Chapter 4

Growth and water use by trees and pastures

4.1. Results

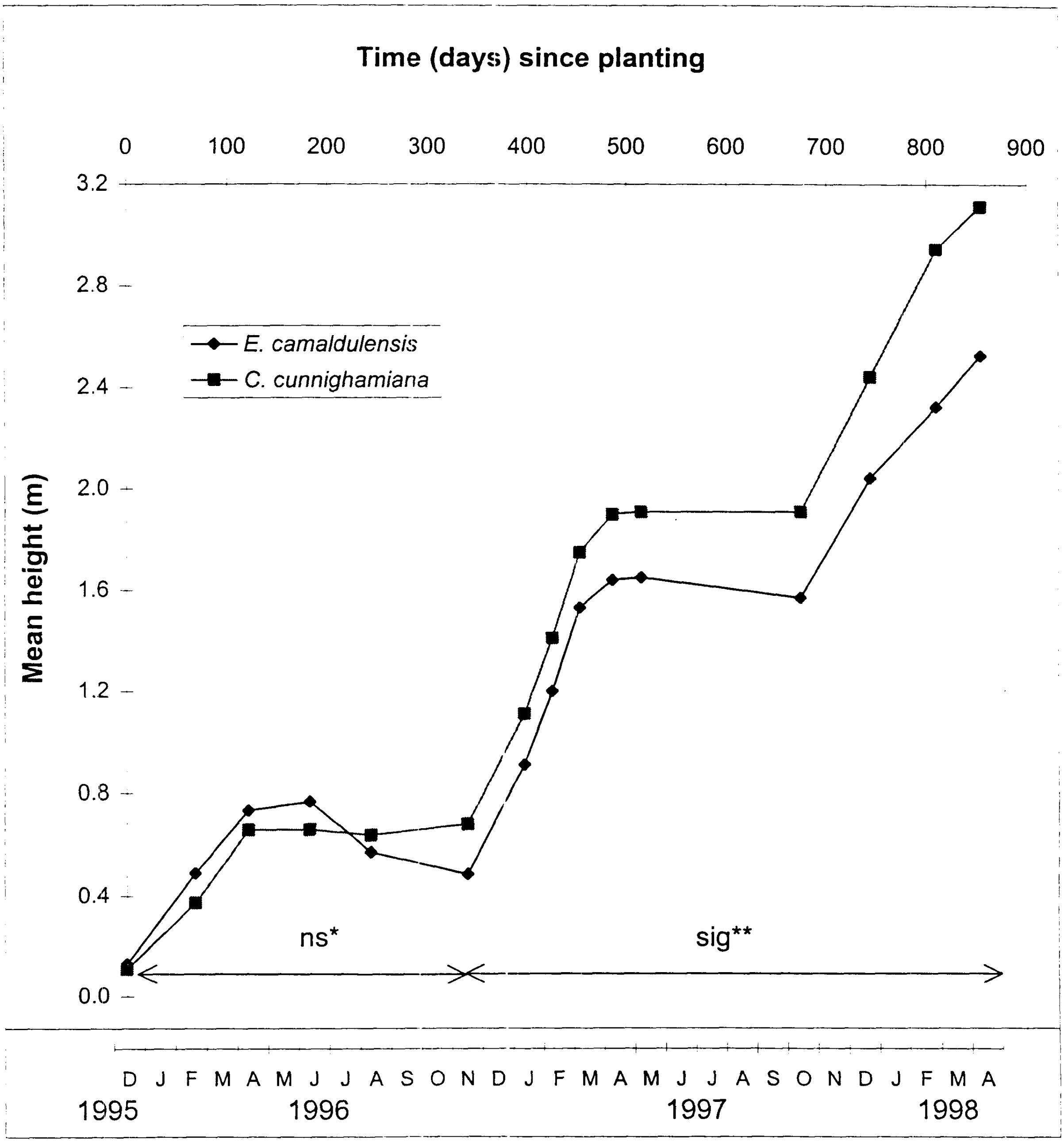
4.1.1. The survival and growth of trees and pasture

4.1.1.1. Tree survival and growth

All the *E. camaldulensis* seedlings and 97% of *C. cunninghamiana* seedlings survived at 3 months after planting. At twelve months after planting, 96% of *E. camaldulensis* and 95% of *C. cunninghamiana* survived.

Plate 2b shows the trees and pasture growing in late November 1997 before the pasture was harvested. In general, the trees grew from November to March of next year with the highest growth rates recorded during the three months of December to February (Figure 4.1). The average heights of *E. camaldulensis* and *C. cunninghamiana* reached 2.52 m and 3.11 m respectively at the end of three growing seasons (from December 1995 to April 1998). *C. cunninghamiana* was significantly ($P<0.001$) taller than *E. camaldulensis*. *E. camaldulensis* trees grew very well in the first growing season (from December 1995 to April 1996) after planting. Mean height reached 0.73 m and was higher than *C. cunninghamiana* (0.66 m), but not statistically significant. However, *E. camaldulensis* was damaged by frosts and cold temperatures in the winters of 1996. Almost all the growing tips of the trees were killed by the early frost on April 11, 1996.

The average height markedly decreased from 0.73 m to 0.49 m (Figure 4.1). This resulted in the average height of *C. cunninghamiana* becoming significantly ($P<0.001$) higher than *E. camaldulensis*. Many plants that were badly affected regrew from their lignotubers in the following spring. Frost damage to *E. camaldulensis* in 1997 winter was much lighter than in the previous winter probably because the trees were larger overall with its average height being reduced from 1.65 m to 1.57 m (Figure 4.1). *C. cunninghamiana* suffered little from the frosts and cold temperatures. However, the growth of some *C. cunninghamiana* seedlings were impeded to some extent due to rabbit and hare grazing in the first two months after planting, although continuing damage was prevented by installing netting fences in the middle of February 1996.



* ns=not significantly different; **sig=significantly different at P<0.001.

Figure 4.1. Height growth of *Eucalyptus camaldulensis* and *Casuarina cunninghamiana* during 29 months since planted.

While *E. camaldulensis* and *C. cunnighamiana* had significantly different height growth, the density treatment still had no significant effect on their height growth after three growing seasons (Figure 4.2a). The average heights were 2.47 m and 2.57 m for *E. camaldulensis* under the densities of 4 x 2 m and 4 x 3.5 m respectively. For *C. cunnighamiana* under the different densities, the average heights were 3.14 m and 3.09 m respectively.

E. camaldulensis had significantly ($P<0.01$) greater mean crown cover (27%) than *C. cunnighamiana* (18%) (Figure 4.2b). *E. camaldulensis* also had larger basal area (3.8 m^2 ha^{-1}) than *C. cunnighamiana* (3.0 m^2 ha^{-1}), but not significantly so (Figure 4.2c). The density treatment had a significant effect on the development of tree crown ($P<0.01$) (Figure 4.2b) and basal area ($P<0.05$) (Figure 4.2c) for both *E. camaldulensis* and *C. cunnighamiana*. The average crown covers were 33% and 21% for *E. camaldulensis* under the densities of 4 x 2 m (D1) and 4 x 3.5 m (D2) respectively. For *C. cunnighamiana* under the different densities, the average crown covers were 24% and 13% respectively. The average basal areas were 4.17 m^2 ha^{-1} and 3.46 m^2 ha^{-1} for *E. camaldulensis* under the densities of 4 x 2 m and 4 x 3.5 m respectively. For *C. cunnighamiana* under the different densities, the average basal areas were 3.86 m^2 ha^{-1} and 2.04 m^2 ha^{-1} respectively.

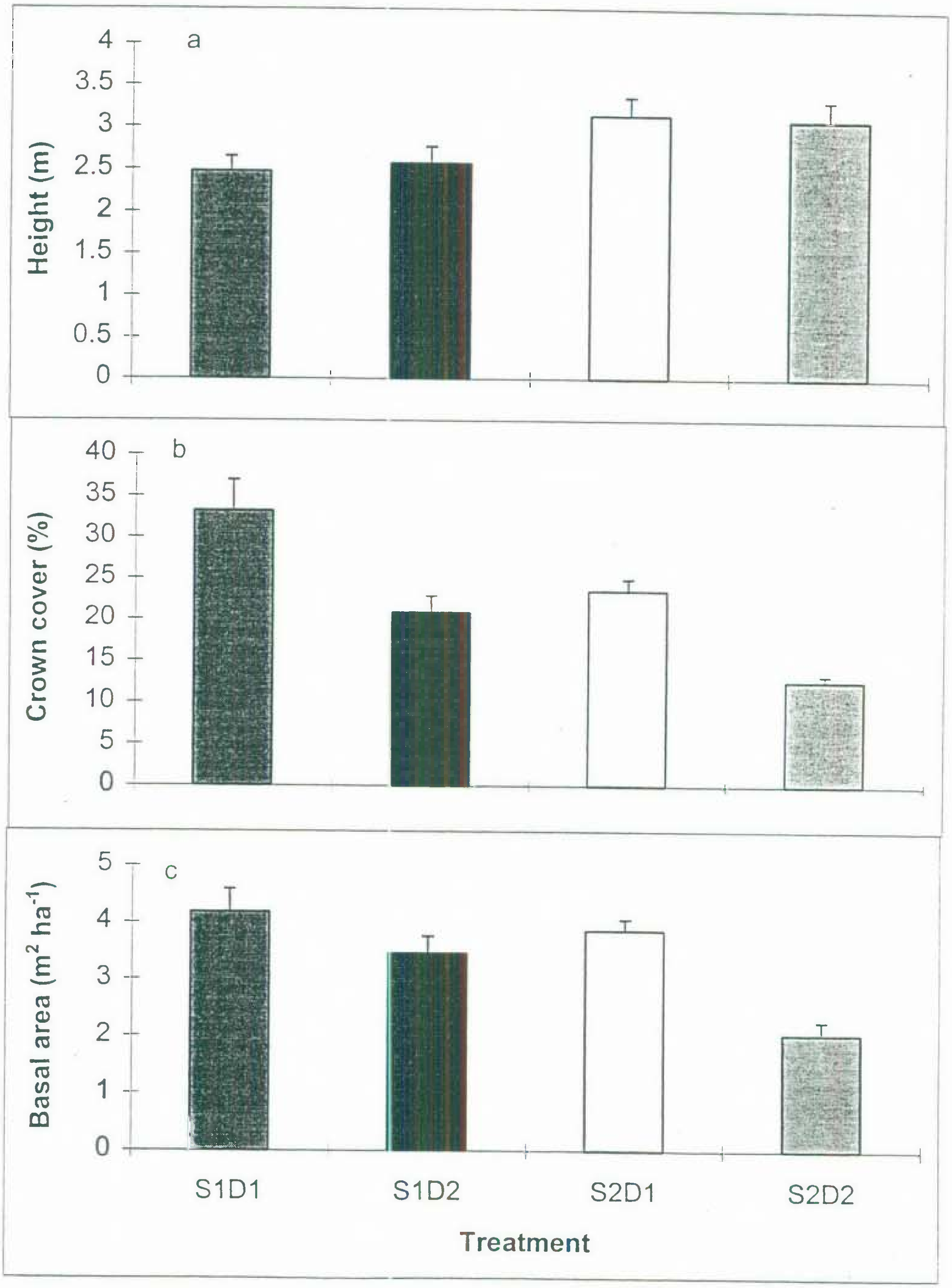


Figure 4.2. The effect of tree species and density treatments on (a) average height, (b) crown cover and (c) basal area. These growth parameters were measured in April 1998, at the end of the third growing season. Bars indicating SEM. S1=*E. camaldulensis*, S2=*C. cunninghamiana*, D1=density as 4 x 2 m, D2= density as 4 x 3.5 m.

