Tradeoffs between pasture production and plant diversity and soil health attributes of pasture systems of central Queensland, Australia

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Abstract

Clearing land of trees and introduction of exotic pastures to enhance pasture production and hence monetary gains is generally practised in Queensland. Large areas of land have been cleared in the past and clearing continues currently. The results from many previous studies on tree clearing emphasised the gains in pasture production, but over periods of less than 10-15 yrs after clearing, thus potentially misleading land managers who plan to continue grazing beyond that time. The present research follows an integrated approach to study the pasture yield and the ecological effects of tree clearing over time-since-clearing on a grazing property in central Queensland, and to evaluate the implications of our findings for the region. The cleared pasture systems were taken at three different times of clearing i.e. 5 yr, 11-13 yr and 33 yr, in comparison to their paired uncleared pastures for three major types of tree communities (<u>representative</u> of the region) <u>Eucalyptus populnea</u>, <u>Eucalyptus melanophloia</u> and <u>Acacia harpophylla, selected on a grazing property</u>.

The effects of clearing were determined for pasture production, pasture plant species, soil properties (organic carbon, available N (NO_3^-), pH_w and microbial biomass (C and N)), and litter production across three different ages of clearing and uncleared treatments of each tree community. With clearing, pasture production generally increased but, plant diversity, litter production and potential return of N and P through litter decreased. Among soil attributes, clearing of trees adversely impacted upon soil pH and microbial biomass, which play an important role in nutrient availability and mineralisation.

The paper evaluates the effects of clearing on individual attributes as well as an integrated effect of these attributes, i.e., overall ecological services. The multivariate analysis for the above mentioned ecological attributes suggested that at the 33 yrs age of clearing, the ecological state of pasture systems changed compared to that at 5 yr or 11-13 yr or at uncleared system. Most likely, a disturbed pasture system may take longer to revert to the original state compared to the time that would have taken to harvest the benefits. Tree clearing may project initial production gains for developing pastures, but these gains are not sustainable over time and are accompanied with loss of plant diversity, soil microbial biomass and nutrient return through litter, and change in soil pH. The results are important for landholders and policy makers to understand the actual benefits or losses of tree clearing for pasture development over a long term.

Key words: Tree clearing, soil organic carbon, soil pH, soil nitrate, soil microbial biomass, pasture yield, litter production, ecosystem functions

1. Introduction

Tree clearing has commonly been practised for greater pasture production and monetary gains in grazing systems of Queensland until recently. Most of the cleared land is then sown to exotic grass species such as <u>Cenchrus ciliaris</u> L. following raking and burning of wooden logs, thus sets up monoculture pastures. The high rates of clearing in the past especially after 1950s, and even lately in 1999-2001, 577,000 ha of land cleared per year (Department of Natural Resources and Mines, 2003), was mainly to develop pastures (94% of total cleared land in 1999-2001). Until 1985, even government policies favoured clearing to develop land for pastoral and agricultural systems (Boulter et al., 2000). Recently, a change in government policies to stop land clearing from 31st of August 2004 was implemented, based mainly upon the losses of biodiversity, without much access to information on the long term effects of clearing on productivity of pasture systems or on soil properties which are equally important for a landholder. Thus, it becomes difficult for the landholders to understand and adapt to the change in governmental policies from clearing (until 1985; Boulter et al., 2000) to that more recently of no clearing, without provision of information on the long-term effects of clearing.

Most studies to date (Scanlan and Burrows, 1990; Burrows, 1993; Burrows et al., 1999) have highlighted the production gains from clearing, but these were limited to <10 years of age of cleared pastures (Scanlan, 2002). Indeed, the initial gain in pasture production with clearing is the only attractive phase for the landholders to clear land for pastures. These earlier studies highlighted the gains in pasture production, but without considering the associated loss of other ecological services. There are increasing concerns that most of the

1   development that occurred in the past involved little understanding of ecosystem functions

2   and of the inherent potential of natural resources available on the Australian continent

3   (Boulter et al., 2000).

4   For this, three major woodland communities, each dominated by <u>Eucalyptus populnea</u> F.

5   Muell.*,* <u>E. melanophloia</u> F. Muell. and <u>Acacia harpophylla</u> F. Muell. ex. Benth. were

6   selected on one property to quantify the impacts of clearing on pasture production and

7   composition, soil properties (organic carbon, available N (NO_3^-), pH_w and microbial

8   biomass (C and N)), and litter production. The impacts were measured over time of at

9   recent (<5 years), medium (11-13years) and old (>30 years)) age of cleared pastures in

10   comparison to their uncleared (intact) woodland pastures of each tree community.

11   Our aim was to study the sustainability of cleared and uncleared pastures in terms of:

12   • pasture yield

13   • plant diversity, and litter production and N and P return

14   • soil health (soil organic carbon, soil NO_3^-, soil microbial biomass and pH)

15   The present research provides important information for the landholders and the policy

16   decision makers to help them to take the correct decisions for the good of future pasture

17   systems based upon the integrated effects of long term clearing on production and other

18   ecological attributes of pasture systems. It is based upon a detailed study conducted on a

19   grazing property in central Queensland region.

1

2   **2. Materials and methods**

3   Paired sites of cleared and uncleared woodlands for E. populnea (poplar box), E.

4   melanophloia (silver-leaved ironbark) and A. harpophylla (brigalow) communities were

5   selected across three age groups of clearing i.e. recent (5 yr), medium (11-13 yr) and old

6   (33 yr) on a property "Avocet" (30 km. south of Emerald) in central Queensland, Australia.

