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Runoff Nitrogen, Phosphorus and Sediment Generation Rates from Pasture Legumes: Addendum to Paddock Scale Water Quality Monitoring for 2013 and 2014 *RRRD009*

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Queensland Government

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Runoff Nitrogen, Phosphorus and Sediment Generation Rates from Pasture Legumes: Addendum to Paddock Scale Water Quality Monitoring for 2013 and 2014 (Project RRRD009)

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Cover photographs: Leucaena pasture (top left), runoff event through flume (top right), leucaena trimming (bottom left) and butterfly pea ley pasture (bottom right) are all sourced from the Brigalow Catchment Study photo archives, courtesy of the Department of Natural Resources and Mines.

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Executive Summary

Nitrogen, phosphorus and sediment were monitored in runoff from virgin brigalow scrub, grass pasture and leguminous pastures from 2010 to 2012 at the Brigalow Catchment Study, located in the Fitzroy Basin. Brigalow scrub is representative of the landscape in its pre-European condition. It was hypothesised that nutrient and sediment loads from a newly established ley pasture (previously cropping) would decline over time as plant cover and biomass increased. The data did not clearly demonstrate this, with trends confounded due to record breaking rainfall and runoff. Consequently the applicability of this data to reflect catchment responses in more typical seasons was unknown. Thus, an additional two years of monitoring was undertaken to capture water quality responses to less extreme climatic sequences.

Rainfall in the period 2013 to 2014 was much closer to the long-term annual average (660 mm) and did not exceed the 60th percentile in either year. Runoff during 2013 supported the 2010 to 2012 result that clearing brigalow scrub for either cropping or grazing increased runoff. Grass pasture continued to display this trend in 2014; however, butterfly pea ley pasture had similar runoff to brigalow scrub. Loads of total, oxidised and dissolved inorganic nitrogen from butterfly pea, grass and leucaena pastures were all lower than virgin brigalow scrub. However, the greatest load of dissolved inorganic phosphorus came from butterfly pea in both years.

There was little change in the relativity of loads between brigalow scrub, grass pasture and leucaena pasture between 2010 and 2014; however, loads from butterfly pea ley pasture showed quiet different dynamics. This catchment typically had the highest nutrient and sediment loads during 2010 to 2012. Conversely, loads from butterfly pea during 2013 and 2014 were similar to the other pasture land uses with loads of total, oxidised and dissolved inorganic nitrogen, total phosphorus and total suspended sediment all less than brigalow scrub.

No temporal trends were detected in the event mean concentrations of nutrients or sediment during 2010 to 2014 from brigalow scrub, grass pasture or leucaena pasture. However, a declining trend was observed for total, oxidised and dissolved inorganic nitrogen and total suspended sediment from butterfly pea ley pasture.

These findings support the hypothesis that higher nutrient and sediment loads are exported from ley pasture during the development phase and then decline over time towards that of long-term grazed landscapes. Loads of nutrients and sediment from long-term grazed landscapes were lower than that of virgin brigalow scrub. No temporal trends were detected in the event mean concentration of nutrients and sediment from brigalow scrub or the established grass and leucaena pastures from wet to dry years. This indicates that not only do these land uses maintain their specific flow signatures in extreme wet seasons, but they also maintain their specific water quality signatures.

The dynamics of dissolved inorganic nitrogen in runoff from established legume and non-legume pastures is still not clear. The risk posed to water quality is likely to be of concern given the concentration of dissolved inorganic nitrogen in runoff from butterfly pea is equal

to that reported for some sugar cane systems. However, these concentrations are typically an order of magnitude less than those from brigalow scrub.

When considering on-ground management action, this study indicates that the establishment stage of a ley pasture is, not unexpectedly, the period of greatest risk to water quality. Conservative grazing management combined with spelling should be promoted in the first year to coincide with the highest risk of total, oxidised and dissolved inorganic nitrogen loss in runoff. Continued management for high cover and biomass will deliver reductions in nutrients and sediment loads past the first year.

The incorporation of a legume ley pasture into a farming system compared to a more permanent legume pasture, such as leucaena, needs to be carefully considered from both an economic and environmental perspective. Switching in and out of legume pastures, particularly ley pastures in cropping enterprises, is a substantial financial investment with the establishment phase proving the greatest risk to water quality.

