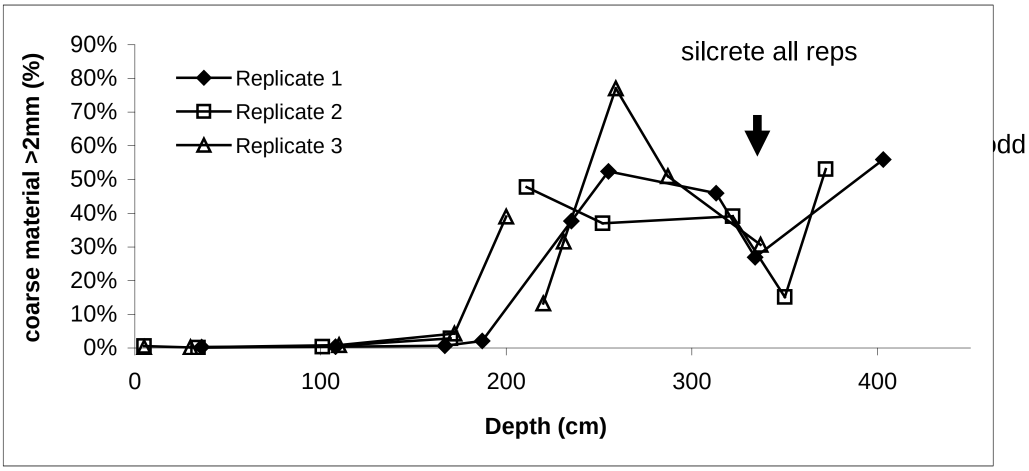

Colwell K (mg/kg)
Total K (mg/kg)
Depth (cm)
Colwell K
Total K
200
150
100
50
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
900

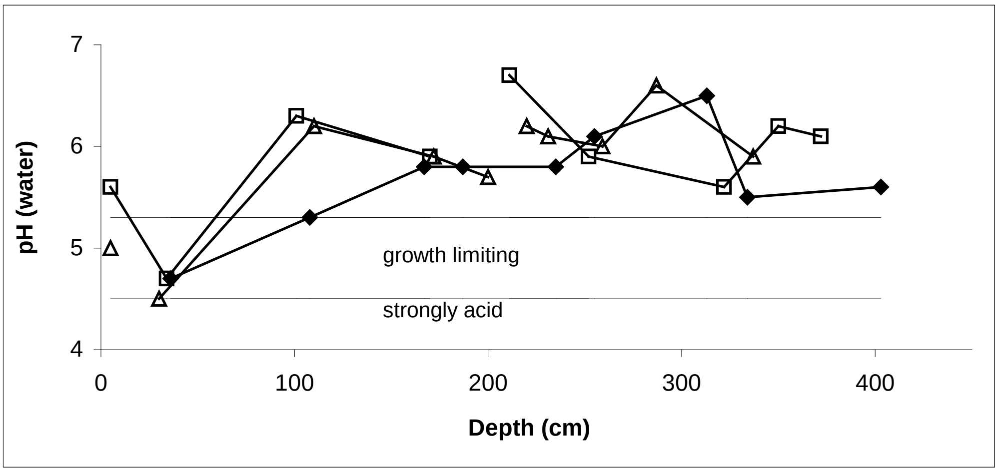

S (mg/kg)
Depth (cm)
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900

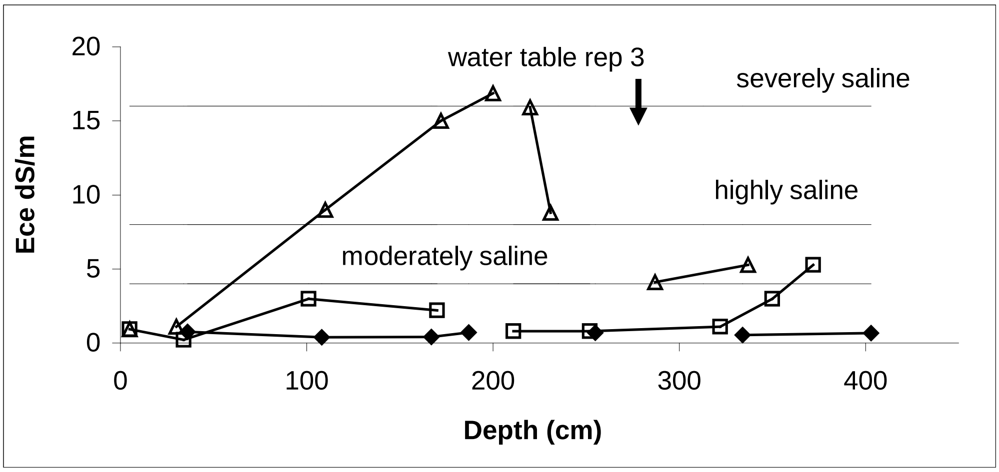

Organic carbon (%)
Depth (cm)
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
900

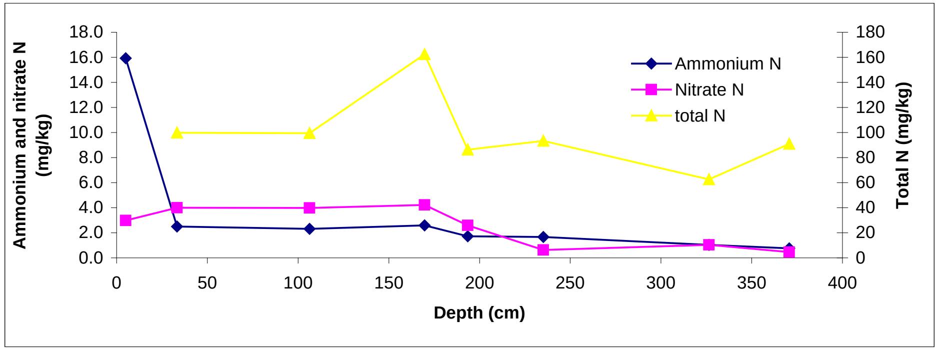
Site 5 Drill log

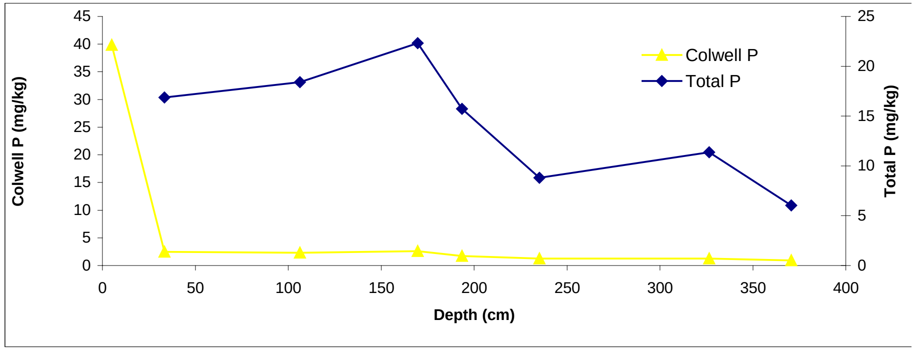
Rep	Depth (cm)	Description
1	0-10	sandy top soil
	10-225	yellow loamy coarse sand.
	225-326	red/orange sandy clay with numerous silcrete bands
	326-342	white clay with red and orange mottles. Small amount silcrete
	375-440	white clay numerous thick bands of silcrete
		450 too hard to drill further
2	0-10	sandy top soil
	10-200	yellow loamy coarse sand.
	200-300	Red/orange sandy loam with pea to marble size red gravel
	300-345	thick bands of very hard silcrete Red loamy clay with white and orange mottles.
	345-389	red clay numerous bands of silcrete
		400 Too hard to drill further
3	0-10	sandy top soil
	10-145	yellow loamy coarse sand.
	150-194	coarse sandy clay - yellow with small red mottles throughout and a few white mottles
	195-215	white clay with orange/redmottles. Small granules of dark red clay.
	215-375	white clay with increasingly thick bands of silcrete
		saturated at 300cm

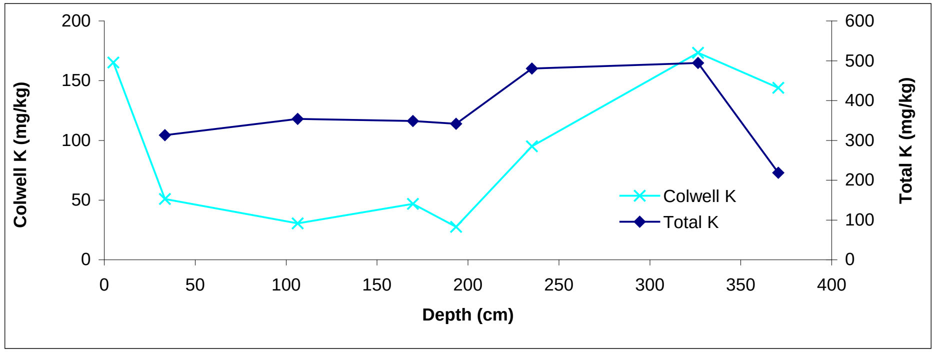

coarse material >2mm (%)
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Replicate 1
Replicate 2
Replicate 3
silcrete all reps
dd
0
100
200
300
400
Depth (cm)

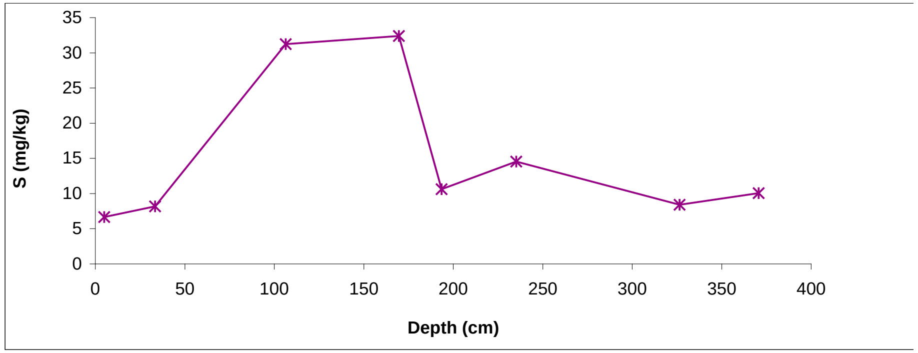

pH (water)
7
6
5
4
growth limiting
strongly acid
0
100
200
300
400
Depth (cm)

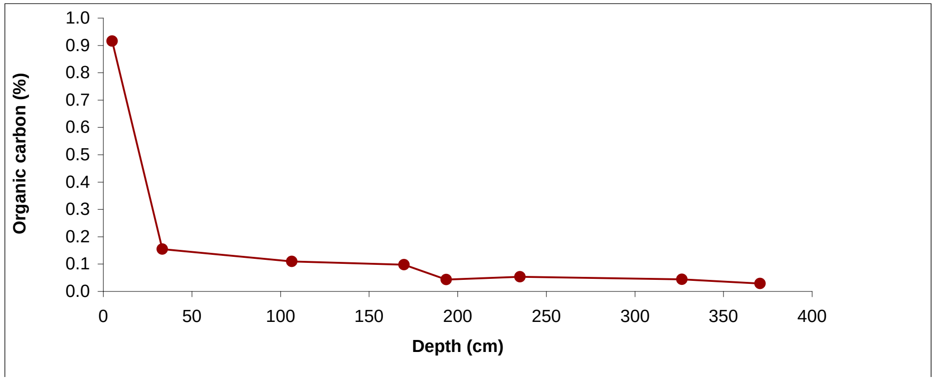

Ece dS/m
20
15
10
5
0
water table rep 3
severely saline
highly saline
moderately saline
0
100
200
300
400
Depth (cm)


Ammonium and nitrate N (mg/kg)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total N (mg/kg)
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
Depth (cm)
Ammonium N
Nitrate N
total N


Colwell P (mg/kg)
45
40
35
30
25
20
15
10
5
0
Total P (mg/kg)
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
Depth (cm)
Colwell P
Total P

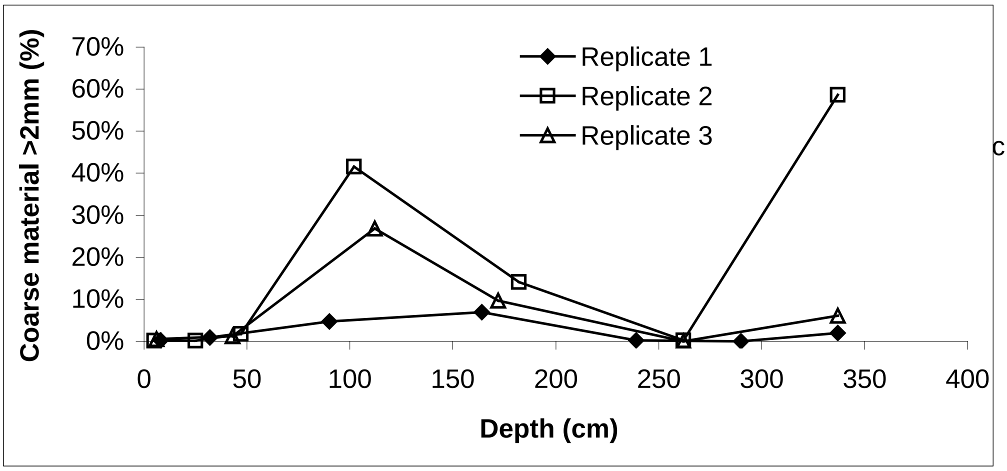

Colwell K (mg/kg)
200
150
100
50
0
Total K (mg/kg)
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
Depth (cm)
Colwell K
Total K


S (mg/kg)
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
Depth (cm)

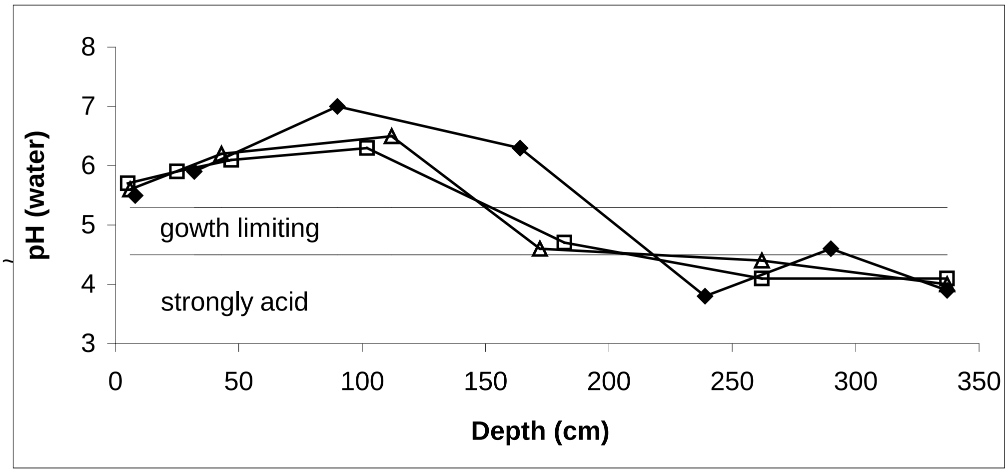

Organic carbon (%)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Depth (cm)

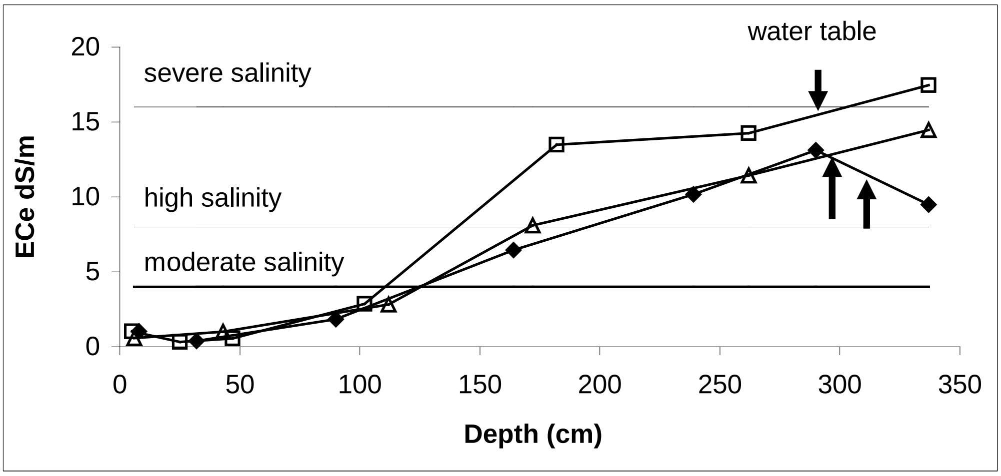
Site 6 Drill log

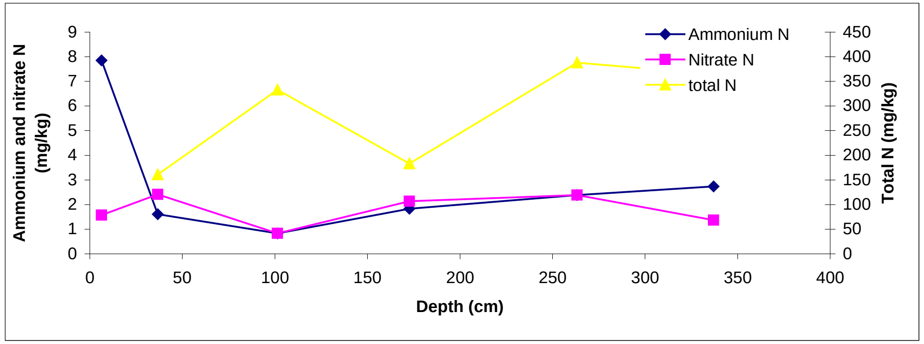
Rep	Depth (cm)	Description
1	0-16	brown sandy loam
	16-23	red sandy loam
	23-225	red loamy clay
	225-375	grey/brown claywith red mottles
		water table 320
2	0-11	red/brown sandy loam
	11-1500	red loamy clay few cemented nodules
	150-375	red clayfew white mottles
	225-300	red and white clay
		water table 290
3	0-10	brown/red sandy loam
	10-40	red sandy loam
	40-150	red clay few cemented nodules
	150-214	red clay
	225-375	red and white clay silcrete bands at 320+
		water table 300

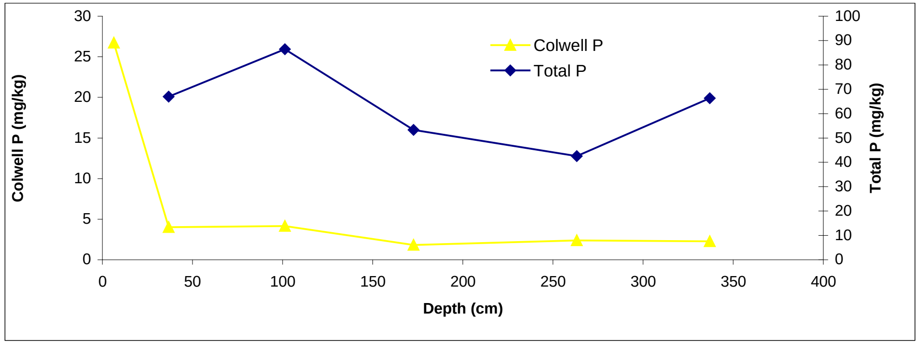

Coarse material >2mm (%)
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350
400
Depth (cm)
Replicate 1
Replicate 2
Replicate 3

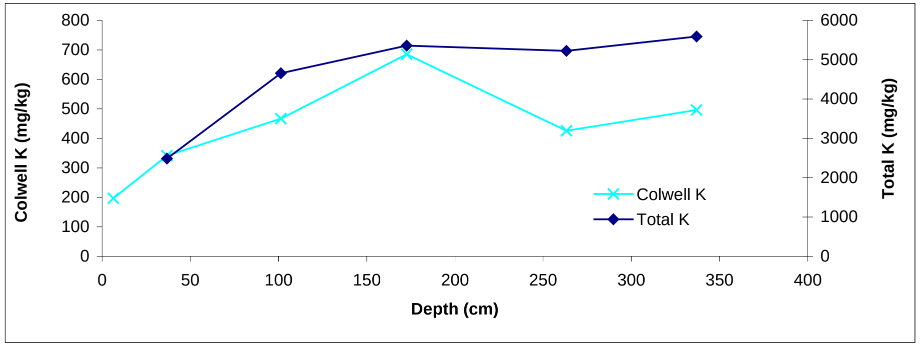
chbich

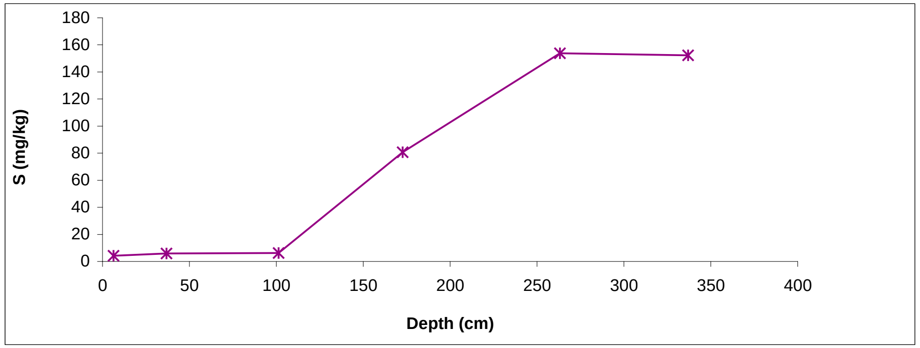

pH (water)
8
7
6
5
4
3
gowth limiting
strongly acid
0
50
100
150
200
250
300
350
Depth (cm)

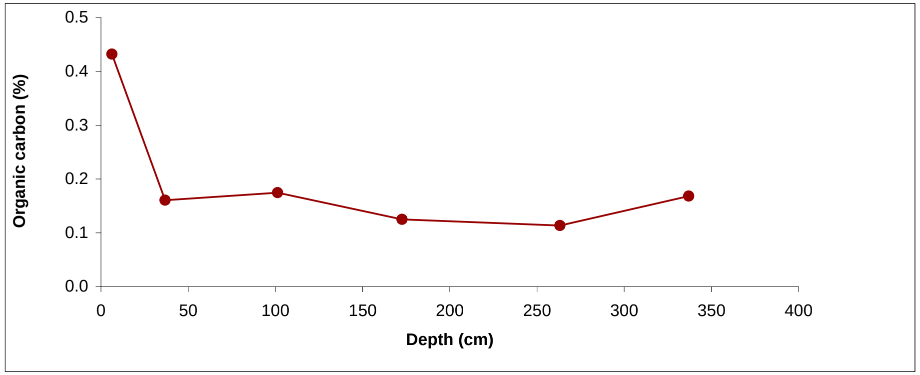

ECe dS/m
20
15
10
5
0
water table
severe salinity
high salinity
moderate salinity
0
50
100
150
200
250
300
350
Depth (cm)


Ammonium and nitrate N (mg/kg)
0
1
2
3
4
5
6
7
8
9
Total N (mg/kg)
0
50
100
150
200
250
300
350
400
450
Ammonium N
Nitrate N
total N
0
50
100
150
200
250
300
350
400
Depth (cm)


Colwell P (mg/kg)
0
5
10
15
20
25
30
Total P (mg/kg)
0
10
20
30
40
50
60
70
80
90
100
Colwell P
Total P
0
50
100
150
200
250
300
350
400
Depth (cm)

