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Pasture production in cleared and uncleared grazing systems of central Queensland, Australia

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Abstract. Clearing land of trees and introducing exotic pastures to enhance pasture and cattle production and hence enterprise financial performance are widely practised in Queensland. The results from many previous studies on tree clearing have emphasised the gains in pasture production, but over periods of less than 10–15 years after clearing. The present study questioned the sustainability of pasture production in cleared systems over a longer time-frame (>10 years of clearing). For this, three different age groups of clearing i.e. 5 year, 11–13 year and 33 year were selected in each of 3 major types of tree communities i.e. *Eucalyptus populnea*, *E. melanophloia* and *Acacia harpophylla* in central Queensland. Paired comparisons of cleared and uncleared (intact) pasture systems were selected for each age group of clearing. The results suggest that the initial gains in pasture production upon clearing were compatible with published studies. However, for longer periods of time since clearing, the gains in pasture production were not sustained and were accompanied by risks of land degradation and loss of pasture plant diversity. For *E. populnea* and *A. harpophylla*, the maximum benefits from clearing were achieved at 13–15 years whereas for *E. melanophloia*, any benefits existed only over a short period of 5–6 years. The study emphasises that each tree community exhibits a specific response with regard to the duration of increased pasture production following clearing. To estimate the total benefits from tree clearing in pasture development, it is important to consider both monetary benefits and non-monetary losses from clearing for different types of tree communities.

Additional keywords: woodland pastures, soils, time after clearing.

Introduction

The reliable availability of pastures in sub-tropical and tropical woodlands is important for land managers if they are to sustain cattle production and financial performance. In Queensland, various practices are employed to enhance pasture production. Clearing of trees followed by raking, burning and then sowing to exotic grasses has been a common practice. Generally the cleared land is sown to exotic productive grass species such as *Cenchrus ciliaris* L. that have higher root : shoot and root length : root biomass ratios than the original woody vegetation (Wilson 1998) and are associated with efficient capture of soil nutrients released upon clearing (Converys 1999). The increase in pasture production with clearing has been demonstrated in previous studies by Burrows *et al*. (1990), Scanlan and Burrows (1990), and Burrows (2002).

The greater pasture production with subsequent improved financial performance from developed (cleared) pastures has led to high rates of tree clearing in Queensland. During 1999–2001, a total of 577 000 ha (∼367 000 ha remnant and 210 000 ha non-remnant woody vegetation) were cleared per annum and ∼94% of the total clearing was to develop land for pastures (Department of Natural Resources and Mines 2003). Clearing trees for pasture and cropping land has historically been favoured under different Australian government policies until 1985 (Boulter *et al*. 2000). The subsequent improvements in cattle production have contributed considerably to overall development (economic returns and employment) in Queensland (ABS 2003).

However, there are increasing concerns that much of the development in the agriculture sector that occurred in the past involved little understanding of the inherent potential

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of the natural resources underpinning production systems (Boulter *et al*. 2000). For example, there could be differential responses in pasture production with clearing depending on vegetation, soil and climate type. Moreover, there are associated risks for pasture run-down, land degradation and loss of biodiversity that have been largely ignored while estimating the benefits from clearing (Rolfe 2002).

In the absence of long-term studies (> 15 years) of pasture systems of Queensland, it is difficult to draw conclusions on the net benefits of tree clearing especially without considering ecosystem services that could affect pasture production. Most of the work reported to date has highlighted improved pasture yields for periods of less than a decade after clearing (Scanlan 2002) and have not addressed the associated changes in various ecological functions. The benefits of clearing could have been overstated in earlier studies conducted over a short-term (<10 years) (e.g. Scanlan and Burrows 1990; Scanlan 1991; Burrows 1993) because the long-term ecological effects were not considered. The present study questions the sustainability of pasture production in cleared pastures and emphasises the need to assess the benefits or otherwise of clearing over a longer term when and if pasture production may stabilise, and to quantify loss if any, of ecosystem function.

With these objectives, research was undertaken to quantify the impact of clearing on pasture biomass for various tree communities using clearing durations of longer than 10 years. Three major types of tree communities, *Eucalyptus populnea* F. Muell. (poplar box), *E. melanophloia* F. Muell. (silver-leaved ironbark) and *Acacia harpophylla* F. Muell. ex. Benth. (brigalow), were selected in central Queensland to quantify the above-ground pasture biomass, plant diversity, soil pH and soil microbial biomass for cleared and uncleared (intact) pasture systems. The study of three different vegetation communities at various times since clearing should provide information about their post-clearing responses with respect to pasture production and ecosystem function. This information will assist in assessing whether cleared pasture systems perform better than uncleared woodland, and in examining the sustainability of cleared systems over time.

