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

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Abstract

The clearing land of trees and introduction of exotic pastures to enhance pasture production and associated monetary gains has been a common practise in Queensland. Previous studies on tree clearing emphasised the gains in pasture production, but over periods of less than 10–15 years after clearing, thus potentially misleading land managers who plan to continue grazing beyond that time. The present research follows an integrated approach to quantify the pasture yield and the effects of tree clearing on pasture species composition, soil properties (organic carbon, available N (NO_3^-), pH_w and microbial biomass (C and N)), and litter production 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 <5, 11–13 and >33 year age of clearing in comparison to their paired uncleared pastures for three major tree communities representative of the region: *Eucalyptus populnea*, *Eucalyptus melanophloia* and *Acacia harpophylla*. The paper evaluates the effects of clearing on individual attributes as well as an integrated effect of these attributes, i.e. overall ecological services. Pasture production generally increased with clearing 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. This, the initial gains in pasture production are not sustainable over time. The multivariate analysis for such ecological attributes suggests that at the >33 year age of clearing, the ecological state of pasture systems changed compared to that at 5 year or 11–13 year or to the uncleared system. A disturbed pasture system will most likely take longer to revert to the original state compared to the time that would have taken to harvest the benefits. The results are important for landholders and policy makers to comprehend the real gains and losses following tree clearing for pasture development over the long term.

Keywords: Tree clearing; Soil organic carbon; Soil pH; Soil nitrate; Soil microbial biomass; Pasture yield; Litter production; Ecosystem functions

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1. Introduction

Tree clearing has, until recently, commonly been practised to achieve greater pasture production and monetary gains in grazing systems of Queensland. Most of the cleared land is sown to exotic grass species such as *Cenchrus ciliaris* L. following raking and burning of wooden logs, leading to monoculture pastures. The high rates of clearing in the past especially after the 1950s, and even recently (e.g. in 1999–2001, 577,000 ha of land were cleared per year (Department of Natural Resources and Mines, 2003)), were mainly to develop pastures (94% of total cleared land in 1999–2001). Until 1985, government policies favoured clearing to develop land for pastoral and agricultural systems (Boulter et al., 2000), and thereafter permission was mandatory from the Queensland Department of Natural Resource to clear land, even for clearing of non-remnant vegetation. From September 2004, a change in government policy stopped land clearing. This was predicated mainly on the losses of biodiversity, and not based upon access to information on the long term effects of clearing on productivity of pasture systems or of the effects on soil properties which are equally important for a landholder. Thus, it is difficult for landholders to understand and adapt to the changes in governmental policies, from promoting clearing to that more recently of prohibiting clearing, without provision of unequivocal evidence 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 did not consider the associated loss of other ecological services. There are increasing concerns that most of the development that occurred in the past involved little understanding of ecosystem functions and of the inherent potential of natural resources available on the Australian continent (Boulter et al., 2000).

To address the ecological issues of clearing trees for gains in pasture production, three major woodland communities, dominated by *Eucalyptus populnea* F. Muell., *E. melanophloia* F. Muell. or *Acacia harpophylla* F. Muell. ex. Benth. were selected on one property to quantify the impacts of clearing on pasture production and composition, soil properties (organic carbon, available N (NO_3^-), pH_w and microbial biomass (C and N)), and litter production. The impacts were measured over a time scale since clearing of recent (<5 years), medium (11–13years) and old (>30 years)) age of cleared pastures in comparison to their uncleared (intact) woodland pastures of each tree community.

The present research provides important information for landholders and policy decision makers to guide them while making objective decisions for the good of future pasture systems based upon the integrated effects of long term clearing on production and other ecological attributes of pasture systems. It is based upon a detailed study conducted on a grazing property in central Queensland region.

2. Materials and methods

Paired sites of cleared and uncleared woodlands for *E. populnea* (poplar box), *E. melanophloia* (silver-leaved ironbark) and *A. harpophylla* (brigalow) communities were selected across three age groups of clearing, i.e. recent (<5 year), medium (11–13 year) and old (>33 year) on a property "Avocet" (30 km south of Emerald) in central Queensland, Australia. The sites were selected with the guidance of research staff at Department of Natural Resources and Mines, and at Environmental Protection Agency, Emerald, to be the representative vegetation types of the region.