4.1.1.2. Pasture establishment and growth

The surface of each pasture plot was entirely covered with improved pasture by May 1996 after sowing in March 1996. The pasture was green but stopped growing in the following winter. The period of growth for the pasture was some 2 months longer than that of the trees, starting to grow about 1 month earlier and stopping about 1 month later than the trees. The biomass (oven-dry matter) of the improved pasture plots and the native pasture within the plantation were 6548 kg ha^{-1} and 3170 kg ha^{-1} respectively during the growing season from September 1996 to May 1997. Drought condition prevailed from January of 1997 to March of 1998. The amount of effluent available for irrigation during that period was just enough to maintain but not to promote its growth. In fact, the pasture did not regrow after the harvest (biomass: 3087 kg ha^{-1}) in December 1997, and some species, such as clovers, failed to maintain their above ground parts.

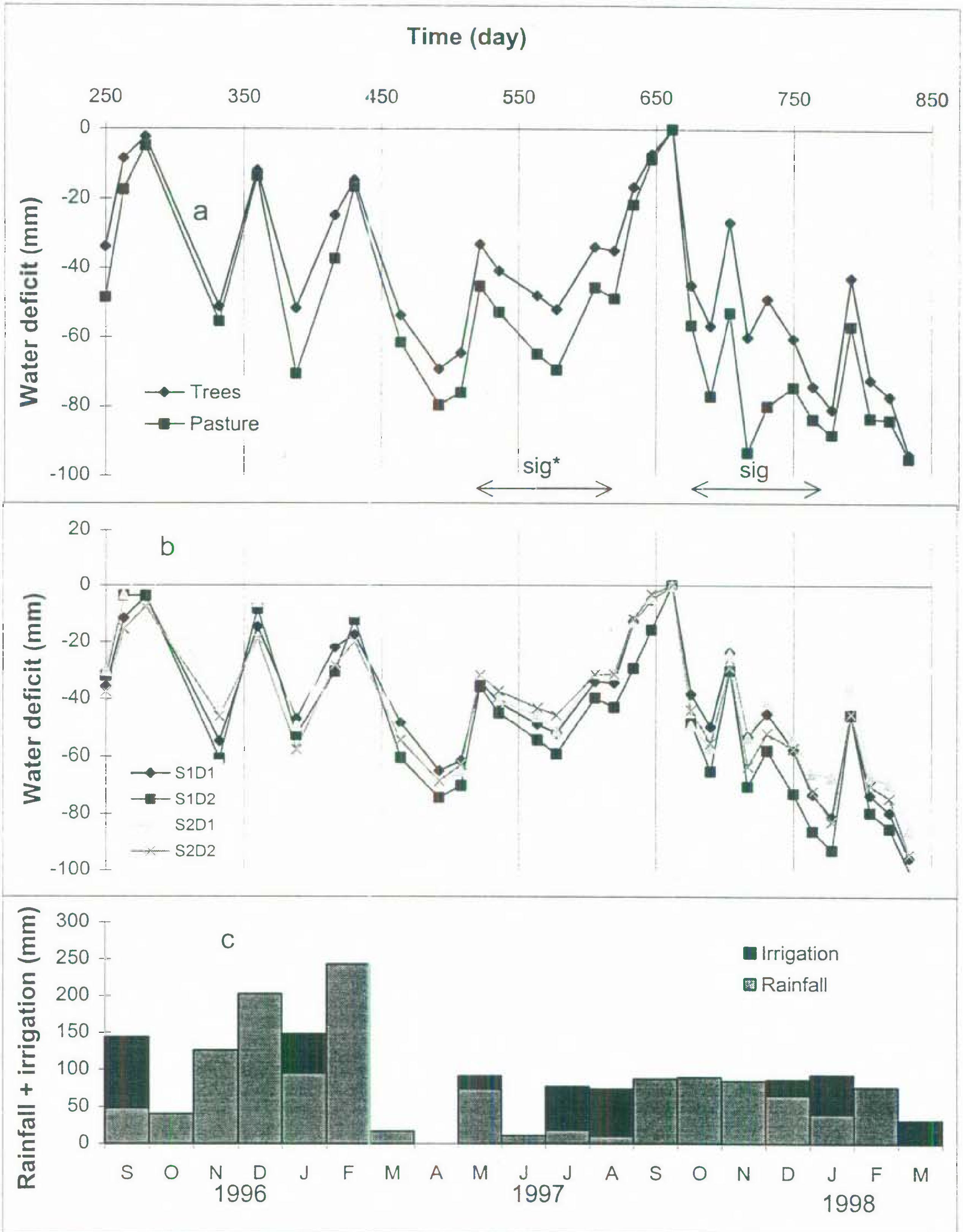
4.1.2. Water use by trees and pasture

4.1.2.1. Soil water deficit

The field capacity for each soil depth in each plot was determined using soil water content data collected on October 10, 1997, when 81 mm rainfall had occurred over the previous 3 days. Therefore, the values of water deficit at different depths for the day (October 10, 1997) were zero and deficit values for all other measurements were calculated on that basis (Figures 4.3, 4.4 and 4.5). In general, water deficit values changed depending mainly on the water input (rainfall and irrigation) (Figure 4.3). Soil water deficits under the pasture were generally larger than under the plantation (Figure

4.3a) except for the periods when soil moistures were close to or reached field capacity following heavy rainfall or irrigation (such as most time of spring and summer of 1996). These deficit differences were significant ($P<0.05$) during the 1997 winter and the period from late October 1997 through January of 1998. For example, water deficits were 51 mm and 70 mm, respectively, for the tree plantation and pasture in July 1997, and reached 60 mm and 93 mm in December that year. Water deficits were not significantly different for *E. camaldulensis* and *C. cunninghamiana* and the different density treatments (Figure 4.3b).

Figures 4.4 and 4.5 show the soil water extraction patterns for different soil depths for the pasture and tree treatments. Seasonal fluctuations in soil moisture deficits was greatest (between about 0 and 50 mm) in the upper part of the soil profile (0-30 cm depth) (Figures 4.4a and 4.5a). Soil moisture deficits in this zone were not significantly different between the tree plots and pasture plots and among the treatments.

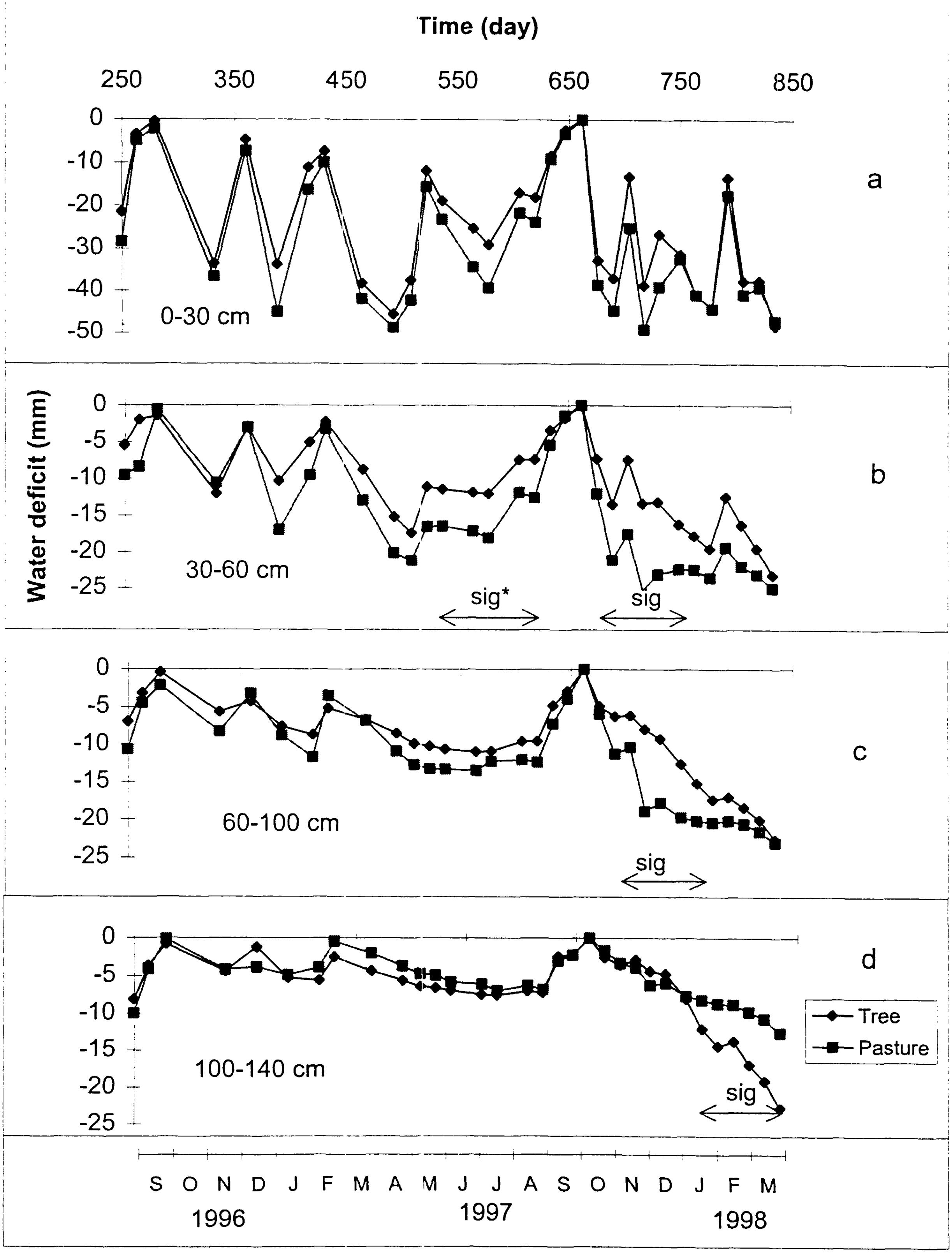


* sig=significantly different at P<0.05.

Figure 4.3. The dynamics of soil water deficit of the tree and pasture plots during the period from September 1996 to March 1998. S1=*E. camaldulensis*, S2=*C. cunninghamiana*, D1=density as 4 x 2 m, D2= density as 4 x 3.5 m.