Materials and methods

Study area and design

Paired sites of cleared and intact/uncleared woodland of *E. populnea*, *E. melanophloia* and *A. harpophylla* communities were selected to represent each of three age groups of clearing i.e. recent (5 year), medium (11–13 year) and old (33 year). The study represents a 3 (types of tree communities) × 3 (time since clearing) × 2 (cleared *v.* intact) factorial design. The paired cleared and uncleared sites were selected in close proximity (*c.* 50 m on either side of a fence) and were assumed to have similar characteristics (e.g. soil type, slope and vegetation) before clearing (as was suggested by the landholder). Grazing management after clearing was similar for both cleared and uncleared sites. The details for methods of clearing and stocking rate at each site are presented in Table 1.

All the sites were located on a grazing property 'Avocet' that comprises a total area of *c.* 5000 ha (NW Long 148.13°E Lat 23.79°S, NE Long 148.16°E Lat 23.80°S, SE Long 148.21°E Lat 23.85°S and SW Long 148.12°E Lat 23.86°S) in central Queensland. The property is located 30 km south of Emerald and has an average annual rainfall of ~600 mm, with sporadic summer storms during November–February contributing to a summer dominance of rainfall. Average (over the 136 years from 1865–2001; data obtained from Bureau of Meteorology 2003) minimum and maximum temperatures during winter (June–August) are 6–8°C and 23–25°C, and during summer (December–February) are 22–24°C and 33–36°C, respectively.

Measurements

Above-ground pasture biomass was studied in fenced exclosures from which grazing was excluded. The exclosures were established in November 2000.

Table 1. Details of clearing time (all sites were chain pulled), post-clearing treatments and annual stocking rate (SR) at cleared and uncleared sites for *E. populnea*, *E. melanophloia* and *A. harpophylla* communities
Sites were set up in November 2000

Tree community	Cleared treatments: Time of clearing	Cleared treatments: Post-clearing treatment	Cleared treatments: SR (adult cattle/ha)	Uncleared treatments: SR (adult cattle/ha)
		E. populnea		
Recent clearing	May 1996	Burnt in Oct. 1999	1/5	1/5
Medium clearing	Dec. 1987	Blade ploughed in 1994	1/3	1/4.8
Old clearing	July 1967	Blade ploughed in 1987	1/6	1/4.8
		E. melanophloia		
Recent clearing	May 1996	Burnt in Oct. 1999	1/5	1/5
Medium clearing	Oct. 1990	Blade ploughed in 1994	1/3	1/3
Old clearing	July 1967	Blade ploughed in 1987	1/6	1/6
		A. harpophylla		
Recent clearing	May 1996	Burnt in Oct. 1999	1/5	1/11
Medium clearing	Dec. 1987	Blade ploughed in 1994	1/3	1/4.8
Old clearing	July 1967	Blade ploughed in 1987	1/6	1/4.8

Above-ground pasture biomass and plant diversity

At each of the eighteen sites an area of 1 ha was selected as representative of the total area (unfenced) and a fenced plot of 10 m × 10 m located centrally in each 1 ha site was established. The quadrat method (Kent and Coker 1992) was used to study the species composition and to estimate the amount of pasture biomass. All plant species in a quadrat were identified and the total aboveground biomass was quantified from five randomly assigned quadrats of 1 m × 1 m area. Quadrats were located at different positions at each sampling date. Plant samples from each quadrat were harvested just above-ground level, taken to the laboratory and dried at 60°C for 48 h.

Measurements were taken for different times (seasons) throughout the year starting in March 2001 and then at four-month intervals, in July 2001, November 2001 and March 2002. In March 2002, the recently cleared site for *E. melanophloia* was accidentally burnt, so measurements for that site were not available.

The average quantity of pasture above-ground biomass for grazing was calculated over a year from the seasonal measurements. For measurements in March taken in both 2001 and 2002, their average was considered along with measurements in July 2001 and November 2001.

