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**Grass or Trees? Performance of riparian buffers under natural rainfall conditions, Australia**

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ABSTRACT: Riparian vegetation can trap sediment and nutrients derived from hillslopes. Most research into the effectiveness of riparian buffers has been experimental and little quantitative data exists on performance under natural field conditions. This study reports on grass and tree buffer performance under natural rainfall conditions in two contrasting Australian environments. Buffers receiving runoff from hillslopes cropped with bananas were monitored over a 4-year period in the wet topics of Far North Queensland (FNQ). Runoff, bedload and suspended loads were measured leaving the crop and leaving 15 m wide dense grass and remnant rainforest riparian buffers. The grass buffer was able to trap >80% of incoming bedload and between 30 and 50% of the suspended sediment and nutrient loads. An adjacent rainforest buffer acted as a temporary store of bedload, and a source area for suspended material. Grass and plantation Eucalyptus globulus buffers receiving runoff from grazed pasture were monitored over a 4-year period in a Mediterranean environment of SW Western Australia. Subsurface flow dominated nutrient and sediment transport in this location. A key result was the seasonal difference between the grass and E. globulus buffers. Sediment and nutrient transport occurred throughout the year in the E. globulus buffer, but only in the winter in the grass buffer. Half the annual loads moving within the E. globulus buffer were transported during intense summer storms. This study demonstrates the benefits of grass buffers, particularly on sloping tropical cropped land and identifies limitations on the effectiveness of tree buffers, although these may have ecological benefits.

KEY TERMS: riparian buffer; rainforest; Eucalyptus globulus; sediment; phosphorus; nitrogen

INTRODUCTION

Many of Australia’s rivers and streams are in poor condition. Most rivers in lowland and agricultural catchments are degraded, with moderate to severe disturbance of riparian and channel habitats, as well as increases in salinity, decreases in flow, changes in flow regime and increased nutrient loads (State of the Environment Advisory Council, 1996). Increasing recognition of poor stream and river health has lead to the investment of public and private funds into stream management. Every year at least $AU 50 million is spent on stream management in Australia (White et al., 1999), and a large proportion of this goes towards fencing and planting riparian lands.

Riparian buffers are areas of managed vegetation situated between agricultural land and streams and can improve stream water quality by removing or retaining pollutants through a combination of physical, biological and chemical processes (Muscutt et al., 1993; Bosskey, 2001). While riparian buffers have been promoted widely, tremendous variations in performance exist within single buffers and between physiographic regions (Gilliam et al., 1997). The majority of studies quoted in the literature supporting the use of riparian buffers for filtering surface runoff are plot scale investigations (e.g. Dillaha et al., 1989; Magette et al., 1989; Arora et al., 1996; Patty et al., 1997; Barfield et al., 1998; Heathwaite et al., 1998) and limited quantitative data exists on buffer performance under natural field conditions (e.g. Peterjohn and Correll, 1984; Daniels and Gilliam, 1996; Sheridan et al., 1999). While plot scale studies are valuable for investigating processes, the conditions often do not accurately represent natural rainfall or runoff conditions. Natural storm durations are often longer than in simulated rainfall studies, and in nature, there are a range of vegetation and topographic conditions, not incorporated into many experimental designs, which can conspire to defeat sediment filtering. Given the many factors that contribute to buffer performance, and the range of performances observed, it is important to monitor buffer performance in a variety of actual field conditions.

Riparian buffer vegetation type may influence performance, although there have been few studies that have directly compared the buffering effectiveness of different vegetation types at the same location. Comparisons of nitrate removal under trees and grass have given variable results, with some authors reporting that tree buffers are less effective (Correll et al., 1997) and others suggesting more effective (Haycock and Pinay, 1993, Osborne and Kovic, 1993). In Sweden, Vought et al. (1994) found that a combined grass and brush buffer retained significantly more total P and phosphate, than either a grass or beech tree buffer. The use of riparian buffers in intensive agriculture has received limited research attention in Australia, and provided the impetus for this study.

