Effects of stem diameter and planting depth on survival and early growth of field-planted willow and poplar.

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Abstract

Willow (*Salix matsudana x alba*) clone 'Tangoio' and poplar (*Populus deltoides x nigra*) clone 'Veronese' have potential as a source of fodder supplementary to pasture in summer droughts. A trial at the Pasture and Crop Unit, Moginie, Massey University, Palmerston North from August 2003 to March 2004 determined the effect of two planting depths (150 mm and 300 mm) and three diameters (10 mm, 25 mm and 35 mm) of stem cuttings 600 mm long on the plant survival, growth, and above and below-ground biomass production of willow and poplar.

Tree species and stem diameter affected plant growth (shoot number, shoot length, and tree height) ($P<0.05$), but there was no significant effect of planting depth. Thick stems (35 mm diameter) produced higher edible (134 vs 33 g/tree) and total shoot dry matter (DM) (654 vs 96 g/tree) than thin stems (10 mm) 225 days after field planting. Similarly, root DM was greater for thick stems (41 g/tree) than thin stems (5 g/tree). Plant survival varied from 91 to 100%, but was significantly greater for medium/thick stems than for thin stems ($P < 0.05$). It is recommended that farmers establishing willow and poplar for fodder plant thick stems (35 mm) for higher tree growth and biomass production.

***Additional keywords*:** *Salix*, *Populus*, tree establishment, fodder biomass.

Introduction

Willow and poplar are widely used multipurpose trees and shrubs with soil conservation, shelter, firewood, ornamental, medicinal, furniture and paper pulp uses, as well as being used for fodder in summer droughts. Like many tree species, willow (*Salix* sp.) and poplar (*Populus* sp.) are slow to establish in comparison to herbaceous species. Previous experience by the authors in Manawatu New Zealand with the establishment of willow using un-rooted stem cuttings in a fodder block showed that willow were very sensitive to unfavorable weather conditions especially for the first 12 months after field planting. Small plants are vulnerable to limited water supply and weed competition. Based on this experience, an experiment was designed to determine the planting size of stems that provided effective growth, biomass production and sustainable establishment of willow and poplar in a fodder block.

Stem cuttings have been used for field establishment for many tree species such as *Pinus radiata* (Anon., 1995), willow (Douglas *et al*., 2003) and poplar (van Kraayenoord and Hathaway, 1986b; van Kraayenoord., *et al*., 1986a). Unrooted stem cuttings are often preferred for field establishment, because they are inexpensive and easy to handle (Zsuffa, 1992), as well as providing uniformity and conformity to the pure species (Newsholme, 1992)

Poplar and willow can be established by vertically planting stem cuttings which are often 1.0-2.0 m long, with diameters of 15-25 mm and 20-40 mm respectively (van Kraayenoord. *et al*., 1986a). (Douglas *et al*., 2003) found that the total yield of willow planted as 2 m stakes was higher than 1.1 m stakes after 2.5 years of field planting. Nevertheless, smaller cuttings of 250 mm long and 10 mm diameter have also been used in plantings in cultivated soil (Hathaway, 1980). According to (Douglas *et al*., 2003), experience from farmers and land managers has shown that burying one-quarter to one-third of the cutting length provides satisfactory plant survival and growth in a range of environments, however there is little research to support this hypothesis.

Based on reviewed literature and experience, our hypothesis was that thicker stem diameters give better plant establishment. To test this hypothesis, three cutting diameters and two planting depths were used.

The objectives of this paper are: (i) to determine the effect of three cutting diameters and two planting depths on plant survival, growth and biomass production of willow and poplar, and (ii) to determine the effect of three cutting diameters and two planting depths on root biomass of willow and poplar.

Materials and Methods

Experimental site

The research was conducted at a Pasture and Crop Unit, Moginie, Massey University, Palmerston North, on a Tokamaru silt loam with aeric fragiaqualf (gleyed yellow-grey earth) from August 2003 to March 2004. Rainfall and temperature during the growing season were obtained from AgResearch Grasslands, Palmerston North, 2.5 km from the experimental site.