7   The sites were selected with the guidance of research staff at Department of Natural

8   Resources and Mines, and at Environmental Protection Agency, Emerald, to be the

9   representative vegetation types of the region.

10   The study represents a 3 (types of tree communities) x 3 (time since clearing) x 2 (cleared

11   v/s uncleared) factorial design. The paired cleared and uncleared sites were selected in

12   close proximity with the assumption to have similar original biophysical characteristics

13   (soil type, slope and vegetation) before clearing (according to information provided by the

14   landholder), and to some extent to minimize variation in grazing management for the same

15   cattle grazed the cleared and their paired uncleared sites. The methods of tree clearing

16   applied to sites slightly differed, along with number of cattle grazing these sites (Table 1).

17   At each site, a representative area of one ha of the total area (minimal >20 ha) at each site

18   was marked for data collection.

19   **2.1 Above-ground pasture biomass and pasture composition**

20   At the centre of the selected 1 ha area at each site, a fenced plot of 10 m x 10 m (exclosure

21   – to exclude grazing) was marked to determine pasture above-ground biomass and

1   composition. The quadrat method (Kent and Coker, 1992) was used and a quadrat size of 1

2   m x 1 m, derived from the stable number of species per unit area based upon preliminary

3   analysis, was chosen. Measurements were taken from five randomly assigned quadrats

4   located at different positions across sampling dates for different seasons in a year; in

5   March 2001, July 2001 and November 2001 and March 2002. All the plant samples from

6   each quadrat were harvested just above-ground level, taken to the laboratory and dried at

7   60 $^{\circ}$C for 48 hours to determine their biomass. Average quantity of pasture above-ground

8   biomass for grazing was calculated over a year from the seasonal measurements. For

9   repeated measurements i.e. March 2001 and March 2002, their average was considered

10   along with the July 2001 and November 2001 seasonal measurements. All types of plants

11   in a quadrat were identified to study the species composition.

12   The data were collected from both the fenced and unfenced sites however the results are

13   presented inhere for fenced plots only, since the trends were similar at both the fenced and

14   unfenced sites (Sangha, 2003).

15   **2.2 Litter production**
16
17   Litter production was measured at unfenced sites (each of one ha) using the paired-plot

18   technique (Wiegert and Evans, 1964). The measurements started in March 2001 and were

19   taken at regular 4 monthly intervals until March 2002. On each occasion, three random

20   quadrats of 1 m x 1 m were laid in three different directions and these quadrats were

21   marked for the next set of readings in their adjacent (paired) quadrats. In each quadrat, the

22   standing green herbage was removed and dead litter fallen on the ground was collected.

23   The samples were screened to exclude large sticks of circumference >1 cm, air dried, and

1   weighed. For the next sampling date in July 2001, litter was collected from the quadrats

2   adjacent to ones that were used in the previous season i.e. March 2001. Samples were

3   processed in the same way as in March 2001. The same procedure was followed in

4   November 2001 and March 2002. To measure the quantity of litter produced per season,

5   amount of litter decomposed during that season was taken into account (Table 2), for

6   example amount of litter produced at time t_0 was X_0 and at t_1 time was X_1, and R_1 was the

7   rate of decomposition for t_0-t_1, so total litter produced during t_0-t_1 = X_1-X_0+R_1 .

8   Decomposition of litter was studied using the litter bag technique over the same sampling

9   dates as for litter production. This was necessary to account for the loss of litter that

10   underwent decomposition between two successive sampling dates, to ensure accurate

11   estimation of the total amount of litter produced over a particular season. The average

12   amount of litter produced over a year was computed from litter produced during different

13   seasons.

14   Litter samples collected in March 2001 (without decomposition) from each site were

15   thoroughly mixed, ground, and analysed for N (using CHN analyser) and P (using ICP)

16   (standard methods described by Carter, 1993; Peverill et al., 1999) at the soil laboratories

17   of Incitec Ltd, Brisbane, Queensland.

18   **2.3 Soil properties**

19   Soil samples were taken (bulked for 8 cores per site) from unfenced sites (1 ha area) in

20   January 2002 using hydraulic soil rig, for different depths (0-5, 5-10, 10-20, 20-30, 30-60

21   cm). Samples were processed to remove visible roots and pebbles, and analysed at the soil

22   laboratories of Incitec Ltd (Brisbane) for soil organic carbon (SOC) (Walkey and Black

1   method using H_2SO_4 and $K_2Cr_2O_7$ in 1:100 dilution, measured colormetrically), soil pH_w (1

2   to 5, soil to water dilution using combination electrode), and soil NO_3^- (1:5 soil to water,

3   centrifuged nitrate measured colorimetrically in segmented flow analyser) (according to

4   methods described in Carter, 1993; Peverill et al., 1999).

5   To determine the microbial biomass of C (SMB-C) and N (SMB-N), samples were taken

6   from the top 0-5 cm soil in March 2002, immediately stored in cold container, and

7   analysed using the chloroform fumigation extraction method (Vance et al., 1987) at the

8   Natural Resource Sciences Laboratories (Department of Natural Resources, Mines and

9   Energy, Indooroopilly, Brisbane, Queensland).

10   **2.4 Statistical analysis**

11   Individual effects of tree clearing on pasture biomass and litter production were analysed

12   using Genstat ver 6.0 (2002). The residual maximum likelihood (REML) (Patterson and

13   Thompson, 1971) method was used. The main effects for type of tree community and

14   uncleared-cleared (recent, medium and old) treatments within each tree community were

15   analysed. Models included the fixed effects of community, clearing treatments plus their

16   interaction (community*cleared-uncleared), and the random effects of age since clearing

17   and uncleared treatments within a community. If the interaction between community and

18   cleared-uncleared treatments was not significant (*P<0.05*) then it was removed from the

19   fixed model to test the main effects. The variance matrix derived from REML analysis was

20   used to calculate approximate LSDs (least significant differences of means) at *P <0.05*.

