CHAPTER 6

FACTORS AFFECTING GERMINATION AND EARLY GROWTH -GLASSHOUSE EXPERIMENTS - RESULTS AND DISCUSSION

6.1 Introduction

It was apparent that distinct differences in substrate characteristics existed (Tables 5.1 and 5.2). These differences may affect germination and early growth through their influences on seedling emergence, root development and nutrition. Experiments 1 to 3 describe the extent to which these spoil characteristics affect the germination and early growth of two tree species which occurred naturally on sites prior to mining and how these characteristics are ameliorated by fertilizers and soil conditioners.

Experiments 4 to 6 examine the growth and survival of planted seedlings and have the following objectives :

(1) to compare the effects of different substrates on the survival and growth of planted seedlings for two species;

(2) to assess which nutrients are limiting to the early growth of planted seedlings for substrates from Hunter Valley No. 1 and C.S.R. Lemington Collieries; and

(3) to assess the optimum rates of fertilizer addition to correct nutrient deficiency on three substrates from C.S.R. Lemington Mine.

6.2 Glasshouse Experiment 1. Effect of Nitrogen, Phosphorus and Substrate Characteristics on Germination and Early Growth.

6.2.1 Objective

To test the effect of different rates of N and P on the germination and early growth of two native tree species sown into three substrates from Hunter Valley No. 1. Mine.

6.2.2. Results

Relevant F values are shown in Appendix 2(i).

Germination commenced six days after sowing. No new germination occurred within the week prior to harvesting.

Both species reacted similarly to the different substrates in terms of germination per cent and germination energy. The shale material was superior in all cases, while the topdressing material was inferior in all cases (Table 6.1).

There was a significant interaction at the five per cent level between species, substrate and N for germination per cent (Table 6.2). *E. maculata* showed a significant response to changing N levels on Sandstone (2) with N5 and N10 giving the best result; varying the level of N had no significant effect on the germination of this species on either Topdressing (1) or Shale (3). In contrast N had no significant effect on the germination per cent of *C. glauca* on any of the substrates.

P had a more pronounced and direct effect on germination (Table 6.3). Varying the rate of P significantly affected the germination of *E. maculata* but not *that of C. glauca*. The addition of P significantly depressed germination of *E. maculata* at the one per cent level, there being no significant difference in germination between the levels of P added. Although the results for *C. glauca* were not significant, there was an increasing trend with increasing levels of added P. This trend may have become significant at higher levels of P.

Table 6.1 Effect of three substrates from Hunter Valley No. 1 Colliery on germination per cent and germination energy for *E. maculata* and *C. glauca*. Data are means for combined N and P treatments.

		SUBSTRATE			
	Species	Topdressing (1)	Sandstone (2)	Shale (3)	Means
Germination	E. maculata	40.00(B)	47.50(B)	57.00(A)	48.17
%	C. glauca	40.37(B)	42.50(B)	55.87(A)	46.25
Germination	E. maculata	1.57(B)	2.22(A)	2.18(A)	1.99
Energy	C. glauca	1.50(B)	1.86(A)	2.12(A)	1.83

L S D's	Germination % (Substrate - Means of 16)	Germination Energy (Substrate - Means of 16)
$P \leq 0.05$	6.84	0.33
$P \leq 0.01$	9.37	0.46

Note: In each row, values marked with the same letter are not significantly different for $P \leq 0.05$

Table 6.2 Effect of N and substrate on the germination per cent of *E.maculata and C. glauca.* Data are means for combined P treatments.

	SUBSTRATE			
Species	Topdressing(1)	Sandstone(2)	Shale(3)	Means(N)
E. maculata				
N0	45.00	35.00	60.50	46.83(A)
N5	39.00	52.00	55.00	48.67(A)
N10	35.50	61.00	52.50	49.67(A)
N20	40.50	42.00	60.00	47.50(A)
Means (S)	40.00(B)	47.50(B)	57.00(A)	
C. glauca				
N0	40.50	45.50	55.00	47.00(A)
N5	34.50	39.50	57.50	43.83(A)
N10	43.00	41.50	59.50	48.00(A)
N20	43.50	43.50	51.50	46.17((A)
Means (S)	40.37(B)	42.50(B)	55.87(A)	
Combined Species				
N0	42.75	40.25	57.75	46.92(A)
N5	36.75	45.75	56.25	46.25(A)
N10	39.25	51.25	56.00	48.83(A)
N20	42.00	42.75	55.75	46.83(A)
Means(S)	40.19(B)	45.00(B)	56.44(A)	

L S D's	Sub.x N tables Indiv. sp. (Mns.of 4)	Sub.x N tables Comb. sp. (Mns.of 8)	Mns.ofN(N) Indiv. sp. (Mns. of 12)	Mns.of N(N) Comb. sp. (Mns. of 24)
$P \le 0.05$	13.68	9.68	7.90	5.59

	Mns. of Substrate (S) Indiv. sp. (Mns. of 16)	Mns. of Substrate (S) Comb. sp. (Mns. of 32)
$P \le 0.05$	6.84	4.84

Note : In each column or row values with the same letter are not significantly different for $P \le 0.05$.

Table 6.3 Effect of P on the germination per cent of *E. maculata* and *C. glauca*. Data are means for combined N treatments and combined substrates.

	Germination %		
Level of P	*E. maculata*	*C. glauca*	Means (P)
P0	59.50	45.00	52.25(A)
P5	42.67	42.83	42.75(C)
P10	42.83	47.33	45.08(BC)
P20	47.67	49.83	48.75(AB)
Means (Sp.)	48.16(A)	46.25(A)	

L S D's (Sp.)	Species x P Table (Means of 12)	Means (P) (Means of 24)	Species Means (means of 48)
$P \leq 0.05$	7.90	5.59	3.95
$P \leq 0.01$	10.82	7.65	5.41

Note: In each column or row values marked with the same letter are not significantly different for $P \leq 0.05$.

The germination energy for both species was not affected by N, but it was affected by varying the rate of P. In addition to the strong main effect of P, there was also a significant species by P by substrate interaction (Table 6.4).

Varying the levels of P had no effect on germination energy of *E. maculata* on Sandstone (2). However, adding P depressed germination energy on Topdressing (1) and Shale (3).

P addition did not affect the germination energy of *C. glauca* on Topdressing (1) and Sandstone (2). However, both P10 and P20 significantly ($P \leq 0.05$) improved germination on Shale (3).

Earlier germination per cent figures include all surface-emerged seedlings. However, some of these seedlings died prior to harvesting. Post-emergence losses (combined species) as measured at harvesting were : Topdressing (1) = 14.3%, Sandstone (2) = 11.6% and Shale (3) = 10.0%. Analysis of survival per cent gave the same trends as for germination per cent.

The effects of substrate on total plant dry weight, root/shoot ratio and total root and shoot dry weights are shown in Table 6.5 Plates 6.1, 6.2 and 6.3 show the effect of four rates of N and P on *E. maculata* seedlings.

Shale (3) produced consistently superior total plant weights for both species while Sandstone (2) was consistently inferior. In order to assess more accurately the source of this variation, root and shoot weights were examined separately (Table 6.5). For *E. maculata* substrate differences were largely attributable to differences in shoot weight. Root weight was less sensitive to substrate differences. For *C. glauca* both root and shoot weight responded similarly to substrate differences.

Sandstone (2) had consistently higher root/shoot ratios for both species. Topdressing (1) had consistently lower ratios and this was

Table 6.4 Effect of P and substrate on the germination energy of *E. maculata* and *C. glauca*. Data are means for combined N treatments.

Species	Level of P	SUBSTRATE Topdressing(1)	Sandstone(2)	Shale(3)	Means(P)
E. maculata	P0	2.78	2.60	3.06	2.81(A)
	P5	0.86	2.00	1.78	1.55(B)
	P10	1.04	1.99	1.93	1.65(B)
	P20	1.61	2.30	1.97	1.96(B)
Means (S)		1.57(B)	2.22(A)	2.18(A)	
C. glauca	P0	1.52	1.64	1.57	1.58(B)
	P5	1.38	2.11	1.44	1.64(B)
	P10	1.36	2.14	2.69	2.06(A)
	P20	1.72	1.54	2.79	2.02(A)
Means (S)		1.50(B)	1.86(A)	2.12(A)	
Combined Species	P0	2.15	2.12	2.32	2.19(A)
	P5	1.12	2.06	1.61	1.60(C)
	P10	1.20	2.06	2.31	1.86(BC)
	P20	1.67	1.92	2.38	1.99(AB)
Means (S)		1.53(B)	2.04(A)	2.16(A)	

L S D's	Indiv. sp Sub. x P Tbls. (Mns.of4)	Indiv.sp Mns.of Sub(S) (Mns.of16)	Indiv.sp Mns.of P(P) (Mns.of12)
$P \leq 0.05$	0.67	0.34	0.39
	Comb. sp. Sub.x P Tbls (Mns. of 8)	Comb. sp. Mns.ofSub(S) (Mns.of 32)	Comb. sp. Mns.of P (P) (Mns.of 24)
$P \leq 0.05$	0.47	0.24	0.27

Note: In each column or row values marked with the same letter are not significantly different for $P \leq 0.05$.

Table 6.5 Effect of substrate on total plant dry weight, root/shoot ratio and total root and total shoot dry weights for *E. maculata* and *C. glauca* growing on three substrates from Hunter Valley No.1 Colliery. Data are means for combined N and P treatments.

		SUBSTRATE			
Growth Variable	Species	Top dressing(1)	Sand stone(2)	Shale(3)	Means (Sp.)
Total Plant Weight (g)	*E. maculata*	6.14	3.27	5.42	4.94(A)
	C. glauca	2.15	1.89	3.19	2.41(B)
Means (S)		4.14(A)	2.58(B)	4.31(A)	
Root/Shoot Ratio	*E. maculata*	0.21	0.60	0.53	0.45(B)
	C. glauca	0.43	0.54	0.53	0.50(A)
Means		0.32(B)	0.57(A)	0.53(A)	
Total Root Weight (g)	*E. maculata*	1.04	1.20	1.88	1.37(A)
	C. glauca	0.64	0.66	1.10	0.80(B)
Means		0.84(B)	0.93(B)	1.49(A)	
Total Shoot Weight (g)	*E. maculata*	5.10	2.07	3.53	3.57(A)
	C. glauca	1.51	1.23	2.09	1.61(B)
Means		3.30(A)	1.65(C)	2.81(B)	

L S D's		Sub. x Sp. Table (Mns. of 16)	Sub. Means (S) (Mns. of 32)	Species Means (Mns. of 48)
Total Plant Weight	$P \leq 0.05$	0.78	0.55	0.45
	$P \leq 0.01$	1.07	0.76	0.62
Root / Shoot	$P \leq 0.05$	0.06	0.03	0.04
	$P \leq 0.01$	0.08	0.05	0.045
Total Root Weight	$P \leq 0.05$	0.26	0.18	0.15
	$P \leq 0.01$	0.36	0.25	0.21
Total Shoot Weight	$P \leq 0.05$	0.57	0.40	0.33
	$P \leq 0.01$	0.78	0.55	0.45

Note : For each variable and within each row or column values marked with the same letter are not significantly different for $P \leq 0.05$.

N0P0 **N5P5** **N10P10** **N20P20**

Plate 6.1 The response of *E. maculata* seedlings grown on Topdressing (1) from Hunter Valley No. 1 Mine to applied N and P.

N0P0 **N5P5** **N10P10** **N20P20**

Plate 6.2 The response of *E. maculata* seedlings grown on Sandstone (2) from Hunter Valley No. 1 Mine to applied N and P.

N0P0 **N5P5** **N10P10** **N20P20**

Plate 6.3 The response of *E. maculata* seedlings grown on Shale (3) from Hunter Valley No. 1 Mine to applied N and P.

more pronounced for *E. maculata* than for *C. glauca*. Substrate effects were the major cause of variation in root/shoot ratio for both species. From the results it was apparent that, for *E. maculata*, the high root/shoot ratio for Sandstone (2) was produced by a low shoot weight rather than a high root weight. For topdressing (1) the converse was true with high shoot weight being responsible for the low root/shoot ratios. *C. glauca* showed similar results. The main difference between the two species was the very low root/shoot ratio of *E. maculata* on Topdressing (1) mentioned earlier.

The effects of N and P on total plant dry weight are shown in Table 6.6 Individual species analysis indicated that *E. maculata* seedlings were consistently heavier than *C. glauca* seedlings and that the two species responded differently to N and P.

Combined species analysis indicated that total dry weight was very significantly ($P \leq 0.01$) affected by N and P and there was a significant interaction between N and P which was independent of species. There were no significant interactions between fertilizer and substrate.

The combined species means indicate a general increase in total dry weight with increasing levels of N and P with an optimum response lying on a plateau between P10-P20 and between N10-N20. These results mainly relate to the strong response of *E. maculata* to applied N and P. At optimum rates of N and P the total weight of *E. maculata* seedlings was 2 - 3 times that of unfertilized seedlings. *C. glauca* did not show a significant response to varying levels of N and P although there was an apparent increasing trend with increasing rates of each element which was similar to that for *E. maculata*. Despite the absence of significant differences, at the optimum rate of N20-P20, the total weight of *C. glauca* seedlings was increased by 80% over that of unfertilized seedlings.

Further analysis of the results revealed that while both N and P had a very significant effect on root weight ($P \leq 0.01$) N had a more

Table 6.6 Effect of N and P on the total dry weight (g) of *E. maculata* and *C. glauca*. Data are means for combined substrates.

Species	Rate of P	RATE OF N N0	N5	N10	N20	Means (P)
E. maculata	P0	3.52	4.11	4.52	6.95	4.78(BC)
	P5	3.62	3.52	4.37	4.71	3.99(C)
	P10	2.99	5.77	7.40	4.77	5.23(AB)
	P20	3.98	4.75	5.44	8.87	5.76(A)
Means (N)		3.53(C)	4.47(B)	5.43(A)	6.32(A)	
C. glauca	P0	1.90	2.21	2.56	2.38	2.26(A)
	P5	2.24	1.59	2.40	2.09	2.08(A)
	P10	2.08	2.49	2.71	3.04	2.58(A)
	P20	2.56	2.08	2.87	3.40	2.73(A)
Means (N)		2.19(A)	2.09(A)	2.64(A)	2.72(A)	
Combined Species	P0	2.70	3.16	3.54	4.66	3.52(BC)
	P5	2.93	2.42	3.38	3.40	3.03(C)
	P10	2.53	4.13	5.06	3.91	3.91(BA)
	P20	3.27	3.42	4.15	6.13	4.24(A)
Means (N)		2.86(B)	3.28(B)	4.03(A)	4.52(A)	

L S D's	N x P Table Indiv. Sp. (Mns.of3)	N x P Table Comb. Sp. (Mns.of6)	Mns.of N and P Indiv. Sp. (Mns.of12)	Mns. of N and P Comb. Sp. (Mns.of24)
$P \leq 0.05$	1.81	1.28	0.90	0.64
$P \leq 0.01$	2.47	1.75	1.24	0.88

Note : Within each row or column values with the same letter are not significantly different for $P \leq 0.05$.

significant effect on shoot weight than P. The effect was stronger for *E.maculata*.

The results for root/shoot ratio were less conclusive than those for total dry weight and are shown in Table 6.7 The results show that when no fertilizer was added *E. maculata* had a higher root/shoot ratio than *C. glauca*. However, at optimum N and P levels root/shoot ratio differences were negligible. The effect of adding N and P varied with species. For *E. maculata* increasing levels of N in the absence of P produced lower ratios. For *C. glauca* the root/shoot ratio did not substantially change. Adding P in the absence of N also resulted in lower root/shoot ratios for *E. maculata* . The reverse applied for *C. glauca*. At optimum levels of N and P for total weight (N10 P10 to N20 P20) the root/shoot ratios for *E. maculata* were still significantly ($P \leq 0.05$) lower than for no fertilizer. At these levels of N and P the root/shoot ratio for *C. glauca* was similar to that for no fertilizer. For *E. maculata* the results reflect the stronger effect of increasing levels of N and P on shoot growth as opposed to root growth, as discussed earlier.