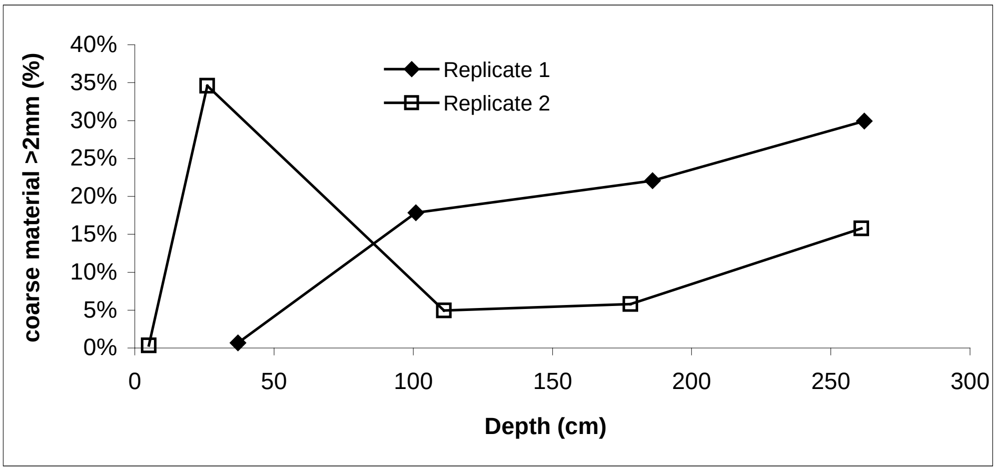

Colwell K (mg/kg)
0
100
200
300
400
500
600
700
800
Total K (mg/kg)
0
1000
2000
3000
4000
5000
6000
Colwell K
Total K
0
50
100
150
200
250
300
350
400
Depth (cm)

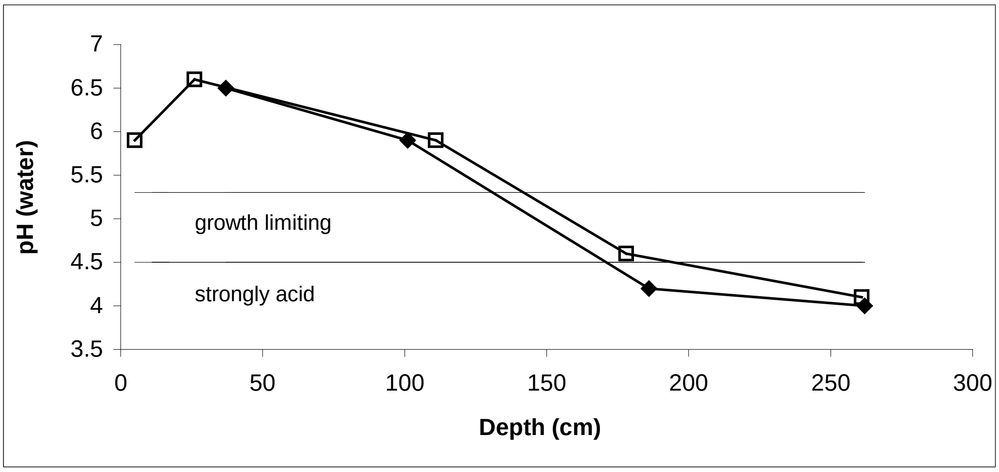

S (mg/kg)
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200
250
300
350
400
Depth (cm)

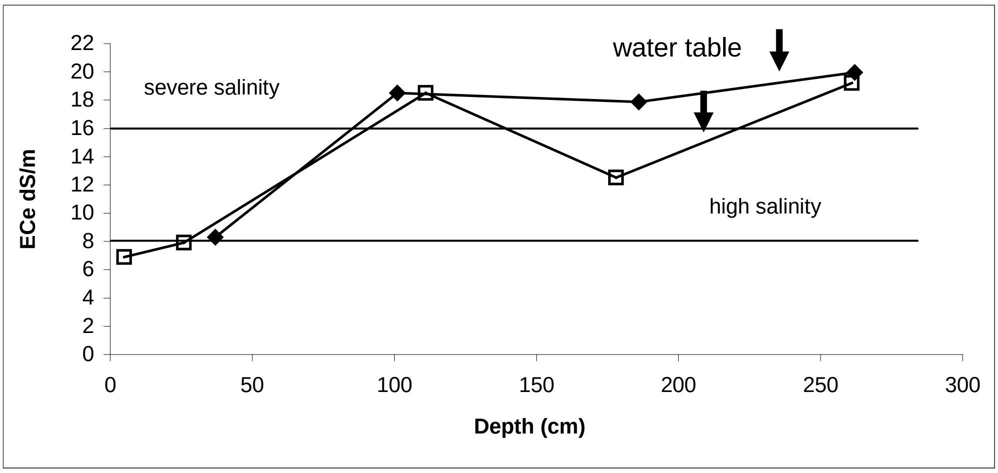

Organic carbon (%)
0.0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
250
300
350
400
Depth (cm)

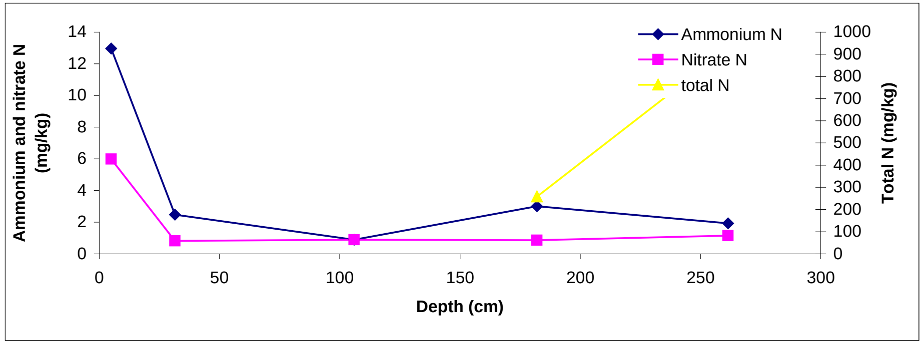
Site 7 Drill log

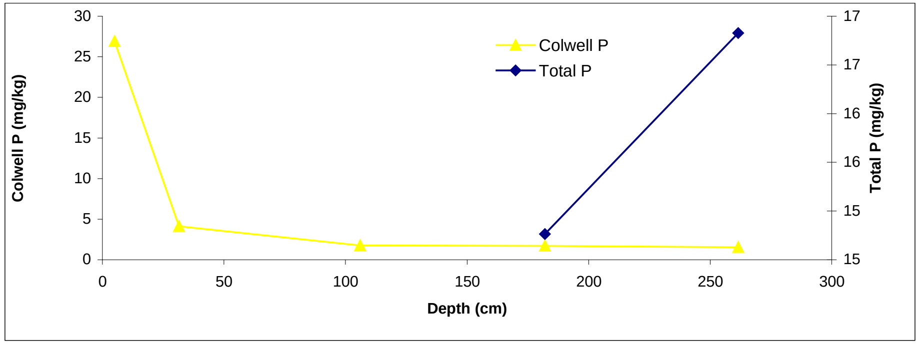
Rep	Depth (cm)	Description
1	0-9	Brown sandy loam
	9-43	brown clay with a few white mottles
	75-148	grey clay with red mottles
	150-296	grey clay with red mottles. >197 red nodules cemented@ 280 thick heavy white clay (moist)
		water table 2.1m. Hard layer at 2.8m (grits)
2	0-25	Brown clay/loam
	0-75	brown clay
	75-298	gritty grey clay with red mottles cemented nodules > 225
		water table 2.35m

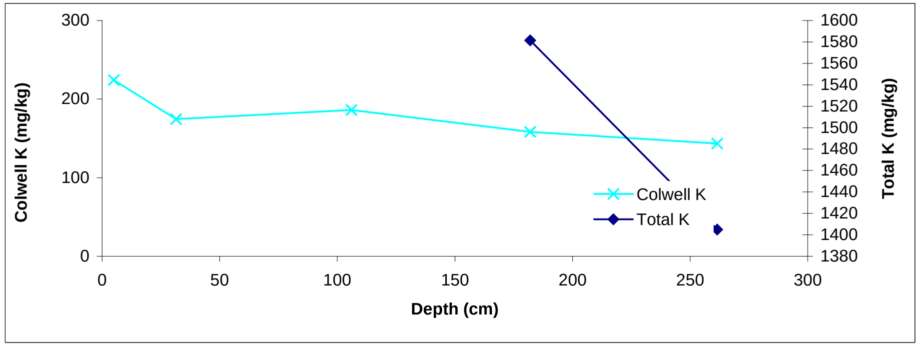

coarse material >2mm (%)
40%
35%
30%
25%
20%
15%
10%
5%
0%
Replicate 1
Replicate 2
0
50
100
150
200
250
300
Depth (cm)

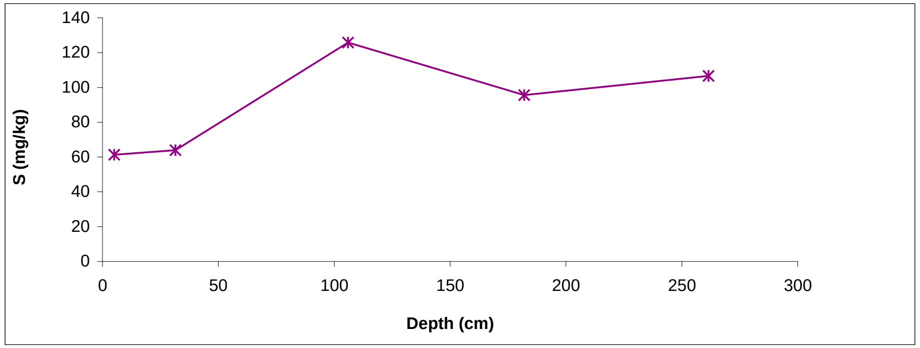

pH (water)
7
6.5
6
5.5
5
4.5
4
3.5
growth limiting
strongly acid
0
50
100
150
200
250
300
Depth (cm)

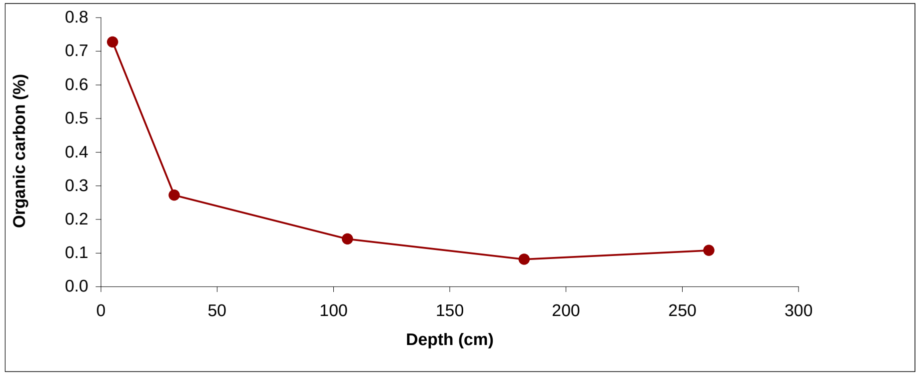

ECe dS/m
22
20
18
16
14
12
10
8
6
4
2
0
water table
severe salinity
high salinity
0
50
100
150
200
250
300
Depth (cm)


Ammonium and nitrate N (mg/kg)
0
2
4
6
8
10
12
14
Total N (mg/kg)
0
100
200
300
400
500
600
700
800
900
1000
Ammonium N
Nitrate N
total N
0
50
100
150
200
250
300
Depth (cm)


Colwell P (mg/kg)
0
5
10
15
20
25
30
Total P (mg/kg)
15
15
16
16
17
17
Colwell P
Total P
0
50
100
150
200
250
300
Depth (cm)

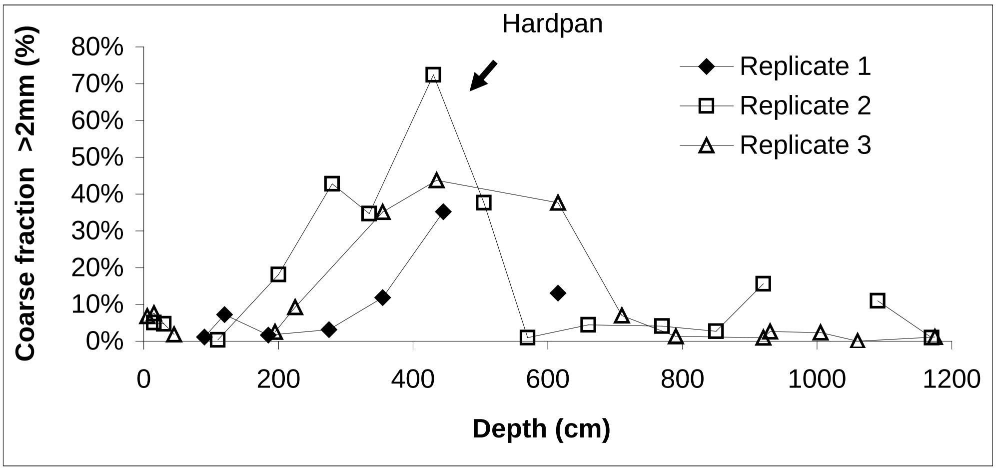

Colwell K (mg/kg)
0
100
200
300
Total K (mg/kg)
1380
1400
1420
1440
1460
1480
1500
1520
1540
1560
1580
1600
Colwell K
Total K
0
50
100
150
200
250
300
Depth (cm)

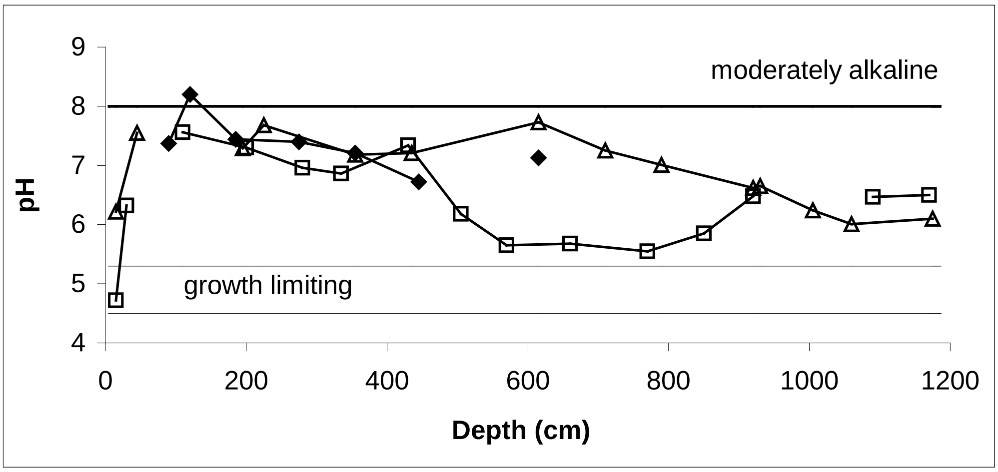

S (mg/kg)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
Depth (cm)

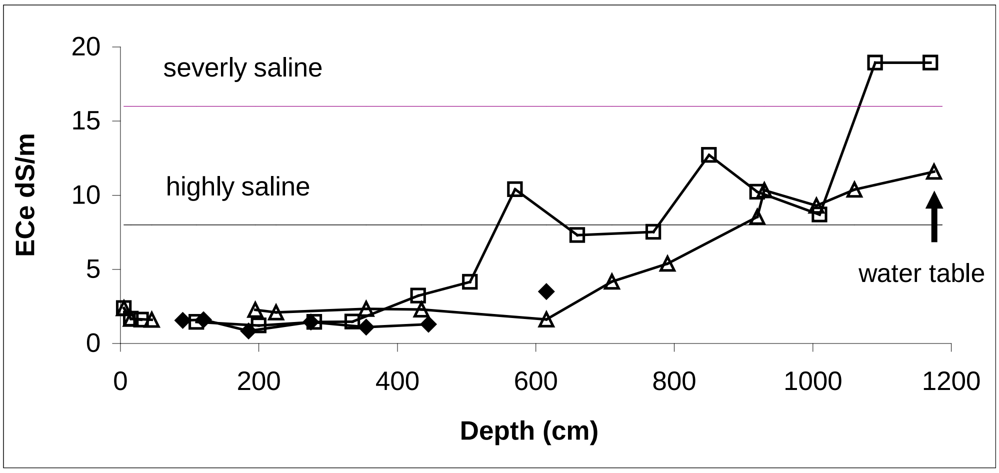

Organic carbon (%)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
50
100
150
200
250
300
Depth (cm)

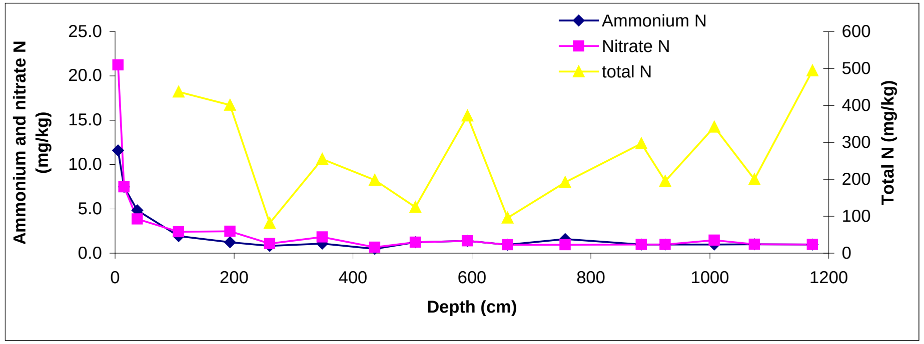
Site 8 Drill log

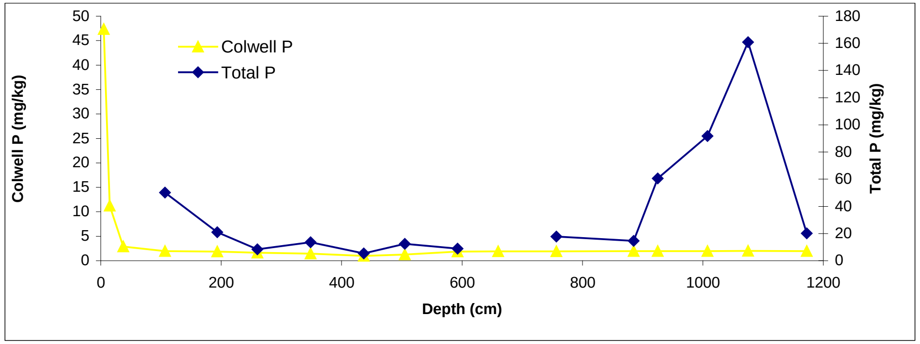
Rep	Depth (cm)	Description
1	40-95	reddish/yellow clay
	95-145	orange clay with weak silcrete layers
	145-380	orange clay/ grey mottles
	250-415	orange clay/ grey mottles
	330-380	grey orange mottles
	415-470	orange/white bands of clay
	480-500	orange/white dry clay
		too hard to drill at 500
2	0-10	sand topsoil
	10-40	sand
	40-520	orange/yellow mottled clay
	530-1190	whiteclays some mottles relic roots at 1000
3	0-10	sand topsoil
	10-20	sand
	40-580	orange/yellow mottled clay
	580-900	whiteclays some mottles
	910-1200	white clay bands coarse quartz
		saturated at 1150

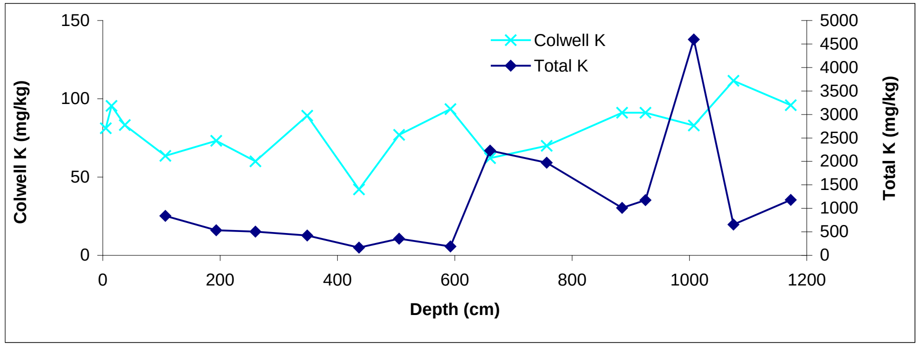

Hardpan
Replicate 1
Replicate 2
Replicate 3
Coarse fraction >2mm (%)
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
200
400
600
800
1000
1200
Depth (cm)

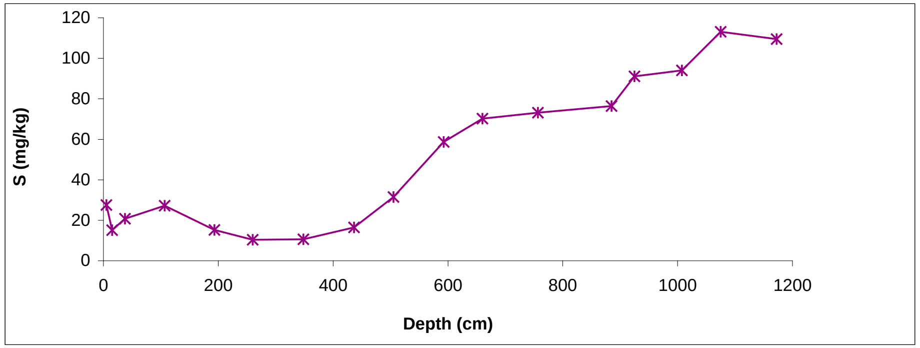

pH
9
8
7
6
5
4
moderately alkaline
growth limiting
0
200
400
600
800
1000
1200
Depth (cm)

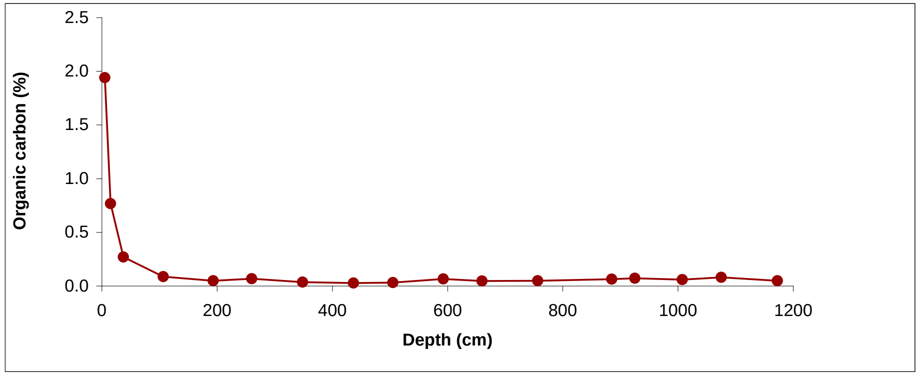

ECe dS/m
20
15
10
5
0
severly saline
highly saline
water table
0
200
400
600
800
1000
1200
Depth (cm)


Ammonium N
Nitrate N
total N
Ammonium and nitrate N (mg/kg)
Total N (mg/kg)
25.0
20.0
15.0
10.0
5.0
0.0
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Depth (cm)


Colwell P
Total P
Colwell P (mg/kg)
Total P (mg/kg)
50
45
40
35
30
25
20
15
10
5
0
180
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Depth (cm)

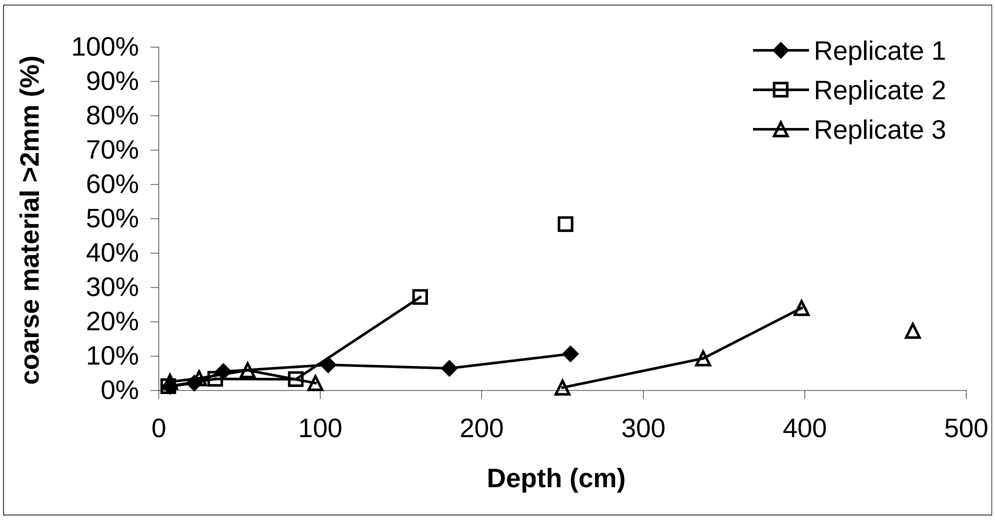

Colwell K
Total K
Colwell K (mg/kg)
Total K (mg/kg)
150
100
50
0
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Depth (cm)

