The Brigalow catchment study: More than 20 years of monitoring water balance and soil fertility of brigalow lands after clearing for cropping or pasture

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Abstract
The Brigalow Catchment Study was established to determine the impact on hydrology and soil fertility when brigalow land is cleared for cropping or pasture. This paired catchment study commenced in 1965, when three catchments were selected in central Queensland, Australia, to represent the extensive brigalow bioregion of approximately 40 million hectares. Catchment hydrology was characterised during a 17-year calibration period (1965–81). In 1982, two of the three catchments were cleared, with one developed for cropping and the other sown to improved pasture. The third catchment was retained as an uncleared control. Soil sampling on 13 occasions from 1981-2007 allowed changes in soil fertility to be characterised. Land development for either cropping or grazing has doubled runoff and increased peak runoff rates. Deep drainage increased dramatically during land development and significant amounts of soil chloride were leached. This continues to occur under cropping. Cropping has resulted in a decline in soil organic carbon, total nitrogen and bicarbonate-extractable phosphorus. Grazing beef cattle on improved pasture however has maintained soil organic carbon and total nitrogen levels, but has shown a greater decline in bicarbonate-extractable phosphorus than cropping.

Key Words
Vertosols, Dermosols, Sodosols, buffel grass, modelling, virgin brigalow scrub.

Introduction
The brigalow bioregions of Queensland and New South Wales occupy 36.7 million hectares, stretching from Dubbo in the south to Townsville in the north. Since European settlement, 58% of this bioregion has been cleared. In 1962, the Brigalow Land Development Fitzroy Basin Scheme commenced, resulting in the clearing of 4.5 million hectares for cropping and grazing. This clearing represents 21% of all clearing in the brigalow bioregions and 32% of the Fitzroy Basin area. In order to quantify the effect of land clearing on hydrology and soil fertility, the Brigalow Catchment Study (BCS) commenced in 1965.

Methods
The BCS (24.81^o S, 149.80^o E) lies in the Dawson subcatchment of the Fitzroy basin, central Queensland, Australia. The region has a semi-arid, subtropical climate. Summers are wet with 70% of the annual average calendar rainfall of 720 mm falling between October and March, while winter rainfall is low. Rainfall is highly variable, ranging from 11 mm or less in any month, to 165 mm in one day. Annual potential evaporation is 2133 mm, and average evaporation is at least twice the average rainfall in all months.

The BCS is a paired catchment study consisting of three small catchments of areas 11.7-16.8 ha. There have been three experimental stages (Table 1). Mean slope of the catchments is 2.5%. Soil types in the catchments comprise associations of Black and Grey Vertosols, some with gilgais, Black and Grey Dermosols, and Black and Brown Sodosols (Isbell 1996). In their native state, the catchments were composed of three major vegetation communities, identified by their most common canopy species; brigalow (*Acacia harpophylla*), brigalow – belah (*Casuarina cristata*) and brigalow – Dawson Gum (*Eucalyptus cambageana*). Understoreys of all major communities are characterized by *Geijera* sp. either exclusively, or in association with *Eremophila* sp. or *Myoporum* sp. The catchments were good quality agricultural land, all equally suitable for cropping or grazing. The Study has been reported comprehensively (Cowie *et al.* 2007; Radford *et al.* 2007; Thornton *et al.* 2007; Silburn *et al.* 2009).

Table 1. The land use history of the three catchments of the Brigalow Catchment Study.

		Land use by experimental stage		
		Stage I	Stage II	Stage III
Catchment	Area (ha)	(Jan 1965-Mar1982)	(Mar 1982-Sep 1984)	(Sep 1984-Dec 2004)
1	16.8	Virgin brigalow scrub	Virgin brigalow scrub	Virgin brigalow scrub
2	11.7	Virgin brigalow scrub	Development	Cropping
3	12.7	Virgin brigalow scrub	Development	Improved pasture

The Stage I calibration phase (17 years) identified the inherent differences in catchment runoff characteristics allowing a calibration for empirical comparison between catchments. Three permanent soil monitoring sites (20 x 20 m) were established in each catchment: two on clay soil, in both an upper and lower-slope position, and the third on a Sodosol. Baseline measurements of soil fertility were taken in 1981.

Stage II commenced in March 1982, when C2 and C3 were developed by clearing vegetation with traditional bulldozer and chain methods. The fallen timber was burnt *in situ* in October 1982. In C2, residual unburnt timber was raked to the contour and burnt. Narrow-based contour banks were constructed at 1.5 m vertical spacing. A grassed waterway was established to carry runoff water from the contour channels to the catchment outlet. In C3, any unburnt timber was left in place, and in November 1982 the catchment was sown to improved pasture by distributing buffel grass seed (*Cenchrus ciliaris* cv. Biloela) on the soil surface. The second soil fertility assessment was undertaken in December 1982, soon after burning.