21   The means from REML analysis were used in presenting the results.

1   For species diversity, Shannon Wiener's index was calculated using species diversity and

2   richness software (Henderson and Seaby, 1998; PISCES Conservation Ltd).

3   For soil properties, the same tool REML was used as for pasture biomass and litter data.

4   The main effects (fixed terms) of tree community (<u>E. populnea</u>, <u>E. melanophloia</u> and <u>A.</u>

5   <u>harpophylla</u>), cleared (recent, medium, old age of clearing) and uncleared treatments, and

6   soil depth (each for 0-5, 5-10, 10-20, 20-30 and 30-60 cm depth) plus their interactions

7   were analysed. The correlation within a treatment across different depths was analysed for

8   all the main effects by applying the most suitable variance model AD2 (Antedependence

9   order 2). There was a significant ($P < 0.05$) three-way interactions (tree

10   community*cleared-uncleared*depth) for main effects in all the soil variables. For each

11   variable, LSDs (least significant differences of means) were used to compare cleared

12   (recent, medium, old) and uncleared treatments for each specific depth in a particular tree

13   type. The means from REML analysis were used to present the results.

14   To examine the integrated effect of studied attributes (pasture yield, species diversity, litter

15   production, SOC, NO_3^-, pH_w and soil microbial biomass (C and N)) in cleared and

16   uncleared pasture systems, data were analysed using multivariate analysis technique i.e.

17   canonical variates analysis (CVA) in Genstat (ver. 6.0) across all tree communities. All the

18   data were standardised for analysis.

19   The CVA was applied to determine the overall effect of clearing, as well as the attribute(s)

20   that would have been strongly influenced by clearing and could lead to differentiate

21   between cleared and uncleared treatments in all tree communities. There were not enough

1 replicates for cleared and uncleared treatments within a tree community to apply CVA to

2 examine the effects in each tree community. However, the data were analysed for all the

3 cleared and uncleared treatments irrespective of tree community. The CVA analysis finds

4 linear combinations of the original variables that maximize the ratio of between-group to

5 within-group variation where groups are cleared and uncleared treatments. Two canonical

6 variates (CV1 and CV2) were considered to explain variation between treatments. The

7 output from CVA presents an integrated impact of clearing in pasture systems.

8 **3. Results**

9 **3.1 Pasture above-ground biomass**

10 On average, pasture biomass was greater at cleared compared to uncleared sites, with

11 maximum production at medium age of clearing for E. populnea and A. harpophylla, and

12 at recent age of clearing for E. melanophloia (Table 3). However, the gains in pasture

13 biomass were not consistent over time-since-clearing and showed a trend to decline at old

14 compared to medium (in E. populnea and A. harpophylla) or recent age (in E.

15 melanophloia) of clearing in all the tree communities. Interestingly, in E. melanophloia,

16 the uncleared and old cleared sites did not differ significantly ($P<0.05$) in pasture yield.

17 Although the pasture yield was greater at cleared than uncleared sites, pasture plant

18 diversity (Shannon Wiener's index of diversity) was significantly greater at uncleared

19 compared to all the cleared treatments in all tree communities (Table 3). Within cleared

20 sites, species diversity declined at medium and old cleared sites compared to recent cleared

21 sites.

1 **3.2 Litter production**

2 The total amount of litter produced over a year (kg ha^{-1}), important to account for the

3 return of nutrients for pasture growth, was greater at uncleared compared to the cleared

4 sites in all the tree communities except the medium cleared treatments (in E. populnea and

5 E. melanophloia) (Table 4). The cleared treatments did not differ significantly ($P<0.05$)

6 from each other in total amount of litter produced per year.

7 The potential amount of N stored in litter produced (yearly) was greater at uncleared

8 compared to cleared sites in all tree types. P content was greater in litter produced at

9 medium cleared site compared to uncleared site in E. populnea and E. melanophloia. In A.

10 harpophylla, litter produced at uncleared sites had significantly ($P<0.05$) greater P content

11 than any of the cleared treatments (Table 4).

12 **3.3 Soil properties (soil organic carbon (SOC), NO$_3^-$, pH$_w$, and soil microbial biomass**
13 **(SMB-C and SMB-N))**

14 Tree clearing had no significant effect on SOC except for recent or medium clearing had

15 greater SOC in 0-10 cm and 30-60 cm depths than uncleared sites in E. populnea and A.

16 harpophylla (Fig. 1). The paired t-test between cleared and uncleared treatments

17 (irrespective of age group or tree type) for the average SOC in 0-60 cm depth also did not

18 suggest any significant effect of clearing. Similarly, the differences between cleared and

19 uncleared treatments were not evident for available N (NO$_3^-$) which was highly variable in

20 the top 0-10 cm depth (Fig. 2).

21 Clearing strongly influenced soil pH$_w$ across all tree communities. Soil pH$_w$ increased

22 significantly ($P<0.05$) with clearing in the top 0-5 cm for E. populnea and A. harpophylla

1   (Fig. 3). A significant increase in pH_w ($P<0.05$) due to clearing at 30-60 cm depth

2   especially at medium and old clearing was evident in all three tree types. The increase in

3   soil pH_w across all depths was closely related to time since clearing across all tree types (at

4   *P<0.05,* Y (increase in soil pH) = a+(-1.29)$^{(-0.041*time-since-clearing)}$; R^2= 0.42, where a varies

5   from 7.0 -7.9 for different tree communities).