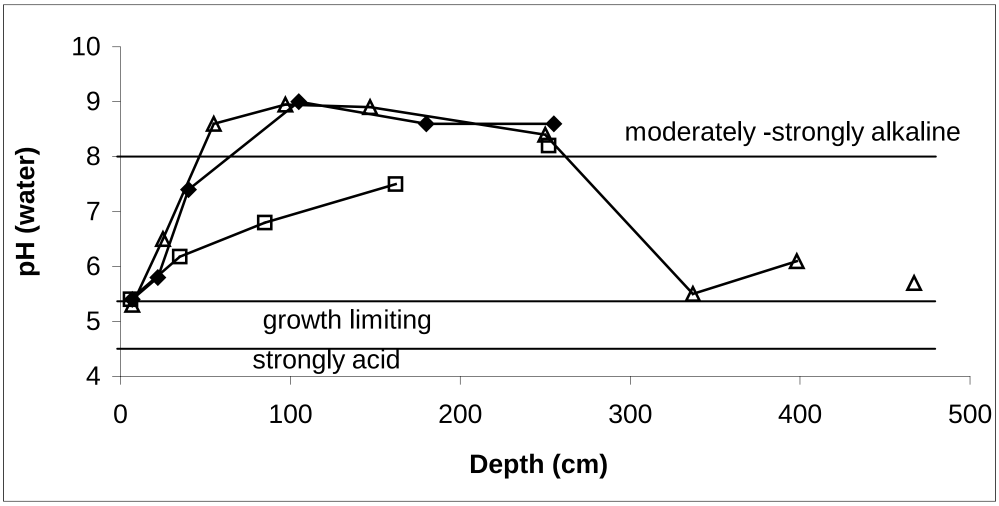

S (mg/kg)
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Depth (cm)

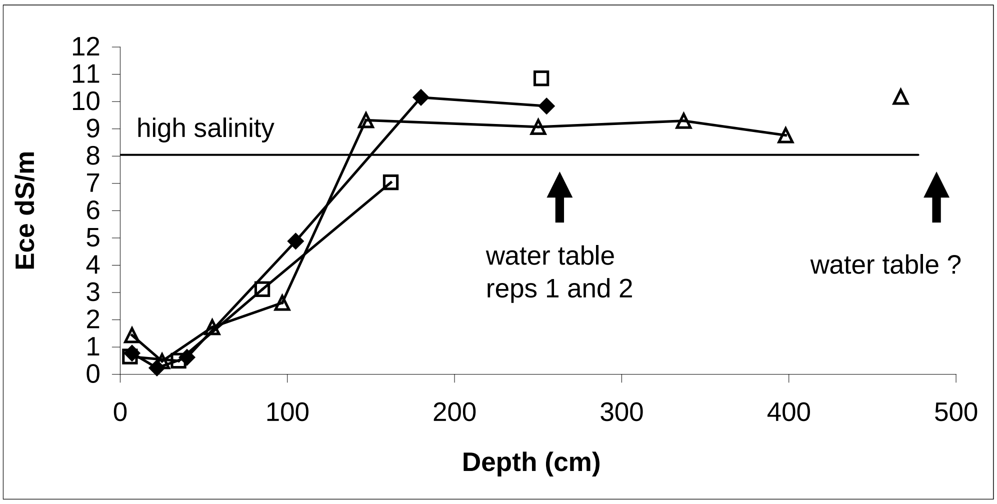

Organic carbon (%)
2.5
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
1000
1200
Depth (cm)

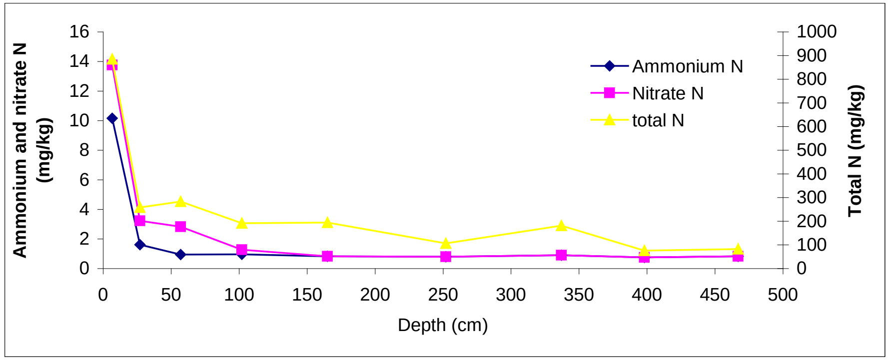
Site 9 Drill log

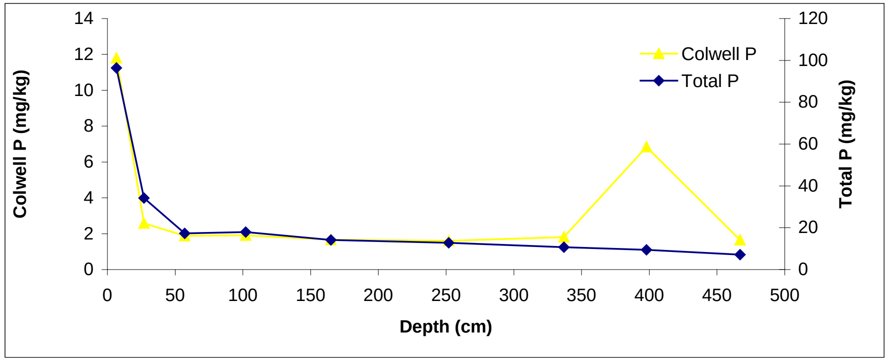
Rep	Depth (cm)	Description
1	0-15	sandy loam topsoil
	15-30	sand
	30-75	orange clay, small grey and red mottles
	75-285	orange clay, bands ofgrey and red mottles gritty quartz throughout
		free water at 3000 - grey clay
2	0-13	sandy loam topsoil
	13-50	sand
	75-225	orange clay, small grey and red mottles
	225-280	blue grey very gritty clay
		free water at 275
3	0-15	sandy loam topsoil
	15-35	sand
	35-450	orange clay, small grey and red mottles
	450-485	as above very gritty
		wet at 520 cm

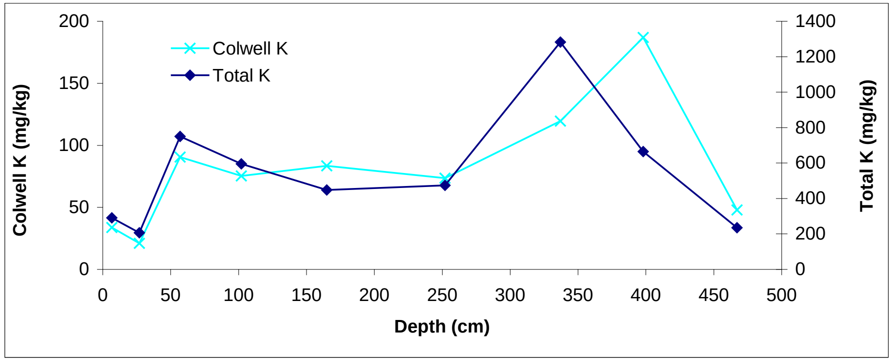

coarse material >2mm (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
Depth (cm)
Replicate 1
Replicate 2
Replicate 3

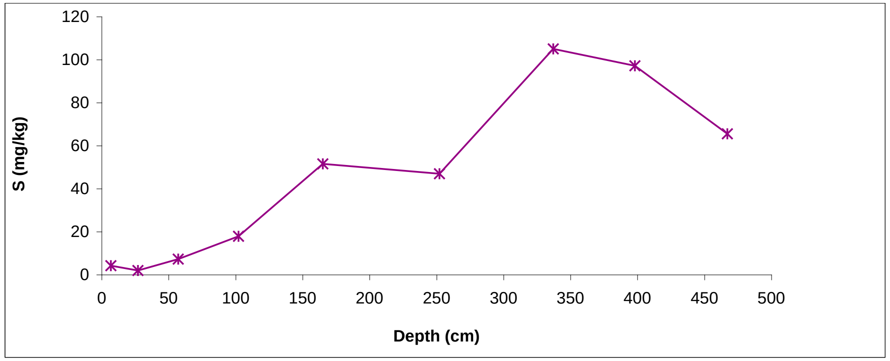

pH (water)
10
9
8
7
6
5
4
0
100
200
300
400
500
Depth (cm)
moderately -strongly alkaline
growth limiting
strongly acid

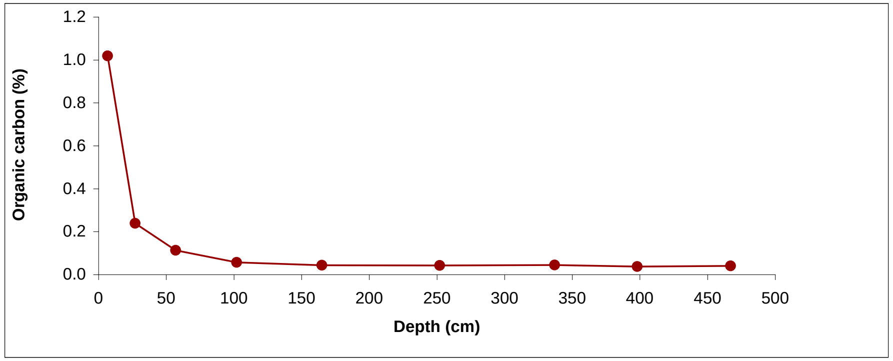

Ece dS/m
12
11
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
Depth (cm)
high salinity
water table
reps 1 and 2
water table ?


Ammonium and nitrate N (mg/kg)
16
14
12
10
8
6
4
2
0
Total N (mg/kg)
1000
900
800
700
600
500
400
300
200
100
0
Ammonium N
Nitrate N
total N
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)


Colwell P (mg/kg)
14
12
10
8
6
4
2
0
Total P (mg/kg)
120
100
80
60
40
20
0
Colwell P
Total P
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)

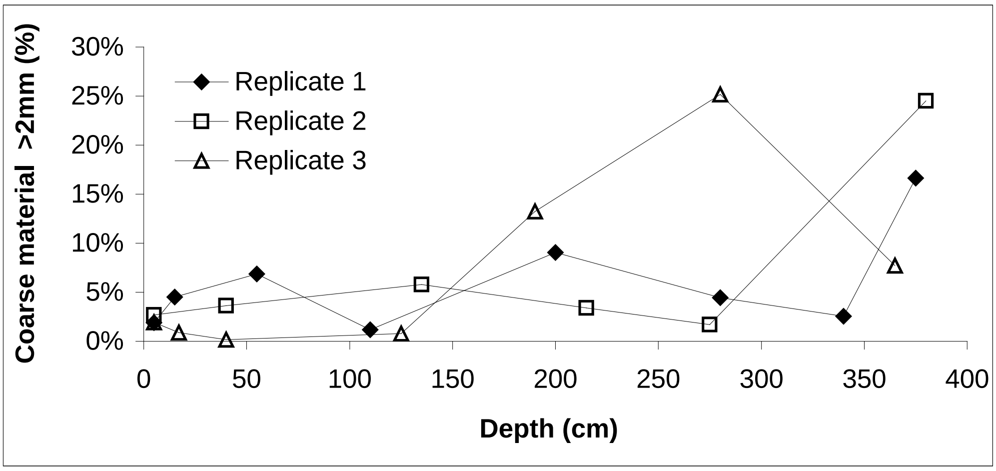

Colwell K (mg/kg)
200
150
100
50
0
Total K (mg/kg)
1400
1200
1000
800
600
400
200
0
Colwell K
Total K
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)

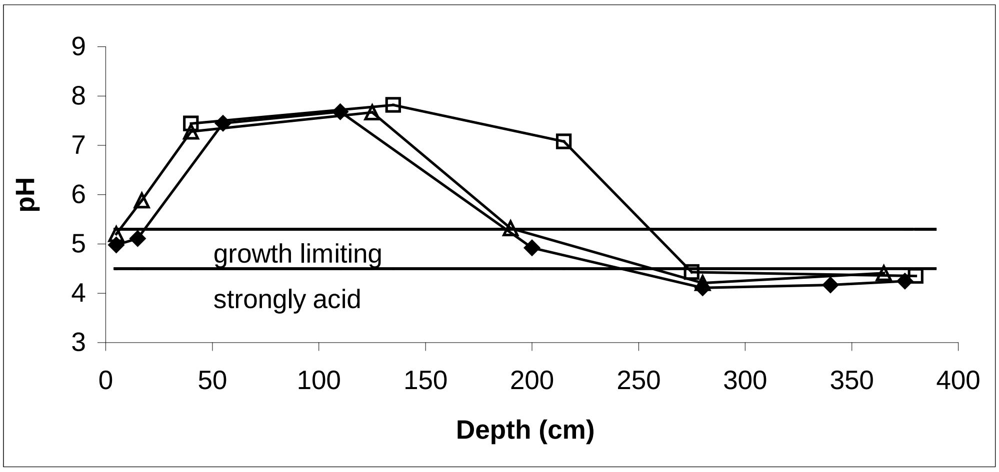

S (mg/kg)
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)

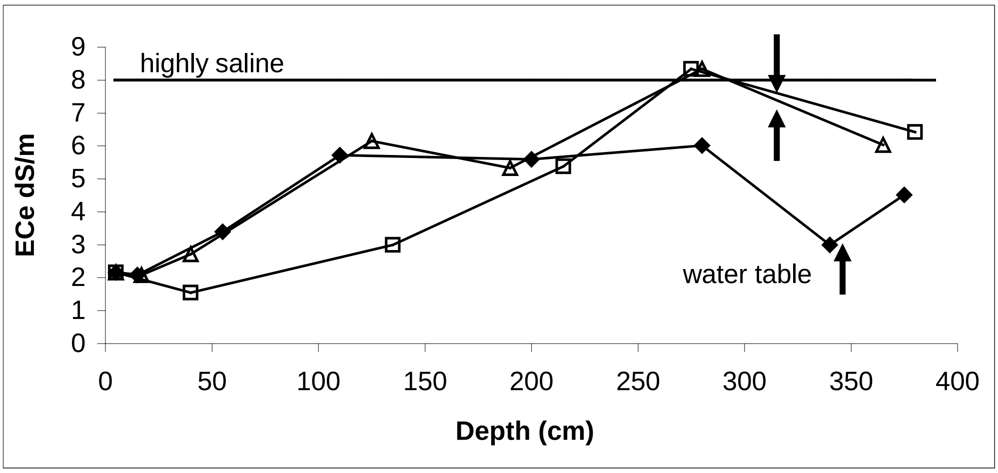

Organic carbon (%)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)

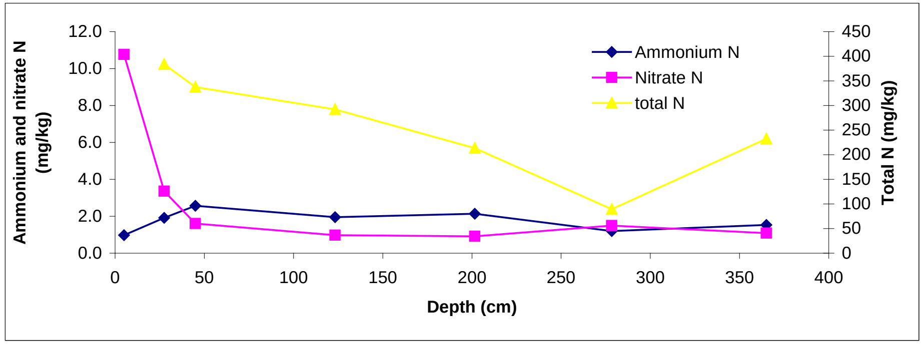
Site 10 Drill log

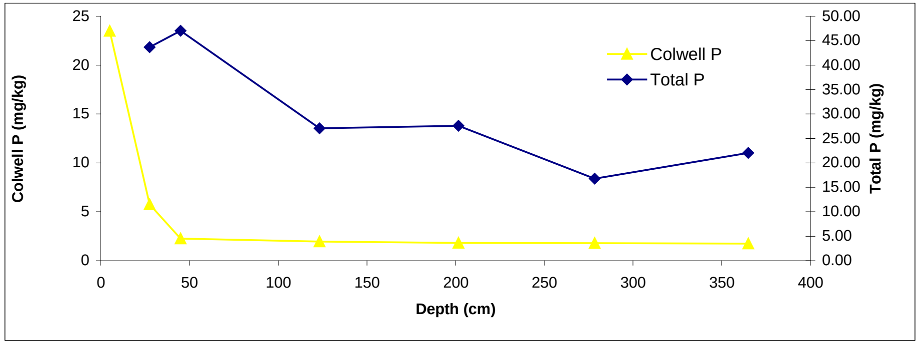
Rep	Depth (cm)	Description
1	0-30	loamy sand
	40-390	grey clay red mottles
		water table at 340
2	0-10	loamy sand
	20-390	clay- grey/brown red mottles
		water table at 320
3	0-25	loamy sand
	30-60	clay dark brown
	60-380	grey clay red mottles
		water table at 320

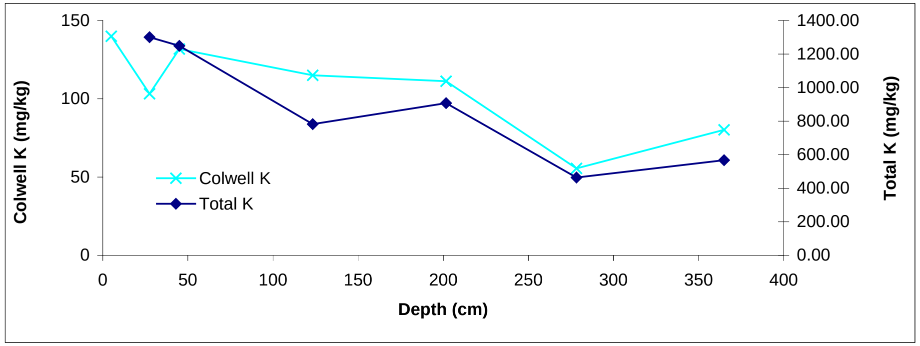

Coarse material >2mm (%)
30%
25%
20%
15%
10%
5%
0%
Replicate 1
Replicate 2
Replicate 3
0
50
100
150
200
250
300
350
400
Depth (cm)

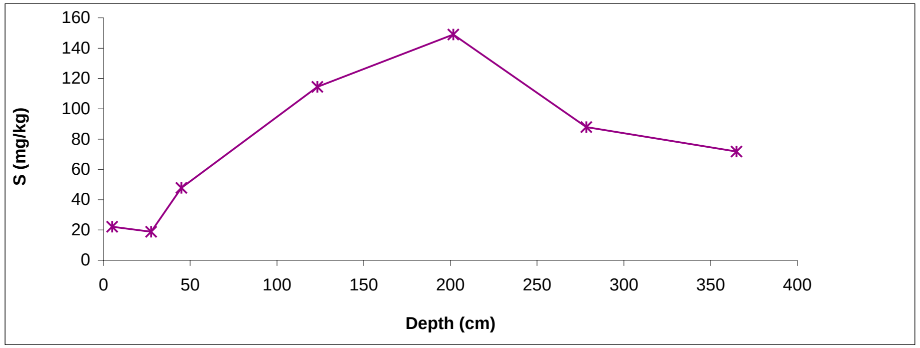

pH
9
8
7
6
5
4
3
growth limiting
strongly acid
0
50
100
150
200
250
300
350
400
Depth (cm)

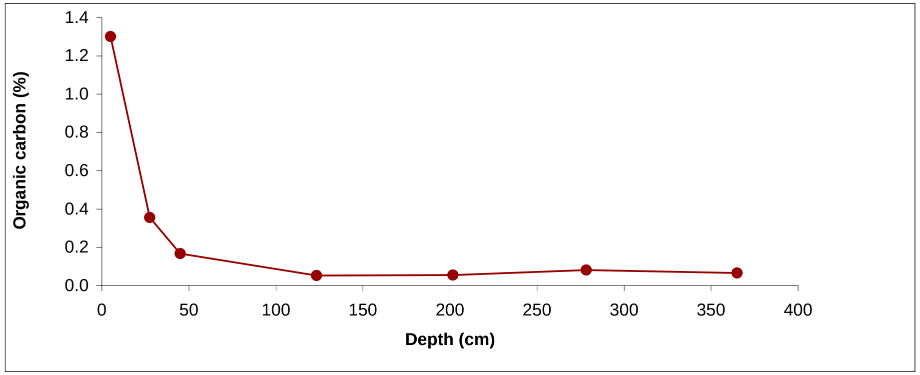

ECe dS/m
9
8
7
6
5
4
3
2
1
0
highly saline
water table
0
50
100
150
200
250
300
350
400
Depth (cm)


Ammonium and nitrate N (mg/kg)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Ammonium N
Nitrate N
total N
450
400
350
300
250
200
150
100
50
0
Total N (mg/kg)
0
50
100
150
200
250
300
350
400
Depth (cm)


Colwell P (mg/kg)
25
20
15
10
5
0
Colwell P
Total P
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Total P (mg/kg)
0
50
100
150
200
250
300
350
400
Depth (cm)

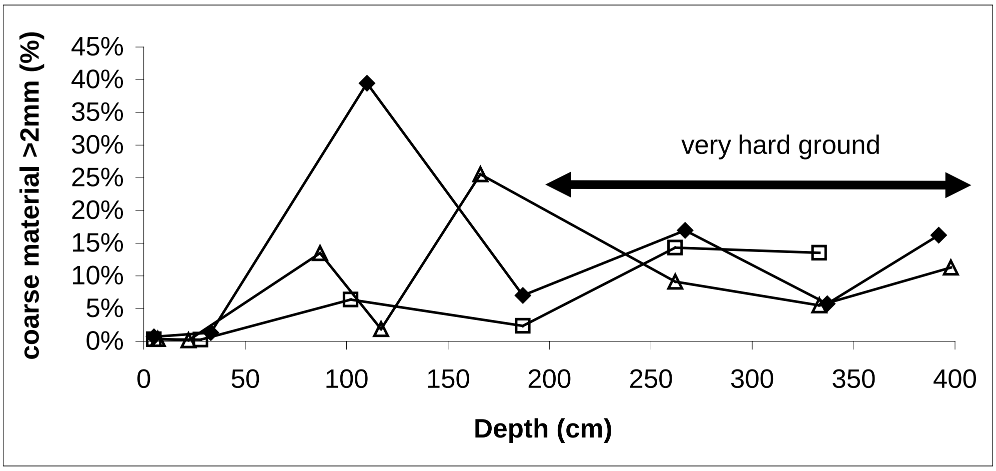

Colwell K (mg/kg)
150
100
50
0
Colwell K
Total K
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
Total K (mg/kg)
0
50
100
150
200
250
300
350
400
Depth (cm)