The study represents a 3 (types of tree communities) × 3 (time-since-clearing) × 2 (cleared versus uncleared) factorial design. The paired cleared and uncleared sites were selected in close proximity with the assumption that they had similar biophysical characteristics (soil type, slope and vegetation) before clearing (according to information provided by the landholder), and to some extent to minimize variation in grazing management for the same cattle grazed the cleared and their paired uncleared sites. The methods of tree clearing applied to sites slightly differed, along with number of cattle grazing these sites (Table 1).

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

Tree community	Cleared treatments		Uncleared (intact) treatments
	Time of clearing	SR (adult cattle ha^{-1})	SR (adult cattle ha^{-1})
E. populnea			
Recent clearing	May 1996	1/5	1/5
Medium clearing	December 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	October 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	December 1987	1/3	1/4.8
Old clearing	July 1967	1/6	1/4.8

At each site, a representative area of 1 ha of the total area (minimum >20 ha) at each site was marked for data collection.

2.1. Above-ground pasture biomass and pasture composition

At the centre of the selected 1 ha area at each site, a fenced plot of 10 m × 10 m (to exclude grazing) was marked to determine pasture above-ground biomass and composition. The quadrat method (Kent and Coker, 1992) was used and a quadrat size of 1 m × 1 m, derived from the stable number of species per unit area based upon preliminary analysis, was chosen. Measurements were taken from five randomly assigned quadrats located at different positions across sampling dates for different seasons in a year; in March 2001, July 2001 and November 2001 and March 2002. All the plant samples from each quadrat were harvested just above-ground level, taken to the laboratory and dried at 60 °C for 48 h to determine their biomass. Average quantity of pasture above-ground biomass for grazing was calculated over a year from the seasonal measurements. For repeated measurements, i.e. March 2001 and March 2002, their average was considered along with the July 2001 and November 2001 seasonal measurements. All types of plants in a quadrat were identified to study the species composition.

The data were collected from both the fenced and unfenced sites, however, the results are presented herein are for fenced plots only, since the trends were similar at both the fenced and unfenced sites (Sangha, 2003).

2.2. Litter production

Litter production was measured at unfenced sites using the paired-plot technique (Wiegert and Evans, 1964). The measurements started in March 2001 and were taken at regular four monthly intervals until March 2002. On each occasion, three random quadrats of 1 m × 1 m were laid in three different directions and these quadrats were marked for the next set of readings in their adjacent (paired) quadrats. In each quadrat, the standing green herbage was removed and dead litter fallen on the ground was collected. The samples were screened to exclude large sticks of circumference >1 cm, air dried and weighed. For the next sampling date in July 2001, litter was collected from the quadrats adjacent to ones that were used in the previous season, i.e. March 2001. Samples were processed in the same way as in March 2001. The same procedure was followed in November 2001 and March 2002. To measure the quantity of litter produced per season, the amount of litter decomposed during that season was taken into account (Table 2). For example, the amount of litter produced at time t_0 was X_0 and at t_1 time was X_1, and R_1 was the rate of decomposition for $t_0 - t_1$, so total litter produced during $t_0 - t_1 = X_1 - X_0 + R_1$. Decomposition of litter was studied using the litter bag

Table 2
Calculations for litter production during different seasons

Amount of litter collected	Seasonal decomposition	Amount of litter produced during different seasons
March 2001 = X_0		
July 2001 = X_1	April 2001–August 2001 = R_1	March 2001–July 2001 = $X_1 - X_0 + R_1$
November 2001 = X_2	August 2001–December 2001 = R_2	July 2001–November 2001 = $X_2 - X_1 + R_2$
March 2002 = X_3	December 2001–April 2002 = R_3	November 2001–March 2002 = $X_3 - X_2 + R_3$

technique over the same sampling dates as for litter production. This was necessary to account for the loss of litter that underwent decomposition between two successive sampling dates, to ensure accurate estimation of the total amount of litter produced over a particular season. The average amount of litter produced over a year was computed from litter produced during different seasons.

Litter samples collected in March 2001 (without decomposition) from each site were thoroughly mixed, ground and analysed for N (using CHN analyser) and P (using ICP) (standard methods described by Carter (1993) and Peverill et al. (1999)) at the soil laboratories of Incitec Ltd., Brisbane, Queensland.