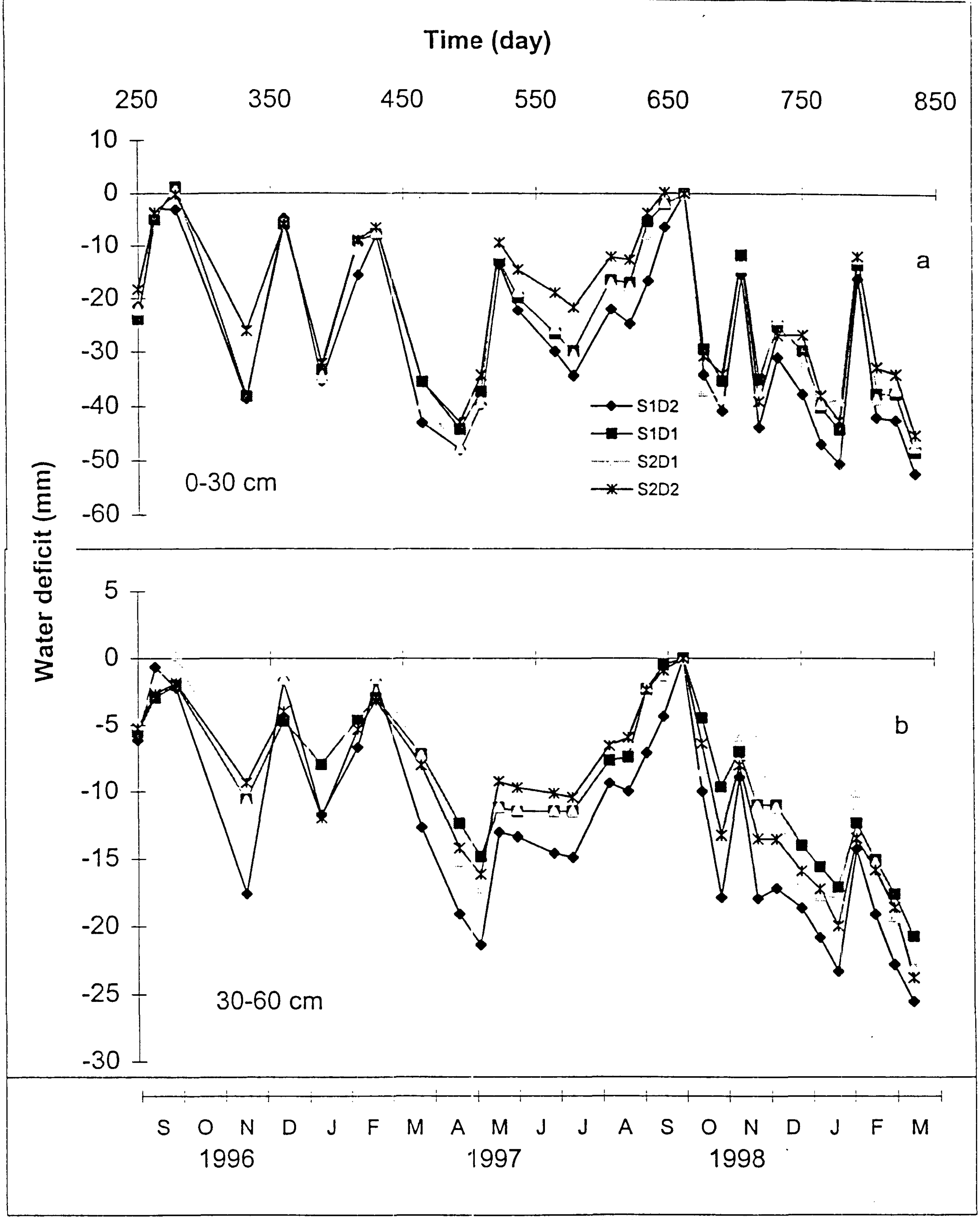
The soil water deficit patterns were similar for the zones at 30-60 cm and 60 -100 cm depth (Figures 4.4b,c). Fluctuations in deficit were between 0 and 25 mm and were much smaller than the surface of 0-30 cm zone. In general, the pasture plots had higher water deficit than the tree plots at depths of 30-60 cm and 60-100 cm. However, the differences were only significant ($P<0.05$) at the depth of 30-60 cm in the 1997 winter and in the period from late October 1997 to January 1998, and at the depth of 60-100 cm during the period from late October to December 1997 (Figure 4.4b,c). It is also interesting to note that the rate of change in water deficit was much slower for the pasture plots from December 1997 to March 1998, while the deficit for tree plots was still decreasing faster until the end of March 1998 when water deficits for both pasture and tree plots became similar. The differences in soil moisture deficit among the tree treatments (Figure 4.5b,c) was not significant in these two zones.

Water deficit patterns in the zone of 100 -140 cm (Figure 4.4d) were different from the other three zones. Although, in general, there were similar deficit values between the tree plots and the pasture at the soil depths of 100-140 cm, the values became significantly different ($P<0.01$) from late January through March 1998 (Figures 4.4d). Over this period, the mean water deficit of the tree plantation was significant higher ($P<0.05$) than that of the pasture. In addition, the rate of change in water deficit for the trees was much greater than the pasture, while the deficit for pasture was changing at a slower rate, as similar as in the zones of 30-60 cm and 60-100 cm depth. The water deficit values were not significantly different between the tree treatments in this zone (Figure 4.5d).



Note: The scale used in Figure a) is half of that in b), c) a * sig=significantly different at P<0.05.

Figure 4.4. Comparison of the soil water extraction patterns for trees and pasture at four different depths in the soil profile.



Note: The scale used in Figure a) is half of that in b), c) and d).

Figure 4.5. Water extraction patterns for the tree treatments. S1=*E. camaldulensis*, S2=*C. cunninghamiana*, D1=density as 4 x 2 m, D2= density as 4 x 3.5 m.

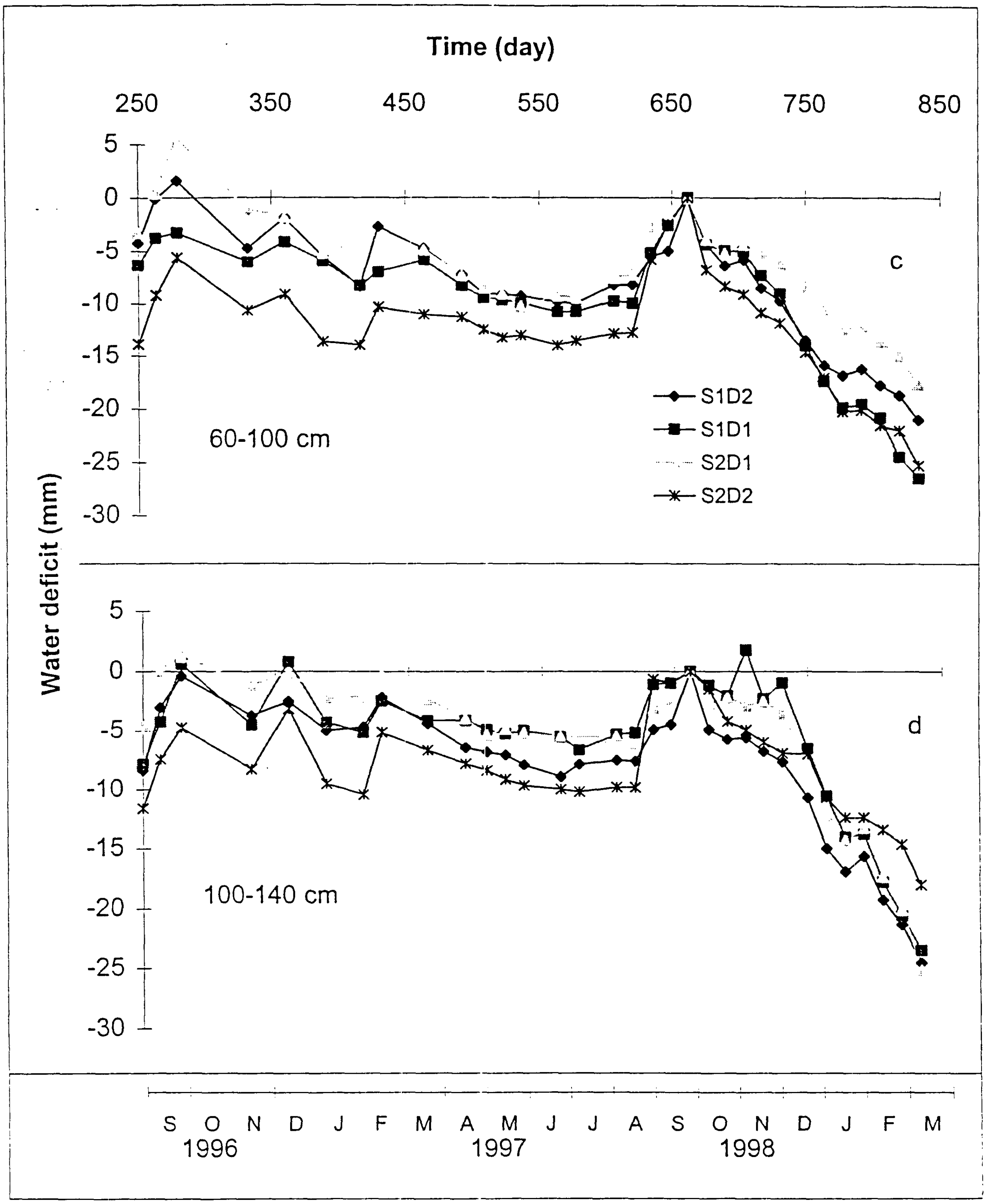


Figure 4.5. (Cont.)

4.1.2.2. Determination of the effective rooting depth

The effective rooting depth of the trees and grasses was estimated in order to separate between deep drainage and evapotranspiration for the tree and pasture plots. Graphs showing water content against time at selected measuring depths were plotted for all the 15 tree and pasture plots (Figure 4.6). The period from October 10 to February 17, 1997 was selected because the trees had reached significant size and both the trees and grasses were growing quickly during the period. Fluctuations are evident on the curves at 20 to 60 cm depths for both tree and pasture plots. Pasture plots also show fluctuations on their curves at 80 and 100 cm depth before December 4, 1997, but this is not the case for the tree plots. Figure 4.7 shows more clearly the changes in soil water content between October 10 and December 4 at the depths of 80, 100 and 120 for the pasture and tree treatments. The changes were significantly different (P<0.001) between the tree and pasture plots at depths of 80 and 100 cm, but not at 120 cm depth (Figure 4.7a), while the changes were not significantly different among the tree treatments at all the three depths (Figure 4.7b).