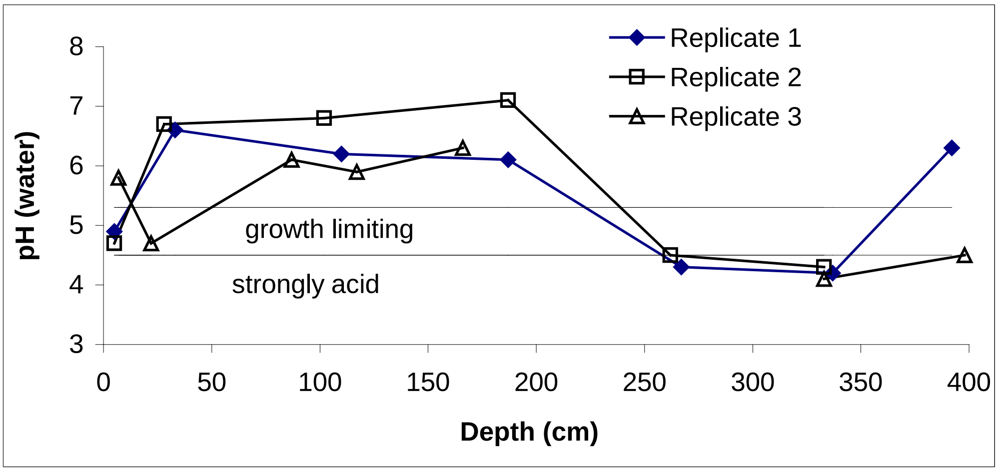

S (mg/kg)
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
Depth (cm)

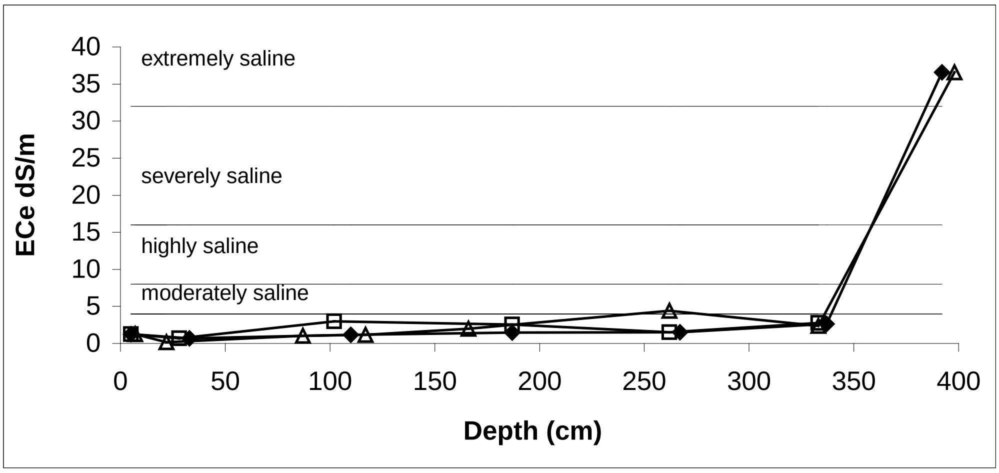

Organic carbon (%)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
Depth (cm)

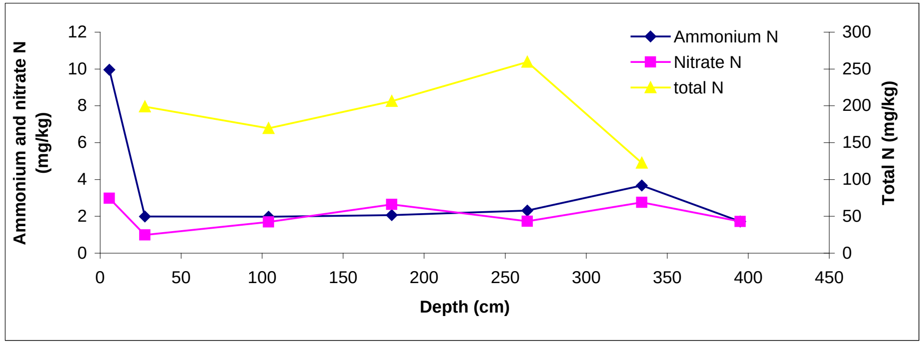
Site 11 Drill log

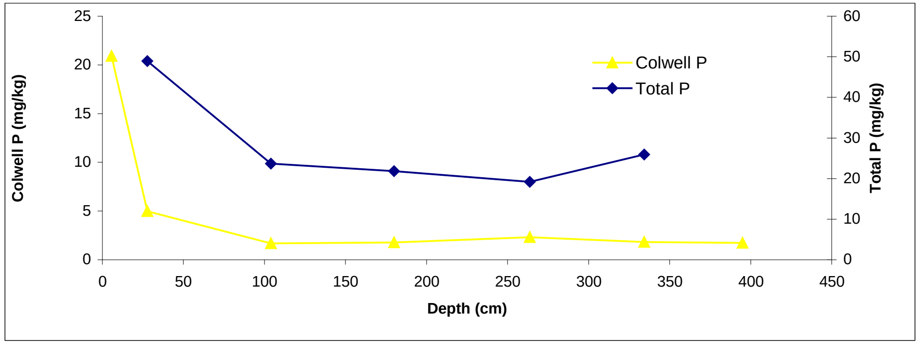
Rep	Depth (cm)	Description
1	0-15	Brown/grey loamysand topsoil
	15-56	red/brown loamy clay
	56-225	red/brownclay with white mottles
	225-375	grey and red mottled clay
	375-410	red and white banded clay silcrete bands at >400
		>410 very hard drilling. Nodules in clay - silcrete?
2	0-10	Brown/grey loamysand topsoil
	10-30	red/brown sandy loam
	30-225	red/brownclay with white mottles
	225-365	red clay with white mottles silcrete throughout
		>300 - very hard drilling
3	0-14	Brown/grey loamysand topsoil
	14-30	red/brown sandy loam
	30-225	red clay with orange mottles silcrete at >175
	225-300	red clay with white mottles. Last 35cm is very compact clay.
	300-420	red and grey bands of clay. Some parts are very dry.
		Grits at 3950 too hard to drill thru

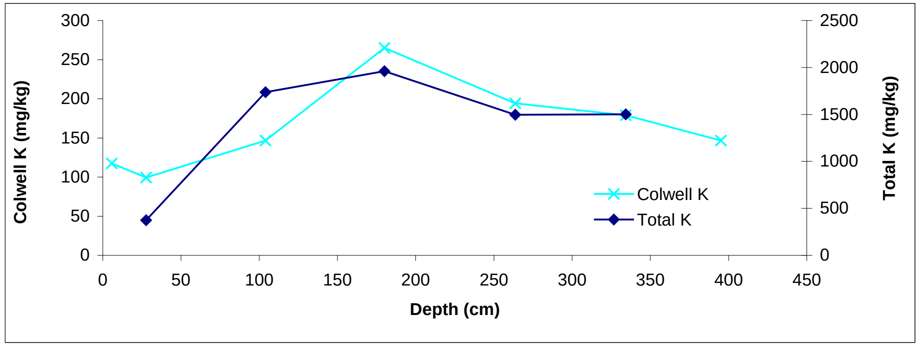

coarse material >2mm (%)
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
50
100
150
200
250
300
350
400
Depth (cm)
very hard ground

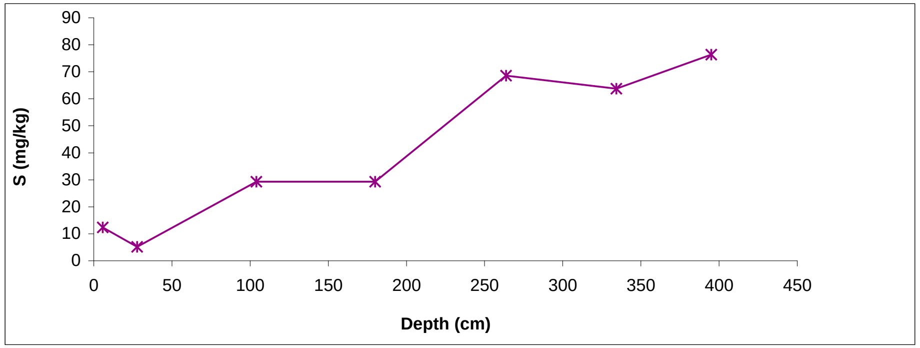

pH (water)
8
7
6
5
4
3
0
50
100
150
200
250
300
350
400
Depth (cm)
Replicate 1
Replicate 2
Replicate 3
growth limiting
strongly acid

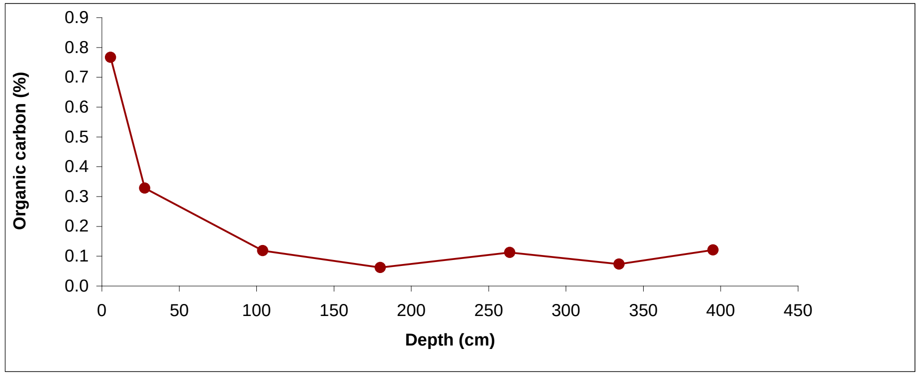

ECe dS/m
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
Depth (cm)
extremely saline
severely saline
highly saline
moderately saline


Ammonium and nitrate N (mg/kg)
Total N (mg/kg)
Depth (cm)
Ammonium N
Nitrate N
total N
0
2
4
6
8
10
12
0
50
100
150
200
250
300
0
50
100
150
200
250
300
350
400
450


Colwell P (mg/kg)
Total P (mg/kg)
Depth (cm)
Colwell P
Total P
0
5
10
15
20
25
0
10
20
30
40
50
60
0
50
100
150
200
250
300
350
400
450

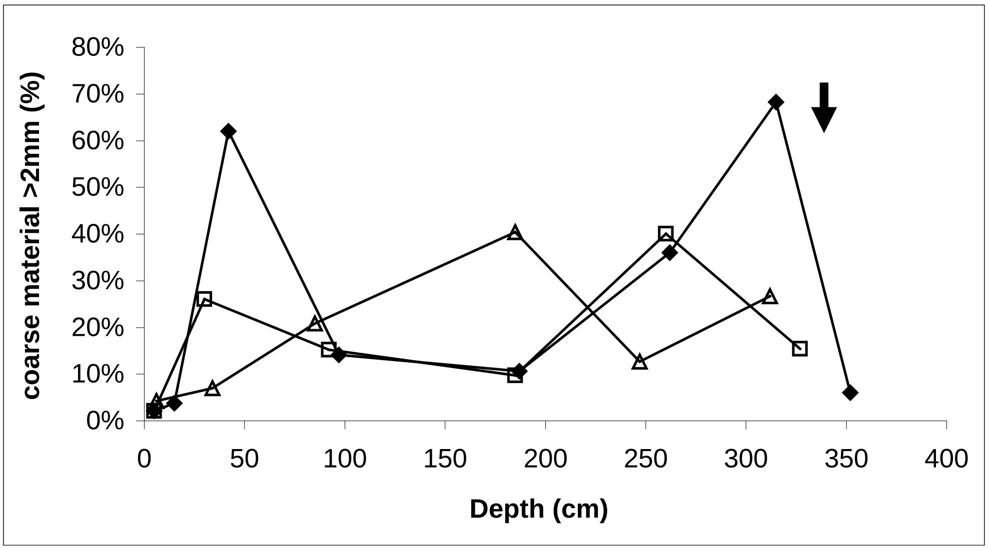

Colwell K (mg/kg)
Total K (mg/kg)
Depth (cm)
Colwell K
Total K
0
50
100
150
200
250
300
0
500
1000
1500
2000
2500
0
50
100
150
200
250
300
350
400
450

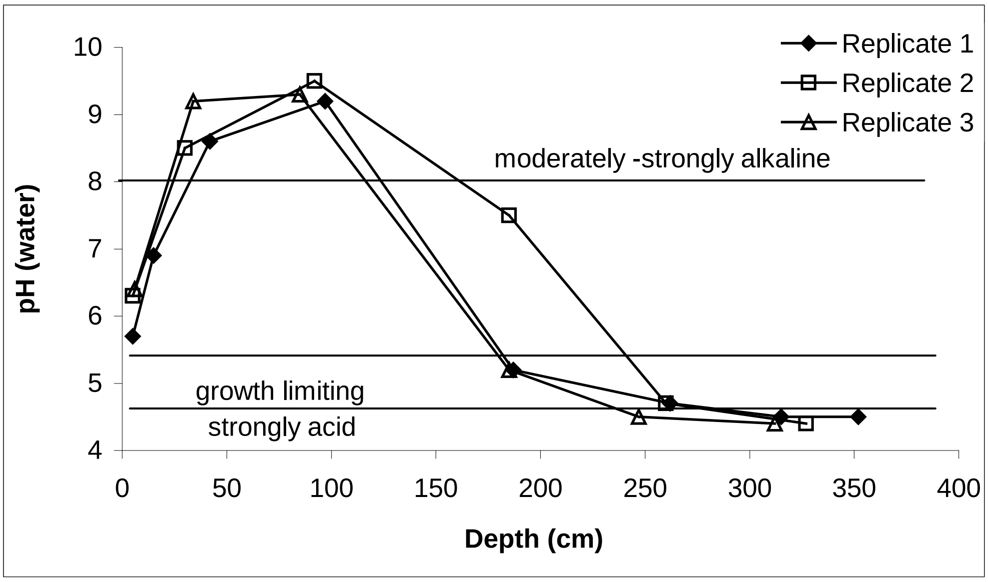

S (mg/kg)
Depth (cm)
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200
250
300
350
400
450

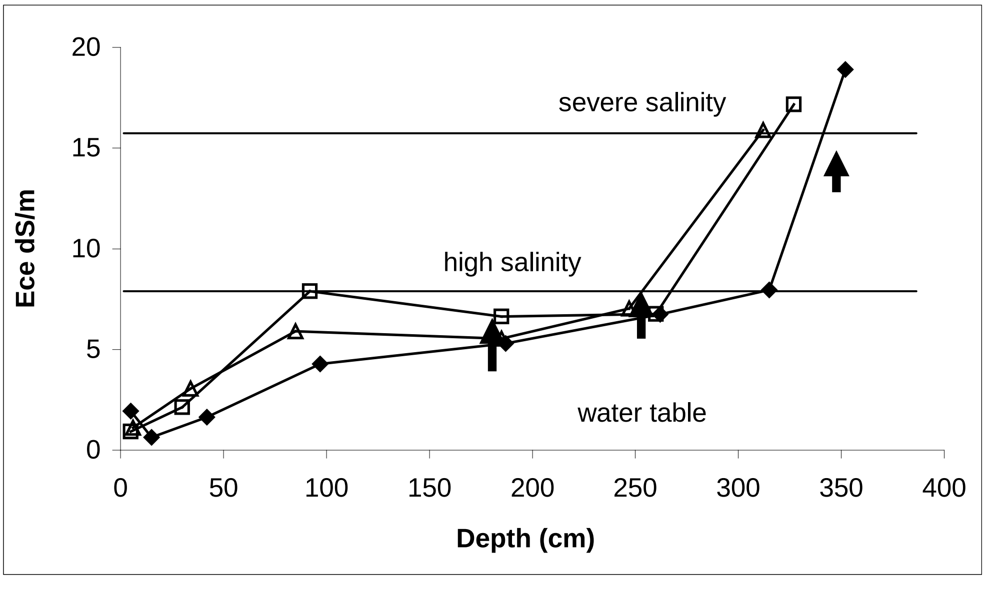

Organic carbon (%)
Depth (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
50
100
150
200
250
300
350
400
450

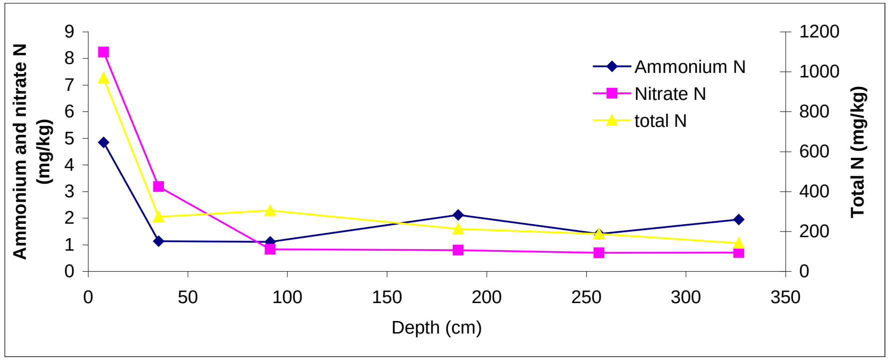
Site 12 Drill log

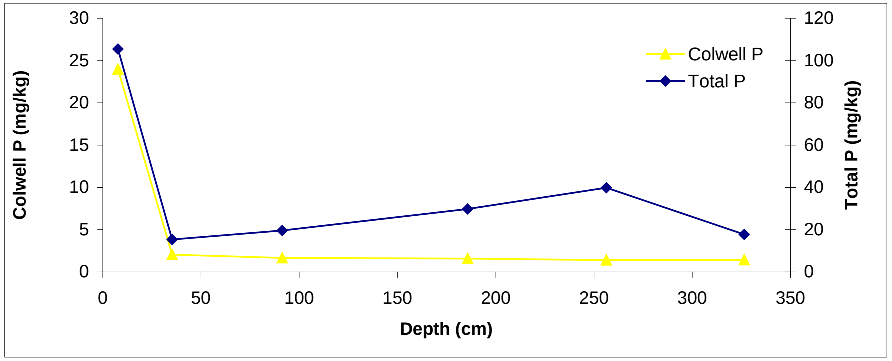
Rep	Depth (cm)	Description
1	0-10	sandy loam topsoil
	10-20	Grey gritty sand
	20-75	grey -brown - white clay
	75-120	grey white clay to 85 cm with red mottle >85 cm
	150-300	red orange clay with grey mottleswith ironstone nodules at 300
	300-330	red clay with cemented quartz layers
	330-375	grey sandy clay
		375 free water
2	0-10	sandy loam topsoil
	10-50	brown clay white mottles
	75-110	yellow-brown gritty clay orange and white mottles
	150-220	yellow-brown gritty clay grey mottles
	225-295	red gritty clay grey mottles
	300-355	grey clay with ironstone in red mottles
		free water at 195
3	0-13	sandy loam topsoil
	13-75	grey gritty clay white mottles at 64 cm
	75-150	brown gritty clay coarse quartz fragments
	150-225	red clay grey mottles plus grits
	225-350	grey red orange clay with ironstone nodules
		free water at 225

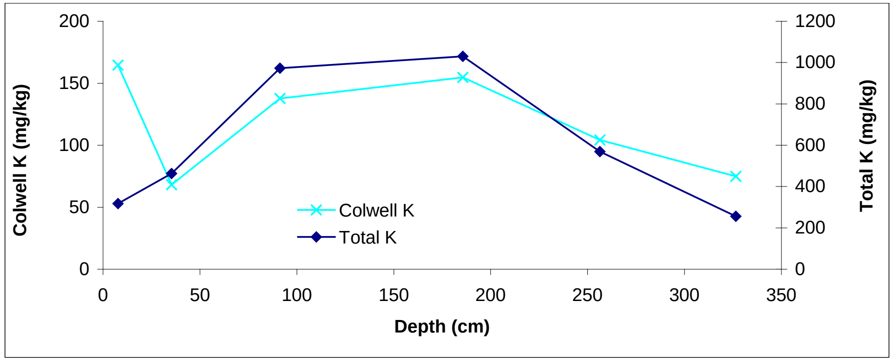

coarse material >2mm (%)
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350
400
Depth (cm)

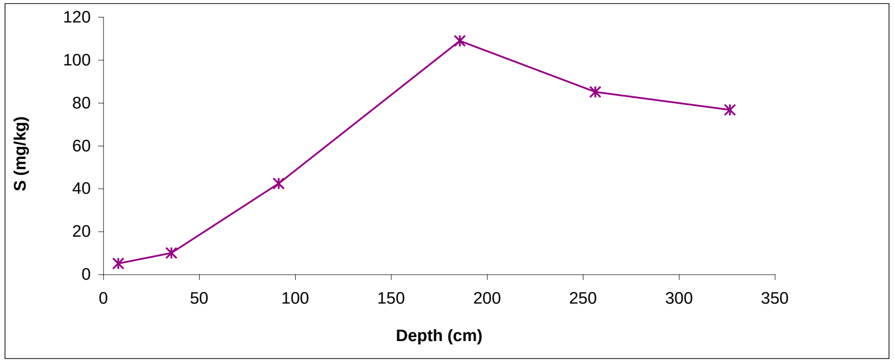

pH (water)
10
9
8
7
6
5
4
Replicate 1
Replicate 2
Replicate 3
moderately -strongly alkaline
growth limiting
strongly acid
0
50
100
150
200
250
300
350
400
Depth (cm)

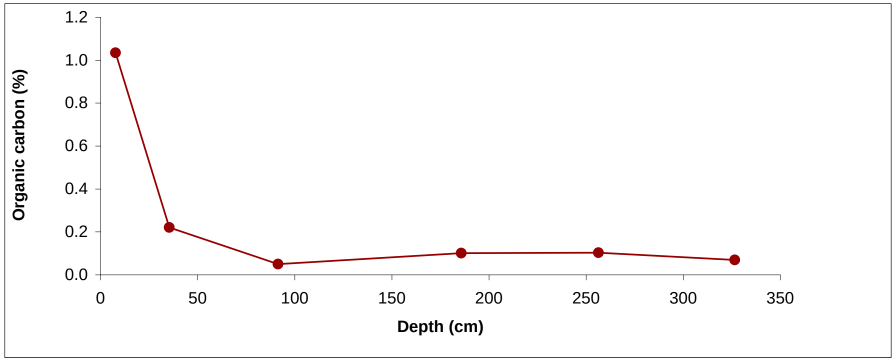

Ece dS/m
20
15
10
5
0
severe salinity
high salinity
water table
0
50
100
150
200
250
300
350
400
Depth (cm)


Ammonium and nitrate N (mg/kg)
0
1
2
3
4
5
6
7
8
9
Total N (mg/kg)
0
200
400
600
800
1000
1200
Ammonium N
Nitrate N
total N
0
50
100
150
200
250
300
350
Depth (cm)


Colwell P (mg/kg)
0
5
10
15
20
25
30
Total P (mg/kg)
0
20
40
60
80
100
120
Colwell P
Total P
0
50
100
150
200
250
300
350
Depth (cm)

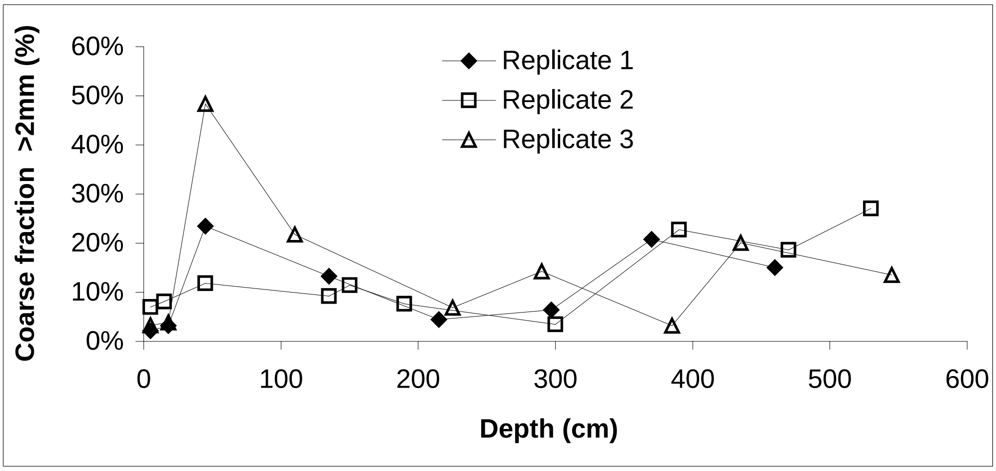

Colwell K (mg/kg)
0
50
100
150
200
Total K (mg/kg)
0
200
400
600
800
1000
1200
Colwell K
Total K
0
50
100
150
200
250
300
350
Depth (cm)

