Chapter 6

A simulation experiment on the effectiveness of trees and pasture in reducing lateral nutrient movement

6.1. Results

6.1.1. Growth responses of trees and pastures

6.1.1.1. Tree growth

Seven measurements of tree height were conducted since the time of planting to age 22 weeks, when the trees were pruned because they reached the glasshouse roof. Both *E. camaldulensis* and *C. cunninghamiana* seedlings were about 50 cm high when planted (Figure 6.1). The young trees grew slowly during the first 13 weeks and their growth rate increased during the following 6 weeks. For the last 4 weeks of the measuring period, trees grew very fast, reaching an average growth rate of 1 - 1.5 cm per day.

The height growth of *E. camaldulensis* was not significantly different with *C. cunninghamiana* for all the measuring events (Figure 6.1a; Table 6.1). In contrast, the two different planting densities affected tree height significantly (Table 6.1), but only for *E. camaldulensis*. *E. camaldulensis* in the 2-tree treatment grew significantly taller ($P<0.05$) than the 4-tree treatment at 13 weeks after planting, and average height difference reached some 40 cm at 22 weeks. The height differences of *C.*

cunninghamiana between the 2-tree and 4-tree planting were not significantly different for all measurement periods, although the height was taller for the 2-tree treatment in comparison with 4-tree treatment (Figure 6.1b).

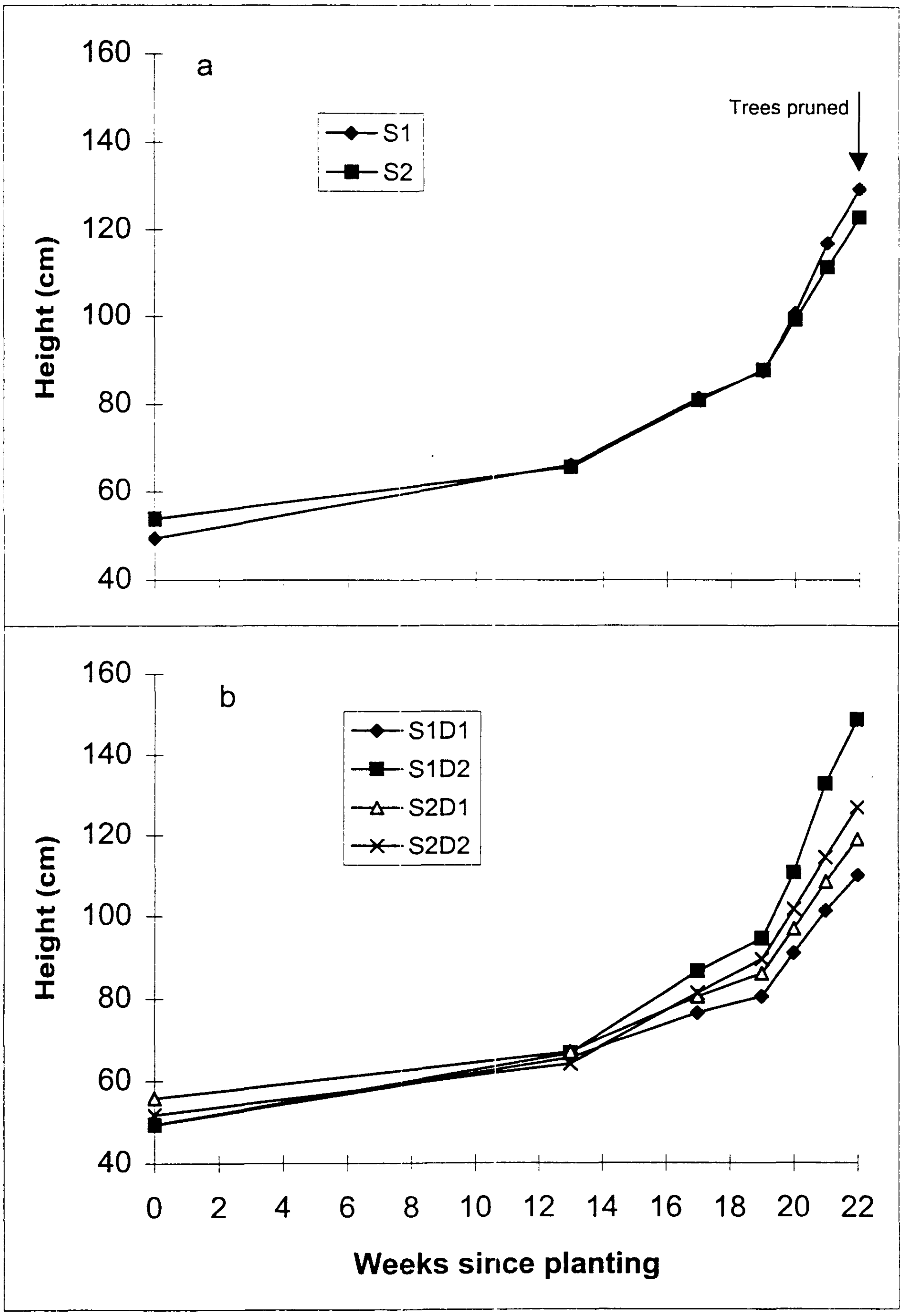

Figure 6.1. The effect of species and density treatments on tree height growth in the glasshouse experiment. S1: *Eucalyptus camaldulensis*; S2: *Casuarina cunninghamiana*; D1: 4 trees plot^{-1}; D2: 2 trees plot^{-1}. Significance is indicated in Table 6.1.

Table 6.1. Analysis of variances for the effect of treatments on tree height growth. #Species=tree species: *E.camaldulensis* and *C. cunninghamiana*. ##Density=tree densities: 4 trees $plot^{-1}$ and 2 trees $plot^{-1}$. *=significantly different at $P<0.05$, **at $P<0.01$, *** at $P<0.001$, ns=not significantly different.

	Main effects		Interaction (species x density)
Weeks since planted	#Species	##Density	
13	ns	ns	ns
17	ns	ns	ns
19	ns	*	*
20	ns	*	*
21	ns	**	**
22	ns	***	***

Measurements of tree diameter growth did not commerce until 19 weeks after planting and ended at 42 weeks. Both the effects of species and planting density treatment significantly contributed to the differences in tree diameter growth (Table 6.2). *C. cunninghamiana* had significantly greater ($P<0.05$) diameter growth than *E. camaldulensis* since 24 weeks after planted both for the 2-tree and 4-tree plots (Table 6.2 and Figure 6.2a). At the last measurement, the average diameter of *C. cunninghamiana* (18.3 mm) was 16.6% greater than that of *E. camaldulensis* (15.7mm). At 42 weeks after planted, the average diameters of trees for the 2-tree plots were 33.6% and 35.5% larger than the 4-tree plots for *E. camaldulensis* and *C.*

cunninghamiana respectively (Figure 6.2b). The diameter growth of the four treatments against time (weeks) since 19 weeks after planting were all linearly related with $R^2>0.98$, although the trees were pruned at 22 weeks.

Table 6.2. Analysis of variances for the effects of treatments on tree diameter growth. #Species=tree species: *E.camaldulensis* and *C. cunninghamiana*. ##Density=tree densities: 4 trees $plot^{-1}$ and 2 trees $plot^{-1}$. *=significantly different at $P<0.05$, **at $P<0.01$, *** at $P<0.001$, ns=not significantly different.

Weeks since planted	Main effects		Interaction (species x density)
	#Species	##Density	
19	**	ns	*
20	**	ns	*
24	*	*	**
30	**	*	***
34	*	*	***
38	*	*	***
42	*	**	***

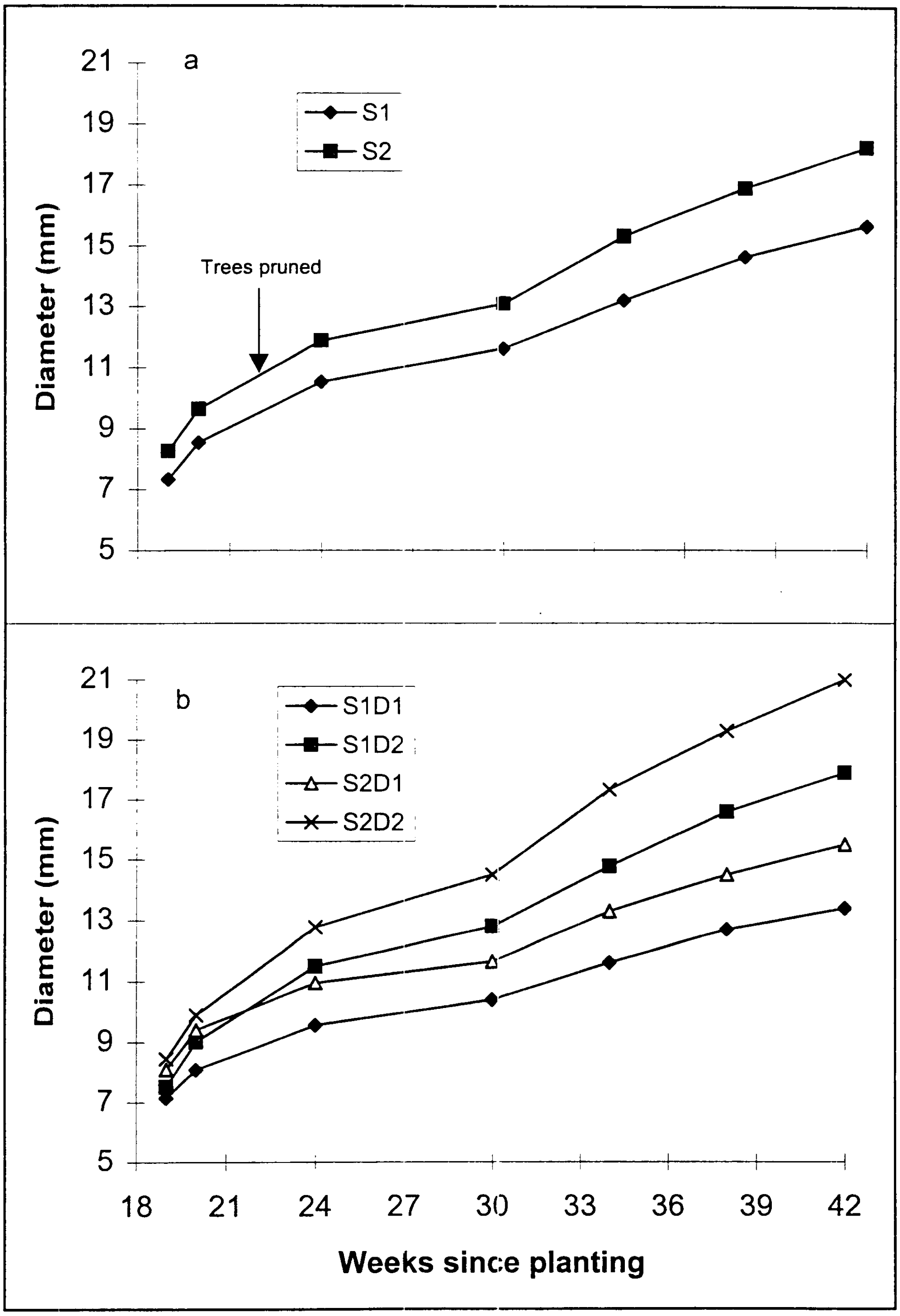

Figure 6.2. The effect of species and density treatments on tree diameter growth in the glasshouse experiment. S1: *Eucalyptus camaldulensis*; S2: *Casuarina cunninghamiana*; D1: 4 trees $plot^{-1}$; D2: 2 trees $plot^{-1}$. Significance is indicated in Table 6.2.

6.1.1.2. Above and below ground biomass

Both species and density treatments significantly affected tree above-ground biomass (Table 6.3). Total above-ground biomass of *C. cunninghamiana* was significantly ($P<0.01$) higher than *E. camaldulensis* for both the 2-tree and 4-tree treatments. Four-tree plots had higher above-ground biomass than 2-tree plots for both species, but the difference was only significant for *C. cunninghamiana.* Foliage biomass, expressed as a proportion of the total above-ground biomass was significantly ($P<0.001$) greater for *C. cunninghamiana* in comparison with *E. camaldulensis*, while the proportion was significantly affected by the different densities only for *E. camaldulensis*.

Total below-ground biomass was not significantly different between the species and density treatments (Table 6.3), although the amount was generally larger for *C. cunninghamiana* in comparison with *E. camaldulensis*, and was larger for the 4-tree plots than the 2-tree plots for both species. *C. cunninghamiana* had significantly ($P<0.05$) more fine roots (diameter<0.3 cm) (also see Plate 3b) and fewer lateral roots (diameter≥0.3cm) than *E. camaldulensis* (also see Plate 3a). The density treatment did not affect the amount of fine roots, but the 4-tree plots had significantly ($P<0.05$) more lateral roots than the 2-tree plots for these two species.

The ratio of below-ground/above-ground biomass was greater for *E. camaldulensis* than *C. cunninghamiana,* but only significant ($P<0.05$) for the 2-tree treatments (Table 6.3). Density affected the ratio differently for the two species. The

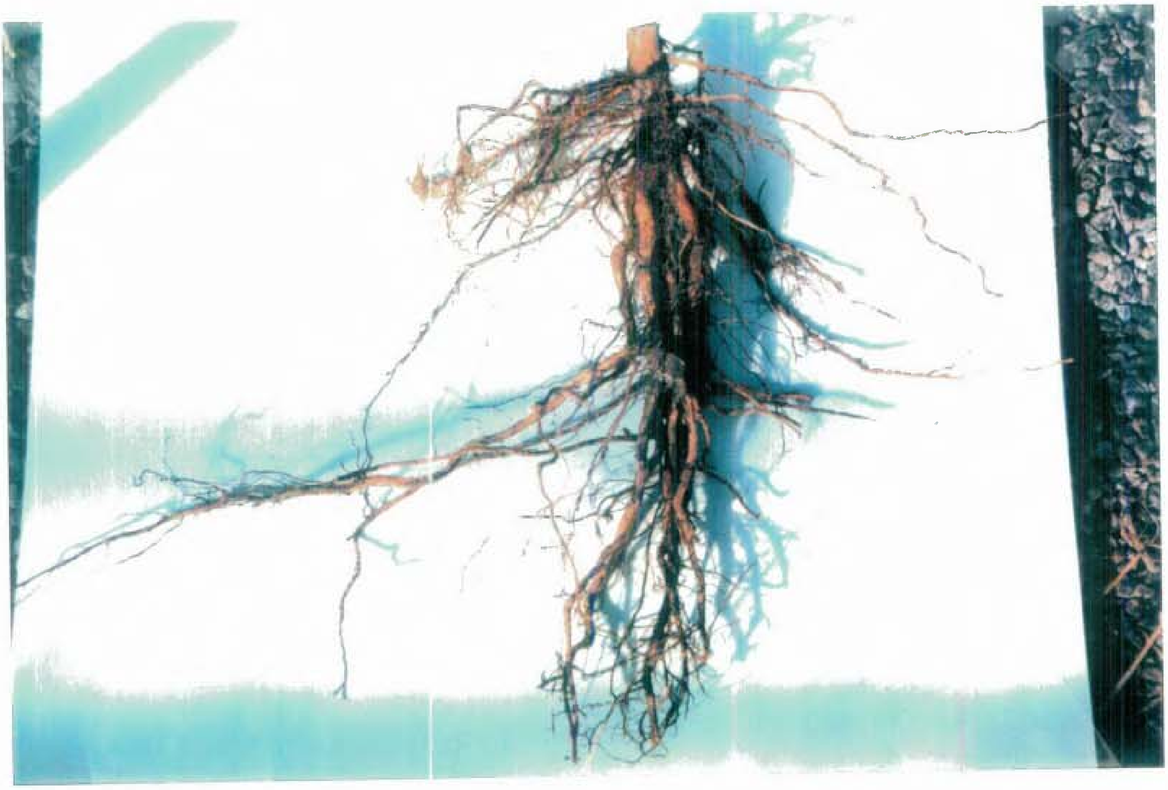

Plate 3a. Showing the deep root system of *E. camaldulensis*.

Plate 3b. Showing the surface dominant root system of *C. cunninghamiana*.

ratio was significantly greater ($P<0.05$) for the 2-tree plots in comparison with the 4-tree plots for *E. camaldulensis*, while the ratio was significantly higher ($P<0.05$) for the 4-tree plots than the 2-tree plots for *C. cunninghamiana*. The ratio of root distribution in the soil B horizon to A horizon, however, was significantly greater ($P<0.05$) for *E. camaldulensis* in comparison with *C. cunninghamiana*. The ratio, however, was not significantly affected by the density treatment.

At harvest, the 4-month pasture produced similar amount of foliage to the 11-month trees, although the trees had significantly ($P<0.001$) greater total above- and below-ground biomass than the pasture (Figure 6.3). The grass roots penetrated the soil B horizon, but the biomass proportion in the B horizon was negligible by comparing with that in the A horizon.

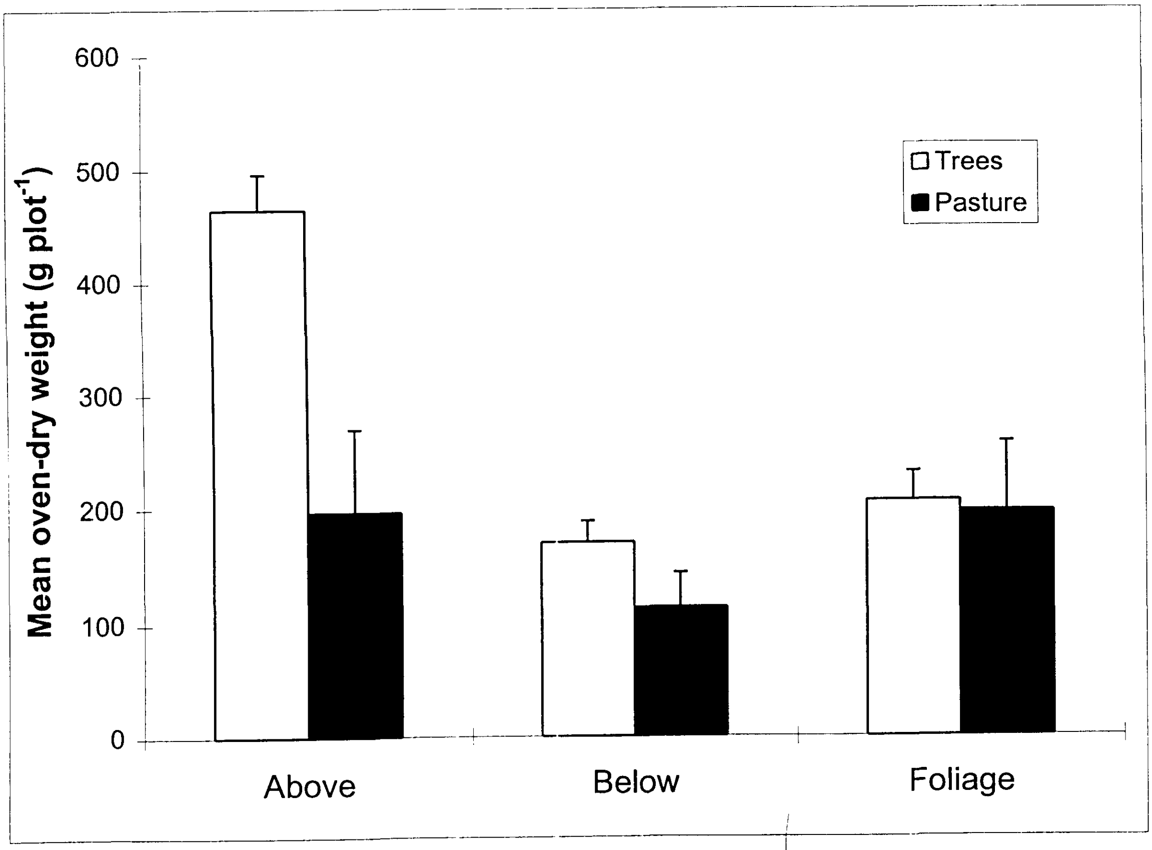

Figure 6.3. Comparison of biomass for trees and pastures in the glasshouse experiment.