6   The SMB-C was significantly ($P<0.05$) greater in uncleared soils (386±37 (standard error

7   of means) mg kg^{-1}) than cleared soils (254±37 mg kg^{-1}) and similarly for SMB-N (greater

8   at uncleared (40.17±3.29) than cleared (29.87±3.45)) sites, when analysed for all the

9   cleared and uncleared sites irrespective of age of clearing or tree type.

10 **3.4 Integrated effect of studied ecological attributes on the stability of a pasture**
11 **system**

12   The combined effect of clearing for various attributes on a pasture system was determined

13   with CVA (Canonical Variates Analysis). Two canonical variates (CV1) and (CV2) were

14   selected for recent, medium, old cleared and uncleared treatments across all tree

15   communities. The first canonical variate (CV1) distinguished the oldest cleared treatment

16   from medium and recent cleared, and uncleared treatments (CV1 explained 90 per cent of

17   variation among these treatments) (Fig 4). The old age of clearing was different to other

18   treatments mainly due to the combined effect of soil NO_3^-, pasture biomass, litter

19   production, species diversity and soil pH_w (Table 5). Comparatively greater values of

20   positive loadings for these attributes than the others suggested that recent and medium

21   cleared, and uncleared treatments had better soils with greater pasture biomass and litter

22   production than that the old cleared treatments. The greater value of negative loading for

1   pH_w demonstrated that pH_w was greater at the oldest clearing than at medium and recent

2   cleared, and uncleared treatments (Table 5).

3   Only a further 7 % of the variation between cleared and uncleared pasture systems was

4   explained by CV2. CV2 showed that the medium cleared treatment was different to the

5   recent and old cleared, and uncleared treatments (Fig 4). The species diversity and SMB-C

6   and SMB-N had a greater influence (positive loadings) on CV2 than did the other

7   attributes (Table 5). However, the differential response across species between age of

8   clearing for pasture yields obscured further meaningful interpretation of CV2.

9   **4. Discussion**

10   In the woodlands of east-central Queensland, the increase in pasture yield upon clearing

11   has been demonstrated in earlier studies by Burrows, (1993), Burrows et al., (1999), and

12   Scanlan and Burrows, (1990), and was also evident in the present study. The present

13   research furthermore demonstrated that more of such benefits exist over the initial years of

14   clearing not over a longer term (>30 years). From pasture production for cattle point of

15   view, the cleared exotic pastures are more beneficial. But the question is how long will the

16   increased pasture production benefits from clearing be maintained? The present study

17   suggested a trend for decline in pasture yield over time-frame since clearing. The benefits

18   of clearing for increase in pasture yield between cleared and uncleared treatments

19   narrowed with age of clearing especially from 13 years to 33 years. The duration of benefit

20   was in fact very short for E. melanophloia. Most importantly, the gains in pasture yield due

21   to clearing are associated with some tradeoffs, for example, loss of some ecological

22   attributes such as:

1   1. Decline in pasture plant diversity which may affect ecosystem stability.

2   2. Lesser return of nutrients through litter decomposition, which can imbalance the

3   nutrient cycle in cleared pastures compared to woodland pastures.

4   3. Changes in soil properties that could, by implication, affect the growth of pasture

5   species over a longer term.

6   **4.1. Impacts of clearing on plant diversity**

7   There is a trade-off between production and species diversity since most of the cleared

8   pastures are sown to one dominant exotic grass species that sets up mono-culture pastures.

9   The diversity of native plant species, important in maintaining various ecosystem functions

10   for the stability of a pasture system (Tilman *et al.,* 1997), is often compromised with high

11   production gains from exotic grass species in cleared pastures.

12   Reduced species diversity in cleared pasture systems could adversely affect the ecosystem

13   function such as hydrology and soil stability. Tilman *et al.* (1997) conducted a detailed

14   study on the diversity-productivity and diversity-sustainability in American grasslands, and

15   reported higher functional diversity in high diversity plots supported higher productivity.

16   The plots with higher number of species had greater functional diversity and were more

17   efficient in allocation of soil nutrients compared to the less diverse plots. The reduced

18   species diversity may affect the use of resources in cleared pastures as the diverse systems

19   possess better potential for use of resources due to greater functional diversity (Tilman,

20   1997). Ash *et al.* (1997) reported that C sequestration in soils improved with grass species

21   which were adapted to the edapho-climatic conditions (mostly native) of pasture systems

1 in northern Queensland. Diversity of native plant species can help in maintaining the

2 ecosystem functions of pasture systems in Queensland, but barely any report is available.

3 A detailed study on species diversity and productivity in native pastures in this context

4 may be very valuable.

5 **4.2. Impacts of clearing on litter production and nutrient return**

6 With clearing, the steady return of nutrients through litter (as in uncleared pastures) was

7 disturbed because of the lesser production of ground litter at cleared sites compared to

8 uncleared sites with a change in vegetation from woodlands to cleared pastures. This could

9 lead to a change in the natural equilibrium of nutrient return to the system that could affect

10 the pasture growth (Williams et al., 1993). The change in litter composition may lead to

11 further changes in microbial communities and in return of nutrients to soil through litter

12 decomposition (Kutsch and Dilly, 1999; Vetaas, 1992).

13 **4.3. Impacts of clearing on soil properties**

14 We acknowledge that there would have been more nutrients released in soil at the time of

15 clearing that would have been taken up quickly by the plants sown to cleared land, but we

16 could not notice the significant effect ($P<0.05$) of clearing on SOC and NO_3^-, most likely

17 due to time factor, since even our recent cleared sites were 5 years old. If the recent

18 clearing would have been 1 or 2 years old, it could be possible to notice increases in soil

19 nutrients, as Lawrence et al., (1988) reported an increase in P content in A. harpophlylla

20 just after clearing.