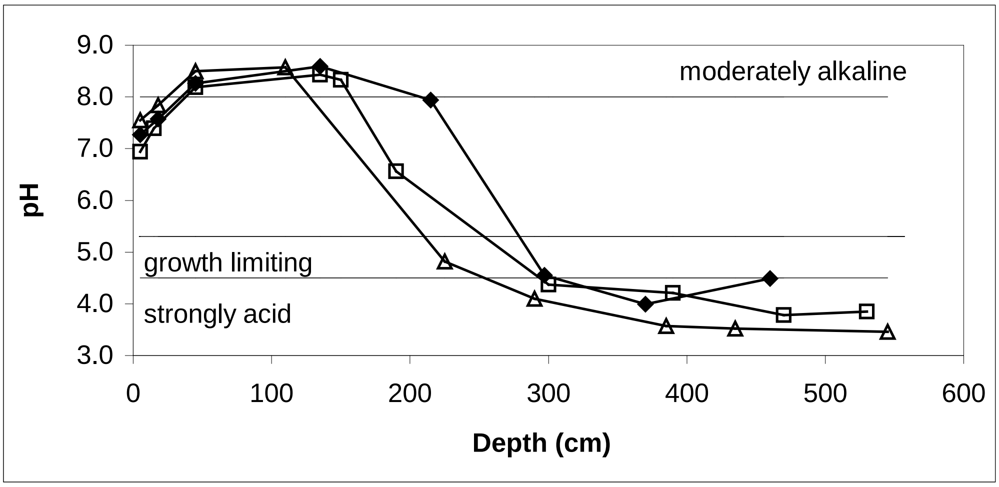

S (mg/kg)
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
Depth (cm)

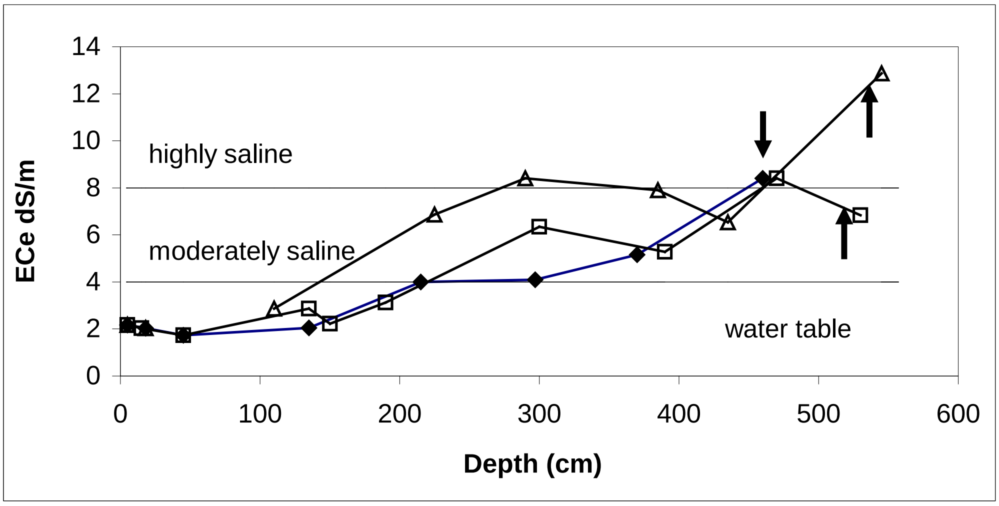

Organic carbon (%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
50
100
150
200
250
300
350
Depth (cm)

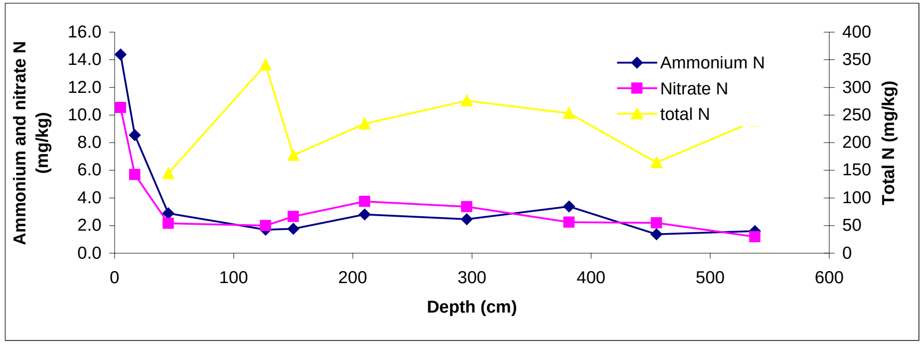
Site 13 Drill log

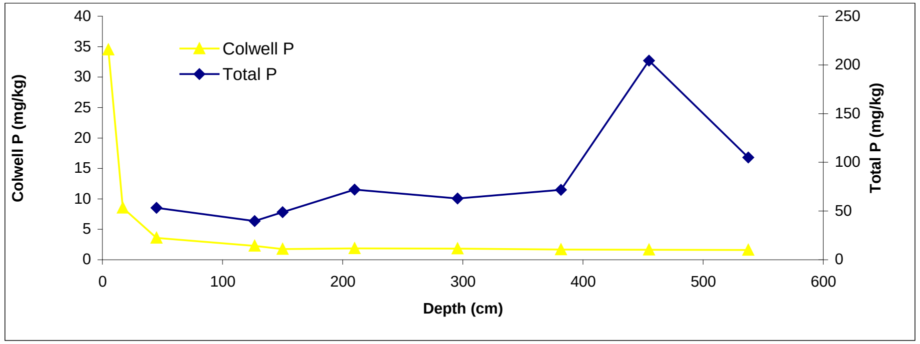
Rep	Depth (cm)	Description
1	0-10	loam topsoil
	10-25	loam
	25-150	red/brown clay and lime nodules
	150-480	red brown clay
		water table at 480
2	0-10	loam topsoil
	10-20	loam
	20-150	red/brown clay and lime nodules
	150-540	red/brown clay
		water table at 520
3	0-10	loam topsoil
	10-25	loam
	25-150	red/brown clay and lime nodules
	150-560	red/brown clay
		water table at 560

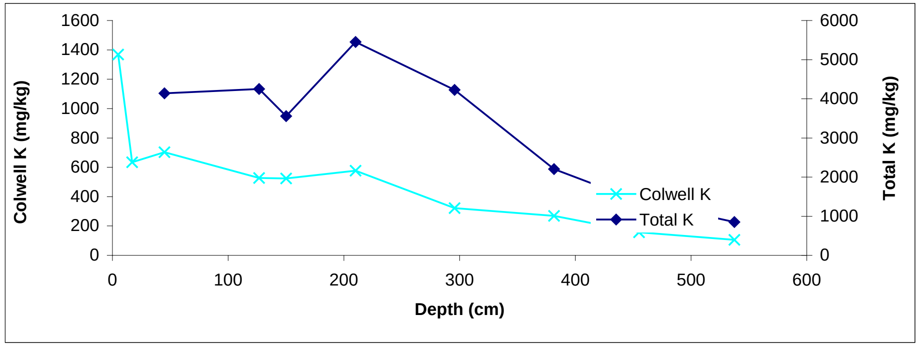

Coarse fraction >2mm (%)
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
Depth (cm)
Replicate 1
Replicate 2
Replicate 3

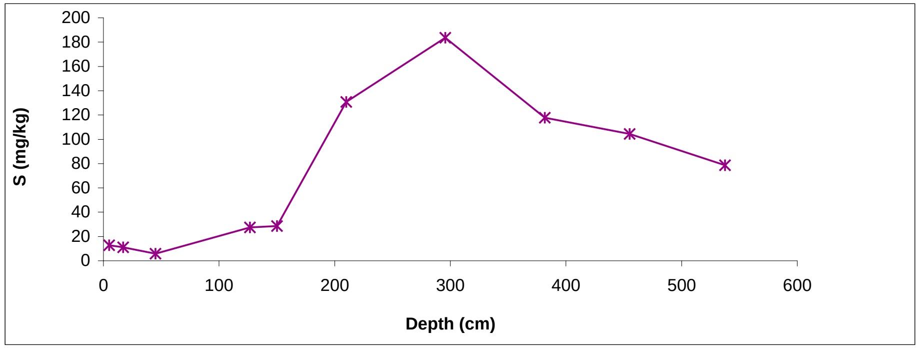

pH
9.0
8.0
7.0
6.0
5.0
4.0
3.0
moderately alkaline
growth limiting
strongly acid
0
100
200
300
400
500
600
Depth (cm)

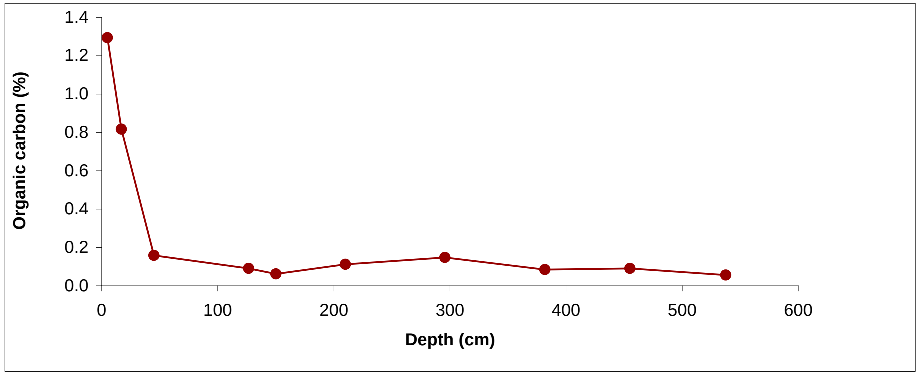

ECe dS/m
14
12
10
8
6
4
2
0
highly saline
moderately saline
water table
0
100
200
300
400
500
600
Depth (cm)


Ammonium and nitrate N (mg/kg)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Total N (mg/kg)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
Depth (cm)
Ammonium N
Nitrate N
total N


Colwell P (mg/kg)
40
35
30
25
20
15
10
5
0
Total P (mg/kg)
250
200
150
100
50
0
0
100
200
300
400
500
600
Depth (cm)
Colwell P
Total P

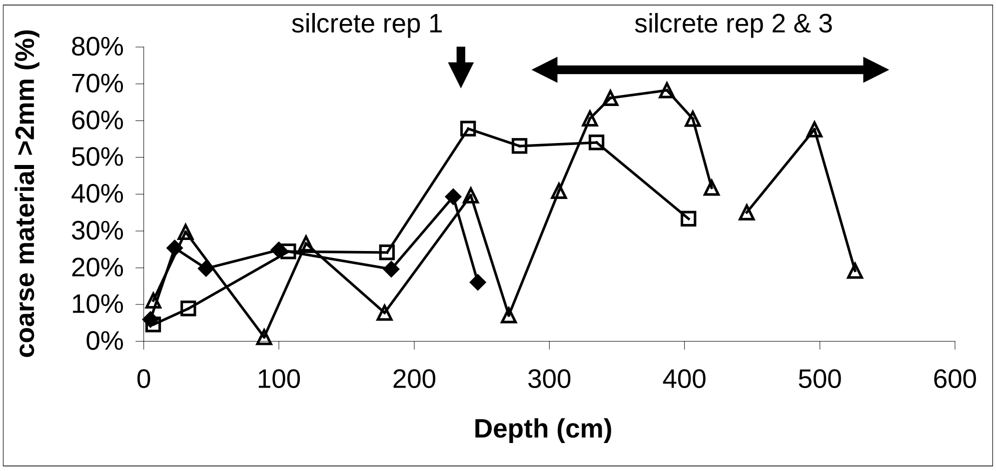

Colwell K (mg/kg)
1600
1400
1200
1000
800
600
400
200
0
Total K (mg/kg)
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
Depth (cm)
Colwell K
Total K

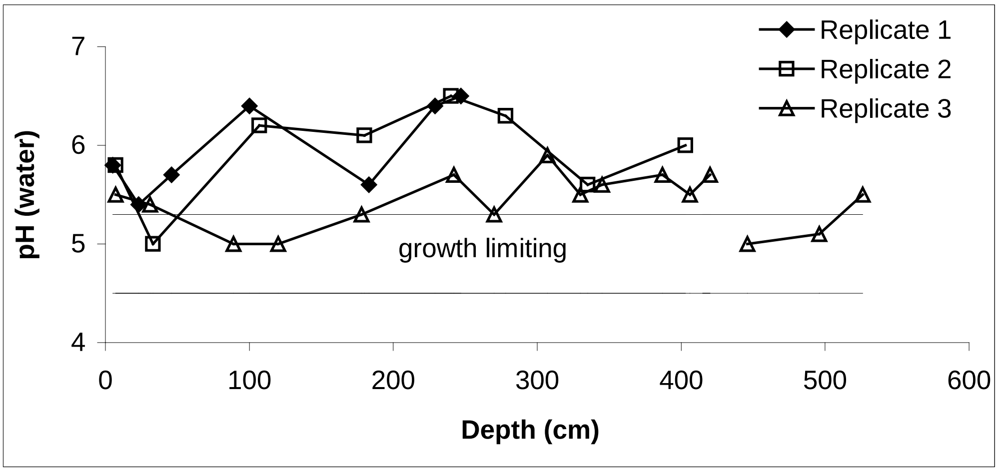

S (mg/kg)
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
Depth (cm)

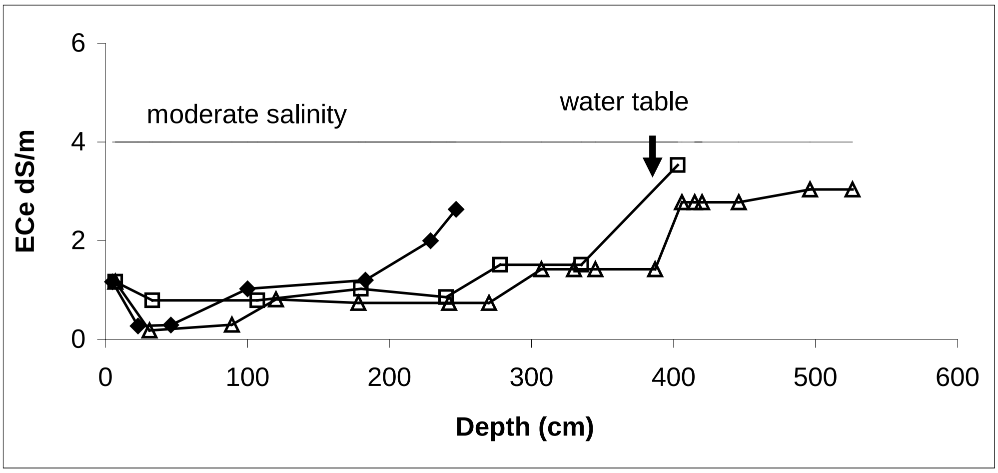

Organic carbon (%)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
Depth (cm)

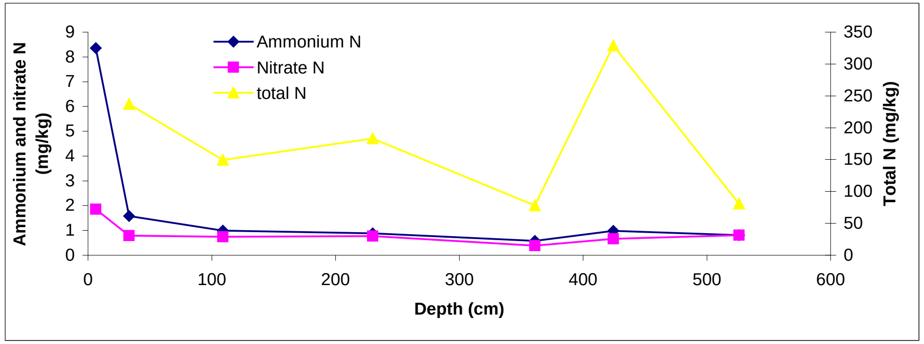
Site 14 Drill log

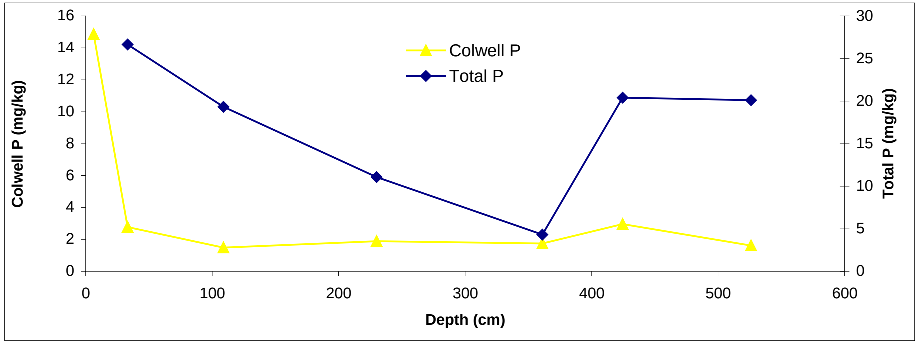
Rep	Depth (cm)	Description
1	0-10	grey sand topsoil
	10-35	red grey mottled clay
	35-215	orange red mottled clay and gravel
	225-232	red clay with white mottles and gravel
	232-262	white clay with orange and red mottles, silcrete throughout
		Couldn't drill beyond 2620mm-too hard
2	0-14	grey sand topsoil
	14-255	light orange clay with orange/red/white mottles.Sml silcrete pieces
	255-300	white clay with red and some orange mottles bands of silcrete throughout
	300-430	red and white mottled clay
		saturated at 370
3	0-13	grey sand topsoil
	13-260	orange mottled clay with gravel
	260-532	red and white mottled clay bands of silcrete throughout

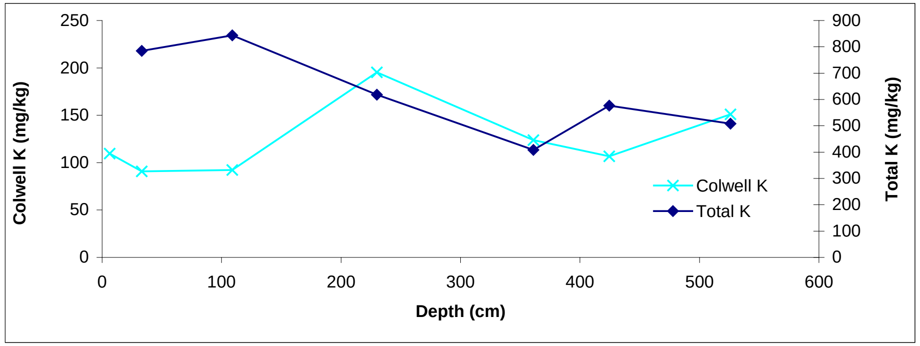

silcrete rep 1
silcrete rep 2 & 3
coarse material >2mm (%)
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
Depth (cm)

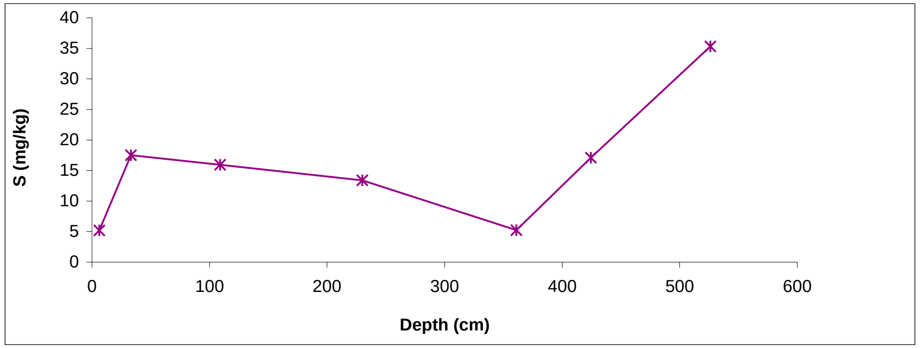

Replicate 1
Replicate 2
Replicate 3
pH (water)
7
6
5
4
growth limiting
0
100
200
300
400
500
600
Depth (cm)

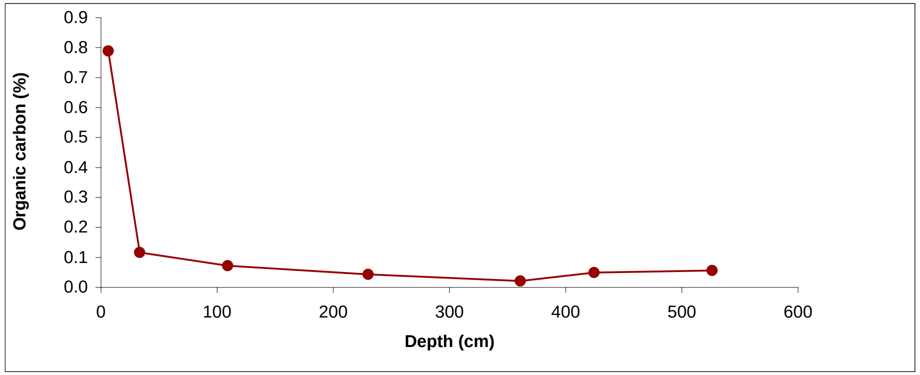

ECe dS/m
6
4
2
0
moderate salinity
water table
0
100
200
300
400
500
600
Depth (cm)


Ammonium and nitrate N (mg/kg)
Total N (mg/kg)
Depth (cm)
Ammonium N
Nitrate N
total N
0
1
2
3
4
5
6
7
8
9
0
50
100
150
200
250
300
350
0
100
200
300
400
500
600


Colwell P (mg/kg)
Total P (mg/kg)
Depth (cm)
Colwell P
Total P
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30
0
100
200
300
400
500
600

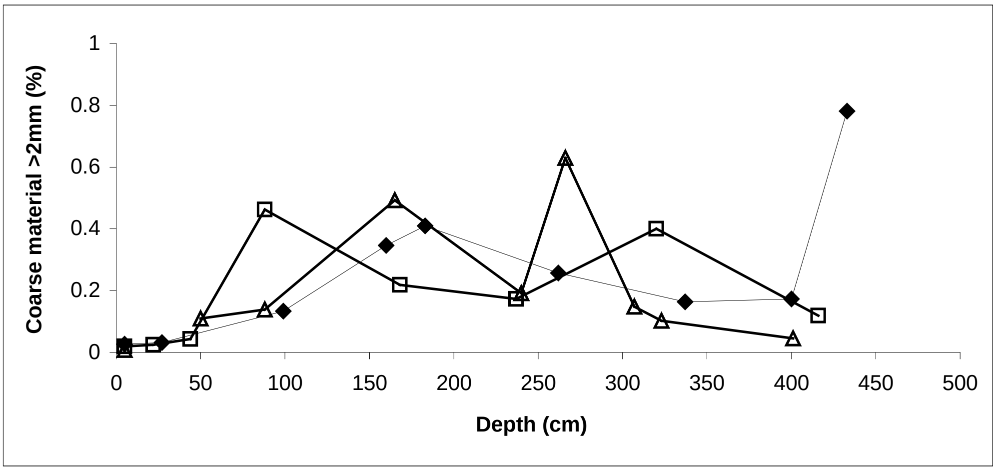

Colwell K (mg/kg)
Total K (mg/kg)
Depth (cm)
Colwell K
Total K
0
50
100
150
200
250
0
100
200
300
400
500
600
700
800
900
0
100
200
300
400
500
600