Table 6.3. Biomass (g plot^{-1}) of the trees growing in glasshouse. $^{\#}$significance: *=significantly different at P<0.05; **P<0.01; ***<0.001; ns=not significantly different. The means in a row with the same letters are not significantly different. $^{\$}$B/A=the ratio of root distribution in soil B and A horizon.

		Eucalyptus camaldulensis		*Casuarina cunninghamiana*		
		4 trees plot^{-1}	2 trees plot^{-1}	4 trees plot^{-1}	2 trees plot^{-1}	$^{\#}$Significance
Above-ground	Stem+branch	238.1a	249.9a	300.1b	251.5a	*
	Foliage	185.0ab	159.4a	259.5c	217.5b	*
	Total	423.1a	409.3a	559.6b	469.0c	**
	Foliage/Total	0.437a	0.389b	0.464c	0.464c	***
Below-ground	Fine root	40.9a	40.5a	56.2b	55.7b	*
	Lateral root	66.7a	58.6b	54.0b	48.4d	*
	Tap root	67.4	58.2	70.4	63.8	ns
	Total	175.0	157.2	180.6	167.9	ns
	$^{\$}$B/A	0.090a	0.075a	0.030b	0.040b	***
Below/Above		0.383a	0.427b	0.363a	0.319c	*

6.1.1.3. Nitrogen and phosphorus accumulation in trees and pastures

Mean concentration of nitrogen and phosphorus in the tissues of *E. camaldulensis*, *C. cunninghamiana* and pastures are given in Table 6.4. N concentration of grass foliage was higher than trees, but the difference was not significant. The stems and branches of *E. camaldulensis* had significantly (P<0.01) higher N concentration than *C. cunninghamiana*. Pasture roots concentrated significantly (P<0.001) more N than both tree species. The concentration of P was not significantly different in the foliage between the two tree species and pasture, and was same in stems and branches for the trees. However, P concentration was significantly higher (P<0.001) in roots of pasture in comparison with trees.

Although *E. camaldulensis* and *C. cunninghamiana* with two density treatments had around double total above- and below-ground biomass in comparison with the pasture (Table 6.5), their N accumulation was only higher by 8% to 18%, and P accumulation was similar or higher by 44% than the pastures respectively. The average rates of N and P accumulation were 0.79 and 0.10 g plot^{-1} month^{-1} for the tree plots respectively, while the rates were 2.01 and 0.23 g plot^{-1} month^{-1} for the pasture plots. The ratio of N accumulation in above-ground biomass to below-ground biomass was significantly greater (P<0.001) for trees than pasture, while the ratio was significantly greater for *E. camaldulensis* by comparison with *C. cunninghamiana*. The ratio of P accumulation in above-ground biomass to below-ground biomass was significantly greater (P<0.001) for the trees in comparison with pasture, while the ratio was significantly higher for *C. cunninghamiana* than *E. camaldulensis*.

Table 6.4. Mean concentration of N and P in the tissue of *Eucalyptus camaldulensis, Casuarina cunningamiana* and pasture in the glasshouse experiment. #significance: **=significantly different at P<0.01; ***<0.001; ns=not significantly different. The means in a row with the same letters are not significantly different.

	Tissue	*E. camaldulensis*	*C. cunninghamiana*	Pasture	#Significance
N (% oven-dry wt.)	Foliage	3.21	2.82	3.44	ns
	Stem and branches	0.92a	0.49b		**
	Roots	0.32a	0.40a	1.14b	***
P (% oven-dry wt.)	Foliage	0.29	0.33	0.29	ns
	Stem and branches	0.11	0.11		ns
	Roots	0.10a	0.10a	0.32b	***

Table 6.5. Comparison of total biomass, and N and P stored in the above- and below-ground biomass for trees and pastures in the glasshouse experiment. #significance: *=significantly different at $P<0.05$; ***<0.001; The means in a row with the same letters are not significantly different.

	E. camaldulensis		*C. cunninghamiana*		Pasture	#Significance
	4 trees plot^{-1}	2 trees plot^{-1}	4 trees plot^{-1}	2 trees plot^{-1}		
Mean oven-dry matter (g plot^{-1})	598.1a	566.5a	740.2b	636.9c	309.9d	***
N (g plot^{-1})	8.69a	7.92b	9.51c	8.77a	8.05b	*
Average N accumulation (g plot^{-1})	8.72a				8.05b	*
N accumulation rate (g plot^{-1} month^{-1})	0.79a				2.01b	***
N above-/below-ground	14.52a	14.73a	12.29b	9.23c	5.22d	***
P (g plot^{-1})	0.98a	0.89a	1.34b	1.11c	0.93a	*
Average P accumulation (g plot^{-1})	1.08a				0.93b	*
P accumulation rate (g plot^{-1} month^{-1})	0.10a				0.23b	***
P above-/below-ground	4.44a	4.58a	6.50b	5.89b	1.60c	***

6.1.2. Nutrient removal by trees and pastures from lateral groundwater flow

6.1.2.1. Evidence from the 'soil nutrient depletion period'

The experimental time for the 'soil nutrient depletion period' covered 10 weeks, in which NO_3-N, PO_4-P, EC and pH were collected and measured in the soil solution. Average values for the soil solution collected from the 5 sampling pipes were used to compare differences between the treatments. NO_3-N concentrations were consistently lower during the 10-week period for the tree treatment in comparison with the bare ground control, but the difference was significant ($P<0.05$) only at 2, 4 and 6 weeks. (Figure 6.4a). On average, tree plots retained more NO_3-N than bare ground plots by 39.9% (Table 6.7). The curve of NO_3-N change for tree plots was fitted a polynomial function $y = 0.3768x^2 - 4.1292x + 11.996$ with $R^2 = 0.9875$ (Figure 6.4a). A dramatic decrease (about 50% of total amount) in NO_3-N concentration of tree treatment was measured for the first 2 weeks, with the rate declining thereafter. On average, tree plots retained more NO_3-N than bare ground plots by 39.9% (Table 6.7). The curve for the bare ground control was fitted a linear function $y = -1.6817x + 10.879$ with $R^2 = 0.9717$ (Figure 6.4). The mean NO_3-N content in the soil solution declined from about 8.0-9.0 to about 0.3-1.1 mg L^{-1} for both tree and no-tree treatments during the 10-week period. The difference between tree species and densities was not significant (Figure 6.4b; Table 6.6).

Measurements of NO_3-N at soil A-B interface at 90 cm from water inlet (Figure 6.5a) showed similar NO_3-N patterns with that collected from the B horizon (Figure 6.5b) for the tree treatments and bare ground control. In both cases, the concentration of NO_3-N was significantly lower ($P<0.05$) at 2, 4 and 6 weeks for trees in comparison with bare ground.

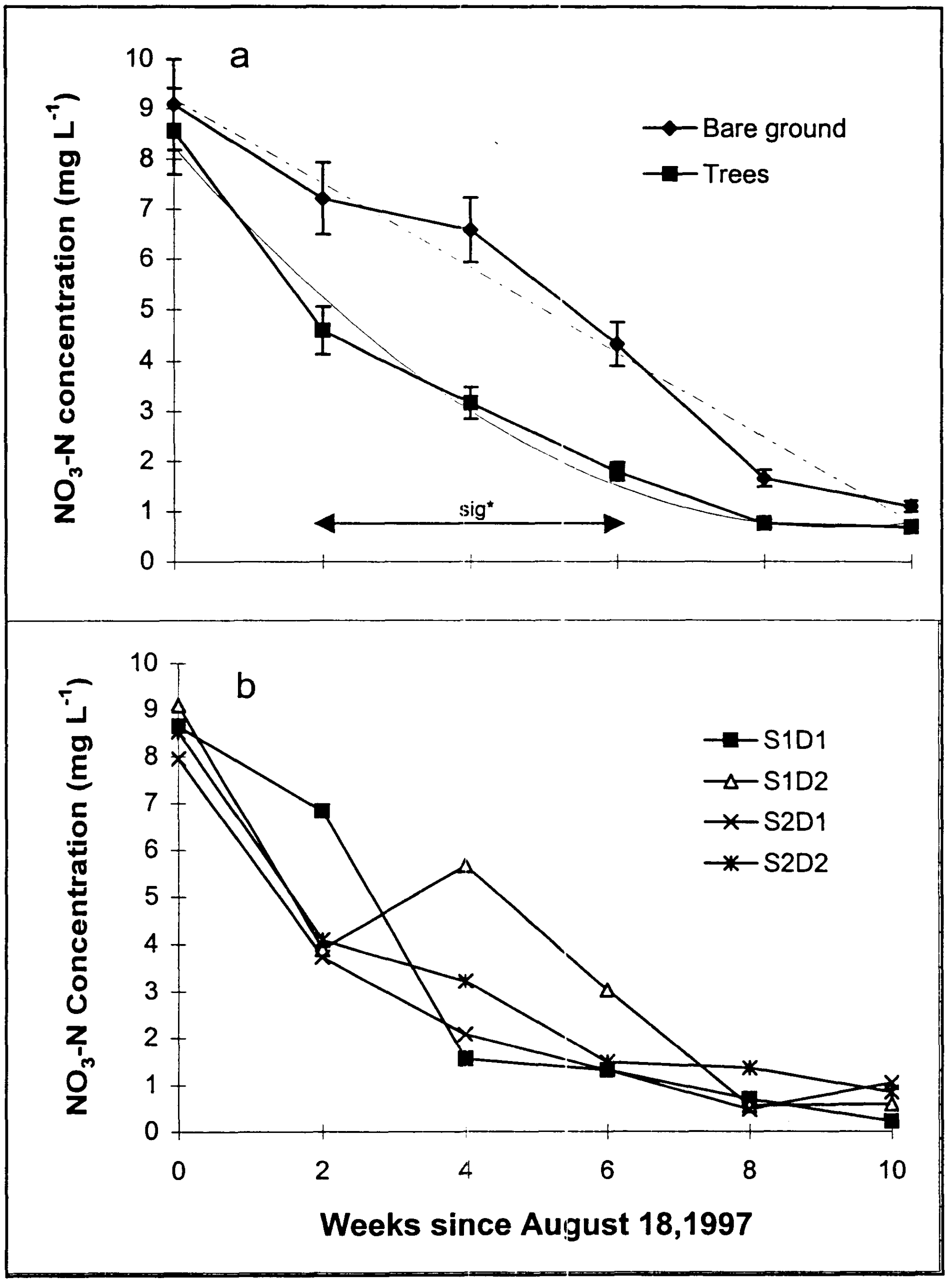

Figure 6.4. Comparison of NO_3-N concentration in soil solution between (a) the tree treatment and bare ground control, and (b) among the tree treatments over the 'soil nutrient depletion period'. The curve for tree plots was fitted a polynomial function $y = 0.3768x^2 - 4.1292x + 11.996$ with $R^2 = 0.9875$. The curve for the bare ground control was fitted a linear function $y = -1.6817x + 10.879$ with $R^2 = 0.9717$. Average values were used from the soil solution collected from the 5 sampling pipes. S1: *Eucalyptus camaldulensis*; S2: *Casuarina cunninghamiana*; D1: 4 trees plot^{-1}; D2: 2 trees plot^{-1}. *sig= significantly different at $P<0.05$.

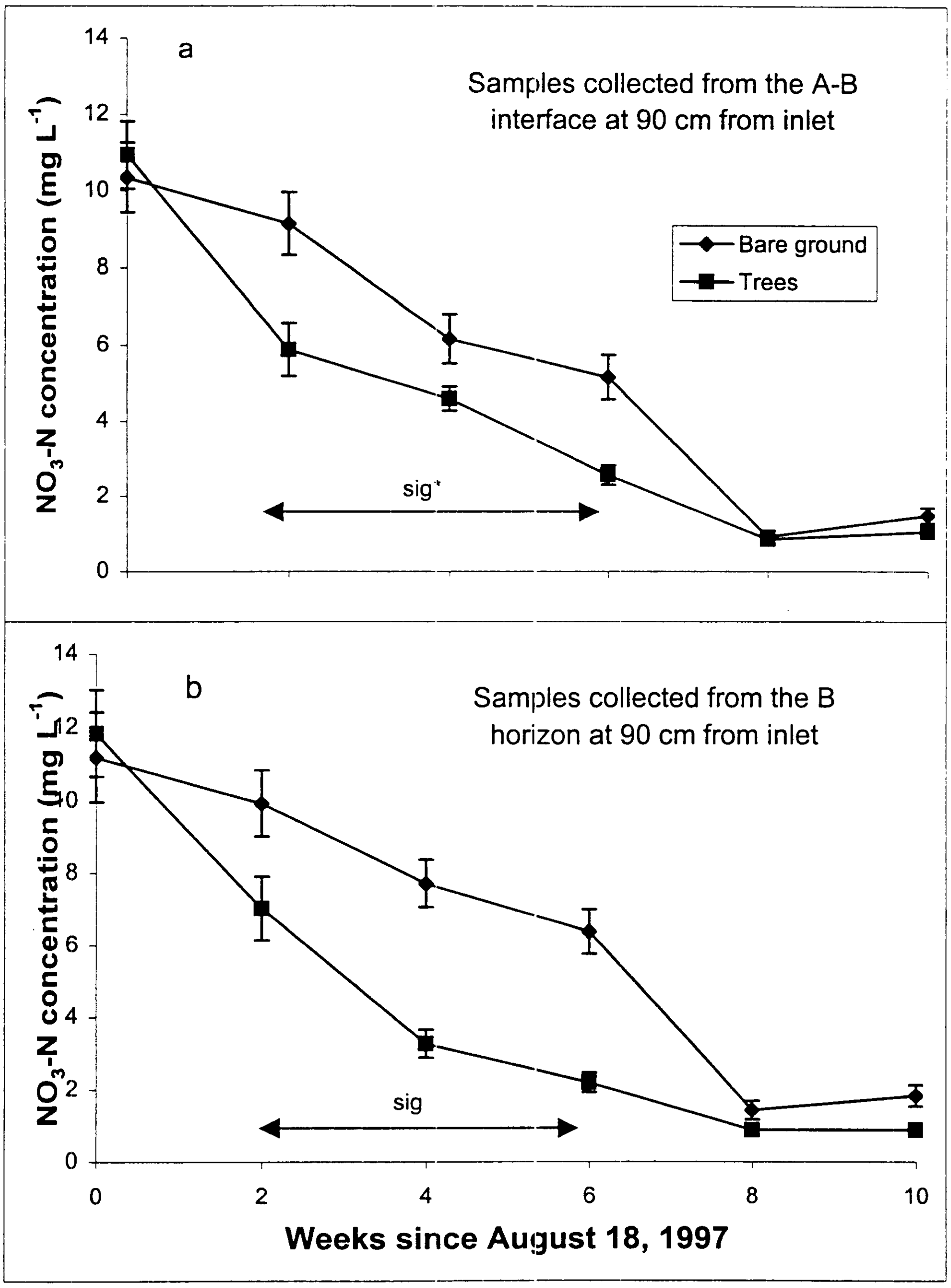

Figure 6.5. Comparison of NO_3-N concentration in soil solution at (a) A-B interface and (b) B horizon for the tree treatments and bare ground control over the 'soil nutrient depletion period'. Measurements were taken from the soil solution collected at 90 cm form water inlet, ie sampling pipes upper 2 and bottom 2 respectively (see chapter 3). *sig=significantly different at $P<0.05$.

Table 6.6. Levels of significance from the analysis of variances for the effect of treatments on NO_3-N concentration in soil solution between the tree treatments over the 'soil nutrient depletion period', ‘low NO_3-N addition period’ and ‘high NO_3-N addition period. $^{\#}$=tree species: *E. camaldulensis* and *C. cunninghamiana*. $^{\#\#}$=tree densities: 4 trees plot^{-1} and 2 trees plot^{-1}. *=significantly different at $P<0.05$, **at $P<0.01$, ns=not significantly different.

Periods		Main effects		Interaction (species x dencity)
		Species$^{\#}$	Density$^{\#\#}$	
Soil nutrient depletion period	Weeks since August 18, 1997			
	0	ns	ns	ns
	2	ns	ns	*
	4	ns	ns	ns
	6	ns	ns	**
	8	ns	ns	ns
	10	ns	ns	ns
Low NO_3-N addition period	Weeks since November 13, 1997			
	0	ns	ns	ns
	2	ns	ns	ns
	4	ns	ns	ns
High NO_3-N addition period	Weeks since March 3, 1998			
	0	ns	ns	ns
	2	ns	ns	ns
	4	ns	ns	ns

The difference in PO_4-P concentration was not significant at each measurement for the tree treatment and bare ground control (Figure 6.6a), and between the tree treatments (Figure 6.6b). The concentration of PO_4-P measured at the soil A-B interface and in the B horizon at 90 cm from water inlet was also not significant between the tree treatment and bare ground (Figure 6.7), although the general difference of PO_4-P concentration between the tree plots and bare ground control was larger in the B horizon than at the A-B interface.

Mean EC values from soil solution were similar for the tree treatment and bare ground over the 10-week experimental period (Figure 6.8a). EC values declined from 0.74 to 0.4 and from 0.7 to 0.38 for tree treatment and bare ground respectively over the period, and both curves fitted a linear function with $R^2 > 0.95$. There were also no significant differences in EC values measured at the A-B interface and in the B horizon at 90 cm from water inlet for the trees and bare ground (Figures 6.8b,c).

Mean pH values for soil solutions were similar for the tree treatment and bare ground (Figure 6.9a), and showed an increasing trend over time. The values of pH increased from 7.06 to 7.49 and from 7.09 to 7.52 for tree treatment and bare ground respectively over the period, and both curves fitted a linear function with $R^2 > 0.92$. The values of pH measured at A-B interface and B horizon at 90 cm from water inlet were also not significantly different for the trees and bare ground (Figures 6.9b,c).