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In 1996 and 1997, monitoring sites were established in Western Australia and Queensland to evaluate the potential of riparian buffers to improve stream water quality (Figure 1). Riparian buffers were identified as a potential water quality management tool in both states and local state agencies were interested in establishing and monitoring demonstration sites. Declining water quality on the south coast of Western Australia (WA) has been linked to agriculture. Eutrophication of coastal water bodies has encouraged algal growth and led to noxious algal blooms in many south coast harbours and estuaries, for example the Peel-Harvey Estuary (Hodgkin and Hamilton, 1993). Farm subsidies have increased adoption of riparian buffers and many blocks of riparian land have been planted with *E. globulus* (*Eucalyptus globulus* Labill. subsp. *globulus*) for pulpwood production. In FNQ, concern centres on reducing sediment exports from intensively cropped hillslopes. Traditional methods of erosion control, for example contour banks and grassed waterways, have not been adopted in north Queensland and this is attributed to the steep and broken topography (Prove et al., 1986). This paper reports on grass and tree buffer performance under natural rainfall conditions in two contrasting Australian environments.

**GRASS AND RAINFOREST BUFFERS, FAR NORTH QUEENSLAND**

Materials and methods

The wet tropics present extreme conditions for testing the effectiveness of riparian buffers, with intensively cropped land receiving high intensity, long duration rainfall. Bananas are planted on steeper land in this region, while sugar cane is generally grown on the flatter land. Two riparian buffers were evaluated in the banana and sugar cane producing area of wet tropical FNQ. The study sites are in the North Johnstone River catchment, which meets the coast at Innisfail. The average rainfall at Innisfail is 3585 mm (BOM, 2001). Most of the annual total rainfall occurs in the wet season, December to April, and is characterised by long duration and high intensity storms. Soils at the sites are krasnozems derived from basalt. Krasnozems are red to brown, acidic, strongly structured clay soils (50-70% clay; Isbell 1994).

Two adjacent hillslopes and riparian buffers were monitored for 4-years (see McKergow et al., 2004 for details). Both hillslopes drained a 7% gradient, 200 m long planar slope planted with bananas. The current crop of bananas was planted in May 1996, in double rows perpendicular to the contours. The mounds along the rows define the boundaries of the contributing area. There was little grass cover between the double rows of banana plants. The 15 m wide grass riparian buffer was planted with signal grass (*Brachiaria decumbens*), a low-growing perennial, which forms a dense vegetation cover. The signal grass buffer was mown regularly during each wet season to prevent the clump-forming guinea grass (*Panicum maximum*) from dominating. The signal grass height varied throughout the monitoring period, but was generally 10 to 40 cm high. The remnant rainforest riparian buffer was 15 to 20 m wide, had no understorey and contained some tree species with buttressed roots.

Runoff volumes and water quality leaving the crop (Upper site, U) and leaving the riparian buffer (Lower site, L) on each hillslope were monitored using identical San Dimas flumes (Wilm et al., 1938), fitted with bedload traps, water level recorders and automatic water samplers. Riparian buffer trapping was calculated for loads using: trapping = (upper load - lower load) / upper load. To measure bedload transport, each San Dimas flume was fitted with a trap that diverted 13% of sediment into a storage drum. Runoff was dispersed over a concrete apron after flowing through the flume and the remaining sediment was able to continue moving through the riparian zone. The storage drums were emptied periodically. Sub-samples were collected and taken to the laboratory for oven drying (at 65 °C for at least 7 days), and the oven dry mass of sediment was converted to equivalent soil loss (kg/ha). Each flume was also fitted with an automatic water sampler and samples were collected at 10 to 30 minute intervals depending on the expected event size. A single flow-weighted composite of surface runoff was prepared per event and sent to the lab for analysis. Samples were analysed for SS, total Kjeldahl N (TKN), total phosphorus (TP) and oxidised-N (OxN), and TN was determined by summing TKN and OxN.

