WASTEWATER IRRIGATED TREE PLANTATIONS: PRODUCTIVITY AND SUSTAINABILITY

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ABSTRACT

An effluent irrigated, short rotation coppice trial was established at the Goulburn Valley Region Water Authority (GVRWA) Shepparton Wastewater Treatment Complex in 1993, by the Centre for Forest Tree Technology and GVRWA. At age 4 years, growth rates and biomass production in this trial are amongst the highest reported in Australia. Sequestration of nutrients applied in effluent requires that trees be managed in relatively short rotations. This study has generated widespread interest among the scientific and wider community, and has provided a basis for detailed scientific studies of tree growth, tree water use, nutrient uptake, and nutrient leaching and denitrification in the soil.

KEYWORDS

Eucalypt plantation, effluent irrigation, nutrient sequestration

1.0 INTRODUCTION

The use of tree plantations for the disposal or re-use of effluent / wastewater has been well established and continues to be investigated throughout Australia, particularly with respect to the sustainability of this land-use (e.g. Myers *et al*. 1995, Polglase and Tunningley 1996).

A major concern with effluent irrigation is the fate of nitrogen (N) and phosphorus (P) in the environment since these nutrients can cause pollution of surface and groundwater. Municipal effluent treated to primary or secondary level often contain greater amounts of these nutrients than can be sequestered by the trees at the rate of irrigation needed to meet the water requirements of trees. While P will not usually be a problem in the short to medium term, particularly on soils with high P adsorption capacity, there is always potential for leaching of N (as nitrate) to groundwater.

Fast growing trees initially accumulate significant amounts of N in foliage, but thereafter the net N requirement of the plantation declines as N is recycled via decomposition of litter and internal translocation. Therefore removal of N and other nutrients by plantations can be maximised by growing trees in short rotations of 3 to 4 years. However, short rotations (< 6 years) may compromise water use, and also limit the potential products to biomass fuels rather than higher value wood products.

A second concern with effluent irrigation arises from the often high concentrations of sodium (Na). Therefore, long-term irrigation has the potential to deleteriously affect soil structure through changes in soil chemistry, and ultimately reduce the productivity of the site and its utility for effluent disposal. Concentrations of Na may be particularly elevated in some effluents where sodium hydroxide is used in food processing industries.

1.1 Previous Research Activity

Studies examining the effects of effluent irrigation on tree plantations in Victoria commenced at least as early as 1973, initially as species screening trials, and later as formal species and provenance comparison trials. Most of these earlier trials were not designed to be continued beyond 3-4 years of intensive study, however, a trial at Wodonga is an exception, and has yielded growth data to age 14 years with mean annual increments (MAI) of 41 and 31 m^3 ha^{-1} yr^{-1} for *Eucalyptus grandis* and *E. saligna* respectively, and provides an important benchmark for the potential productivity of effluent irrigated tree plantations (Baker 1998). This initial research has been successful in encouraging effluent irrigated plantation schemes.

Recently, research has become more philosophically biased towards: the profitable reuse of effluent, rather than simple disposal; the sustainability of land use under effluent irrigation; the silvicultural management of plantations to achieve specific objectives such as the production of high-value sawlogs; and the optimisation of nutrient sequestration and water use.

1.2 Shepparton Short Rotation Coppice Trial

A project examining the sustainability of eucalypt tree plantations using municipal effluent is being conducted within the Short Rotation Coppice Trial at the Goulburn Valley Region Water Authority (GVRWA) Wastewater Treatment Complex at Shepparton. The trial was designed to determine whether the long-term irrigation of tree plantations with effluent is sustainable within alternative silvicultural treatments, by measuring changes in soil properties, the input of water and nutrients in effluent, tree growth, sequestration of nutrients and salts in trees and soil, and monitoring groundwater depth.