The site was sprayed with Roundup Renew XTRA contain 1.1 kg glyphosate ha^{-1} to eliminate the existing pasture. Manual weeding was conducted on 23 October 2003 and 28 January 2004. Versatill (300 g clopyralid/litre) was sprayed on 12 December 2003. Orthene (195 g/litre acephate plus 346 g/litre ethylene glycol) was sprayed on 28 February 2004 to control willow sawfly (*Nematus oligospilus*).

Experimental treatments and design

Stem cuttings were planted on 6 August 2003 at 1.0 m x 1.0 m spacing (10,000 stems/ha). Factorial treatments were arranged in three randomized complete blocks (RCBD) and each experiment unit was 5 m x 5 m with 36 plants per plot. Both willow and poplar were established from 600 mm long stakes.

The treatments were:

1. Stem diameter: The three stem diameters were; (i) 10 mm (range 9-12 mm); (ii) 25 mm (range 20-30 mm); and iii) 35 mm (ranges 31-40 mm). The mean diameter of stakes was measured at the mid-length of the stake.
2. Planting depth: Either (i) 150 mm or (ii) 300 mm of the stake was pushed into the soil.
3. Plant species: The species were (i) Tangoio willow (*Salix matsudana x alba*), and ii) Veronese poplar (*Populus deltoids x nigra*)

Tree measurements

Tree survival was surveyed on 9 December 2003 and 16 March 2004. Growth performance of willow and poplar (height, no. of shoot, shoot length) was measured monthly. Eight sampling trees were chosen from each treatment across the plot. Three Tangoio willow and three Veronese poplar per treatment were harvested using different trees each time on 6 January 2004 and 16 March 2004. Fresh material was divided into edible (leaf and stem < 5mm) and non-edible (stem > 5 mm), and oven-dried at 80 ^{o}C for 24 hours to determine edible dry matter (DM) and total DM production. However, non-edible with bigger stems were oven-dried from 24 hours to 186 hours at 80 ^{o}C . Below ground biomass (roots) measurement included root number, root length and root DM.

Site volumetric soil moisture was measured monthly at 150 mm and 300 mm from October 2003 to March 2004 using Time Domain Reflectometry (TDR). Six pairs of permanent TDR probes were inserted randomly in the experimental area, approximately 150 mm away from the base of a tree. Monthly

All data were analysed using the PROC GLM procedure of SAS (SAS, 2001) using the Least Significant Difference test at the 5% significance level.

Results

Weather

The total rainfall during the growing season (2003/2004) was 886 mm, with rainfall during summer 77.6 mm, 91.6 mm and 299.4 mm being for December 2003, January and February 2004, respectively. The mean maximum and minimum temperatures during the growing season were 18.6 ^{o}C and 9.8 ^{o}C, respectively.

Soil water content (SWC).

SWC from 13 October 2003 to 15 March 2004 is presented in Figure 1. SWC at 0-150 mm soil strata, ranged from 27 % to 43%, with a mean of 34.1%. During the three summer months, the SWC was 31%, 33% and 38% on 15 December 03, 23 January 04, and 25 February 04, respectively (Figure.1). SWC at 0-300 mm depth ranged from 27% to 37% with a mean of 30%. On 15 December 03, 23 January 04 and 25 February 04, SWC was 27%, 29% and 35%, respectively (Figure 1).

Survival of stem cuttings

Stem diameter ($P < 0.05$) and planting depth ($P < 0.05$) affected survival of stem cuttings 123 days after field planting (Table 1). Species and treatment interactions had no effect on tree survival. Highest survival rate of 99% was found for 35 mm and 25 mm stem diameters, whereas the lowest survival rate (93%) was found for 10 mm stem diameter (Table.1). Stem cuttings planted at 150 mm soil depth had greater survival than at 300 mm planting depth (98% vs 96%). At 224 days after planting, there was a significant effect of stem diameter on survival ($P < 0.05$). However, there were no significant effects for species, depth or treatment interactions on survival. Higher survival was found for the thick stem diameters of 25 mm and 35 mm compared to the thin stem diameter of 10 mm, with means of 99, 98 and 93%, respectively.