Analysis of the two species combined revealed an N x P interaction which was, however, only significant at the ten per cent level. The interaction was the result of a general decrease in root/shoot ratio with increasing levels of N, while increasing levels of P had no effect. This result again relates to the stimulating effect of increasing levels of N on shoot growth discussed earlier.

The results of an analysis of the levels of N, P, Ca, Mg, K, Na, Mn, Zn and Fe in the foliage of *E. maculata* seedlings at harvesting can be seen in Table 6.8. The results did not lend themselves to analysis of variance and hence only general trends are discussed.

Prior to fertilizer addition (N0 P0), plants in Topdressing (1) had much higher N and P levels than those in the other two substrates. The levels of N and P in Sandstone (2) and Shale (3) did not vary greatly. This variation in foliar nutrient concentrations does not

Table 6.7 Effect of N and P on root/shoot ratio for *E. maculata* and *C. glauca*. Data are means for combined substrates.

Species	Rate of P	RATE of N N0	N5	N10	N20	Means (P)
E. maculata	P0	0.62	0.50	0.39	0.35	0.47(A)
	P5	0.48	0.43	0.32	0.33	0.39(B)
	P10	0.40	0.52	0.41	0.51	0.46(A)
	P20	0.44	0.51	0.47	0.49	0.48(A)
Means (N)		0.49(A)	0.49(A)	0.40(B)	0.42(B)	
C. glauca	P0	0.48	0.47	0.42	0.44	0.45(B)
	P5	0.60	0.47	0.45	0.51	0.51(AB)
	P10	0.50	0.55	0.51	0.49	0.51(AB)
	P20	0.66	0.45	0.53	0.47	0.53(A)
Means (N)		0.56(A)	0.48(B)	0.48(B)	0.48(B)	
Combined Species	P0	0.55	0.49	0.40	0.40	0.46(A)
	P5	0.54	0.45	0.39	0.42	0.45(A)
	P10	0.44	0.53	0.46	0.50	0.48(A)
	P20	0.55	0.48	0.50	0.48	0.50(A)
Means (N)		0.52(A)	0.49(AB)	0.44(C)	0.45(BC)	

L S D's	N x P Table Indiv. Sp. (Mns.of3)	N x P Table Comb. Sp. (Mns. of6)	Mns.of N and P Indiv. Sp. (Mns.of12)	Mns. of N and P Comb. Sp. (Mns.of24)
$P \leq 0.05$	0.13	0.09	0.07	0.05
$P \leq 0.01$	0.18	0.13	0.09	0.06

Note : Within each row or column values with the same letter are not significantly different for $P \leq 0.05$.

Table 6.8 Levels of nutrients in the foliage of *E. maculata* seedlings grown in three substrates from Hunter Valley No. 1 Colliery, 98 days after sowing.

Fertil. Treat.	Subst -rate	N %	P ppm	N/P	Ca	Mg	K	Na	Mn	Zn	Fe
					Foliar Nutrient Concentration ppm						
N0P0	Top(1)	3.21	1360	24	5410	5220	11350	8555	430	85	115
	Sand(2)	0.85	900	9	6190	3840	6180	8840	300	70	350
	Shale(3)	0.89	725	12	7050	6570	5770	8430	275	80	1130
N5P0	Top(1)	2.63	1135	23	4810	4720	10400	8370	330	75	135
	Sand(2)	0.84	810	10	5970	4320	6470	9640	360	75	290
	Shale(3)	0.88	725	12	4990	4720	5510	7475	305	70	605
N10P0	Top(1)	2.55	1160	22	5570	5160	10800	8200	385	75	135
	Sand(2)	1.03	790	13	4410	3300	5710	7470	280	60	155
	Shale(3)	1.17	650	18	4820	4770	6020	7915	330	50	805
N20P0	Top(1)	2.47	1025	24	4830	4290	10740	7485	320	65	125
	Sand(2)	0.90	710	13	4750	3920	5950	8140	310	85	220
	Shale(3)	0.91	605	15	4380	4490	5350	7560	280	75	360
N20P20	Top(1)	2.39	1105	22	5320	3750	9530	6060	285	60	160
	Sand(2)	0.82	950	9	6290	5040	4660	7440	305	55	570
	Shale(3)	0.99	940	16	3930	4270	5680	5680	815	45	440

Note: (i) Analysis undertaken by the Wood Technology and Forest Research Division of the N.S.W. Forestry Commission.

(ii) Analysis undertaken on shoot material above cotyledon.

correspond with substrate N and P levels shown in Table 5.1. As an example, in Table 5.1, Topdressing (1) had a much lower total N than Shale (3) and lower P levels than the other two substrates.

The addition of N to Topdressing (1) resulted in a sharp drop in foliar N. The addition to Sandstone (2) and Shale (3) did not greatly affect foliar N levels.

The addition of P appeared to have a minimal effect on foliar P levels for all substrates.

For Topdressing (1) changes in the N:P ratio were small. Sandstone (2) had consistently low ratios over all treatments, while Shale (3) showed a general increase with increasing rates, with a substantial increase between No fertilizer and N20 P20.

In all fertilizer treatments except N20 P20 Topdressing (1) had the lowest foliar Fe concentrations and Shale (3) had the highest. Foliar Fe concentrations in Shale (3) were generally more than three to six times those for Topdressing (1).

With the exception of a general decline in Na concentration in seedlings in Topdressing (1) with increasing fertilizer levels no other clear patterns were apparent.

6.2.3 Discussion

Germination

Germination differences between *E. maculata* and *C. glauca* were expected. Species germination differences were recognized by Theophrastus, who lived from c. 372 to 287 BC. Many other researchers (e.g. Haigh 1983) have recognized that different species have different strategies of germination.

Substrate differences were the major cause of germination differences. For both species, Shale (3) was the most favourable substrate for germination, while Topdressing (1) was the least favourable. The reasons for differences in germination per cent and energy between substrates were not readily apparent although surface crusting was evident for all substrates on some pots during the final stages of the experiment. Surface crusting has been attributed by several authors (e.g. Emmerton 1983) to be a major factor in reducing germination on coal mine spoil. The effect of various chemical additives likely to affect surface crusting will be further examined in experiment 2. Other factors may also be involved. Differences in substrate moisture and temperature characteristics, even for short periods of time, may have had some effect, particularly on the rate of germination. Haigh (1983) stated that the rate of water uptake by seeds is initially dependent on the water potential gradient between the seed and its environment. Allerup (1958) also stated that water uptake becomes increasingly temperature dependent during its course. Consequently, even under glasshouse conditions, it is possible that differences in substrate physical characteristics (e.g. particle size composition, colour) may lead to differences in moisture availability and temperature, which may in turn affect germination. In addition to possible direct effects, differences in time to emergence may be further affected by competitive effects. In a closely spaced crop, Salter *et al.* (1981) demonstrated that differences in time to emergence was further reinforced by competitive growth throughout the development of the crop. With many pots having over 25 seedlings, competition effects within this experiment were likely.

Overall the germination of *E. maculata* seed was more sensitive to applied N and P than *C. glauca*. The addition of N and P generally disadvantaged the germination of *E. maculata*.

No single explanation can be given to explain adequately all the observed effects of N and P on germination. The positive germination response of *E. maculata* on Sandstone (2) at higher levels of N disagrees with the detrimental effect of applied N on the same species reported by

Lawson (1983) and in other species by Christensen (1974), Pulsford *et al.* (1965), and Ting (1945). The adverse effect of applied P on the germination of *E. maculata* conflicted with results by Lawson (1983) who showed a positive germination response for the same species.

Various researchers (Haigh 1983, Heydecker 1974, Ells 1963) have commented on the beneficial effects on germination by priming with various K salts and with polyethylene glycol. However, it is unlikely that those (or similar effects) applied in this experiment. If germination is regarded in the purely physiological sense of resumption of active growth by the embryo, it is doubtful whether this could be affected by nutrients (Brown and Johnston 1980, Hunter and Whiteman 1974). Germination, as discussed here, refers to the appearance of the seedlings above the ground, and therefore embraces not only germination proper but also the post-germination stage during which the hypocotyl elongates and carries the cotyledons above the soil surface. It is most likely that the influence of nutrients occurred during this immediate post-germination stage, although the actual mechanisms are unclear.

Early Seedling Growth

The relative suitability of substrates for early seedling growth differed from their relative suitability for germination. Both Topdressing (1) and Shale (3) gave plant weights superior to those of Sandstone (2). Considering the fact that seedlings in Topdressing (1) were slower to germinate, their growth rate must have been faster than for seedlings in the other two substrates to be comparable to Shale (3) and superior to Sandstone (2) at the end of the experiment. For this reason it can be summarised that, had the experiment been allowed to run longer the relative growth advantage of seedlings in Topdressing (1) would perhaps have become more apparent.

All substrates were considered deficient in N and P (Table 5.1) and observed growth responses to applied N and P were predictable. The significant growth response to N and P and the interaction observed between these two elements is in agreement with the findings of Bevege

(1983) and Irving (1986) who both showed a significant N by P interaction for several species on a range of coal mine spoil material in Queensland.

Seedlings grew better in Topdressing (1) prior to fertilizer addition than in the other two substrates. High levels of N and P in the foliage of *E. maculata* seedlings growing in Topdressing (1) prior to fertilizer addition (Table 6.8) combined with the higher total weights of these seedlings indicates that more N and P was available for plant growth than was the case for the other two substrates. This was despite relatively low initial levels of N and P in Topdressing (1) (Table 5.1). Differences in nutrient availability may be associated with differences in pH observed in Table 5.1.

It was apparent that plant dry weights increased with increasing levels of applied N and P for all three substrates. However, comparison of foliar N and P levels between N0 P0 and N20 P20 (optimum rate) did not show a corresponding increase in N and P levels. This effect may relate to the fact that foliar concentrations, as presented in Table 6.8, do not take cognizance of the major biomass differences that occurred between substrates and between fertilizer treatments (Plates 6.1, 6.2 and 6.3). Foliar concentrations in Table 6.8 do not reflect total nutrient uptake by plants and hence may not accurately reflect growth trends due to dilution of foliar nutrients in larger plants. This dilution effect is apparent when foliar N concentrations for *E. maculata* in Topdressing (1) for N0 P0 and N20 P20 are compared (3.2% and 2.4% respectively - Table 6.8). When these concentrations were multiplied by shoot dry weight (2.2 g and 6.1 g respectively) it was apparent that seedlings in N0 P0 had only half the weight of N (7.04 g) when compared to seedlings in N20 P20 (14.64 g). In this regard, the proposal by Ward *et al.* (1985) that high leaf N concentrations generally suggest a better nutritional status and higher growth potential may not always apply.

Bell (1985) considered the ratio of foliar N and P to be a better guide to maximum yield. Assuming an optimum N:P ratio for *E. maculata* exists between (or around) 18 (Wise and Pitman 1981) and 20 (Schönau 1981) then at the optimum treatment of N20 P20 both Topdressing

(1) and Shale (3) conform reasonably closely. Seedlings on Sandstone (2) appear to be deficient in N. The low ratio for Sandstone (2) agrees with the relatively low dry weights of *E. maculata* seedlings at optimum fertilizer levels. Consequently, the foliar N:P ratio provides a more useful index of plant vigour than either N and/or P concentrations.

It was apparent that even at the optimum levels of N and P significant growth differences existed between substrates. The inability of applied N and P to rectify differences in plant growth suggests either that other nutrients are deficient or that other restricting chemical and/or physical substrate differences exist. Glasshouse experiments 4 and 5 confirmed that other elements were deficient.

Early Survival

Adjusting results for the number of surviving seedlings (as opposed to total germinants) had no effect on results. The symptoms of necrotic seedlings closely resembled the symptoms of fungal induced 'damping off' commonly observed in nurseries. In this regard, the higher loss rate observed in the topdressing material may be associated with expected higher populations of soil micro-organisms in this material compared to the other two substrates. It was apparent that once seedlings developed true leaves, mortality declined considerably. This suggested that new emergents were more sensitive to damping off in the cotyledon stage. This is commonly the case in most amenity and production nurseries.

6.2.4 Summary

1. Germination differences were apparent between substrates but the effect could not be attributed to any consistent or obvious physical or chemical soil factor.

2. There was no consistent germination advantage in adding N and P.

3. Growth differences were apparent between substrates but the relative suitability of substrates for growth varied from that for germination. Growth differences could not be attributed to any physical or chemical spoil factor.

4. There was a strong growth response, particularly by *E. maculata* to applied N and P.

5. The ratio of foliage N and P concentrations was considered a more useful guide to plant biomass response to fertilizer addition than either N or P concentrations.

6.3 Glasshouse Experiment 2. Effect of Soil Amendments on Germination, Early Growth and Survival

6.3.1 Introduction and Objective

Surface hardening was observed on all three spoil materials in glasshouse experiment 1. Surface hardening has been shown to be a major factor in restricting emergence (Emmerton 1983).

An experiment was designed to test the effect of three different soil amendments, considered likely to reduce surface hardening, on the germination and early growth of two species in three substrates used in the previous experiment.

6.3.2 Results

Relevant F values are shown in Appendix 2(ii).

Substrate differences were again the major source of differences in germination although the effect of substrate on germination per cent varied from that observed in glasshouse experiment

1. Sandstone (2) (38.5%) had superior germination to Topdressing (1) (29.2%) which was in turn superior to Shale (3) (17.5%).

C. glauca (33.1%) had a higher germination percentage than *E. maculata* (23.7%).

Seedling mortality was high compared to glasshouse experiment 1. However, per cent mortality was similar for all substrates. This resulted in relative substrate survival per cent being the same as for germination per cent.

Soil amendment had no significant effect on germination per cent or survival per cent. However, there was a significant effect on germination energy (Table 6.9). Terrasorb produced superior germination energy for both species and on all three substrates.

The effect of substrate on total plant weight and root/shoot ratio were similar to those observed in glasshouse experiment 1. However, as a result of the relatively long duration of this experiment (184 days) compared to other experiments, the superior growth trend observed for seedlings in Topdressing (1) in glasshouse experiment 1 had longer to assert itself. Consequently, Topdressing (1) produced superior plants. Sandstone (3) again produced inferior plants.

Terrasorb also had a beneficial effect on root weight, shoot weight, total weight and average weight (Table 6.10). For root weight, shoot weight and total weight the effect was common to both species and to all three substrates. This is interpreted as a flow-on effect from enhanced germination energy observed earlier, leading to larger plants at harvesting. When total weight was adjusted for the number of surviving seedlings (average weight) there were significant species x soil amendment (Table 6.11) and substrate x soil amendment (Table 6.12) interactions. These interactions indicated that for average weight the beneficial effect of Terrasorb was restricted to *E. maculata* on Topdressing (1).

Table 6.9 Effect of four soil amendments on germination energy. Data are means for combined species and substrates.

	Soil Amendment	Germination Energy
	Terrasorb	0.84 (A)
	Nil	0.67 (AB)
	Gypsum (3t ha^{-1})	0.50 (B)
	Alginure	0.50 (B)
	Gypsum (6t ha^{-1})	0.49 (B)
L S D	$P \leq 0.05$	0.23

Note : Values marked with the same letter are not significantly different for $P \leq 0.05$.

Table 6.10 Effect of four soil amendments on plant dry weights. Data are means for combined species and substrates.

Soil Amendment	Variable Root wt. (g)	Shoot wt. (g)	Total wt. (g)	Average wt. (g)
Alginure	1.20 (B)	3.81 (B)	5.01 (B)	0.51 (B)
Gypsum (3t ha^{-1})	1.42 (B)	3.73 (B)	5.14 (B)	0.41 (B)
Gypsum (6t ha^{-1})	1.36 (B)	3.42 (B)	4.79 (B)	0.37 (B)
Nil	1.76 (B)	4.40 (B)	6.16 (B)	0.53 (B)
Terrasorb	3.04 (A)	7.25 (A)	10.29 (A)	1.08 (A)
L S D's $P \leq 0.05$	0.74	1.63	2.18	0.34

Note : Values in the same column and marked with the same letter are not significantly different for $P \leq 0.05$.

