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Survival and growth to age 8 of four *Populus maximowiczii* × *P. nigra* clones in field trials on pastoral hill slopes in six climatic zones of New Zealand.

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Abstract

In New Zealand, poplars are commonly planted on moist, unstable pastoral hill country to combat soil erosion. Four *Populus maximowiczii* × *P. nigra* experimental clones, bred for soil stabilisation, were trialled on pastoral land in six different climatic zones. The experimental clones (identified as NZ5033, NZ5034, NZ5035, NZ5036) were planted together with six New Zealand-bred commercially available clones (four *P. deltoides* × *P. nigra* clones, either 'Toa' (*P.* × *euramericana* × *P. yunnanensis*) or 'Kawa' (*P. deltoides* × *P. yunnanensis*), and 'Shinsei' (*P. nigra* × *P. maximowiczii*)). The clones were planted as unrooted 3-m poles on open, generally sloping (and often broken) terrain. Replication was 5 or 10 poles per clone/site/year subclass. Survival, height and diameter at breast height (DBH) were measured six to eight years after establishment. Survival of the experimental clones was similar to that of the commercial clones. For height and DBH, NZ5034 was a superior clone, NZ5035 was an average clone, NZ5033 was an average to below-average clone, and NZ5036 was a below-average clone, compared with the commercial clones tested in the trials.

The *P. maximowiczii* × *P. nigra* clones are considered particularly suitable for colder sites subject to severe winter frosts and to warmer sites with regular rainfall, where their high rust resistance is an advantage. They also showed a high tolerance to wind. They are less suited to sites prone to salt spray and to summer drought.

Keywords: climatic zone; clonal; field trial; New Zealand; *Populus maximowiczii* × *P. nigra*.

Introduction

The genus *Populus* is distributed throughout the temperate zone of the Northern Hemisphere where some 30 species are known. Because of easy hybridisation between species, many spontaneous hybrid poplars have arisen and many more have been produced by artificial hybridisation. These hybrid poplars are further propagated vegetatively by cuttings. Throughout the world, hybrid poplars are utilised commercially for timber and wood products, soil stabilisation, phytoremediation and biomass (Kollert et al., 2011).

Poplars are not native to New Zealand and the first introductions were made between 1840 and 1850 during the early days of European settlement. The Lombardy poplar (*Populus nigra* L.'Italica') and the American cottonwood (*P. deltoides* W. Bartr. ex Marsh. 'Virginiana') were the earliest introductions. The number of poplars planted for soil conservation and erosion control has increased rapidly since 1950 and their timber potential has became better appreciated. As a result, a large number of selected clones were introduced from Europe, America, Japan and China. A collection of over 200 poplar clones, mostly of *P. deltoides, P. nigra, P. trichocarpa* Torrey et Gray and

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P. × *euramericana* Dode (Guinier) are maintained by The New Zealand Institute for Plant & Food Research Limited at Aokautere nursery near Palmerston North, for research and breeding purposes. Experimental crosses are carried out to develop clones more suitable for niche environments and purposes, and to provide a wider range of commercially available phenotypes as protection against new pests and diseases and changing climate (Bisoffi, 1990).

In New Zealand, poplars are commonly planted on moist, unstable pastoral hill country to prevent or reduce soil erosion (Wall et al., 1997, Wilkinson, 1999), generally as unrooted 3-m poles (McIvor et al., 2008). The New Zealand Government, through the Ministry of Agriculture and Forestry, has developed programmes to reduce erosion in pastoral hill country, which are operated through regional authorities. Some 700 000 ha of pastoral land in New Zealand is considered erosion-prone, and soil stabilisation for approx. 20 000 ha per year is being achieved currently. Slips often occur just below gently sloping hillcrests where downhill slopes become steeper, frequently because of seepage water from the hillcrests flowing out over impervious layers. As a protection against slippage, one or two rows of poplars or tree willows (*Salix alba* L., *Salix matsudana* Koidz., *S. matsudana* × *alba*) are planted 8 – 12 m apart in this changing slope zone (Wilkinson, 1999).

Like many international poplar breeding programmes New Zealand's programme has depended on contestable government funding. There have been periods of both high and low breeding activities and, as in this case, only a few clones from a single cross might be field trialled at any one time.

New Zealand's pastoral hill country climate is complex and varies from warm subtropical in the far north to cool temperate in the far south. Clones have been found not to perform equally well in all regions of the country. The use of drought-tolerant clones is favoured in eastern regions which generally have warm dry summers with low rainfall and where the requirement for rust resistance is not so critical. In contrast, high rust resistance is favoured in clones used in western regions which generally receive higher summer rain. In these areas, drought tolerance is not so significant. For these reasons, experimental clones are trialled across the entire range of New Zealand climatic zones. Many locations experience high wind runs, and salt tolerance is also an important survival issue in coastal hill country. The expected increase in extreme weather events (heavy rain storms, high winds, prolonged drought) due to climate change has made it imperative that poplar clones covering a wider range of tolerances are made available for commercial use in New Zealand. However, some farmers are reluctant to plant poplars for soil stabilisation or are concerned about future tree-management issues. The hazards to stock and farm infrastructure resulting from breakage of large branches or uprooting of trees in high winds due to a large sail area has been raised as an objection. Therefore, it is important for our breeding programme to provide poplar clones with a fastigiate form and demonstrate that new clones will retain their fastigiate form when planted in a wide-spaced regime.

Populus maximowiczii A. Henry (a native of Japan) was introduced into the New Zealand breeding programme in 1993 to add resistance to insect- and mammalian herbivores, and to the poplar rust diseases present in New Zealand. *Populus maximowiczii* was hybridised with *P. nigra* to retain the fastigiate form favoured in New Zealand to minimise wind damage and shading when planted in a silvopastoral situation for the prime purpose of soil stabilisation.