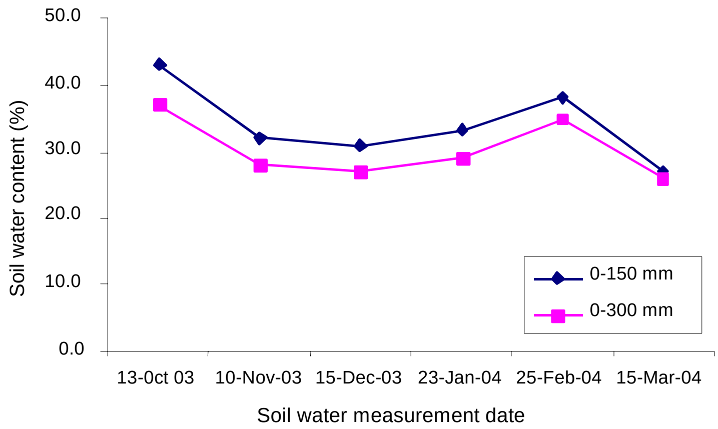

Figure 1. Volumetric soil water content (%) at 0-150 mm and 0-300 mm during the growing season for the willow and poplar site.

Table 1. Effects of stem diameter and planting depth for 600 mm long stakes on willow and poplar survival.

Species	Stem diameter (mm)	Planting depth (mm)	Tree survival (%) Days after planting 123	224
Poplar:				
Veronese	10	150	95	91
Veronese	10	300	94	93
Veronese	25	150	100	98
Veronese	25	300	99	99
Veronese	35	150	100	99
Veronese	35	300	98	96
Willow:				
Tangoio	10	150	95	95
Tangoio	10	300	92	92
Tangoio	25	150	100	100
Tangoio	25	300	98	98
Tangoio	35	150	100	100
Tangoio	35	300	99	98
SEM			1.5	2.0
Variable:			Probability	
Species (S)			0.49330	0.34950
Stem diameter (P)			0.00010	0.00060
Planting depth (D)			0.02250	0.32650
S*P			0.56930	0.93290
S*D			0.49330	0.31750
P*D			0.47910	0.75690
S*P*D			0.56930	0.57210

Stastandard error of the least square means

Effect of cutting diameter and planting depth on plants growth

Shoot number

There were significant differences (P<0.05) for the interaction of (i) species and stem diameter, and (ii) stem diameter and planting depth on shoot number (Table 2). No significant effect was observed on interaction of species, planting depth and stem diameter, and species and planting depth, except for the first 62 DAP (Table 2.). Tangoio willow produced higher shoot numbers from the thick stem diameter of 35 mm than 25 mm and 10 mm. However, for Veronese poplar, thin stem diameters of 10 mm produced higher shoot numbers compared to 35 mm and 25 mm for the first 62 DAP. Higher shoot number was observed for 35 mm stem diameter compared to thinner stem diameters on later observation dates.

Species and stem diameter had significant effects (P< 0.05) on shoot number. For example, at 198 DAP Tangoio produced greater shoot numbers than Veronese (11 vs 6). Thick stem diameter produced greater shoot numbers compared to thin stem diameter (P <

0.05). At 198 DAP, the thick stem diameter of 35mm produced greater shoot numbers (11) than 25 mm and 10 mm with a mean of 8 and 5 shoots, respectively. A similar trend was found for other observation dates. No significant effect was observed for planting depth on shoot number except for 32 DAP.

Table 2. Effects of stem diameter and planting depth of willow and poplar on shoot number.