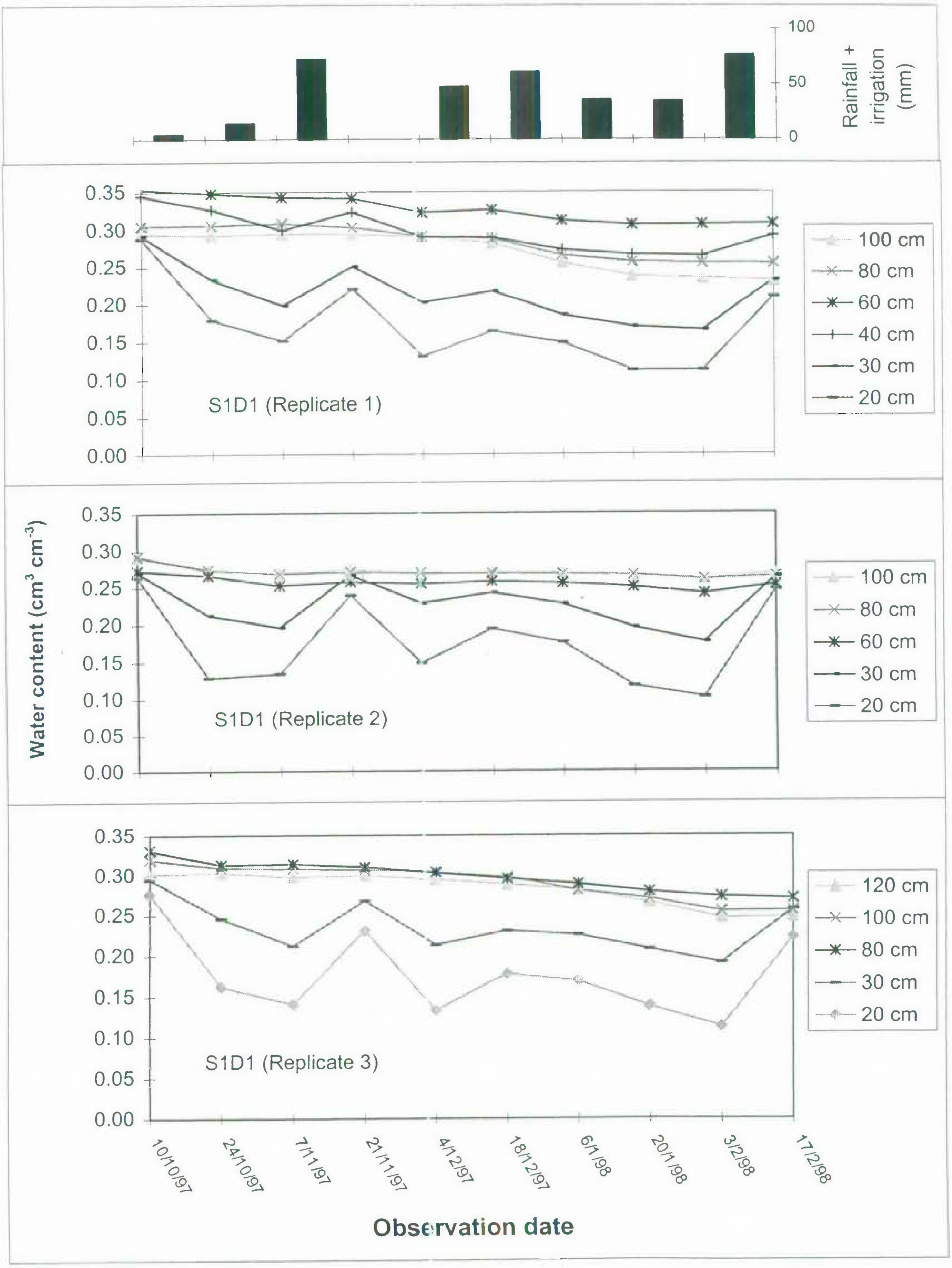


Figure 4.6. Water content against time at selected measuring depths for all the 15 tree and pasture plots to determine the effective rooting depth. S1=*E. camaldulensis*, S2=*C. cunninghamiana*, D1=density as 4 x 2 m, D2= density as 4 x 3.5 m.

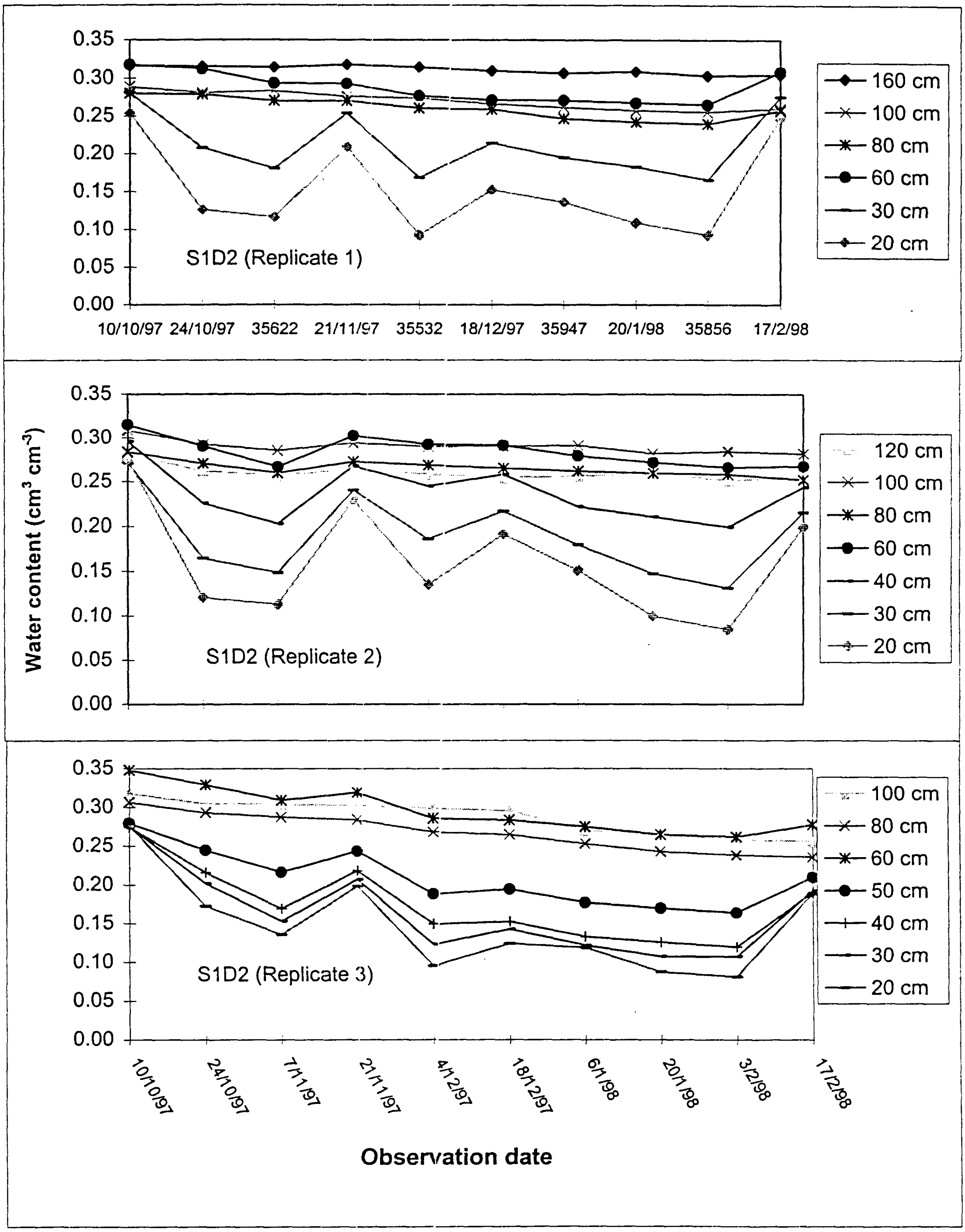
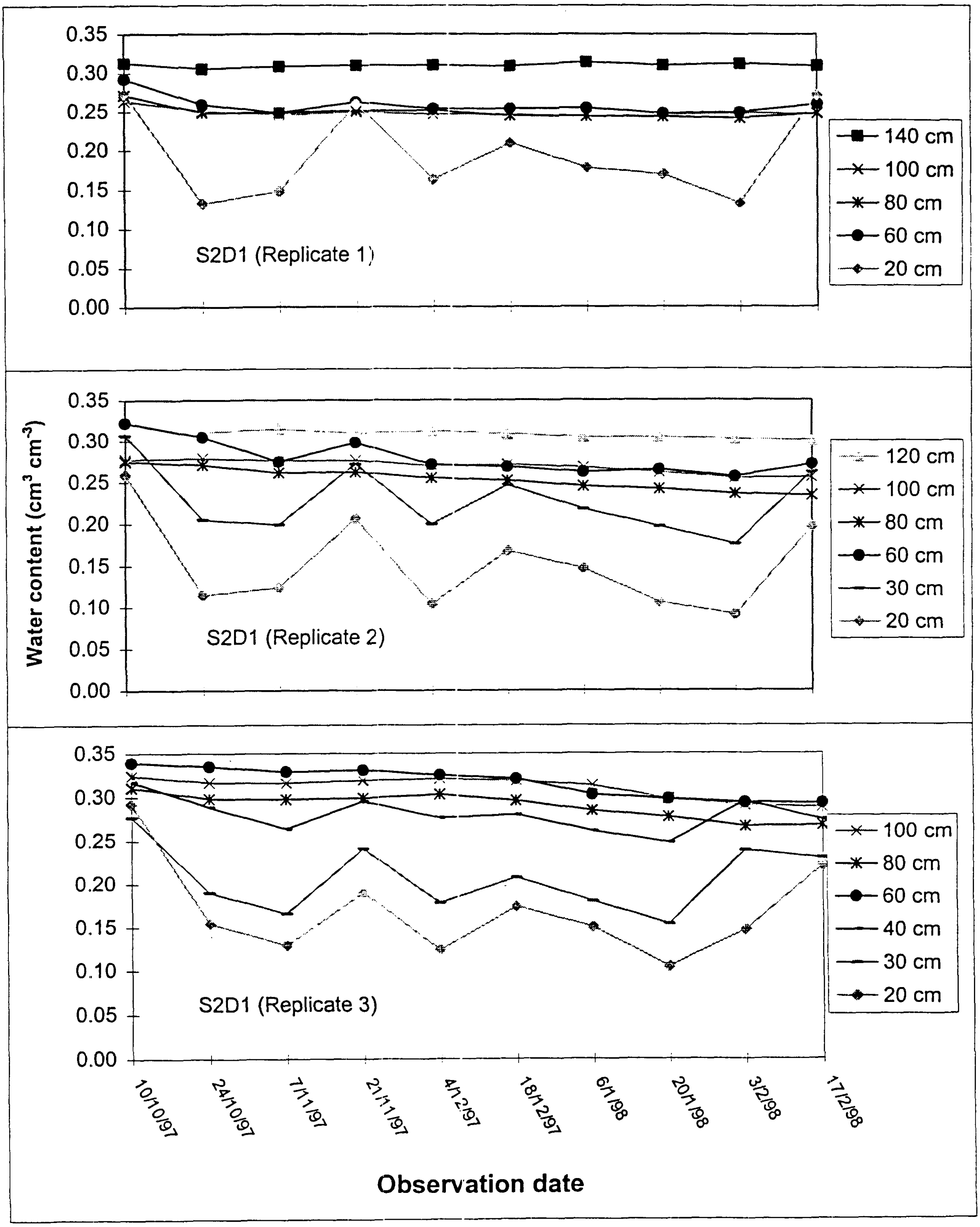


Figure 4.6. (Cont)