Hybridisation of these two poplar species has been carried out in overseas breeding programmes. The hybrid clone NM6 (*Populus nigra* × *P. maximowiczii*) was reported by Noh et al. (1986) as characterised by its fast growth rate, high resistance to cold weather, disease and acidic soil conditions as well as its suitability for a wide variety of forest lands. Other reports on *P. nigra* × *P. maximowiczii* (notably NM6) and *P. maximowiczii* × *P. nigra* hybrids include their use in breeding programmes for biomass production and disease resistance (McMahon et al., 2008, Steenackers et al., 1990) and their application in phytoremediation trials (Zalesny et al., 2006, Cavaleri et al., 2004). The addition of *P. maximowiczii* × *P. nigra* clones to the range of available poplar clones in New Zealand is important to add resilience to future pest and disease incursions (Broberg & Borden, 2005; Ramirez et al., 2004). New Zealand is fortunate in that it is isolated not only from many of the poplar insect pests that are present in the northern hemisphere, but also from some of the disease organisms that attack poplars. However, New Zealand has a favourable climate in which new pests and diseases are likely to establish quickly. Unfortunately, successful new incursions of both pests and diseases have already occurred (Charles & Allan, 2000) and more can be expected in the future. Therefore, poplar clones with a range of resistance that are adapted to various climates are needed to provide for future needs for soil conservation and biomass. Susceptibility to *Septoria musiva* Peck canker has been reported for some *P. nigra* × *P. maximowiczii* hybrid clones (Strobl & Fraser, 1989) and could be seen as a risk for clones of *P. maximowiczii* × *P. nigra*. However, this pathogen is not known to affect widely spaced poplars in New Zealand.

The objective of the study was to compare field performance of four experimental poplar clones with commercialised clones in a widely spaced silvopastoral situation under a range of contrasting climatic conditions in New Zealand. This is the first reported

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field trial of experimental *Populus maximowiczii* × *P. nigra* clones in New Zealand.

Materials and methods

Trial Sites

Field trials were established to compare the performance of four new experimental poplar clones with already available commercial clones at six sites. The trial sites are located at Parakai, 50 km northwest of Auckland, Mapiu 30 km north of Taumarunui, Rissington 20 km northwest of Napier, Ashhurst 17 km northeast of Palmerston North, Windwhistle 50 km west of Christchurch and at Miller's Flat, 60 km southeast of Alexandra (Figure 1). The site at Mapiu was only lightly grazed but the other five sites were located on intensively grazed farmland. The six sites varied in a number of ways, including climate, topography and aspect. Details of each site are given in Table 1. Mean temperature and annual rainfall data presented in Table 1 were determined from data collected from the National Institute of Water and Atmosphere (NIWA) weather recording station nearest to the trial site (Auckland for Parakai, Taumaranui and Taupo (ground frosts) for Mapiu, Napier for Rissington, Palmerston North for Ashhurst, Lincoln for Windwhistle and Alexandra for Miller's Flat sites respectively), and over the period January 1999 – December 2002. Rainfall data supplied by the landowner was used for the Miller's Flat site replacing Alexandra weather station data. Mean number of days with ground frost was determined for the period 1971 – 2000 from the same weather stations.

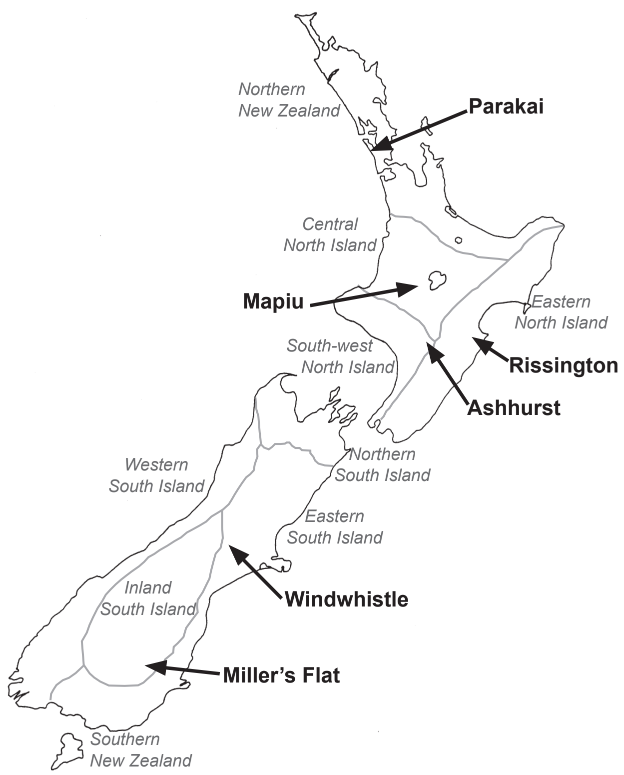

FIGURE 1: Approximate location of each trial site and its position within one of New Zealand's climatic zones (map courtesy of National Institute of Water and Atmosphere (NIWA), www.niwascience.co.nz/edu/resources/climate/overview).

Slope angle range was determined for each site by measuring slope angle at several positions for gentlest and steepest. Overall slope across the three trial sites at each location was assessed to determine slope category using the slope groupings of Lynn et al. (2009). Erosion status was assessed qualitatively from observations of frequency and severity of shallow slope erosion scars at each trial sites.

These sites were selected to test the adaptability of the experimental poplar material to a range of prevailing abiotic environmental conditions: salt spray (Parakai), drought (Rissington and Windwhistle), severe wind (Ashhurst and Windwhistle), and cold (Miller's Flat).

Planting material

Ten New Zealand-bred clones were used in the trial each year (1999, 2000 and 2001), of which four were experimental *Populus maximowiczii* × *P. nigra* clones and the remaining six were commercially available clones. The commercial clones used were 'Selwyn', 'Weraiti', 'Dudley' and 'Otahuao' (all *P. deltoides* × *P. nigra* clones), 'Toa' (*P.* × *euramericana* × *P. yunnanensis*), 'Kawa' (*P. deltoides* × *P. yunnanensis*) and 'Shinsei' (*P. nigra* × *P. maximowiczii*). The clone 'Toa' used in 1999 and 2000 was replaced by clone 'Kawa' in 2001. All planting material was grown at the National Poplar and Willow Breeding Nursery at Aokautere, Palmerston North.