Contents

List of Figures

List of Tables

Abbreviations

DIN	Dissolved Inorganic Nitrogen: Oxidised Nitrogen (NO_x-N) + Ammonium-Nitrogen (NH_4-N)
DIP	Dissolved Inorganic Phosphorus, also known as Filterable Reactive Phosphorus (FRP) and Orthophosphate (PO4-P)
DNRM	Department of Natural Resources and Mines
EMC	Event Mean Concentration
NH_4-N	Ammonium-Nitrogen
NO_x-N	Oxidised Nitrogen: Nitrate-Nitrogen (NO_3-N) + Nitrite-Nitrogen (NO_2-N)
TN	Total Nitrogen: Total Kjeldahl Nitrogen (TKN) + Oxidised Nitrogen (NO_x-N)
TP	Total Phosphorus
TSS	Total Suspended Solids

Acknowledgements

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Introduction

In the period 2010 to 2012, substantial loads of total suspended sediments and dissolved inorganic nitrogen were reported in runoff from virgin brigalow scrub (Thornton and Elledge 2013). This brigalow scrub is representative of the broader Brigalow Belt Bioregion in its pre-European condition. Even larger loads of these parameters were lost from long-term cropping land recently planted to ley pasture. However, in contrast, nutrient and sediment loads from long-term grazed landscapes were comparatively low.

The authors hypothesised that high loads of nutrients and sediment would occur from ley pastures in the development phase, due to low cover levels and the disturbance of soil by planting activities. As pastures establish, it was expected that loads would decline as pasture cover and biomass increased. This may result in loads being similar to that of long-term grazed landscapes which are lower than virgin brigalow scrub (Thornton and Elledge 2013).

Monitoring from 2010 to 2012 did not support this hypothesis. However, the climatic sequence was two extreme wet seasons followed by an above average rainfall year that yielded less than average runoff. Due to such extreme rainfall, the appropriateness of this data to reflect the long-term behaviour of the land uses was uncertain. Thus, the paddock scale monitoring component of Reef Rescue Research and Development Water Quality Program Project RRRD009 (Thornton and Elledge 2013, Chapter 3) was extended over 2013 to 2014 to answer two key questions:

(1) Will loads of total suspended solids and dissolved inorganic nitrogen from butterfly pea ley pasture decrease over time, as the pasture becomes well established?

(2) Is the data collected from 2010 to 2012 applicable to periods of less extreme rainfall, or did record rainfall result in record loss of nutrients and sediment?

Methods

This study is an extension of the paddock scale water quality monitoring that occurred from 2010 to 2012 at the Brigalow Catchment Study, near Theodore in central Queensland (Thornton and Elledge 2013). This report covers the 2013 hydrological year (October to September) and the 2014 hydrological year until June 30. Whilst the 2014 data set doesn't cover the whole year, no additional runoff events were expected as July to October is the late-dry season.

Loads and event mean concentrations (EMCs) of nitrogen, phosphorus and sediment in runoff from virgin brigalow scrub, representative of the landscape in its pre-European condition, were compared, to loads and EMCs from three pasture types: (1) grass only, (2) butterfly pea, and (3) leucaena. Thornton and Elledge (2013) provide a comprehensive description of the study site, experimental design, analytical methods and data analyses (Chapters 2 and 3). The only departure from this methodology was the addition of 2013 data to the calculation of grand average annual EMC used for estimating water quality data where no measured data was available.

Results

Loads and EMCs for 2013 to 2014

Rainfall during 2013 was 682 mm, which was the 57th percentile of the long-term Brigalow Catchment Study records (mean annual rainfall 660 mm from 1965 to 2013). All catchments had three runoff events, with brigalow scrub having the lowest total runoff and grass the highest (Table 1). Despite having the lowest total runoff, brigalow scrub had the highest loads of total, oxidised and dissolved inorganic nitrogen. Brigalow scrub and butterfly pea had the equal highest load of total phosphorus. Butterfly pea had the highest loads of dissolved inorganic phosphorus and ammonium-nitrogen. Leucaena had the highest load of total suspended sediments.

Loads of total, oxidised and dissolved inorganic nitrogen from all pasture land uses were less than that of brigalow scrub; however, ammonium-nitrogen loads were higher (Figure 1). Total phosphorus loads from all pasture catchments were comparable to brigalow scrub. Loads of dissolved inorganic phosphorus from grass and leucaena were less than that of brigalow scrub; however, the load from butterfly pea was substantially higher.