Species	Stem diameter (mm)	Planting depth (mm)	Shoot number Days after planting 32	62	93	133	164	198
Poplar:								
Veronese	10	150	5	6	6	6	6	6
Veronese	10	300	5	6	5	5	4	4
Veronese	25	150	2	2	4	5	5	5
Veronese	25	300	4	5	7	6	6	5
Veronese	35	150	5	6	7	7	7	7
Veronese	35	300	3	3	5	7	6	6
Willow:								
Tangoio	10	150	9	11	8	8	7	7
Tangoio	10	300	5	6	6	7	6	5
Tangoio	25	150	11	14	15	15	13	12
Tangoio	25	300	7	11	15	17	15	13
Tangoio	35	150	15	15	20	18	17	16
Tangoio	35	300	16	18	19	17	15	14
SEM			0.8	0.9	1.0	0.8	0.7	0.7
Variable:			Probability					
Species (S)			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Stem diameter (P)			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Planting depth (D)			0.0433	0.1346	0.5106	0.4636	0.2601	0.1208
S*P			0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
S*D			0.0241	0.0614	0.2984	0.6512	0.9035	0.9066
P*D			0.1819	0.0413	0.0176	0.0113	0.0098	0.0263
S*P*D			0.0006	0.0001	0.4466	0.7530	0.4077	0.6290

Shoot length

There were significant differences ($P<0.05$) for the treatment interactions of (i) species, stem diameter and planting depth, (ii) species and stem diameter, and (iii) stem diameter and planting depth on shoot length, but no significant difference was observed for the interaction of species and planting depth except for the first 93 DAP (Table 3). For instance at 198 DAP , Tangoio with 35 mm diameter stem produced longer shoots (151 cm) compared to the 25 mm and 10 mm diameter stems with a mean of 126.4 cm and 65.8 cm respectively. A similar pattern was observed for Veronese.

Tangoio produced longer shoots (P< 0.05), compared to Veronese. At 198 DAP, the mean shoot length of Tangoio was greater than Veronese (117 cm vs. 88 cm). A similar trend was found for other observation dates. Thick stem diameter produced longer shoots compared to thin stem diameter (P < 0.05). For example at 198 DAP, the thick stem diameter of 35mm produced longer shoots compared to the 25 mm and 10 mm stem diameters with means of 134 cm, 110 cm and 64 cm, respectively. A similar trend was found for other dates of measurement. However no significant effect was found for planting depth on shoot length, except for 62 and 93 DAP (Table 3).

Table 3. Effects of cutting diameter and planting depth of willow and poplar on shoot length.

Species	Stem diameter (mm)	Planting depth (mm)	Shoot length (cm) Days after planting 62	93	133	164	198
Poplar:							
Veronese	10	150	5	7	19	27	48
Veronese	10	300	7	8	22	32	48
Veronese	25	150	3	13	45	66	93
Veronese	25	300	2	12	53	79	107
Veronese	35	150	5	19	55	75	103
Veronese	35	300	4	18	64	91	126
Willow							
Tangoio	10	150	8	17	40	52	70
Tangoio	10	300	5	12	38	47	57
Tangoio	25	150	16	36	75	96	126
Tangoio	25	300	10	31	78	99	126
Tangoio	35	150	16	47	94	118	151
Tangoio	35	300	17	46	97	119	151
SEM			0.6	1.2	2.5	3.5	4.9
Variable:			Probability				
Species (S)			0.0001	0.0001	0.0001	0.0001	0.0001
Stem diameter (P)			0.0001	0.0001	0.0001	0.0001	0.0001
Planting depth (D)			0.0480	0.0053	0.1432	0.2318	0.6574
S*P			0.0001	0.0001	0.0001	0.0001	0.0001
S*D			0.0001	0.0390	0.8534	0.2274	0.0653
P*D			0.0001	0.0588	0.0024	0.0005	0.0001
S*P*D			0.0002	0.8635	0.0776	0.0139	0.0218

Table 4. Effects of cutting diameter and planting depth of willow and poplar on tree height.