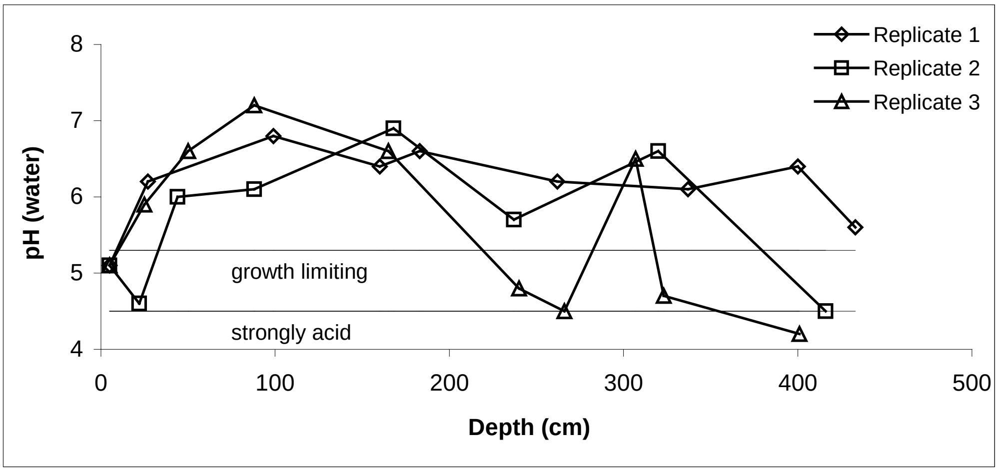

S (mg/kg)
Depth (cm)
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600

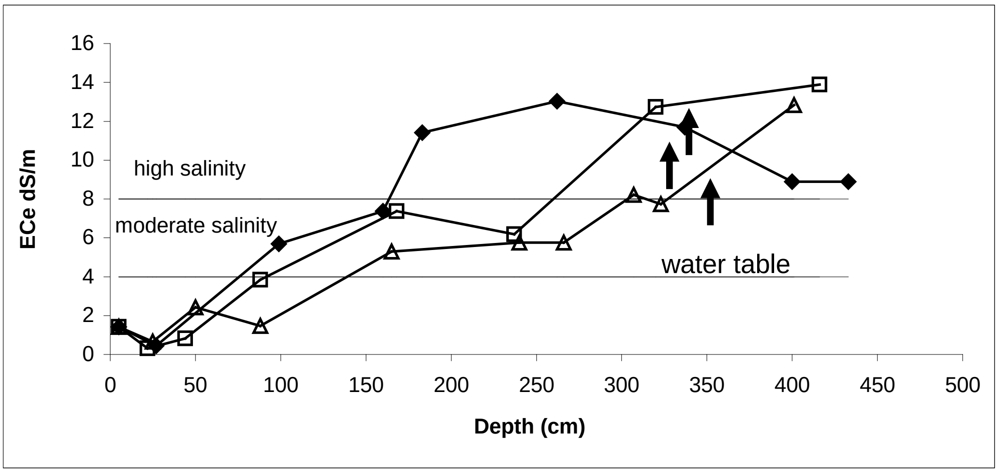

Organic carbon (%)
Depth (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
100
200
300
400
500
600

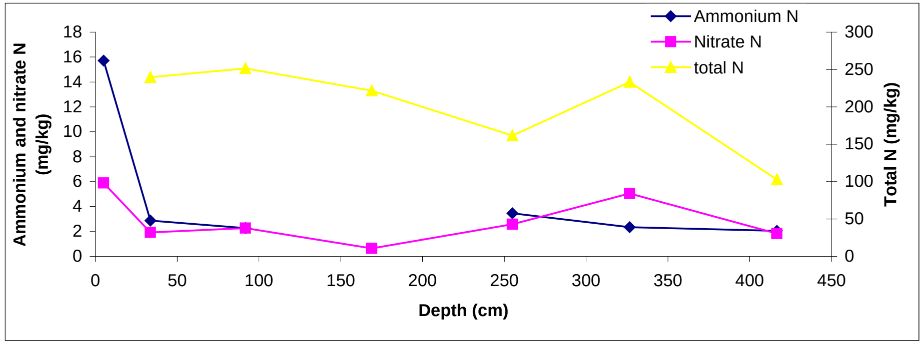
Site 15 Drill log

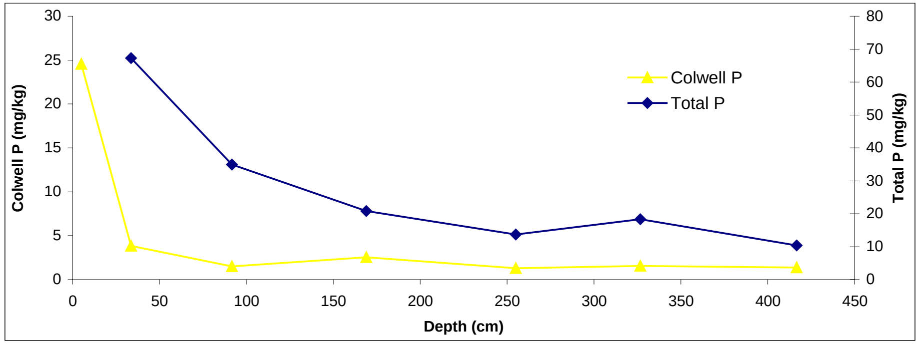
Rep	Depth (cm)	Description
1	0-10	brown/red sand loam
	10-44	red loamy clay
	44-225	red clay withwhite mottles irregular bands of silcrete throughout
	225-425	gritty white clay with red mottles
	425-441	extremely hard silcrete plugs - orange to very dark red.
		water table at 3.1m
2	0-10	brown/red sand loam
	10-33	red loamy clay
	33-375	red clay withwhite mottles irregular bands of silcrete throughout
	375-450	white clay with red mottles.
		water table at 3.25m
3	0-10	brown/red sand loam
	10-40	red loamy clay
	40-375	red clay withwhite mottles irregular bands of silcrete throughout
	375-447	gritty white clay with red mottles
		water table at 3.5m

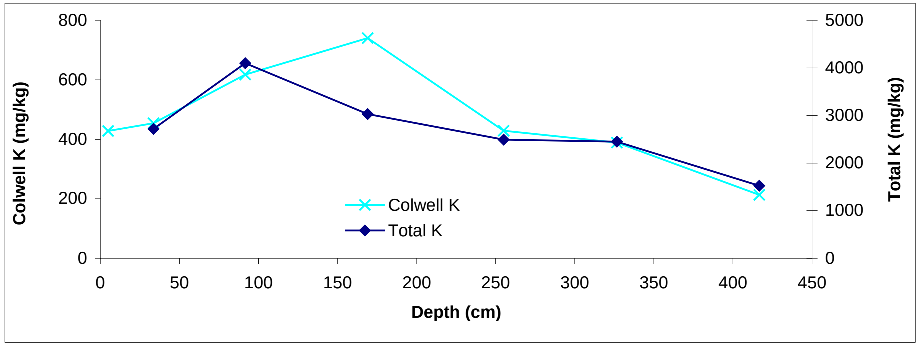

Coarse material >2mm (%)
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)

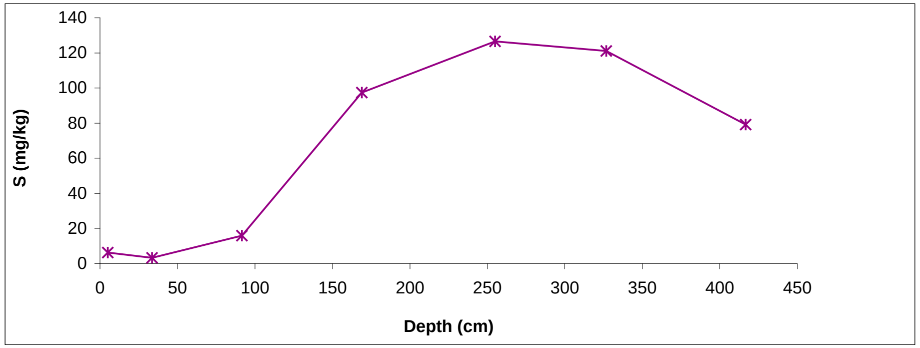

Replicate 1
Replicate 2
Replicate 3
pH (water)
8
7
6
5
4
growth limiting
strongly acid
0
100
200
300
400
500
Depth (cm)

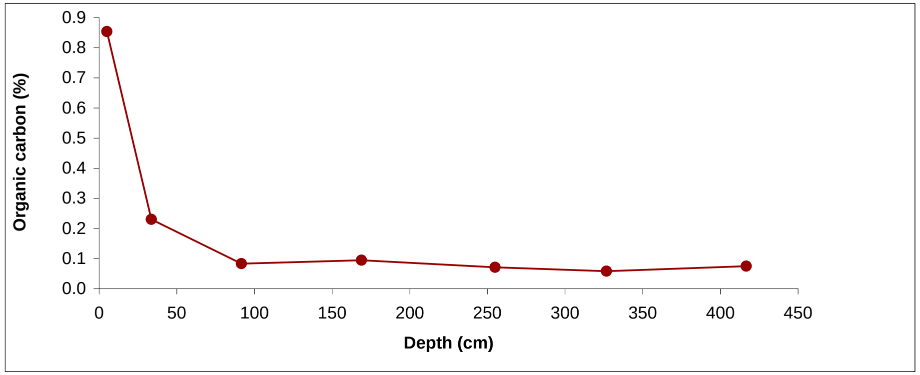

ECe dS/m
16
14
12
10
8
6
4
2
0
high salinity
moderate salinity
water table
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)


Ammonium N
Nitrate N
total N
Ammonium and nitrate N (mg/kg)
Total N (mg/kg)
Depth (cm)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
0
50
100
150
200
250
300
350
400
450


Colwell P
Total P
Colwell P (mg/kg)
Total P (mg/kg)
Depth (cm)
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350
400
450

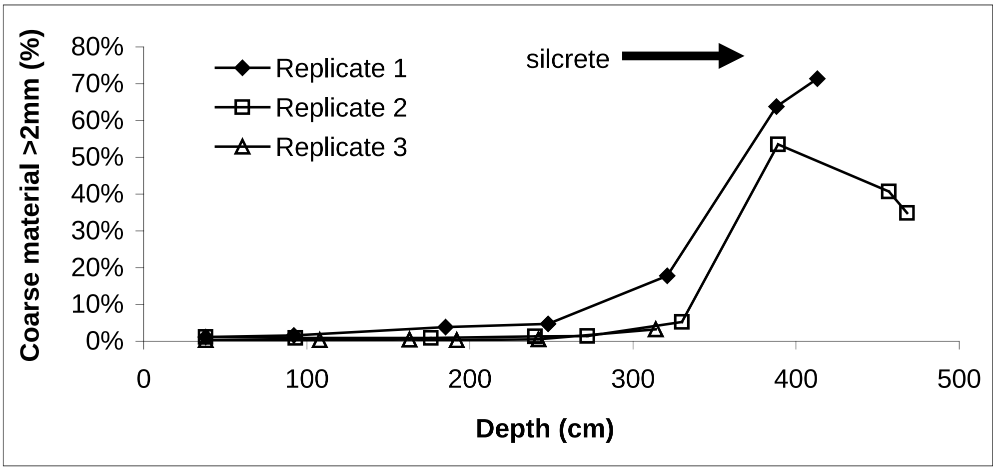

Colwell K
Total K
Colwell K (mg/kg)
Total K (mg/kg)
Depth (cm)
0
200
400
600
800
0
1000
2000
3000
4000
5000
0
50
100
150
200
250
300
350
400
450

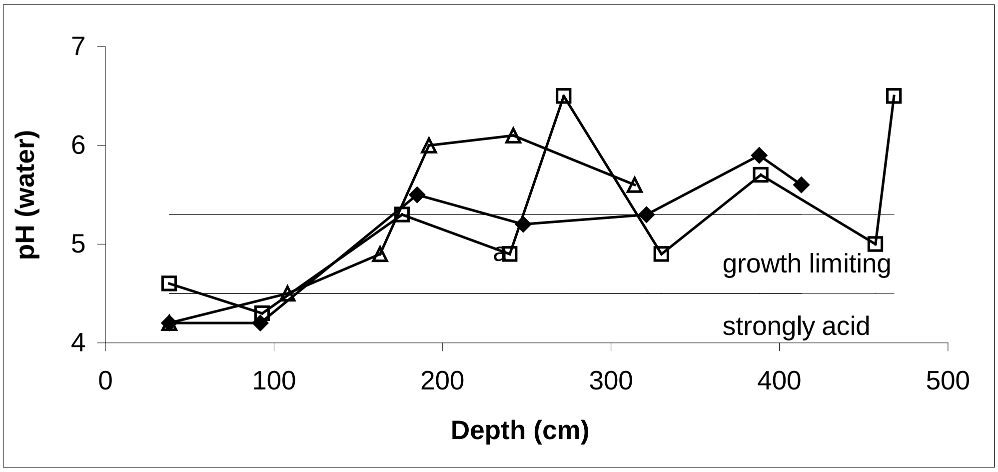

S (mg/kg)
Depth (cm)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450

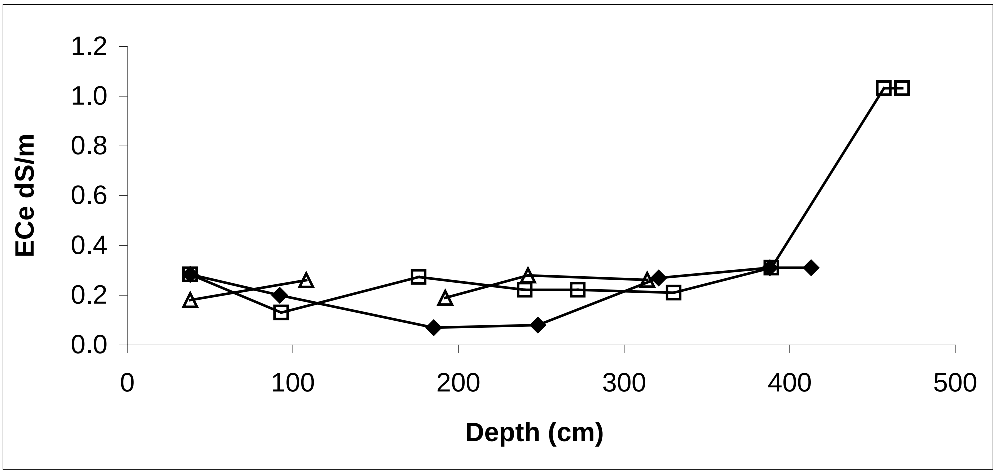

Organic carbon (%)
Depth (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
50
100
150
200
250
300
350
400
450

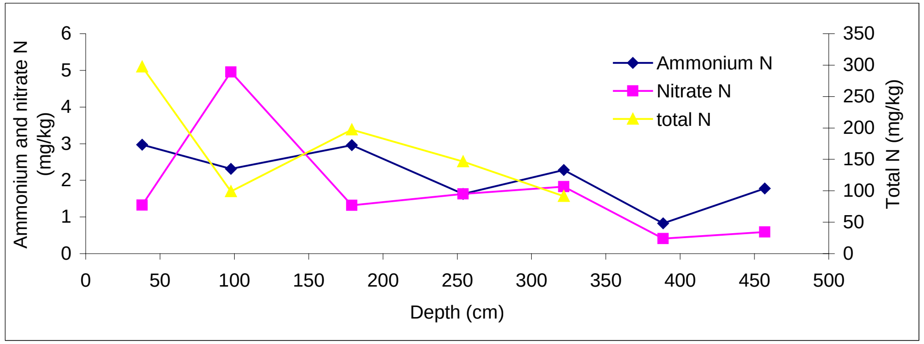
Site 16 Drill log

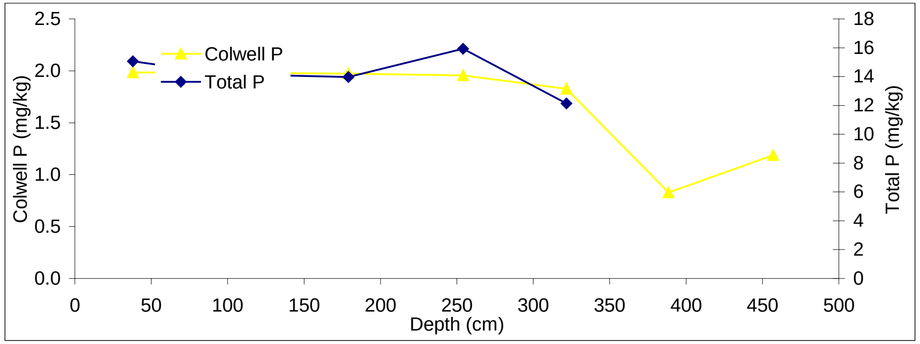
Rep	Depth (cm)	Description
1	0-75	yellow sand
	75-225	yellow coarse loamy sand.
	225-375	yellow coarse loamy sand red slightly cemented segregations increasing with depth
	375-426	as above plus increasing silcrete with depth
		470 - too hard to drill further
2	0-75	yellow sand
	75-225	yellow coarse loamy sand.
	255-360	yellow coarse loamy sand red slightly cemented segregations increasing with depth
	375-470	as above plus increasing silcrete with depth
		500 - too hard to drill further
3	0-75	yellow sand
	75-225	yellow coarse loamy sand.
	225-327	yellow coarse loamy sand red slightly cemented segregations increasing with depth
		450 too hard to drill further

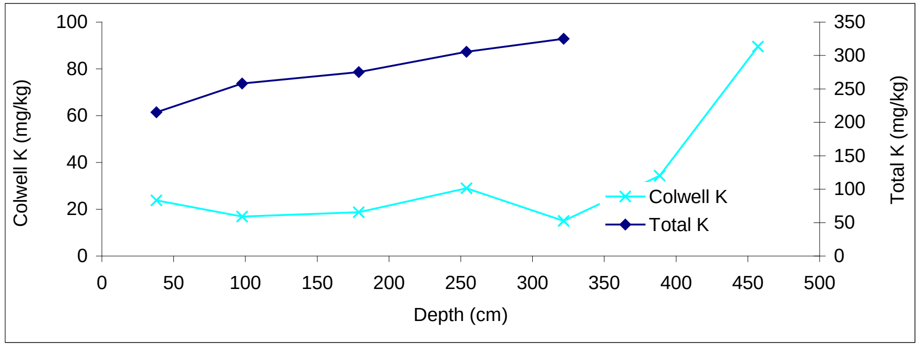

Coarse material >2mm (%)
80%
70%
60%
50%
40%
30%
20%
10%
0%
Replicate 1
Replicate 2
Replicate 3
silcrete
0
100
200
300
400
500
Depth (cm)

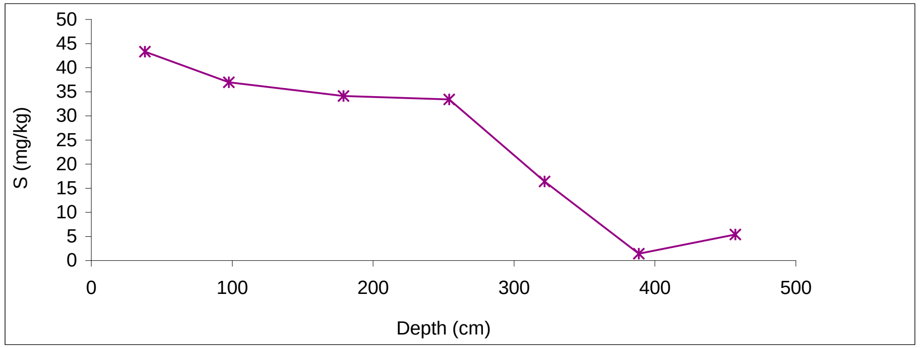

pH (water)
7
6
5
4
growth limiting
strongly acid
0
100
200
300
400
500
Depth (cm)

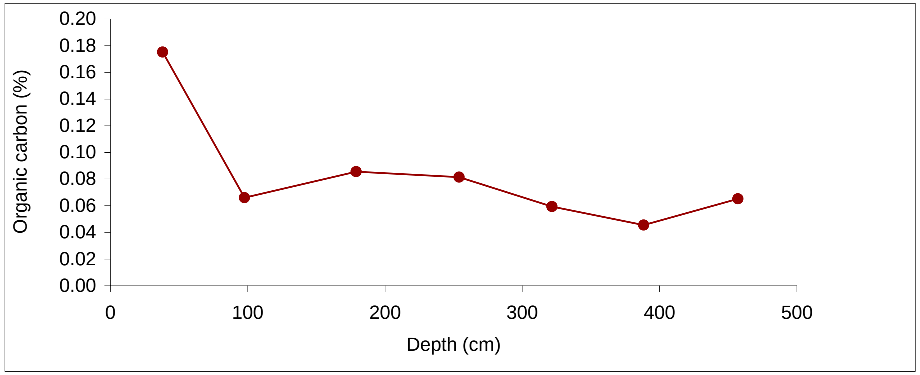

ECe dS/m
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
Depth (cm)


Ammonium and nitrate N (mg/kg)
6
5
4
3
2
1
0
Total N (mg/kg)
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)
Ammonium N
Nitrate N
total N


Colwell P (mg/kg)
2.5
2.0
1.5
1.0
0.5
0.0
Total P (mg/kg)
18
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)
Colwell P
Total P

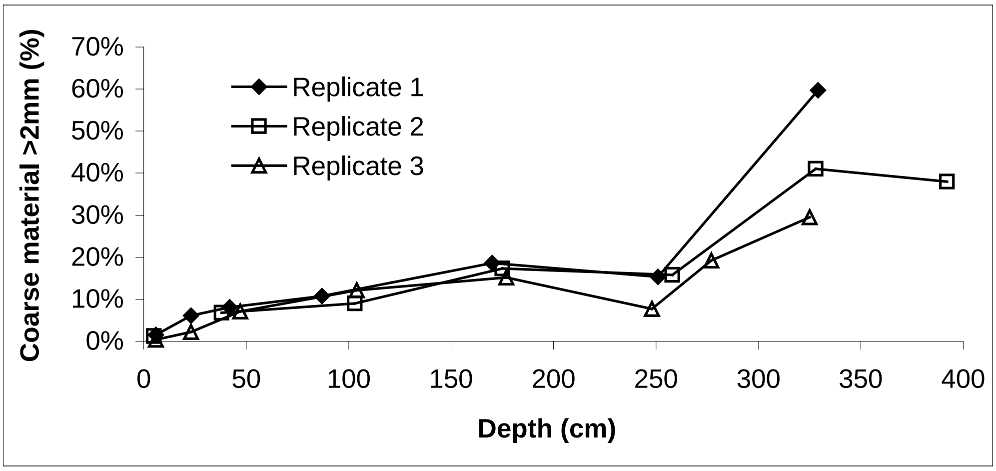

Colwell K (mg/kg)
100
80
60
40
20
0
Total K (mg/kg)
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
500
Depth (cm)
Colwell K
Total K

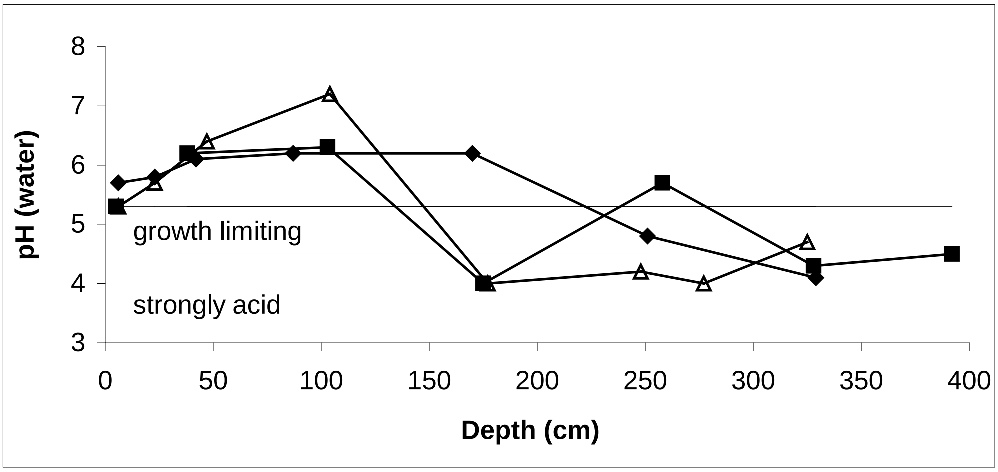

S (mg/kg)
50
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
Depth (cm)