2.3. Soil properties

Soil samples were taken (bulked for 8 cores per site) from unfenced sites in January 2002 using a hydraulic soil rig, for different profile depths (0–5, 5–10, 10–20, 20–30, 30–60 cm). Samples were processed to remove visible roots and pebbles, and analysed at the soil laboratories of Incitec Ltd. (Brisbane) for soil organic carbon (SOC) (Walkey and Black method using H_2SO_4 and $K_2Cr_2O_7$ in 1:100 dilution, measured colormetrically), soil pH_w (1–5, soil to water dilution using combination electrode) and soil NO_3^- (1:5 soil to water, centrifuged nitrate measured colorimetrically in segmented flow analyser) according to methods described by Carter (1993) and Peverill et al. (1999).

To determine the microbial biomass of C (SMB-C) and N (SMB-N), samples were taken from the top 0–5 cm soil profile in March 2002, immediately stored in a cold container, and analysed using the chloroform fumigation extraction method (Vance et al., 1987) at the Natural Resource Sciences Laboratories (Department of Natural Resources, Mines and Energy, Indooroopilly, Brisbane, Queensland).

2.4. Statistical analysis

Individual effects of tree clearing on pasture biomass and litter production were analysed using Genstat ver 6.0 (2002). The residual maximum likelihood (REML) (Patterson and Thompson, 1971) method was used. The main effects for type of tree community and uncleared–cleared (recent, medium and old) treatments within each tree community were analysed. Models included the fixed effects of community, clearing treatments plus their interaction (community × cleared–uncleared), and the random effects of age since clearing and uncleared treatments within a community. If the interaction between community and cleared–uncleared treatments was not significant ($P < 0.05$) then it was removed from the fixed model to test the main effects. The variance matrix derived from REML analysis was used to calculate approximate least significant differences of means (LSDs) at $P < 0.05$. The means from REML analysis were used in presenting the results.

For species diversity, Shannon Wiener's index was calculated using species diversity and richness software (Henderson and Seaby, 1998; PISCES Conservation Ltd.).

For soil properties, the same tool REML was used as for pasture biomass and litter data. The main effects (fixed terms) of tree community (*E. populnea*, *E. melanophloia* and *A. harpophylla*), cleared (recent, medium, old age of clearing) and uncleared treatments, and soil depth (each for 0–5, 5–10, 10–20, 20–30 and 30–60 cm depth) plus their interactions were analysed. The correlation within a treatment across different depths was analysed for all the main effects by applying the most suitable variance model AD2 (Antedependence order 2). There were significant ($P < 0.05$) three-way interactions (tree community × cleared–uncleared × depth) for main effects in all the soil variables. For each variable, LSDs were used to compare cleared (recent, medium, old) and uncleared treatments for each specific depth in a particular tree type. The means from REML analysis were used to present the results.

To examine the integrated effect of studied attributes (pasture yield, species diversity, litter production, SOC, NO_3^-, pH_w and soil microbial biomass (C and N)) in cleared and uncleared pasture systems, data were analysed using multivariate analysis technique, i.e. canonical variates analysis (CVA) in Genstat (ver. 6.0) across all tree communities. All the data were standardised for analysis.

The CVA was applied to determine the overall effect of clearing, as well as the attribute(s) that would have been strongly influenced by clearing and could lead to differentiate between cleared and uncleared treatments in all tree communities. There were not enough replicates for cleared and uncleared treatments within a tree community to apply CVA to examine the effects in each tree community. However, the data were analysed for all the cleared and uncleared treatments irrespective of tree community. The CVA analysis finds linear combinations of the original variables that maximize the ratio of between-group to within-group variation where groups are cleared and uncleared treatments. Two canonical variates (CV1 and CV2) were considered to explain variation between treatments. The output from CVA presents an integrated impact of clearing in pasture systems.

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	1222c	2.5201a
Recent	1855bc	2.2478b
Medium	4019a	0.3217d
Old	2974ab	0.7941c
E. melanophloia		
Uncleared	2879ab	2.3881a
Recent	4174a	1.6142b
Medium	2519ab	1.2675c
Old	2231b	1.1236d
A. harpophylla		
Uncleared	1035b	2.4751a
Recent	2458ab	1.7729b
Medium	4700a	0.2068d
Old	3294a	0.6318c

Different letters (a–d) within a column denote significant difference at $P < 0.05$ between treatments within a tree community.

3. Results

3.1. Pasture above-ground biomass

Pasture biomass was on average greater at cleared compared to uncleared sites, with maximum production at medium age of clearing for *E. populnea* and *A. harpophylla*, and at recent age of clearing for *E. melanophloia* (Table 3). However, the gains in pasture biomass were not consistent over time-since-clearing and tended to decline at old compared to medium (in *E. populnea* and *A. harpophylla*) or recent age (in *E. melanophloia*) of clearing in all the tree communities. Interestingly, in *E. melanophloia*, the uncleared and old cleared sites did not differ significantly ($P < 0.05$) in pasture yield.