Prior to planting in August 1993, the site was laser graded, ripped to a depth of at least 60 cm, mounded along the rows, and given a pre-establishment weed control treatment comprising both residual and knockdown herbicides. The trial incorporates comparisons of coppice rotation length, planting density and tree species (Baker *et al.* 1994):

Rotation length:	3, 6 or 12 years
Density :	1333 sph or 2667 sph
Species:	*Eucalyptus globulus* or *E. grandis*

During the first four years of the planned 12-year experiment, the study has generated valuable data on the growth of effluent-irrigated plantations. Some results have challenged general assertions regarding water use by irrigated trees. This paper presents data collected to age 4 years, incorporating coppice regrowth to age 1 year in the 3-year rotation.

2.0 DISCUSSION

2.1 Rainfall, irrigation and evaporation

Rainfall, irrigation and evaporation data, and effluent analysis data for the period September 1993 to August 1997 are presented in Table 1. The effluent is a high-sodium water balanced with moderate levels of Ca and Mg. The sodium adsorption ratio (SAR) of the effluent (5.3 to 6.2) indicates that there is a minimal or slight risk of a reduction in soil permeability resulting from increasing exchangeable Na (EPA 1991).

Irrigation rates from age 2-3 and 3-4 years were less than desired (approximately 10ML/ha) because of operational constraints associated with site works. Tree water use rates from age 2-3 years (580-680 mm) were also lower than anticipated in the Shepparton climate (Baker *et al.* 1997).

Table 1: ***Summary of rainfall, evaporation, irrigation and effluent analysis data to age 4 years at Shepparton.***

	Age (years)			
	0 to 1	**1 to 2**	**2 to 3**	**3 to 4**
Rainfall (mm)	622	500	519	354
Evaporation (mm)	1219	1559	1372	1541
Irrigation (mm)	525	906	594	651
No. of irrigations	10	11	11	12
Mean effluent analysis:				
pH		8.1	7.9	nd
EC (dS/m)		1.43	1.34	1.45
NH4-N (mg/L)		10.3	3.0	5.1
NO3-N		0.2	1.3	0.9
NO2-N		0.1	0.3	0.5
TKN		24.7	16.6	17.3
TCN		25.0	18.0	18.6
Total-P		5.2	5.3	5.0
Cl		201	166	175
Na		184	200	200
Ca		61	49	51
Mg		19	18	17
K		31	34	33
SAR		5.3	6.2	6.1

nd = not determined

2.2 Groundwater monitoring

From December 1995 to September 1997, shallow groundwater depth beneath the plantation appeared to follow a seasonal trend, with average depths varying from (-2.0 to -3.8 m) and being greatest in September. Electrical conductivity of groundwater varied on average from 0.5 - 8.0 dS/m and EC appeared to be least during late autumn - early winter.

From February 1997 (approximately 4 months after coppicing), groundwater in the 3-year rotation was shallower than that in the 12-year rotation, indicating that the unharvested trees were either using more water than the coppice regrowth, or alternatively that groundwater accessions were greater under the coppice. The trend of deepening groundwater observed from February 1997 is consistent with the relatively low rainfall (180 mm) and low irrigation rate (230 mm) during this period.

NO_2+NO_3-N concentrations in the groundwater varied by five orders of magnitude between sample bores, and declined from approximately 10 mg/L to 0.1 mg/L during the study period. The decline in concentration with time may reflect a continuing, although at a reducing rate, loss of N from the soil to groundwater (approximately 500 kg/ha during the first 3 years of irrigation).

2.3 Soil chemical properties

Irrigation with the alkaline effluent increased soil pH (0.8 to 2.3 units) in the surface 20 cm of soil, whereas pH declined in the subsoil (0.3 to 0.6 units) (Table 2). Except for the 0-5 cm depth, the EC of soil-water extracts increased two to three times after 3 years of irrigation. However, the salinity is moderate overall (max. 0.22 dS/m) and unlikely to affect tree growth.

Total N in the surface 15 cm of soil decreased to 60-80% of initial concentrations after 3 years of irrigation suggesting that mineralisation of N has been significant. The loss of N was associated with loss of soil C, and generally soil C to N ratios did not change. Total P concentrations in soil increased by 9 to 18% at all depths analysed.