Species	Stem diameter (mm)	Planting depth (mm)	Tree height (cm) Days after planting 133	164	198
Poplar					
Veronese	10	150	62	76	104
Veronese	10	300	52	69	91
Veronese	25	150	86	108	143
Veronese	25	300	92	130	171
Veronese	35	150	98	129	173
Veronese	35	300	100	141	190
Willow:					
Tangoio	10	150	91	109	132
Tangoio	10	300	75	88	105
Tangoio	25	150	130	159	191
Tangoio	25	300	117	151	181
Tangoio	35	150	145	175	208
Tangoio	35	300	138	167	203
SEM			3.9	4.4	5.6
Variable:			Probability		
Species (S)			0.0001	0.0001	0.0001
Stem diameter (P)			0.0001	0.0001	0.0001
Planting depth (D)			0.1491	0.6223	0.9792
S*P			0.0172	0.2170	0.6137
S*D			0.0007	0.0001	0.0001
P*D			0.0047	0.0019	0.0002
S*P*D			0.0711	0.5166	0.4198

Tree height

There were significant differences (P<0.05) for the treatment interactions of (i) species and planting depth, and (ii) stem diameter and planting depth on tree height (Table 4). No significant effect was observed for the interaction of species and cutting diameter on tree height. For example, at 198 DAP, willow planted at 150 mm depth was taller than 300 mm depth (177 cm vs 165 cm). In contrast with Tangoio, Veronese was significantly taller at a planting depth of 300 mm than 150 mm (156 mm vs 140 cm) (Table 4).

Species and stem diameter had significant effects on tree height (P<0.05). At 198 DAP, the mean height of Tangoio was higher compared to Veronese (171 cm vs 148 cm). A similar trend was observed on the other observation dates. Thick stem diameter produced taller trees than the thin stems.

Table 5a. Effects of cutting diameter and planting depth on edible DM of willow & poplar.

Species	Stem diameter (mm)	Planting depth (cm)	Edible DM (g/tree) Days after planting 150	225
Poplar:				
Veronese	10	150	27	44
Veronese	10	300	12	38
Veronese	25	150	30	65
Veronese	25	300	33	69
Veronese	35	150	35	154
Veronese	35	300	32	158
Willow:				
Tangoio	10	150	18	28
Tangoio	10	300	9	21
Tangoio	25	150	44	89
Tangoio	25	300	38	68
Tangoio	35	150	64	134
Tangoio	35	300	65	91
SEM			9.9	21.6
Variable:			Probability	
Species (S)			0.0540	0.2156
Stem diameter (P)			0.0005	0.0001
Planting depth (D)			0.3878	0.3759
S*P			0.0488	0.2184
S*D			0.9839	0.3528
P*D			0.6898	0.7686
S*P*D			0.8577	0.7686

Effect of cutting diameter and planting depth on biomass production

Above-ground biomass production

Tangoio and Veronese were affected by the interaction of stem diameter and species on edible DM at 150 DAP (Table 5a). Tangoio with 35 mm stem diameter produced higher edible DM than 25 mm and 10 mm stem diameters with means of 65 g/tree, 41 g/tree and 14 g/tree, respectively. A similar pattern was observed for the Veronese. There was a significant effect ($P < 0.05$) for cutting diameter on edible DM. Thick stem diameter produced higher edible dry matter than the small cutting diameter for both species. However, there was no significant effect of planting depth on edible DM (Table 5a).

There was a significant effect ($P<0.05$) for cutting diameter on total shoot biomass (Table 5b). For example at 225 DAP, stem diameter of 35 mm produced higher total shoot biomass than 25 mm and 10 mm in the order 654 g/tree > 309 g/tree > 96 g/tree. Nevertheless, no significant effects were found for species, planting depth and treatment interactions (Table 5b).

Table 5b. Effects of cutting diameter and planting depth on total DM for willow & poplar.