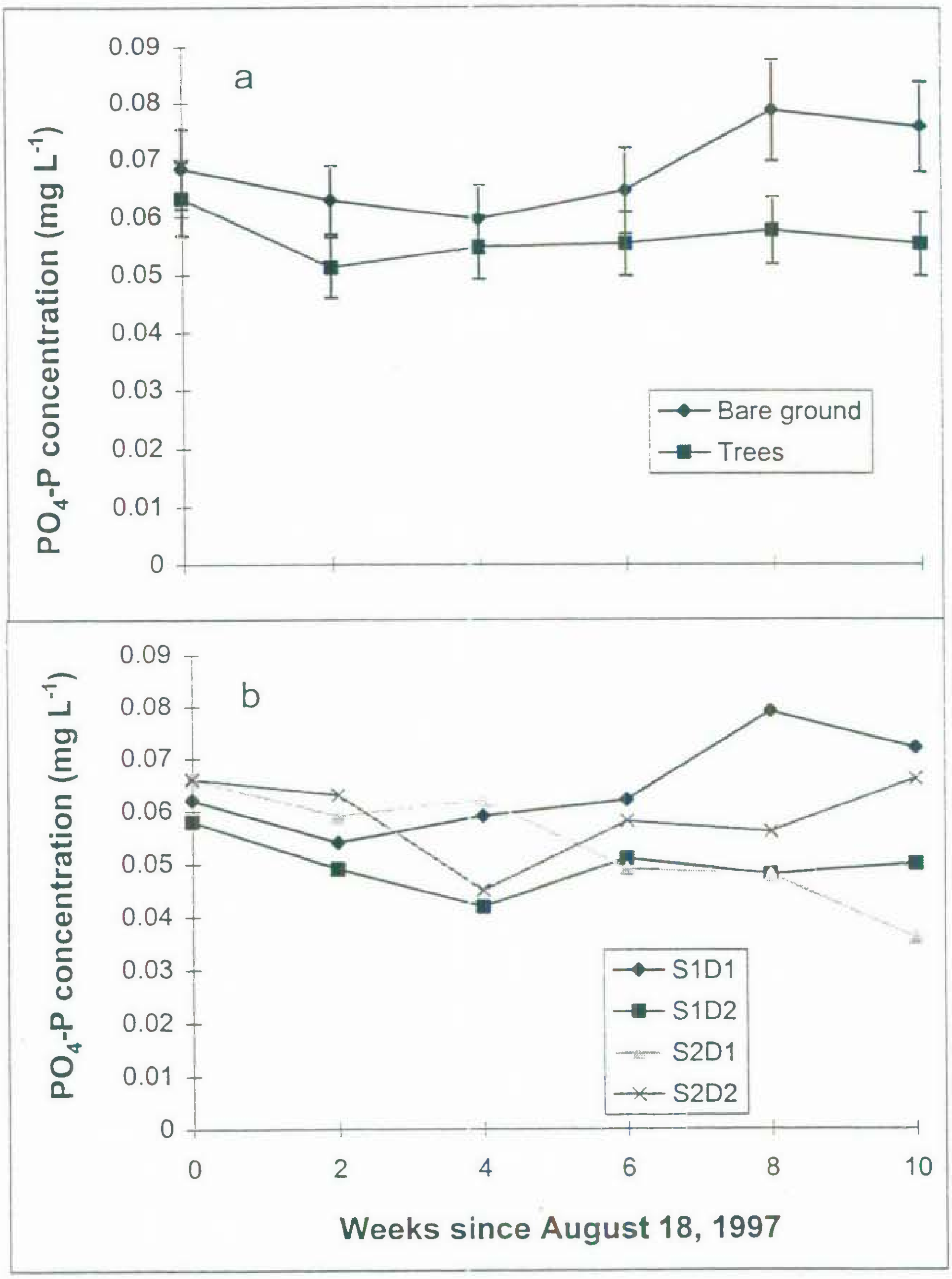

Figure 6.6. Comparison of PO_4-P concentration in soil solution between (a) the tree treatment and bare ground control and (b) among the tree treatments over the 'soil nutrient depletion period'. Average values were used from the soil solution collected from the 5 sampling pipes. S1: *Eucalyptus camaldulensis*; S2: *Casuarina cunninghamiana*; D1: 4 trees plot^{-1}; D2: 2 trees plot^{-1}. The differences were not significant.

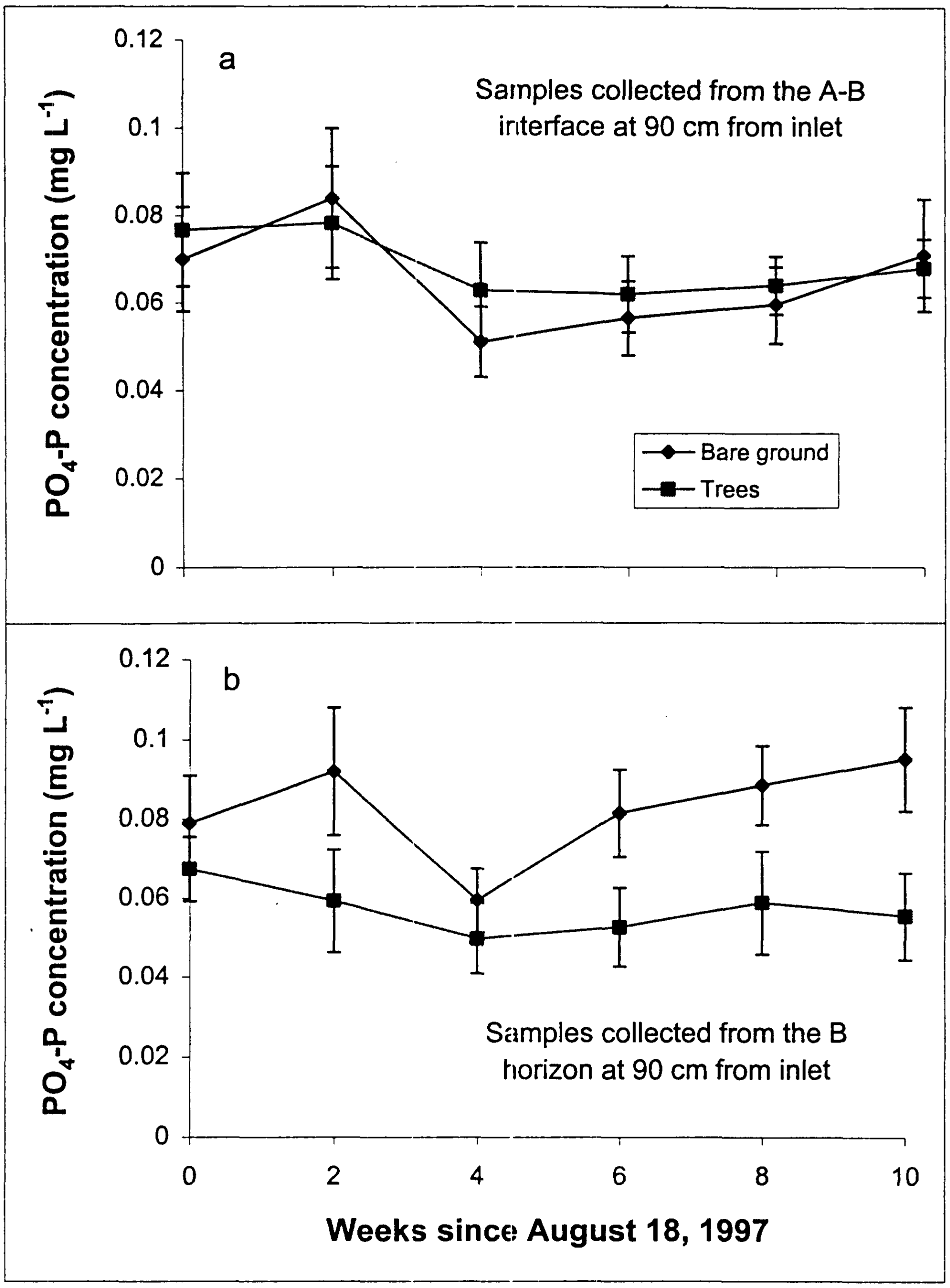

Figure 6.7. Comparison of PO_4-P concentration in soil solution at (a) the soil A-B interface and (b) in the B horizon for the tree treatments and bare ground control over the 'soil nutrient depletion period'. Measurements were taken from the soil solution collected at 90 cm form water inlet, ie sampling pipes upper 2 and bottom 2 respectively (see chapter 3). No significant differences were observed.

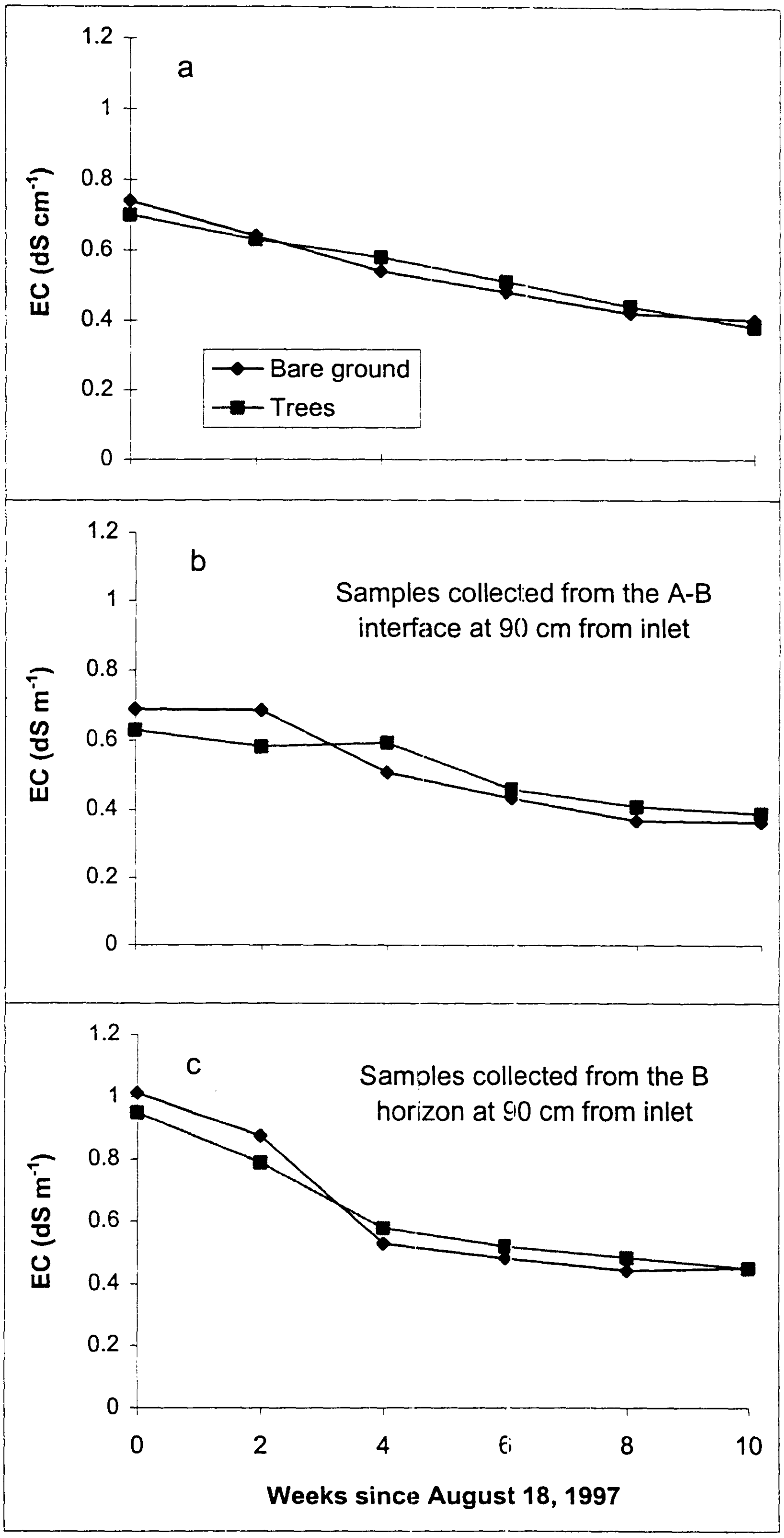

Figure 6.8. Comparison of EC values in soil solution for the tree treatments and bare ground control over the 'soil nutrient depletion period'. The values were calculated from the measurements in soil solution collected from the 5 sampling pipes (upper 1 and 2, bottom 1 and 2 and outlet), and at 90 cm form water inlet (sampling pipes upper 2 and bottom 2) respectively (see chapter 3). The differences were not significant.

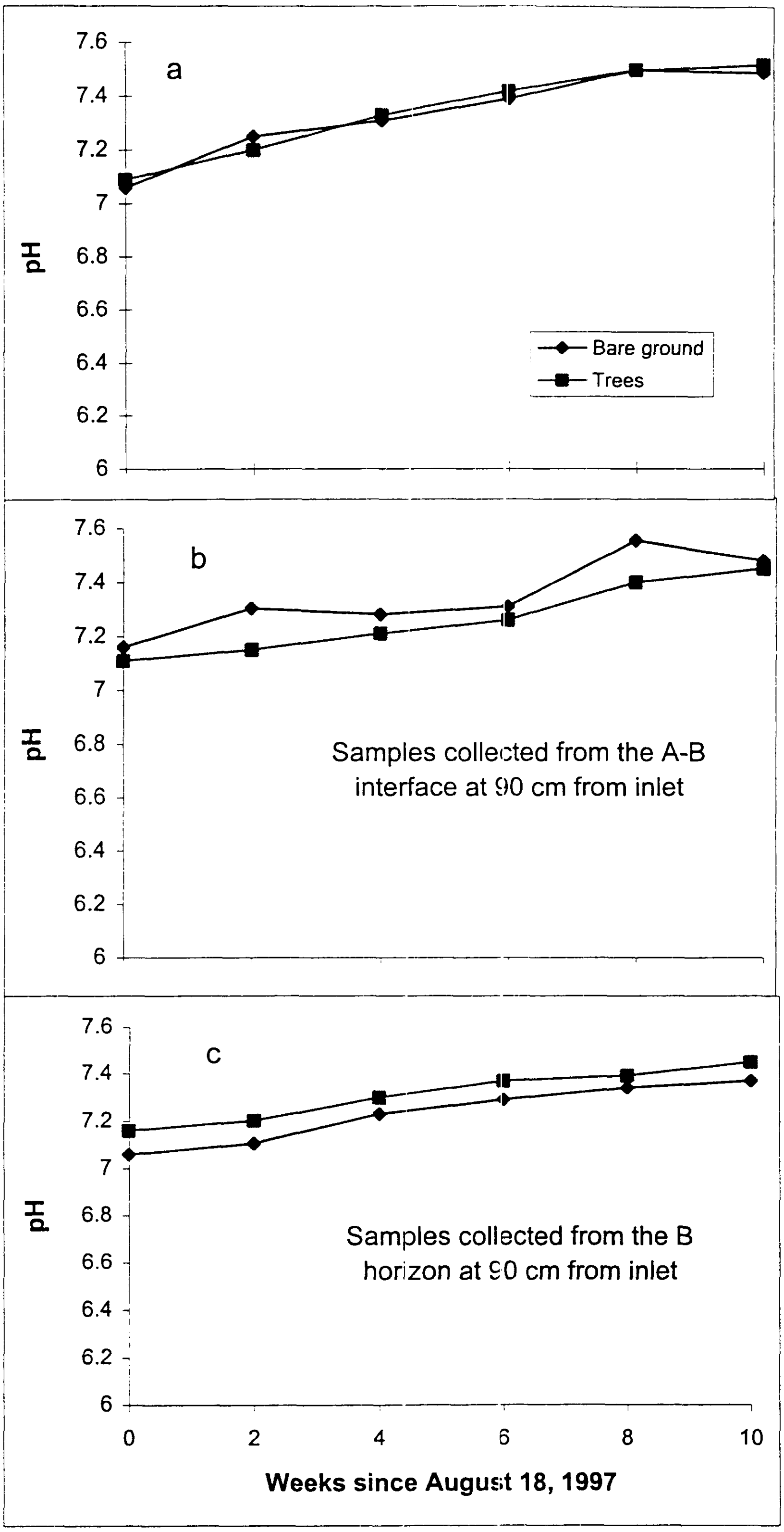

Figure 6.9. Comparison of pH values in soil solution for the tree treatments and bare ground control over the 'soil nutrient depletion period'. The values were calculated from the measurements in soil solution collected from the 5 sampling pipes (upper 1 and 2, bottom 1 and 2 and outlet), and at 90 cm form water inlet (sampling pipes upper 2 and bottom 2) respectively (see chapter 3). The differences were not significant.

6.1.2.2. Evidence from the 'low NO_3-N addition period'

Removal of NO_3-N by trees from lateral groundwater flow was examined in this period by adding 10 mg N L^{-1} of KNO_3 solution at the rate of 5 litres per day. The values of NO_3-N concentration were averaged for the 3 measurements at 2, 4 and 6 weeks since November 1, 1997 because the differences over time were not significant. The NO_3-N concentrations in soil solutions were not significantly different among the tree treatments (Table 6.6), while the tree plots, on average, retained more NO_3-N than the bare ground plots by 33.1% (Table 6.7).

The concentration of NO_3-N was significantly ($P<0.01$) lower in the soil solution collected above and below the tree zone at A-B interface flow (sampled through sampling pipes upper 1 and upper 2) for tree plots in comparison with the bare ground plots (Figure 6.10a). The level of NO_3-N decreased from 10 mg L^{-1} at the inlet to 3.19 mg L^{-1} and 6.91 mg L^{-1} at 90 cm from inlet for the tree plots, and for the bare ground plots respectively. However, the differences in NO_3-N concentration for the B horizon flow were not significant between the tree and bare ground plots (Figure 6.10b). The level of NO_3-N concentration in soil solution was consistently lowere than 1.5 mg L^{-1} in the B horizon both for tree and bare ground plots.

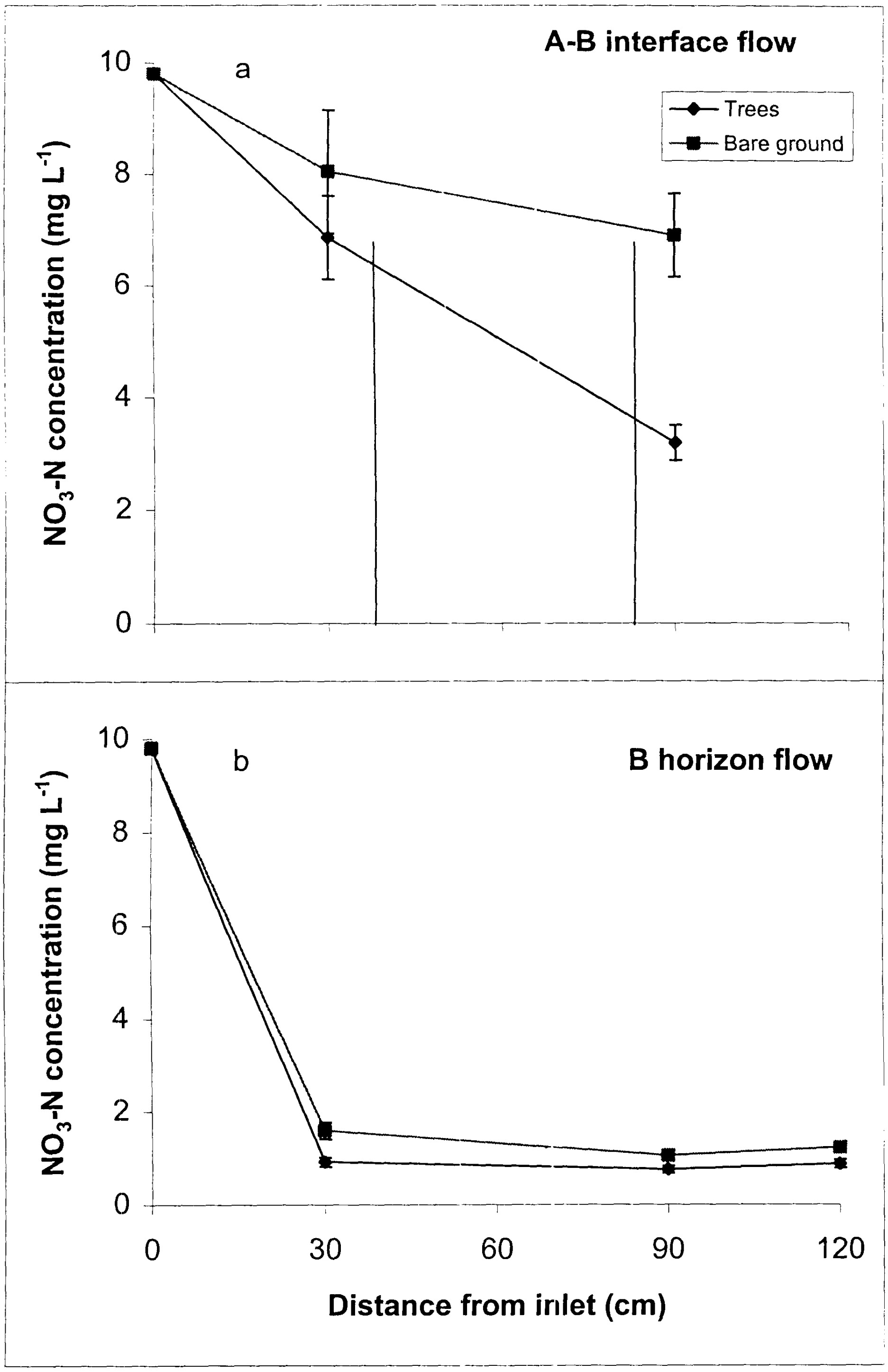

Figure 6.10. The effect of tree treatments on NO_3-N concentration in lateral (a) A-B interface flow and (b) B horizon flow compared with bare ground control during the 'low NO_3-N addition period'. The values of NO_3-N concentration were the averages of 3 measurements at 2, 4 and 6 weeks since November 1, 1997.