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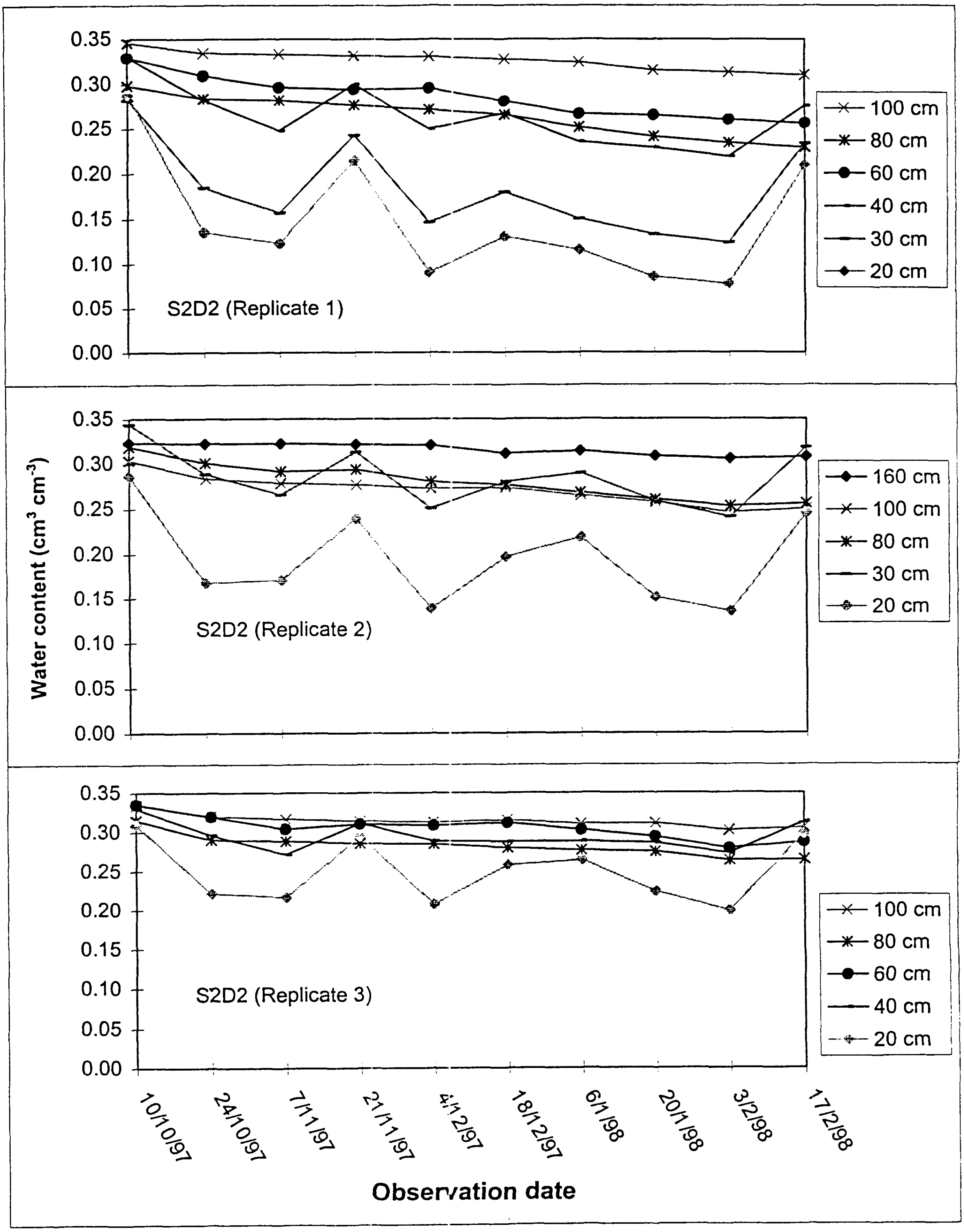

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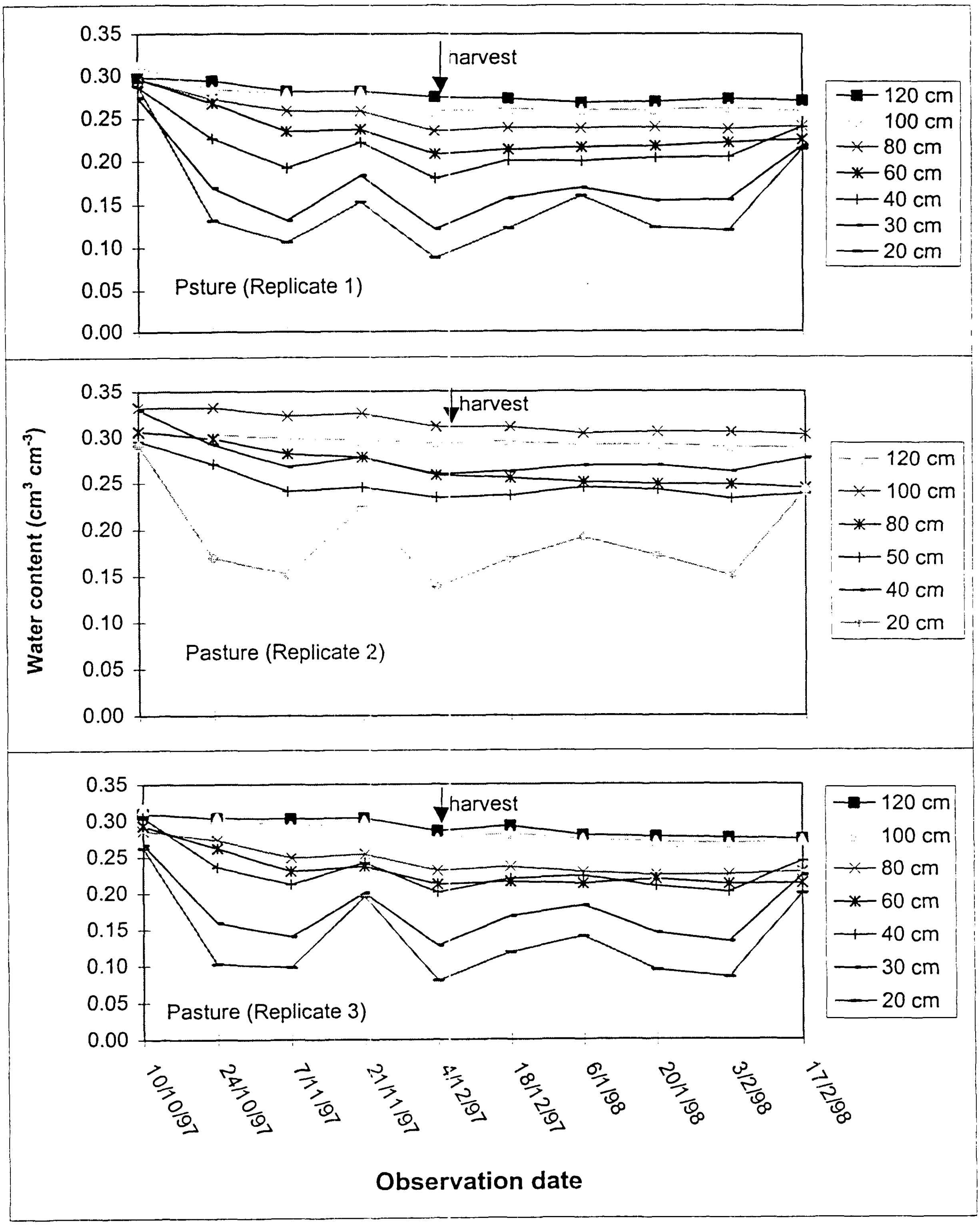

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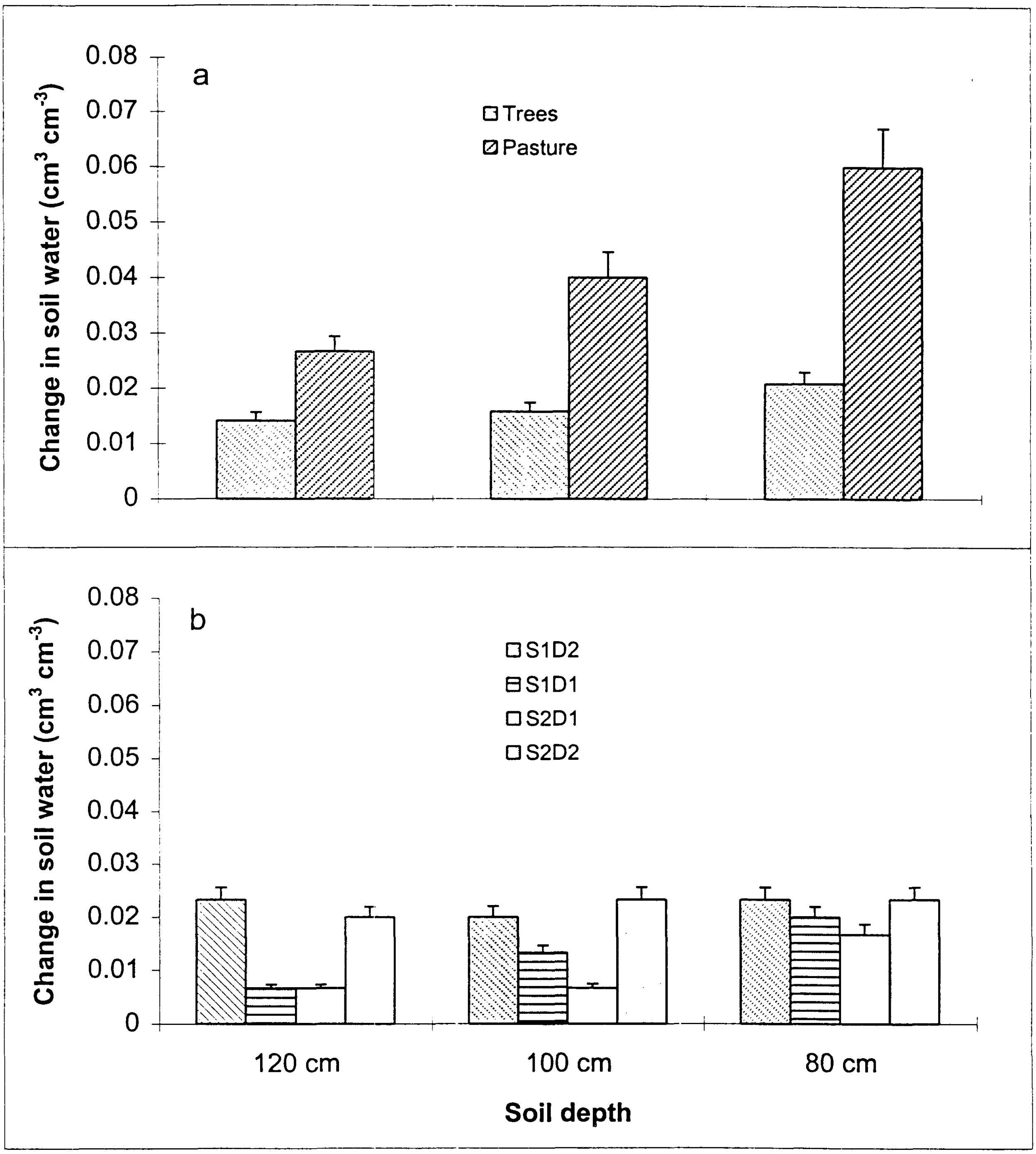

Figure 4.7. Change of soil water content for the tree and pasture treatments at the depths of 120 cm, 100 cm and 80 cm from October 10 to December 4, 1997. Bars indicating SEM. S1=*E. camaldulensis*, S2=*C. cunninghamiana*, D1=density as 4 x 2 m, D2=density as 4 x 3.5 m.

Pasture plots were harvested on December 8, 1997. The harvesting reduced evapotranspiration from the plots and hence may have reduced the level of the fluctuations in the soil water content curves for the pasture plots at 80 and 100 cm depth after December 4 (Figure 4.6). This suggested that the rooting system of grasses have influenced the water removal to these depths. It was expected, through examining the water extraction pattern (Figure 4.4d), that the tree rooting system could be deeper than that of grasses, rather than shallower. The fact that the effect of the rooting system on soil water content was not as significant in the tree plots as in the pasture plots (Figure 4.6) possibly resulted from the relatively sparse tree density. Therefore, the effective rooting depth is estimated to be 100 cm for both the pasture and tree plots. The water loss above and below 100 cm was considered, to be evapotranspiration loss and drainage loss respectively.

4.1.2.3. Water use and water balance

Figure 4.8 shows the seasonal patterns of daily water use for trees and pasture together with water input from September 1996 to March 1998. Both the trees and pastures evapotranspired more water in the period between September 1996 and March 1997 than between September 1997 and March 1998 (Figures 4.8a). Little difference in water use between the tree and pasture plots was evident in the autumn and winter of 1997 (Figure 4.8a). Water use among the four tree treatments was not significantly different (Figure 4.8b) either.