Tree basal area and density

At intact woodland sites, basal area and number of trees per unit area were quantified using the TRAPS method (Transect Recording And Processing System) (Back *et al*. 1997). At each site three transects of 50 m × 4 m area were established and all the woody trees and shrubs greater than 1.5 m height were included for measurements. Tree basal area was estimated from the circumference taken with a measuring tape at 30 cm above the ground. Averages were calculated for all the trees and shrubs that occurred in three transects and expressed as basal area (m^2/ha) for each tree community. The number of trees in each transect were also counted. Differences among the communities were then determined by analysis of variance.

Soil properties (soil pH and soil microbial biomass)

Eight soil samples were collected at randomly selected different distances and directions from a central point in each site from the representative 100 m × 100 m (unfenced) area. Each sample was taken at 0–5, 5–10, 10–20, 20–30, and 30–60 cm using a hydraulic soil corer and dried at 40°C. All 8 samples from a site were bulked for each depth. Visible roots and pebbles were removed during processing. The samples were analysed for pH (1 : 5 soil : water) at the soil laboratories of Incitec Ltd, Brisbane.

Eight additional soil samples were taken randomly from the top 0–5 cm in March 2002 at each site to examine soil microbial biomass carbon (MBC) and nitrogen (MBN). These samples were bulked for each site and were analysed using the chloroform fumigation extraction method (Vance *et al*. 1987) at the Natural Resource Sciences Laboratories (Department of Natural Resources and Mines, Brisbane, Indooroopilly, Qld).

Statistical analysis

Pasture biomass data were analysed using GENSTAT ver 6.0 (2002). The residual maximum likelihood (REML) (Patterson and Thompson 1971) method was used. The uncleared treatments of a tree community were considered as replicates while there were no replicates within a tree community for cleared treatments. Pasture biomass data for each season and the average per year were compared across all cleared and uncleared treatments.

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 l.s.d. (least significant differences of means) at $P < 0.05$. The means from REML analysis were used in presenting the results.

For plant species diversity, Shannon–Wiener's index was calculated using species diversity and richness software (Henderson and Seaby 1998).

REML was applied using GENSTAT ver 6.0 (GenStat Committee 2002) as for pasture biomass to study the change in soil pH with age of clearing. For soil microbial biomass, paired *t*-tests were applied to compare means for all the cleared and uncleared treatments.

Results

Clearing generally enhanced the amount of pasture biomass but not at all sites and at all assessment times (Fig. 1, Table 2). The medium age of clearing (after 13 years) had a significantly greater pasture biomass ($P < 0.05$) compared with the uncleared sites in *E. populnea* and *A. harpophylla*, but not for *E. melanophloia.* For *A. harpophylla*, the amount of pasture was also significantly greater ($P < 0.05$) in old cleared compared with uncleared sites except in November 2001.

The amount of pasture biomass in the *E. populnea* and *A. harpophylla* communities was greater from recent to medium and then declined at old age of clearing but these differences were only significant ($P < 0.05$) at some assessment times (Fig. 1). For *E. melanophloia*, interestingly, clearing had no significant effect on pasture biomass between different ages since clearing and uncleared sites. However, between the cleared sites, pasture biomass was significantly greater at recent compared to old cleared sites for July and November 2001 (Fig. 1).

A comparison between uncleared sites of the different tree communities showed that *E. melanophloia* supported the maximum pasture yield (2879 kg/ha) compared to *E. populnea* (1222 kg/ha) and *A. harpophylla* (1035 kg/ha) communities (Table 2). Some of the differences in pasture biomass between tree communities can be explained by tree basal area and tree density with a general trend of reduced pasture biomass with increasing tree basal area and density (Fig. 2).

Uncleared sites were more species-diverse than cleared sites in all tree communities as quantified by Shannon–Wiener's index of diversity and by the number of species (Table 3). Within cleared sites, species diversity declined at medium and old cleared sites compared to recently cleared sites, for all three communities.