Table 6.11 Effect of four soil amendments on the average plant dry weight of *E. maculata* and *C. glauca.* Data are means for combined substrates.

Soil Amendment	Species *E. maculata* (g)	*C. glauca* (g)	Means (C)
Alginure	0.85	0.17	0.51 (B)
Gypsum (3t ha^{-1})	0.68	0.13	0.41 (B)
Gypsum (6t ha^{-1})	0.64	0.10	0.37 (B)
Nil	0.87	0.19	0.53 (B)
Terrasorb	1.84	0.33	1.08 (A)
Means (Sp.)	0.98 (A)	0.18 (B)	

L S D's	Species Means (Sp.) (Mns. of 20)	Soil Amend.Means (C) (Mns. of 12)	Sp.x Soil Amend. Table (Mns. of 6)
$P \leq 0.05$	0.21	0.34	0.48

Note: Values marked with same letters are not significantly different for $P \leq 0.05$.

Table 6.12 Effect of four soil amendments on average plant dry weight for three substrates from Hunter Valley No. 1 Colliery. Data are means for combined species.

Soil Amendment	Substrate Topdressing(1) (g)	Sandstone(2) (g)	Shale(3) (g)	Means(C)
Alginure	0.82	0.29	0.41	0.51(B)
Gypsum (3t ha^{-1})	0.71	0.39	0.12	0.41(B)
Gypsum (6t ha^{-1})	0.58	0.39	0.15	0.37(B)
Nil	0.92	0.51	0.16	0.53(B)
Terrasorb	2.19	0.62	0.44	1.09(A)
Means (S)	1.04(A)	0.44(B)	0.25(B)	

L S D's	Means of Substrates (S) (Mns. of 20)	Means of Soil Amend(C) (Mns. of 12)	Sub. x Soil Amend. Table (Mns. of 4)
$P \leq 0.05$	0.26	0.34	0.59

Note : In each row or column values marked with the same letter are not significantly different for $P \leq 0.05$.

Root/shoot ratio was not significantly affected by soil amendment.

6.3.3 Discussion

Germination

As found in glasshouse experiment 1, substrate differences were again the major cause of germination differences. The change in substrate germination levels from those observed for the same substrate in glasshouse experiment 1 may relate to weathering of the substrates and changed glasshouse conditions such as temperature.

Terrasorb, being a water absorbing polymer, can absorb up to 200 times its own weight of water (manufacturer's pamphlet). This may have resulted in improved water availability leading to better imbibition and higher germination energy by seeds in the Terrasorb treatment. In addition when Terrasorb comes into contact with water there is considerable expansion of the granules and a distinct bubbling/upheaval effect on the surface and this may result in a more rapid emergence of the hypocotyl. The effect on germination energy may have occurred through a reduction in surface crusting or a more general decompaction of the treated layer (or both). With finely sorted substrate materials, crusting could have occurred due to re-sorting of particles under the influence of watering with a consequent reduction in pore space. This could occur in essentially coarse textured, low clay materials so that the flocculation/dispersion phenomena described by Emmerton (1983) need not be involved. This could help explain why gypsum had no effect, i.e. crusting was a physical rather than a chemical effect. Applied gypsum had no effect on germination, again confirming the physical nature of the effect of Terrasorb on germination energy.

Early Growth

As in glasshouse experiment 1, substrate differences were again the major cause of growth differences. The superior growth of seedlings in Topdressing (1) was even more apparent in this experiment due to the longer duration of the experiment.

Following the beneficial effect of Terrasorb on germination energy, the subsequent enhanced effect of Terrasorb on root, shoot and total weights was predictable. The broad effect of Terrasorb on germination energy for both species and for all three substrates confirms the physical nature of the effect proposed earlier. With this in mind, the specific beneficial effect of Terrasorb on the growth of *E. maculata* in Topdressing (1) was surprising. This effect may relate to one or more of the following.

(i) Reduced competition between *E. maculata* seedlings due to a smaller number of surviving seedlings, resulting in larger individual seedlings. This effect would not appear until total weight was adjusted for the number of surviving seedlings. This result would have been encouraged by the relatively long duration of this experiment allowing competitive effects to be more strongly expressed.

(ii) The statistical effect of high *E. maculata* average weights compared to *C. glauca* (Table 6.11). This would facilitate the greater likelihood of significant differences between treatments for *E. maculata*.

(iii) Superior growth of seedlings generally on Topdressing (1) (Table 6.12).

Per cent mortality was almost identical on all three substrates, suggesting that losses resulted from general glasshouse causes e.g. damping off, rather than specific substrate effects.

Terrasorb overcame one of the disadvantages of Topdressing (1) described in glasshouse experiment 1, i.e. low germination energy. However, the important disadvantages of low germination per cent and unfavourable root/shoot ratio were not obviated.

6.3.4 Summary

1. Substrate differences again affected germination but the relative order of substrate germination varied from glasshouse experiment 1.

2. Terrasorb increased germination energy on all three substrates and a physical effect was implied.

3. Terrasorb only improved growth on Topdressing (1). This result could not be attributed to any physical or chemical spoil characteristics.

6.4 Glasshouse Experiment 3. Effect of Different Watering Regimes on the Physical and Chemical Characteristics of Substrates.

6.4.1 Introduction

Glasshouse experiments 1 and 2 indicated differences in germination between substrates. However, there was no readily obvious physical or chemical factor which explained these differences. The effect of Terrasorb on germination energy in glasshouse experiment 2 also intimated a physical change in surface spoil characteristics although the actual mechanism was unclear.

6.4.2. Objective

An experiment was designed to examine changes in substrate physical and chemical characteristics under two different watering regimes over time using similar substrates to those used in glasshouse experiments 1 and 2 (substrates from Hunter Valley No. 1 Mine). The primary objective was to relate any changes in substrate characteristics to germination results observed in glasshouse experiment 1.

6.4.3 Results

Effect of Watering Regime and Substrate on Crust Strength

Relevant F values are shown in Appendix 2(iii).

Substrate crust strength was dependent on the type of watering regime and time. The highly significant interaction of these factors is shown in Figure 6.1

For the water 1 day treatment, the crust strength of all substrates increased with time as soil moisture decreased. At day 11, Shale (6) had the highest crust strength, while Topdressing (4) had the lowest crust strength. Sandstone (5) and Shale (6) dried faster than Topdressing (4) and the rate of increase of surface crust strength of both these materials was greater than Topdressing (4) up to 11 days. Despite substrate drying being incomplete after 11 days a comparison of the graphs suggest that relative substrate crust strength differences, apparent in the later stages of drying, would have been maintained.

Watering for five consecutive days maintained crust strengths at low levels over the first five days. After cessation of watering, crust strengths showed minimal increase until day 7. At this time values increased rapidly. However, levels did not approach those in the watered 1 day treatment due to higher moisture contents at the close of the experiment.

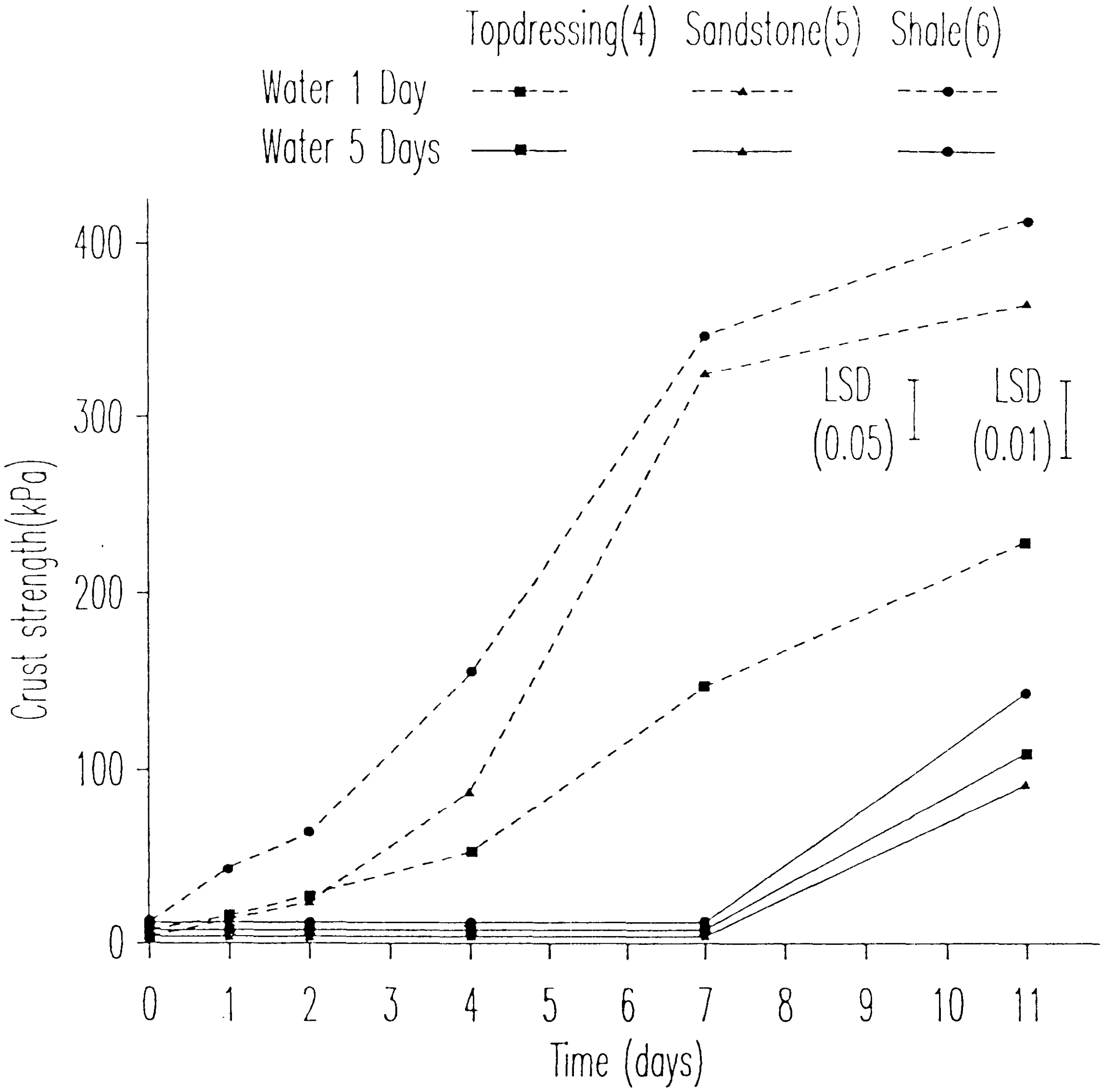

Figure 6.1 Effect of substrate, time and watering regime on surface crust strength for three substrates from Hunter Valley No. 1 Colliery. Data are means of five penetrometer readings per time interval.

Comparing the four days after which significant drying commenced (day 1 and day 7 for the water 1 day and water 5 days treatments, respectively) it was apparent that the rate of increase in surface crust strength varied between substrates. The rate of increase was approximately the same for Shale (6) i.e. the Shale (6) response was independent of the watering regime. However, for both Topdressing (4) and Sandstone (5) the rate of increase was much greater for the water 5 days treatment. Differences in the rate of substrate crust strength development under different watering regimes explained the interactive effect noted in Figure 6.1 between substrate, watering regime and time.

Effect of Particle Size Composition on Crust Strength

Due to the lack of replicated measurements, no statistical analysis of substrate particle size percentages was undertaken. However, the results do indicate trends and these can be seen in Table 6.13.

Prior to wetting, Topdressing (4) had a higher clay and silt component than the other two substrates together with lower fine and coarse sand components. Shale (6) had almost twice the coarse sand component of both Topdressing (4) and Sandstone (5). Comparing the pre-wet and water 1 day results revealed a general increase in the clay and fine sand component in the surface layer 11 days after watering. This was associated with a general decrease in the silt component. Shale (6) showed the most dramatic change in surface particle composition, the most notable change being a 45% decrease in the silt component 11 days after wetting. This was associated with a general increase in per cent composition of the other three particle sizes.

However, this result may well be anomalous as it disagrees with the general pattern and it is difficult to envisage a mechanism causing such a particle size change which is related to one watering episode. However, the result could be due to re-sorting effects. Topdressing (4)

Table 6.13 Particle size analysis of the surface 5mm before and after wetting for two watering regimes and three substrates from Hunter Valley No. 1 Colliery.

Watering regime/ time	Particle Size	Substrate		
		Topdressing (4)	Sandstone (5)	Shale (6)
Prior to Wetting	clay	36	27	30
	silt	26	22	22
	fine sand	26	38	24
	coarse sand	12	13	24
After 11 days water 1 day	clay	39	27	34
	silt	21	20	12
	fine sand	28	40	28
	coarse sand	12	13	26
After 11 days water 5 days	clay	39	28	31
	silt	24	21	20
	fine sand	26	41	25
	coarse sand	11	10	24

showed less dramatic but similar changes in composition. Sandstone (5) showed negligible change.

The water 5 days treatment did not conform to the trends emerging in the water 1 day treatment. Changes between the water 1 day and water 5 days regimes for Shale (6) included an increase in the silt content for all three substrates. This effectively reversed particle size changes that occurred in the water 1 day treatment. Consequently, there was little difference in the composition prior to wetting and for the water 5 day treatment for Shale (6). The two other substrates also showed little change.

The similar response of Sandstone (5) and Shale (6) combined with the large size of the samples lends support to the sensitivity of the above results in indicating real changes despite the absence of confidence limits.

Effect of Watering Regime, Substrate and Time on pH

The effect of substrate and time on pH can be seen in Figure 6.2. The results for each substrate were averaged for each watering treatment.

The pH varied with substrate and over time. Initial substrate pH levels were different. Topdressing (4) was neutral. Shale (6) was slightly alkaline and Sandstone (5) was moderately alkaline. Immediately following watering the pH of all substrates rose dramatically. From day 1 onwards, levels began to drop steadily, the rate of decline slowing as the rate of drying decreased. At day 11 pH levels were still dropping slowly although the original pre-wet levels had not been reached. Shale (6) showed the greatest increase following wetting and the greatest decrease upon drying.