Table 1: Runoff event based flow and water quality data from the brigalow scrub, butterfly pea ley pasture, grass only pasture and leucaena pasture at the Brigalow Catchment Study for the 2013 hydrological year.

Parameter	Brigalow Scrub	Butterfly Pea	Grass	Leucaena
Area (ha)	16.8	11.7	12.7	23.3
Total Discharge (mm)	53	137	211	171
Events (n)	3	3	3	3
TN Load (kg/ha)	10.2	3.8	5.1	4.4
TN EMC (mg/L)	20.2	2.4	2.6	2.7
NO_x-N Load (kg/ha)	2.16	0.36	0.69	0.35
NO_x-N EMC (mg/L)	4.47	0.33	0.42	0.28
NH_4-N Load (kg/ha)	0.05	0.47	0.12	0.15
NH_4-N EMC (mg/L)	0.10	0.19	0.07	0.13
DIN Load (kg/ha)	2.21	0.83	0.81	0.50
DIN EMC (mg/L)	4.57	0.52	0.49	0.41
TP Load (kg/ha)	0.94	0.94	0.76	0.80
TP EMC (mg/L)	2.19	0.73	0.41	0.51
DIP Load (kg/ha)	0.19	0.71	0.42	0.29
DIP EMC (mg/L)	0.29	0.57	0.22	0.17
TSS Load (kg/ha)	432	54	386	632
TSS EMC (mg/L)	1019	55	186	427

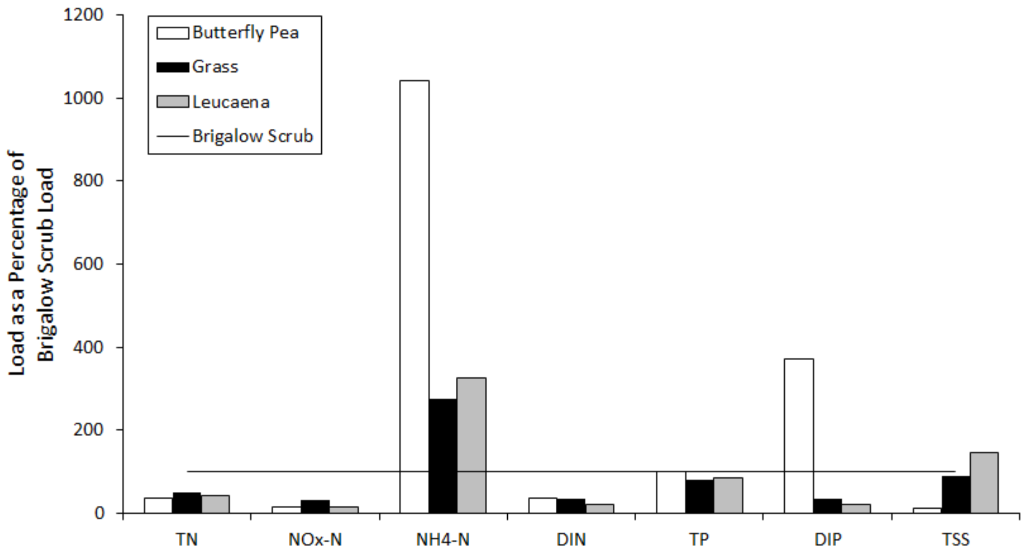

Figure 1: Nutrient and sediment loads (kg/ha) for the 2013 hydrological year from the butterfly pea ley pasture, grass only pasture and leucaena pasture as a percentage of the load from the virgin brigalow scrub catchment.

Rainfall during 2014 to June 30 was 607 mm, which was the 58th percentile of the long-term Brigalow Catchment Study records for those nine months of the year. All catchments had an equal or greater number of runoff events compared to 2013; however, all pasture catchments had lower runoff totals whilst the brigalow scrub had a higher runoff total (Table 2). It is likely that the total runoff and loads from leucaena are an underestimate due to localised contour bank failure allowing runoff to leave the catchment without passing through the monitoring equipment.