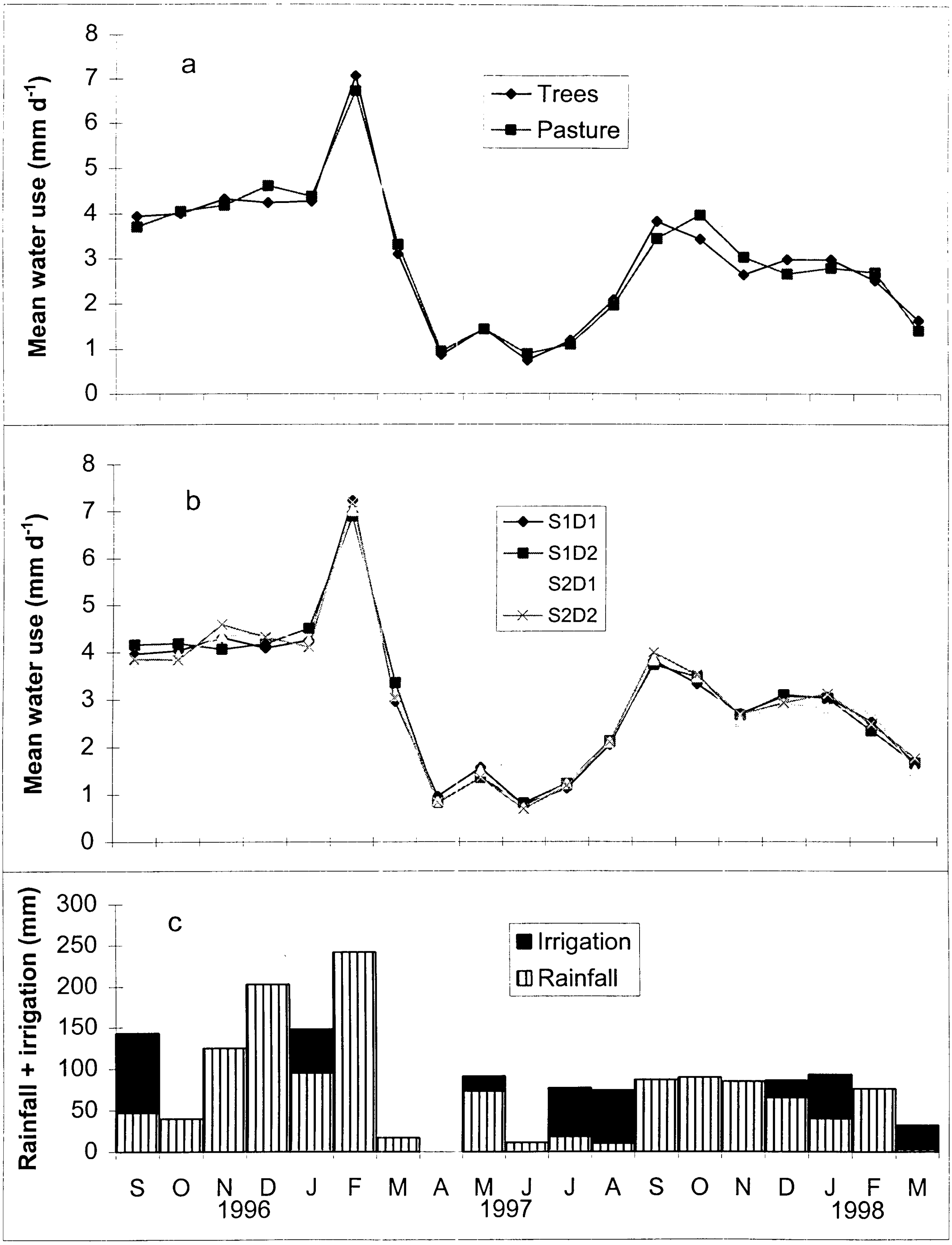

Figure 4.8. Seasonal patterns of daily water use for the tree and pasture treatments. S1=*E. camaldulensis*, S2=*C. cunninghamiana*, D1=density as 4 x 2 m, D2=density as 4 x 3.5 m.

E. camaldulensis was damaged by frost and cold temperatures during the 1996 winter and its water use, consequently, would have been affected in the following growing season. Therefore, in order to compare, in more detail, water use between the trees and pasture in growing seasons, only the third growing season (September 25, 1997 to March 31, 1998) was selected (Figure 4.9). The pasture had significantly ($P<0.05$) higher evapotranspiration rate for about 4 fortnights till early December 1997 when the pasture plots were harvested. The water use for the trees became higher than the pasture during most following period (except for one fortnight in February 1998), but not significantly (except for one fortnight in December 1997). In summary, the trees and pasture used similar amount of water over the 26 weeks, being 505 mm and 519 mm respectively (Figure 4.10).

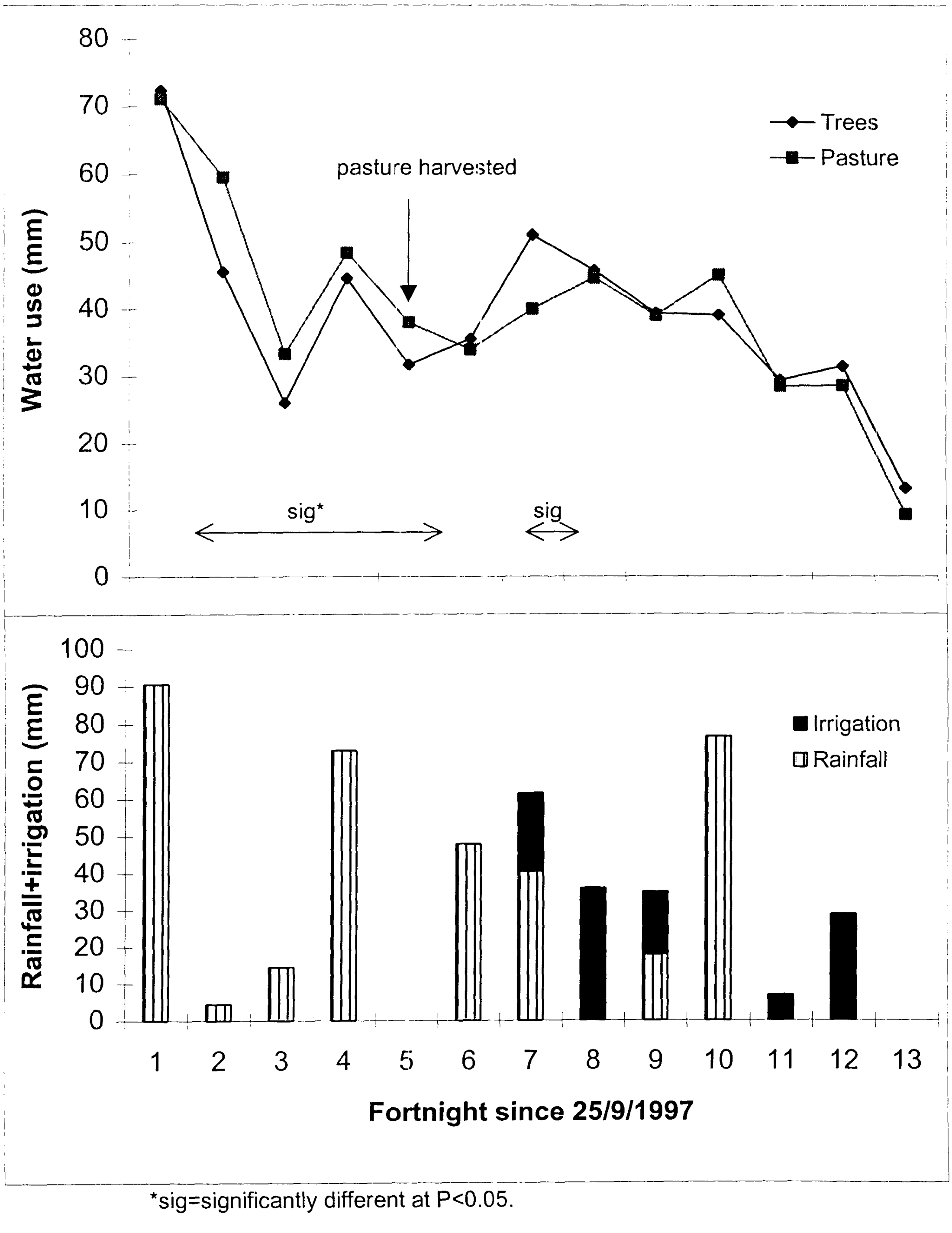

Figure 4.9. Comparison of water use for the trees and pasture during the 13 fortnights since September 25, 1997 (third growing season).

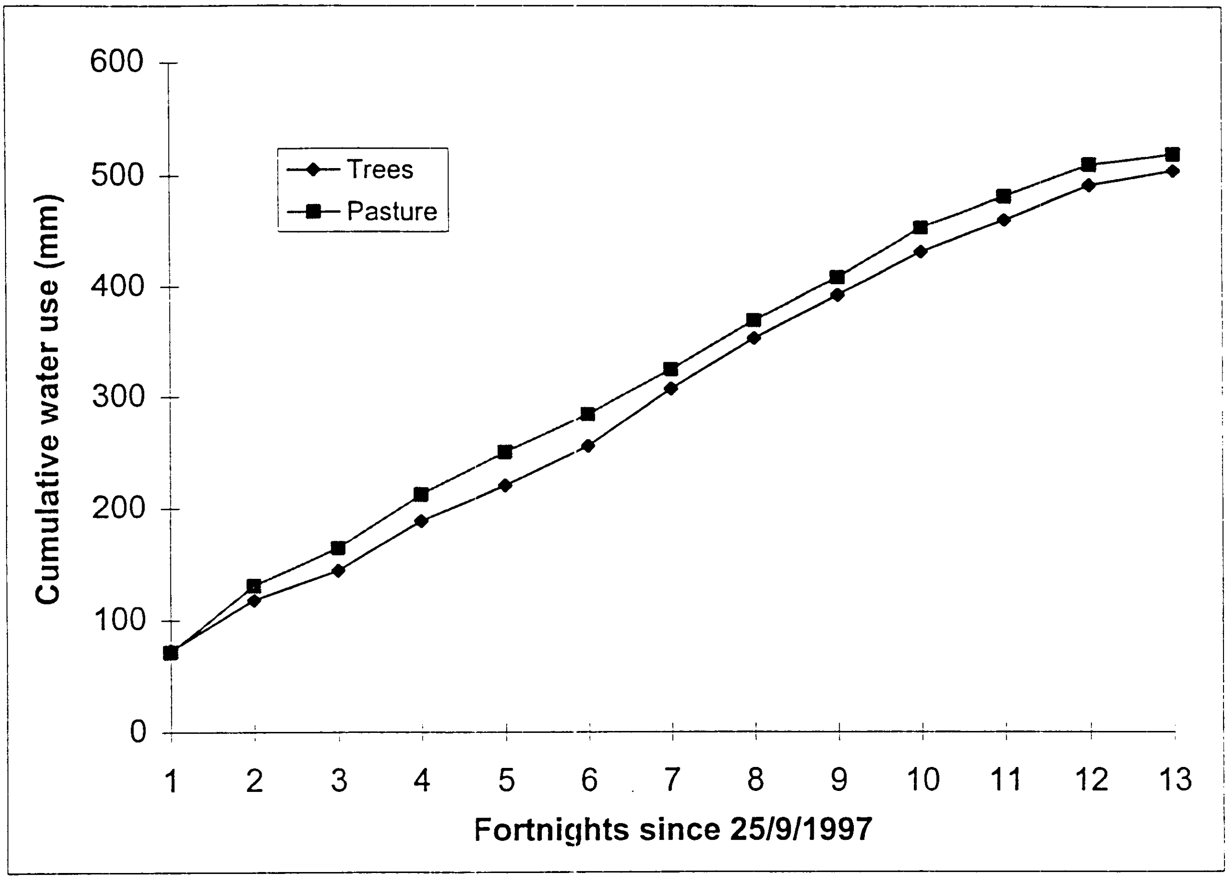

Figure 4.10. Mean cumulative water use by the trees and pastures over 13 fortnights since September 25, 1997 (third growing season).