Figure 6.3 shows the specific effect of each watering regime on average substrate pH over time. Both treatments rose to similar pH

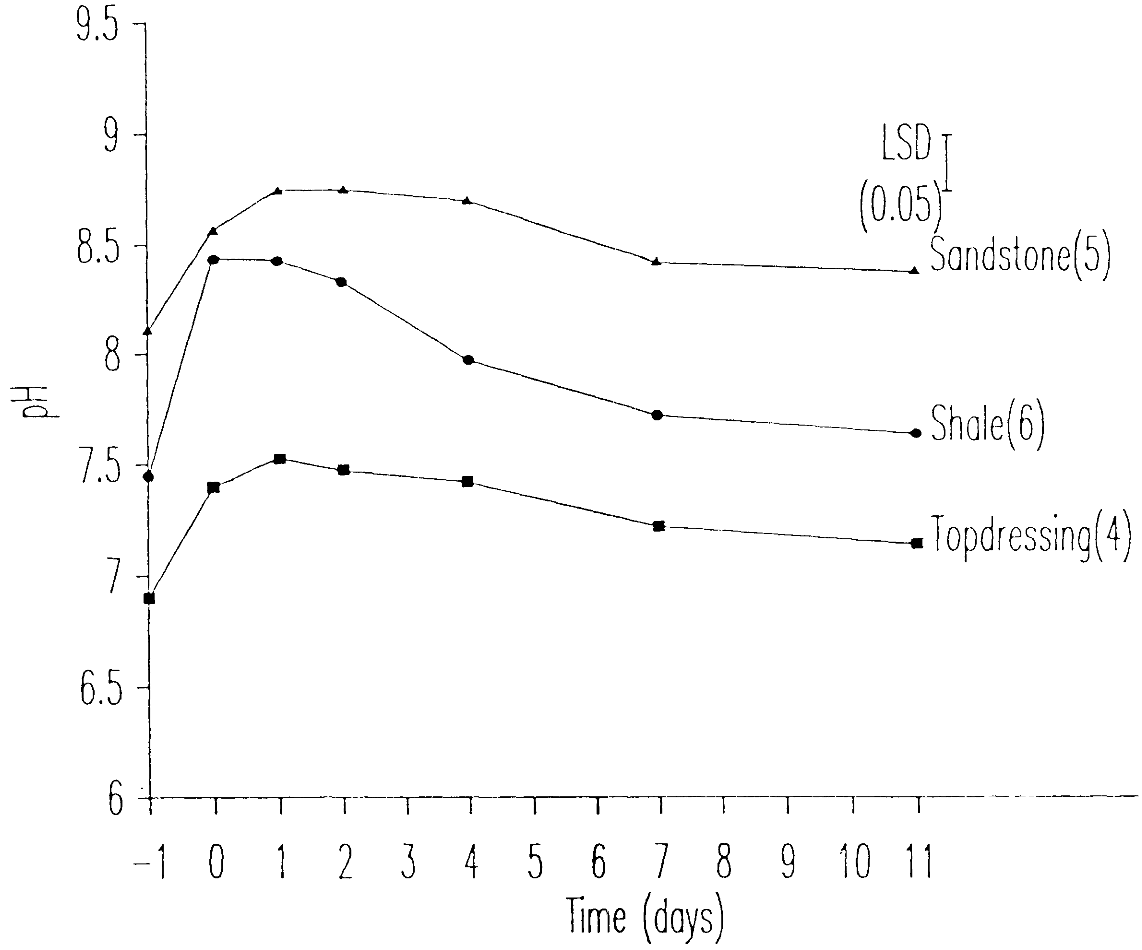

Figure 6.2 Effect of substrate and time on pH for three substrates from Hunter Valley No. 1 Colliery. Data are mean pH for combined watering regimes.

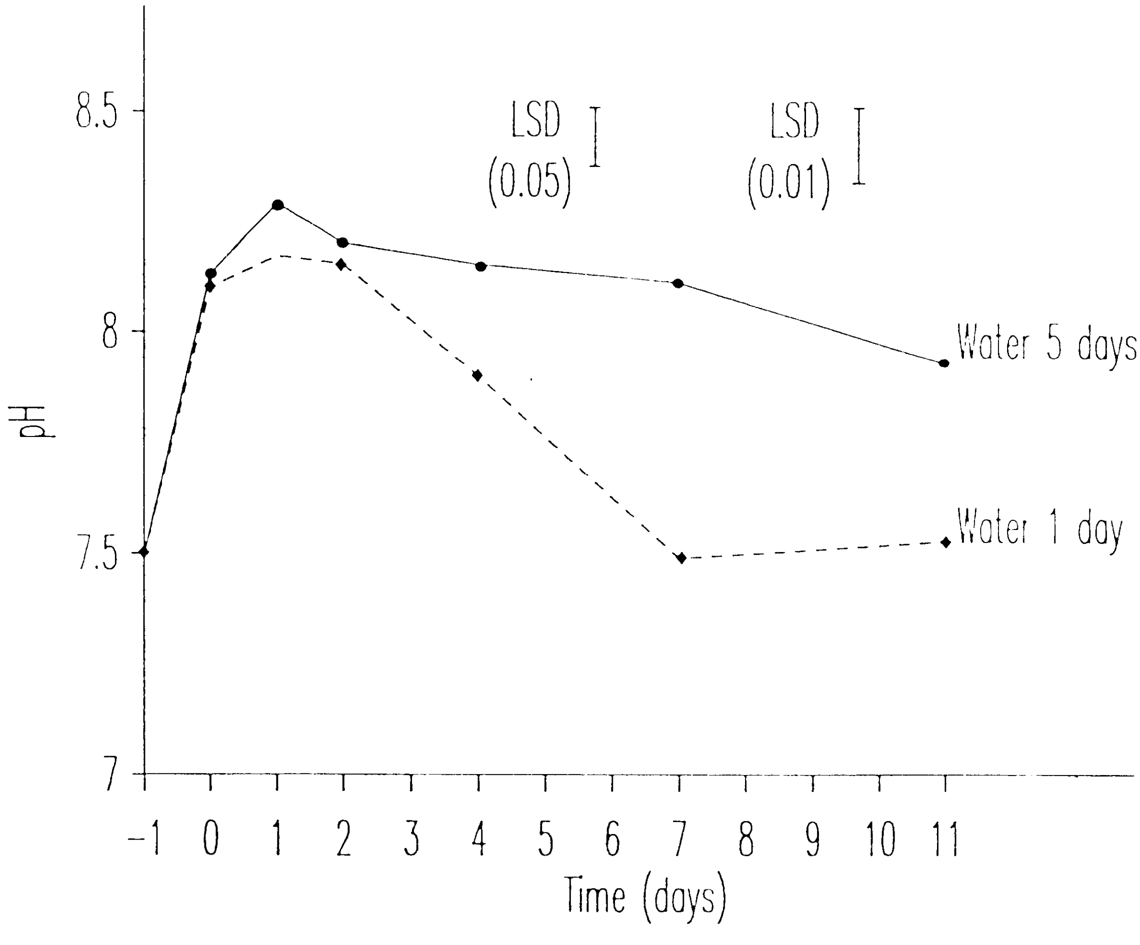

Figure 6.3 Effect of watering regime and time on pH. Data are mean pH combined over substrates.

levels after watering. The water 1 day treatment quickly dropped upon peaking and had returned to the original level after 7 days. Continued watering maintained higher levels. After watering ceased on day 5, pH levels dropped slowly and the rate of decrease was slower than for the water 1 day treatment.

Effect of Watering Regime, Substrate and Time on Salinity

EC ($\mu S\ cm^{-1}$) of material in the surface 5 mm was used as an assessment of salinity. Substrate had a strong main effect on salinity. There were significant interactions between watering regime and time (Figure 6.4) and substrate and time (Figure 6.5).

There was a sharp drop in salinity immediately following watering. After day 2 salinity increased rapidly for the water 1 day treatment and rose to levels above pre-watering levels. Levels stabilized after 7 days. For the water 5 day treatment levels rose slowly following the initial decline in salinity. The rate of increase was considerably slower than for the water 1 day treatment and salinity levels at day 11 had not reached pre-watering levels. Figure 6.5 indicates that the salinity of Shale (6) increased much more rapidly than the other two substrates, and the rate of increase in salinity shown in Figure 6.4 was largely influenced by the effect of Shale (6).

There was a strong similarity between variation in crust strength with time (Figure 6.1) and variation in salinity with time (Figure 6.4). There was an inverse relationship between salinity and pH variation (Figure 6.3) with time.

Effect of Substrate on Gravimetric Water Content

Substrate, watering regime and time all had highly significant main effects on gravimetric water content. There was an interactive effect between these three variables which, although not significant at the five per cent level, was significant at the ten per cent level. The

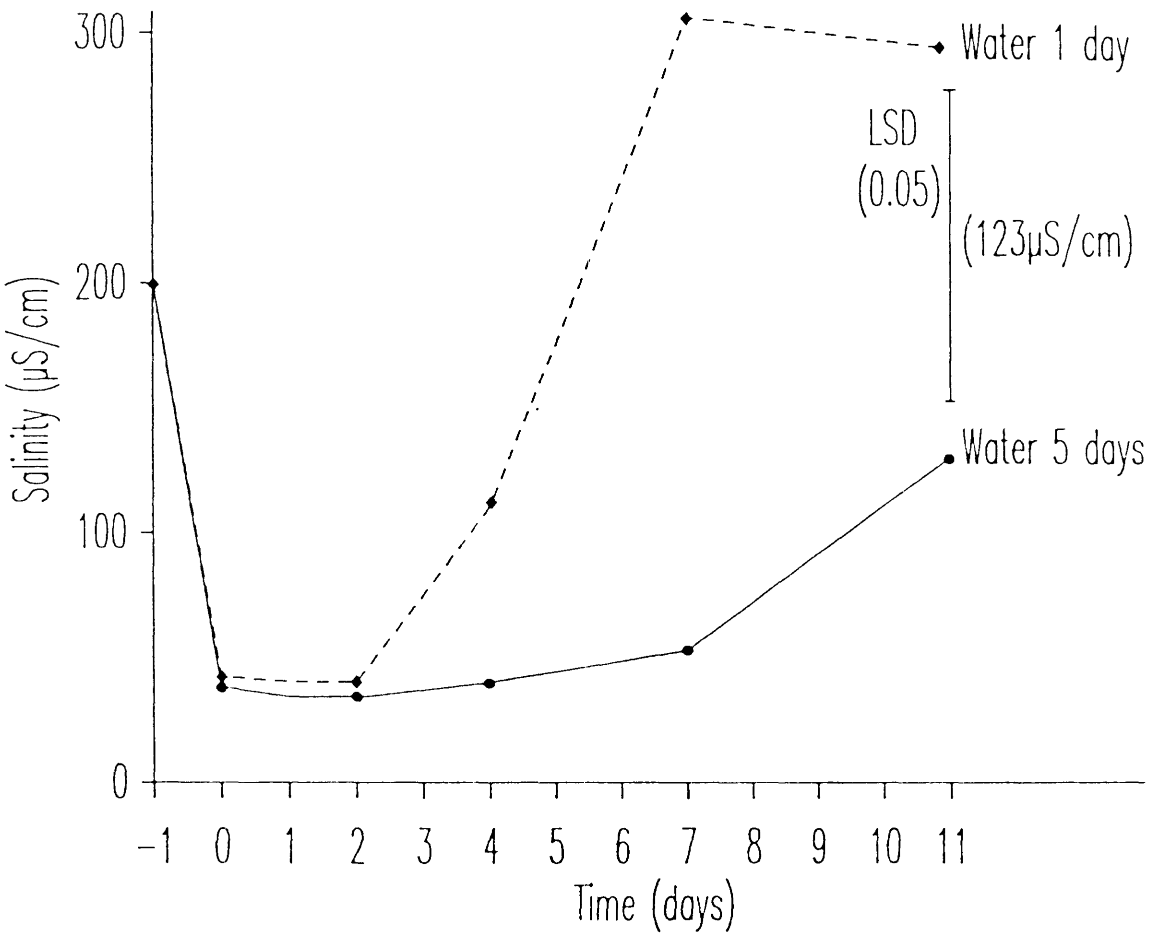

Figure 6.4 Effect of watering regime and time on salinity. Data are mean EC combined over substrates.

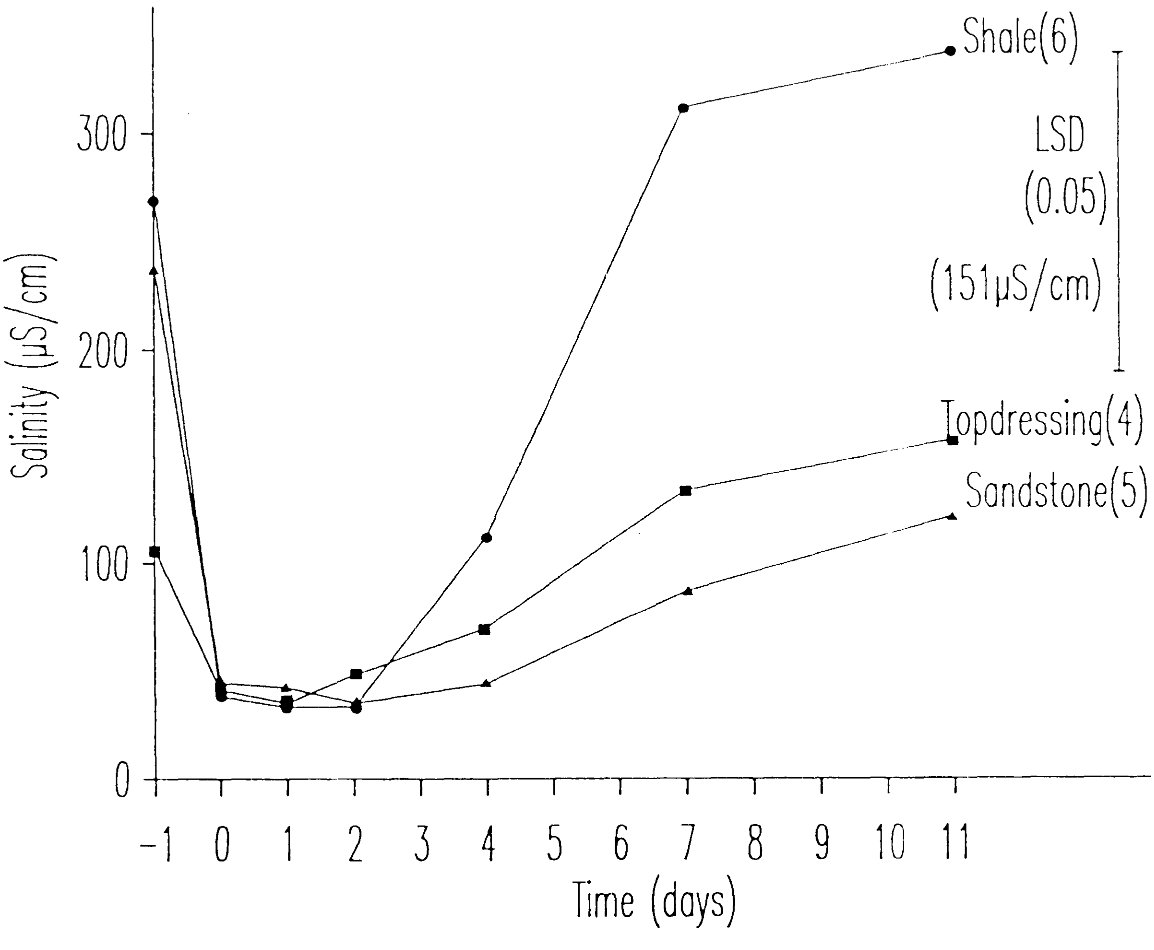

Figure 6.5 Effect of substrate and time on salinity. Data are mean EC combined over watering regimes.

result of this interaction is shown in Figure 6.6. Field capacities and permanent wilting points for each substrate have been superimposed on the figure to indicate during what period, and at what levels, moisture would be available to plants.

Generally, Topdressing (4) showed a greater ability to take up water and to retain water in an available state longer for both watering regimes. For the water 1 day treatment the gravimetric water content of Sandstone (5) and Shale (6) dropped below wilting point between 4 and 5 days. For Topdressing (4) wilting point occurred between day 6 and 7. For the water 1 day treatment Sandstone (5) had a higher water content in the first three days after wetting. However, Sandstone (5) dried more rapidly than Shale (6) and had the lowest water content after 11 days. For the water 5 day treatment there was no significant difference between the water content of Sandstone (5) and Shale (6) over the duration of the experiment. For this treatment, water content did not drop below wilting point for any substrate during the course of the experiment.

6.4.4 Discussion

Surface Crusting

Cross sections of surface layers were taken at 11 days using a razor blade. The cross sections indicated the formation of surface crusts. This was further confirmed by the early resistance to insertion of the penetrometer probe followed by a "breakthrough" effect. However, as drying progressed there was a general hardening of the contents of the pot which tended to mask the effects of surface crusting. This effect emphasized the point that the penetrometer only measured "strength" rather than crusting *per se*.