Loads of all parameters from grass and leucaena were similar or lower than 2013 (Table 2). Lower loads of total nitrogen, total phosphorus and dissolved inorganic phosphorus were also observed from brigalow scrub and butterfly pea; however, loads of oxidised and dissolved inorganic nitrogen were higher in 2014 from brigalow scrub. Ammonium-nitrogen loads from brigalow scrub and grass varied little between the two years; however, loads were lower in 2014 from butterfly pea and leucaena.

Comparison of 2014 loads as a percentage of that from brigalow scrub showed similar trends to 2013 (Figure 2). Loads of total, oxidised and dissolved inorganic nitrogen from all pasture land uses continued to be less than that of brigalow scrub. Total phosphorus from all pasture catchments was lower than brigalow scrub, and dissolved inorganic phosphorus from butterfly pea remained higher than brigalow scrub.

Table 2: Runoff event based flow and water quality data from the brigalow scrub, butterfly pea ley pasture, grass only pasture and leucaena pasture at the Brigalow Catchment Study for the 2014 hydrological year to June 30. * Discharge is likely an underestimation due to localized failure of contour banks.

Parameter	Brigalow Scrub	Butterfly Pea	Grass	Leucaena
Area (ha)	16.8	11.7	12.7	23.3
Total Discharge (mm)	75	74	99	48*
Events (n)	4	3	5	4
TN Load (kg/ha)	9.9	2.0	2.6	1.0
TN EMC (mg/L)	12.2	3.6	3.2	2.3
NO_x-N Load (kg/ha)	3.82	0.68	0.29	0.18
NO_x-N EMC (mg/L)	6.96	1.36	0.52	0.61
NH_4-N Load (kg/ha)	0.05	0.07	0.17	0.05
NH_4-N EMC (mg/L)	0.05	0.07	0.03	0.13
DIN Load (kg/ha)	3.87	0.74	0.46	0.23
DIN EMC (mg/L)	7.01	1.43	0.55	0.74
TP Load (kg/ha)	0.50	0.38	0.32	0.18
TP EMC (mg/L)	0.51	0.66	0.26	0.31
DIP Load (kg/ha)	0.12	0.28	0.17	0.07
DIP EMC (mg/L)	0.10	0.45	0.17	0.11
TSS Load (kg/ha)	364	78	338	74
TSS EMC (mg/L)	618	177	916	185

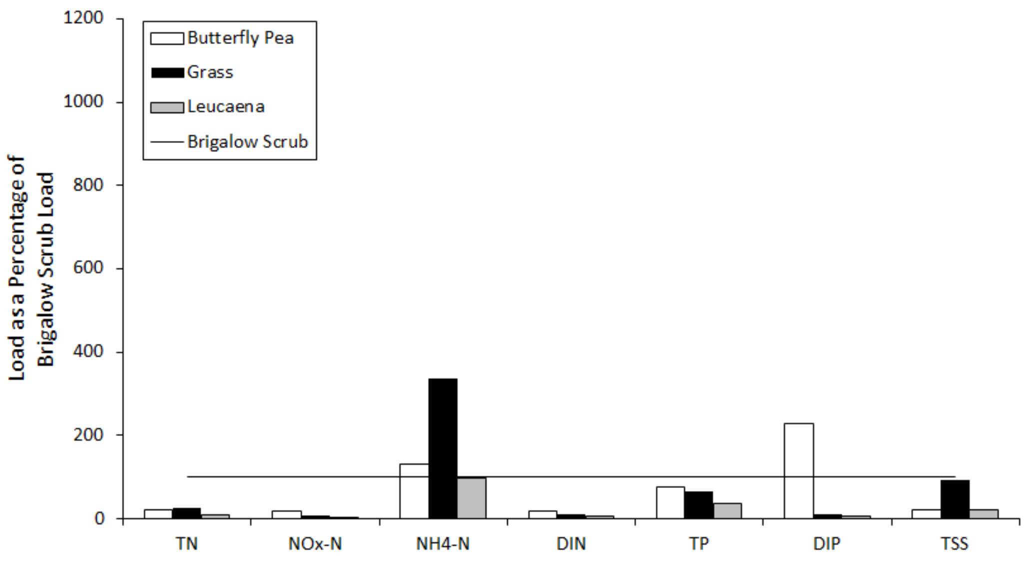

Figure 2: Nutrient and sediment loads (kg/ha) for the period October 1 to June 30 in the 2014 hydrological year from the butterfly pea ley pasture, grass only pasture and leucaena pasture as a percentage of the load from the virgin brigalow scrub catchment.