Table 2 : ***Soil chemical properties, initially and after 3 years, beneath effluent irrigated Eucalyptus globulus and E. grandis at Shepparton.***

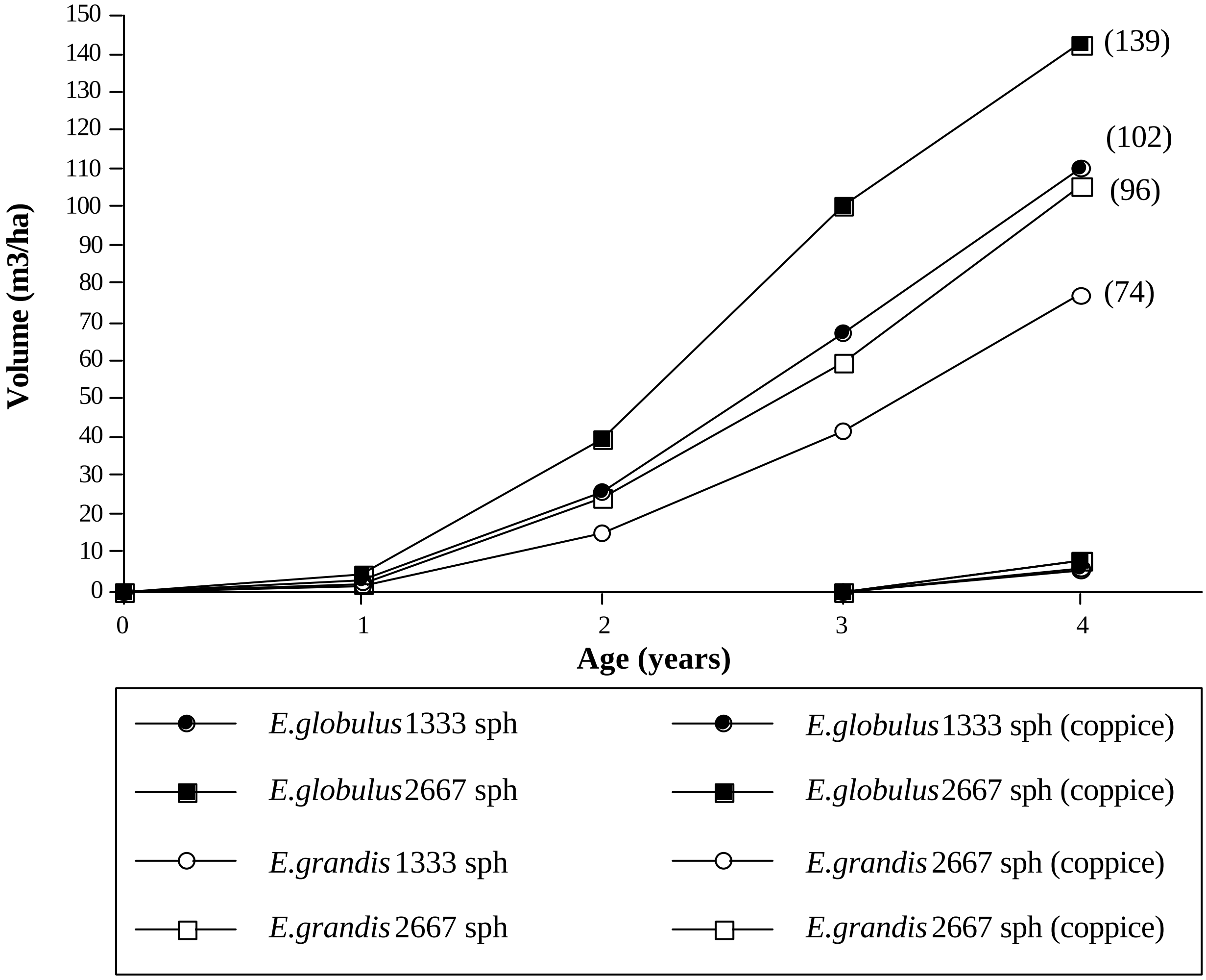
Depth (cm)	PH		EC (dS/m)		Total N (g/kg)		Total P (mg/kg)		ESP	
	Initial	**3 yrs**	**Initial**	**3 yrs**	**Initial**	**3 yrs**	**Initial**	**3 yrs**	**Initial**	**3 yrs**
0-5	4.88	7.20	0.15	0.14	2.09	1.84	350	411	0.9	7.2
5-10	5.13	6.94	0.08	0.15	1.73	1.35	318	358	1.1	13.7
10-15	5.52	6.82	0.06	0.16	1.16	0.74	291	316	1.5	14.3
15-20	6.06	6.90	0.04	0.16	0.69	0.57	264	298	1.9	12.8
40-50	7.87	7.31	0.08	0.22	0.40	0.40	282	326	6.7	7.8
70-80	8.61	8.33	0.14	0.22	0.37	0.27	236	278	10.6	9.5