The relative rates of substrate crust hardening (Figure 6.1) corresponded with the relative rates of substrate drying (Figure 6.6) i.e. Shale (6) dried faster and had a faster rate of crust hardening. For all three substrates the time at which crust strength maximized

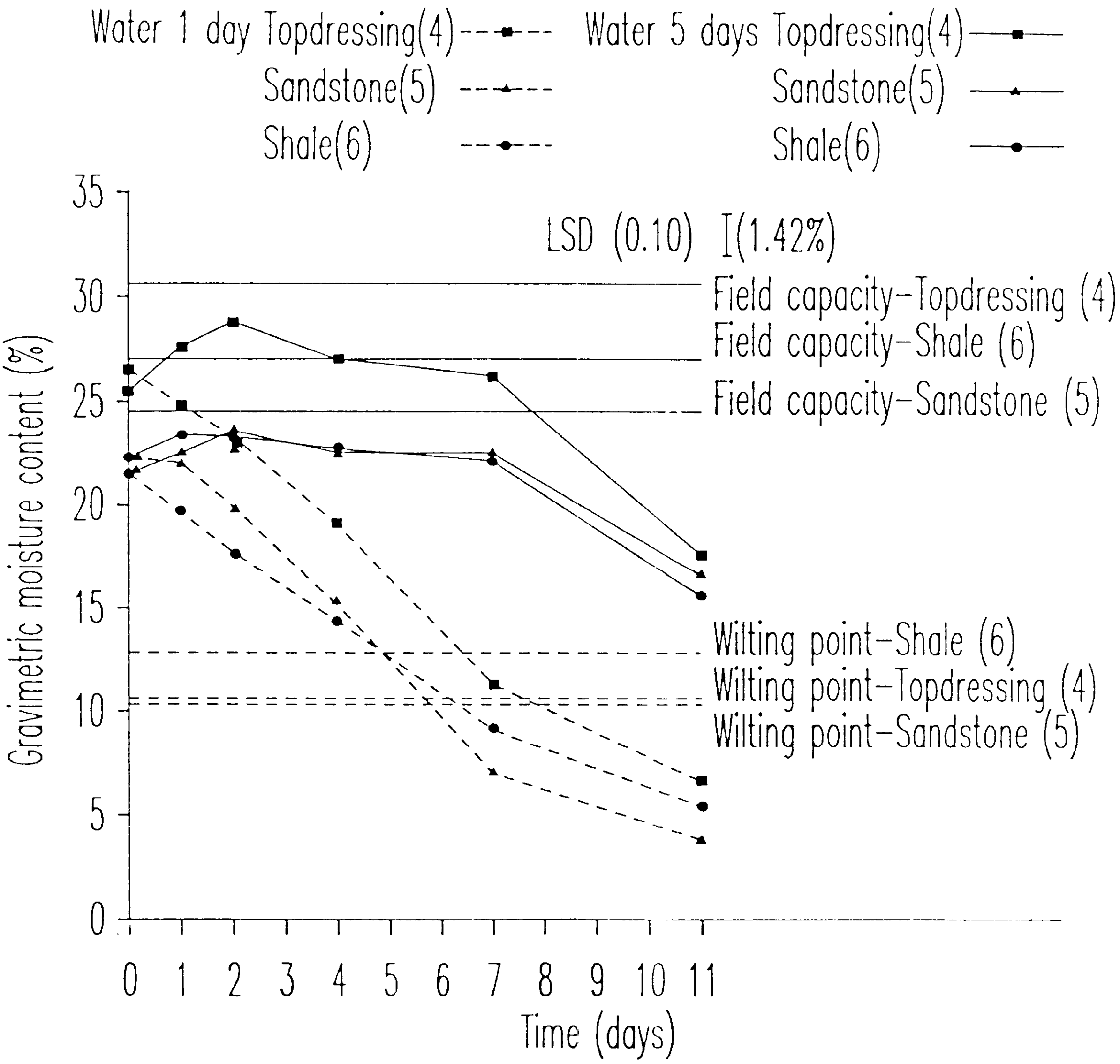

Figure 6.6 Effect of watering regime and time on gravimetric moisture content for three substrates from Hunter Valley No. 1 Colliery.

(Figure 6.1) corresponded approximately to the wilting point of each substrate (Figure 6.6). This suggests that substrate crust hardening was linked with substrate drying. These results agree with Emmerton (1983) who related measurements of crust strength to spoil moisture content. He found that resulting regression relationships explained between 24% and 93% of the total variation in crust strength.

Other factors may also explain the differences in surface crust strengths. Ferry and Olsen (1975) showed that soils high in organic matter generally do not tend to crust. Other things being equal, more organic material creates a more stable structure, but good mixing with the mineral matter (principally the clay) is necessary (Guillet and Roullier, 1982). Table 5.1 indicated that Shale (6) had a higher organic content (9.86%) compared to Sandstone (5) (0.76%) and Topdressing (4) (2.71%). However, the effect of the organic material in soil or spoil is dependent on its decomposability (Tisdall *et al.* 1978, Greenland 1965 a and b). The organic material in Shale (6) was largely carbonaceous material which was not readily decomposable. Despite this, some soils with finely divided organic material will crust significantly at high pH. Crusts formed under these conditions tend to be "rubbery" and result from dispersion of soluble organic materials at the surface. This is most likely to occur on saline, alkali soils - so called "black alkali", and is commonly observed on raw humus sands (Corbett 1969). The degree to which carbonaceous materials in Hunter Valley spoils with high pH are akin to the "mor" material found in black alkali soils can be partly gauged by comparing changes in pH over time (Figures 6.2 and 6.3) with the rate at which crust strength increases (Figure 6.1). The high pH readings early in the sequence (Figures 6.2 and 6.3) are not reflected in high initial crust strengths (Figure 6.1). This suggests that these spoil materials do not react the same way as black alkali soils under the influence of high pH which probably reflects the qualitative differences in the nature of the organic matter.

Surface crust strength may also be affected by particle size distribution and the "packing effect" of dispersed clay, sealing the voids between sand grains. Hence, there is potential for interaction between particle size distribution ("texture") and ESP, as the latter influences dispersive behaviour of the colloids. Kemper and Noonan (1970) stated that relatively high sand contents (50 to 80%) may provide solid matrices which do not swell, shrink or crack, and hence become a dense hard crust with clay particles between the sand grains swelling and sealing the surface when the soil is wet. Guillet and Roullier (1982) proposed that structural stability increases up to a clay content of about 50%, then markedly decreases because of the cracks that then form. They also considered that soils with silt contents that do not exceed 30-35% and with a considerable sand content, the balanced texture ensures a suitable structure with good hydrological characteristics. Consequently, in regard to sand, silt and clay composition (Table 6.13), Topdressing (4) was predisposed to better structural stability than both Sandstone (5) and Shale (6) and therefore less prone to high crust strength. This agrees with results in Table 6.1. However, it is important to note here that the particle size distributions refer to treated samples where certain components such as organic matter, amorphous material and calcite have been removed. For this reason, the size distribution obtained is not exactly the same as that of the untreated material of the same diameter distribution.

The nature of the clay also has an influence on dispersion and the ability to form hard surface crusts. Illite/kaolinite clay types are commonly found in topsoils and overburden materials within the Hunter Valley (Elliott, 1987). Illite clays tend to be rich in K. The common occurrence of illite clays is confirmed by the fact that K was one of the few elements not deficient in any of the substrates tested from Hunter Valley No. 1 Mine (glasshouse experiment 5). In spoil materials, and particularly loams and silty loams where the clay fraction is predominantly illite, dispersion occurs at a lower ESP than for other clay types. This effect is linked with the water content for dispersion. Russell and Greacen (1977) showed that the water content for dispersion of illite clays decreased rapidly with increasing SAR. In this regard Topdressing (4) with a SAR of 0.37 was less prone to dispersion than Sandstone (5) (0.47) and Shale (6) (1.91). These levels parallel crust strength levels (Figure 6.1).

Shearing of wet soils leading to dispersion and crust formation would be encouraged by the mechanical breakdown of soil aggregates (Russell and Greacen 1977). This would occur during stripping, stockpiling and recontouring of spoil materials and through frequent handling and sieving during the experimental handling phase. Some substrates, being the immediate product of parent material weathering and blasting, would have little initial aggregate structure to begin with and, hence, are more prone to dispersion.

While the above explanations may help explain differences in substrate crust strengths, relative crust strength levels did not coincide with relative levels of germination observed in either glasshouse experiments 1 or 2.

pH

The response following watering and during subsequent drying suggests a strong relationship between pH and the soil-water ratio. This is supported by Russell (1961) who stated that the higher the ratio of water to soil, the higher is the apparent pH of the soil.

The effect may also relate to the presence of alkaline materials in the town water supply. Town water is taken from the Hunter River and routinely treated with lime ($CaCO_3$) at 35 ppm and alum ($AlK(SO_4)_2.12H_2O$) at 15 ppm (Muswellbrook Shire Council 1986). The pH of treated water can vary considerably and daily readings of treated water (taken at treatment time) varied between 7.8 and 8.3 during the experiment. However, there is a 3 to 4 day lag time between treatment and usage. Within the wider period March 11th to March 25th, 1986, the pH varied from 7.8 to 9.3. Extremes of pH shown in Figures 6.2 and 6.3 may be partly explained by fluctuations in the pH of treated water. The initial effect of applied town water on EC may be explained by the precipitating effect of residual alum on ions in solution. As evaporation progressed salts would be returned to the surface and the EC would be expected to increase.

Daily variation in the chemical composition of applied water confounds the results and makes interpretation and extrapolation of results difficult.

It is unlikely that pH changes reflected mineralization of spoil organic material. The response time for mineralization, assuming adequate organic matter and soil micro-organisms are present, is considerably longer than the period of this experiment (Russell 1961, Gerretson-Cornell 1986).

The more favourable pH of Topdressing (4) does not explain poor germination in this material observed in glasshouse experiment 1.

Salinity

The early decrease in salinity was probably related to a flushing effect of salts from the surface layer or the precipitating effect of alum. Subsequent increases in salinity relate to a movement towards the surface of salts in solution and by a reduction in water content at the surface. These results were similar to those of Emmerton (1983). Relative levels of salinity (Figure 6.5) do not directly correlate with substrate germination differences in glasshouse experiment 1. However, the general pattern of salinity increase did correlate with the general pattern of crust hardening (Figure 6.1). Salinity may indirectly affect germination through dispersive effects discussed earlier.

Gravimetric Moisture Content

The amount of water held in soil depends *inter alia* on texture and structure. As discussed, the extensive handling of these substrates during mining and prior to potting would have destroyed much of their structure. In the case of Sandstone (5) and Shale (6) (which were the products of recent weathering of parent rock), there was little structure to begin with. Consequently, texture differences would become even more critical to water retention. In this regard, soils with a larger proportion of clay and silt particles would hold more moisture. The more favourable water holding and drying characteristics of Topdressing (4) therefore relate to a higher clay plus silt component (62%) than that of either the Shale (6) (52%) or Sandstone (5) (49%). While these differences may be critical to germination, survival and growth in the field, it is unlikely that differences in moisture content would have affected germination under optimum glasshouse conditions.

6.4.5 Summary

1. Differences in crust strength, drying rate, salinity and pH response between substrates were observed under two watering regimes over time.

2. None of these effects adequately explained germination differences apparent in glasshouse experiment 1.

6.5 Glasshouse Experiment 4. Nutrient Omission Experiment. C.S.R. Lemington Colliery.

6.5.1 Introduction

Earlier glasshouse experiments examined germination responses to fertilizer and substrate and attempted to explain these responses. To a lesser extent glasshouse experiments 1 and 2 also examined the subsequent flow-on effects of germination treatments on early growth. These experiments did not look at the particular fertilizer requirements of young seedlings as distinct from germination fertilizer requirements, nor did they examine the particular requirements of planted seedlings as opposed to seedlings developing *in situ* from seed. Fox (1984) stated that early growth requirements may be different from germination requirements. Because of the historical importance of planting seedlings in coal-mine rehabilitation in the Hunter Valley, determination of the specific nutrient requirements of planted seedlings is important to the success of reafforestation in this area.

6.5.2 Objective

To test the effect of omitting nutrients on survival and early seedling growth for three substrates from C.S.R. Lemington.

6.5.3 Results

Relevant F values are shown in Appendix 2(iv).

Survival of *E. maculata* in Shale (12) was very poor due to the high content of soluble salts as indicated by a very high conductivity (1870 μ S cm^{-1}). This result supports the limit of 1580 μ S cm^{-1}, proposed by Hannan and Elliott (1980) (Table 5.1) for *E. maculata*. Consequently, this substrate was excluded from analysis and the following results include only Topdressing (10) and Sandstone (11) unless stated otherwise. Survival of *C. glauca* was not affected by substrate and no *C. glauca* seedlings died on Shale (12). Substrate significantly affected the survival of *E. maculata* (Table 6.14).

The responses for the two species were significantly different for all six growth variables measured. *E. maculata* grew more rapidly than *C. glauca* although the latter was taller. The relative responses were two to three times greater on Topdressing (10) than on Sandstone (11). Despite the good survival of *C. glauca* seedlings on Shale (12), the average total weight of seedlings was only 25% that for Sandstone (11).

There was a highly significant species x substrate interaction for total weight. This interaction is contained within Table 6.15.

Table 6.14 Effect of two substrates from C.S.R. Lemington Colliery on survival per cent of *E. maculata* and *C. glauca*. Data are means for combined fertilizer treatments.

Species	SUBSTRATE Topdressing (10)	Sandstone(11)	Means (Sp.)
E. maculata	83.3	95.6	89.4(B)
C. glauca	100.0	100.0	100.0(A)
Means (S)	91.7(B)	97.8(A)	

L S D's	Species mns (Sp.) (Mns. of 18)	Substrate Mns. (S) (Mns. of 18)	Sp. x Sub. Table (Mns. of 9)
$P \leq 0.05$	5.4	5.4	7.6
$P \leq 0.01$	7.8	Not sig.	11.0

Note: In each row or column values with the same letter are not significantly different for $P \leq 0.05$.

Table 6.15 Effect of nutrient omission on the total dry weight of *E. maculata* and *C. glauca* for two substrates from C.S.R. Lemington Colliery

Nutrients Added	Substrate: Topdressing (10) *E. maculata* (g)	Topdressing (10) *C. glauca* (g)	Sandstone (11) *E. maculata* (g)	Sandstone (11) *C. glauca* (g)	Means (Combined Substrates) *E. maculata* (g)	Means (Combined Substrates) *C. glauca* (g)
All	20.66	8.22	13.37	7.63	17.01	7.92
" -N	16.73	7.30	5.19	3.73	10.96	5.51
" -P	4.14	8.32	1.49	3.52	2.81	5.92
" -K	16.81	7.83	8.39	5.58	12.60	6.70
" -Mg	21.05	8.10	9.74	6.75	15.39	7.42
" -S	14.44	8.70	8.15	6.15	11.29	7.42
" -Ca	17.76	8.04	6.88	9.12	12.32	8.58
" -Trace elem.	25.10	8.09	9.90	5.15	17.50	6.62
None	21.58	7.12	8.39	3.80	14.98	5.46
Means (Sp.)	17.59	7.97	7.94	5.71	12.76	6.84

L S D's	Species Means (Sp.) (Mns. of 18)	Sub. x Sp. Means (Mns. of 5)	Sp.Mns. x Nut. Mns.Table (Mns. of 2)	Sp. x Sub. x Nut. Table (Mns. of 1)
$P \leq 0.05$	1.74	2.46	5.22	Not
$P \leq 0.01$	2.53	3.58	Not sig.	analysed.

Substrate had a highly significant main effect on root/shoot ratio. The ratio of Sandstone (11) (0.49) was significantly superior to the ratio for Topdressing (10) (0.35) at the one per cent level.

Nutrient omission had a significant effect on shoot weight, total plant weight and average weight. Root weight was not significantly affected by nutrient omission at the five per cent level, but was significant at the ten per cent level. There was a significant interaction between species and nutrient omission for total weight. This interaction is contained within Table 6.15. For combined substrates *E. maculata* demonstrated multiple responses to addition of N, P, K, S and Ca. Despite the absence of significant response ($P \leq 0.05$) for *C. glauca*, the minus N and P treatments reduced growth by 30% and 25% respectively compared to the All treatment. For *E. maculata* the minus P treatment produced the greatest reduction in total weight (-83%), compared to the All treatment. The effect of other elements was less dramatic with minus N (-35%), minus S (-34%), minus K (-26%) and minus Ca (-28%) producing similar reductions in total weight. However, it was possible that individual substrate responses may have been masked in the combined analysis. Unfortunately, the experimental design did not allow analysis of second order interactions. Despite this, the results of nutrient omission for each species on each substrate have been shown in Table 6.15 for non-statistical comparison. The results suggest that the effect of nutrient omission on both species was more pronounced on Sandstone (11) than on Topdressing (10). This effect is highlighted by the small differences in total weight between the All and the None treatments for both species on Topdressing (10) and correspondingly large differences in total weight on Sandstone (11).