EMC Trends for 2010 to 2014

Temporal trends for key nutrient and sediment parameters for the combined study period of 2010 to 2014 are shown in Figures 3 to 6. Annual loads and EMCs for 2010 to 2012 are presented in Thornton and Elledge (2013). No clear temporal trends were observed in the brigalow scrub, grass or leucaena catchments for any parameter. In contrast, EMCs of total nitrogen (Figure 3), oxidised nitrogen (Figure 4), dissolved inorganic nitrogen (Figure 5) and total suspended sediments (Figure 6) from butterfly pea ley pasture were greatest in the first year and showed an overall declining trend with time. No trends were observed from butterfly pea ley pasture for ammonium nitrogen, total phosphorus or dissolved inorganic phosphorus.

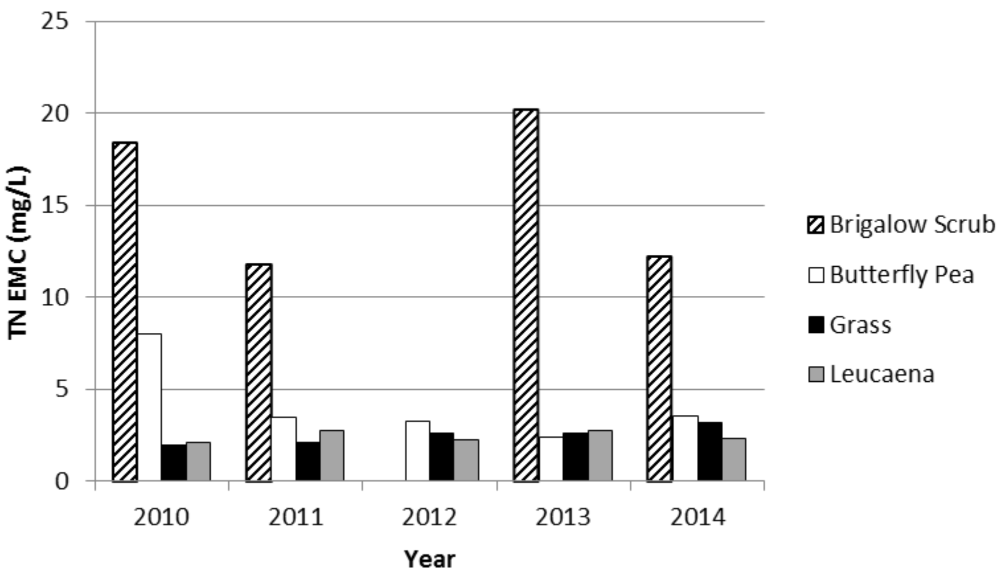

Figure 3: Event mean concentration of total nitrogen for the 2010 to 2014 hydrological years from the virgin brigalow scrub, butterfly pea ley pasture, grass only pasture and leucaena pasture.