21 A prominent effect of clearing was evident on soil pH_w for increase with age of clearing

22 that adversely affected the availability of soil nutrients (Sangha, 2003). The change in

1 microbial biomass is also an important indicator of any change in soil health for greater

2 SMB is responsible for mineralisation of organic matter and hence the return of nutrients

3 for pasture growth (Jenkinson and Ladd, 1981). Loss of soil stability in terms of soil pH_w

4 and soil microbial biomass, thus, compromised pasture production gains.

5 The changes in soil pH_w or soil microbial biomass occur mainly due to change in soil

6 processes which are the result of change in vegetation structure from woodlands to open

7 grasslands (Sangha, 2003; Vetaas, 1992; Bruce et al., 2000). The composition and eco-

8 physiological traits of plant species in an ecosystem affect the soil properties through

9 availability and quality of root exudates which are an important nutrient source for

10 microbes (Klein et al., 1988), and through alterations in nutrient competition (Bardgett et

11 al., 1999). Introduction of exotic grass species such as C. ciliaris, and clearing of native

12 vegetation would have disturbed the plant-soil relationship in cleared pasture systems.

13 A change from a multi-species system in native woodlands to monocultures of C. ciliaris

14 (predominantly, and with some other species; Sangha, 2003) results in a loss of species

15 diversity, litter composition, nutrient return to soil that affects the rate of mineralisation of

16 nutrients and their availability for pasture growth. Decline in microbial biomass at cleared

17 compared to uncleared sites may be the result of the integrated effect of litter composition,

18 decomposition of organic matter, change in soil properties, and in part may to due to

19 differences in soil micro-climate. The impact of clearing on overall ecosystem stability was

20 evident from the CVA (Fig 4) as the old pastures were situated differently than the

21 uncleared pastures. More importantly, over a long term, these effects (of nutrient return,

22 soil pH_w or microbial biomass) will become more apparent as they intensify with time. If,

1   in order to maximize production gains some of these soil properties such as pH_w (increased

2   about 1-2 units at all old cleared sites) or soil microbial biomass (decreases) change, then,

3   would the restoration of original capacity of land be possible over the same period of time

4   for which the benefits (e.g. 13 to 30 years) were harvested? Quite possible, it may take

5   longer than that. Thus, the opportunity cost for the lost ecosystem functions that were

6   traded for short-term monetary gains, will increase with time. It is important to note that

7   trees also provide other ecosystem services such as shade from sun and shelter in rain for

8   cattle that contribute to improvement in their health conditions (Daly, 1984).

9   Despite the loss of plant diversity and soil health attributes with clearing, if we just account

10 for the visible monetary benefits, they are not sustainable either. The monetary value of

11 pasture biomass produced per year (assuming if all to be consumed) was also calculated

12 according to the amount of beef produced from the amount of pasture consumed over a

13 year per cattle (182.5 kg weight gain/yr from 3139 kg/yr dry matter uptake; Minson and

14 McDonald, (1987), valued at the rate of AUD 1.50/kg of livestock weight). The yearly

15 maximum monetary gains were obtained at medium age of clearing for <u>E. populnea</u> (AUD

16 331 ha^{-1}) and <u>A. harpophylla</u> (AUD 371 ha^{-1})*,* and at recent age of clearing (AUD 552 ha^{-1})

17 for <u>E. melanophloia</u> (Fig 4). However, the increased benefits were not sustained over time-

18 since-clearing and declined at old clearing in all tree communities. Indeed, for <u>E.</u>

19 <u>melanophloia</u>, after 33 yrs of clearing, the monetary gains (AUD 246 ha^{-1} yr^{-1}) were less

20 than that at uncleared site (AUD 328 ha^{-1} yr^{-1}) (Fig 5).

21 Clearing led to a notable change in the ecological state of pastures from the uncleared to 33

22 years cleared pasture systems. The old cleared pastures differed significantly from

1 uncleared pastures in terms of ecological attributes, thus, suggesting that trees in uncleared

2 pastures are important for maintaining pasture systems in the long-term. Trees provide a

3 stable environment due to their shade, litter, stable hydrological cycle, recycling of

4 nutrients, and by providing substrate for various soil microbial activities that results in

5 improved physical and chemical conditions of soil. Williams et al. (1993) suggested that

6 clearing of trees influences and disturbs the equilibrium of soil processes (nutrient

7 recycling and decomposition). Once a natural woodland system is disturbed, it becomes

8 more difficult to restore. Although, we agree that the production gains are important but

9 the time frame for those gains and the associated loss of ecosystem functions suggest that

10 these gains could be easily offset.

11 **5. Conclusions**

12 Increase in pasture production upon clearing occurred at the cost of loss of plant species

13 diversity (hence the functional diversity of various plant groups), and loss of litter

14 production and nutrient return. Together with the loss of soil microbial biomass and

15 increase in soil pH these could also notably affect other associated ecosystem functions

16 such as nutrient mineralisation, and hence the soil processes that support plant growth. A

17 compromise must be searched for and struck when clearing to maintain ecosystem

18 functions for sustainable pasture systems.

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Table 1. Details of time of clearing (all sites were chain pulled) and annual average stocking rate (SR) at cleared and uncleared sites for <u>E. populnea</u>, <u>E. melanophloia</u> and <u>A. harpophylla</u> communities.