Results

During the monitoring period rain was recorded on around 100 days per wet season and several events lasting a couple of days and exceeding 500 mm were recorded each wet season. Surface runoff only occurred in response to rainfall and flows greater than 1 L/s were recorded during only 5% of the total monitoring record. The median discharges at both sites were just over 5 L/s and even during large events peak flow rates were always under 30 L/s.

The signal grass buffer performed consistently, and trapped bedload and suspended material. Bedload dominated the total sediment load when inter-row grass cover was low and the crop was young and the grass buffer was able to trap
considerable amounts of bedload (Figure 2a). During one event, only 4 kg of the 4161 kg of bedload passing through the upper flume reached the lower flume and the key area of bedload deposition was at the upper edge of the buffer. Data gaps prevent an overall trapping estimate, but up to the middle of the second wet season > 80% of bedload was trapped. Trapping during the third wet season was not as high (50%), but this was the season of lowest bedload input with the suspended sediment load dominating the total sediment load trapping. Trapping of suspended material was considerable throughout the monitoring period, with the grass buffer trapping 46% SS, 26% TN, and 40% TP (Figure 2b). Trapping was extremely variable for individual events and many factors may have influenced trapping, including riparian hydrology, buffer vegetation condition, incoming load and sediment particle size. For example, SS trapping in the grass buffer varied between –175% and 92% and the median trapping efficiency was 39% (IQR=60%). The buffer trapped TP consistently, and this is likely to reflect the dominance of sediment associated P. For TN, trapping varied between –300 and 80% and the buffer was typically a TN source area when exfiltration occurred. The data suggests that deposition was the key SS and TP removal mechanism at the grass buffer as both concentrations and loads were reduced (Figure 2 and 3). For example, the SS load was reduced 45% (Figure 2) and the median SS concentration decreased by 46% between the upper and lower sites, from 0.277 to 0.150 g/L (Figure 3, Mann Whitney, p=0.003).
low rolling hills with gentle slopes. The land use is predominantly improved pastures of annual subterranean clovers and ryegrass and stocking rates are generally 10 sheep per hectare. Farmers have been diversifying during the past decade and integrating commercial tree cropping, in particular E. globulus, into traditional farming practices. Water availability is a critical requirement for growing E. globulus through to maturity (Harper et al., 1998), which is one reason why riparian areas are common plantation sites.

Two adjacent planar hillslopes and buffers were monitored for 3-years (see McKergow et al., submitted, for more details). The regenerating grass riparian buffer was fenced in 1997 and the E. globulus buffer was planted and fenced in 1989. No understorey has established under the E. globulus buffer. The buffers were evaluated over a ten metre width, measured perpendicular to the stream. The experimental hillslopes were 350 m long with a 12% gradient and uneven micro-topography. Subsurface flow was measured at two depths (A- and B-horizons) in both the grass and E. globulus riparian buffers and samples were collected for water quality analysis.

Surface runoff was measured at 20 locations in the riparian buffers with runoff plots. In each riparian buffer five plots were positioned immediately below the fence (input from paddock to buffer) and five plots were placed 10 m into the riparian buffer (output from a 10 m buffer). Ten plots were constructed in each riparian buffer as the spatial variability in runoff volumes was expected to be large, given the uneven micro-topography. The plots were not confined and so their contributing areas were not predetermined. The plots were two metre wide PVC troughs with concrete aprons to provide smooth contact with the soil surface. Ten percent of runoff flowing through the plots was directed through a splitter to storage drums and the remaining 90% of runoff was returned to the riparian buffer as dispersed flow. On each site visit, the runoff volume in each drum was measured and a sample collected for analysis. Surface runoff samples were therefore a composite of single or multiple events. The time between site visits varied between 1 and 7 days, depending on weather conditions. All samples were analysed for TP, filterable reactive phosphorus (FRP), TN, electrical conductivity (EC) and SS.

Results

During the monitoring most rain fell between April and October, typical of this Mediterranean climate. Rainfall totals were generally below average with the exception of 1998.