The four experimental clones, NZ5033, NZ5034, NZ5035 and NZ5036, shared a common parentage, *Populus maximowiczii* Henry '73-011-078' × *P. nigra* var. Thevestina. The pollen was a mix from two *P. nigra* var. Thevestina clones 76234 and 76239-6 selected from seed sourced from Izmit, Turkey. *Populus maximowiczii* Henry '73-011-078' was selected from a seed lot obtained in 1973 from Oji Pulp and Paper Company, Hokkaido, Japan, a region with harsh, cold winters. *Populus maximowiczii* × *P. nigra* clones were initially selected at Aokautere nursery, Palmerston North by the breeder for resistance to the fungi *Melampsora larici-populina* Kleb. and Marssonina *brunnea* (Ell. & Ev.) Magn. Of the 235 seedlings produced in the cross, 210 were resistant. Five clones were selected after three years of nursery assessment for performance in pole-production trials from 1997/8. These five were selected for ease of strike from

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TABLE 1: Climatic data and site information for the six trial sites

Variable	**Trial site**					
	Parakai	**Mapiu**	**Rissington**	**Ashhurst**	**Windwhistle**	**Miller's Flat**
Climate zone	Northern New Zealand	Central North Island	Eastern North Island	South-west North Island	Eastern South Island	Inland South Island
Latitude	36° 39′	38° 38′	39° 26′	40° 17′	43° 31′	45° 45′
Longitude	174° 24′	175° 13′	176° 41′	175° 47′	171° 40′	169° 28′
Temp. (°C) in hottest month:						
Mean	19.3	18.3	18.1	18.1	16.8	15.8
Mean daily max.	24.3	24.6	23.3	23.1	23.1	22.4
Temp. (°C) in coldest month:						
Mean	10.4	7.5	8.4	8.5	5.8	4.3
Mean daily min.	5.9	2.5	3.7	4.5	1.0	-0.3
Prevailing wind	SW	SW	W	NW	NW (sum.) SW (wint.)	NW
Mean ground frosts/y	<1	32	7	16	36	83
Altitude (m)	30	360	190	200	280	200
Aspect	NW	N	Variable	W, NW	SW	SE, NE
Mean annual rainfall, (mm)	1166	1478	1150	1172	1010	900[1]
Slope (°)	15 – 22	22 – 32	5 – 22	20 – 30	0 – 19	12 – 28
Slope group	Strongly rolling	Steep	Rolling	Moderately steep	Rolling	Moderately steep
Erosion status	Slight	Marked	Low	Marked	Nil	Slight
Soil type	Sandy clay loam	Clay	Sandy-loam	Clay-loam	Stony, some clay	Silt-loam
Climatic limiting factors	Salt spray	None recognised	Drought	Wind	Wind, drought	Cold
Grazing intensity	High	Low	High	High	High	High

[1] *supplied by landowner.*

cuttings, straight stems, resistance to *Chondrostereum purpureum* (Pers.) Pouzar, 1959 (silverleaf fungus) low number of side shoots, and vigour as both cuttings and poles (assessed through diameter and height). Of the five clones selected, four were subsequently selected for the national trials. Ten poles of each clone were planted at each site in 1999 and 2000 and either 10 (Ashhurst and Miller's Flat) or five of each clone in 2001. Trials were planted at the sites in three successive years, 1999 – 2001, to compensate for a possible planting- or establishment failure. The exceptions were at Ashhurst and Miller's Flat (2000 – 2001 only). The experimental clone NZ5033 was not planted at Rissington in 1999, and the clone 'Kawa' replaced 'Toa' in 2001 because of a shortage of suitable 'Toa' material.

Establishment

The planting material was unrooted 3-m poles normally planted to a depth of 0.8 m into uncultivated pasture either by ramming or by excavating a hole when the site was stony (at Windwhistle). The experimental design was randomised complete blocks (either 10 or 5 blocks) with each clone being represented once in each block. Poles were planted in rows across the slope at 10 m spacing within rows and 20 m between rows. The trial was marked out on the site and a planting plan supplied to the landowner who then planted the supplied, colour-coded material. All trial sites were in grazed pasture and poles were planted by the landowners without any releasing or weed control. At the intensively grazed sites (all excepting Mapiu), the poles were enclosed with plastic sleeves

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to prevent grazing stock eating the bark. The sleeves split or were removed as the trees outgrew them (5 – 7 years). Landowners were asked to exclude cattle from the paddock until the trees were at least three years old. From site to site, the terrain varied from rolling to steep, Table 1. Old slip scars were more frequent and extensive at Ashhurst and Mapiu. The experimental design sought to minimise the impact of differences across the slope, particularly at sites where there were undulations or old slip scars across the slope.

At each trial site, plantings in successive years were located adjacently, or close by in a similar situation. The sites were visited and heights and survival measured in 2002, 2004 and 2007. Only 2007 data are reported here.

Measurements and calculations

Height in metres was determined using an inclinometer at a measured distance from the tree and calculated using trigonometry. Diameter at breast height (DBH) in centimetres was measured at 1.4 m above ground. These measurements were taken for all trees at the different sites between 27 April and 18 July 2007. Any tree deaths were recorded. No data were collected on rust incidence, since measurements at most sites were made after leaf fall.

An assessment of relative wood production was calculated for the 1999 trial trees using the formula:

$$\text{Wood volume in m}^3\text{ (V)} = \text{tree height} \times \text{DBH}^2 \times 10^{-4}.$$

Statistical Analysis

Linear mixed models (GenStat 13th edition, VSNi Ltd, Hemel Hempstead, UK, 2010) with site, year and clone as fixed effects, and site x year, block within site x year, and clone within site x year as random effects, were used to analyse height and DBH data from the three years of trials. Site was included as a fixed effect because the trial sites were chosen to represent different climate regimes. Year was included as a fixed effect to adjust for the fact that some sites were only planted in some years. Both height and DBH were log-transformed for analysis, to stabilise the variability. For both height and DBH the clone within site x year random effect was zero, so more complex statistical models were not investigated. Data collected from the 1999 trial at Parakai and from the 2000 and 2001 trials at Windwhistle were not included in the statistical analyses because of negligible (0 – 4%) survival rates. These poor survival rates were deemed to be unrelated to the intrinsic properties of the trial trees and are described in the results section under survival.