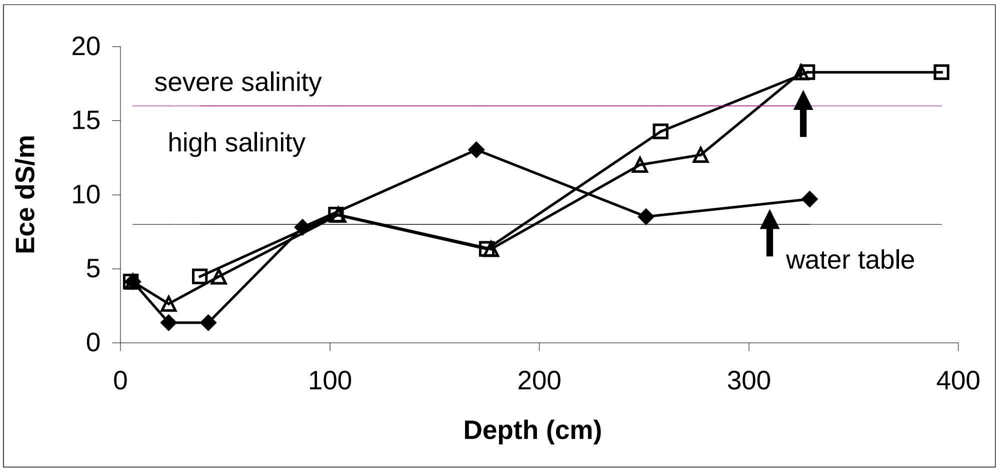

Organic carbon (%)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
100
200
300
400
500
Depth (cm)

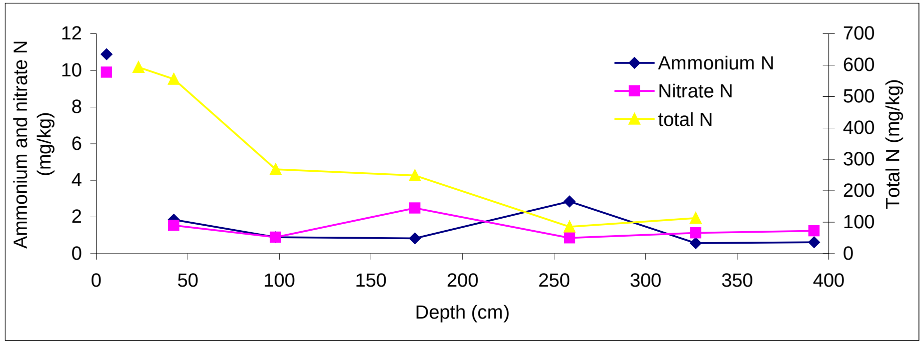
Site 17 Drill log

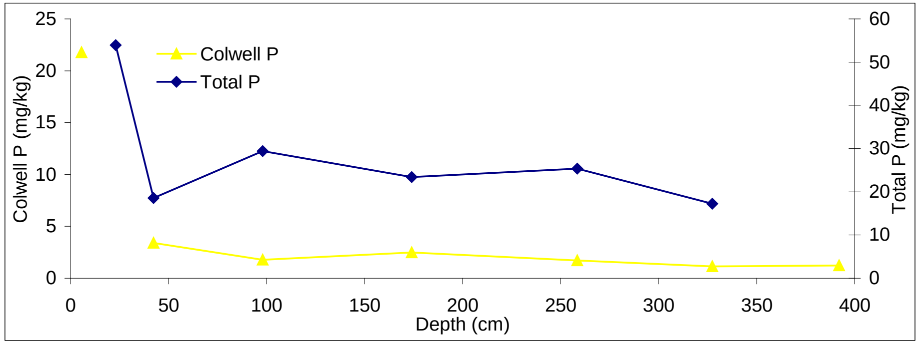
Rep	Depth (cm)	Description
1	0-11	grey/brown sandy loam
	11-51	orange brown sandy clay
	75-150	brown clay with orange and white mottles
	150-357	white clay with red mottles numerous silcrete layers below 245
		water table 3.2m
2	0-10	brown sandy loam
	10-26	orange/brown sandy loam
	26-130	brown clay with red/orange/white mottles
	150-409	red/white/orange mottled clay increasing silcrete bands with depth
		Water table 3.3m
		500 - too hard to drill further
3	0-13	brown sandy loam
	13-33	orange sandy loam
	33-150	brown clay with orange mottles
	150-270	grey clay with orange and red mottles
	225-270	grey clay - crumbly. A few orange and red mottles
	270-350	red clay with white and orange mottles increasing bands of silcrete with depth
		hole collapsed at 2.8m - no water depth recorded. Hard drilling below 3300cm

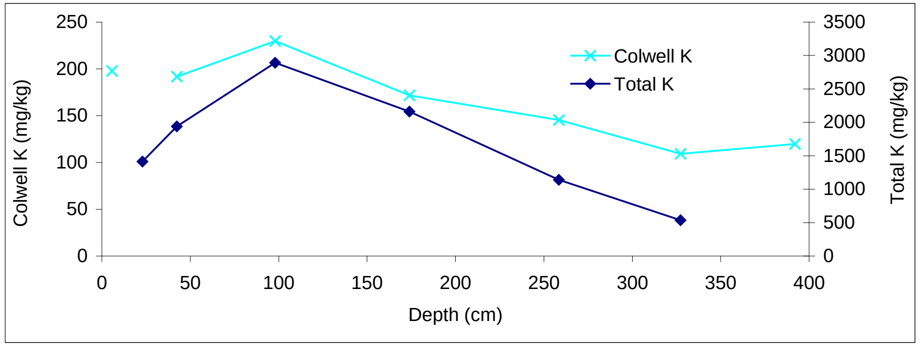

Coarse material >2mm (%)
70%
60%
50%
40%
30%
20%
10%
0%
Replicate 1
Replicate 2
Replicate 3
0
50
100
150
200
250
300
350
400
Depth (cm)

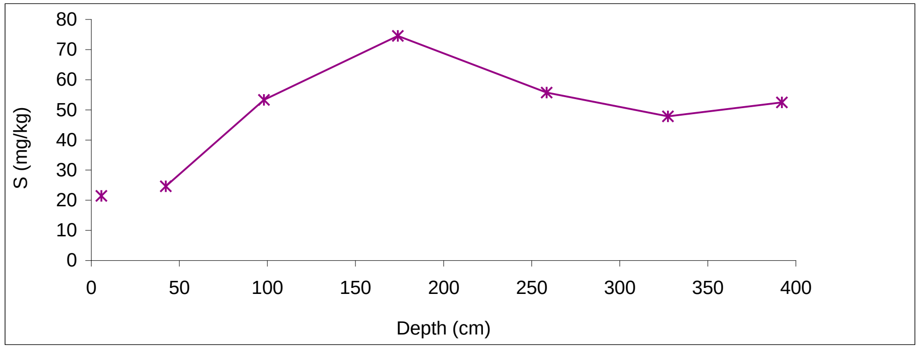

pH (water)
8
7
6
5
4
3
growth limiting
strongly acid
0
50
100
150
200
250
300
350
400
Depth (cm)

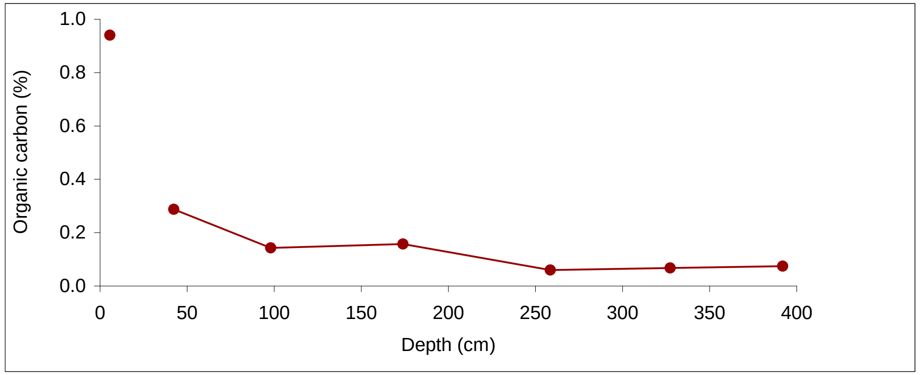

Ece dS/m
20
15
10
5
0
severe salinity
high salinity
water table
0
100
200
300
400
Depth (cm)


Ammonium and nitrate N (mg/kg)
12
10
8
6
4
2
0
Total N (mg/kg)
700
600
500
400
300
200
100
0
Ammonium N
Nitrate N
total N
0
50
100
150
200
250
300
350
400
Depth (cm)


Colwell P (mg/kg)
25
20
15
10
5
0
Total P (mg/kg)
60
50
40
30
20
10
0
Colwell P
Total P
0
50
100
150
200
250
300
350
400
Depth (cm)

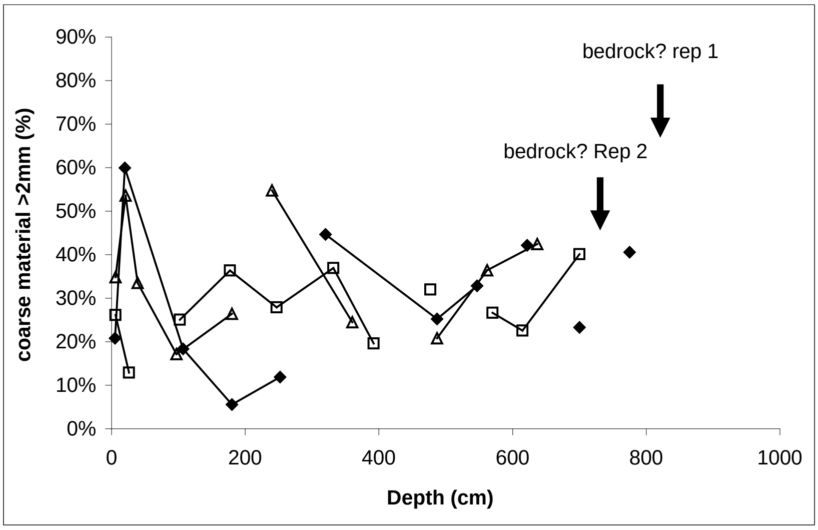

Colwell K (mg/kg)
250
200
150
100
50
0
Total K (mg/kg)
3500
3000
2500
2000
1500
1000
500
0
Colwell K
Total K
0
50
100
150
200
250
300
350
400
Depth (cm)


S (mg/kg)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Depth (cm)

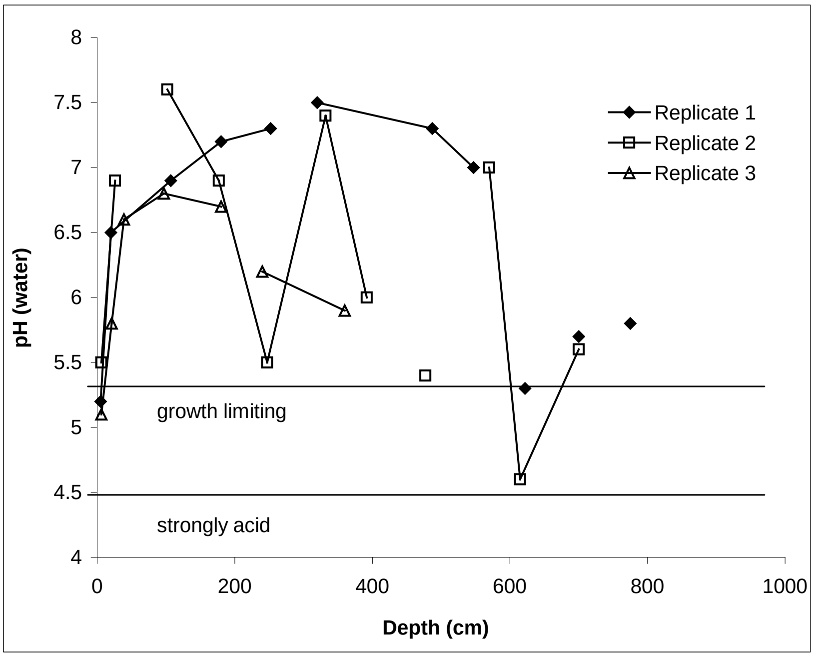

Organic carbon (%)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
Depth (cm)

Site 18 Drill log

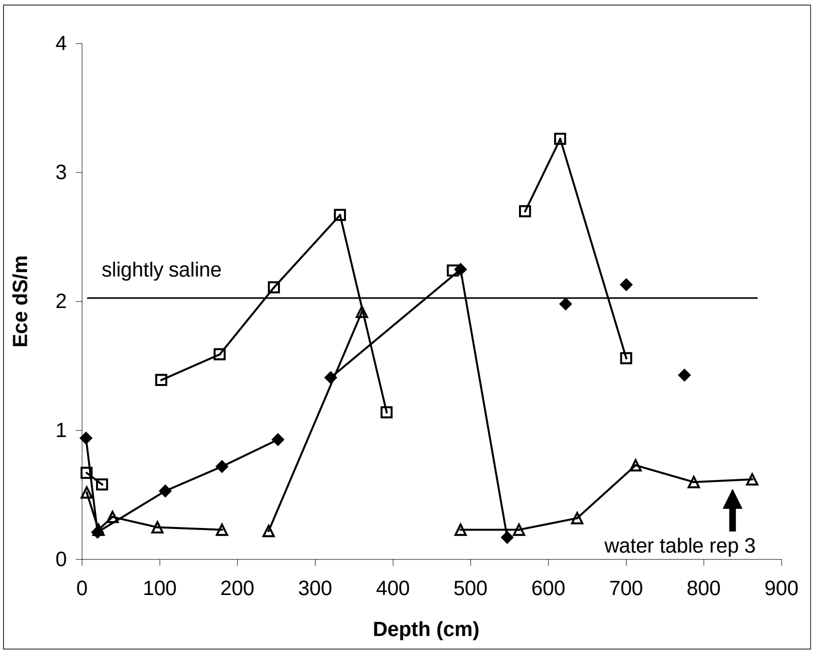
Rep	Depth (cm)	Description
1	0-10	Topsoil
	10-45	gravelly sand
	45-150	orange/red mottled clay
	150-450	White clay red mottles/bands with some cementing
	450-525	White clay red mottles/bands with some cementing
	525-555	white kaolin clay with red cemented ironstone bands
	555-750	deep red cemented ironstone bands
	750-800	as above + mica
		?bedrock at 800
2	0-13	Topsoil
	13-40	gravelly sand
	40-150	orange clay
	150-205	orange red mottled clay quartz grit
	225-300	white/grey clay red mottles gritty
	300-675	white clay red mottles (some cementing) gritty
	675-725	red/white/grey bands gritty some cementing in red bands mica at 6750
3	0-13	topsoil
	13-45	gravelly sand
	45-150	brown/orange clay + ironstone gravel
	150-750	white clay with red bands -some cementing
	750-900	saprolite with micas
		free water at 770



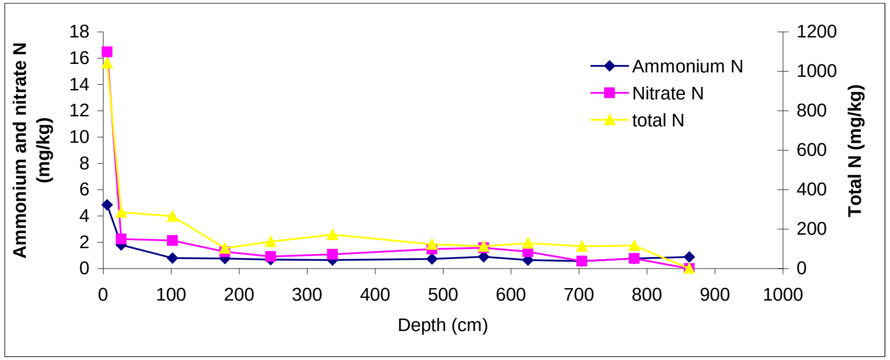
bedrock? rep 1
bedrock? Rep 2
coarse material >2mm (%)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
0
200
400
600
800
1000
Depth (cm)

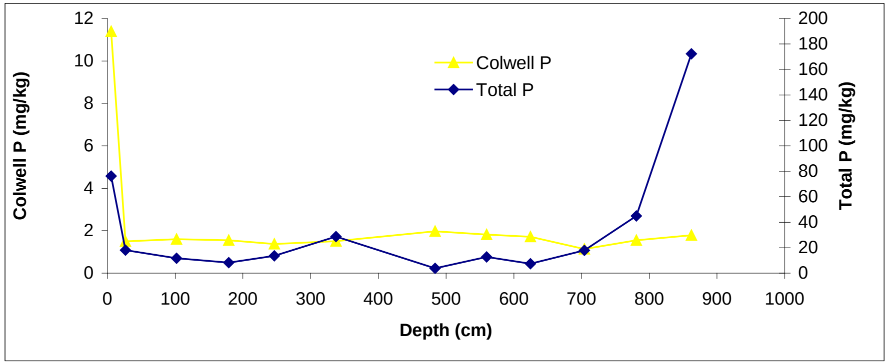


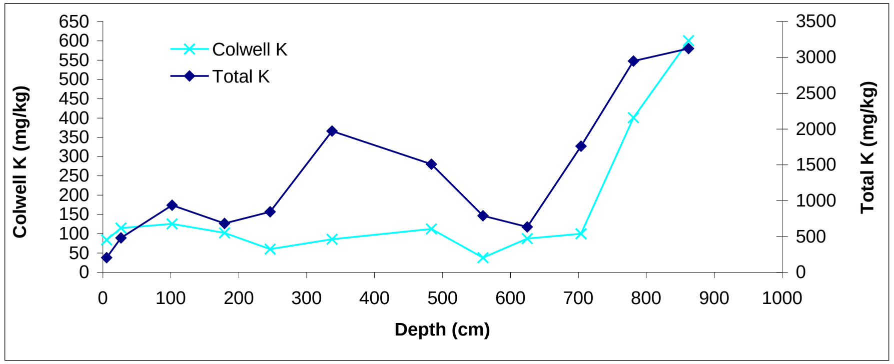
pH (water)
4
4.5
5
5.5
6
6.5
7
7.5
8
Replicate 1
Replicate 2
Replicate 3
growth limiting
strongly acid
0
200
400
600
800
1000
Depth (cm)

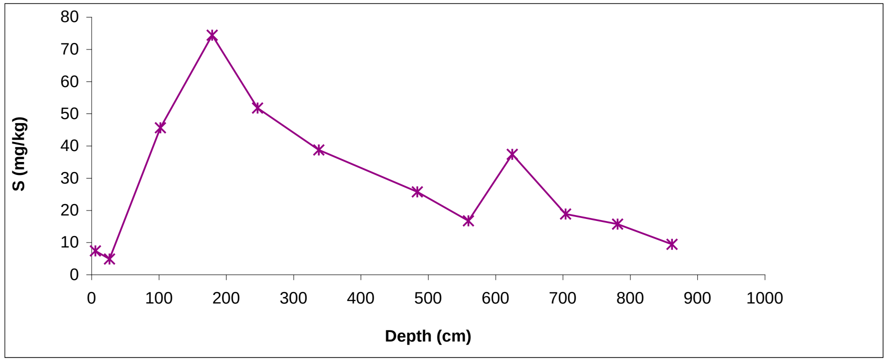


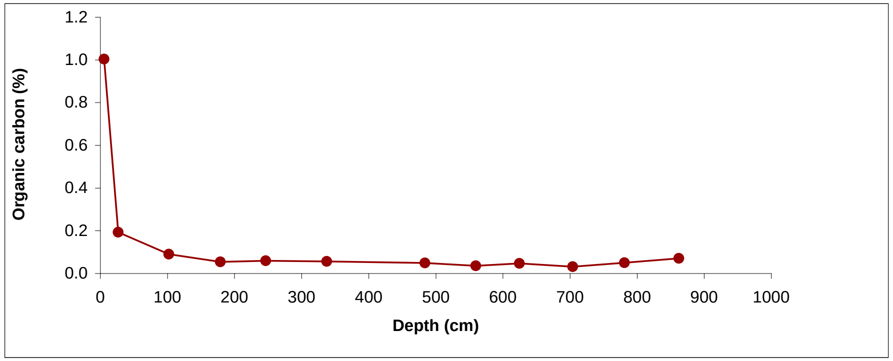
Ece dS/m
0
1
2
3
4
slightly saline
water table rep 3
0
100
200
300
400
500
600
700
800
900
Depth (cm)


Ammonium and nitrate N (mg/kg)
0
2
4
6
8
10
12
14
16
18
Total N (mg/kg)
0
200
400
600
800
1000
1200
Depth (cm)
0
100
200
300
400
500
600
700
800
900
1000
Ammonium N
Nitrate N
total N


Colwell P (mg/kg)
0
2
4
6
8
10
12
Total P (mg/kg)
0
20
40
60
80
100
120
140
160
180
200
Depth (cm)
0
100
200
300
400
500
600
700
800
900
1000
Colwell P
Total P

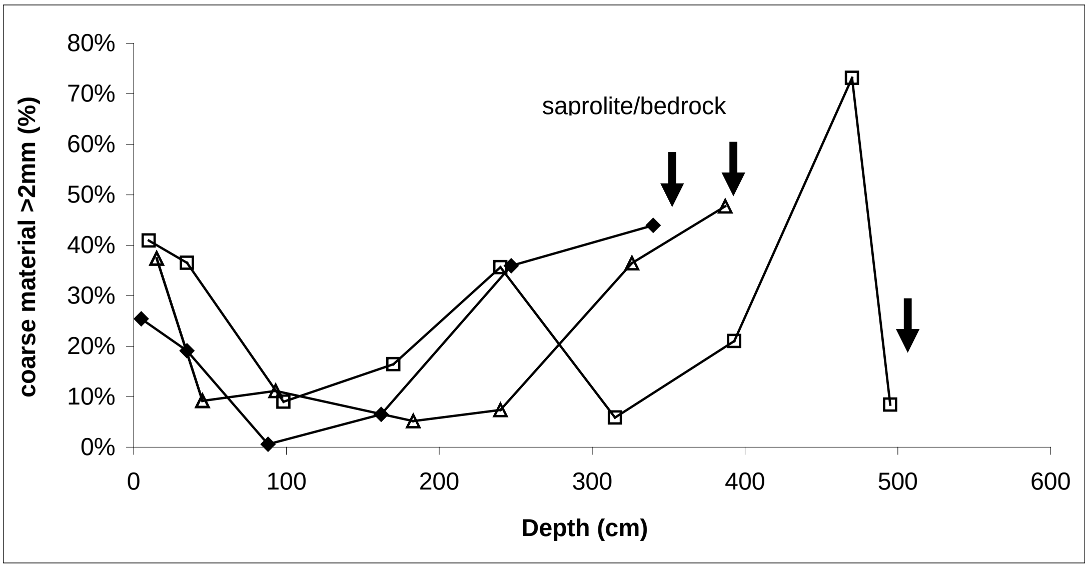

Colwell K (mg/kg)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
Total K (mg/kg)
0
500
1000
1500
2000
2500
3000
3500
Depth (cm)
0
100
200
300
400
500
600
700
800
900
1000
Colwell K
Total K