6.1.2.3. Evidence from the 'high NO_3-N addition period'

Priori to this period, the bare ground controls were planted with pasture and grown for 7 weeks before the experimental conditions were applied. The NO_3-N concentration in the added solution was increased to 20 mg L^{-1}. The values of NO_3-N concentration were the averages of 3 measurements at 2, 4 and 6 weeks since February 20, 1998. The NO_3-N concentration in the soil solution was not significantly different among the tree treatments (Table 6.6) and between the tree plots and pasture plots (Table 6.7). The effect of trees and pasture on NO_3-N concentration in soil solution was not significantly different both for the lateral A-B interface flow (Figure 6.11a) and B horizon flow (Figure 6.11b). The level of NO_3-N concentration decreased from 20 mg L^{-1} at the inlet to about 4 mg L^{-1} at 90 cm from inlet in the A-B interface flow for both tree and pasture treatments. The NO_3-N concentration in the soil solution was consistently lower (<1.0 mg L^{-1}) in the soil B horizon both for the tree and pasture plots.

6.1.2.4. Summary of the experiment

Considering both the low and high NO_3-N addition experimental periods together, NO_3-N concentrations at the A-B interface flow were reduced to a similar level (around 4 mg L^{-1}) (Figure 6.12a) for the tree plots as soil solutions flowed past the trees. This suggests that the efficiency of NO_3-N removal by trees was higher when the soil solution concentration was high. The level of NO_3-N concentration in the B horizon flow was not significantly different for the higher and lower NO_3-N addition (Figure 6.12b).

The efficiency of trees in removal of NO_3-N by comparison with pastures and bare ground in the glasshouse experiment is summarised in Table 6.7. NO_3-N concentration values are the averages of three measurements in each period. The measurements at 2, 4 and 6 weeks since August 18, 1997 during the nutrient depletion period are selected for this calculation because the trees still grew slowly during the days around August 18, 1997, about 12 weeks since planted (see Figure 6.1), and NO_3-N concentration in soil solution became very low after 8 weeks since August 18, 1997 both for tree plots and bare ground control (see Figure 6.4).

In summary, using NO_3-N concentration in soil solution as an indicator, trees exhibited higher efficiency in removal of NO_3-N in comparison with bare ground control and pastures, but significantly only when compared with bare ground. Trees reduced significantly more NO_3-N from lateral A-B interface flow than bare ground during the 'nutrient depletion period' and the 'low NO_3-N addition period'. The reduction was also significant for lateral B horizon flow during the 'nutrient depletion period'.

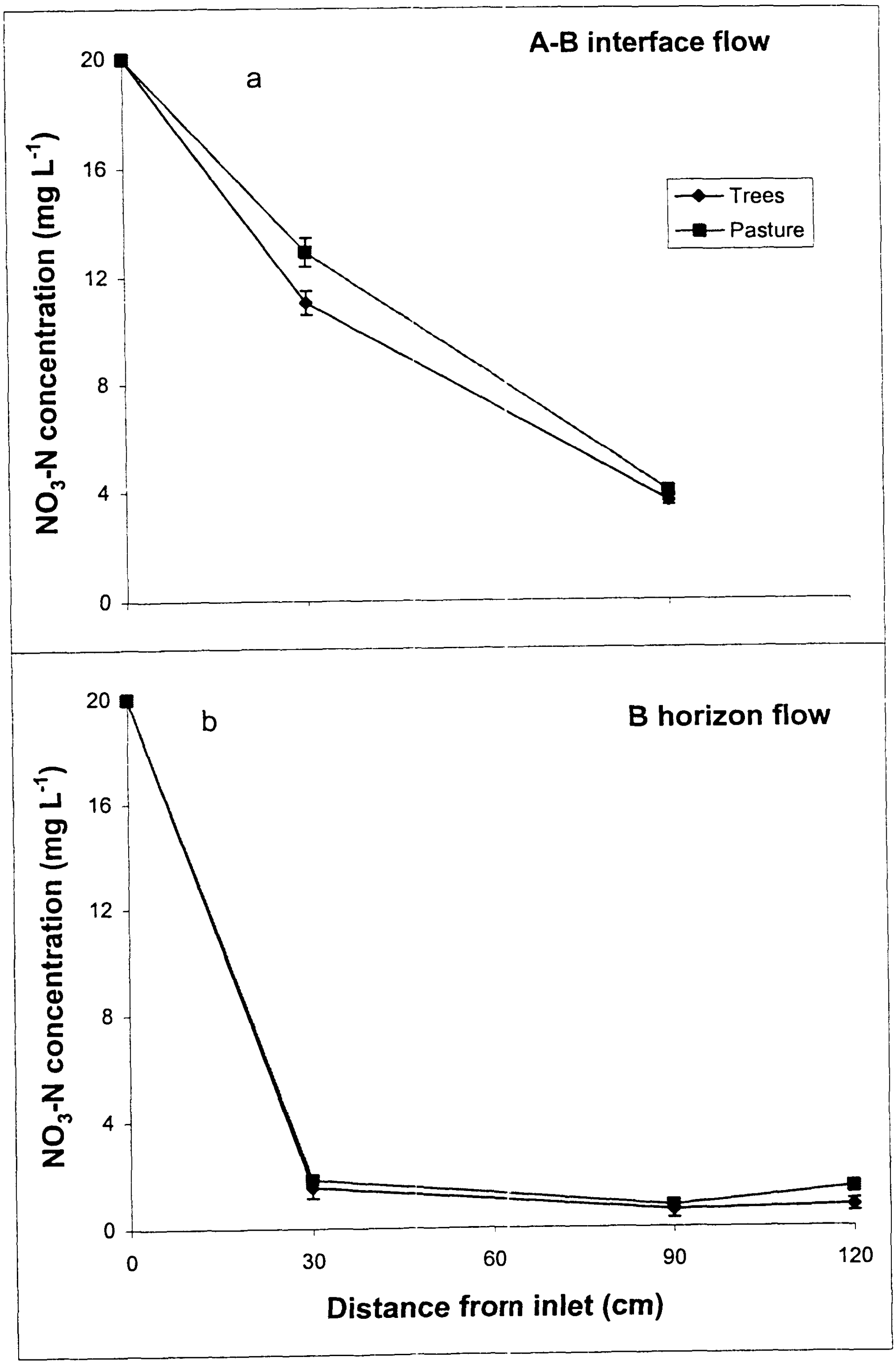

Figure 6.11. Effects of trees and pastures on NO_3-N concentration in lateral A-B interface flow and B horizon flow during the 'high NO_3-N addition period'. The values of NO_3-N concentration were the averages of 3 measurements at 2, 4 and 6 weeks since February 20, 1998. The differences were not significant.

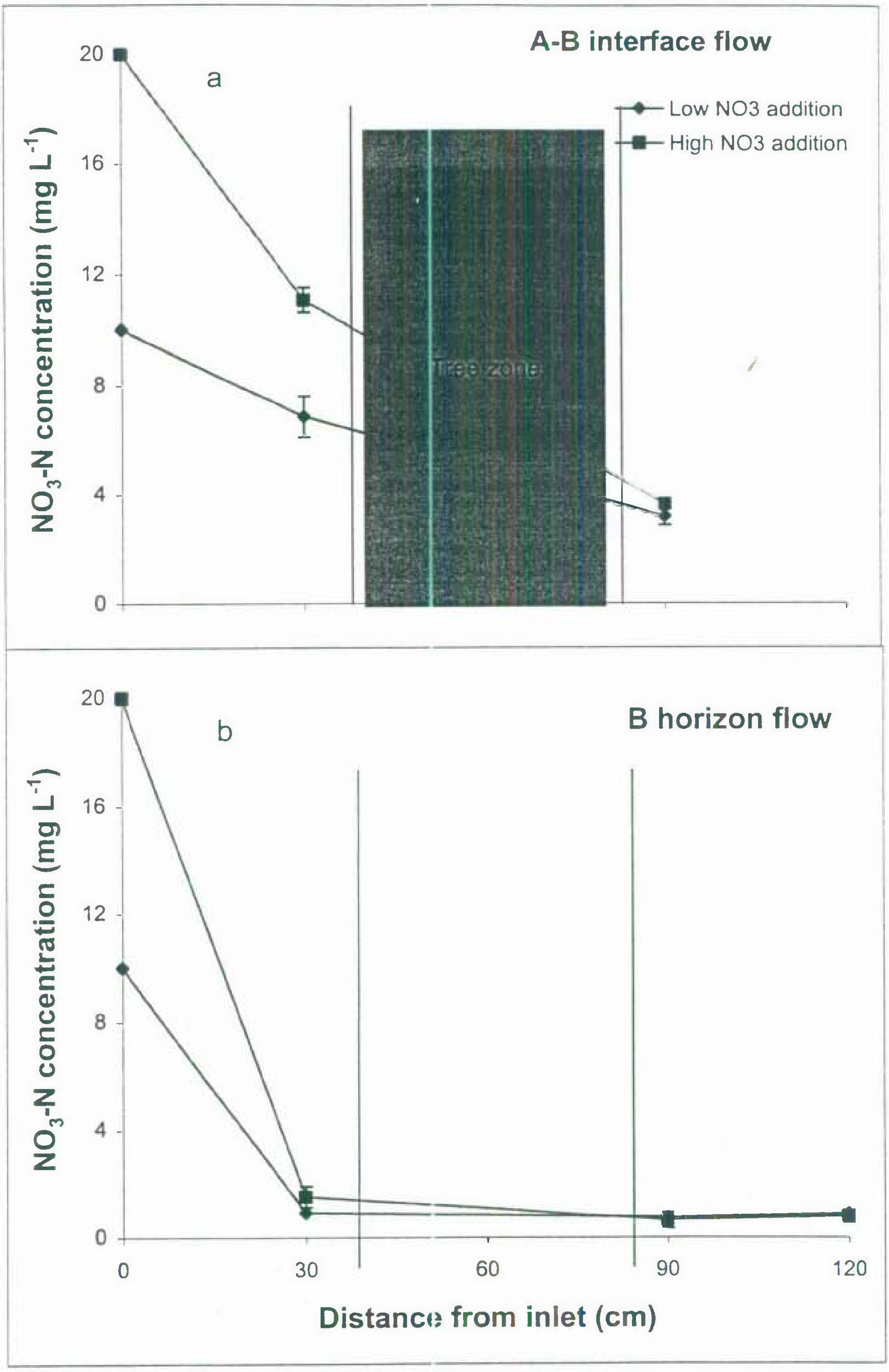

Figure 6.12. Comparison of the efficiency of tree zone in NO_3-N removal (a) for the A-B interface flow and (b) the B horizon flow during the low and high NO_3-N addition periods.

Table 6.7. The efficiency of trees in removing NO_3-N from soil solution in comparison with pastures and bare ground in the glasshouse experiment. NO_3-N concentration values are the average of three measurements in each period. The measurements at 2, 4 and 6 weeks during the nutrient depletion period were selected for this calculation (see text for explanation). [#]Average: each value is the average of 5 values measured from the solution samples collected from the 5 sampling pipes respectively. [##]Upper 2=values from the solution sample collected form the sampling pipe Upper 2 that was located at the soil A-B interface at 90 cm from inlet. [###]Bottom 2= values from the solution sample collected form the pipe Bottom 2 that was located at the soil B horizon at 90 cm from inlet. [$]significance: *=significantly different at $P<0.05$; **$P<0.01$; ***<0.001; ns=not significantly different. Unit: $mg\ L^{-1}$.

Periods	Trees	Bare ground	Pasture	[$]Significance	Difference due to trees	%
Nutrient depletion period						
[#]Average	3.16	5.26		***	2.10	39.9
[##]Upper 2	4.34	6.82		**	2.48	36.3
[###]Bottom 2	4.17	8.01		***	3.84	47.9
Low NO_3 addition period						
Average	2.52	3.77		*	1.25	33.2
Upper 2	3.19	6.91		***	3.72	53.8
Bottom 2	0.75	1.05		ns	0.30	28.6
High NO_3 addition period						
Average	3.52		4.20	ns	0.68	16.2
Upper 2	3.62		3.99	ns	0.37	9.3
Bottom 2	0.69		0.80	ns	0.11	13.3

6.1.3. Comparison of water use by trees and pasture

The water use of the treatments is shown in Figure 6.13. *E. camaldulensis and C. cunninghamiana* trees with two densities were not significantly different in water use over the 4-week measured period. The tree plots, however, used significantly more ($P<0.001$) water (about 40% more, on average) than the pasture plots.

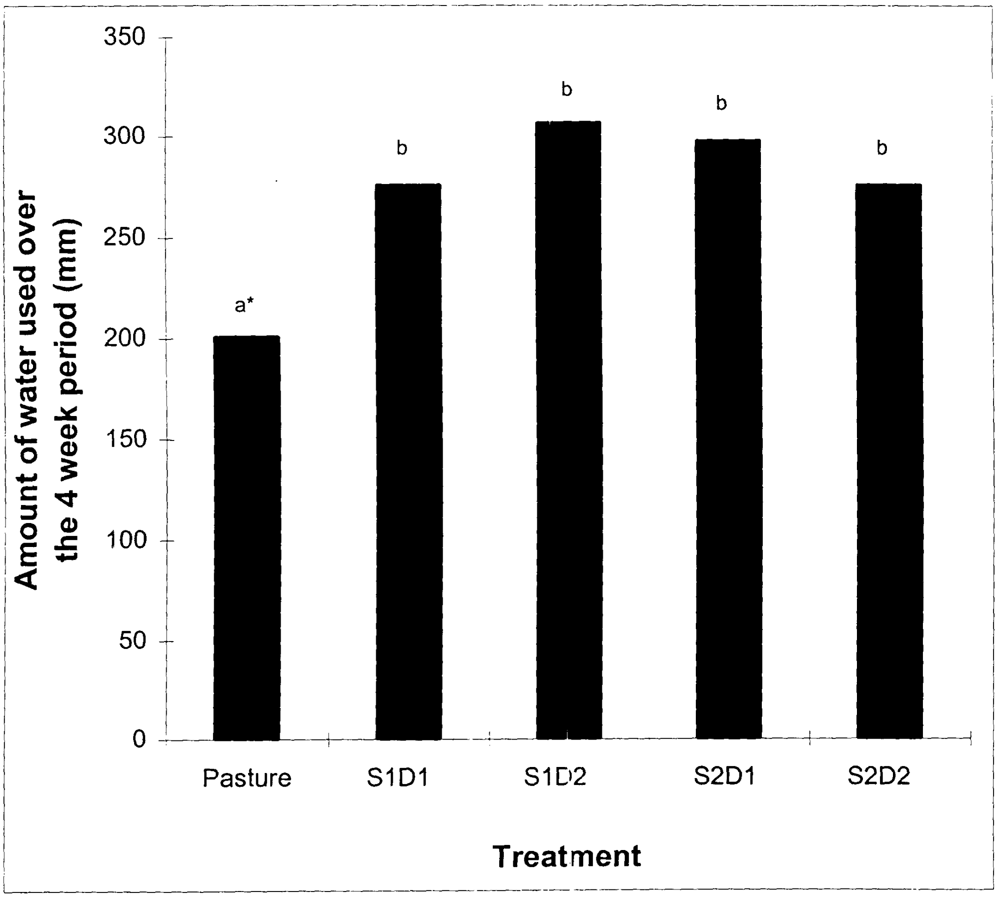

Figure 6.13. Comparison of water use between the tree and pasture treatments during the 4 weeks since April 1, 1998. S1: *Eucalyptus camaldulensis*; S2: *Casuarina cunninghamiana*; D1: 4 trees plot^{-1}; D2: 2 trees plot^{-1}. *The means with different letters are significantly different at $P<0.001$.

6.2. Discussion

6.2.1. Growth responses of trees and grasses

Both *E. camaldulensis* and *C. cunninghamiana* trees grew slowly during the first 13 weeks after planting (Figure 6.1) primarily due to winter conditions and low temperatures in the glasshouse frequently went down to 5 °C at night. As trees were pruned at 22 weeks, comparison of height growth was limited to the early experimental period. The difference in height growth was not significant between *E. camaldulensis* and *C. cunninghamiana* during this period (Figure 6.1a), while the 2-tree treatment was taller than the 4-tree treatment for both species, although the difference was significant only for *E. camaldulensis* (Figure 6.1b). The diameter growth was linearly related for all the tree treatments (Figure 6.2). The 2-tree treatment resulted in significantly higher diameter growth rates for both *E. camaldulensis* and *C. cunninghamiana.* This suggests that the trees were too dense so that their growth in diameter was limited to some extent. Consequently the 4-tree treatment restricted growth in both height and diameter, and this was reflected in individual tree biomass.

Previous studies (Awe *et al.* 1976; Jacobs 1955) recorded that *E. camaldulensis* has a particularly high root/shoot ratio, an attribute contributing to its success in an arid environment and its ability to tap into deep groundwater. Awe *et al.* (1976) measured the root/shoot ratios for 6 provenances of *E. camaldulensis* and found they were between 0.35 and 1.21 under different water regimes. Bell *et al.* (1993) reported that the root/shoot ratios of 2 provenances and 5 clones of *E. camaldulensis* were from 0.44 to 0.78. In this study, the root/shoot ratios of *E. camaldulensis* were 0.38 and 0.43 respectively for the 4-tree and 2-tree treatment (Table 6.3), which were at the lower level in comparison with other published results. However, the soil for the above two experiments were sand or partly sand with clay, while the soil used in this study was a strongly duplex soil with a sandy clay loam horizon over clay. Soil type may have decreased the development of the root system to some degree.

Tree root habit is reflected in the distribution of roots in the soil profile. *E. camaldulensis* has a strong tap root system (Plate 3a) and also develops sinker roots from major lateral roots (Jacobs 1955), while *C.* cunninghamiana has a more fibrous root system with a weaker tap root (Plate 3b). Consequently, *E. camaldulensis* had more roots growing in the soil B horizon in comparison with *C. cunninghamiana* (Table 6.3), which suggests that *E. camaldulensis* could more efficiently use sub-surface soil water and tolerate drier environmental conditions. *C. cunninghamiana* is likely to use the surface soil moisture more efficiently than *E. camaldulensis* because it has a higher proportion of fine roots in the surface soil. Both tree species had much greater above- and below-ground biomass than the pasture (Figure 6.3).