Performance

Mean height and DBH in each year for surviving trees at each site was used to rank the performance of the experimental clones among all the clones used in the trial. Individual clones were excluded from the overall average in any particular year if there weren't data from all sites in the trial in that year, either because the clone was not planted at that site in that year (NZ5033 in 1999 at Rissington) or because all representatives of that clone had died by the time the trial was assessed in 2007 ('Kawa' and 'Weraiti' at Miller's Flat in 2001,'Selwyn' at Mapiu in 2001).

Results

General characteristics of the experimental clones

All four experimental clones were characterised by a dominant leader, straight stems, steeply angled and light branching, relatively smooth bark, and a high degree of uniformity at similar locations. Double leaders were rare. Neither palatability of foliage to browsers, e.g. possums, nor the degree to which bark was damaged by browsing stock were assessed, although significant bark damage was observed for the trees planted at Mapiu in the 2001 trial. In general, branches of experimental clones were lighter and steeper angled than those of the commercial clones.

Survival

Excluding data from Parakai in 1999 and from Windwistle in 2000 and 2001 (for which survival was 0 – 4%), survival of all clones across all sites and for all years was similar at between 70% and 80% with the exception of 'Kawa', which had a lower survival rate of 57% (Table 2). Overall survival of the experimental clones across all sites was 74%. This was comparable with 'Shinsei' (75%), the *P. deltoides* × *nigra* clones (74%) and 'Toa' (78%) and higher than for the commercial clone 'Kawa', although this clone was only included in 2001 trials.

Poor survival at some sites in some years was attributed to many factors. These included: poor planting (poles were planted too shallow and not rammed at Windwhistle in the 2000 and 2001 plantings); mortality from ring barking by animals (domestic deer were allowed into the trial paddock at Parakai in 1999 and feral goats severely damaged the trial at Mapiu in 2001); trees being pushed over by cattle (Windwhistle in 2001); severe cold frosts (Miller's Flat 2001); and unsuitability (dry, windy) of weather at the site (part of Rissington 1999). Only 4% of trees survived from the 1999 planting at Parakai, and 0% from the 2000 and 2001 plantings at Windwhistle. At Miller's Flat during the cold winter of 2001, survival of the experimental

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clones was much higher than survival of most of the commercial clones (2002 data not reported). No losses were attributed to windthrow, although wind was a significant factor at Parakai, Rissington, Windwhistle and Ashhurst. Some losses occurred for faster-growing trees when protective sleeves failed to split and the tree weakened and snapped at the base of the trunk before the sleeve could be manually removed. Of the experimental clones, NZ5034 was most affected, three deaths being due to this cause. There was low survival of all clones on the drier microsites (upper hillslopes, ridges and rises), which were prevalent over part of the trial site at Rissington in 1999. This factor accounted for the lower overall survival in that year (Table 2). Survival across all trials was very similar for all clones despite variability between trial sites attributable to the factors mentioned previously.

Performance

The 2007 mean height and DBH data for each clone for all planting years for each site are shown in Tables 3 and 4, respectively. The 2007 mean height and DBH data for each clone in each planting year without separation for sites are shown in Figures 2 and 3, respectively.

(a) Height

All fixed effects were significant ($p<0.05$). Mean heights for all clones were similar for planting years 1999 and 2000, and much lower for trees planted in 2001 (p = 0.01, Figure 2). For example, mean height (m) for NZ5034 at Rissington was 10.8 ± 2.6, 12.8 ± 2.4 and 8.1 ± 1.1 for the 1999, 2000 and 2001 plantings, respectively, Equivalent heights (m) in 1999, 2000 and 2001 for 'Otahuao' were 9.4 ± 3.8, 8.9 ± 1.8 and 5.2 ± 1.0, for 'Selwyn' were 8.8 ± 2.8, 10.2 ± 2.3 and 5.9 ± 2.0, and for NZ5036 were 6.6 ± 2.1, 9.1 ± 2.9 and 5.7 ± 0.8.

The experimental clone NZ5034 was the tallest clone at half the trial sites, and not significantly different from the tallest at two other sites (Table 3). The other experimental clones performed similarly to commercial clones at Ashhurst, Windwhistle and Miller's Flat, better than most commercial clones at Mapiu, and worse at Parakai and Rissington. When compared with 'Shinsei' (a currently available commercial *P. nigra* × *P. maximowiczii* hybrid), clone NZ5034 was taller, significantly so at Rissington, not significantly at the other sites.

TABLE 2: Percentage survival of each clone and all clones at each site all sites for each trial year and combined years. Data from the Parakai 1999 trial and Windwhistle 2000 and 2001 trials are not included (see Results text for details).

		Trial Site						
		Parakai[1]	**Mapiu**	**Rissington**	**Ashhurst**	**Windwhistle[2]**	**Miller's Flat**	**All sites**
Clone	NZ5036	73	84	68	45	100	95	74
(all years)	NZ5033	67	92	40	75	100	65	73
	NZ5034	47	84	76	35	100	90	71
	NZ5035	53	84	76	60	100	90	76
	'Shinsei'	47	88	76	70	100	70	75
	'Weraiti'	87	88	80	85	90	30	76
	'Selwyn'	73	68	96	70	90	40	72
	'Otahuao'	87	68	72	70	100	50	71
	'Toa'	60	80	70	80	100	80	78
	'Dudley'	73	72	84	90	90	60	77
	'Kawa'	80	100	20	60	-	0	57
	Total	**67**	**79**	**81**	**67**	**97**	**63**	
Year	1999	nc	85	61	-	97	-	82
(all clones)	2000	70	92	82	77	nc	79	80
	2001	62	52	80	57	nc	47	57

- = no trial
nc = not calculated
[1] Data for the 2000 and 2001 trials only
[2] Data for the 1999 trial only

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TABLE 3: 2007 Mean height (m) of trees across all three planting years compared using mixed effect model. Results are back-transformed from log scale. Means followed by the same letters indicate no significant difference within site at p = 0.05 (pairwise Type 1 error rate).