Stage III commenced in 1984. In C2, the first crop sown was sorghum (September 1984), followed by annual wheat for nine years. Fallows were initially managed using mechanical tillage (disc and chisel ploughs), which resulted in significant soil disturbance and low soil cover. In 1992 a minimum tillage philosophy was introduced and in 1995 opportunity cropping commenced with summer (sorghum) or winter (wheat) crops sown when soil water content was adequate. No nutrient inputs were used. In C3, the buffel grass pasture established well with >5 plants/m^2 and 96% groundcover achieved before cattle grazing commenced in December 1983. Stocking rate was 0.3-0.7 head/ha (each beast typically 0.8 adult equivalent), adjusted to maintain pasture dry matter levels >1000 kg/ha without feed or nutrient supplementation.

Soil fertility was assessed annually from 1981-1987 and then in 1990, 1994, 1997, 2000, 2003 and 2008.

Results

Runoff from the three catchments in their virgin state during Stage I averaged 34 mm/yr; approximately 5% of annual rainfall. Peak runoff rate averaged 3.4 mm/hr. Runoff data from Stage I was used to develop linear relationships to estimate runoff from C2 and C3 given known runoff from C1. This calibration was used to compare Stage III measured runoff from C2 and C3 with estimations of runoff had they not been cleared. This showed an increase of 42 mm/yr when brigalow scrub is developed for cropping and 38 mm/yr when developed for grazed pasture (Figure 1). Peak runoff rate from brigalow scrub increased to 6.9 mm/hr in Stage III however land development resulted in an additional 149% increase in peak runoff rate from the cropping catchment and 67% increase from the pasture catchment.

In 1981 prior to land development, soil chloride showed similar profiles across all sites, typically increasing to 0.4-0.6 m depth and then remaining relatively constant (Figure 2). Chloride mass in the clay soils was similar, with 25 t/ha of chloride to 1.5 m depth, however chloride mass in the sodosols was as low as 4.9 t/ha. During the land development phase (Stage II), the upper slope clay and sodosol sites in C2 showed significant loss of soil chloride, while all sites in C3 showed significant loss.

Subsequent reductions in soil chloride under cropping were only significant in the upper clay soil, while under pasture, no further significant change occurred (Figure 2). Chloride mass balance analysis indicates deep drainage of 0.17 mm/yr for clay soils and 0.26 mm/yr for Sodosols under virgin brigalow scrub. These drainage rates increased during the land development phase to 59 mm/yr for C2 and 32 mm/yr for C3. Since development, deep drainage has averaged 19.8 mm/yr under cropping and 0.16 mm/year under pasture.

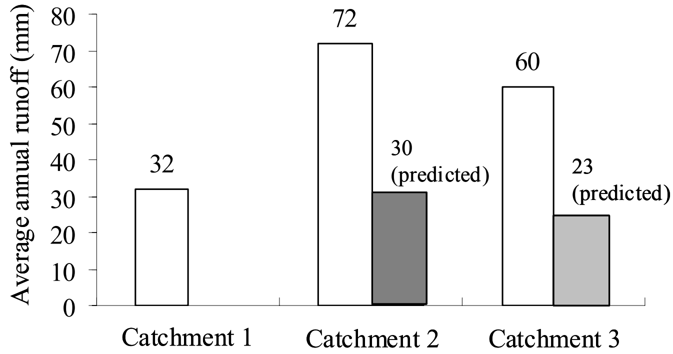

Figure 1. Observed runoff from the three catchments during the land use comparison phase (Stage III) of the trial (□), and the predicted runoff from catchments 2 (■) and 3 (■) had they remained uncleared. All data has been rounded to zero decimal places.

In their virgin state the three catchments had similar soil fertility. From 0-0.1m, levels of organic carbon (OC) (Walkley and Black) ranged from 1.8 to 2.2%, soil total nitrogen (TN) (Kjeldahl) from 0.18 to 0.21%, and extractable phosphorus (CP) (Colwell) from 10.3 to 11.0 mg/kg. No significant changes in OC levels occurred in the scrub or pasture catchments over the 26-year land use comparison; however, the cropping catchment showed a 48% decline in OC (Figure 3). Similarly, no significant changes in TN levels occurred in the scrub or pasture catchments, while the cropping catchment showed a 64% decline in TN. Burning of the pulled timber in C2 and C3 resulted in significant increases of CP, to levels of 36.8 and 34.3 mg/kg respectively. These levels decreased over the 26 years in both the cropping and pasture catchments by 45% and 65% respectively