When compared to the All treatment, the total weight of *E. maculata* seedlings on Topdressing (10) was reduced by 15% or more for the minus P (-80%), minus N (-19%), minus K (-19%) and minus S (-29%) treatments. The None treatment slightly increased total weight. Response to nutrient additions were much more pronounced and extensive for *E. maculata* on Sandstone (11) with all treatments resulting in a 25% reduction or greater, in total weight.

None of the treatments reduced the total weight of *C. glauca* seedlings on Topdressing (10) by more than 15% when compared to the All treatment. However, on Sandstone (11) *C. glauca* demonstrated multiple responses to minus N (-51%), minus P (-54%), minus K (-27%), minus S (-19%) and minus trace elements (-32%). The results for *C. glauca* on Shale (12) gave different results with responses to minus P (-42%), minus Mg (-30%), minus S (-25%) and minus Ca (-19%) being deficient. However, due to poor growth of seedlings on Shale (12) as a result of high salinity levels, the results for Shale (12) must be viewed with some caution.

Omission of N, P and Ca significantly increased the root/shoot ratio of *E. maculata* as a consequence of reduction in shoot weight; root weight was not significantly affected by nutrient omission at the five per cent level. The root/shoot ratio of *C. glauca* was only significantly increased by the minus N treatment. Consequently, treatments producing lower shoot weights automatically produced higher root/shoot ratios and vice versa.

The only treatment which significantly affected survival was minus P which depressed survival of *E. maculata.* This effect was more pronounced for Sandstone (11) (-35%) than for Topdressing (10) (-15%).

The results of the analysis of levels of N, P, K, Mg and Ca in the foliage of *E. maculata* and *C. glauca* seedlings at harvesting can be seen in Table 6.16. The results did not lend themselves to analysis of variance and hence only general trends are discussed.

For *E. maculata,* foliar N levels were generally higher in Topdressing (10) than in Sandstone (11). This corresponded with heavier seedlings in Topdressing (10) (Table 6.15). However, Sandstone (11) showed more dramatic changes in foliar N levels, particularly for the None and minus P treatments. This corresponds with more dramatic changes in the total weight of *E. maculata* seedlings in Sandstone (11) than in Topdressing (10) for the same treatments (Table 6.15). For Topdressing (10) and Sandstone (11), omitting N, as in the minus N and control

Table 6.16 Levels of important nutrients in the foliage of *E. maculata* and *C. glauca* seedlings grown in two substrates from C.S.R. Lemington Colliery.

Species	Substrate	Fertil. Treat.	Foliar Nutrient Level (% by weight) +					
			N*	P**	K**	Mg**	Ca**	N/P Ratio
E. maculata	Top (10)	All	2.18	0.13	0.97	0.40	0.50	17
"	"	None	1.97	0.11	1.01	0.40	0.39	18
"	"	- N	1.77	0.18				10
"	"	- P	2.60	0.15				17
"	"	- K			1.08			
"	"	- Mg				0.36		
"	"	- Ca					0.39	
"	Sand (11)	All	2.09	0.20	1.07	0.43	0.71	10
"	"	None	0.95	0.04	0.68	0.32	0.62	24
"	"	-N	1.81	0.15				12
"	"	-P	1.32	0.04				33
"	"	-K			1.09			
"	"	-Mg				0.36		
"	"	-Ca					0.56	
C. glauca	Top (10)	All	2.22	0.11				20
"	"	None	2.49	0.09				27
"	"	-N	2.16	0.11				20
"	"	-P	1.66	0.07				24
"	Sand (11)	All	2.09	0.09				23
"	"	None	1.05	0.07				16
"	"	-N	0.88	0.11				8
"	"	-P	1.93	0.06				30

* Kjeldahl method) As reported in Lambert
** Murphy and Riley Method (1962)) (1982)

\+ Analysis undertaken with the assistance of the Department of Botany, University of New England.

treatments, produced lower N levels than for the All treatments. This paralleled a reduction in shoot, and in turn total weight, when N was omitted (Table 6.15). The most dramatic reduction in foliar N occurred for the control for Sandstone (11) where the N level was approximately half that for the All treatment. This reduction did not correspond with a proportionate reduction in total weight (Table 6.15).

C. glauca showed similar trends in foliar nutrient concentrations to *E. maculata*. Of particular importance was the result for Sandstone (11) which showed a dramatic increase in foliar N levels when N was added. Such an increase was not apparent for Topdressing (10). The result was consistent with dramatic changes in the total weight of *C. glauca* seedlings in response to nutrient omission on Sandstone (11). These changes were not apparent on Topdressing (10).

For *E. maculata* foliar P levels were not greatly affected by omitting P for Topdressing (10). This was not the case for Sandstone (11) where foliar P levels for the None and minus P treatments were only approximately 20% of the All treatment levels. P levels for the minus N treatment were intermediate. Foliar P levels for *C. glauca* were similar for the None and minus P treatments for both substrates. While changes in foliar P levels reflected general substrate growth trends they were not always an accurate guide to treatment growth responses apparent in Table 6.15.

The variability of the foliar nutrient level/growth response association was exemplified in the K results. For *E. maculata* in Topdressing (10) foliar K levels for the None and minus K treatments did not vary greatly from the All treatment. This result does not reflect the substantial growth reductions apparent for *E. maculata* in Topdressing (10) (Table 6.15) for the minus K treatment. However, the None treatment for Sandstone (11) did result in a substantial drop in foliar K and corresponded with a reduction in total weight for this treatment. For *E. maculata*, foliar Mg levels did not vary greatly between treatments for either substrate. However, foliar Ca levels did drop substantially for *E. maculata* in both substrates when Ca was omitted.

6.5.4 Discussion

There was a strong contrast in growth and survival between *E. maculata* and *C. glauca*. *C. glauca* was less affected by substrate differences and even survived and grew (albeit poorly) in the strongly alkaline Shale (12) which was originally discarded from analysis. The ability of *C. glauca* to survive in N-deficient soils (and harsh environments) has been partly attributed to symbiosis with the N-fixing *Frankia* bacteria (Reddell *et al.* 1985). However, as no nodulation was noted on any of the seedlings, the response of *C. glauca* observed in this experiment must relate to inherent genetic adaptability. The absence of nodulation after 126 days, particularly in the topdressing material was surprising, and may reflect the immaturity of seedlings rather than the absence of *Frankia*. Had nodulation occurred for one of the substrates, variations in substrate response may have been greater.

E. maculata was more sensitive to differences in substrate than *C. glauca*. Survival of *E. maculata* was superior in Sandstone (11) but Topdressing (10) gave superior seedling total weights. If relative survival was an artefact of glasshouse conditions, as was suggested in earlier experiments, growth may be the more important selection criterion for substrate suitability.

The less dramatic response of *C. glauca* to substrate differences was paralleled by its greater capacity to satisfy its nutrient requirements - it displayed no deficiency symptoms or growth depression due to nutrient omission on Topdressing (10). Where nutrient omission responses were shown for Sandstone (11), these were less extensive and less severe than for *E. maculata*. The two species appear to differ in their nutrient requirements and/or in their ability to take up nutrients. It is quite likely that the critical limits for *C. glauca* are well below those critical nutritional values listed in Table 5.1.

Under conditions of deficient P nutrition, the survival and growth of *E. maculata* was greatly reduced. Other omissions had no effect on survival. The results for minus P were significantly inferior to the

None treatment. P deficiency was exacerbated in the presence of other nutrients, indicating the importance of nutrient balance in fertilizer additives.

The effect of nutrient omission on plant growth varied between species and substrates. For *E. maculata* on Topdressing (10) omitting N, P, K and S all produced growth response, while for Sandstone (11) all nutrients tested produced growth responses. *C. glauca* did not show any nutrient deficiencies on Topdressing (10) while N, P, K, S and trace elements were considered deficient on Sandstone (11). These results highlight the need for balanced species and substrate specific fertilizer programmes, if optimising plant growth is an objective. The task may not be so daunting if further research indicates general genus, rather than species requirements. In addition, N, P, K and S were common deficiencies for both species on Sandstone (11) and for *E. maculata* on both substrates.

This experiment ran for only 126 days. It could be expected that had the experiment been allowed to run longer, treatment differences would have been more pronounced in the glasshouse environment because of limited growing media. However, in the field such limitations do not exist and long term response to fertilizer could vary dramatically from the glasshouse results.

Despite the absence of significance levels, the results of foliar nutrient analysis did correspond with general substrate growth differences. However, for both species, foliar nutrient analyses correspond more closely with both initial substrate nutrient levels and with treatment induced growth responses for Sandstone (11) than for Topdressing (10). In the case of N and P, this probably related to the lower ability of Sandstone (11) to supply nutrients and was probably a result of lower inherent total N and water soluble P levels (Table 5.1) Changes in foliar nutrient levels were also more dramatic for *E. maculata* than *C. glauca*, supporting the greater sensitivity of *E. maculata* to nutrient deficiencies and nutrient addition. However, changes in foliar nutrient levels did not always correspond with treatment induced growth trends.

Foliar N/P ratios for Topdressing (10) and Sandstone (11) for the None treatment for *E. maculata* were 18 and 24 respectively. These were close to Schönau's (1981) optimum figure of 20 for *E. maculata*. Assuming Schonau's ratio to be correct the low ratio for *E. maculata* for the All treatment for Sandstone (11) suggested that the levels of N and P applied in this experiment were not at the correct ratio and/or rates for this species in this substrate. This was further confirmed by the low weight of *E. maculata* seedlings generally on Sandstone (11) and the inability of fertilizer to improve growth to that experienced on Topdressing (10). In this case, the N/P ratio appears a useful tool in predicting the adequacy of applied N and P and the need for subsequent factorial rate experiments.

While foliar nutrient concentrations were considered a reasonable guide to likely nutrient deficiencies, their accuracy as a predictive tool varied considerably between species and substrates. Generally, their value in predicting nutrient deficiencies was no greater than that obtained by examining substrate nutrient levels in Table 5.1. In this experiment, foliar nutrient analysis was not considered sufficiently sensitive to predict consistently, differences in the degree of plant response to nutrient omission.

6.5.5 Summary

1. P was the most important deficient nutrient in plant growth followed by N and S. Other nutrients were deficient but the effect was variable.

2. *E. maculata* was more responsive to nutrient omission than *C. glauca* and hence was a more useful guide to optimum broadacre fertilizer application rates.

3. Seedlings on Sandstone (11) showed a more dramatic and varied response to nutrient omission than seedlings on Topdressing (10). Consequently, specific fertilizer treatments will be required for each substrate if optimizing growth is an objective.

4. Correct nutrient balance was more important to healthy plant growth than the presence of individual nutrients.

5. Foliar N/P ratio provides one method of assessing whether a correct balance has been achieved between applied N and P.

6.6 Glasshouse Experiment 5. Nutrient Omission Experiment. Hunter Valley No. 1. Colliery

6.6.1 Introduction

Glasshouse experiment 4 indicated that N and P were the two major deficient elements in the growth and survival of *E. maculata* seedlings on two substrates from C.S.R. Lemington Mine. It was important to determine if these or other deficiencies applied at other mines and in other substrates. Due to the less responsive nature of *C. glauca* to nutrient variations, this species was not included in this experiment.

6.6.2 Objective

To test the effect of omitting various nutrients on early seedling growth and survival of *E. maculata* in three substrates from Hunter Valley No. 1 Mine.

6.6.3 Results

Relevant F values are shown in Appendix 2(v).

Survival was affected by substrate differences. Topdressing (7) had significantly higher survival (90.6%) than both Sandstone (8) (61.7%) and Shale (9) (52.8%) which were not significantly different. None of the fertilizer treatments affected seedling survival.

Seedling total weight was significantly affected by both substrate and treatment differences. There was a significant interaction between substrate and fertilizer for total weight (Table 6.17). For all fertilizer treatments Topdressing (7) produced the heaviest seedlings while Sandstone (8) produced the lightest. Plates 6.4, 6.5, 6.6 and 6.7 show the effect of All, minus N, minus P and None treatments on *E. maculata* for each substrate.

For Topdressing (7) only P was considered limiting to growth, the minus P treatment reducing total weight by 18% compared to the All treatment. For Sandstone (8) multiple responses occurred and included P (-74%), S (-74%), trace elements (-53%), Mg (-50%) and N (-45%). For Shale (9) responses to nutrient omission included P (-73%), N (-66%), S (-42%) and Ca (-30%).

The effect of omitting nutrients on total dry weight was restricted to an effect on shoot dry weight. Nutrient omission had no significant effect on root dry weight.

As a direct consequence of the variable effect of nutrient omission on shoot and root weight, omitting nutrients had a highly significant effect on root/shoot ratio, as did substrate. There was a significant interaction between substrate and fertilizer for root/shoot ratio (Table 6.18). Generally, Sandstone (8) and Shale (9) had higher ratios than Topdressing (7) with the high ratio for Sandstone (8) being a product of low shoot rather than high root weights. To a lesser degree this also applied to Shale (9). For Topdressing (7) nutrient omission did not affect the root/shoot ratio compared to the All treatment. For Sandstone (8) only the minus N treatment increased the ratio. For Shale (9) deleting both N and P increased the ratio. As mentioned, these

Table 6.17 Effect of nutrient omission on the total dry weight (g) of *E. maculata* seedlings grown in three substrates from Hunter Valley No. 1 Colliery.

Nutrients Added	SUBSTRATE Topdressing (7)	Sandstone (8)	Shale (9)	Means (F)
All	40.79	5.78	14.34	20.31(ABC)
" -N	40.21	3.18	4.87	16.09(CD)
" -P	33.23	1.50	3.87	12.87(D)
" -K	44.69	6.78	17.02	22.83(A)
" -Mg	46.47	2.87	14.94	21.43(A)
" -S	40.36	1.49	8.26	16.70(BCD)
" -Ca	40.95	7.74	10.07	19.59(ABC)
" -Trace Elements	44.64	2.71	15.13	20.83(AB)
None	36.12	2.10	4.13	14.14(D)
Means of Substrate (S)	40.83(A)	3.80(C)	10.29(B)	

L S D's	Fertil. Means (Mns. of 6)	Subst. Means (Mns. of 18)	Fertil.x Sub.Table (Mns. of 2)
$P \leq 0.05$	4.64	2.68	8.04
$P \leq 0.01$	6.22	3.62	11.02

Note: Values with the same letter are not significantly different for $P \leq 0.05$.

Topdressing (7) Sandstone (8) Shale (9)

Plate 6.4 The response of *E. maculata* grown in three substrates from Hunter Valley No. 1 Mine to "All" nutrients.

Topdressing (7) Sandstone (8) Shale (9)

Plate 6.5 The response of *E. maculata* grown in three substrates from Hunter Valley No. 1 Mine to minus N.

Topdressing (7) Sandstone (8) Shale (9)

Plate 6.6 The response of *E. maculata* grown in three substrates from Hunter Valley No. 1 Mine to minus P.

Topdressing (7) Sandstone (8) Shale (9)

Plate 6.7 The response of *E. maculata* grown in three substrates from Hunter Valley No. 1 Mine to "No" nutrients.

Table 6.18 Effect of nutrient omission on the root/shoot ratio of *E. maculata* grown in three substrates from Hunter Valley No. 1 Mine.