While the cation exchange complex of the surface soil continues to be dominated by Ca and that of the subsoil by Mg, after 3 years of irrigation the ESP of the surface soil has increased seven- to twelve-fold to a maximum of 14%. Thus the surface soil has become sodic (ESP 6-15). While increased soil ESP resulting from effluent irrigation is expected, there may be no practical effect of increased sodicity. For example, under effluent irrigated trees at Wagga Wagga, ESP increased from less than 2% to 25% in the surface 60 cm after 5 years, but this increase did not explain the decreased *in situ* soil saturated hydraulic conductivity (Balks *et al*. 1996). They concluded that the increased sodicity of the soil may only be practically significant if the soil is to be disturbed by cultivation. While there has been no marked increased subsoil sodicity after 3 years of effluent irrigation at Shepparton, the relatively low Ca to Mg ratios have the potential to exacerbate any future increases in sodicity.

2.4 Tree growth and biomass accumulation

Survival and growth of both *E. globulus* and *E. grandis* is excellent, with survival varying between 86 and 96%, and average volume growth of *E. globulus* (126 m^3/ha) being approximately 1.4 times that of *E. grandis* (91 m^3/ha) to age 4 years (Figure 1). Tree volume growth trends to age 4 years for both species indicate that the Short Rotation Coppice Trial is amongst the most productive eucalypt plantations in Australia. For example, the MAIs at age 4 years were 27 and 36 m^3 ha^{-1} yr^{-1} for *E. globulus* and 19 and 26 m^3 ha^{-1} yr^{-1} for *E. grandis* for the 1333 and 2667 sph densities respectively. This compares with reported growth rates for other irrigated plantations at age 4 years, such as a MAI of 33 m^3 ha^{-1} yr^{-1} for *E. saligna* (1500 sph) and 31 m^3 ha^{-1} yr^{-1} for *E. grandis* (1300 sph) at Wodonga (Hopmans *et al*. 1990), a MAI of 34 m^3 ha^{-1} yr^{-1} for *E. grandis* (age 3 years) at Gympie (Cromer *et al*. 1993), and a MAI of 15 m^3 ha^{-1} yr^{-1} for *E. grandis* and 34 m^3 ha^{-1} yr^{-1} for *E. globulus* (2200 sph) at Bolivar (Boardman 1996).

Figure 1: ***Stem volume growth of effluent irrigated Eucalyptus globulus and E. grandis at Shepparton. Total above-ground biomass (Mg/ha) at age 4 years is presented in brackets.***



At age 4 years, total above-ground biomass in the four treatments varied between 74 and 139 Mg/ha (oven-dry weight), with biomass of *E. globulus* being approximately 1.4 times that of *E. grandis*, and biomass of the 2667 sph treatment 1.3 to 1.4 times that of the 1333 sph treatment. As occurred for volume growth, biomass accumulation between age 3 and 4 years in the Short Rotation Coppice Trial (35 to 57 Mg/ha) also continues to be amongst the highest reported in Australia.