Average least significant ratio at p = 0.05: for all sites average = 108%; within site = 121% except for comparisons with 'Kawa', which is 142% (Two means are significantly different if the ratio of the larger to the smaller is more than the least significant ratio).

Clone	Trial Site						
	Parakai	Mapiu	Rissington	Ashhurst	Windwhistle	Millers Flat	Overall average
NZ5033	5.1 cde	9.5 bc	6.1 f	4.9 c	8.7 ab	5.6 b	6.4 f
NZ5034	5.7 bcd	11.6 a	10.5 a	6.0 ab	10.2 a	6.8 ab	8.1 a
NZ5035	4.9 de	9.8 bc	7.2 def	5.9 abc	8.0 b	5.8 b	6.7 cdef
NZ5036	4.5 e	8.5 cd	6.6 ef	5.2 bc	8.1 b	6.2 ab	6.3 f
'Shinsei'	5.1 cde	9.7 d	7.8 cde	6.4 ab	8.5 ab	6.3 ab	7.1 cd
'Weraiti'	6.0 bcd	8.2 de	9.7 ab	6.6 a	7.8 b	6.2 ab	7.3 bc
'Selwyn'	5.3 cde	7.1 e	7.9 cde	6.3 ab	7.5 b	6.5 ab	6.7 def
'Otahuao'	6.3 bc	7.7 de	7.2 def	5.6 abc	7.6 b	5.6 b	6.6 ef
'Toa'	6.8 b	9.8 bc	8.8 bc	5.6 abc	8.9 ab	7.2 a	7.7 ab
'Dudley'	6.2 bc	8.0 de	8.2 bcd	5.9 ab	7.8 b	6.3 ab	7.0 cde
'Kawa'	10.1 a	12.7 a	8.6 abcdef	6.2 abc	NS	NS	

NS = trees planted no survivors (overall averages not calculated for line-year combinations with this clone)

TABLE 4: 2007 Diameter at breast height (cm) of trees across all three planting years compared using mixed effect model. Results are back-transformed from log scale. Means followed by the same letters indicate no significant difference within site at p = 0.05 (pairwise Type 1 error rate).

Average least significant ratio at p = 0.05: for all sites average = 111%; within site = 128% except for comparisons with 'Kawa', which is 147% (Two means are significantly different if the ratio of the larger to the smaller is more than the least significant ratio).

Clone	Trial Site						
	Parakai	Mapiu	Rissington	Ashhurst	Windwhistle	Millers Flat	Overall Average
NZ5033	7.2 bcd	12.8 a	10.1 d	6.6 b	13.5 a	8.6 c	9.4 b
NZ5034	8.0 bc	15.4 a	15.8 a	7.6 b	13.2 a	10.0 abc	11.2 a
NZ5035	6.3 cde	13.9 a	11.3 cd	7.8 b	11.0 ab	8.6 c	9.5 b
NZ5036	5.0 e	10.1 bc	10.0 d	6.3 b	11.3 ab	8.5 c	8.2 d
'Shinsei'	6.2 cde	15.0 a	13.4 abc	10.8a	11.9 ab	11.5 ab	11.1 a
'Weraiti'	6.8 bcd	8.7 cd	15.4 a	8.0ab	10.3 ab	10.8 abc	9.7 b
'Selwyn'	5.7 de	7.0 e	11.9 bcd	7.8 b	9.5 b	10.1 abc	8.4 cd
'Otahuao'	8.0 bc	8.9 cd	11.7 bcd	6.9 b	11.0 ab	9.0 bc	9.1 bc
'Toa'	8.9	13.7 a	14.4 ad	7.2 b	13.6 a	12.7 a	11.4 a
'Dudley'	7.6 bcd	8.1 de	13.1 abc	7.2 b	10.4 ab	10.4 abc	9.3 bc
'Kawa'	15.6 a	14.4 ab	17.0 ab	8.2ab	NS	NS	

NS = trees planted no survivors (overall averages not calculated for line-year combinations with this clone)

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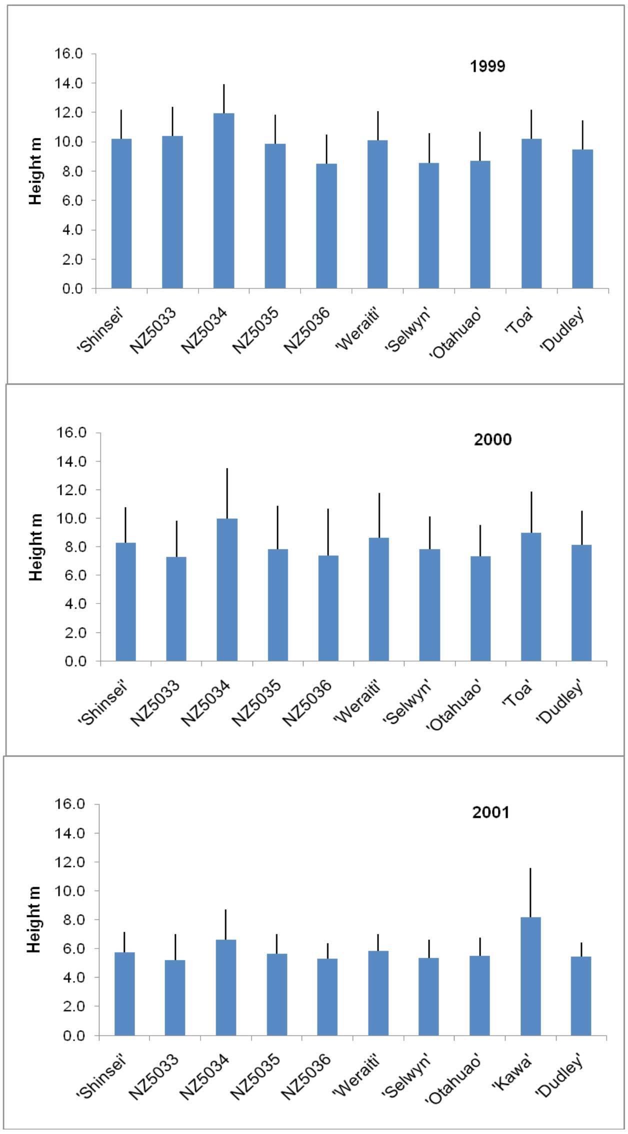

FIGURE 2: Mean height recorded in 2007 for each clone from each planting trial, including all trial sites. Error bars are standard errors of the means.