Although the pasture yield was greater at cleared than uncleared sites, pasture plant diversity (Shannon Wiener's index of diversity) was significantly greater at uncleared compared to all the cleared treatments in all tree communities (Table 3). Within cleared sites, species diversity declined at medium and old cleared sites compared to recent cleared sites.

3.2. Litter production

The total amount of litter produced over a year, important to account for the return of nutrients for pasture growth, was greater at uncleared compared to the cleared sites in all the tree communities except for the medium cleared treatments in *E. populnea* and *E. melanophloia* communities (Table 4). The cleared treatments did not differ significantly ($P < 0.05$) from each other in total amount of litter produced per year.

The potential amount of N stored in litter produced over a year was greater at uncleared compared to cleared sites in all tree types. P content was greater in litter produced at medium cleared site compared to uncleared site in *E. populnea* and *E. melanophloia*. In *A. harpophylla*, litter produced at uncleared sites had significantly ($P < 0.05$) greater P content than any of the cleared treatments (Table 4).

Table 4
Litter production (kg ha^{-1} $year^{-1}$) 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	1732a	866b	1299ab	949b
N	15.30a	8.04b	6.63b	4.49b
P	0.58b	0.60b	1.10a	0.50b
E. melanophloia				
Litter production	1948a	1107b	1515ab	1226b
N	11.40a	4.38b	6.56b	10.39ab
P	0.84ab	0.50b	0.95a	0.51b
A. harpophylla				
Litter production	2596a	1346b	1191b	1084b
N	29.97a	6.55b	5.49b	6.32b
P	0.87a	0.55b	0.63b	0.67b

Different letters (a and b) within a row denote significant difference at $P < 0.05$ between treatments within a tree community.

3.3. Soil properties

Tree clearing had no significant effect on SOC except that for recent or medium clearing which had greater SOC in 0–10 cm and 30–60 cm depths than uncleared sites in *E. populnea* and *A. harpophylla* (Fig. 1). The paired *t*-test between cleared and uncleared treatments (irrespective of age group or tree type) for the average SOC in the 0–60 cm profile showed no effect of clearing. Similarly, the differences between cleared and uncleared treatments were not evident for available N (NO_3^-) which was highly variable in the top 0–10 cm depth (Fig. 2).

Clearing strongly influenced soil pH_w across all tree communities. Soil pH_w increased significantly ($P < 0.05$) with clearing in the top 0–5 cm for *E. populnea* and *A. harpophylla* (Fig. 3). A significant increase in pH_w ($P < 0.05$) due to clearing at 30–60 cm depth especially at medium and old clearing was evident in all three tree communities. The increase in soil pH_w across all depths was closely related to time-since-clearing across all tree types (at $P < 0.05$, Y (increase in soil pH) = $a + (-1.29)^{(-0.041 \times \text{time-since-clearing})}$; $R^2 = 0.42$, where '*a*' varies from 7.0 to 7.9 for different tree communities).

The SMB-C was significantly ($P < 0.05$) greater in uncleared soils (386 ± 37 mg kg^{-1} (standard error of means)) than in cleared soils (254 ± 37 mg kg^{-1}) and similarly for SMB-N (uncleared 40.17 ± 3.29 mg kg^{-1}, cleared 29.87 ± 3.45 mg kg^{-1}), when analysed for all the cleared and uncleared sites irrespective of age of clearing or tree type.