The proportion of total biomass in stemwood and stembark increased from 23-33% at age 1 year, to 61-70% at age 4 years. At age 4 years, foliage biomass in *E. globulus* varied from 11.8 to 15.5 Mg/ha, substantially higher than in *E. grandis* (7.0 to 7.3 Mg/ha). Foliage biomass increased by 32-38% between age 3 and 4 years in *E. globulus* and by 29-33% in *E. grandis*. At age 4 years, as at age 3 years, foliage biomass was similar in *E. grandis* 2667 sph and *E. grandis* 1333 sph, whereas foliage biomass was substantially greater in *E. globulus* 2667 sph than in *E. globulus* 1333 sph. Foliage biomass at age 4 years at Shepparton for *E. grandis* and *E. globulus* compares with other irrigated plantations, such as 5-7 Mg/ha for *E. grandis* and 10-18 Mg/ha for *E. globulus* at Bolivar (Boardman *et al.* 1996).

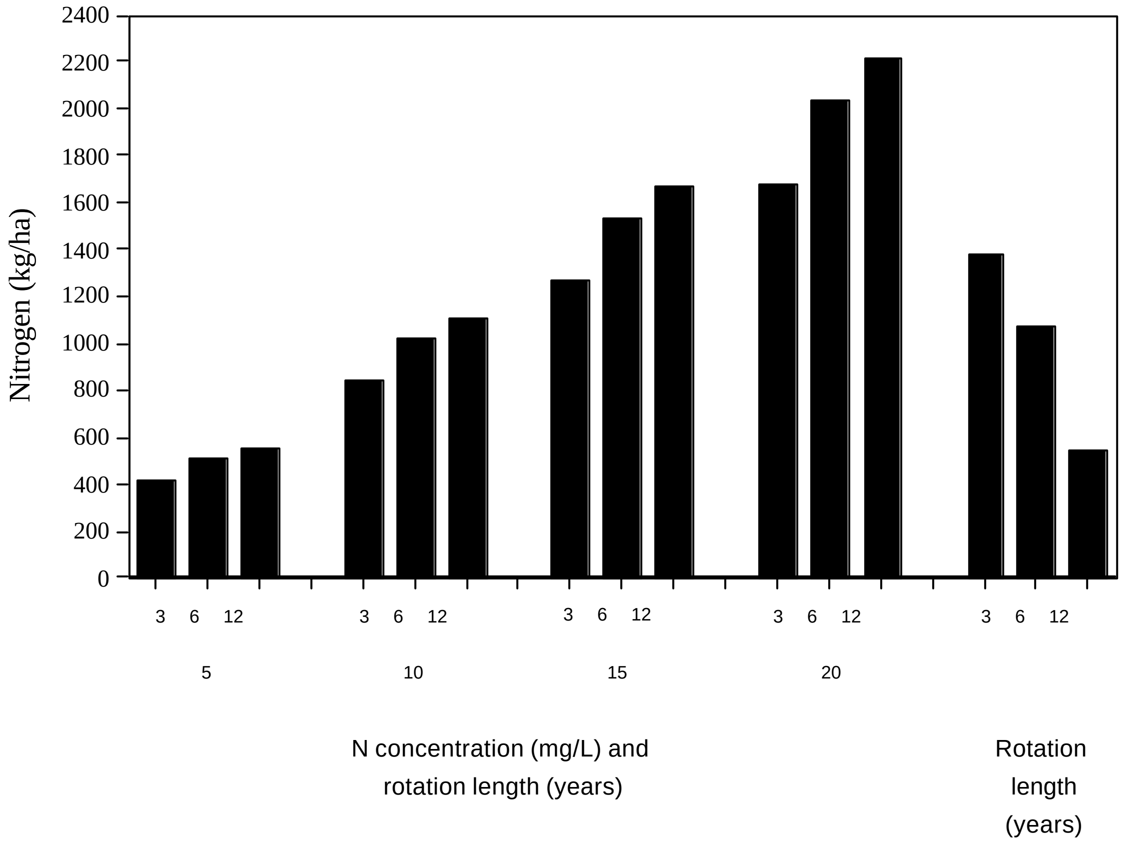
Coppice growth rates for both species were between 1.8 and 5.8 times greater than those of the trees at age 1 year (Figure 1). At age 1 year, total above-ground biomass of the coppice in the four treatments varied between 5.1 and 7.8 Mg/ha (oven-dry weight), with the biomass of *E. globulus* being approximately 1.2 to 1.3 times that of *E. grandis* and the biomass of the 2667 sph treatment 1.2 to 1.3 times that of the 1333 sph treatment. Total biomass of the coppice at age 1 year was generally greater than that of the trees at age 1 year.