Tree community	Cleared treatments		Uncleared (intact) treatments
	Time of clearing	SR (adult cattle/ha)	SR (adult cattle/ha)
E. populnea Recent clearing	May 1996	1/5	1/5
Medium clearing	Dec 1987	1/3	1/4.8
Old clearing	July 1967	1/6	1/4.8
E. melanophloia Recent clearing	May 1996	1/5	1/5
Medium clearing	Oct 1990	1/3	1/3
Old clearing	July 1967	1/6	1/6
A. harpophylla Recent clearing	May 1996	1/5	1/11
Medium clearing	Dec 1987	1/3	1/4.8
Old clearing	July 1967	1/6	1/4.8

Table 2. Calculations for litter production during different seasons.

Amount of litter collected	Seasonal decomposition	Amount of litter produced during different seasons
Mar 2001 = X_0		
July 2001= X_1	Apr 2001-Aug 2001= R_1	Mar 2001-July01= X_1-X_0+R_1
Nov 2001= X_2	Aug 2001-Dec 2001= R_2	July 2001-Nov01= X_2-X_1+R_2
Mar 2002 = X_3	Dec 2001-Apr 2002 = R_3	Nov 2001-Mar02 = X_3-X_2+R_3

Table 3 Yearly average pasture biomass (kg ha^{-1}), and Shannon Wiener's index of species diversity at uncleared, and at recent, medium and old age cleared treatments of E. populnea, E. melanophloia and A. harpophylla communities.

Tree type	Pasture biomass*	Shannon Wiener's index
E. populnea		
Uncleared	1222^c	2.5201^a
Recent	1855^{bc}	2.2478^b
Medium	4019^a	0.3217^d
Old	2974^{ab}	0.7941^c
E. melanophloia		
Uncleared	2879^{ab}	2.3881^a
Recent	4174^a	1.6142^b
Medium	2519^{ab}	1.2675^c
Old	2231^b	1.1236^d
A. harpophylla		
Uncleared	1035^b	2.4751^a
Recent	2458^{ab}	1.7729^b
Medium	4700^a	0.2068^d
Old	3294^a	0.6318^c

*different superscripts in a column represent significant difference at *P<0.05* for cleared and uncleared treatments within a tree community.

Table 4. Litter production (kg ha^{-1}yr^{-1}) and potential content of N and P (kg ha^{-1}) stored in annual amount of litter produced at uncleared and cleared (recent, medium and old) sites for E. populnea, E. melanophloia and A. harpophylla communities.

Site		Uncleared	Recent	Medium	Old
E. populnea	Litter production	1732^a	866^b	1299^{ab}	949^b
	N	15.30^a	8.04^b	6.63^b	4.49^b
	P	0.58^b	0.60^b	1.10^a	0.50^b
E. melanophloia	Litter production	1948^a	1107^b	1515^{ab}	1226^b
	N	11.40^a	4.38^b	6.56^b	10.39^{ab}
	P	0.84^{ab}	0.50^b	0.95^a	0.51^b
A. harpophylla	Litter production	2596^a	1346^b	1191^b	1084^b
	N	29.97^a	6.55^b	5.49^b	6.32^b
	P	0.87^a	0.55^b	0.63^b	0.67^b

*different superscripts in a row represent significant difference at P<0.05 between any two treatments in each of the tree community.

Table 5. Loading values for various variables from the canonical variate analysis for recent, medium and old cleared, and uncleared treatments.

Variables	Loading values for CV1	Loading values for CV2
Pasture biomass	3.60	-0.47
Species diversity	2.54	0.86
Litter production	3.40	-0.39
Soil organic carbon	-1.80	-0.07
Soil pH_w	-3.24	0.09
Soil NO_3^-	3.82	-0.27
Soil microbial biomass-C	1.86	0.25
Soil microbial biomass-N	0.72	0.55
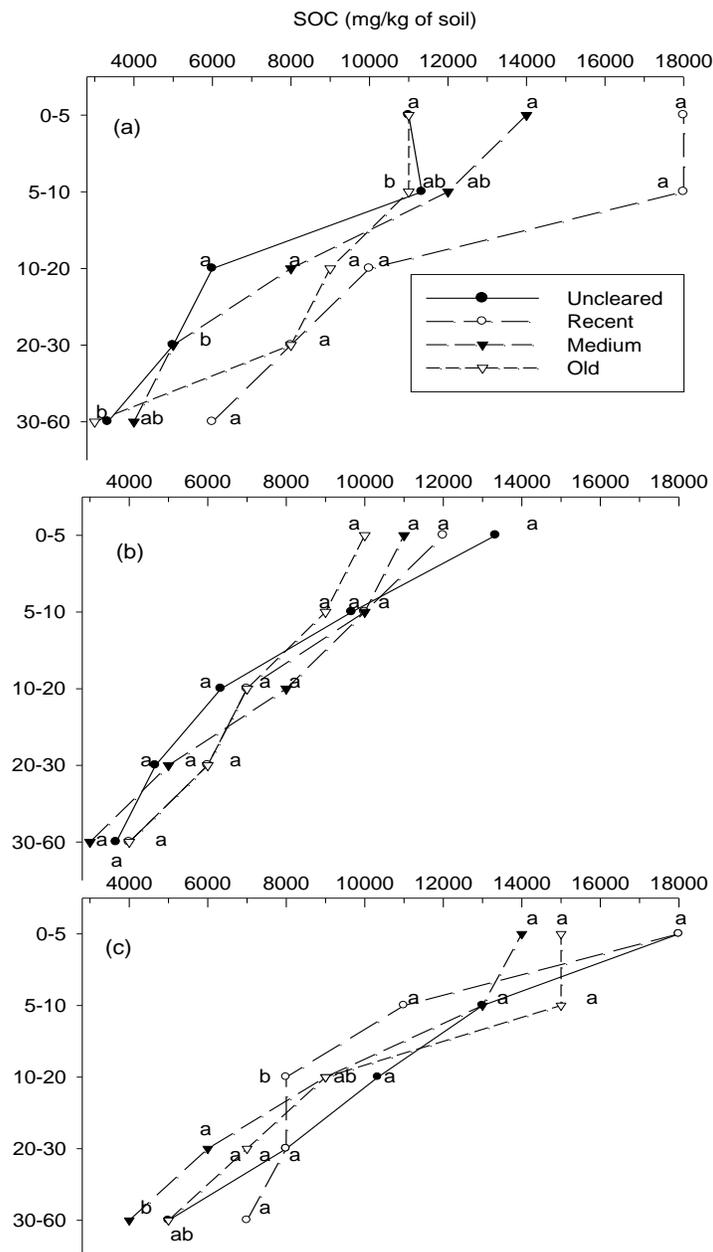
Fig. 1. Soil organic carbon (SOC) at recent, medium and old cleared, and uncleared treatments for a) <u>E. populnea</u>, b) <u>E. melanophloia</u> and c) <u>A. harpophylla</u> communities.