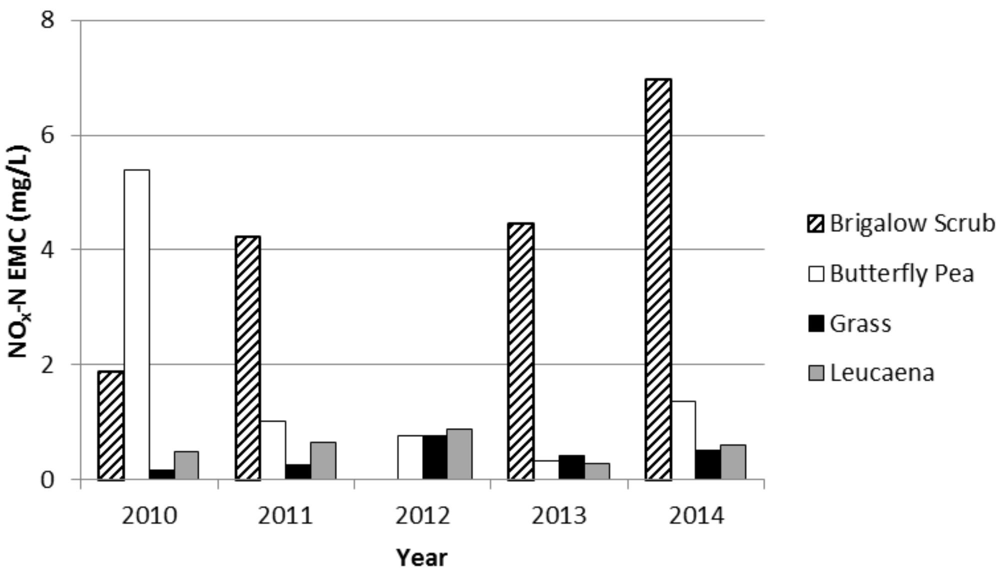

Figure 4: Event mean concentration of oxidised nitrogen for the 2010 to 2014 hydrological years from the virgin brigalow scrub, butterfly pea ley pasture, grass only pasture and leucaena pasture.

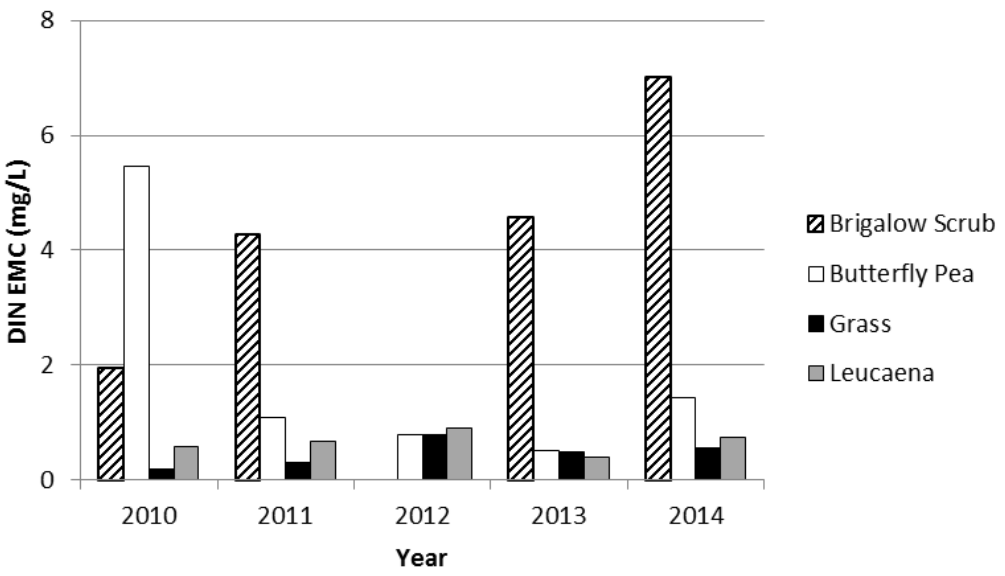

Figure 5: Event mean concentration of dissolved inorganic nitrogen for the 2010 to 2014 hydrological years from the virgin brigalow scrub, butterfly pea ley pasture, grass only pasture and leucaena pasture.