The water balance of the plantation and pasture during this period is presented in Table 4.1. There was only an average of 12 mm runoff recorded during this period, because there were few strong rainfall events, as well the total rainfall being relatively low (also see Figure 4.9). Deep drainage was also low. The plantation, however, had a near two-fold drainage (20 mm) by comparison with the pasture (10 mm).

Table 4.1. Water balance (mm) of the tree plantation and pasture from 25/9/1997 to 31/3/1998.

	Plantation	Pasture
Precipitation (P)	366	366
Irrigation (I)	110	110
Runoff (R)	12	12
Drainage (D)	20	10
Change in soil water content (ΔW_p)	-61	-65
Water use (E)	505	519

4.2. Discussion

4.2.1. The survival and growth of trees and pasture

4.2.1.1. Tree survival

The most important factor in establishing effective vegetated buffer strips for intercepting lateral groundwater flow and nutrients is that the trees survive and grow in a healthy and vigorous way. Both *E. camaldulensis* and *C. cunninghamiana* had high survival rates at 3 months and 12 months after planting in this study. Frost and cold temperatures caused the death of 4% of young *E. camaldulensis* trees in the first winter after planting. However, only one or two young trees were lost during the second winter. The cause for the loss of 5% of *C. cunninghamiana* (including the replaced seedlings at 3 months) was not clear. Waterlogging may have occurred around many trees to some extent, because there was heavy rainfall in the summer of 1995/1996.

The survival rates of *E. camaldulensis* and *C. cunninghamiana* in this experiment were in the high rank by comparison with the results from other studies including the same species or different species for the Northern Tablelands (Curtis 1991; Reid *et al.* 1996; Stewart and Flinn 1984). Table 4.2 compares the survival rates of these two species planted only on the Northern Tablelands and in some other locations in Australia. *E. camaldulensis* is an introduced native species and *C. cunninghamiana* is an indigenous species (or local native species) on the Northern Tablelands. The result from this experiment, therefore, agreed with Curtis' (1991) conclusion that for establishing native species plantations on the Northern Tablelands, a high survival rate similar to that from anywhere else in Australia can be achieved if the relatively easy and appropriate planting techniques are followed. However, Curtis (1989) recommended that *C. cunninghamiana* not be used as a plantation tree species, due to its very low survival and growth rates, when grown on Palaeozoic metasediments and podzolic soils on the Northern Tablelands based on 10 planting trials from 1982 to 1987.

Table 4.2. Comparison of survival and growth for *E. camaldulensis* and *C. cunninghamiana* from different experiments in Australia.

Species	Survival rate (%)	Mean height (cm)	Age	Location	Author	Comment
E. camaldulensis	100	73	3 months	Northern Tablelands, NSW	From this study	Irrigated with effluent
E. camaldulensis	96	91	12 months	as above	as above	as above
C. cunninghamiana	97	66	3 month	as above	as above	as above
C. cunninghamiana	95	110	12 months	as above	as above	as above
E. camaldulensis	71	93	26 months	Northern Tablelands, NSW	Reid *et al.* 1996	Not irrigated
C. cunninghamiana	77	--	7 weeks	as above	as above	as above
C. cunninghamiana	2.4	20	30 months	Northern Tablelands, NSW	Curtis 1989	Not irrigated
C. cunninghamiana	--	250	42 months	Northern Tablelands, NSW	Wall 1997	as above
C. cunninghamiana	--	270	52 months	as above	Wall 1997	as above
C. cunninghamiana	--	270	63 months	as above	Wall 1997	as above
C. cunninghamiana	--	790	102 months	as above	Wall 1997	as above
E. camaldulensis	98	--	12 months	Horsham, Vic.	Stewart & Flinn 1984	Irrigated with wastewater
E. camaldulensis	94	--	12 months	Mildwra, Vic.	as above	as above
E. camaldulensis	81	--	12 months	Merbein, Vic.	as above	as above
E. camaldulensis	98	--	12 months	Robinvale, Vic	as above	as above
E. camaldulensis	66	--	12 months	Kyabram, Vic	as above	Irrigated with river water
C. cunninghamiana	89	--	12 months	Horsham, Vic.	as above	Irrigated with wastewater
C. cunninghamiana	56	--	12 months	Merbein, Vic.	as above	as above
C. cunninghamiana	80	--	12 months	Mildwra, Vic.	as above	as above
E. camaldulensis	--	1003	45 months	Alice Springs, NT (site 1)	Stewart *et al.* 1986	Irrigated with wastewater
E. camaldulensis	--	660	45 months	Alice Springs, NT (site 2)	as above	as above

Contrasting suggestions have been made that there are some sites where native species cannot be re-established because the environment condition has changed too much (Parker 1990). Reid *et al.* (1996), through their planting experiment on the Nothern Tablelands, reported that locally occurring species and genotypes (e.g. *E. dalrympleana, E. bridgesiana* and *E. nova-anglica*) had repeatedly performed poorly. Thus they concluded "that local condition (particularly soil moisture and temperature, but possibly soil fertility as well) are now sufficiently different to the pre-European condition to hinder the successful re-establishment of such species in reforestation sites, at least until the presence of pioneer plantings and soil amendments have mitigated the extreme conditions". It is very difficult to justify the contrasting claims because experimental conditions between studies, especially the techniques used in planting and managing the trees, are very different. Despite these different opinions, more and more people have recognized the importance of re-establishing native trees, and many practical programs have been carried out on the Northern Tablelands area (Curtis 1991).

4.2.1.2. Tree growth

Growth rates of *E. camaldulensis* and *C. cunninghamiana* in this study are also in the top rank by comparison with the same species (Table 4.2) or from the same genus and were reported from the same area (Curtis 1989; Jones 1997; Reid *et al.* 1996; Thorburn 1995; Wall 1997). However, these two species could grow much faster under better climatic and soil conditions in Australia. For example, Stewart and Flinn (1984) reported that the mean dominant height and diameter at 1.3 m above ground level of 4-year old *E. camaldulensis* irrigated with wastewater at four sites in Victoria were 8.9 m and 9.1 cm respectively. Growth at Tullimba was significantly less being 2.5 m at the end of the third growing season. Bell *et al.* (1993), by using an artificial drum experiment, reported that under favorable nutrient and water conditions, the largest of the 9-month-old *E.camaldulensis* plants raised from both seed and tissue culture exceeded 2.5 m in height.

4.2.1.3. Pasture establishment and growth

The results showed that improved pasture could be successfully established in a few months in this experimental area. The pasture also has a 2 months longer growing season than the trees. In terms of water use and particularly nutrient depletion, the longer growing period for pastures (on the basis of proper management, such as harvesting regularly and on time) is undoubtedly an advantage. Assuming that the young trees had not significantly affected natural pasture biomass production between the tree lines because canopy development was not extensive (27% for *E. camaldulensis* and 18% for *C. cunninghamiana*), it could be concluded that the improved pasture greatly increased the grassland biomass and hence has a greater potential role in removing nutrients through assimilation and accumulation.

However, the results indicated that the growth and production of the improved pasture was affected by dry conditions. This is a disadvantage when trying to maintain pasture as vegetated buffer strips. The trees, in contrast, were not significantly affected by the dry condition because they could use water further down the soil profile (see the sections 4.1.2). Thus, the tolerance of trees to drought is an advantage for the maintenance and management of the plants in vegetated buffer strips.

4.2.1.4. Factors affecting the survival and growth of trees and pasture

The factors affecting the survival and growth of the trees and pasture in this study include frost and cold temperatures, weed competition, rabbit/hare browsing, insect damage, irrigation and waterlogging, and fertilizing. As described above, most *E. camaldulensis* seedlings suffered damage from frost and cold temperatures, and had problems with insect damage to some extent. *C. cunninghamiana* was affected by rabbit and hare browsing. Mowing and hoeing effectively controlled weed competition. Some waterlogging occurred but did not affect tree survival and growth significantly. Irregular irrigation with cattle effluent relieved drought stress that occasionally occurred during the experimental period. The trees and pasture were fertilized, but no tests of the effects of the fertilizing on tree growth were undertaken because the purpose of the fertilization was only to promote their establishment and early growth.

(1) Frost and cold temperature

One characteristic of the climate of the Northern Tablelands is the frequent frosts and cold temperature that can dramatically damage seedlings and thus reduce their survival rates (Curtis 1989; Reid *et al.* 1996; Wall 1997). However, for *E. camaldulensis*, the result of this experiment was different from that of Reid *et al.* (1996). This species, in this experiment, suffered from frosts and cold temperature to a significant extent in the first two winters after planting so that many young trees died back to ground level and 4% totally died at 12 months. In the investigation of Reid *et al.* (1996), however, *E. camaldulensis* was recommended as one of the best species to tolerate frost. The reason for the contrasting results was not clear, but one possible explanation is due to the different microclimates of the experimental sites because frosts usually occur quite patchily (Cremer 1990a) and frost hollows develop in low parts of the landscape where the drainage of air is impeded. Frost tolerance needs to be considered when choosing *E. camaldulensis* as a plantation tree species on the Northern Tablelands. *C. cunninghamiana*, however, has not been reported to have problems with frost and cold temperature in this area. This was also confirmed through this experiment.

Trees are most vulnerable to frost damage when they are between seedling stage and about 1.2 m height. Many methods have been suggested to protect seedlings from frost damage (Cremer 1990a). However, some methods such as using plastic film shelters, are costly and hence are impractical to use for large plantations. Curtis (1989) reported that milk carton guards had a significant role to play in preventing frost damage to seedlings of some local native tree species over the first winter on the Northern Tablelands.

(2) Weed competition

Weed and grass growth in plantations is a dominant factor reducing tree survival rate and inhibiting early tree growth on the Northern Tablelands (Curtis 1991; Wall 1997), as well as in other areas in Australia (Fagg and Cremer 1990). Effective control of weeds is often crucial to the successful establishment of trees no matter whether they are planted individually, in shelterbelts, or in large plantations. Using conventional cultivation methods alone can rarely lead to satisfactory result, thus chemical and mechanical methods are often used to control weeds. Spraying before planting is a cost-effective way to control weeds during the initial growing period (Wall 1997). In this experiment, weeds were effectively controlled by clear cultivation prior to planting, machine-mowing combined with hand-hoeing during the first two growing seasons. Competition from weeds and grass was very strong, especially in early spring before the trees started to grow. During the third growing season, weed competition around the individual trees had been overcome by tree growth, so that hoeing was not used and only the native pasture between tree rows were mown twice.