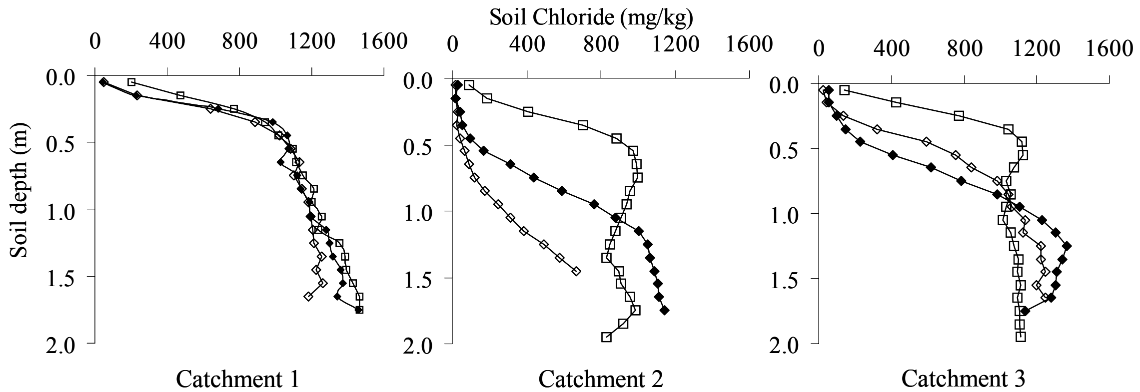

Figure 2. Average soil chloride profiles for the upper slope clay soil in each catchment pre-clearing (1981) (□), immediately after land development (1983) (♦) and after 16 years of land use (2000) (◊).

Discussion

At this site, land development for either cropping or grazing had significant effects on catchment water balance and fertility. A doubling of runoff and increased peak runoff rates under both agricultural systems resulted in increased risk of erosion and transport of nutrients and agricultural chemicals off-site. Agricultural production opportunities are also forgone as water for crop or pasture growth is lost.

An increased salinity risk is also of concern, primarily associated with the large increase in deep drainage and chloride leaching during the development phase of each land use and the ongoing deep drainage under cropping. The removal of chloride from the upper soil profile may however provide agricultural production benefits if initial chloride levels are a constraint to crop or pasture growth.

The three soil fertility parameters investigated all showed significant decline under cropping. Even if fertility decline is arrested via the application of fertiliser, the soil is unlikely to return to its virgin fertility level while continuing to be cropped. Modelling suggests that the application of nitrogen fertiliser to this system will improve TN levels, however limiting rainfall will not allow an increase in cropping frequency and hence dry matter production, so OC levels will not be improved (Huth *et al.* 2009).

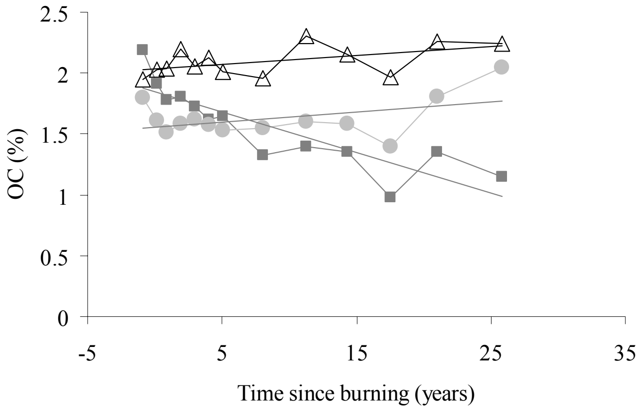

Figure 3. Average organic carbon levels (0-0.1 m) in the untreated brigalow scrub catchment (∆), linear trend (–**), over 26 years, compared to levels in the catchment developed for cropping (■), linear trend (**–**), and the catchment developed for pasture (●), linear trend (**–**).**

Unlike cropping, grazed pasture appears capable of maintaining both OC and TN levels, however significant amounts of TN are likely to be held in a plant-unavailable form, which may be limiting to pasture growth. The greater decline in CP in the pasture catchment compared to the cropping catchment suggests that even though more P is removed in grain than in beef, continuous production of dry matter in the pasture system results in less available P than in a cropping system, where dry matter production occurs for only a few months of the year.

Conclusions

Development of brigalow lands for cropping and grazing has significantly altered water and nutrient balances, with increased runoff and peak runoff rates, increased drainage and decreased soil OC, TN and CP under cropping and decreased CP under pasture. Based on these indicators, pasture appears more analogous to the native brigalow landscape than cropping. The relevance of these findings to the larger brigalow bioregion will help to guide future investment in natural resource management. The length of record and breadth of data collected at this site can be considered a model in its own right, providing a point of truth for landscape and process modelling activities and a benchmark to assess the effects of slow, subtle and complex processes such as climate change on semi-arid subtropical Australian landscapes. To better facilitate these activities, open access to BCS data is available online at www.derm.qld.gov.au/science/projects/brigalow/index.html.

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