The pasture accumulated N and P more efficiently than the trees, although the trees accumulated absolutely larger amount of the nutrients by having greater biomass than the pasture (Table 6.5). This suggests that pasture could more efficiently filter N and P, provided that proper management methods, such as harvesting on time, were adopted. This is based on the hypothesis that removal of nutrients due to nutrient assimilation by plants is one of the main processes for vegetated filter strips in reducing nutrient transport (Lowrance 1992; O'Neill and Gordon 1994).

6.2.2. Nutrient removal in soil solution by trees and pasture

The tree treatments demonstrated significantly higher capacity in retain NO_3-N in the vegetation-soil system in comparison with bare ground through the measurements in the 'nutrient depletion period' and the 'low NO_3 addition period'. During the 'nutrient depletion period', tree treatments on average retained more NO_3-N than bare ground by 39.9% (Figure 6.4; Table 6.7). Retention by trees for the A-B interface flow was 36.3 higher than bare ground, while for the B horizon flow it was 47.9% (Figure 6.5; Table 6.7). During the 'low NO_3 addition period', a loss of NO_3-N was recorded as nutrient rich water migrated through the soil. The loss was significantly greater with tree treatments than bare ground (Figure 6.10a; Table 6.7). In a similar study, O'Neill and Gordon (1994) also demonstrated that trees (Carolina poplar) were effective in lowering subsurface NO_3-N concentrations as soil solution flowed through the rooting zones of trees.

The trees did not show a significantly greater ability in retaining lateral moving NO_3-N in comparison with pasture (Table 6.7). During the 'high NO_3-N addition period', the loss of NO_3-N was not significantly different with the tree and pasture treatments as NO_3-N enriched water flowed through the soil (Figure 6.11). The two tree species with two different planting densities also did not show significant influences in reducing NO_3-N associated with lateral moving water for any of the experimental periods (Figure 6.4b; Table 6.6).

Considering the three soil solution collection and analysis periods overall, the efficiency of NO_3-N removal from lateral ground flow by trees was greater when NO_3-N concentration was relatively higher in the soil (Figures 6.4b, 6.5 and 6.12a). This response may be due to trees taking up more NO_3-N when more NO_3-N is available in the soil solution (Lowrance 1992; O'Neill and Gordon 1994) or that denitrification was higher when the NO_3-N content in soil was higher (Hill 1996; Nelson *et al.* 1995).

The result from the high NO_3-N addition period showed that the 3-month-old pasture took up comparable amount of NO_3-N as the 10-month-old *E. camaldulensis* and *C. cunninghamiana* trees under glasshouse conditions. This suggests that pasture can be used in designing and implementing vegetative buffer strips to remove NO_3-N from laterally moving shallow groundwater. This result is, however, to some extent, in conflict with some published results. Osborne and Kavacic (1993) suggested that a forest riparian zone in Illinois, USA was more efficient in removing NO_3-N from shallow groundwater than an adjacent grass riparian area. A poplar vegetated riparian zone in England was found to retain more NO_3-N from groundwater than a grass riparian strip (Haycock and Pinay 1993). Verchot *et al.* (1997a,b) reported that nitrate attenuation in a grass-vegetated field edge was lower compared to a forest.

Nevertheless, all these studies were based on real matured forest. Therefore, it must be very cautious to make some reasonable interpretation based on the comparison. A limitation of this glasshouse experiment was that the surface soil (15 cm deep) and particularly the subsoil (20 cm deep) were relatively shallow by comparison with the field experiment site, which might have had some effects on the experiment results. Denitrification might also be lower under field condition.

Despite the fact that many different types of vegetated buffer strips have been reported as having the ability to remove NO_3-N from subsurface water (e.g. Osborne and Kovacic 1993; Paterson *et al.* 1993), there is still considerable uncertainty about the relative importance of removal mechanisms. Most researchers have suggested that the major processes are vegetation uptake (e.g. Lowrance 1992; O'Neill and Gordon 1994; Paterson *et al.* 1993) and denitrification (e.g. Haycock and Pinay; Jacobs and Gilliam 1985; Verchot *et al.* 1997b). Monitoring and analysing soil solutions during the 'soil nutrient depletion period' and the 'low NO_3 addition period' in this glasshouse experiment indicated that the both processes are likely to contribute to the NO_3-N reduction. The significantly lower NO_3-N levels in soil solutions from the tree treatments in comparison with the bare ground control (Figures 6.4a, 6.5 and 6.10) may be due largely to tree uptake. The fact that the NO_3-N levels declined from 10 mg L^{-1} at the inlet to 6.91 mg L^{-1} at 90 cm from inlet (Figure 6.10a), however, might due largely to the process of denitrification.

The comparison of NO_3-N concentration dynamics for the A-B interface flow and B horizon flow in the low and high NO_3-N addition periods (Figures 6.10, 6.11 and 6.12) demonstrated that the removal of NO_3-N by trees and pasture mainly occurred in lateral A-B interface flow. The results from the low and high NO_3-N addition periods also showed that NO_3-N concentrations were all significantly lower for the soil solutions collected from the bottom sampling pipes (Figures 6.10, 6.11 and 6.12). This indicated that the clay subsoil had dramatically intercepted the vertical

NO_3-N leaching, and that an important pathway of NO_3-N loss would be through the lateral shallow groundwater flow when the soil was saturated.

In the 'nutrient depletion period', the PO_4-P concentration did not significantly change both for tree plots and bare ground. Phosphorus is relatively immobile and is usually held by the soil in complex forms (LWRRDC, 1993; Myers *et al.* 1995). The PO_4-P concentration in the soil solution from the glasshouse experiment was comparable to that collected from the deep observation wells, but was much lower (up to 5 times) than that collected from the shallow wells in the field experiment site at Tullimba (see Chapter 5). The difference might be partly due to the phosphorus additions to the field site through effluent irrigation and fertilizer application. The values of pH increased and EC decreased in the 10-week nutrient depletion experimental period, reflecting nutrient removal during the leaching process.

6.2.3. Water use by trees and pasture

The *E. camaldulensis* and *C. cunninghamiana* trees were densely planted in the glasshouse experiment. Thus, it was in expectation that the results of water use for the trees and pasture growing in the glasshouse would be different from that in the field site (see Chapters 4 and 5). On average, the tree plots used about 40% more water than the pasture plots under the glasshouse condition, while the water use by the tree and pasture plots were basically similar and the pastures even used more water than the trees in some periods in the field experiment. The result from the glasshouse experiment suggests that the trees in the field may use significantly more water than pasture when the trees develop in the field to occupy the site both in terms of roots and crown.

6.3. Conclusion

The height growth was not significantly different between *E. camaldulensis* and *C. cunninghamiana* during the early 22 week period of this experiment. *E. camaldulensis* in the 2-tree treatment grew significantly taller than the 4-tree treatments after 13 weeks since planting. During 11-month experimental period, *C. cunninghamiana* had significantly higher growth rate in diameter and total biomass in comparison with *E. camaldulensis*. The growth of *E. camaldulensis* was affected by the density treatments more than *C. cunninghamiana*. *E. camaldulensis* had more roots growing in the soil B horizon in comparison with *C. cunninghamiana*, while *C. cunninghamiana* had more fine roots growing in the surface soil, which reflects the rooting habit of both species.

The tree treatments retained significantly more NO_3-N associated with shallow (A-B interface flow) groundwater movement than bare ground. NO_3-N reduction was not significantly different between trees and pasture, and among the tree treatments. However, the pastures took up and accumulated NO_3-N more efficiently than the trees. The average rates of N and P accumulation were 0.79 and 0.10 g plot^{-1} month^{-1} for the tree plots respectively, while the rates were 2.01 and 0.23 g plot^{-1} month^{-1} for the pasture plots. The experiment also showed that the efficiency of NO_3-N removal by trees was greater when NO_3-N concentration was relatively higher in the soil.

Trees used more water than the pasture plots by about 40%, while the water used among the tree treatments was not significantly different. This suggests that the trees in the field may use significantly more water than pasture when the trees develop in the field to occupy the site both in terms of roots and crown.

Chapter 7

General discussion and conclusions

The overall objective of this study was to investigate the effectiveness of established buffer strips with the trees of *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* and improved pasture in intercepting lateral groundwater flow and nutrients from the effluent disposal area associated with a beef cattle feedlot on the Northern Tablelands of NSW. For this study, survival and growth of the trees and pasture were measured, their water use was estimated, and their potential to decrease water table, reduce groundwater movement and remove nutrients, particularly NO_3-N from groundwater and soil were determined. This field study was complemented with a simulated glasshouse experiment on the ability of trees and pastures to intercept nutrients.

This chapter integrates the results and discussion from the preceding chapters and generally address the following questions: 1) The perspective of using the two tree species as components in VBSs for the Northern Tablelands which is closely related to their survival, growth and effectiveness at intercepting lateral groundwater and nutrients; 2) The comparison of tree and pasture VBSs; 3) The main mechanisms involved in NO_3-N removal from lateral moving groundwater by VBSs; 4) The design options of VBSs for the Northern Tablelands. Two integrated VBS models will be presented.

7.1. The perspective of using the two tree species as components in VBSs for the Northern Tablelands

The results from this project demonstrate the potential use of *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* for establishing VBSs on the Northern Tablelands. Survival rates of the both species were high, although they were damaged to some extent by frost and by rabbit/hare browsing respectively (Chapter 4). Their growth rates were among the highest in comparison with results from other experiments conducted with the same species in the region. These results show that *E. camaldulensis* and *C. cunninghamiana* can be successfully established as tree species for a VBS in this area. However, establishing *E. camaldulensis* may have difficulty in the higher altitudes of the Northern Tablelands, and thus some protective measures and management should be adopted during earlier developed stages (Chapter 4).

Because the trees were young (<3 years) and the planting densities were low in relation to maximising water use, the tree treatments under the field condition did not show significant effects at intercepting lateral groundwater movement and nutrients from the effluent disposal area (Chapter 5). The tree plots even had a lower capacity for extracting soil water than the improved pasture in some periods (Chapter 4). However, the fact that the soil water deficit at 60-100 and 100-140 cm depths increased for the tree plots under dry conditions experienced between January and March 1998 showed that the trees may extract soil water from deeper in the profile and hence have the potential to trap and take up nutrients from deeper groundwater. Consequently the trees are able to tolerate dry condition. In the glasshouse experiment, the tree plots used significantly more water (by about 40%) than the pasture plots, and showed significant potential to deplete NO_3-N from soil solution (Chapter 6). This indicates that trees, when used in VBSs, will have a potential role in trapping NO_3-N (by using more water) and removing NO_3-N (by plant uptake) from adjacent effluent disposal areas or croplands.

In the field experiment, *Casuarina cunninghamiana* was significantly taller than *Eucalyptus camaldulensis* at the end of the third growing season, while the crown cover of *E. camaldulensis* was significantly greater than that of *C. cunninghamiana*. At this stage, the high density plots had large crown cover and greater basal area than the thinner ones (Chapter 4). However, the growth differences due to the different treatments did not produce significantly consequent effects on lateral groundwater and nutrient interception (Chapters 4 and 5). The possible cause is that the tree development and planting densities were such that they were unable to express their potential in water and nutrient relationships at this stage of growth and development (Chapter 5).

In the glasshouse experiment, *C. cunninghamiana* showed greater growth in height, diameter and total biomass than *E. camaldulensis.* Also, they had some differences in root structure. *C. cunninghamiana* had more fine roots (<0.3 cm dia.) and fewer dominant lateral roots (≥0.3 cm dia.) than *E. camaldulensis,* whereas *E. camaldulensis* distributed more roots in the soil B horizon and had storage tap root development by comparison with *C. cunninghamiana*. These two tree species, however, did not demonstrate significant differences at depleting NO_3-N and PO_4-P from lateral flowing soil solutions and in water consumption (Chapter 6). *E. camaldulensis* has a strong tap root system and also develops sinker roots from major lateral roots, while *C.* cunninghamiana has a more fibrous root system with a weaker tap root. Consequently, *E. camaldulensis* had more roots growing in the soil B horizon in comparison with *C. cunninghamiana* (Chapter 6), which suggests that *E. camaldulensis* could more efficiently use sub-surface soil water and tolerate drier environmental conditions. *C. cunninghamiana* is likely to use the surface soil moisture more efficiently than *E. camaldulensis* because it has a higher proportion of fine roots in the surface soil. Considering the results from the field experiment and glasshouse experiment together, it can be concluded that the two tree species have similar potential roles to play in intercepting lateral groundwater movement and nutrients when they are used in VBSs.

These results, however, are observed from the field experiment over a relatively short time frame during development stages and partly based on the glasshouse experiment. Also, very limited information is available on the long term performance and potential of *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* or other native tree species in plantations, shelterbelts or windbreaks on the Northern Tablelands. Therefore, further long time investigation and observations are necessary on both the growth of these species and their influence on the removal of contaminants from groundwater and soil.

7.2. Tree *vs*. pasture vegetated buffer strips

The fundamental function of VBSs is to reduce pollutants moving from adjacent areas and ultimately into receiving waters. Thus the basic standard of judging the efficiency of VBSs lies in their effectiveness in trapping and removing pollutants.

A basic question concerning the efficiency of VBSs is: are forested VBSs more effective than pasture VBSs at reducing nutrients in groundwater? Many researchers prefer grasses to trees or shrubs when considering mainly the ability of VBSs to remove nutrients and sediment in surface runoff. For example, Dillaha *et al.* (1989) suggested using grasses or legumes and advised against shrubs for vegetated filter strips, principally because grasses or legumes are more effective than shrubs at removing nutrients and sediments in surface runoff. Kumar *et al.* (1992) reported that five common riparian weeds had an important role in protecting soil from water erosion and in promoting phosphorus removal.

Some studies have compared the effectiveness of forests and pastures in reducing nutrients from lateral groundwater flow. Osborne and Kovacic (1993) reported that the forested VBS in Illinois, USA was more effective at reducing NO_3-N concentration than was the pasture VBS, but was less efficient at retaining total and dissolved phosphorus. A poplar vegetated riparian zone in England was found to retain 99% of the NO_3-N input in groundwater, while a pasture VBS retained 84% of the NO_3-N during the winter months (Haycock and Pinay 1993).

Because the trees were relatively young, the present study was unable to conclusively compare the effectiveness of the trees and pastures at reducing nutrient contamination in groundwater. However, some suggestions can be summarised through analysing their growth, water use in the field experiment and through the glasshouse experiment.

In the field experiment, the improved pasture commenced growth earlier in spring and stopped growth later in autumn when compared with the trees, provided that soil moisture conditions were not limiting (Chapter 4). The longer growing period for pasture may be an advantage when used in VBSs, both in terms of water consumption and nutrient depletion. Comparison of the measured soil water deficit in the improved pasture and the plantation demonstrated that the pasture had greater potential to use soil water than the plantation at this early stage of growth and developments (Chapter 4.).

The amount of 279.4 kg ha^{-1} of N and 25.0 kg ha^{-1} of P were removed from the pastures by harvest during the growing seasons of 1996/1997 and 1997/1998, while no any nutrients were removed from the tree plots, except for the accumulation of 49.1 kg ha^{-1} of N and 9.4 kg ha^{-1} of P in above-ground biomass (Chapter 5). This demonstrated that the improved pasture may be used to take up and remove N and P more efficiently than the plantation at early stage of development, provided that appropriate management adopted (such as harvesting on time). However, the trees were able to tolerate dry condition better than the pasture (Chapter 4 and above section). During the glasshouse experiment, the trees, on average, accumulated 8.72 g/plot of N and 1.08 g/plot of P in about 11 months, while the pastures accumulated 8.05 g/plot of N and 0.93 g/plot of P in only about 4 months (Chapter 6). This clearly showed that pastures can more efficiently assimilate and accumulate NO_3-N than *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* trees. However, the tree plots used about 40% more water than the pasture plots. Therefore, integrating all the results together, a combination of trees and pasture is likely to produce an effective design for VBSs.

7.3. The main mechanisms involved in NO_3-N removal from lateral moving groundwater by VBSs

Most previous studies have suggested that the major processes in removing NO_3-N from subsurface water by VBSs are vegetation uptake and denitrification (e.g. Groffman *et al.* 1991; Groffman *et al.* 1992; Jordan *et al.* 1993; Simmons *et al.* 1992). However, there is considerable uncertainty as to the relative importance of these two processes (Hill 1996). Peterjohn and Correll (1984) reported that 33% of the NO_3-N loss from groundwater in a Maryland (USA) riparian zone was attributed to the forest uptake. O'Neill and Gordon (1994) suggested that Carolina poplar trees effectively reduced NO_3-N concentration in soil solution by increasingly taking up NO_3-N enriched subsurface solution.

In contrast, Verchot *et al.* (1997b) reported that NO_3-N attenuation in forest soils was almost exclusively through denitrification and that plant uptake was insignificant. Lowrance (1992) concluded that denitrification could remove large amounts of NO_3-N from riparian forest groundwater if the water table was within 60 cm of the soil surface where denitrification rates were highest. Haycock and Pinay (1993) have suggested that vegetation uptake is the major retention mechanism in summer because this is the season of maximum plant growth and denitrification may be less important because soils become more aerated as the watertable declined. In contrast, denitrification is the major NO_3-N mechanism in winter because plants are inactive.

The results from the glasshouse experiment in this present study demonstrated that N uptake by trees and pastures was a main mechanism in the processes of NO_3-N removal from lateral moving soil solution. The trees took up and accumulated from 7.9 to 9.5 g of N in their above- and below-ground biomass in each plot on average during the 11-month growing period (Chapter 6). This N uptake by trees significantly reduced the NO_3-N concentration in soil solution at the soil A-B interface in the tree treatments in comparison with the bare ground control. The pastures accumulated about 8 g of N in each plot during the 4-month growing period. The uptake of N both by trees and pastures resulted in the NO_3-N concentration levels in lateral moving A-B interflow were not significantly different between the tree and pasture treatments.

The N and P accumulation in biomass were not measured for the tree treatments in the field experiment at Tullimba, but were estimated to be on average 49.1 0 and 9.4 0 kg ha^{-1} respectively during the 28 month growing period, according to the result of Stewart *et al.* (1990) (Chapter 5). For thie period, 279.4 and 25.0 kg ha^{-1} of N and P respectively, were removed from the pasture treatments by harvest. Nevertheless, the N and P removal did not significantly affect NO_3-N concentration both in deep and shallow groundwater, although the significantly lower P concentration level in the surface soil of the pasture plots might have resulted from P removal.

In this present study, no attempt was made to measure denitrification in the NO_3-N removal processes both in the field and glasshouse experiments. The results from the glasshouse, however, indicated that denitrification might be one of the main mechanisms contributed to the NO_3-N reduction from the soil solution (Chapter 6). During the 'low NO_3 addition period', the consistently lower NO_3-N level in soil solution of the tree treatments in comparison with the bare ground control was largely due to tree uptake. However, the substantial reduction of NO_3-N in soil solution in the bare ground treatment was likely to result from denitrification.