(3) Damage by rabbits/hares

The damage caused by rabbit and/or hare browsing to young trees is a widely occurring problem, not only on the Northern Tablelands (Curtis 1991; Reid *et al.* 1996) but also in all the areas around Australia (Cremer 1990b; Myers *et al.* 1995). Using milk carton guards is usually recommended as a simple and effective method to prevent rabbit and hare browsing (Curtis 1989; Wall 1997), although rabbit/hare-proof fencing, however, is often necessary in more severe cases (Reid *et al.* 1996; Myers 1995; and as in this study). In this investigation, the *C. cunninghamiana* seedlings were protected only with milk carton guards for the first 2 months, so that rabbits/hares browsed parts of the seedlings protruding from the cartons. *E. camaldulensis* did not suffer any damages from rabbit or hare browsing in this experiment. The pasture suffered some damage from rabbit/hare grazing, but not seriously.

(4) Insect damage

During the three growing seasons, minor leaf damage caused by insects was regularly observed for *E. camaldulensis*, while almost no insect damage to *C. cunninghamiana* had occurred. The main insects found to damage *E. camaldulensis* were leaf eaters (e.g. caterpillars (Lepidoptera), sawflies (Hymenoptera)) which fed on leaves and often killed the tree growing tips. Sapsuckers were also observed, such as leafhoppers, and scale insects. The trees were effectively protected from significant insect damage by spraying insecticides several times in each growing season. Usually, a low level of damage by insects can be expected, but the risk of extensive defoliation due to insects is greatest with *Eucalyptus* (Myers *et al.* 1995). Therefore, insect population levels should be monitored regularly, with insecticide spraying used when necessary to prevent major damage. However, the use of insecticides will only give short- term protection, and can not provide real control of insect population (Tanton 1990). In this study, the pasture plots had no serious problems with insect damage.

(5) Waterlogging and drought

Reid *et al.* (1996) reported that the mean seedling survival rate for 7 tree species was <80% after 7 weeks because of waterlogging resulting from the heavy rainfall in the 1995-96 summer, although the planting was a high-input design provided with a well-prepared seedbeds (deep-ripping to 900 mm and deep placement of slow-released fertilizer to 500 mm), irrigation, good weed control, and superior tree guards for wind and frost protection. *E. camaldulensis* and *C. cunninghamiana*, however, were reported to perform well due to their tolerance to waterlogging in their experiment. The results from present study were comparable to that of Reid's. The trees were planted in December of 1995 and experienced some waterlogging, but almost all had survived at 3 months. There have been many studies about the effect of waterlogging and associated salinity on *Eucalyptus* and *Casuarina* trees in Australia (e.g. van der Moezel *et al.* 1988). However, there have been few studies on the effects of waterlogging on plantation trees on the Northern Tablelands. Further research, therefore, should be promoted.

Drought commonly causes seedling mortality and decreases growth rates of young trees on the Northern Tablelands (Curtis 1991; Reid *et al.* 1996; Thorburn 1995; Wall 1997) as well as in many other locations in Australia (LWRRDC 1993; Polglase *et al.* 1994). Watering at planting together with follow up watering can greatly reduce the mortality of seedlings under dry weather. Drought has also been a frequent limiting factor for pasture production in Australia (Moore 1970). In this experiment, the trees and pasture experienced a drought in the late summer of 1997/1998 that severely affected pasture growth while there was little evidence of reduced tree height growth.

(6) Irrigation with effluent

Using tree plantations for the disposal of effluent not only provides an alternative to dealing with the problem of water system contamination, but also gives a great benefit through the reuse of water and nutrients to increase wood production and to increase the environmental amenity (LWRRDC 1993; Stewart *et al.* 1991; Myers *et al.* 1995). This has particularly important implications in Australia because water deficits are the primary limitation to terrestrial productivity throughout most of Australia (Myers 1992; Polglase *et al.* 1994). In considering the relative importance of water and nutrients in effluent, Polgalase *et al.* (1994), through the Wagga Effluent Plantation Project, concluded that it was water, not nutrients which significantly limited the growth of trees during the first 2 years. However, many investigations have indicated that *Eucalyptus* plantations have positively responded to fertilizer applications both in early growth and final yields (Cromer *et al.* 1981). Fertilizer applications at planting tend to be more advantageous than those after the first weeding (Schonau and Herbert 1989). Therefore, irrigating tree plantation with nutrient-rich effluent may have benefits both for the growth of young trees and for the yields of the plantations at harvesting.

4.2.2. Water use by trees and pasture

4.2.2.1. Soil water deficit

Comparison of soil water deficit under different vegetation types growing under the same environmental condition provides an indication of the water use capacity of each type. Under the same natural conditions, larger soil water deficit values for one type of vegetation means it has a relatively better capacity to use water. The result from the soil water deficit investigation in this study showed that soil water deficit under the pasture were generally larger than under the plantation (Figure 4.3a) although not consistently and statistically so. However, it can not be concluded at this stage that the improved pasture has the ability to use more water than the trees of *E. camaldulensis* and *C. cunninghamiana* because tree crown development was such that trees are unlikely to dominate the water relation in the plantation and the native grasses were still the main contributors to water use. Another explanation for high water use in the improved grasses was that the started growing about one month earlier than the trees in spring when the soil moisture and temperature were suitable. The grasses had reached around 70 cm high with complete ground covered in late October, while the trees had just started to grow.

Soil water extraction patterns for the tree and pasture treatments showed that seasonal fluctuations in soil moisture deficit were greatest in the upper part of the soil profile (0-30 cm depth). Fluctuations resulted from the periodic rainfall and irrigation inputs together with the rapid removal of moisture from the zone due to a higher rooting density in this part of the profile. The results also showed that the water deficit fluctuations for the soil profiles at 30-60 cm and 60-100 cm depth were similar in pattern but with a much smaller amplitude than that of the upper profile. Significant contributing factors to this pattern are that the major soil physical properties are similar (light medium clay to medium clay) for the two lower zones, but different from the upper zone (sandy clay loam) and the rooting density in the lower soil layers was lower than in the upper layer. The higher soil water deficit of the pasture than the tree treatment was mainly attributed to the two soil profiles of 30-60 cm and 60-100 cm because the pasture plots had generally higher water deficit than the tree plots at these two zones, though the difference was not consistently statistically significant (Figure 4.4b,c).

Considering the soil water extraction patterns together with water input and the growth and management of the trees and pasture, some conclusions and explanations can be drawn. Firstly, soil evapotranspiration tended to be a dominant contributor to water removal in the upper layer (0-30 cm depth) of the soil profile. Secondly, the pasture could extract more moisture from the soil than the trees at this stage of development, but this depends on the length of the growing season and water inputs. For instance, during the period from October 10 to December 4, 1997, the water deficit for the pasture was significantly larger than that of the tree plots, because the grasses started growing earlier in spring than the trees and rainfall was sufficient in that period to maintain good growth. Thirdly, grass harvesting, which occurred on December 8, 1997, greatly influenced pasture water extraction, so the trends in the water deficit curve for pasture changed thereafter (Figures 4.4b,c).

Furthermore, trees could extract soil water from deeper down the profile when there was lack of sufficient water input at the soil surface. Dry condition in the late summer of 1997/1998 prevented pasture growth after harvesting and the above-ground parts of some species died, thereby, decreasing water removal from the soil profile (Figure 4.4b,c,d). In contrast, the trees continued to extract water from deeper in the profile (Figure 4.4d).

Soil water deficit was dictated by both the water input from rainfall and irrigation and the quantity of water lost by evapotranspiration. Given that rainfall and irrigation were same for all experimental treatments, the larger soil water deficit under the pasture than the plantation indicated that the pasture had greater potential to use soil water than the plantation by end of the third growing season. When designing vegetated buffer strips for the Northern Tablelands area to reduce nutrient transport associated with groundwater, using pasture crops, therefore, may has more advantages than trees during the early stages of tree development. While the benefits of using grass vegetated buffer strips to remove pollutants from surface runoff has been well reported (eg Dillaha 1989; Dillaha *et al.* 1985), there has been very few studies on their roles in reducing pollutants associated with groundwater movement. Further research is needed in this aspect.

4.2.2.2. Determination of the effective rooting depth

Effective rooting depth needs to be estimated when using water balance methodology to determine water use by vegetation (McGowan and Williams 1980a,b). The effective rooting depth, or root extraction depth was estimated to be 100 cm for both the pasture and tree plots in this experiment by plotting water content against time (from October 10 to February 17, 1997) for all the 15 tree and pasture plots. However, determining effective rooting depth, is technically difficult, and it is often defined arbitrarily (Honeysett *et al.* 1992; Myers *et al.* 1996). Even if it was determined very carefully by using techniques, such as tensionmeters, neutron probe data (as in this study), or direct rooting depth measurements, the effective rooting depth indicates only the maximum identifiable depth of water extraction. It does not guarantee the presence of active roots (Gregory *et al.* 1978). Roots may be present in a horizon without extracting water and water may move downwards through the soil before being taken up by the plants.

4.2.2.3. Water use and water balance

Water use during the second growing season (1996/1997) was higher than the third season (1997/1998) (Figure 4.8a,b) because of the higher levels of water availability through input of rainfall and irrigation (Figure 4.8c). No difference in water use between the four tree treatments was recorded because the trees had not developed to a stage to dominate the water relation in the plantation. Myers *et al.* (1996) reported for their experimental plantation irrigated with municipal effluent, that plantation water use before canopy closure was dominated by the pasture under the trees. Canopy development for *E. camaldulensis* and *C. cunninghamiana* in this experiment was still far beyond closure even at the end of the third growing season (see section 4.1.1.1). The results from the water use was calculation corresponded to that from water deficit observations. The pasture used more water than the trees for 4 fortnights since September 25, 1997 till the middle of December 1997, when the pasture was harvested (Figure 4.9).

Water use of the trees and the pasture during the early developing period (before 3 years) depends on seasons, soil moisture conditions, and management. When the soil moisture conditions are appropriate, the grasses may use more water than the young trees during early spring and late autumn because the grasses have a longer growing season than the trees. Under dry condition, trees extract more soil water than grasses because the dry conditions greatly decrease the growth of grasses and even cause them to die, while the trees can keep growing by using water from deeper down the soil profile. Pasture harvesting may decrease water use for a short time afterwards, but may also extend the period of water use by preventing grasses from maturing earlier and hence prolonging their growing period.

Many studies have reported water use for plantations, natural forest, woodlands, crops and pastures. It seems, in general, that trees can use much more water than grassland. For instance, Greenwood *et al.* (1985) reported that annual evapotranspiration was 390 mm for pastures, while it was 2300 mm for *Eucalyptus maculata* and 2700 mm each for *E. globulus* and *E. cladocalyx*. Farrington *et al.* (1989) reported that annual total evapotranspiration of a *Banksia* woodland was 666 mm. However, it is very difficult to compare the results from different studies, because the conditions of climate, soils, tree age, management status etc for each study differs greatly. One should, therefore, be cautious in extrapolating conclusions from the results to cover water use over wider areas.

4.3. Conclusions

The survival rates of both *E. camaldulensis* and *C. cunninghamiana* were high, although they were damaged to some extent, by frost and by rabbit/hare browsing respectively. 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 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 improved pasture had more than twice the biomass than that of the native pasture. The pasture started growing earlier in spring and stopped growing later in autumn than the trees when the soil moisture conditions were appropriate. Both tree species, however, could tolerate drier conditions than the pasture.

In general, water deficit and water use among *E. camaldulensis* and *Casuarina cunninghamiana* with the two different planting densities were not significantly different over the first three growing seasons. This was possibly because the trees did not support sufficient leaf area to dominate water relations in the plantation. The general larger water deficit of the improved pasture indicated that pasture has a greater potential to use soil water than the plantation at this early stage. However, pasture water use, in comparison with the plantation, was more dependent on soil moisture conditions, growing seasons, and management.