Species	Stem diameter	Planting depth	Total DM (g/tree) Days after planting	
	(mm)	(cm)	150	225
Poplar:				
Veronese	10	150	55	116
Veronese	10	300	44	112
Veronese	25	150	156	281
Veronese	25	300	187	333
Veronese	35	150	365	713
Veronese	35	300	214	743
Willow:				
Tangoio	10	150	60	93
Tangoio	10	300	39	64
Tangoio	25	150	214	327
Tangoio	25	300	165	296
Tangoio	35	150	347	654
Tangoio	35	300	403	508
SEM			38.8	84.8
Variable:			Probability	
Species (S)			0.1406	0.2375
Stem diameter (P)			0.0001	0.0001
Planting depth (D)			0.2912	0.6696
S*P			0.2808	0.4398
S*D			0.3958	0.3443
P*D			0.7624	0.8482
S*P*D			0.1327	0.8199

Below-ground biomass

Root number

There was a significant interaction (P <0.05) for species and stem diameter on number of roots/tree (Table 6). Tangoio with thick stem diameter produced a higher number of roots/tree than the thin diameter (P<0.05). For example, at 225 DAP, Tangoio with 35 mm stem diameter had higher root number than 25 mm and 10mm with means of 130, 102 and 52, respectively. Similarly for Veronese the order was 34, 31 and 23. However no significant effects were observed for the other treatment interactions (Table 6).

There were significant differences for species and stem diameter on root number (P<0.05). For example at 225 DAP, mean root number was higher for Tangoio than Veronese (95 vs 30). Higher root number was observed at 35 mm (82) and 25 mm (67) stem diameter than 10 mm (37). There was no significant effect of planting depth on root number (Table 6).

Table 6. Effects of stem diameter and planting depth of 600 mm stakes of willow and poplar on root number per tree.

Species	Stem diameter (mm)	Planting depth (cm)	Root number/tree Days after planting 150	225
Poplar:				
Veronese	10	15	17	29
Veronese	10	30	17	17
Veronese	25	15	27	22
Veronese	25	30	32	41
Veronese	35	15	17	23
Veronese	35	30	18	45
Willow:				
Tangoio	10	15	34	54
Tangoio	10	30	38	49
Tangoio	25	15	65	91
Tangoio	25	30	67	114
Tangoio	35	15	91	138
Tangoio	35	30	123	121
SEM			6.4	14.9
Variable:			Probability	
Species (S)			0.0001	0.0001
Stem diameter (P)			0.0001	0.0012
Planting depth (D)			0.0649	0.5625
S*P			0.0001	0.0141
S*D			0.1843	0.5796
P*D			0.2315	0.3916
S*P*D			0.1570	0.4855

Total root length

There was interaction ($P < 0.05$) for species and stem diameter on total root length at 150 DAP (Table 7). Tangoio with thick stem diameter (35 mm) had higher total root length than 25 mm and 10 mm in order of 1068 cm, 690 cm and 261 cm respectively. Similarly with Veronese, thick stem diameter of 25 mm (384 cm) and 35 mm (247 cm) produced higher total root length than 10 mm stem diameter (180). However no interaction of species and stem diameter was observed at 225 DAP.

There were no significant differences on other interaction. There were significant differences ($P < 0.05$) between species and stem diameter on total shoot length. For example at 225 DAP, Tangoio produced higher total root length than Veronese (1194 cm vs 541 cm). Thick stem of 35 mm and 25 mm produced longer total root length than 10 mm stem diameter with mean of 1346 cm, 911 cm and 345 cm respectively. However no significant difference was found between planting depth and total root length.

Table 7. Effects of stem diameter and planting depth for 600 mm stakes of willow and poplar on total root length.

Species	Stem diameter (mm)	Planting depth (mm)	Total root length (cm) Days after planting 150	225
Poplar:				
Veronese	10	150	204	423
Veronese	10	300	157	199
Veronese	25	150	416	475
Veronese	25	300	353	598
Veronese	35	150	279	594
Veronese	35	300	216	959
Willow				
Tangoio	10	150	302	462
Tangoio	10	300	219	295
Tangoio	25	150	790	1334
Tangoio	25	300	590	1237
Tangoio	35	150	1162	2473
Tangoio	35	300	975	1359
SEM			115.2	304.5
Variable:			Probability	
Species (S)			0.0001	0.0012
Stem diameter (P)			0.0001	0.0005
Planting depth (D)			0.1224	0.3030
S*P			0.0005	0.0613
S*D			0.4633	0.1337
P*D			0.9028	0.6719
S*P*D			0.9446	0.1873

Root dry matter.