Many authors (e.g. Groffman *et al.* 1992; Haycock and Pinay 199; Lowrance 1992) have suggested that the presence of vegetation in VBSs is necessary for higher rate of denitrification because vegetation can provide available soil carbon for the bacterial process. Vegetation may affect denitrification by providing energy to denitrifying bacteria through litter decomposition and root exudates. Therefore, the C cycle associated with the type of surface vegetation within a riparian buffer strip may have an effect on the retentive efficiency of the strip. Further research is needed, not only to separate and quantify the two NO_3-N reduction processes, ie N uptake by vegetation and denitrification, but also to understand the interactions between vegetation and the denitrifying microorganisms.

7.4. Design of VBSs for the Northern Tablelands

7.4.1. Requirements for design of VBSs

In the field experiment of this study, the planted trees and improved pasture were designed as a VBS to reduce nutrient loss from the liquid effluent disposal area associated with the beef cattle feedlot. However, in practice, VBSs cmust be considered as just one component of best management practice (BMP) for catchment management. VBSs can be used to control non-point source pollution from croplands, grazing lands as well as liquid or solid waste disposal areas. VBSs include natural forms such as wetlands, grasslands, floodplain vegetation and natural forests, and artificial forms such as plantations, pastures and artificial wetlands. In agricultural regions, most of the natural systems have been seriously disturbed (eg. Cullen 1991; Schultz *et al.* 1995) or removed, and consequently, non-point source contamination to our water system has become a serious environmental, economical and social problem. Therefore, artificial VBSs can be used as one eco-engineering technique to attenuate the problem. The issue then becomes as to how to design and install VBSs to achieve the desired goals.

7.4.2. Specific factors influencing the design and installation on the Northern Tablelands

In designing and installing VBSs, a range of factors should be considered, including aims, soil physical and chemical properties, topography of the site, hydraulic load, pollutant load, climate, cost etc (Chapter 2). Specific factors affecting the design and installation of VBSs under conditions experienced on the Northern Tablelands will be addressed. Firstly, because the relatively short growing period, low temperatures and high incidence of frosts, tree growth is restricted even under high inputs of fertiliser, irrigation, protection from damage by insects, wildlife etc. (Reid *et al.* 1996; and Chapter 4). To some extent, these components limit the usefulness and effectiveness of trees in VBSs but careful species selection can address many of these issues. Therefore, tree species should be used in combination with perennial grasses in designing VBSs to reduce surface runoff run-off and soil erosion and to minimise nutrient movement in surface and subsurface water flow. Except for where there already exist natural tree zones, the development of a tree VBS should include a grass zone, at least in the earlier stages of tree development.

Secondly, tree species to be used in a VBS fir the Northern Tablelands area should include following characteristics: 1) relatively higher survival and growth rates, 2) tolerance to frost and cold temperatures, 3) tolerance to waterlogging and drought, and in some case 4) tolerance to salinity. Besides, species with different rooting habitats also should be considered. For examples, trees tend to be deeper rooting and penetrate into soil B horizon in some condition. Pasture species (including legumes), in general, should be selected to be compatible with the goals of agriculture. This means that the selected grasses should be targeted to produce forages as well as serving the prime functions of a VBS.

Finally, cost-effectiveness of VBSs must be considered. Any proposed strategy, regardless of its ecological merits, needs to be economically feasible and socially acceptable if it is to be implemented at the landscape level (Osborne and Kovacic 1993). As economic costs of establishing and maintaining VBSs can be high, it is imperative that the design and installation be based on both economic feasibility as well as sound scientific information.

7.4.3. Two integrated VBSs models for Northern Tablelands

7.4.3.1. Model 1: a tree zone combined with a pasture zone

Based on the results of the field and glasshouse experiment in this study and considering all the factors affecting functional efficiencies, an integrated model (Figure 7.1) is recommended for VBSs used on the Northern Tablelands. This model includes some tree species with good deep root systems such as *E. camaldulensis* and others with surface dominant root system such as *C. cunninghamiana* and improved pasture. The total width of the VBS is generally designed to be 20 m, which is arbitrarily determined according to published studies (e.g. Barling and Moore 1994; Osborne and Kovacic 1993; Schultz *et al.* 1995; and Chapter 2). However, widths of VBSs can vary according to the size of the adjacent field, the slope of the area, rainfall and evaporation (ie how much water it is likely to handle), run-on catchment area, soil properties and economic considerations.

In this VBS model, both trees and pastures are used. The buffer strip consists of two zones: a pasture zone and a tree zone. The pasture zone is designed to be 10 m wide but it can varydepending on local conditions, and is directly adjacent to the field where surface runoff and lateral groundwater flow are generated. Perennial species including grasses and legumes are recommended in this zone to reduce soil erosion, filter sediment and its associated chemicals, and help surface water infiltrate into the soil. This pasture zone can help protect the immediately downslope tree zone and sets the stage so the tree zone can perform at its maximum potential. Effective sediment trapping in the tree zone requires that runoff enter that portion of the zone in the form of sheet flow (Dillaha and Hayes 1992). The pasture zone is designed to spread out the flow and prevent runoff (once it occurs) from adjacent land uses forming eroded channels into the tree zone. Meanwhile, the pasture zone can reduce, to some extent, nutrient level in shallow groundwater by taking up nutrients for their growth. The pasture filter zone needs periodic maintenance including removal of sediment, re-establishment of vegetation, and filling in channels that form.

The tree zone is located immediately downslope of the pasture zone. This tree zone is also designed as 10 m wide but can vary according to local circumastances, where two lines of trees with good deep root systems and another two lines of trees with surface dominant root system are interplanted. This design can maximise their function in trapping nutrients transported by shallow groundwater because some trees have relatively deeper root system, while others have more fine roots in surface soil (Chapter 6). The density for the trees in this design is 2 m x 2 m, but can vary according to local conditions. The primary function of the tree zone is to remove, transform, or store nutrients, sediments and other pollutants flowing through the groundwater as well as over the soil surface. Where shallow groundwater flows through the root zones of trees, large amounts of nitrate can be reduced by plant uptake and denitrification in the soil before the groundwater enters a stream or drains into deep groundwater.

This integrated VBS model is designed to consider both short- and long-term effectiveness of VBSs, and to integrate the advantages of both trees and pastures in removing nutrients and reducing water flow from adjacent fields. The pasture zone can be established and function in the short term, while tree zone can be more efficient in the longer term. The pasture zone is more effective in removing surface sediments and associated nutrients, while tree zone is more beneficial at in intercepting water and nutrients flowing through groundwater. The proposed VBS model is also designed to consider both ecological and economic aspects of VBS development and management. Improved pastures are generally more productive and compatible with the goal of agriculture by produce quality hay (Pang 1996; Osborne and Kovacic 1993). Trees also can be used for producing timber, and in some case, for producing nuts, fruit and berries etc.

7.4.3.2. Model 2: a tree zone with pasture understorey layer

This model is designed according to the same philosophy used in the Model 1 which is to integrate the advantages of trees (both with deep root systems and surface dominant root systems) and pastures, but the pattern of installation is different. The width of this model is also designed as 20 m, but it can vary according to local conditions. Two lines with surface dominant root systems and three lines with deep root systems are planted as alternate rows with pasture strips in between. Tree density will be 4 m x 3 m with distance between lines being 4 m. Pastures will be established between the tree lines as ground cover.

In comparing with Model 1 with Model 2, the latter has advantages for long-term management because of the low tree density design. The pasture between the tree lines will function in removing nutrients from soil surface runoff and from lateral moving shallow groundwater at early stage of development. The disadvantage is that the pastures between the tree lines will be more difficult to manage and the production of the pasture will be lower in comparison with Model 1.

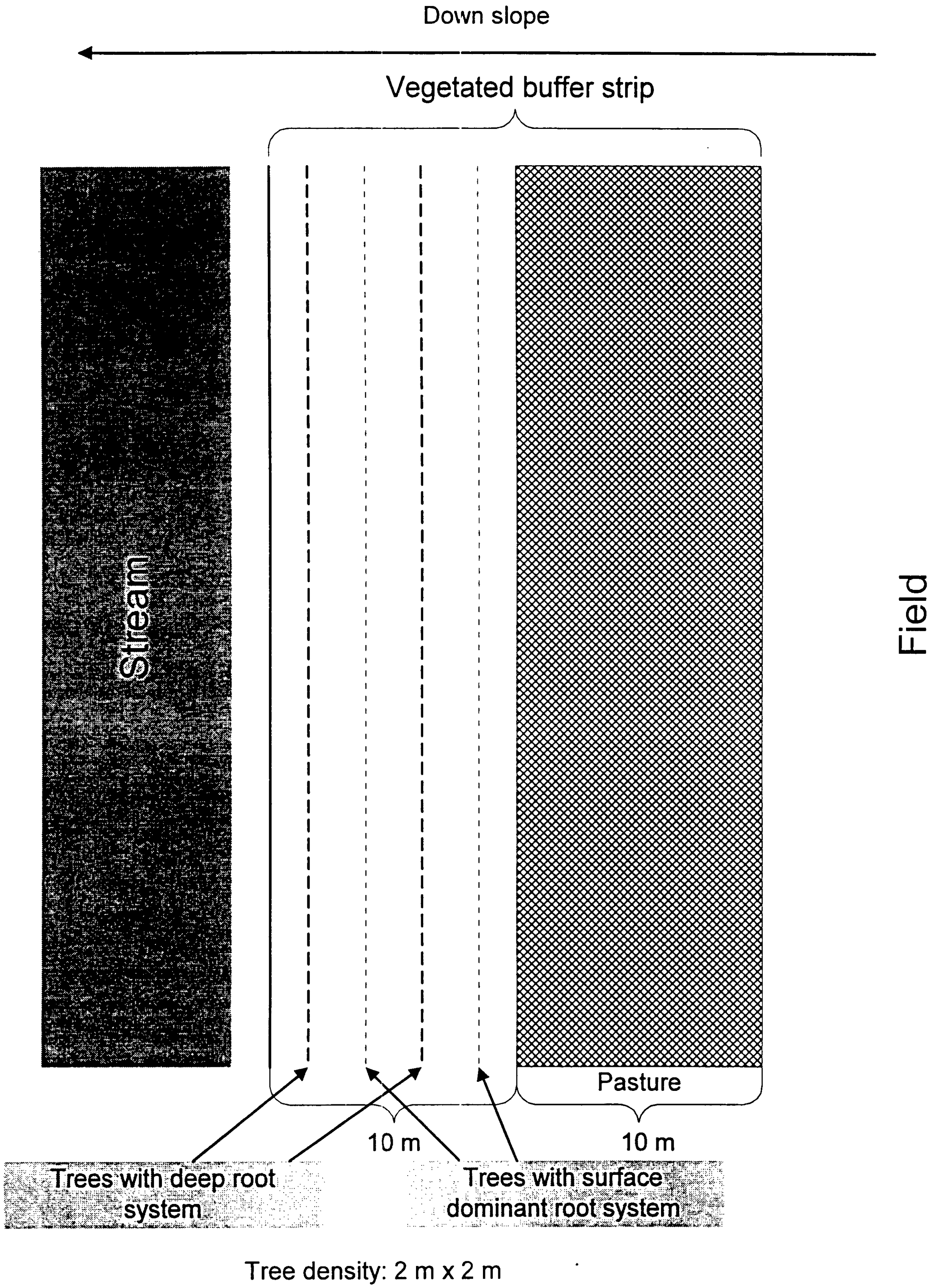

Figure 7.1. Integrated VBS model 1 for use on the Northern Tablelands, NSW by designing a tree zone using trees with deep root systems and the trees with surface dominant root systems, combined with a improved pastures zone.

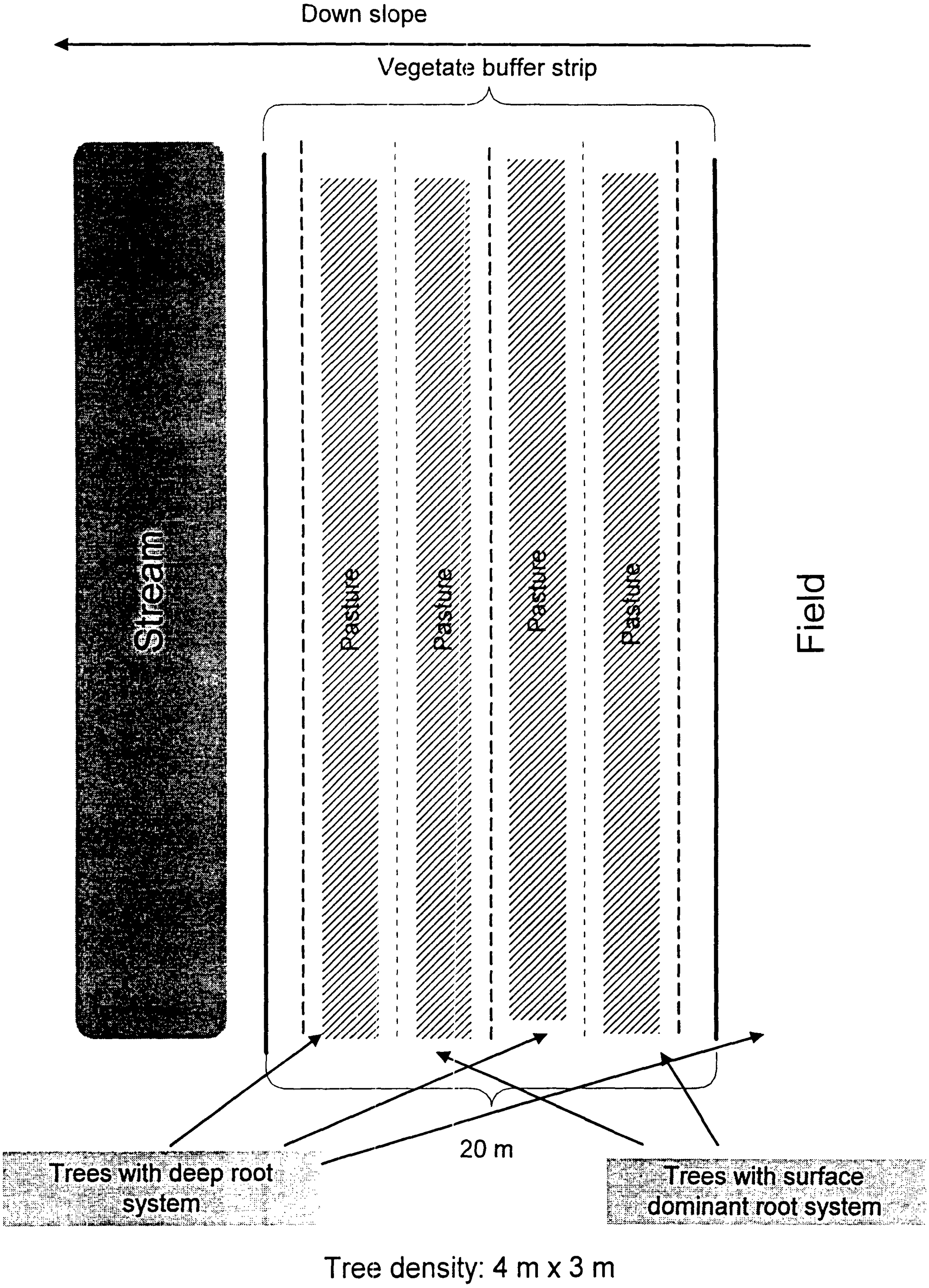

Figure 7.2. Integrated VBS model 2 for use on the Northern Tablelands, NSW by interplanting the trees with deep root systems, the trees with surface dominant root systems and improved pastures.

7.5. Limitations associated with this study and the questions that needs further research

There are two limitations in this study. Firstly, the trees of *E. camaldulensis* and *C. cunninghamiana* were relatively young in the field experiment and the measurements and results reflect the fact that trees had not dominated the water and nutrient relationships in the plantation plots. Therefore, the results drawn from the experiment are difficult to extrapolate to the longer-term role of trees at intercepting lateral groundwater flow and nutrients, although the results are valuable to demonstrate the general water and nutrient relations for the trees at this stage of development. The glasshouse experiment was used to compliment the field experiment and demonstrated that nutrient removal by trees and pastures occurs from lateral flow. Secondly, the observation time was relatively short. The conclusions drawn from shorter-term observation provide valuable results for early development but need to be supplemented with longer-term observations.

There are still many unanswered questions regarding the utility and efficiency of VBSs. These general questions have been discussed in Chapter 2. Here, several questions relating to this study and to the conditions in Australia generally are elucidated. First, information available on the performance of VBSs in Australia is surprisingly limited. Most research on VBSs has been carried out in the United States and Europe and is not directly transferable to many of the environments in Australia (Barling and Moore 1994). Therefore, basic research on potential roles, mechanisms of reducing contamination from surface and subsurface water, and design of VBSs is still needed in Australia. The second important aspect is that research must involve long-term observations on the performance of VBSs to determine their functional efficiency and ecological sustainability. The experiment at Tullimba is designed to extend over 15-20 years, which is appropriate for the long-term goals for VBSs. Continuing observations will provide more detailed information on the performance of trees and pastures in VBSs. Thirdly, there is an need to determine the appropriate dimensions of VBSs under conditions for regions throughout Australia, but particularly for Northern Tablelands. Fourthly, modelling study needs to describe and predict the performance of VBSs and to help in the design of VBSs. Finally, cost-effectiveness studies of VBSs need be conducted particularly to ensure VBSs are both ecologically and economically viable.

7.6. Conclusion

1. In the field experiment, the survival and height growth rates for both *E. camaldulensis* and *C. cunninghamiana* were high in comparison with the results from the same region, although they were damaged, respectively, by frost and by rabbit/hare browsing to some extent. At the end of the third growing season, *C. cunninghamiana* was significantly taller than *E. camaldulensis*, but the crown cover of *E. camaldulensis* was significantly greater than that of *C. cunninghamiana*. The planting density treatment had no significant effect on height growth for the both species, while the high stocking rate plots had significantly larger crown cover and greater basal area in comparison with the lower stocking rate. The pasture started growth earlier in spring and ended growth later in autumn than the trees when the soil moisture conditions were not limiting. Both tree species, however, could tolerate very dry condition compared with the pasture.

2. Water deficit and water use among the tree treatments was not significantly different over the first three growing seasons. The improved pastures generally had larger water deficit than the tree plantation at this stage of development. However, water use by pastures, in comparison with plantations, was more dependent on soil moisture conditions, growing seasons, and management.

3. The tree and pasture treatments did not produce significant effects on water tables beneath the experimental zone and in the strips immediately above and below the plantation zone. Using soil water storage as an indicator, trees and pastures did not show a significant effect on intercepting lateral groundwater flow overall at this stage of development.

4. The results from the field experiment showed that tree and pasture treatments did not significantly affect the interception of lateral NO_3-N and PO_4-P movement at this stage of growth and development. The different tree treatments also did not show significant difference in reducing lateral nutrient movement. However, the analysis of soil N and P balance shows that improved pastures may take up and remove N and P more efficiently than trees at this stage provided that proper management, such as harvesting on time, is adopted.

5. In the glasshouse experiment, *C. cunninghamiana* had higher growth rates in diameter and total biomass in comparison with *E. camaldulensis*. The growth of *E.*

camaldulensis was affected by the density treatments more than *C. cunninghamiana*. *E. camaldulensis* had more roots penetrated into the soil B horizon than *C. cunninghamiana*, while *C. cunninghamiana* had more fine roots in the surface soil than *E. camaldulensis*, which reflects the rooting habit of both species.

6. In the glasshouse experiment, trees used more water than the pasture plots by about 40%, while the water used among the tree treatments was not significantly different. This suggests that the trees in the field may use significantly more water than pasture when the trees develop in the field to occupy the site both in terms of roots and crown.