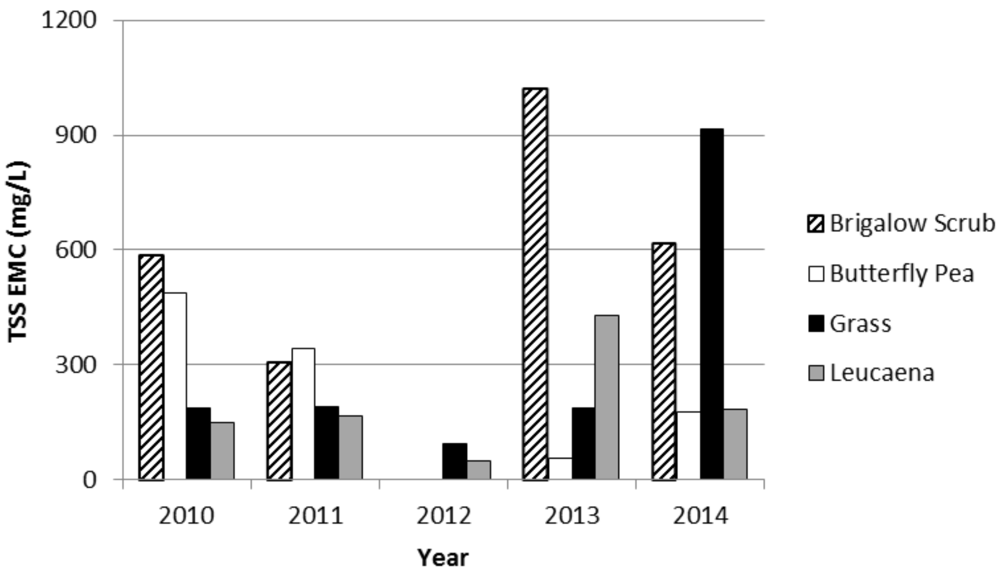

Figure 6: Event mean concentration of total suspended sediments for the 2010 to 2014 hydrological years from the virgin brigalow scrub, butterfly pea ley pasture, grass only pasture and leucaena pasture.

Discussion

In contrast to record breaking rainfall in the 2010 to 2012 period (Thornton and Elledge 2013), rainfall in 2013 and 2014 was much closer to the long-term annual average. The number of runoff events from all pasture land uses was also similar to the long-term average of four per year (Thornton *et al.* 2007); however, brigalow scrub had more events in 2013 and 2014 than its long-term average of two per year. Direct comparison of runoff totals for 2013 support the observation of Thornton *et al.* (2007) that clearing brigalow scrub for either cropping or grazing increases the runoff component of the water balance. Runoff totals for 2014 also indicate greater runoff from grass pasture than brigalow scrub, but similar runoff between butterfly pea ley pasture and brigalow scrub.

Comparison of nutrient and sediment loads between the pasture land uses and brigalow scrub showed that loads of total, oxidised and dissolved inorganic nitrogen were lower from the pasture catchments. Total phosphorus loads from pasture were similar to or lower than brigalow scrub, whereas the highest loads of dissolved inorganic phosphorus came from butterfly pea ley pasture in both years.

There was little change in the relativity of loads between brigalow scrub and the established grass and leucaena pastures for both the 2010 to 2012 (Thornton and Elledge 2013) and the 2013 to 2014 monitoring periods. In contrast, butterfly pea ley pasture typically had the highest nutrient and sediment loads during 2010 to 2012, whereas loads in 2013 to 2014 were similar to the other pasture land uses. During 2013 to 2014, butterfly pea exported less total, oxidised and dissolved inorganic nitrogen, total phosphorus and total suspended sediment than brigalow scrub. Loads of dissolved inorganic phosphorus was typically higher from butterfly pea in both monitoring periods. Ammonium-nitrogen loads were highest from butterfly pea, with similar loads from brigalow scrub, grass and leucaena in 2010 to 2012, but loads varied both within and between catchments in 2013 to 2014.

Comparison of loads can be confounded by the interrelationship of load and flow; that is, as flow increases load increases. An alternative method of comparing water quality across land uses and time that is not biased by flow is to compare event mean concentrations (EMCs). However, as the combined study periods only allow for the calculation of five annual average EMCs, robust statistical analyses was not possible and only visual assessment could be made. For the 2010 to 2014 period, no temporal trends were apparent in the EMCs for nutrients and sediment from brigalow scrub. This was the expected outcome from the control treatment. Similarly, EMCs for nutrients and sediment from the established grass and leucaena pastures showed no apparent trends over the combined study period. However, two clear trends were apparent in the EMCs from butterfly pea. Firstly, total nitrogen was highest in the first year of monitoring and then decreased to an average of 40% of the 2010 EMC for the following four years. This behavior was reflected in oxidised and dissolved inorganic nitrogen, but not ammonium-nitrogen. Secondly, total suspended sediment EMC declined over time with the EMC reported in the final year of monitoring being only 36% of its first year EMC.

When considering EMCs over the period 2010 to 2014, the data supports the hypothesis that high loads of nutrients and sediment may be expected from ley pastures in their development phase. The data also shows that these effects decline over time with loads approaching that of long-term grazed landscapes within five years. The data also shows that loads from all pasture land uses are typically lower than brigalow scrub which is indicative of the landscape in its pre-European condition. The high EMCs of total, oxidised and dissolved inorganic nitrogen from butterfly pea in 2010 compared to the other pasture types can be attributed to tillage associated with planting and renovation activities, and also nitrogen fixation by the young ley pasture (Thornton and Elledge 2013). The subsequent decline in EMCs can then be attributed to the uptake of nitrogen by pasture as it matures and by the establishment of other non-leguminous species (Thornton and Elledge 2013). The decline in total suspended sediment EMC from butterfly pea can be explained by the increase in pasture cover and biomass making the soil less prone to erosion (Thornton and Elledge 2013). The continued decline of these EMCs over time reinforce the benefits to water quality by the replacement of cropping with a butterfly pea ley pasture, as noted by Thornton and Elledge (2013).