Nutrients Added	SUBSTRATE Topdressing (7)	Sandstone (8)	Shale (9)	Means (F)
All	0.40	0.37	0.30	0.86(AB)
" -N	0.39	0.99	1.47	0.94(A)
" -P	0.32	0.48	0.94	0.58(BC)
" -K	0.35	0.34	0.38	0.36(C)
" -Mg	0.50	0.43	0.39	0.44(C)
" -S	0.36	0.30	0.34	0.33(C)
" -Ca	0.37	0.44	0.39	0.40(C)
" -Trace elements	0.35	0.54	0.37	0.42(C)
None	0.29	1.24	1.05	0.86(AB)
Mns. of Substrates(S)	0.37(B)	0.57(A)	0.62(A)	

L S D's	Fertil. Mns (F) (Mns. of 6)	Subst. Mns. (S) (Mns. of 18)	Fertil. x Sub. Table (Mns. of 2)
$P \leq 0.10$	0.25	0.13	0.44
$P \leq 0.05$	0.31	0.18	Not sig.
$P \leq 0.01$	0.41	Not sig.	Not sig.

Note: Values with the same letter are not significantly different for $P \leq 0.05$.

results relate to changes in shoot growth in response to nutrient omission.

6.6.4 Discussion

For *E. maculata* Topdressing (7) proved generally superior to the other two substrates, having better total weight, individual root and shoot weights and seedling survival under glasshouse conditions. It was inferior only for root/shoot ratio.

The superior survival in the topdressing material contrasts with the lower survival of germinated seedlings in material from the same mine in glasshouse experiment 1. Survival in topdressing material from C.S.R. Lemington Mine in glasshouse experiment 4 was also inferior. These apparent conflicting results do not support the selective occurrence and effect of soil pathogens discussed in earlier germination experiments. Furthermore, while pathogens may be a factor in *in situ* germination experiments, they would be less likely to affect established seedlings used in this experiment. Due to the absence of potentially limiting chemical characteristics (Table 5.1), the effect most likely relates to the physical characteristics of substrates. Poor water infiltration and ponding was noted on all substrates in this experiment and particularly on Sandstone (8) and Shale (9). This may relate to the 'closed pot system" used in nutrition experiments and also to poor water infiltration in these substrates. This could result from poor soil structure, particularly in newly exposed and weathered overburdens, leading to impeded infiltration through rearrangement of soil particles which, in turn, may result in anaerobic soil conditions.

Physical characteristics affecting survival could also be expected to affect growth. However, as this experiment indicated, good survival and growth have not always been linked. Despite this, the superior growth of seedlings in topdressing material has been a common factor in all glasshouse experiments. This outcome may be partly explained by more favourable chemical characteristics; more favourable nutrient availability due to a lower pH than other substrates. However, there is some evidence in this experiment to suggest that the physical characteristics of newly weathered substrates (e.g. sandstone and shale materials) are inferior to those of topdressing material within the restrictions of a pot trial under glasshouse conditions and lead to inferior growth.

In all experiments the inability of fertilizer addition to compensate for substrate growth differences further confirms the importance of physical effects on growth.

In this experiment the higher root/shoot ratios for Sandstone (8) and Shale (9) relate to retarded shoot growth, rather than enhanced root growth. Conversely, the lower ratio for Topdressing (7) relates to enhanced shoot growth. However, other factors may also be involved. If one considers that the rate of root growth depends *inter alia* on the amount of carbohydrates the aerial parts of the plant translocate to the root system (Russell 1961) and that carbohydrates, not immediately needed by the aerial parts of the plant are translocated to the root system under a priority arrangement then the lower ratio for the topdressing material may well express a less stressful and more favourable growing medium producing healthier plants. Consequently, some caution must be applied in drawing conclusions about field survival potential from these results. At best, it can be said that due to optimum water availability under glasshouse conditions, there was no direct correlation between survival and root/shoot ratio and that the importance of the root/shoot ratio in affecting seedling survival was not tested.

The effect of nutrient omission on the growth of *E. maculata* varied considerably between substrates. Topdressing (7) was only deficient in P, and the deficiency of this element was much less severe than for Sandstone (8) and Shale (9). The degree of P deficiency does not correlate with the relative levels of either total P or water soluble P in these substrates shown in Table 5.1. Nutrient availability is therefore being affected by other factors, including probably pH. Sandstone (8) showed inadequate supply of N, P, S, trace elements and Mg for *E. maculata*. Shale (9) was limited in supplying N, P, S and Ca. In all three substrates, deficiencies of N and/or P were predicted in Table 5.1, (although the degree of P deficiency and its affect on plant growth was not). For Sandstone (8) the Mg deficiency was not pre-empted in Table 5.1, nor was the low availability of Ca in Shale (9). However, these results may well reflect the inadequacy of suggested critical values which largely apply to agricultural crop response.

K, which was limiting to growth in both Topdressing (10) and Sandstone (11) in glasshouse experiment 4, was not deficient in any of the substrates in this experiment. This difference in response was predicted in Table 5.1 although the results do suggest that the critical levels of K (0.2-0.3 me %, Bevege 1986) may be too low for *E. maculata*. Topdressing material from Hunter Valley No. 1 Mine had a more adequate nutrient regime than topdressing material from C.S.R. Lemington Mine. With the exception of P, this result was also predicted in Table 5.1. Despite these dissimilarities, it was apparent that differences between substrates within each mine were generally as great, if not greater than differences between mines. This corresponds with the findings of Russell (1978) for Queensland mines. The considerable variation in chemical characteristics of similar looking materials from within each mine also attests to the wide variation that can occur over short distances as proposed by Riley (1975).

The effect of adding nutrients, particularly N and P, in decreasing the root/shoot ratio must also be viewed in the context of field "hardiness". As discussed earlier, a high ratio should imply greater resistance in dry conditions than a low ratio. However, in the absence of any critical ratio for *E. maculata*, the fact that these trees were grown in pots, and in the context that nutrient addition can develop a healthier plant, interpretation of the relevance of a reduction in the ratio in response to fertilizer addition to the field is difficult. Glasshouse experiments 1 and 6 both indicate that adequate supply of P is critical to root growth of *E. maculata*.

In all experiments the presence of vesicular-arbuscular (VA) mycorrhizal fungi was not confirmed. Nutrient availability to trees with VA mycorrhiza is different to un-innoculated trees.

6.6.5 Summary

1. P was the most seriously deficient nutrient followed by N and S. Other nutrients were deficient but the effects were variable.

2. Nutrient balance and rate of supply are more crucial than so-called "critical nutrient levels" or deficiencies.

3. Topdressing material produced better seedling growth and survival than the other two substrates. The reason for this was not obvious.

4. The fact that fertilizer addition could not fully compensate for substrate's inability to supply nutrients suggests either that optimum fertilizer components and/or ratios were not achieved or that substrate growth differences are not simply attributable to fertility, and that other physical or chemical spoil factors are limiting.

6.7 Glasshouse Experiment 6. Effect of Nitrogen and Phosphorus on Two Species Grown on Three Substrates from C.S.R. Lemington Mine.

6.7.1 Introduction

N and P were identified as the two major deficient elements in substrates from both C.S.R. Lemington and Hunter Valley No. 1. Mines. The next important step was to determine what rates of each element were optimum for individual species and substrates.

6.7.2 Objective

To test the effect of four rates each of N and P on early growth and survival of *E. maculata* and *C. glauca* for three substrates from C.S.R. Lemington Colliery.

6.7.3 Results

Relevant F values are shown in Appendix 2(vi).

Substrate differences were again the major source of variation in root, shoot and total weight. Survival was not affected by substrate. Survival did vary between species with *E. maculata* (99% survival) being superior to *C. glauca* (92%).

There were significant substrate x species interactions for root, shoot and total weight. The later interaction is shown in Table 6.19.

There was also a highly significant substrate x species interaction for root/shoot ratio (Table 6.20). Poor infiltration of applied water was noted on Sandstone (14) and Shale (15) by the end of the experiment. This appeared to be associated with a hardening of the surface layers.

Applied P had a strong effect on root weight. There was a highly significant substrate x species x P interaction for root weight (Table 6.21). Maximum root weight for *E. maculata* occurred at P25. For *C. glauca* maximum root weight occurred on a plateau between P50 and P100. N did not have a significant effect on root growth.

Both P and N had highly significant main effects on shoot weight. The effect of N and P on the growth of *E. maculata* on each substrate is shown in Plates 6.8, 6.9 and 6.10. Of the two elements, P

Table 6.19 Effect of three substrates from C.S.R. Lemington Colliery on the total dry weight (g) of *E. maculata* and *C. glauca*. Data are means for combined N and P treatments.

Species	SUBSTRATE Topdressing (13)	Sandstone (14)	Shale (15)	Means (Sub.)
E. maculata	14.35	2.29	5.61	7.42(A)
C. glauca	6.17	3.28	2.41	3.95(B)
Means (Sp.)	10.26(A)	2.78(C)	4.01(B)	

L S D's	Substrate Mns. (Sub.) (Mns. of 48)	Species Mns. (Sp.) (Mns. of 32)	Sub. x Sp. Table (Mns. of 16)
$P \leq 0.05$	0.42	0.52	0.74

Note: Values in the same row or column with the same letter are not significantly different for $P \leq 0.05$.

Table 6.20 Effect of three substrates from C.S.R. Lemington Colliery on the root/shoot ratio of *E. maculata* and *C. glauca*. Data are means for combined N and P treatments.

	SUBSTRATE			
Species	Topdressing(13)	Sandstone(14)	Shale(15)	Means(Sp.)
E. maculata	0.32	0.35	0.42	0.36(B)
C. glauca	0.50	0.39	0.54	0.48(A)
Means (S)	0.41(B)	0.37(B)	0.48(A)	

L S D's	Spec.Means(Sp.) (Mns. of 48)	Subst.Means(S) (Mns. of 32)	Spec.x Sub.Table (Mns. of 16)
$P \leq 0.05$	0.034	0.041	0.058
$P \leq 0.01$	0.046	0.057	0.080

Note: Values in the same row or column with the same letter are not significantly different for $P \leq 0.05$.

Table 6.21 Effect of substrate and P on the total root dry weight (g) of *E. maculata* and *C. glauca*. Data are means for combined N treatments.

Species	Level of P	SUBSTRATE Topdressing(13) (g)	Sandstone(14) (g)	Shale(15) (g)	Means (Sub.) (g)
E. maculata	P0	3.04	0.43	0.55	1.34(B)
	P25	4.06	0.40	1.69	2.05(A)
	P50	3.27	0.73	1.58	1.86(A)
	P100	3.42	0.63	1.88	1.98(A)
Means (P)		3.45(A)	0.55(C)	1.42(B)	
C. glauca	P0	1.76	0.14	0.15	0.68(C)
	P25	1.82	0.64	0.50	0.99(B)
	P50	2.20	1.57	0.95	1.57(A)
	P100	2.30	0.97	1.39	1.55(A)
Means (P)		2.02(A)	0.83(B)	0.75(B)	

L S D's	Means of P (Mns. of 16)	Means of Substrate (Mns. of 12)	Substrate x P Tables (Mns. of 4)
$P \leq 0.05$	0.26	0.30	0.52
$P \leq 0.01$	0.36	0.41	0.72

Note: Values in the same row or column and with the same letter are not significantly different for $P \leq 0.05$.

P0 P25 P50 P100

Plate 6.8 The response of *E. maculata* grown on Topdressing (13) from C.S.R. Lemington Mine to applied N and P.

P0 P25 P50 P100

Plate 6.9 The response of *E. maculata* grown on Sandstone (14) from C.S.R. Lemington Mine to applied N and P.

P0 P25 P50 P100

Plate 6.10 The response of *E. maculata* grown on Shale (15) from the C.S.R. Lemington Mine to applied N and P.

was the major source of experimental variation. The result was similar for total weight and root/shoot ratio. Of significance to future field studies was the absence of any significant main effect of N on average height.

There were no significant N x P interactions for total weight. However, there was a highly significant species x substrate x P interaction as well as a highly significant species x substrate x N interaction for total weight. The results of these interactions are shown in Figures 6.7, 6.8, 6.9 and 6.10 respectively.

E. maculata showed greater variation between substrates for both applied N and P than did *C. glauca*. For *E. maculata* there was no significant increase ($P \leq 0.05$) in total weight for all three substrates above 25 kg P ha^{-1} for the rates tested. For this species seedlings on both Topdressing (13) and Shale (15) responded more to applied P than did seedlings on Sandstone (14). There was no significant increase in total weight for all three substrates above 50 kg N ha^{-1} for the rates tested. As for applied P, plants in Topdressing (13) and Shale (15) responded more to applied N than did plants in Sandstone (14). For Sandstone (14) increasing rates above 100 kg N ha^{-1} significantly depressed total weight.

For *C. glauca* there was no significant increase in total weight above 50 kg P ha^{-1} for all three substrates. The result for N was more variable. For Topdressing (13) applying N had either no significant effect or depressed total weight (e.g. at 100 kg N ha^{-1}). There was a similar result for Shale (15) where applying N did not improve total weight. Only plants in Sandstone (14) responded positively to applied N, the rate at which total weight was optimized being 100 kg N ha^{-1}. *C. glauca* seedlings on Sandstone (14) showed a greater response to applied N and P than those on the other two substrates.

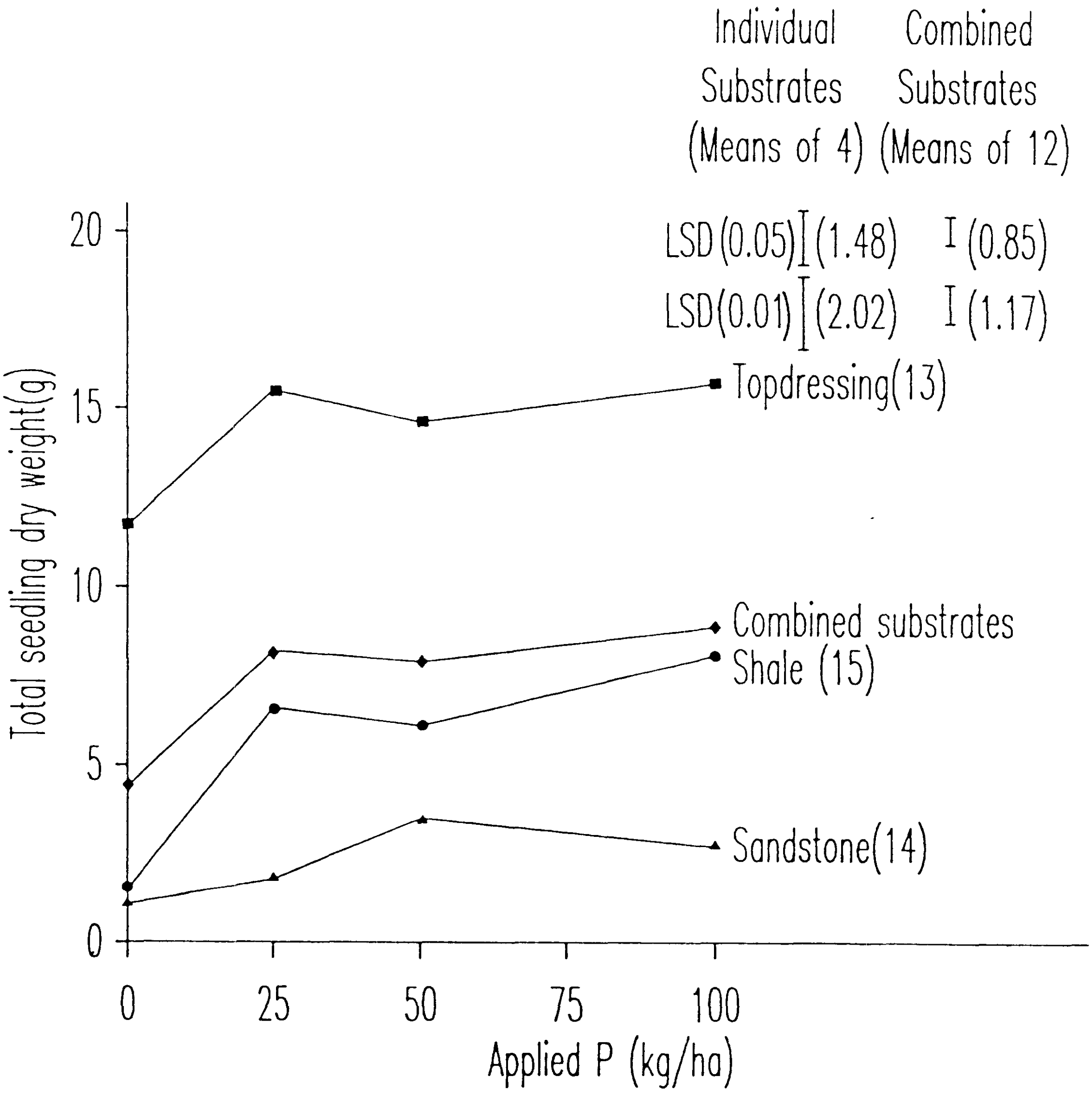

Figure 6.7 Effect of P applied as $NaH_2PO_4.2H_2O$ on total plant dry weight of *E. maculata* for three substrates from C.S.R. Lemington Colliery. Data are means for combined N treatments.