7. In the glasshouse experiment, trees effectively removed NO_3-N, but not PO_4-P, associated with soil A-B interface flow. NO_3-N reduction was not significantly different between trees and pastures and among the tree treatments. However, the pastures took up and accumulated NO_3-N more efficiently than the trees. The average rates of N and P accumulation were 0.79 and 0.10 g plot^{-1} month^{-1} for the tree plots respectively, while the rates were 2.01 and 0.23 g plot^{-1} month^{-1} for the pasture plots. The experiment also showed that the efficiency of NO_3-N removal by trees was greater when NO_3-N concentration in soil solution was higher in the soil under the experimental conditions

References

Addiscott, T. (1996). A critical review of the value of buffer zone environments as a pollution control toll. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Alexandra, J.(1991). The role of trees in the sustainable management of irrigated land. In: Heuperman, A.F. (ed.), Trees as a tool for resource management in irrigation areas. Tatura, Victoria, Australia: Department of Agriculture, Victoria. pp. 83-102.

Anderson, J.E., Nowak, R.S., Ratzlaff, T.D., & Mrkham, O.D. (1993). Managing soil moisture on waste burial sites in arid regions. *Journal of Environmental Quality, 22,* 62-69.

Arora, K., Mickelson, S.K., & Baker, J.L. (1995). Evaluating vegetative buffer strips for berbicide retention. American Society of Agricultural Engineers. No: 95-2699.

Attiwill, P.M., & Leeper, G.W. (1987). *Forest soil and nutrient cycles.* Melbourne, Australia: Melbourne University Press.

Aull, G.H., Loudon, T.L., & Gerrish, J.B. (1980). Runoff quality enhancement with a vegetated buffer. American Society of Agricultural Engineers. No: 80-2538.

Awe, J.O., Shepherd, K.R., & Florence, R.G. (1976). Root Development in Provenances of *Eucalyptus camaldulensis* Dehn. *Australian Forestry, 39,* (3) 201-209.

Baker, T.G., Dyck, W.J., Barton, P.G., Oliver, G.R., & Nicholson, G. (1990). Effect of irrigation with sewage effluent on decomposition of litter in *Pinus radiata* forests. *Forest Ecology and Management, 31,* 205-214.

Barfield, B.J., Tollner, E.W., & Hayes, J.C. (1979). Filtration of sediment by simulated vegetation I. steady-state flow with homogeneous sediment. *Transactions of the American Society of Agricultural Engineers, 22,* (3) 540-548.

Barling, R.D., & Moore, I.D. (1994). Role of buffer strips in management of waterway pollution: a review. *Environmental Management, 18,* (4) 543-558.

Bell, D.T., van der Moezel, P.G., Bennett, I.J., McComb, J.A., Wilkins, C.F., Marshall, S.C.B., & Morgan, A.L. (1993). Comparison of growth of *Eucalyptus camaldulensis* from seeds and tissue culture: root, shoot and morphology of 9-month-old plants grown in deep sand and sand over clay. *Forest Ecology and Management, 57,* 125-139.

Bendixen, T.W., Hill, R.D., DuByne, F.T., & Robeck, G.G. (1969). Cannery waste treatment by spray irrigation-runoff. *J. WPCF, 41,* 385-391.

Bennett, B. (1993). Green forests and clean rivers - smart sewage use on trial at Wagga. *ECOS, 77,* 14-17.

Bingham, S.C., Westerman, P.W., & Overcash, M.R. (1980). Effect of grass buffer zone length in reducing the pollution from land application areas. *Transactions of the American Society of Agricultural Engineeers, 23,* 330-335.

Black, S.A., Graveland, D.N., Nicholaichuck, W., Smith, D.W., Tobin, R.S., Webber, M.D., & Bridle, T.R. (1984). Manual for land application of treated municipal wastewater and sludge. Environmental Protection Service, Environment Canada.

Boardman, R.(1991). Impacts on planted trees and soils of re-using effluents and waste water in Australian Environments-a review. In: Ryan, P.J. (ed.), Third Australian Forest Soil and Nutrition Conference: Productivity in perspective. Forestry Commission of NSW, Sydney, Australia. pp. 87-106.

Boland, D., Brooker, M.I.H., Chippendale, G.M., Hall, N., HyLand, B.P.M., Johnston, R.D., Kleinig, D.A., & Turner, J.D. (1984). *Forest trees of Australia.* Melbourne: Nelson-CSIRO.

Bolger, P.(1991). Modeling the effect of trees on watertables. In: Heuperman, A.F. (ed.), Trees as a tool for resource management in irrigation areas. Department of Agriculture, Victoria, Australia. pp. 46-58.

Booth, T.H., & Pryor, L.D. (1991). Climatic requirements of some commercially important eucalypt species. *Forest Ecology and Management, 43,* 47-60.

Borg, H., Hordcare, A., & Batini, F. (1988). Effects of logging in stream and river buffers on watercourses and water quality in the southern forest of Western Australia. *Australian Forestry, 51,* 98-105.

Bosch, D.D., Hubbard, R.K., West, L.T., & Lowrance, R.R. (1994). Subsurface flow patterns in a riparian buffer system. *Transactions of the American Society of Agricultural Engineers, 37,* (6) 1783-1790.

Bray, R.H., & Kurtz, L.T. (1945). Determination of total organic and available forms of phosphorus in soil. *Soil Science, 59,* 39-45.

Bremner, J.M. (1965). Inorganic forms of nitrogen. In: Black, C.A. (Ed.), *Methods of soil analysis, Part 2: Chemical and Microbiological properties.* USA: American Society of Agronomy, Inc. Publisher.

Bren, L.J. and Turner, A.K. (1980). Hydrologic output of small catchment: Implication for management. *Australian Forestry. 43,* 111-117.

Brinson, M.M. (1993). Changes in the functioning of wetlands along environmental gradients. *Wetlands, 13,* 65-74.

Burgoon, P.S., Reddy, K.R., DeBusk, T.A., & Koopman, B. (1991). Vegetated submerged beds with artificial substrates. II: N and P removal. *Journal of Environmental Engineering, 117,* (4) 409-424.

Burton, J.R. (1993). The Hydrology of 'Tullimba'. Department of Resource Engineering, The University of New England, Armidale, NSW. pp. 1-12.

Burton, J.R. (1993). Engineering properties of Tullimba soils. Environmental Impact Statement for the Proposed Cattle and Beef Industry CRC for Meat Quality Research Facility, Appendix 4. pp. 1-33.

Cameron, A.L., & Henderson, L.E. (1979). *Environmental considerations for forest harvesting.* CSIRO Division Forest Research, Harvesting Research Group. Canberra, Australia:

Campell, C.A. (1990). Protection from grazing. In: Cremer, K.W. (Ed.), *Trees for rural Australia.* Sydney and Melbourne: Inkata Press. pp. 183-198.

Chaubey, I., Edwards, D.R., Daniel, T.C., Moore, J.P.A., & Nichols, D.J. (1994). Effectiveness of vegetative filter strips in retaining surface-applied swine manure constituents. *Transactions of the American Society of Agricultural Engineers, 37,* (3) 845-850.

Chaubey, I., Edwards, D.R., Daniel, T.C., & Nichols, D.J. (1993). Effectiveness of vegetative filter strips in controlling losses of surface-applied poultry litter constituents. American Society of Agricultural Engineers. No: 93-2011,

Clinick, P.F. (1985). Buffer strip management in forest in forest operations: a review. *Australian Forestry, 48,* (1) 34-44.

Collett, I.J. (1993). 'Tullimba' cattle research facility agronomic assessment. NSW Agriculture. pp. 1-27.

Colletti, J.R. Schultz, R.C. Mize, C.W. Hall, R.B. and Twarok C.J. (1991). An Iowa demonstration of agroforestry: short-rotation woody crops. For Chron 67: 258-262.

Cook, R.J. (1996). The potential impactof buffer zones in agricultural practice. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Cooper, A.B. (1990). Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. *Hydrobiologia, 202,* 13-26.

Cooper, J.R., & Gilliam, J.W. (1987). Phosphorus redistribution from cultivated fields into riparian areas. *Soil Science Society of American Journal, 51,* 1600-1604.

Cooper, J.R., Gilliam, J.W., Daniels, R.B., & Robarge, W.P. (1987). Riparian Areas as filter for agricultural sediment. *Soil Science Society of American Journal, 51,* 416-420.

Correll, D.L. (1996). Buffer zones and water quality protection: general principles. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.), Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Crane, W.J.B. and Myers, B.J.(1991). Optimising nutrient fixation in effluent irrigated forests. In: Ryan, P.J. (ed.), Third Australian soil and nutrition conference: productivity in perspective. Forestry Commission of NSW, Sydney, Australia. pp. 114-115.

Cremer, K.W. (1990a). Frost. In: Cremer, K.W. (Ed.), *Trees for rural Australia.* Sydney and Melbourne: Inkata Press. pp. 217-224.

Cremer, K.W. (1990b). *Trees for rural Australia.* Melbourne and Sydney: Inkata Press.

Cromer, R.N., Cameron, D.M., Cameron, J.N., Flinn, D.W., Neilsen, W.A., Raupach, M., Snowdon, P., & Waring, H.d. (1981). Response of eucalypt species to fertiliser applied soon after planting at several sites. *Australian Forestry, 44,* (1) 3-13.

Cromer, R.N., Tompkins, D., & Barr, N.J. (1982). Irrigation of *Pinus radiata* with wastewater: tree growth in response to treatment. *Australian Forestry Research, 13,* 57-65.

Crownover, S.H., Comerford, N.B., Neary, D.G., & Montgomery, J. (1995). Horizontal groundwater flow pattern through a cypress swamp-pine. *Soil Science Society of American Journal, 59,* 1199-1206.

Cullen, P. (1991). Land use and declining water quality. *Australian Journal of Soil and Water Conservation, 4,* (3) 4-8.

Curtis, D. (1989). Eucalypt re-establishment on the Northern Tablelands of New South Wales. Msc. thesis. The University of New England, Armidale, Australia.

Curtis, D. (1991). Farm trees on the Northern Tablelands - the next decade. *Australian Journal of Soil and Water Conservation, 4,* (4) 9-14.

Delgado, A.N., Periago, E.L., & Viqueira, F.D. (1995). Vegetated filter strips for water purification: A review. *Bioresource Technology, 51,* 13-22.

Delgado, M.A., Dillaha, T.A., Gilliam, J.W., Bouraoui, F., & Parsons, J.E. (1992). Nitrogen transport and cycling in vegetative filter strips. American Society of Agricultural Engineers. No: 92-2624.

Devito, K.J., & Dillon, P.J. (1993). The influence of hydrologic condition and peat oxia on the phosphorus and nitrogen dynamics of a conifer swamp. *Water Resource Research, 29,* 2675-2685.

Diaz-Fierros, F., Nunez, A., & Lopez, E. (1990). Risk of water contamination by superficial runoff resulting from the spreading of cattle slurry. INRA Editions. pp. 482-486.

Dickson, B.C. and Schaeffer, D.J. (1996). Ecorestoration of riparian forests for non-point source pollution control: policy and ecological consideration in agroecosystem watersheds. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Dickey, E.C., & Vaderholm, D.H. (1981). Vegetative Filter treatment of livestock feedlot runoff. *Journal of Environmental Quality, 10,* (3) 279-284.

Dillaha, T.A. (1989). Water quality impacts of vegetative filter strips. American Society of Agricultural Engineers. No: 89-2043.

Dillaha, T.A., & Hayes, J.C. (1992). Vegetative filter strips: II. Application of design procedures. American Society of Agricultural Engineers. No: 92-2103.

Dillaha, T.A. and Inamdar, S.P. (1996). Buffer zones as sediment traps or sources. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Dillaha, T.A., Reneau, R.B., Mostaghimi, S., & Lee, D. (1989). Vegetative filter strips for Agricultural non-point source pollution control. *Transactions of the American Society of Agricultural Engineers, 32,* (2) 513-519.

Dillaha, T.A., Sherrard, J.H., & Lee, D. (1986). Long-term effectiveness and maintenance of vegetative filter strips. Virginia Polytechnic Institute and State University-Virginia Water Resources Research Center. No: 153, pp. 1-39.

Dillaha, T.A., Sherrard, J.H., Lee, D., Mostaghimi, S., & Shanholtz, V.O. (1985). Sediment and phosphorus transport in vegetative filter strips: Phase I, Field studies. American Society of Agricultural Engineers. No: 85-2043.

Dillaha, T.A., Sherrard, J.H., Lee, D., Mostaghimi, S., & Shanholtz, V.O. (1988). Evaluation of vegetative filer strips as a best management practice for feed lots. *Journal of Water Pollution Control in feedlots, 60,* 1231-1238.

Downes, M.T., Howard-Williams, C. and Schipper, L.A. (1996). Long and short roads to riparian zone restoration: nitrogen removal efficiency. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Doyle, R.C., Stanton, G.C., & Wolf, D.C. (1977). Effectiveness of forest and grass filters in improving the water quality of manure polluted runoff. American Society of Agricultural Engineers. No: 77-2501.

Doyle, R.C., Wolf, D.C., & Bezdicek, D.F. (1974). Effectiveness of forest buffer strips in improving the water quality of manure polluted runoff. American Society of Agricultural Engineers, St Joseph. pp. 299-302.

Droste, R.L. (1997). Theory and practice of water and wastewater treatment. John Wiley and Son. New York.

Edwards, W.M., Owens, L.B., & White, R.K. (1983). Managing runoff from a small, paved beef feedlots. *Journal of Environmental Quality, 12,* (2) 281-286.

Emmett, B.A., Hudson, P.A., & Reynolds, B. (1994). The impact of a riparian wetland on stream water quality in a recently afforested upland catchment. *Journal of Hydrology, 162,* 337-357.

Fagg, P.C., & Cremer, K.W. (1990). Weed control and water conservation. In: Creamer, K.W. (Ed.), *Trees for rural Australia.* Melbourne and Sydney: Inkata Press. pp. 161-182.

Fail, J.H., Hamzah, M.N., Haines, B.L. and Todd, R.L. (1986) Above and below ground biomass, production, and element accumulation in riparian forests of an agricultural watershed. In: Correll, D.L. (Ed.), *Watershed research perspectives*. Smithsonian Press, Wash. DC, pp. 193-224.

Farrington, P., Greenwood, E.A.N., Bartle, G.A., Beresford, J.D., & Watson, G.D. (1989). Evaporation from *Banksia* woodland on a groundwater mound. *Journal of Hydrology, 105,* 173-186.

Farrington, P., Salama, R.B., Watson, G.D., & Bartle, G.A. (1992). Water use of agricultural and native plants in a western Australian wheatbelt catchment. *Agricultural Water Management, 22,* 357-367.

Finlayson, B.L. and Wong, N.R. (1982). Storm runoff and water quality in an undisturbed forested catchment. *Australian Forestry Research. 12,* 303-315.

Fleischer, S., Joelsson, A. and Stibe, L. (1996). The potential role of ponds as buffer zones. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Foster, A. (1996). Function and Design of vegetation filter strips: an annotated bibliography. Texas State Soil and Water Conservation Board, Texas, USA.

Gillespie, A.R., Miller, B.K., & Johnson, K.D. (1995). Effects of ground cover on tree survival and growth in filter strips of the Corn-belt Region of the Midwestern US. *Agriculture, Ecosystems and Environment, 53,* 263-270.

Gough, S.C. (1988). Stream water quality protection using vegetated filter strips: structure and function related to sediment control. University of Missouri, Columbia, USA.

Grayson, R.B., Finlayson, B.L.., Jayasuriya, M.D.A.., & O'Shaughnessy, P.J.. (1992). The effects of a clear-felling and harvesting operation on the quality of stream flow from a mountain ash forest. Land and Water Resources Research and Development Corporation.

Greacen, E.L. (1981). *Soil water assessment by the neutron method.* CSIRO, Australia.

Greacen, E.L., Correll, R.L., Cunnigham, R.B., Johns, G.G., & Nicoils, K.D. (1981). Calibration. In: Greacen, E.L. (Ed.), Soil water assessment by the neutron method. CSIRO, Adelaide, Australia. pp. 50-81.

Greene, G. (1993). A meteorological data assessment for the Tullimba feedlot. Department of Resource Engineering, University of New England, Armidale, Australia. pp. 1-15.

Greenwood, E.A.N., Biddiscombe, E.F., Rogers, A.L., Beresford, J.D., & Watson, G.D. (1994). The influence on groundwater levels and salinity of a multi-species tree plantation in the 500 mm rainfall region of south-western Australia. *Agricultural Water Management, 25,* 185-200.

Greenwood, E.A.N., Klein, L., Beresford, J.D., & Watson, G.D. (1985). Difference in annual evaporation between grazed pasture and Eucalyptus species in plantations on a saline farm catchment. *Journal of Hydrology, 78,* 261-278.

Greenwood, E.A.N., Milligan, A., Biddiscombe, E.F., Rogers, A.L., Beresford, J.D., Watson, G.D., & Wright, K.D. (1992). Hydrologic and salinity changes associated with tree plantation in a saline agricultural catchment in southwestern Australia. *Agricultural Water Management, 22,* 307-323.

Gregory, P.J., McGowan, M., & Biscoe, P.V. (1978). Water relations of winter wheat 2. Soil water relation. *Journal of Agricultural Science*, 91, 103-116.

Gregory, S.V., Svanson, F.J., Mckee, W.A., & Cummins, K.W. (1991). An ecosystem perspective of riparian zones. *Bioscience, 41*, 540-551.

Groffman, P.M., Axelrod, E.A., Lemunyon, J.L., & Sullivan, W.M. (1991). Denitrification in grass and forest filter strips. *Journal of Environmental Quality, 20*, (3) 671-674.

Groffman, P.M., Gold, A.J., & Simmons, R.C. (1992). Nitrate dynamics in riparian forests: microbial studies. *Journal of Environmental Quality, 21*, 666-671.

Hairsin, P. (1996). Comparing grass filter strips and near-natural riparian zones for trapping sediment and sorbed nutrients. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Hairsine, P., & Prosser, I. (1997). Reducing erosion and nutrient loss with perennial grasses. *Australian Journal of Soil and Water Conservation, 10*, (1) 8-14.

Harris, A.R. (1983). Changes in a sandy forest soil under northern hardwoods after 5 years of sewage effluent irrigation. *Soil Science Society of American Journal, 47,* 800-805.

Haycock, N.E., & Burt, T.P. (1993). Role of floodplain sediments in reducing the nitrate concentration of subsurface runoff: a case study in the Cotswolds, UK. *Hydrological processes, 7,* 287-295.

Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (1996). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Haycock, N.E., & Pinary, G. (1993). Groundwater nitrate dynamics in grass and poplar vegetated riparian buffer strips during the winter. *Journal of Environmental Quality, 22,* (2) 273-278.

Hayes, J.C., & Dillaha, T.A. (1992). Vegetative filter strips: I. Site suitability and procedures. American Society of Agricultural Engineers. No: 92-2102.

Heuperman, A.F.(1991). Overview of potential benefits and problems associated with the growing of trees in irrigation areas. In: Heuperman, A.F. (ed.), Trees as a tool for resource management in irrigation areas. Tatura, Victoria, Australia: Department of Agriculture, Victoria. pp. 2-6.

Heuperman, A.F., Stewart, H.T.L., & Wildes, R.A. (1984). The effect of eucalypts on water table in an irrigation area of northern Victoria. *Water Talk, 52,* 4-8.

Hill, A.R. (1991). A groundwater nitrogen budget for a headwater swamp in an area of permanent groundwater discharge. *Biogeochemistry, 14,* 209-224.