(b) Diameter at breast height (DBH)

Again, all fixed effects were significant, with older trees having bigger diameters (p = 0.01, Figure 3).

At each site, experimental clone NZ5034 had a similar or larger DBH than the biggest commercial clones 'Toa' and 'Weraiti' (Table 4). Generally, NZ5034 also had a similar DBH to 'Shinsei', except at Ashhurst (where 'Shinsei' was significantly thicker) and Rissington (where NZ5034 was significantly thicker).

(c) Performance across different planting years

Mean height for all the experimental *P. maximowiczii* × *P. nigra* clones combined was 10.1, 8.1 and 5.9 m for the 1999, 2000 and 2001 plantings, respectively, which was similar to the mean height of the commercial clone 'Shinsei' of 10.2, 8.3 and 5.2 m for the 1999, 2000 and 2001 plantings, respectively. This compares with the mean height for the *P. deltoides* × *nigra* clones taken collectively which was 9.4, 8.0 and 4.0 m for 1999, 2000 and 2001, respectively. For 'Toa', the 2007-mean heights were 10.2 m for the 1999 planting, and 9.0 m for the 2000 planting, and for 'Kawa' planted in 2001 mean height by 2007 was 6.8 m. Mean DBH was higher for the experimental *P. maximowiczii* × *P. nigra* clones than for all the *P. deltoides* × *nigra* clones in each year, but was lower than for the commercial clones 'Toa' ,'Kawa' and 'Shinsei'. The differences were not significant (p>0.05).

The site x year random effect for height was marginal (p = 0.07) and for DBH was significant (p = 0.01),

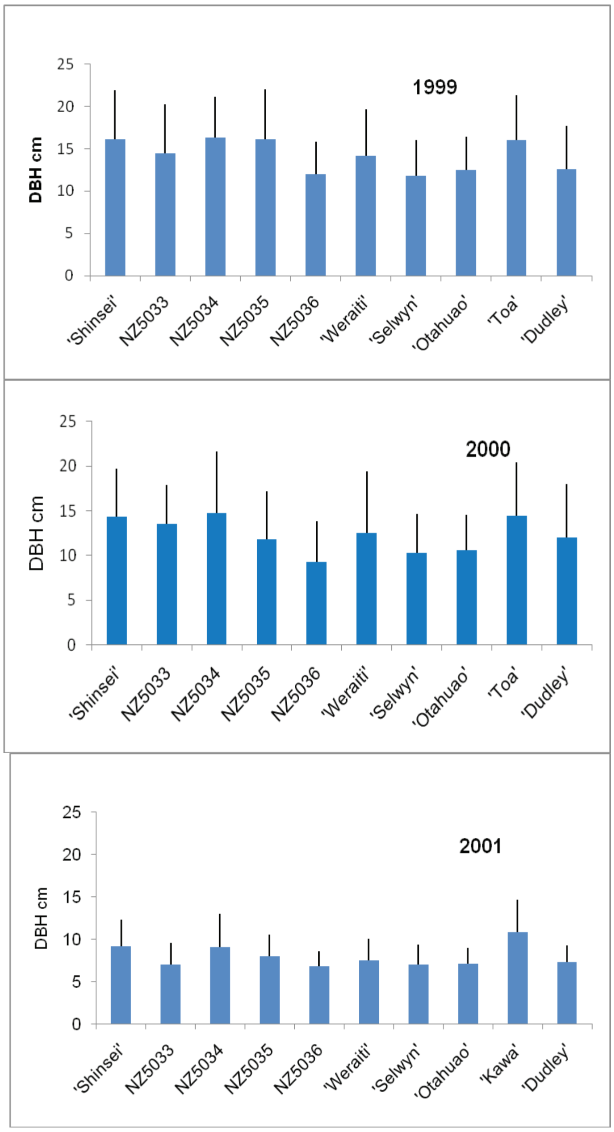

FIGURE 3: Mean diameter at breast height (DBH) recorded in 2007 for each clone from each planting trial, including all trial sites. Error bars are standard errors of the means.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

suggesting the rate of establishment varied between sites. At Mapiu and Rissington, trees planted in 1999 and 2000 tended to be similar size, and larger than those planted in 2001; while at Ashhurst, Miller's Flat and Parakai, the difference between trees planted in 2000 and 2001 is not as large (these sites had either no trees planted in 1999 or no survival of 1999-planted trees).

The site x clone x year random effect for height was zero, and for DBH was not significant (p = 0.94), indicating that patterns of results for clones at a site were similar (on the log scale, so proportional on the original scale) across years.

(d) Clone and clone x site interactions

Comparing the performance of the experimental clones, Mapiu and Rissington were more favourable sites than were Parakai, Ashhurst or Miller's Flat (Tables 3 & 4). Clone x site interaction showed that experimental clones generally showed best relative performance at Mapiu.

One site, Parakai, was close to the coast and the experimental clones performed poorly there (Table 5), although typically their means were not significantly lower than at Ashhurst or Miller's Flat.

The experimental clones performed better than the commercial clones at Mapiu; at the other sites the differences were not so pronounced.

(e) Ranking the performance of the experimental clones

A relative ranking (based on height and DBH mean values across years and sites) of all clones used in the trials is shown in Table 5. Clone NZ5034 outperformed all other trialled clones, and height and DBH were closely correlated. Clone NZ5035 was average in performance and NZ5036 was a poor performer. Clone NZ5033 was an inconsistent performer with high, low and average rankings in the three years of trial planting.

(f) Wood volume

Relative wood production of the experimental clones based on data from the 1999 planting is shown in Table 6. There was a significant difference between the clones (p < 0.001), and a significant site x clone interaction (p = 0.01) but no significant difference in average level between sites (p = 0.6) Clones NZ5034 and NZ5033 showed the highest relative wood volume of the experimental clones, and compared very favourably with the commercial (*P.* × *euramericana* × *P. yunnanensis*) clone 'Toa', a clone recommended as being suitable for timber production.