By comparing the pollutant load entering the riparian buffer (upper plots) with that leaving it (lower plots), the buffer effectiveness can be assessed. Overall, the grass buffer reduced nutrient and SS loads by 50 to 60%. Trapping in the E. globulus buffer was less effective, particularly for SS where overall load reductions were less than 20% (Table 1). The variability in load reductions was high, particularly for the nutrients, with a more consistent picture emerging for the SS loads. Suspended sediment concentrations were typically higher in the E. globulus buffer, and on several occasions, it was a SS source area.

A key difference between the two buffers was the summer hydrologic behaviour. No surface runoff was measured in the grass buffer during the intense summer storms, so surface nutrient and sediment transport was limited to winter in this buffer. In 1999, infiltration-excess overland flow transported half the annual sediment and nutrient load during intense two summer storms in the E. globulus buffer.

Table 1. Total loads, runoff volumes and efficiencies for the grass and E. globulus buffers.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Buffer</th>
<th>Upper load (g)</th>
<th>Lower load (g)</th>
<th>Trapping (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP</td>
<td>Grass</td>
<td>2.6</td>
<td>1.2</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>E. globulus</td>
<td>3.1</td>
<td>1.0</td>
<td>37</td>
</tr>
<tr>
<td>TN</td>
<td>Grass</td>
<td>71</td>
<td>30</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>E. globulus</td>
<td>74</td>
<td>43</td>
<td>42</td>
</tr>
<tr>
<td>SS</td>
<td>Grass</td>
<td>310</td>
<td>184</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>E. globulus</td>
<td>606</td>
<td>479</td>
<td>21</td>
</tr>
<tr>
<td>Runoff (m³)</td>
<td>Grass</td>
<td>40</td>
<td>19</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>E. globulus</td>
<td>25.5</td>
<td>26</td>
<td>-3</td>
</tr>
</tbody>
</table>

DISCUSSION

Vegetation density at the ground is very important for promoting surface runoff ponding and sediment deposition. Any vegetation that has a dense ground layer, which provides high resistance to runoff, will promote sediment deposition. Grass is more likely to have these characteristics than trees. Signal grass forms a dense vegetation cover in the wet tropics, and was able to trap sediment, colonise the deposits and permanently trap bedload and suspended material. In contrast, no understorey was supported in either the rainforest or E. globulus buffers and they were unable to trap consistently. Sediment was deposited in the rainforest buffer, but it remained uncovered on the ground surface and could be re-suspended during subsequent events. This has been observed in tree buffers elsewhere due to sparse groundcover and channelised flow (Smith, 1992; Jordan et al., 1993).

Despite high soil losses, the grass buffer in FNQ trapped high sediment loads. An important factor enhancing effectiveness in this environment was the well-aggregated soil, which is transported as water stable aggregates, 2-4 mm in diameter. The sediment eroded has the transport characteristics of sand or gravel, although it consists of clay particles bound by non-crystalline iron and aluminium oxides and hydroxides (Cotching, 1995). Soil matrix particle size distributions, may therefore be of little use in an evaluation of the ability of buffers to filter surface runoff. Much of the bedload trapping occurred at the upslope edge of the buffer or within the first few metres, suggesting that a dense grass buffer less than 15 m wide, may be able to trap significant quantities of bedload from planar slopes in this environment. Farm management practices that maintain aggregate structure, and therefore encourage backwater deposition, will ensure high trapping under conditions of high bedload delivery.

The signal grass buffer in the wet tropics showed no signs of a long-term decline in performance. Sediment did not build up at the upper edge of the signal grass buffer despite high sediment delivery rates (up to 70 t/ha). This finding...
contrasts with that of Dillaha et al. (1989), who observed accumulations of sediment at the field-buffer interface, which later became dikes and diverted runoff from the buffers. Our study suggests that sediment removal may not be required at the buffer-crop interface if good grass cover is maintained.

Suspended material trapping was at the lower end of the range previously reported for buffers below cropped land monitored under natural rainfall conditions (Arora et al., 1996; Daniels and Gilliam 1996; Patty et al., 1997; Sheridan et al., 1999). In the wet tropics, this is most likely due to the extreme conditions, including the magnitude of runoff and steeper slopes, compared with previous studies.