Tangoio with a thick stem diameter had a greater root DM than with a thin stem diameter at 225 DAP ($P<0.05$) (Table 8). A similar pattern was observed for Veronese. However, there were no significant effects of other treatment interactions on root DM (Table 8).

There were significant effects of species and stem diameter on root DM ($P <0.05$). For example at 225 DAP, Veronese produced higher root DM than Tangoio (27.7 g/tree vs 12.0 g/tree). Root DM was significantly higher for the 35 mm stem diameter than 25 mm and 10 mm with means of 40.7 g/tree, 14.3 g/tree and 4.4 g/tree respectively. There was a significant effect of planting depth on root DM at 150 DAP, but no effect at 225 DAP (Table 8).

Table 8. Effects of stem diameter and planting depth of willow and poplar on root dry matter.

Species	Stem diameter (mm)	Planting depth (mm)	Root DM(g/tree) Days after planting 150	225
Poplar:				
Veronese	10	150	0.9	8.2
Veronese	10	300	0.3	4.8
Veronese	25	150	3.0	18.1
Veronese	25	300	1.7	16.0
Veronese	35	150	3.2	66.9
Veronese	35	300	1.6	52.2
Willow:				
Tangoio	10	150	1.2	4.0
Tangoio	10	300	0.3	1.0
Tangoio	25	150	5.0	15.1
Tangoio	25	300	2.6	8.1
Tangoio	35	150	7.9	29.2
Tangoio	35	300	3.8	14.3
SEM			1.7	10.4
Variable;			Probability	
Species (S)			0.0223	0.0152
Stem diameter (P)			0.0014	0.0002
Planting depth (D)			0.0147	0.2226
S*P			0.1620	0.0516
S*D			0.3494	0.8970
P*D			0.4529	0.6907
S*P*D			0.8144	0.9807

Discussion

Tree survival and SWC

The high survival rate for the Tangoio willow and Veronese poplar was aided by the high rainfall (887 mm) and soil moisture during the establishment growing season (August 2003 to March 2004). The major limitations for establishment of willow are inadequate soil moisture and excessive weed competition (Hathaway, 1986; (Hudson, 1997). Nevertheless, survival was greater for trees established from 35 mm and 25 mm diameter stems (600 mm long) than 10 mm diameter stems. Observations reported in the practical literature support this experimental finding that size of cutting affects tree survival during establishment (Zierke, 1994; Hoag, 2004). This may be due to the thick stem diameter, having higher nutrient and carbohydrate reserve (Zierke, 1994; Macpherson, 1995; Hoag, 2004). Also, the thick stem diameters resulted in greater root production, which could have increased water and nutrient uptake to the establishing trees. Control of competition from pasture and weed species improves trees establishment (Abrahamson *et al*., 2002). Understorey pasture and weeds in this experiment were controlled by a combination of herbicides and manual weeding to minimise weed competition to ensure better growth and higher survival.

Tree growth and biomass

Tangoio willow and Veronese poplar growth were more strongly influenced by stem diameter than planting depth. At the greatest stem diameter used (35 mm) both Tangoio willow and Veronese poplar produced higher shoot number and length, tree height, root number and length, root DM, edible and total shoot DM than trees established from 10 mm diameter stem cuttings. This result was supported by the strong correlation of physical size of cutting on poplar growth (Bowersox, 2001). However, there was no significant advantage to growth and biomass production in planting willow and poplar at 150 mm or 300 mm depth. Planting depth was clearly not an important factor that influenced tree growth and biomass production. However, Beaton (1987) recommended planting poles deep to improves tree stability.

It is recommended that farmers establishing willow and poplar for fodder plant thick stems (35 mm) for higher tree growth and biomass production.

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