Discussion

Growth rate and resistance to adverse factors are the two most important targets of breeding and selection (Thielges, 1985). Clonal selection is a branch of any poplar breeding programme, starting with an abundant and genetically varied material and ending up with a limited number of clonal cultivars to be grown commercially on a large scale (Bisoffi & Gullberg, 1996). Selection in the nursery is particularly desirable because of the limited space needed by plants at this stage. However, field trials are needed to determine and evaluate such traits as growth rate, drought and cold tolerance for long-lived trees that, because of their size, need a great deal of space. These field trials should be carried out in the environments where the trees are going to be used commercially.

Control of local test environments can often prove to be a crucial factor in the efficiency of evaluation trials; typical poplar trials in New Zealand are conducted on slopes and in soils that are often heterogeneous. Spatial correlations in heterogeneous soils may decrease the power of tests and may also bias the estimates of variance (Bisoffi & Gullberg, 1996). Randomised complete blocks were employed to accommodate any spatial heterogeneity as far as possible.

In this study the trials were established in different climatic zones throughout New Zealand. These climatic zones vary in their mean daily temperatures, their exposure to wind, their proneness to summer drought, their average rainfall and the severity of their winter and out-of-season frosts. While the average annual rainfall for the six trial sites does not vary greatly, some sites receive good summer rain (Mapiu) whereas others (Rissington and Windwhistle) are prone to summer drought, making tree establishment difficult in drought years.

All the experimental clones performed less well than commercial clones at the coastal site and may be more susceptible to salt spray, in which case the commercial clones provide better options for coastal sites. It is the opinion of the breeder (A. Wilkinson pers. comm.) that *P. maximowiczii* × *P. nigra* should not be planted at sites exposed to salt spray.

In moist inland environments with good rainfall and summer growing conditions, as at Mapiu, *P. maximowiczii* × *P. nigra* clones (NZ5036 excepted) showed high survival and growth and, with their more fastigiate form and higher rust resistance, should provide landowners with improved options. The less vigorous NZ5036 may be suitable for situations where size management of the trees could present difficulties or where fast growth is not a requirement. The incidence of poplar rust was not evaluated. Trees were measured following leaf fall when incidence and severity of rust could not be ascertained. Rust infection

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

TABLE 5: Relative performance for each experimental clone among all trialled clones for mean height (Ht) and mean diameter at breast height (DBH) at each site, in each planting year (Highest mean set to 100, lowest mean set to 0). Overall average given not shown if data unavailable from some sites in the trial for that year for a clone, due to no planting or no survival.

Clone	Year	Trial Site													
		Parakai		Mapiu		Rissington		Ashhurst		Windwhistle		Miller's Flat		Overall average	
		Ht	DBH	Ht	DBH	Ht	DBH	Ht	DBH	Ht	DBH	Ht	DBH	Ht	DBH
NZ5033	1999	Ex	Ex	64	91	NP	NP	NP	NP	37	90	NP	NP		
	2000	36	52	47	61	0	0	0	20	Ex	Ex	8	10	0	27
	2001	0	19	51	43	0	0	0	0	Ex	Ex	0	7	0	10
NZ5034	1999	Ex	Ex	100	100	87	73	NP	NP	100	88	NP	NP	100	100
	2000	51	55	100	100	100	85	65	32	Ex	Ex	68	10	100	100
	2001	36	48	71	100	100	97	26	35	Ex	Ex	89	10	100	100
NZ5035	1999	Ex	Ex	67	98	28	14	NP	NP	26	38	NP	NP	40	59
	2000	20	31	72	77	18	13	49	37	Ex	Ex	28	10	52	44
	2001	77	75	1	30	61	55	66	53	Ex	Ex	5	8	32	46
NZ5036	1999	Ex	Ex	15	28	0	0	NP	NP	23	41	NP	NP	0	4
	2000	0	0	63	46	28	1	9	0	Ex	Ex	1	10	4	0
	2001	4	3	8	33	36	0	1	15	Ex	Ex	59	10	9	0
'Shinsei'	1999	Ex	Ex	55	97	63	87	NP	NP	44	71	NP	NP	48	96
	2000	23	34	59	86	21	21	55	100	Ex	Ex	51	10	37	90
	2001	6	6	35	84	54	85	100	100	Ex	Ex	32	7	40	90
'Weraiti'	1999	Ex	Ex	26	29	100	100	NP	NP	7	20	NP	NP	39	42
	2000	74	59	20	18	87	100	100	46	Ex	Ex	36	10	50	53
	2001	18	9	0	1	64	48	69	44	Ex	Ex	NS	NS		
'Selwyn'	1999	Ex	Ex	0	0	50	52	NP	NP	0	0	NP	NP	3	0
	2000	46	28	0	0	49	25	80	37	Ex	Ex	43	10	22	14
	2001	5	0	NS	NS	41	22	51	35	Ex	Ex	58	1		
'Otahuao'	1999	Ex	Ex	6	10	63	73	NP	NP	3	33	NP	NP	9	15
	2000	82	78	15	26	25	21	17	8	Ex	Ex	0	10	3	20
	2001	26	21	16	38	23	5	45	30	Ex	Ex	100	1	22	13
'Toa'	1999	Ex	Ex	56	91	63	62	NP	NP	48	100	NP	NP	50	92
	2000	100	89	71	74	63	79	35	20	Ex	Ex	100	10	63	86
	2001	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP		
'Dudley'	1999	Ex	Ex	24	13	50	47	NP	NP	14	24	NP	NP	18	6
	2000	97	100	11	10	53	68	42	16	Ex	Ex	54	10	31	44
	2001	11	12	10	0	48	23	56	36	Ex	Ex	39	3	18	19
'Kawa'	1999	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP		
	2000	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP		
	2001	100	100	100	81	57	100	60	45	Ex	Ex	NS	NS		

Ex = site excluded due to low survival
NP = no planting
NS = trees planted no survivors (overall averages not calculated for line-year combinations with this).