The potential of riparian buffers to filter surface runoff can be undermined by the inability of surface runoff to infiltrate. Infiltration may enhance sediment deposition by reducing the volume of surface runoff, but saturation or surface crust may limit infiltration into riparian soils. Most studies with natural rainfall report reductions in runoff within riparian buffers (e.g. Arora et al., 1996; Patty et al., 1997) and exfiltration is rarely reported in the buffer performance literature (e.g. Sheridan et al., 1999). Saturation occurred in both Queensland and Western Australia and under these conditions, the buffers were more likely to be pollutant source areas and the buffer’s main function is to prevent erosion rather than trap sediment and nutrients. A surface crust in the *E. globulus* buffer in Western Australia was the likely cause of infiltration excess overland flow during intense summer storms.

The relative importance of surface runoff may also reduce the potential of riparian buffers to improve stream water quality. The inclusion of subsurface flow monitoring in WA highlights the need to consider all flowpaths. Despite reasonable trapping, the actual surface runoff loads were minor compared with subsurface loads. Subsurface flow was the dominant flow and pollutant path through the riparian buffers, with at least 20 times more runoff and 3 times the nutrient load moving via subsurface flowpaths than surface runoff. Simple ratios of delivery through the different pathways suggest that about 15% of the total sediment and nutrient loads were filtered from surface runoff rather than the 60% suggested by the surface runoff data alone. Duplex soils are common throughout southern Australia and with good pasture cover filterin surface runoff is likely to be a minor riparian buffer function. However, other riparian buffer functions may be important for improving stream water quality, such as reducing bank erosion and removing pollutant generating activities from streams (e.g. McKergow et al., 2003).

Rainforest or tree buffers may also be important from an ecological perspective to help maintain stream ecosystem health (Bunn et al., 1999). Our results indicate that rainforest buffers in the wet tropics should consist of two zones: a managed grass buffer to trap sediment and associated pollutants exiting from the cropped area upslope of any rainforest buffer.

CONCLUSIONS

This study has evaluated the performance of grass and tree riparian buffers for filtering surface runoff.

In the wet tropics, where hillslope erosion is the dominant sediment source on steep cropped lands, dense grass riparian buffers can trap significant amounts of bedload, SS, TP and TN and prevent these from entering streams. Bedload trapping was consistently high and deposition was focused in a backwater at the upper edge of the signal grass buffer. Deposits were quickly colonised by signal grass and were not reworked. In contrast, the riparian rainforest buffer performed poorly and was a source area of suspended material. Bedload was deposited during several events, but the material was not permanently trapped and was reworked during subsequent events. Rainforest buffers should therefore consist of two zones, a grass buffer upslope of a rainforest buffer.

In WA, nutrient and sediment transport was dominated by B-horizon subsurface flow, which carries loads at least three times greater than surface runoff. In this pasture catchment, where surface cover was good, sediment and nutrient trapping by riparian buffers was extremely variable and linked to riparian hydrology. During the monitoring period the grass buffer trapped between 50 and 60% of the incoming SS, TN, and TP loads. Trapping efficiencies in the *E. globulus* buffer were lower, and between 20 and 40% of the SS, TN, and TP loads were retained in the buffer. A key difference between the grass and *E. globulus* riparian buffers was their hydrologic response to intense summer storms. Surface runoff was measured in the *E. globulus* riparian buffer during several summer storms and evidence suggests that surface crust reduced the soil’s infiltration capacity. In the grass buffer all rain infiltrated. Nutrient concentrations were high during summer and pasture cover was minimal, so the risk of sediment and nutrient transport by surface runoff in *E. globulus* riparian buffers is high.

This study demonstrates that riparian buffers can play a role in mitigating the off site impacts of agriculture. The hillslope scale investigations provide realistic trapping figures in contrast to many short-term experimental studies, which tend to overestimate trapping efficiencies. Grass buffers generally trapped less than 60% of the incoming sediment and nutrient loads. Tree buffers were less effective and tended to be nutrient and sediment source areas.

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