Soil pH and soil microbial biomass were markedly affected by clearing. Soil pH increased significantly

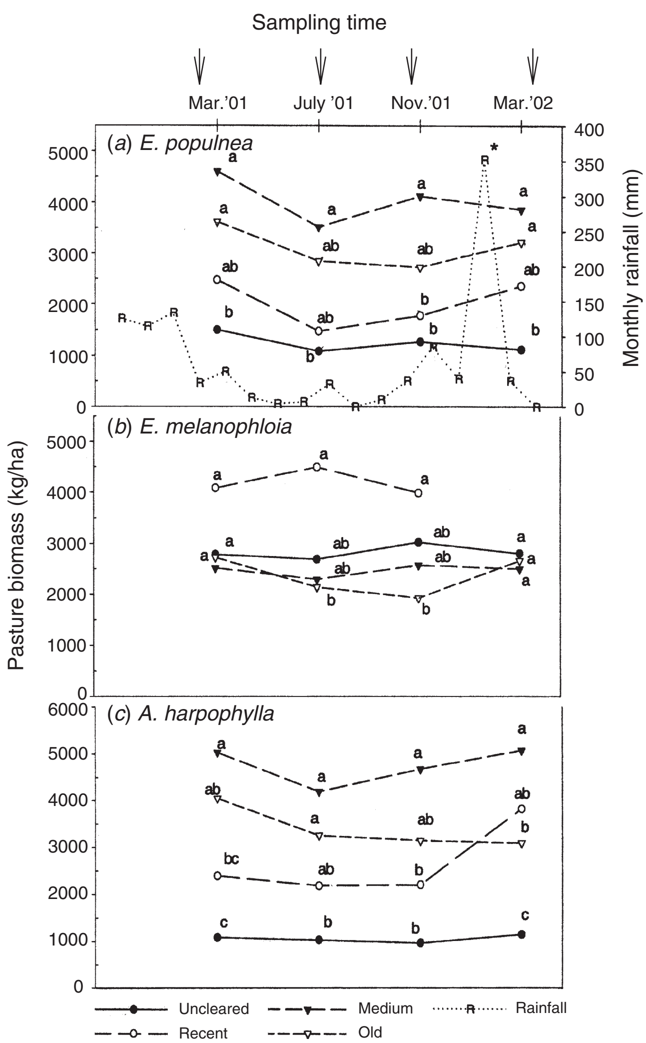

Fig. 1. Pasture biomass (kg/ha) and monthly rainfall (mm) in fenced plots for various cleared and uncleared treatments for (*a*) *E. populnea*, (*b*) *E. melanophloia* and (*c*) *A. harpophylla* communities (similar rainfall as at *E. populnea*, for *E. melanophloia* and *A. harpophylla* sites). Any two treatments with different letters on any one sampling date within a tree community denote significant difference at $P < 0.05$ using REML.

($P < 0.05$) with time since clearing for all tree types (Table 4).

Soil microbial biomass both for C and N, was significantly ($P < 0.05$) greater at uncleared compared to cleared sites (Table 5; overall mean for all the cleared *v.* uncleared treatments).

Discussion

The present study indicated that each of the communities had a specific response to clearing but the general trend was an initial increase in pasture biomass followed by a decline in the case of the *E. populnea* and *A. harpophylla* communities. In the *E. melanophloia* community, any increase in pasture biomass at 5–6 years after clearing was not significant and was followed by a significant decline to 33 years of clearing.

Among the uncleared sites, *E. melanophloia* had the highest pasture biomass which may explain the lack of significant increase after clearing. These results may in part be due to the lower tree density and tree basal area for the *E. melanophloia* community compared to *E. populnea* and *A. harpophylla* communities. Burrows (2002) showed that for a given basal area, *E. melanophloia* and *E. populnea* supported more pasture yield than *A. harpophylla*. Lower

Table 2. Yearly average amount of pasture biomass (kg/ha) in fenced plots (exclosures) for uncleared and cleared (recent, medium and old age of clearing) treatments for *E. populnea*, *E. melanophloia* and *A. harpophylla* communities

Different lowercase in a row and uppercase in a column represent the significant levels of difference at $P < 0.05$ between treatments using REML (Residual Maximum Likelihood method)

Tree community	Uncleared	Recent	Medium	Old
E. populnea	1222Bc	1855Bbc	4019ABa	2974Aab
E. melanophloia	2879Aab	4174Aa	2519Bab	2231Ab
A. harpophylla	1035Bb	2458ABab	4700Aa	3294Aa