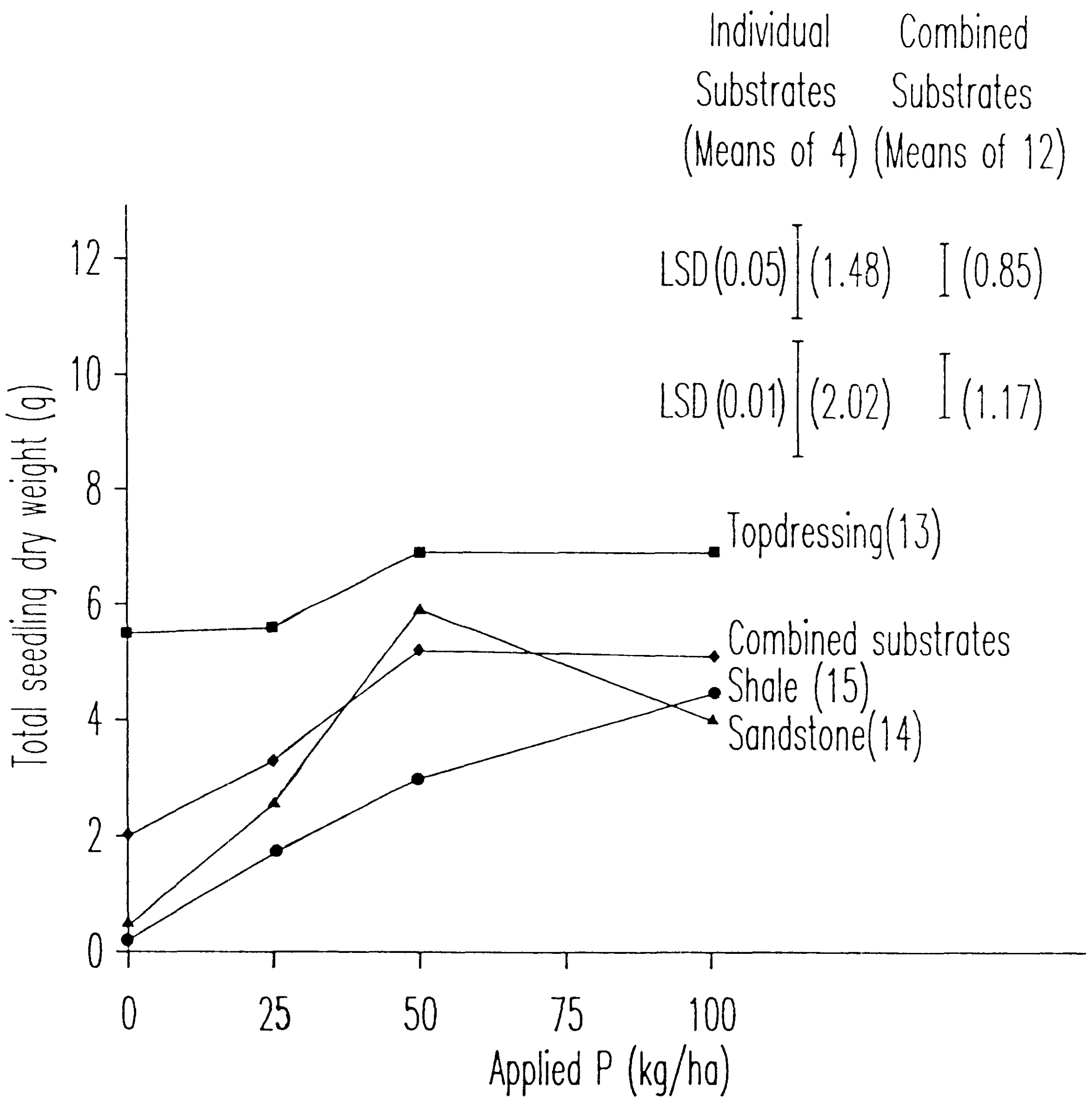

Figure 6.8 Effect of P applied as $NaH_2PO_4.2H_2O$ on total plant dry weight of *C. glauca* for three substrates from C.S.R. Lemington Colliery. Data are means for combined N treatments.

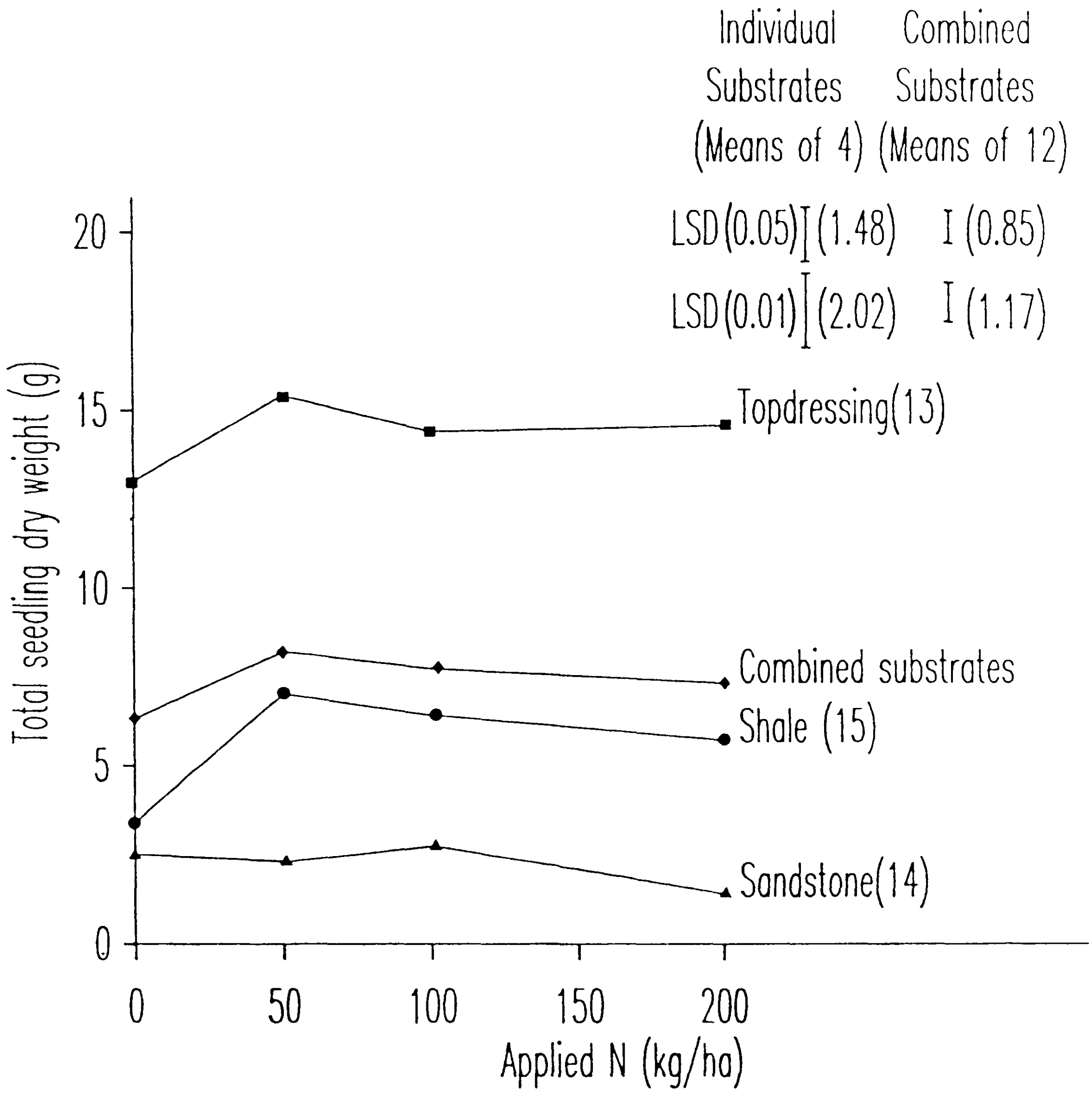

Figure 6.9 **Effect of N applied as NH_4NO_3 on total plant dry weight of *E. maculata* for three substrates from** C.S.R. Lemington **Colliery. Data are means for combined P treatments.**

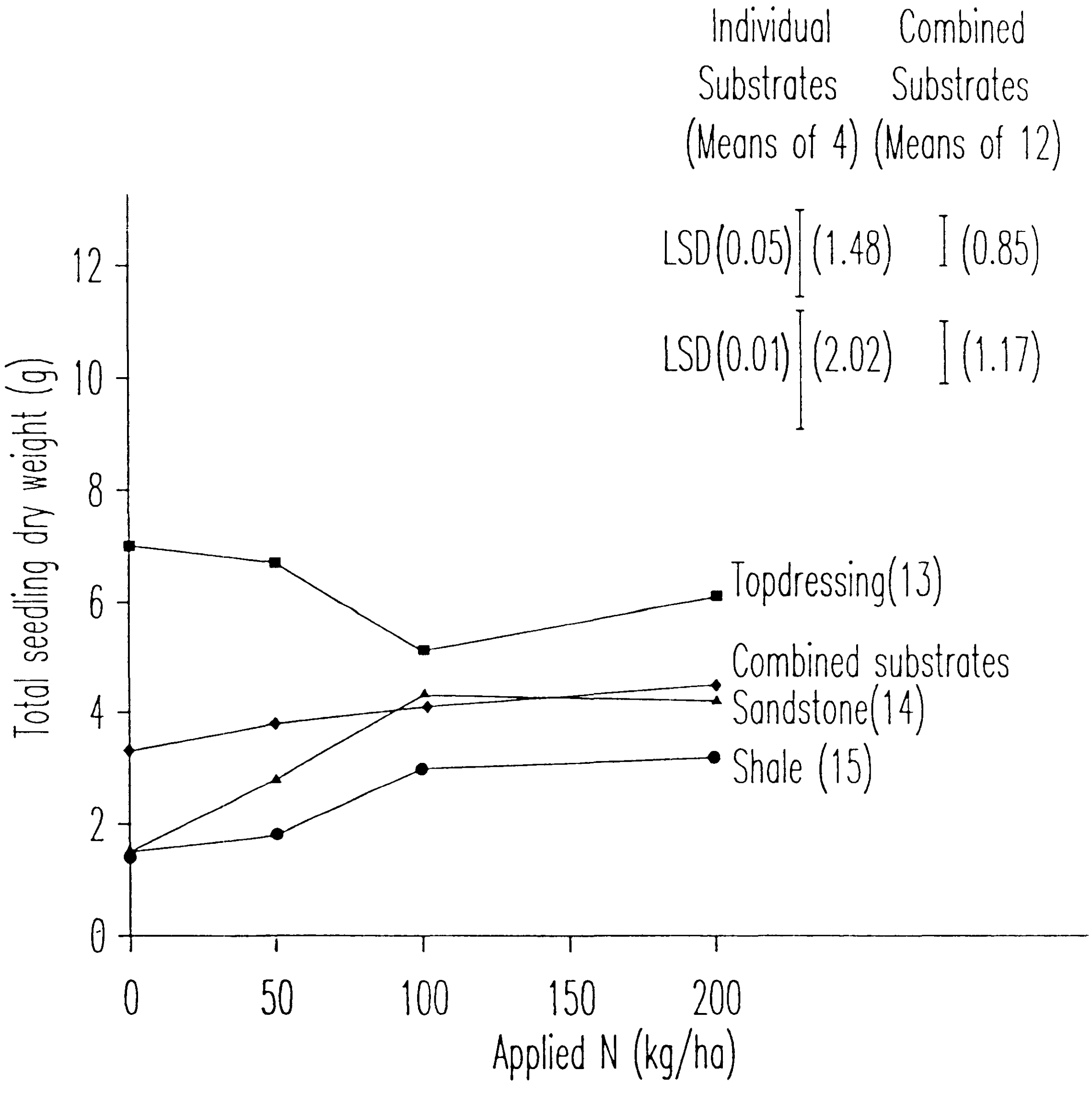

Figure 6.10 Effect of N applied as NH_4NO_3 on total plant dry weight of *C. glauca* for three substrates from C.S.R. Lemington **Colliery. Data are means for combined P treatments.**

6.7.4 Discussion

The dominant effect of substrate on growth, observed in previous glasshouse experiments, was again evident. As in earlier experiments, the topdressing material again produced superior total weights, while the sandstone material produced inferior growth. The same trend applied for root and shoot weights. Contrary to the findings in glasshouse experiments 4 and 5, inferior growth was not always associated with the highest root/shoot ratios.

E. maculata responded more dramatically to substrate differences than did *C. glauca*. This was consistent with a greater tolerance by *C. glauca* to external factors observed previously in earlier experiments.

For *E. maculata*, Shale (15) which produced intermediate total weights, had the highest (most favourable) root/shoot ratio. This, unlike glasshouse experiments 4 and 5, suggests a high root/shoot ratio was determined by factors other than poor shoot growth. Table 6.21 indicated that the root weight of *E. maculata* in Shale (15) increased dramatically when P was applied. The increase was greater than for the other two substrates and explained the higher root/shoot ratio of *E. maculata* in Shale (15).

Other differences between the results of this and earlier experiments were also observed. Substrate, which affected survival of *E. maculata* seedlings in glasshouse experiments 4 and 5 had no effect on survival in this experiment. No explanation can be given for this variation with the possible exception that experiment 6 was conducted in cooler weather than experiments 4 and 5, (Table 4.1). This may have resulted in less damping off or may have exerted some effect through moisture availability.

The importance of N and P to healthy seedling growth was further confirmed. Both elements were important to shoot weight and total weight. Of the two, P was the more important. Only P had a significant effect on root growth. This result presents one option for favourably increasing field root development, and hence survival. Although N significantly affected shoot weight it did not significantly affect seedling height. If this trend continued into late growth and/or in the field, the use of height as an indicator of applied N response may not be appropriate.

Although there was no significant interaction between N and P, the effect of both elements was dependent on the species and substrate involved. This means that specific optimum fertilizer combinations are needed for each species and possibly for each substrate. In this case, the optimum rates for *E. maculata* were N50 P25 for all three substrates. The result for *C. glauca* was more variable with optimum rates of N0 P50, N100 P50, N0 P50 for Topdressing (13), Sandstone (14) and Shale (15) respectively. Due to the variable nutrient omission response between mines observed in glasshouse experiments 4 and 5, it is likely that optimum rates of N and P will also vary between mines, as well as between substrates within each mine.

6.7.5 Summary

1. The general importance of N and P to healthy seedling growth on a wider range of substrates than those previously tested was further confirmed.

2. The optimum rates of N and P for early growth of dibbled seedlings were higher than those for direct sown seedlings (glasshouse experiment 1) although a direct comparison was difficult due to the use of different substrates from different mines.

3. P addition had the potential to increase root weight. This result presents one option for favourably increasing field root development and hence field hardiness.

4. Topdressing material again produced superior growth.