Hill, A.R. (1996). Nitrate removal in stream riparian zones. *Journal of Environmental Quality, 25,* 743-755.

Honeysett, J.L., Beadle, C.L., & Thorburn, P.J. (1992). Evapotranspiration and growth of two contrasting species of eucalypts under non-limiting and limiting availability. *Forest Ecology and Management, 50,* 203-216.

Honeysett, J.L., White, D.A., Worledge, D., & Beadle, C.L. (1996). Growth and water use of *Eucalyptus globulus* and *E. nitens* in irrigated and rainfed plantations. *Australian Forestry, 59,* (2) 64-73.

Hook, J.E., & Kardos, L.T. (1978). Nitrate leaching during long-term spray irrigation for treatment of secondary sewage effluent on woodland sites. *Journal of Environmental Quality, 7,* (1) 30-34.

Hubbard, R.K., & Sheridan, J.M. (1983). Water and nitrite-nitrogen losses from a small, upland, coastal plain watershed. *Journal of Environmental Quality, 12,* (2) 291-295.

Hubbard, R.K., Vellidis, G., Lowrance, R.R., Davis, J.G., & Newton, G.L. (1999). Using riparian buffers to treat animal waste. In: Anonymous, *Animal Waste and the Land-water Interface.* Florida, USA: Boca Raton. pp. 127-134.

Iowa State Agroforestry Research Team. (1994). Multiple benefits from constructed multi-species riparian buffer strips (CMRBS). Iowa State Agroforestry Research Team, Iowa, USA.

Jacks, G., Joelsson, A., & Fleischer, S. (1994). Nitrogen detention in forested wetlands. *Ambio, 23,* 358-362.

Jacobs, M.R. (1955). Growth habits of the eucalypts. Comm. Govt. Printer, Canberra, Australia. 262 pp.

Jacobs, T.C., & Gilliam, J.W. (1985). Riparian Losses of nitrate from agricultural drainage waters. *Journal of Environmental Quality, 14,* (4) 472-478.

Johnson, K.(1984). Introduction. In: Off-river disposal of treated sewage effluent to reduce nutrient levels in the River Murry. River Murry Commission, Wodonga, Victoria, Australia. pp. 1-2.

Jones, B.E. (1997). 'Talking trees' a study of information networks and tree planting performance in a New England landcare group. M. Sc. thesis. University of New England, Armidale, Australia.

Jordan, T.E., Correll, D.L., & Weller, D.E. (1993). Nutrient interception by a riparian forest receiving inputs from adjacent cropland. *Journal of Environmental Quality, 22,* 467-473.

Kumar, R., Ambasht, R.S., & Srivastava, N.K. (1992). Conservation efficiency of five common riparian weeds in movement of soil, water and phosphorus. *Journal of Applied Ecology, 29,* 737-744.

Lawrie, R. (1993). Soil of proposed beef cattle CRC, 'Tullimba'. NSW Agriculture. pp. 1-12.

Lee, D., Dillaha, T.A., & Sherrard, J.H. (1989). Modeling phosphorus transport in grass buffer strips. *Journal of Environmental Engineering, 115,* (2) 409-427.

Leeds, R.P., Brown, L.C., Sulc, M.R., & VanLiehout, L. (1993). Vegetative filter strips: application, installation and maintenance. In: Ohio State University Agricultural Extention Factsheet. Ohio State University, USA. No: AEX-467.

Leuning, R., Kriedemann, P.E., & McMurtrie, R.E. (1991). Simulation of evapotranspiration by trees. *Agricultural Water Management, 19,* 205-211.

Lowrance, R.R. (1992). Groundwater nitrate and denitrification in a coastal plain riparian forest. *Journal of Environmental Quality, 21,* 401-405.

Lowrance, R.R., Leonard, R., & Sheridan, J.M. (1985). Managing riparian ecosystems to control non-point pollution. *Journal of Soil and Water Conservation,* (1) 87-91.

Lowrance, R.R., Todd, R.L., & Asmussen, L. (1983). Waterborne nutrient budgets for the riparian zone of an agricultural watershed. *Agriculture, Ecosystems and Environment, 10,* 371-384.

Lowrance, R.R., Todd, R.L., & Asmussen, L.E. (1984). Nutrient cycling in an agricultural watershed: I. Phreatic movement. *Journal of Environmental Quality, 13,* (1) 22-27.

Lowrence, I. (1993). Establishing nutrient targets. Algal management strategy background paper 3. Algal Management Working Group, Murray-Darling Basin commission, Australia.

LWRRDC. (1993). Reclaimed water - a valuable resource. Canberra, Australia.

Magette, W.L., Brinsfield, R.B., Palmer, R.E., & Wood, J.D. (1986). Vegetated filter strips for non-point source pollution control. American Society of Agricultural Engineers. No: 86-2024.

Magette, W.L., Brinsfield, R.B., Palmer, R.E., & Wood, J.D. (1987). Nitrogen movement to ground water and surface water from poultry litterAmerican Society of Agricultural Engineers. No: 87-2022.

Magette, W.L., Brinsfield, R.B., Palmer, R.E., & Wood, J.D. (1989). Nutrient and sediment removal by vegetated filter strips. *Transactions of the American Society of Agricultural Engineers, 32,* (2) 663-667.

Mather, R.J. (1969). An Evaluation of cannery waste disposal by overland flow spray irrigation. In: *Climatology, C.W. Thornthwaite Ass.*, XXII (2).

McGowan, M. (1974). Depth of water extraction by roots. In: Anonymous, *Isotopes and radiation techniques in soil physics and irrigation studies.* Vienna: International Atomic Energy Agency. pp. 435-445.

McGowan, M., & Williams, J.B. (1980a). The water balance of an agricultural catchment. I. Estimation of evaporation from soil water records. *Journal of Soil Science, 31,* 217-230.

McGowan, M., & Williams, J.B. (1980b). The water balance of an agricultural catchment II. Crop evaporation: seasonal and soil factors. *Journal of Soil Science, 31,* 231-244.

McIntyre, B.D., & Riha, S.J. (1991). Hydraulic conductivity and nitrogen removal in an artificial wetland system. *Journal of Environmental Quality, 20,* 259-263.

Meat Research Corporation (1996). Feedlot consistency and sustainability key program business plan. Australia. 40 pp.

Mensforth, L.J., Thorburn, P.J., Tyerman, S.D., & Walker, G.R. (1994). Sources of water used by riparian *Eucalyptus camaldulensis* overlying highly saline groundwater. *Oecologia, 100,* 21-28.

Mickelson, S.K., & Baker, J.L. (1993). Buffer strips for controlling herbicide runoff losses. American Society of Agricultural Engineers. No: 93-2084

Moore, R.M. (1970). *Australian Grasslands.* Australian National University Press, Canberra, Australia.

Morris, J.(1991). Tree water use processes and salinity management in irrigation areas. In: Heuperman, A.F. (ed.), Trees as a tool for resource management in irrigation areas. Tatura, Victoria, Australia: Department of Agriculture, Victoria. pp. 8-21.

Murphy, J., & Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural water. *Anal Chim Acta, 27,* 31-36.

Muscutt, A.D., Harris, G.L., Bailey, S.W., & Davies, D.B. (1993). Buffer zones to improve water quality: a review of their potential use in UK agriculture. *Agriculture, Ecosystems and Environment, 45,* 59-77.

Myers, B.J. (1992). Effluent loading rates for irrigated plantations - a water balance model. *Australian Forestry, 55,* 39-47.

Myers, B.J., Bond, W.J., Falkineer, R.A., O'Brien, N.D., Polglase, P.J., Smith, C.J., & Theiveyanathan, S. (1995). Effluent irrigated plantations: design and management. CSIRO Division of Forestry, CSIRO, Australia. No: 2, pp. 1-24.

Myers, B.J., & Talsma, T. (1992). Site water balance and tree water status in irrigated and fertilized stands of *Pinus radiata*. *Forest Ecology and Management, 52,* 17-42.

Myers, B.J., Theiveyanathan, S., O'Brien, N.D., & Bond, W.J. (1996). Growth and water use of *Eucalyptus Grandis* and *Pinus radiata* plantation irrigated with effluent. *Tree Physiology, 16,* 211-219.

Nelson, W.M., Gold, A.J., & Groffman, P.M. (1995). Spatial and temporal variation in groundwater nitrate removal in a riparian forest. *Journal of Environmental Quality, 24,* 691-699.

Northcote, K.H., Hubble, G.D., Isbell, R.F., Thompson, C.H. & Bettenay, E. (1975). A description of Australian soils. CSIRO, Melbourne, Vic., pp. 170.

Nothcote, K.H. (1979). *A factual key for the recognition of Australian soils.* Rellim Technical Publications, Adelaide, Australia.

Nutter, W.L. (1986). Future direction: forest wastewater application. In: Cole, D.W., Henry, C.L., & Nutter, W.L. (Eds.), *The forest alternative for treatment and utilization of municipal and industrial wastes.* University of Washgton Press, . Seattle and London. pp. 55-109.

O'Loughlin, E.M., Short, D.L. and Dawes, W.R. (1989). Modelling the hydrological responses of catchment to land use change. In: Hydrology and water resources symposium, Christchurch, New Zealand. The Institution of Engineers, Australia. National Conference Publication No. 89/19.

O'Neil, G.J., & Gordon, A.M. (1994). The nitrogen filtering capability of Carolina poplar in an artificial riparian zone. *Journal of Environmental Quality, 23,* 1218-1223.

Ormenik, J.M., Abernathy, A.R., & Male, L.M. (1981). Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. *Journal of Soil and Water Conservation, 36,* 227-231.

Osborne, L.L., & Kovacic, D.A. (1993). Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology, 29,* 243-258.

Overcash, M.R., Bingham, S.C., & Westerman, P.W. (1981). Predicting runoff pollutant reduction in buffer zones adjacent to land treatment sites. *Transactions of the American Society of Agricultural Engineeers, 24,* (2) 430-435.

Overman, A.R., & Leseman, W.G. (1982). Soil and groundwater changes under land treatment of wastewater. *Transactions of the American Society of Agricultural Engineers,* 381-387.

Pang, Q. (1996). Simulation of effects of root and canopy properties on water flow in the soil-plant-atmosphere system. PhD thesis, University of New England, Armidale, Australia.

Parker, J.N. (1990). Provenance and the paddock tree. Paper prepared for the A.F.D.I. 1990 Biennial conference, Bunbury, WA, Australia.

Parsons, J.E., Gilliam, J.W., Dillaha, T.A., and Munoz-Carpena, R.(1995). Removal of sediment and nutrients with vegetated and riparian buffers. Clean Water-Clean Environment-21st Century Conference, Kansas City, Missouri. pp. 155-158.

Paterson, K.G., & Schnoor, J.L. (1993). Vegetative alteration of nitrate fate in unsaturated zone. *Journal of Environmental Engineering, 119,* (5) 986-993.

Peterjohn, W.T., & Correll, D.L. (1984). Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology, 65,* (5) 1456-1475.

Petersen, R.C., Petersen, L.B.M., & Lacoursiere, J. (1992). A building-block model for stream restoration. In: Boon, P.J., Calow, P., & Petts, G.E. (Eds.), *River conservation and Management.* John Wiley &Sons Ltd. USA pp. 293-309.

Phillips, J.D. (1989). An Evaluation of the factors determining the effectiveness of water quality buffer zones. *Journal of Hydrology, 107,* 133-145.

Phillips, J.D. (1989). Non-point source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology, 110,* 221-237.

Phillips, S., & Grant, I. (1994). Nutrient recycling in southern Australian agriculture. *Australian Journal of Soil and Water Conservation, 7,* 24-27.

Polglase, P.J., Myers, B.J., Theiveyanathan, S., Falkineer, R.A., Smith, C.J., O'Brien, N.D., and Bond, W.J. (1994). Growth and water and nutrient balance in the Wagga efluent plantation project. In: Recycled Water Co-ordination Committee and AWWA (ed.), Expanding reuse horizons: recycled water seminar. CSIRO, Australia. pp. 163-170.

Polglase, P.J., Tompkins, D., Stewart, L.G., & Falkineer, R.A. (1995). Mineralization and Leaching of Nitrogen in an effluent-irrigated pine plantation. *Journal of Environmental Quality, 24,* 911-920.

Prosser, I., Hairsine, P. Wilson, C. and Herron, N. (1996). The potential role of riparian buffers for improvinf water quality in Australia. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Purvis, A., Hoehn, J.P., Sorenson, V.L., & Pierce, F.J. (1989). Farmer's response to a filter strip program: results from a contingent valuation survey. *Journal of Soil and Water Conservation, 44,* (5) 501-504.

Rayment, G.E., & Higginson, F.R. (1992). *Australian laboratory handbook of soil and water chemical methods.* Melbourne and Sydney: Inkata Press.

Reid, N., Chilcott, C., & Nott, R. (1996). LWRRDC UNE 12 - Third milestone report. University of New England, Armidale, Australia. No: 12, pp. 4-7.

Riddle-Black, D., Mainstone, C.P. and Alker, G. (1996). Economical viable buffer zones-the case for short rotational forest plantations. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (ed.). Buffer Zones: their processes and potential in water protection. Quest Environmental, UK.

Robertson, W.D., Cherry, J.A., & Sudicky, E.A. (1991). Groundwater contamination from two small septic systems on sand aquifers. *Ground Water, 29,* 82-92.

Robinson, C.A., Ghaffarzadeh, M., & Cruse, R.M. (1996). Vegetative filter strip effects on sediment concentration in cropland runoff. *Journal of Soil and Water Conservation, 50,* (3) 227-230.

Salama, R.B., Bartle, G.A., & Florence, R.G. (1994). Water use of plantation *Eucalyptus camaldulensis* estimated by groundwater hydrographic separation techniques and heat pulse method. *Journal of Hydrology, 156,* 163-180.

Schnable, R.R. (1986). Nitrate concentration in a small stream as affected by chemical and hydrologic interactions in the riparian zone. In: Correll, D.L. (Ed.), *Watershed research perspectives.* Washington, DC. Smithsonian Press. pp. 263-281.

Schonau, A.P.G., & Herbert, M.A. (1989). Fertilizing Eucalyps at plantation establishment. *Forest Ecology and Management, 29,* 221-244.

Schultz, R.S., Collettii, J.P., Isenhart, T.M., Simpkins, W.W., Mize, C.W., & Thompson, M.L. (1995). Design and placement of a multi-species riparian buffer strip system. *Agricultural Systems, 29,* 201-226.

Shimp, L.F., Tracy, J.C., Davis, L.C., Lee, E., Huang, W., & Eriscson, L.E. (1993). Beneficial effects of plants in the remediation of soil and groundwater contaminated with organic materials. *Critical Reviews in Environmental Science and technology, 23,* (1) 41-47.

Simmons, R.C., Gold, A.J., & Groffman, P.M. (1992). Nitrate Dynamics in riparian forests: groundwater studies. *Journal of Environmental Quality, 21,* 659-665.

Smith, C.M. (1989). Riparian pasture retirement effects on sediment, phosphorus and nitrogen in channelised surface runoff from pastures. *N Z J Mar Freshwater Res, 23,* 139-146.

Snowdon, P., & Benson, M.L. (1992). Effects of combinations of irrigation and fertilization on the growth and above-ground biomass production of *Pinus radiata. Forest Ecology and Management, 52,* 87-116.

SSCRRA (Senate Standing Committee on Rural and Regional Affairs). (1992). Enviromental impact of feedlots. In: SSCRRA (Ed.), *Beef cattle feedlots in Australia.* Senate Printing Unit, Parliament House, Australia. pp. 67-68.

Stewart, H.T.L.(1991). Trees for effluent disposal and nutrient management. In: Heuperman, A.F. (ed.), Trees as a tool for resource management in irrigation areas. Tatura, Victoria, Australia: Department of Agriculture, Victoria. pp. 37-45.

Stewart, H.T.L., Allender, E., Sandell, P., & Kube, P. (1986). Irrigation of tree plantations with recycled water: 1. Research developments and case studies. *Australian Forestry, 49,* (2) 81-88.

Stewart, H.T.L., & Flinn, D.W. (1984). Establishment and early growth of trees irrigated with wastewater at four sites in Victoria, Australia. *Forest Ecology and Management, 8,* 243-256.

Stewart, H.T.L., Hopmans, P., & Flinn, D.W. (1990). Nutrient accumulation in trees and soil following irrigation with municipal effluent in Australia. *Environmental Pollution, 63,* 155-177.

Stogsdill, W.R., Wittwer, R.F., Hennessey, T.C., & Dougherty, P.M. (1992). Water use in thinned loblolly pine plantations. *Forest Ecology and Management, 50,* 233-245.

Tanton, M.T. (1990). Insects. In: Cremer, K.W. (Ed.), *Trees for rural Australia.* Inkata Press, Sydney and Melbourne, Australia. pp. 199-207.

Thorburn, R.G. (1995). An assessment of native tree plantings conducted by the Stonehenge/Glencoe Landcare Group on the Northern Tablelands of New South Wales. Bachelar thesis. University of New England, Armidale, Australia.

Urie, D.H. (1986). The status of wastewater irrigation of forests, 1985. In: Cole, D.W., Henry, C.L., & Nutter, W.L. (Eds.), *The forest alternative for treatment and utilizition of municipal and industrial wastes.* University of Washington Press, Seattle and London. pp. 26-41.

U.S.Department Agriculture. (1985). Agricultural statistics. Government Printing Office. USA.

USDA-Soil cccconservation Service. (1991). *National handbook of conservation practices.* USDA-SCS, Washington DC, USA.

van der Moezel, P.G., Watson, L.E., Pearce-Pinto, G.V.N., & Bell, D.T. (1988). The responses of six *Eucalyptus* species and *Casuarina obesa* to the combined effect of salinity and waterlogging. *Australian Journal of Plant Physiology, 15,* 465-474.

Verchot, L.V., Franklin, E.C., & Gilliam, J.W. (1997). Nitrogen cycling in Piedmont vegetated filter zones: I. Surface soil processes. *Journal of Environmental Quality, 26,* 327-336.

Verchot, L.V., Franklin, E.C., & Gilliam, J.W. (1997). Nitrogen cycling in Piedmont vegetated filter zones: II. Subsurfacce nitrate removal. *Journal of Environmental Quality, 26,* 337-347.

Wall, J. (1997). Sustainability of the Armidale fuelwood industry on the Northern Tablelands of New South Wales: resource yield, supply, demand and management options. PhD thesis. University of New England, Armidale, Australia.

Webster, A. (1984). Intercepting channel seepage in the Wimmera-Mallee: the use of trees and wheat grass. *Water Talk, 52,* 9-12.

Welsch, D. (1991). Riparian forest buffers-function and design for protection and enhancement of water resources. USDA-FS Pub. No. NA-PR-07-91. USDA-FS, Radnor, PA, USA.
Whalley, R.D.B., & White, G.J. (1993). Vegetation of 'Tullimba'. Department of Botany, University of New England, Armidale, Australia. pp. 1-9.

Yates, P., & Sheridan, J.M. (1983). Estimating the effectiveness of vegetated floodplains/wetlands as nitrate and orthophosphorus. *Agriculture, Ecosystems and Environment, 9,* 303-314.

Young, R.A., Huntrods, t., & Anderson, W. (1980). Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. *Journal of Environmental Quality, 9,* (3) 483-487.

Young, R.A., Otterby, M.A., & Roos, A. (1982). An evaluation system to rate feedlot pollution potential. In: Agricultural Research Service (Ed.), *Agricultural reviews mannuals*. Department of Agriculture, USA.