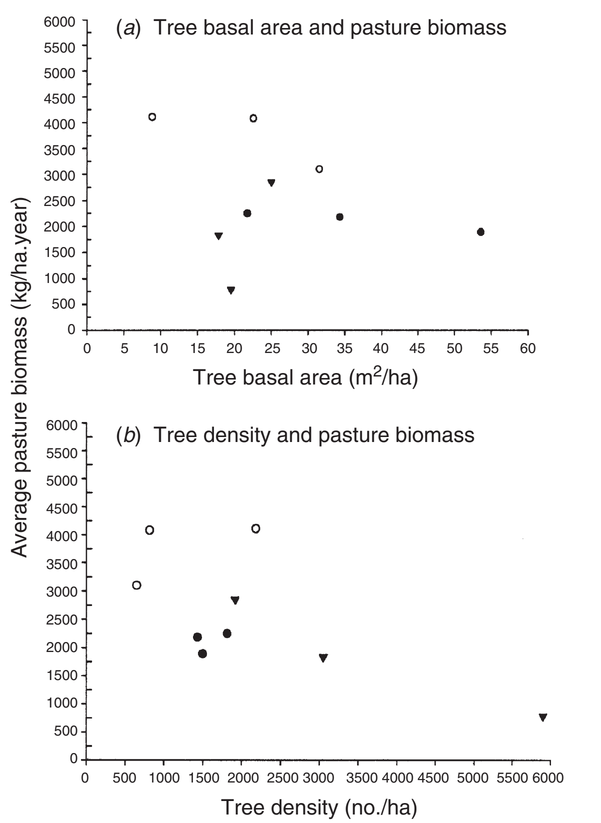

Fig. 2. Pasture biomass at uncleared sites for *E. populnea* (●), *E. melanophloia* (○) and *A. harpophylla* (▼) in relation to: (*a*) Tree basal area and (*b*) Tree density.

Table 3. Plant species number (no./ha.year) and Shannon–Wiener's index of species diversity for uncleared, and recent, medium and old age cleared sites for *E. populnea*, *E. melanophloia* and *A. harpophylla* communities

Within columns, means followed by different letters represent significant difference at $P < 0.05$ for cleared and uncleared treatments within a tree community

Tree type	Treatments	Species number	Shannon–Wiener's index
E. populnea	Uncleared	32a	2.5201a
	Recent	21b	2.2478b
	Medium	13d	0.3217d
	Old	18c	0.7941c
E. melanophloia	Uncleared	37a	2.3881a
	Recent	24b	1.6142b
	Medium	17c	1.2675c
	Old	19c	1.1236d
A. harpophylla	Uncleared	34a	2.4751a
	Recent	25b	1.7729b
	Medium	9d	0.2068d
	Old	10c	0.6318c

tree basal area and density reduces the competition between trees and grass for soil nutrients and moisture (Burrows *et al*. 1988; Burrows 1993). The present data for *E. populnea* and *E. melanophloia* fitted closely the pasture yield-tree basal area relationships developed by Burrows (2002) for these species, but suggested a different relationship for *A. harpophylla*. According to Burrows (2002), pasture biomass of uncleared *A. harpophylla* community was predicted to be zero at 21 m^2/ha basal area, whereas in the present study uncleared *A. harpophylla* (with 21 m^2/ha basal area) supported on average *c.* 1400 kg/ha pasture biomass.

The data from the present study confirm the earlier reported increases in pasture biomass after tree clearing, but show that the increase in pasture biomass holds only for the initial years, and then declines when the age of clearing is greater than 10–20 years. The increase in pasture biomass with clearing has also been intimated from pasture yield and tree basal area relationships developed for various eucalypt and acacia woodlands (Walker *et al*. 1972, 1986; Burrows *et al*. 1990; Scanlan 1991; Burrows 1993, 2002). However, most of the studies to date have quantified the relationship between pasture yield and tree clearing for only a few years after clearing, but not over a longer period (Scanlan 2002).

The present research questions the sustainability of pasture production following clearing when a multi-decadal view is taken. The first few years post-tree clearing, with increased pasture yield, is indeed the most attractive phase for a producer to maximize economic gains due to clearing. Release of soil nutrients upon clearing (Lawrence *et al*. 1988) and absence of competition between trees and grasses for nutrients, soil moisture and light (Burrows *et al*. 1988; Obot 1988; Belsky *et al*. 1989; Belsky 1994; Mordelet and Menaut 1995) facilitates grass species establishment and pasture production. Nevertheless, other reports from tropical savannas suggest a positive role of trees in terms of shade and nutrients that enhance pasture production (Weltzin and Coughenour 1990; Belsky 1994; Jackson and Ash 1998) and for higher nitrogen content and *in vitro* dry matter digestibility in pastures with trees compared to those without trees (Jackson and Ash 2001).