The same letter at any one sampling depth denotes no significant difference at P<0.05 between any two cleared or uncleared treatments within a tree community.
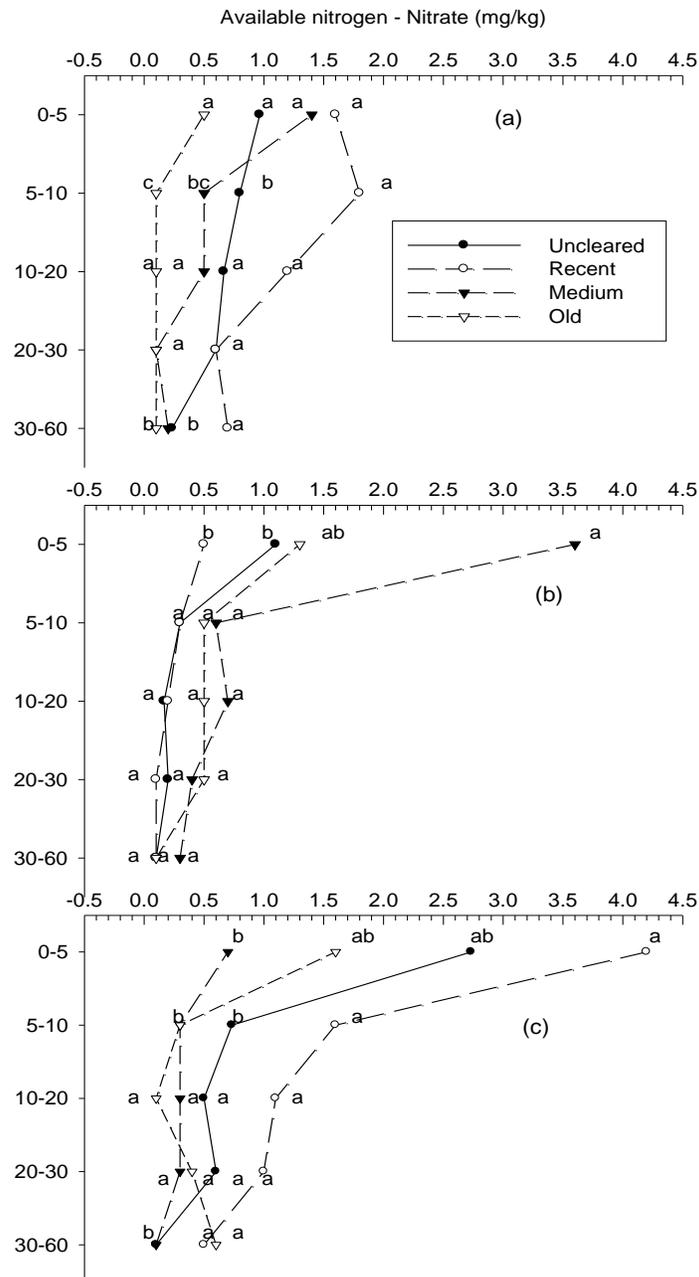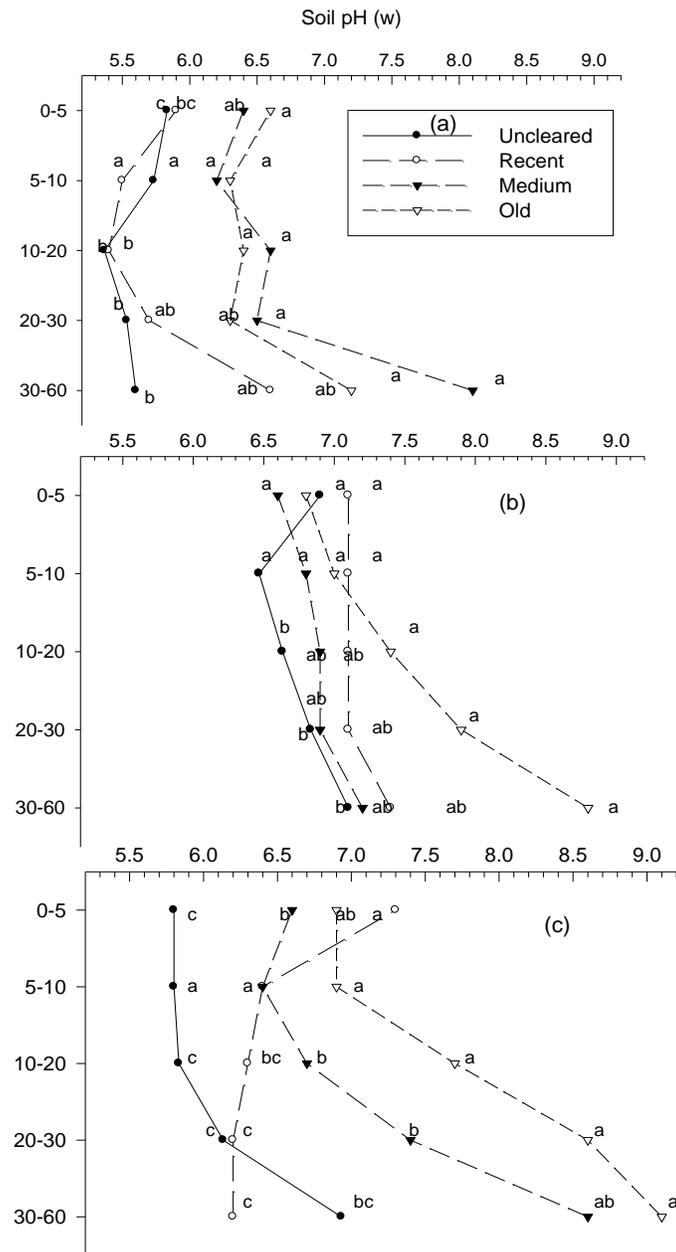
Fig. 2. Soil available nitrogen (NO$_3^-$) at recent, medium and old cleared, and uncleared treatments for a) <u>E. populnea</u>, b) <u>E. melanophloia</u> and c) <u>A. harpophylla</u> communities.