2.5 Nutrient sequestration in trees

Across species, above-ground elemental uptake by the trees generally increased approximately in proportion to biomass accumulation to age 4 years. Above ground elemental uptake by the coppice (age 1 year) was similar to that of the trees at the same age. At age 4 years, N accumulation was high in both *E. globulus* and *E. grandis*, varying between 320 and 450 kg/ha across species and densities. More than half of the accumulated N was held in foliage. However, the proportion of N in the stem will tend to increase with age, as this component eventually dominates total biomass.

Data from the present study can be used to model the effects of rotation length on N sequestration (and therefore potential removal in whole tree harvesting) under different scenarios of effluent irrigation. In the present study, rates of effluent disposal for the 3-, 6- and 12-year rotations are estimated to total 85, 100 and 110 over a 12 year period to optimize tree growth and minimize the build-up of salt in the root zone of the soil profile. The projected biomass production for a 12 year cycle of rotations at 3-, 6- and 12-years is 330, 390 and 350 Mg/ha respectively for *E. globulus* growing at an estimated peak MAI of 45 m^3 ha^{-1} yr^{-1}.

Figure 2: ***Inputs of N in effluent and accumulation in tree biomass over a 12-year cycle of rotations of Eucalyptus globulus at Shepparton.***



The estimated input of N in effluent of varying concentrations, in relation to the amount of N sequestered in the potentially harvestable biomass produced under the 3 rotation lengths (Figure 2) indicates that: (i) N sequestration in potentially harvestable biomass is maximized for very short rotations (3 years), (ii) only for effluent N concentrations of less than approx. 15 mg/L can short rotations ensure that N inputs are approximately balanced by N removals in harvested biomass, and (iii) for longer rotations (12 years), average effluent N concentrations need to be reduced to approximately 5 mg/L to achieve a similar balance of inputs and outputs.

3.0 CONCLUSIONS

To age 4 years, growth and biomass accumulation in the Short Rotation Coppice Trial is greater in *E. globulus* than in *E. grandis*, and greater in the high density (2667 sph) treatment than the lower density (1333 sph) treatment. Growth rates and biomass accumulation in this trial continue to be amongst the highest in eucalypt plantations in Australia.

Growth and biomass accumulation in the coppice (age 1 year), growth and biomass accumulation was greater than in the trees at the same age. However, above-ground elemental uptake by the coppice did not vary substantially from that of the trees at age 1 year.

Trends in the depth of shallow groundwater have become apparent as monitoring has continued over almost 2 years. The effects of harvesting the 3-year rotation treatment on groundwater depth are also apparent.

The increases in soil salinity (to 80 cm depth) and development of surface soil sodicity after 3 years of effluent irrigation appear presently inconsequential for tree growth and irrigation management. However, increases in soil salinity will need to be controlled using an adequate irrigation leaching fraction.

Maximum nutrient sequestration in the biomass and potential maximum removal from the site would be achieved with whole-tree (above-ground components) harvesting of *E. globulus* planted densely and managed on a short rotation (approximately 3 years).

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