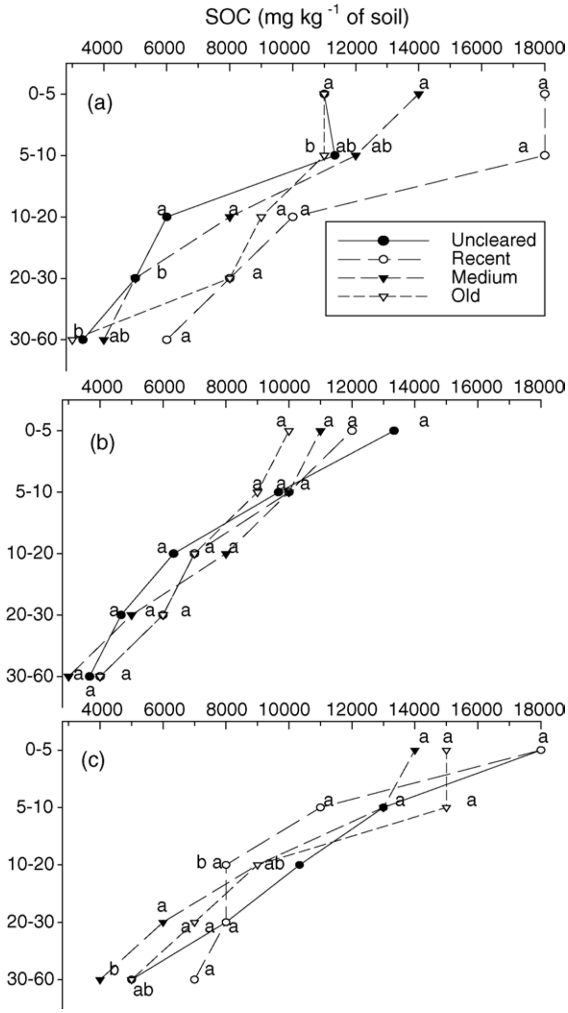

Fig. 1. Soil organic carbon (SOC) at recent, medium and old cleared, and uncleared treatments for (a) *E. populnea*, (b) *E. melanophloia* and (c) *A. harpophylla* communities. The same letter at any one sampling depth denotes no significant difference at $P < 0.05$ between any two cleared or uncleared treatments within a tree community.

3.4. Integrated effects of ecological attributes of a pasture system

The combined effect of clearing on various attributes of a pasture system was determined with canonical

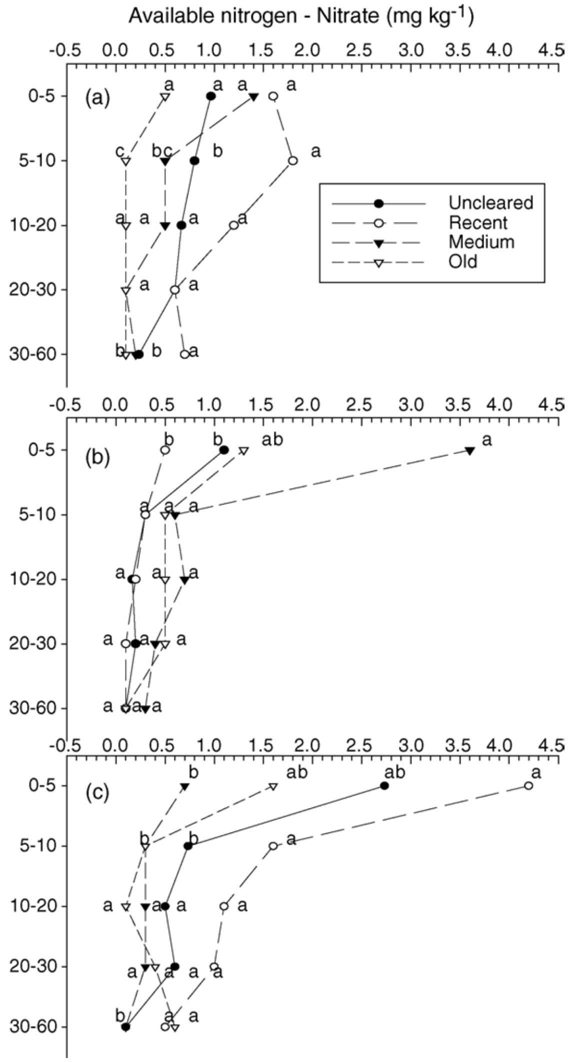

Fig. 2. Soil available nitrogen (NO_3^-) at recent, medium and old cleared, and uncleared treatments for (a) *E. populnea*, (b) *E. melanophloia* and (c) *A. harpophylla* communities. The same letter at any one sampling depth denotes no significant difference at $P < 0.05$ between any two cleared or uncleared treatments within a tree community.