Using long-term (1965 to 2011) data from the Brigalow Catchment Study, Thornton *et al.* (2012) investigated the hypothesis that the effect of land development on increased catchment flows are reflected in smaller events and that the effects of forests, land cover and land use are not as obvious during high flows. The authors rejected this hypothesis as they found that increases in runoff associated with land development were still detected in large flood events at a small catchment scale. Thus, the absence of EMC trends from brigalow scrub and the established grass and leucaena pastures in both the extremely wet (2010 to 2011) and more average (2012 to 2014) rainfall years indicates that not only do land uses maintain their specific flow signatures in extreme wet seasons, but they also tend to maintain their specific water quality signatures.

Thornton and Elledge (2013) reported consistently higher loads and EMCs of dissolved inorganic nitrogen from leucaena than grass only pasture in the 2010 to 2012 monitoring period. The authors suggested that if this result could be attributed to the legume component of the pasture, then the high levels of anthropogenic dissolved inorganic nitrogen exported from the Burdekin Basin may be partly due to the extensive areas of pasture improvement undertaken over many decades using leguminous *Stylosanthes spp*. However, no conclusive answer was provided by the addition of 2013 and 2014 data. Dissolved inorganic nitrogen loads were greater from grass than leucaena in 2013, which was a direct result of greater runoff as EMCs were similar. However, total runoff and dissolved inorganic nitrogen load from leucaena were half that from grass in 2014, despite EMC from leucaena being 135% of that from grass. These interpretations are confounded by the likely underestimation of flow from leucaena during 2014 due to localised failure of contour banks. Whilst the understanding of dissolved inorganic nitrogen loads in these systems is still evolving, comparison of both grass and leucaena EMCs with the literature shows that these values are comparable with data from the sugar cane industry, which is considered to be high risk to Great Barrier Reef water quality (Waterhouse *et al.* 2012). Certainly, these results sit within the range of the 10^{th} percentile (0.254 mg/L) and the median (0.772 mg/L) of 22 sugar cane studies reviewed by Bartley *et al*. (2012).

Certainty around runoff water quality from agricultural land uses in the Fitzroy Basin can only be achieved with continued monitoring. This is due to high variability in rainfall which affects both total runoff and nutrient and sediment dynamics. In particular, dissolved inorganic nitrogen has been shown to pose a high risk to water quality and further research is required to better understand its dynamics in grazed landscapes within reef catchments.

Implications for Land Management

The translation of this work into management action for landholders indicates that the establishment stage of ley pasture is, not unexpectedly, the period of greatest risk to water quality. Conservative grazing management combined with spelling should be promoted in the first year to coincide with the highest risk of total, oxidised and dissolved inorganic nitrogen loss. Ongoing management for high plant cover and biomass will continue to minimise nutrient and sediment lost in runoff past the first year.

The incorporation of a ley pasture compared to a more permanent legume pasture into farming systems needs to be carefully considered if managing for a water quality outcome. If a permanent switch from cropping to grazing is being considered, this study indicates that a persistent leucaena pasture may be preferable to a ley pasture, due to the current agronomic recommendations of a three to five year lifespan for butterfly pea ley pasture (Collins and Grundy 2005). In this example, the leucaena pasture has a single high risk establishment period followed by a trend of declining nutrient and sediment loads, whereas the ley pasture will have a high risk establishment period every three to five years associated with replanting or aggressive pasture renovation.

However, if a landholder prefers to retain enterprise flexibility, then a ley pasture will be the easiest to transition back into cropping. Managing for a water quality outcome in this instance requires careful attention to initial crop establishment and weed control to ensure adequate plant populations and pasture vigor. This, followed by conservative grazing management, will assist the ley pasture to persist productively for the longest period. This delays the period of high risk to water quality associated with replanting or aggressive pasture renovation. All of these activities are well within the scope of current industry best management practices.

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