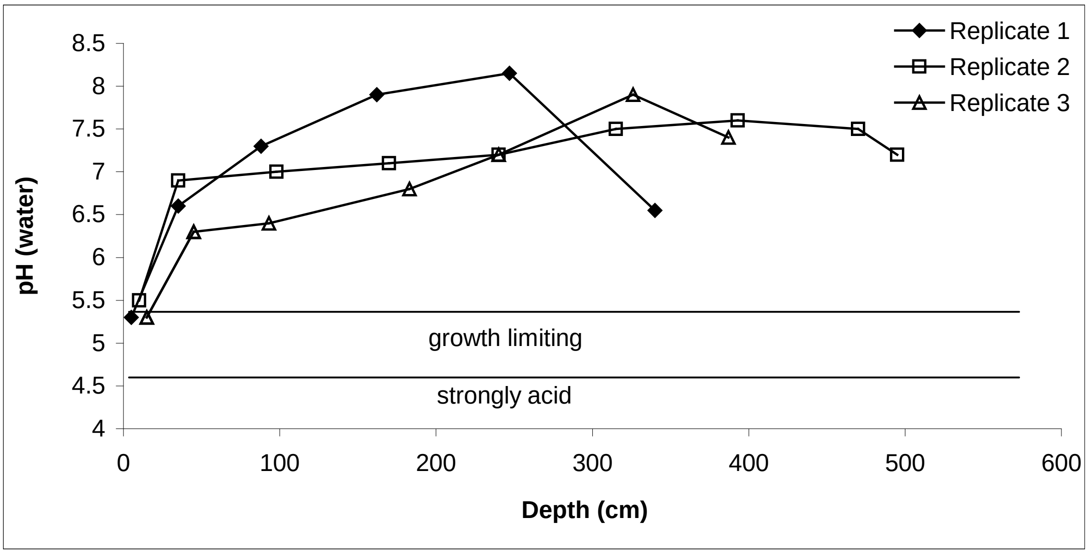

S (mg/kg)
0
10
20
30
40
50
60
70
80
Depth (cm)
0
100
200
300
400
500
600
700
800
900
1000

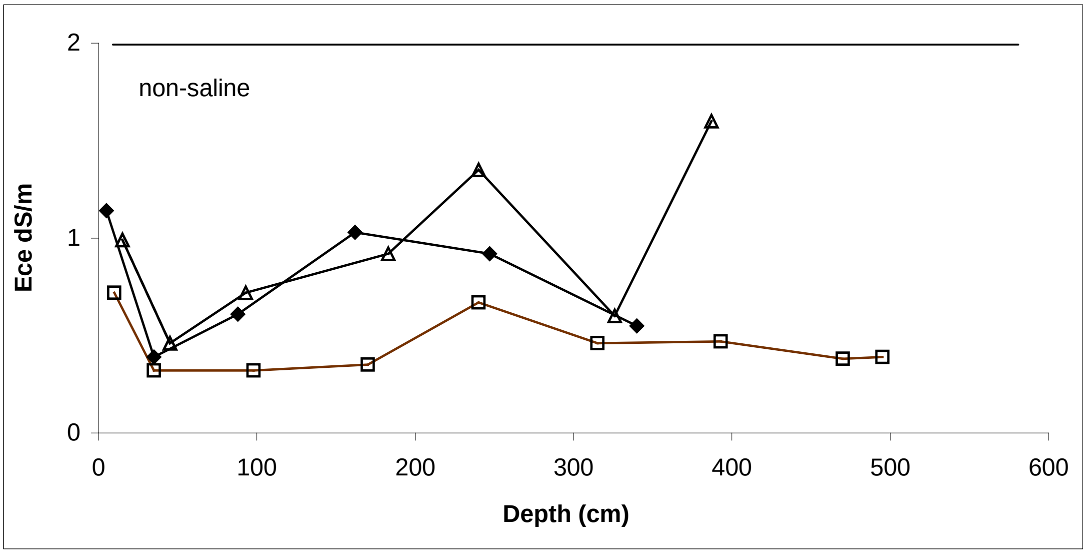

Organic carbon (%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Depth (cm)
0
100
200
300
400
500
600
700
800
900
1000

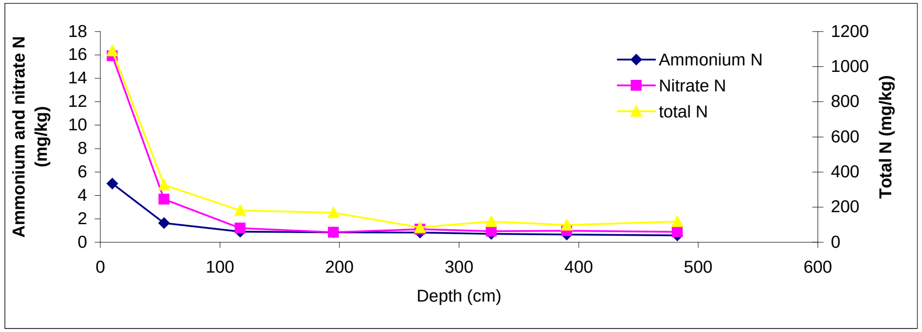
Site 19 Drill log

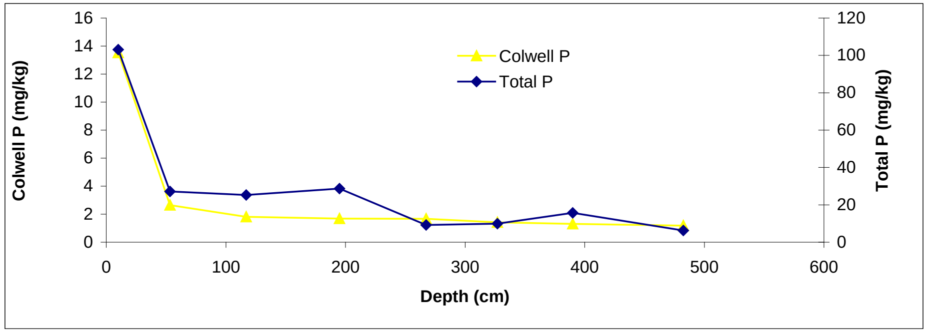
Rep	Depth (cm)	Description
1	0-10	sandy loam topsoil
	10-150	orange/brown clay some ironstone nodules
	150-200	brown claywith grey mottles
	200-300	grey clay with red bands very gritty ?cemented at 200
	300-345	gritty rotten rock with clay and mica
	375-380	saprolite - dry
2	0-19	sandy loam topsoilwith irone stone nodules
	19-150	orange clay with irone stone nodules
	150-200	red/white clay ironstone in red bands
	200-300	as above
	300-450	grey gritty clay few red mottles very gritty to cemented quartz at 430
	375-430	as above with very gritty to cemented quartz at 430
	490-500	brown clay / saprolite
		?bedrock at 500
3	0-30	sandy loam topsoil
	30-75	orange clay with red mottles
	75-150	orange clay with red and white mottles gritty
	150-300	grey-white clay with red and orange mottles very gritty
	225-255	as above
	300-355	red clay with orange bands very coarse grits and mica
	375-400	saprolite with bedrock
		dry at 400

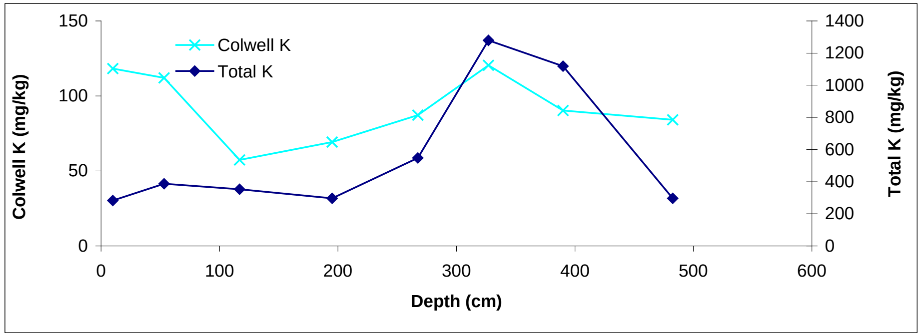

coarse material >2mm (%)
80%
70%
60%
50%
40%
30%
20%
10%
0%
saprolite/bedrock
0
100
200
300
400
500
600
Depth (cm)

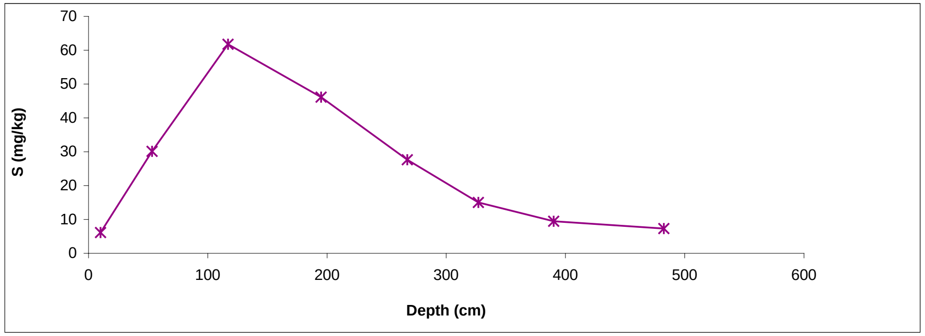

pH (water)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
Replicate 1
Replicate 2
Replicate 3
growth limiting
strongly acid
0
100
200
300
400
500
600
Depth (cm)

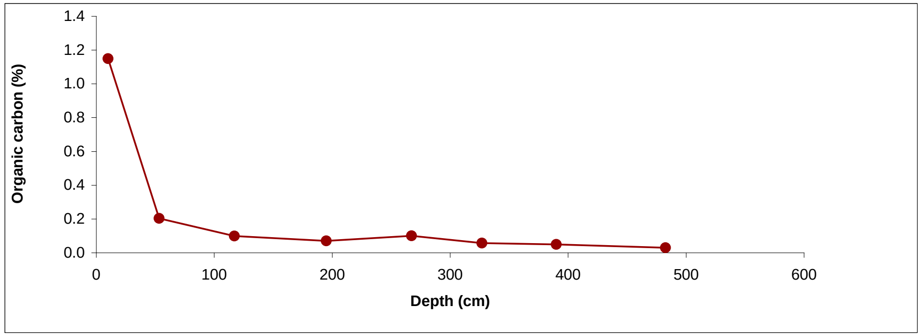

Ece dS/m
2
1
0
non-saline
0
100
200
300
400
500
600
Depth (cm)


Ammonium and nitrate N (mg/kg)
18
16
14
12
10
8
6
4
2
0
Total N (mg/kg)
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
Depth (cm)
Ammonium N
Nitrate N
total N


Colwell P (mg/kg)
16
14
12
10
8
6
4
2
0
Total P (mg/kg)
120
100
80
60
40
20
0
0
100
200
300
400
500
600
Depth (cm)
Colwell P
Total P

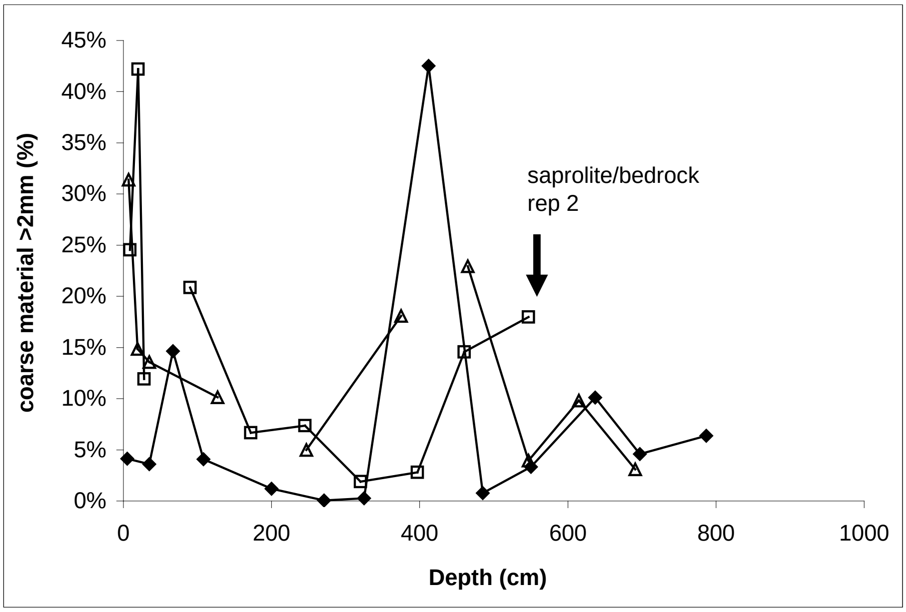

Colwell K (mg/kg)
150
100
50
0
Total K (mg/kg)
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
Depth (cm)
Colwell K
Total K

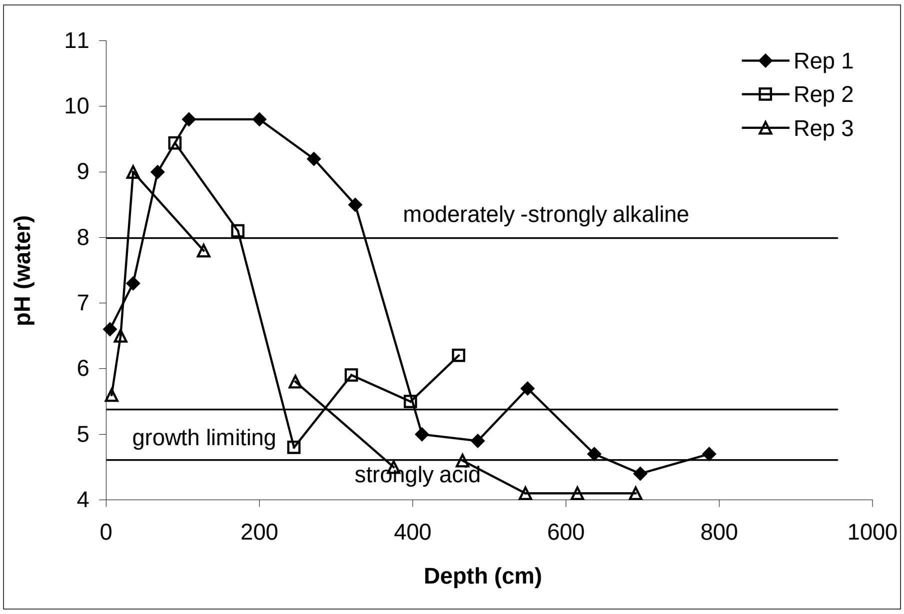

S (mg/kg)
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
Depth (cm)

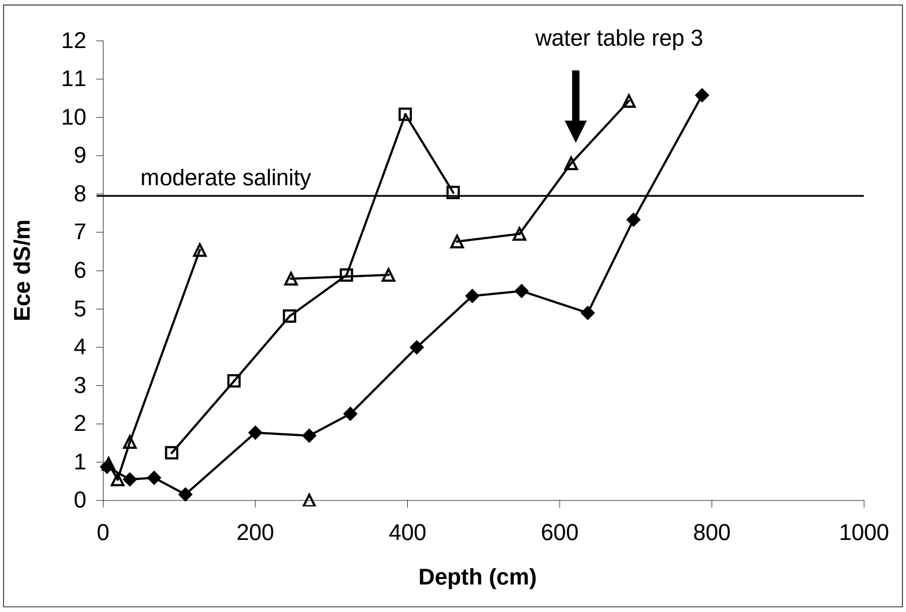

Organic carbon (%)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
Depth (cm)

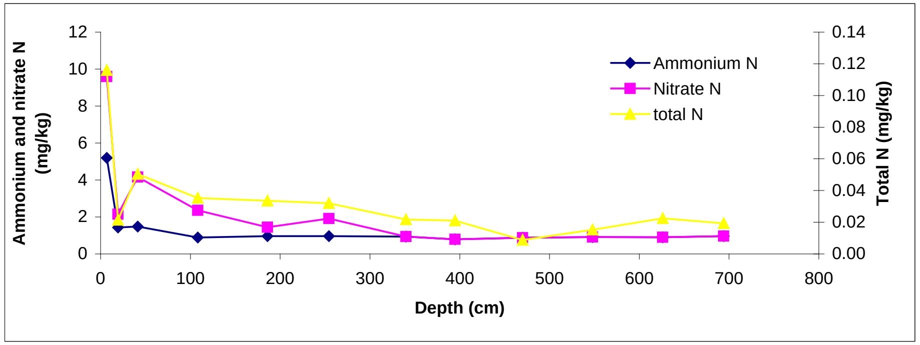
Site 20 Drill log

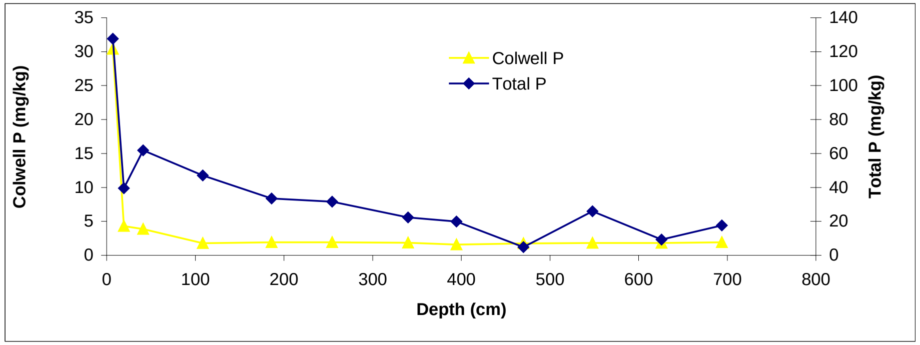
Rep	Depth (cm)	Description
1	0-10	sandy loam topsoil
	10-150	yellow/brown clay gritty
	150-225	yellow/brown clay gritty + lime nodules
	225-3375	orange red mottled clay
	375-520	red/orange/grey mottled clay iron stone nodule throughout, relic root at 450
	525-575	grey clay red and orange mottles
	600-675	white/grey clay red mottles
	675-750	red orange mottled clay
	750-825	white sand
		dry at 7.8 m
2	0-18	sandy loam topsoil
	18-30	grey/white gravelly sand
	30-200	orange clay with ironstone gravel
	200-300	red clay white mottles
	300-340	cemented ironstone
	340-420	white /grey clay gritty
	450-470	white /grey clay gritty with layers of cemented/saprolite
	470-570	grey clay saprolite bedrock at 580 dry
		bedrock at 580 dry
3	0-14	sandy loam topsoil
	14-25	white sand little gravel
	25-75	orange brown loamy clay
	75-200	gritty orange clay
	200-375	white clay red mottles ironstone
	375-500	red and white bands of clay cementing in red bands
	500-600	white clay with red mottles
	600-630	white clay with red mottles with grits
	675-710	grey clay with gritty quartz
		free water at 610

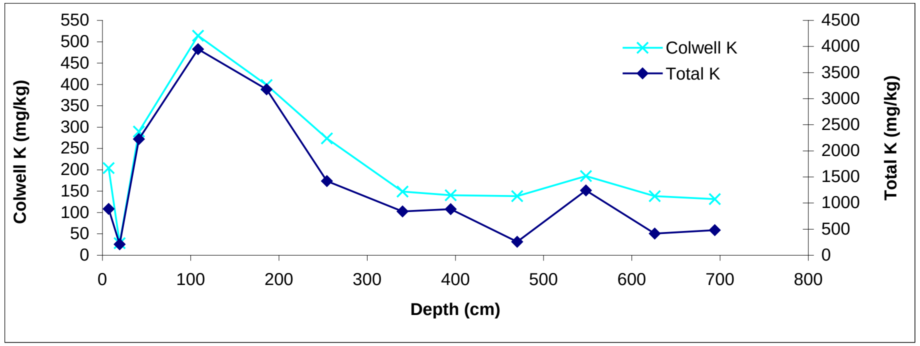

coarse material >2mm (%)
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
200
400
600
800
1000
Depth (cm)
saprolite/bedrock
rep 2

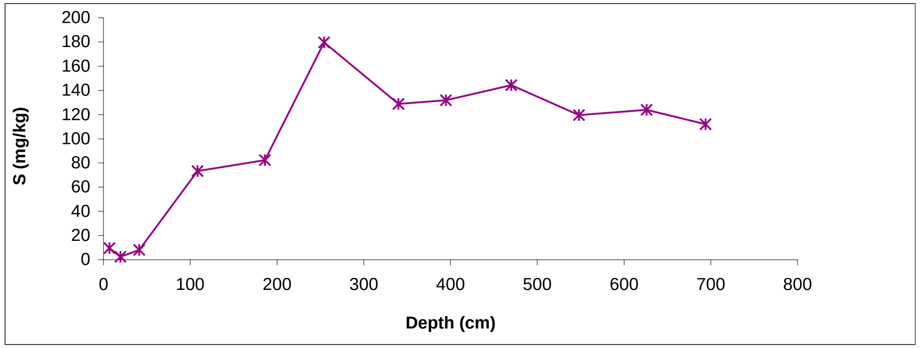

pH (water)
11
10
9
8
7
6
5
4
0
200
400
600
800
1000
Depth (cm)
Rep 1
Rep 2
Rep 3
moderately -strongly alkaline
growth limiting
strongly acid

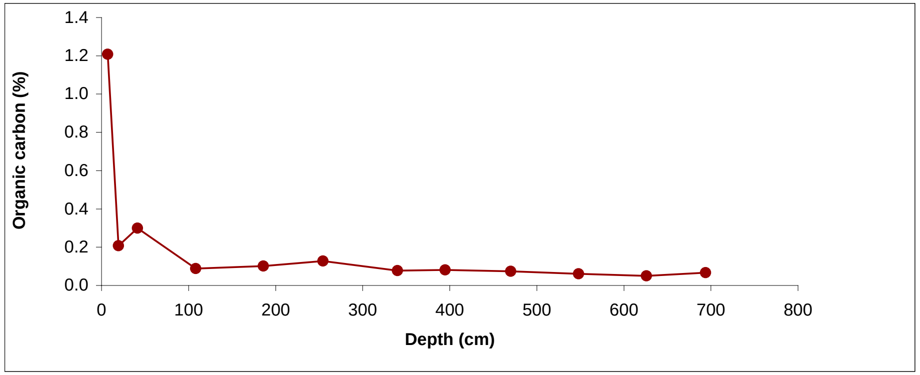

Ece dS/m
12
11
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
Depth (cm)
water table rep 3
moderate salinity


Ammonium and nitrate N (mg/kg)
12
10
8
6
4
2
0
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Total N (mg/kg)
Ammonium N
Nitrate N
total N
0
100
200
300
400
500
600
700
800
Depth (cm)


Colwell P (mg/kg)
35
30
25
20
15
10
5
0
140
120
100
80
60
40
20
0
Total P (mg/kg)
Colwell P
Total P
0
100
200
300
400
500
600
700
800
Depth (cm)


Colwell K (mg/kg)
550
500
450
400
350
300
250
200
150
100
50
0
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Total K (mg/kg)
Colwell K
Total K
0
100
200
300
400
500
600
700
800
Depth (cm)


S (mg/kg)
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Depth (cm)


Organic carbon (%)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
700
800
Depth (cm)

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Productivity of Mallee Agroforestry Systems

by Adam Peck, Rob Sudmeyer, Dan Huxtable, John Bartle and Daniel Mendham

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This report provides the only available long-term, large sample measurements of mallee belt yield and competition impact. The analysis showed that a strong improvement in profitability might be achieved by widening the inter-row space of the standard two-row belt (currently 2 m) out to 8 m or more.

The report aims to provide hard evidence for policy makers, professions, entrepreneurs, natural resources management operatives and farmers to enable sound judgements to be made about likely viability of mallee biomass production. In particular, it hopes to sustain the confidence of the large number of farmers in WA who have undertaken pre-commercial mallee planting and indicated the grass-roots strength of the mallee concept.

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