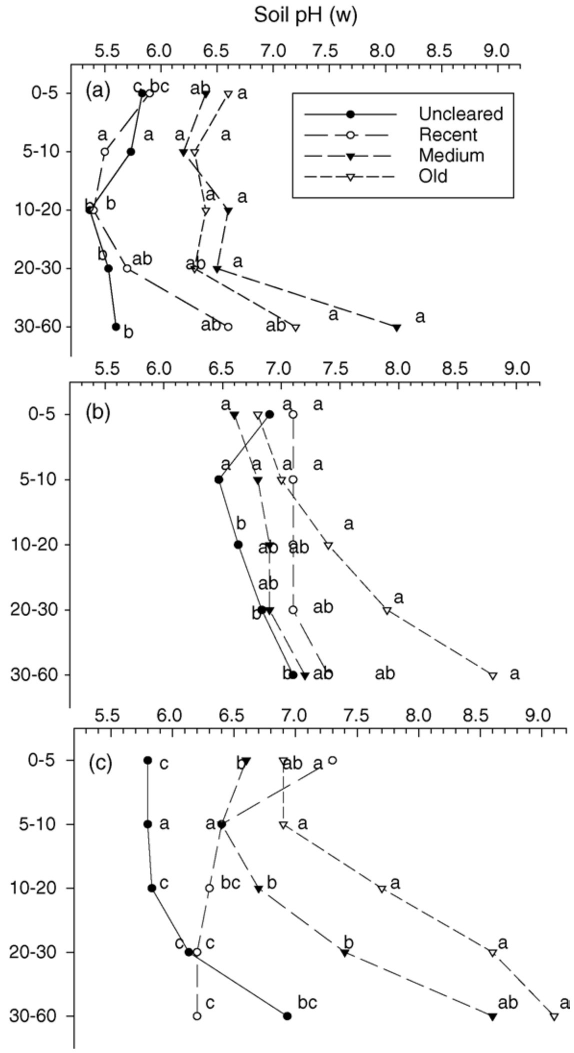

Fig. 3. Soil pH_w at recent, medium and old cleared, and uncleared treatments for (a) *E. populnea*, (b) *E. melanophloia* and (c) *A. harpophylla* communities. The same letter at any one sampling depth denotes no significant difference at $P < 0.05$ between any two cleared or uncleared treatments within a tree community.

variates analysis. Two canonical variates (CV1) and (CV2) were selected for recent, medium, old cleared and uncleared treatments across all tree communities. The first canonical variate (CV1) distinguished the oldest cleared treatment from medium and recent cleared, and uncleared treatments (CV1 explained 90% of variation among these treatments) (Fig. 4). The old age of clearing was different to other treatments mainly due to the combined effect of soil NO_3^-, pasture biomass, litter production, species diversity and soil pH_w (Table 5). Comparatively greater values of positive loadings for these attributes than the others suggested that recent and medium cleared, and uncleared treatments had better soils with greater pasture biomass and litter production than those of the old cleared treatments. The greater value of negative loading for

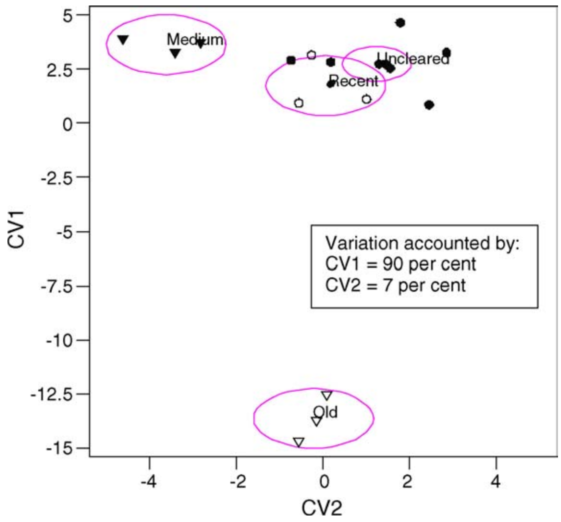

Fig. 4. Relationship between first and second canonical variates for cleared (recent, medium and old) and uncleared treatments (with 95% confidence regions around means).

pH_w demonstrated that pH_w was greater at the oldest clearing than at medium and recent cleared, and uncleared treatments (Table 5).

Only a further 7% of the variation between cleared and uncleared pasture systems was explained by CV2. CV2 showed that the medium cleared treatment was different to the recent and old cleared, and uncleared treatments (Fig. 4). The species diversity and SMB-C and SMB-N had a greater influence (positive loadings) on CV2 than did the other attributes (Table 5). However, the differential response across species between age of clearing for pasture yields obscured further meaningful interpretation of CV2.