The same letter at any one sampling depth denotes no significant difference at P<0.05 between any two cleared or uncleared treatments within a tree community.

Fig. 3. Soil pH$_w$ at recent, medium and old cleared, and uncleared treatments for a) <u>E. populnea</u>, b) <u>E. melanophloia</u> and c) <u>A. harpophylla</u> communities.

The same letter at any one sampling depth denotes no significant difference at P<0.05 between any two cleared or uncleared treatments within a tree community.
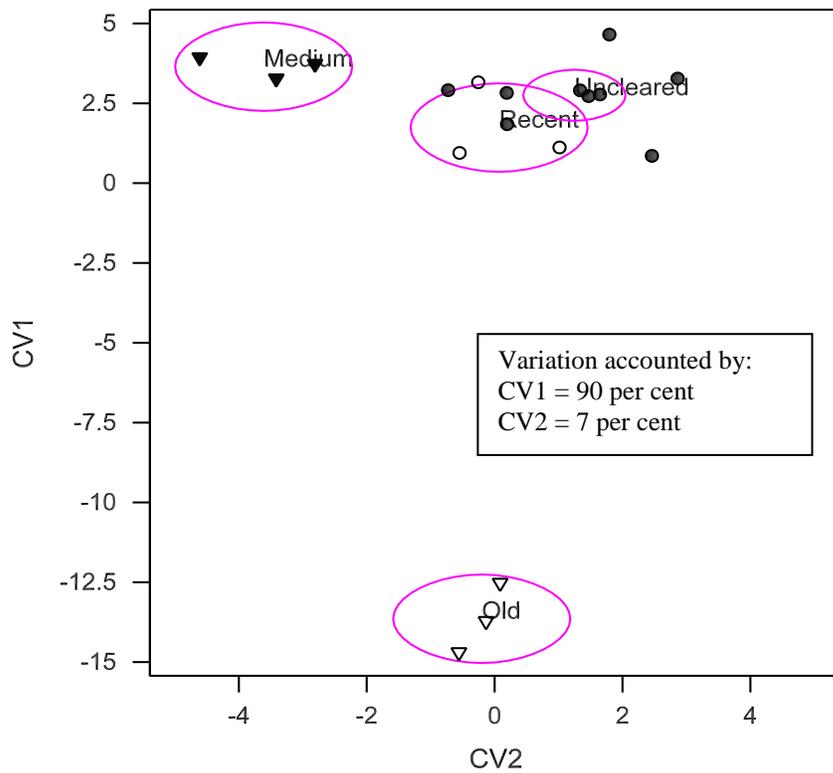
Fig 4. Relationship between first and second canonical variates for cleared (recent, medium and old) and uncleared treatments (with 95 per cent confidence regions around means).
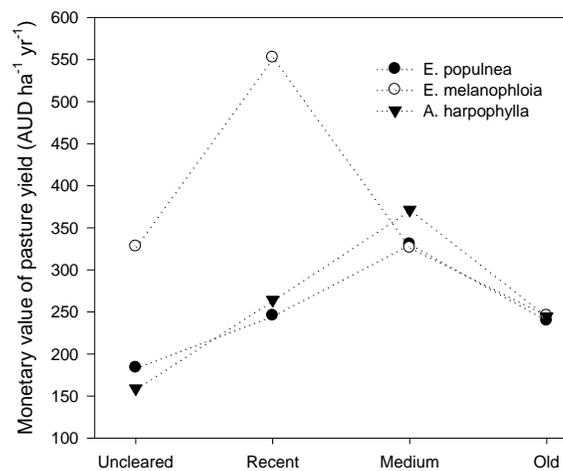

Fig 5.The monetary value of pasture yield produced at uncleared, recent, medium and old cleared sites for <u>E. populnea</u>, <u>E. melanophloia</u> and <u>A. harpophylla</u> communities.