The trends for decline in pasture biomass from medium to old age of clearing for all the tree communities indicates the absence of a long-term major gain from clearing. In the case of the *E. melanophloia* community the benefit from clearing was for a very short time, if at all. Assessments of the benefits of clearing based upon the initial gains in pasture production, could therefore be inappropriate when calculated over the long-term. Scanlan (2002) suggested that the 'stable stage' of pasture production over time after clearing should be considered as a standard against which to compare productivity rather than the initial phase of very high production. The 'stable stage' may be different for different communities, and as apparent from the present study, it could be reached at, or after, 33 years of clearing in *E. populnea* and *A. harpophylla* communities or could have already been reached in *E. melanophloia* where old and uncleared sites had similar pasture biomass.

The short-term gains in pasture production due to clearing may be offset by the loss of some long-term ecological services such as:

- Loss of pasture plant diversity and its possible importance in pasture quality and ecosystem stability (derived from the functional diversity of different species).
- Changes in soil properties that could, by implication, affect the growth of pasture species.

Table 4. Soil pH (1 : 5 soil : water extract method) (mean values for 0–60 cm depth ± standard error of mean) for uncleared, and recent, medium and old age cleared sites for *E. populnea*, *E. melanophloia* and *A. harpophylla* communities

Within rows, means followed by different letters represent significant difference at $P < 0.05$

	Uncleared	Recent	Medium	Old
E. populnea	5.62 (±0.09)a	6.28 (±0.38)b	7.05 (±0.40)b	7.63 (±0.16)c
E. melanophloia	6.85 (±0.09)a	7.22 (±0.07)b	7.13 (±0.27)b	7.8 (±0.37)c
A. harpophylla	6.13 (±0.21)a	6.27 (±0.27)a	7.43 (±0.40)b	7.84 (±0.41)b

Table 5. Mean (±s.e.) values across tree communities and time since clearing for soil microbial biomass for carbon and nitrogen
Within rows, means followed by different letters represent significant difference at $P < 0.05$ (8 d.f.) after applying *t*-test

	Uncleared	Cleared
Microbial biomass – carbon (mg/kg)	385.9 (±37)a	253.6 (±37)b
Microbial biomass – nitrogen (mg/kg)	40.17 (±3.29)a	29.87 (±3.45)b

Sowing cleared land to a dominant exotic grass species such as *C. ciliaris* has set up mono-cultures with reduced pasture species diversity that could adversely affect pasture quality. No detailed study has been conducted on the role of species diversity in pasture quality for pasture systems in Queensland. Reduced species diversity in pasture systems could affect the ecosystem function in terms of 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 also supported higher productivity. A similar role of plant diversity (functional diversity) in maintaining the ecosystem functions in Queensland pasture systems should be investigated. A more diverse pasture mix would provide some resilience should an exotic pasture species be affected by pests or disease.

Soil pH showed a notable increase with age of clearing, to such an extent that it adversely affected the availability of soil nutrients (Sangha *et al*. 2005). There was a loss of microbial biomass with clearing that would most likely lead to less mineralisation of soil organic matter, and hence lower availability of nutrients for plant growth and the noted decline in pasture production over time as reported here. The changes in soil pH or soil microbial biomass occur mainly due to change in soil processes with clearing (Sangha *et al*. 2005). But, over a longer term, such effects of soil pH or microbial biomass on nutrient availability will possibly become more apparent. If, in order to maximize production gains some of these soil properties such as pH (increased ~1–2 units at all old cleared sites) or soil microbial biomass (decreases) change, would the restoration of the original capacity of land (soil functions such as nutrient mineralisation) be possible over a short period of time? Possibly it may take longer to restore soil function than it would have taken to harvest the benefits of clearing.

Without doubt large increases in pasture production occur in response to clearing in *E. populnea*, *A. harpophylla* and possibly *E. melanophloia* communities of central Queensland and this response is exploited by cattle producers. The benefits of tree clearing depend on the potential of each system and more importantly, they do not necessarily persist over a longer time post-clearing. There is also more exposure to risk of soil degradation and loss of faunal and floral species diversity with clearing. A total value assessment for gains in pasture production following clearing, including quantification of negative impacts of clearing on soils and on litter production and nutrient recycling, could provide a better understanding of net costs or benefits due to tree clearing in pasture systems, and could help landholders and policy makers to be objective in their decisions on tree clearing.

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