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

4. Discussion

In the woodlands of east-central Queensland, pasture yield has been shown to increase upon clearing by Burrows (1993); Burrows et al. (1999) and Scanlan and Burrows (1990), and was also evident in the present study. The present research furthermore demonstrated that much of the benefit was evident during the initial years of clearing and was not maintained at the same level over a longer term (>30 years). Cattle benefit more from the greater biomass of introduced exotic pasture species, but for how long will the increased pasture production benefits from clearing be maintained? The present study suggested a trend for decline in pasture yield as time-since-clearing progressed. The benefits of clearing for increase in pasture yield between cleared and uncleared treatments narrowed with age of clearing especially from 13 to 33 years. The duration of benefit was in fact very short for *E. melanophloia*. More importantly, the gains in pasture yield due to clearing were associated with some tradeoffs, for example, loss of some ecological properties such as:

(1) Decline in pasture species diversity which may affect ecosystem stability.
(2) Lesser return of nutrients through litter decomposition, which can imbalance the nutrient cycle compared to that in woodland pastures.
(3) Changes in soil properties that could, by implication, affect the growth of pasture species over a longer term.

4.1. Impacts of clearing on species diversity

There is a tradeoff between production and species diversity since most of the cleared pastures were sown to one dominant exotic grass species that promotes monoculture pastures. The diversity of native plant species, important in maintaining various ecosystem functions for the stability of a pasture system (Tilman et al., 1997), was compromised with high production gains from exotic grass species in cleared pastures.

Reduced species diversity in cleared pasture systems could adversely affect ecosystem functions such as those related to hydrology and soil stability. Tilman et al. (1997) conducted a detailed study on the diversity-productivity and diversity-sustainability in American grasslands, and reported higher functional diversity in high diversity plots that supported higher productivity. The plots with higher number of species were more efficient in allocation of soil nutrients for plant growth compared to the less diverse plots. The reduced species diversity may affect the use of resources in cleared pastures as diverse systems possess better potential for use of resources such as soil nutrients (Tilman, 1997). Likewise, Ash et al. (1997) reported that C sequestration in soils improved with grass species which were adapted to the edapho-climatic conditions (mostly native) of pasture systems in northern Queensland, and diversity of native plant species should, therefore, sustain the ecosystem functions of pasture systems in Queensland, although evidence for this effect is not available. A detailed study on species diversity and productivity in native pastures in this context may be very valuable.

4.2. Impacts of clearing on litter production and nutrient return

With clearing, the steady return of nutrients through litter was disturbed because of the lesser production of ground litter at cleared sites compared to uncleared sites with the change in vegetation from woodlands to cleared pastures. This could lead to a change in the natural equilibrium of nutrient return to the system that could affect pasture growth (Williams et al., 1993). The change in litter composition may lead to further changes in microbial communities and in return of nutrients to soil through litter decomposition (Kutsch and Dilly, 1999; Vetaas, 1992).

4.3. Impacts of clearing on soil properties

We acknowledge that there would have been a release of nutrients in the soil at the time of clearing that would have been taken up quickly by the plants sown to cleared land, but we could not detect any effect ($P < 0.05$) of clearing on SOC and NO_3^-. If the recently cleared pastures were to have been 1 or 2 years of age, it may have been possible to quantify increases in soil nutrients, as Lawrence et al. (1988) reported an increase in P content in *A. harpophlylla* soon after clearing.

There was a prominent effect of clearing on soil pH_w; it increased with age of clearing such that it would have adversely affected the availability of soil nutrients (Sangha, 2003). The change in microbial biomass is also an important indicator of any change in soil health for greater SMB is responsible for mineralisation of organic matter and hence the return of nutrients for pasture growth (Jenkinson and Ladd, 1981). Loss of soil functionality in terms of soil pH_w and soil microbial biomass compromised pasture production gains.

The changes in soil pH_w and soil microbial biomass occur mainly due to change in soil processes which are the result of change in vegetation structure from woodlands to open grasslands (Sangha, 2003; Vetaas, 1992; Bruce et al., 2000). The composition and eco-physiological traits of plant species in an ecosystem affect the soil properties through availability and quality of root exudates (these are important nutrient sources for microbes (Klein et al., 1988)), and through alterations in nutrient competition (Bardgett et al., 1999). Introduction of exotic grass species such as *C. ciliaris*, and clearing of native vegetation would have disturbed the plant-soil relationship in cleared pasture systems.