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TABLE 6: Mean wood volumes measured in m^3 (SE of mean in brackets) for the trialled clones planted in 1999 at each site excluding Parakai compared using the mixed effect model. Trials were not planted at Ashhurst or Miller's Flat in 1999. Results are back-transformed from log scale. Means followed by the same letters indicate no significant difference with in site at p = 0.05 (pairwise Type 1 error rate).

Average least significant ratio at p = 0.05: for all sites average = 253%; within site = 247% (two means are significantly different if the ratio of the larger to the smaller is more than the least significant ratio).

Clone	**Trial Site**							
	Mapiu		**Rissington**		**Windwhistle**		**Overall average**	
'Shinsei'	0.32	a	0.22	a	0.16	ab	0.23	ab
NZ5033	0.28	a	NP		0.22	a	0.25	ab
NZ5034	0.48	a	0.25	a	0.24	a	0.31	a
NZ5035	0.34	a	0.07	b	0.13	ab	0.15	bcd
NZ5036	0.10	c	0.07	b	0.14	ab	0.10	cd
'Weraiti'	0.11	bc	0.33	a	0.11	ab	0.16	bc
'Selwyn'	0.07	c	0.15	ab	0.09	b	0.10	d
'Otahuao'	0.11	c	0.18	ab	0.12	ab	0.12	cd
'Toa'	0.25	ab	0.18	ab	0.22	a	0.22	ab
'Dudley'	0.12	c	0.13	ab	0.12	ab	0.11	cd

NP = no planting

is likely to have reduced growth of some clones at some sites during the period of the trial.

The experimental clones, as a group, were no better adapted to summer drought environments than the currently available commercial clones (at either the Rissington or Windwhistle sites). However, NZ5034 ranked highly in this environment and on the results of this trial is recommended for summer drought environments.

The degree of tolerance to wind run is not easy to assess on terrain with gullies and variable protection from landscape features like nearby hills. However at the site where wind run was greater and more frequent (Ashhurst), ranking was lower in the experimental clones when compared with their ranking at most other sites. The rankings for NZ5034 were confounded by deaths of the most vigorous trees by plastic sleeve strangulation. The *P. maximowiczii* × *P. nigra* clones could be planted in windy sites in a mix with other, commercial, clones, and monitoring of their performance would add useful knowledge of their tolerance to high wind run.

The experimental clones survived prolonged severe cold (Miller's Flat) much better than commercial clones without a *P. maximowiczii* and *P. nigra* parentage. They were outperformed in growth variables by some commercial clones but their high survival in climates experiencing severe and prolonged frosts should be exploited. It is costly to replace dead trees.

As a group, the *P. maximowiczii* × *P. nigra* clones grew better across all sites and in all years than the *P. deltoides* × *P. nigra* clones in the trial. Currently, around 80% of commercial sales of poplars for all uses are of *P. deltoides* × *nigra* clones, with a further 16% being 'Kawa' (data from National poplar and willow nursery managers 2009 – 10 pers. comm.). While recognising the phenotypic variability within both taxonomic groupings, the experimental clones should offer alternative choices that will match or outperform the *P. deltoides* × *P. nigra* clones in many environments, particularly if our climate becomes more extreme.

These experimental poplar clones were developed primarily for soil stabilisation on pastoral hill slopes. Effectiveness of the trees is measured by their capacity to anchor soil and, for this, root development is paramount. It was shown by McIvor et al. (2008, 2009) and Tandon et al. (1991) for *P. deltoides* × *P. nigra* and *P. deltoides* trees within this age range that root biomass and root length are proportional to DBH. Assuming that this is true for all *Populus* clones, the experimental clones are likely to have comparable root mass and root length to the commercial clones. Further work is needed to understand how the roots are distributed for the *P. maximowiczii* × *P. nigra* clones.

Rapid growth may not be favoured by landowners if they perceive that it will result in larger trees requiring more management during their lifetime. For this reason, the slower-growing clone NZ5036 may be more suitable than other, commercial, clones currently available. Further assessment of performance after

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12 – 15 years will be needed to clarify if the slower growth rate ultimately results in a smaller tree or just a slower-growing tree.

Considerable damage is caused to pastoral trees by strong winds, so performance in windy situations is an important selection factor. Little damage to the crowns of the experimental clones was observed. It is expected that once mature, these trees will have a narrow canopy, which will be less vulnerable to wind-throw or crown damage than commercial clones with wider crown development.

While these experimental poplar clones have been bred primarily for pastoral soil conservation and shelter, their establishment as woodlots for producing woodchip for fuel in industrial heat plants or for timber production should be also be considered as future options. Since data on wood volume was collected at approximately halfway through a harvest cycle, these trends may not apply closer to the expected harvest time. Wood production would be better assessed for the *P. maximowiczii* × *P. nigra* clones in close-planted clonal trials with more uniform growing conditions. Measurements of wood density and mechanical properties are yet to be carried out.

Conclusion

Four experimental *P. maximowiczii* × *P. nigra* clones, trialled in six climatic zones, performed equally well or better in terms of survival, height and diameter growth compared with other commercial clones trialled. There were notable differences between individual experimental clones. The experimental clones showed greater frost hardiness, less tolerance of salt conditions, and similar response to windy and summer-dry environments, compared with the commercial clones tested, particularly the *P. deltoides* × *P. nigra* clones. Based on mean rankings of all trialled clones (Table 5) for height and DBH, NZ5034 was the top-performing clone, NZ5035 was average-performing, NZ5033 was average to below average, and NZ5036 was relatively poor.

Of the four experimental clones trialled, NZ5034 and NZ5035 should be released for commercial use in pastoral hill slope stabilisation across all climatic zones in New Zealand. Clone NZ5033 could be considered for release for use in zones with regular summer rain or on slopes where water stress will be lower. Clone NZ5036 could be considered for further trials in certain local environments where lower vigour would be an advantage, e.g. pastoral or horticultural shelter. None of the experimental clones tested should be planted at coastal sites where there is salt exposure. Further monitoring of these clones is warranted.

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