A change from a multispecies system in native woodlands to monocultures of predominantly *C. ciliaris* with a few other species (Sangha, 2003) results in a loss of species diversity, change in litter composition, and a reduced nutrient return to soil that affects the rate of mineralisation of nutrients and their availability for pasture growth. Decline in microbial biomass at cleared compared to uncleared sites may be the result of the integrated effects of litter composition, decomposition of organic matter, change in soil properties, and in part may be due to differences in soil micro-climate. The impact of clearing on overall ecosystem functionality was evident from the CVA (Fig. 4) as the old pastures were situated apart from the uncleared pastures. More importantly, these effects (of nutrient return, soil pH_w and microbial biomass) will become more apparent as they intensify with time. If, in order to maximize production gains some of these soil properties such as pH_w (increased about 1–2 units at all old cleared sites) or soil microbial biomass (decreases) change, then, would the restoration of original capacity of land be possible over the same period of time for which the benefits (e.g. 13–30 years) were harvested? Thus, the opportunity cost for the lost ecosystem functions that were traded for short-term monetary gains, will increase with time. It is important to note that trees also provide other known ecosystem services such as shade from sun and shelter in rain for cattle that contribute to improvement in their health conditions (Daly, 1984). The close correlation between the contraction of wooded central Queensland and the decline in annual rainfall (McKeon et al., 2002) may suggest other ecosystem functions of trees in this environment.

Despite the loss of plant diversity and soil health attributes with clearing, even simply accounting for the visible monetary benefits shows that they are not sustainable either. The monetary value of pasture biomass produced per year (assuming it were all to be consumed) was calculated as to the amount of beef produced from the amount of pasture consumed over a year per cattle (using the conversion rate of x kg weight gain/year from 1000 kg year^{-1} dry matter uptake; Minson and McDonald, (1987)) and sold at AUD 1.50 kg^{-1} of livestock weight. The maximum yearly monetary gains were obtained at medium age of clearing for *E. populnea* (AUD 331 ha^{-1}) and *A. harpophylla* (AUD 371 ha^{-1}), and at recent age of clearing (AUD 552 ha^{-1}) for *E. melanophloia* (Fig. 4). However, the increased benefits were not sustained over time-since-clearing and declined at old clearing in all tree communities. Indeed, for *E. melanophloia*, after 33 years of clearing, the monetary gains (AUD 246 ha^{-1} year^{-1}) were less than that at uncleared site (AUD 328 ha^{-1} year^{-1}) (Fig. 5).

Clearing led to a notable change in the ecological state of pastures from those of the uncleared to 33 years cleared pasture systems. The old cleared pastures differed significantly from uncleared pastures in terms of ecological attributes. This implies that trees in uncleared pastures are important for maintaining pasture systems over the long-term. Trees provide a stable environment due to their shade, litter, hydrological cycle, recycling of nutrients, and by providing substrate for various soil microbial activities that result in conservation of the physical and chemical conditions of the soil. Williams et al. (1993) suggested that clearing of trees influences and disturbs the equilibrium of soil processes, specifically nutrient recycling and decomposition. Once a natural woodland system is disturbed, it becomes difficult to restore. Although the production gains are important, the short time frame for those gains and the associated loss of ecosystem functions suggest that the gains are not sustainable.

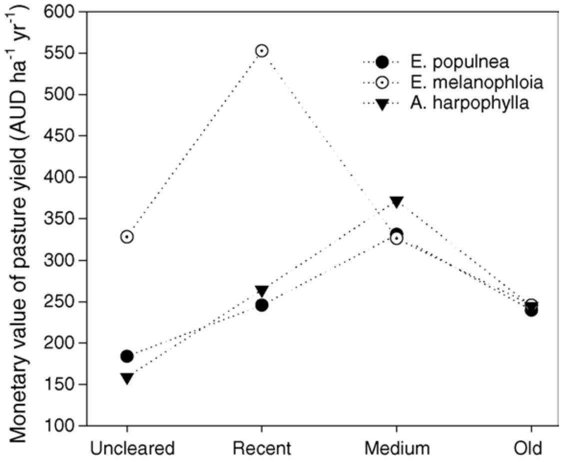

Fig. 5. The monetary value of pasture yield produced at uncleared, recent, medium and old cleared sites for *E. populnea*, *E. melanophloia* and *A. harpophylla* communities.

5. Conclusions

Increase in pasture production upon clearing was offset by loss of plant species diversity and their functional diversity, and loss of litter production and nutrient return. Together with the loss of soil microbial biomass and the increase in soil pH, these could notably affect other associated ecosystem functions such as nutrient mineralisation, and hence the soil processes that support plant growth. A compromise must be searched for when clearing trees to promote pasture growth while maintaining ecosystem functions for sustainable pasture systems.

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