From Forest Nursery Notes, Summer 2008

87. Results from four *Pinus patula* water planting trials in the summer rainfall region of South Africa. Rolando, C. A. and Little, K. M. Southern Hemisphere Forestry Journal 69(1):9-17. 2007.

Southern Hemisphere Forestry Journal 2007, 69(1): 9–17
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SOUTHERN HEMISPHERE
FORESTRY JOURNAL
ISSN 1991–931X
doi: 10.2989/SHFJ.2007.69.1.2.164

Results from four *Pinus patula* water planting trials in the summer rainfall region of South Africa

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Planting with water is used by some forestry companies in South Africa to reduce post-planting water stress. Four trials were implemented to test the response in survival of *Pinus patula* to water applied at planting. Two trials each were situated in the KwaZulu-Natal Midlands and Mpumalanga escarpment. The first trial at each site was planted in spring (October) and the second in summer (February). Watering treatments consisted of different quantities of water used in the planting operation and included 0.5l, 2l, 4l and no water. At all sites the planting treatment affected the depth at which the seedlings were planted. Only at the spring-planted trial in the KwaZulu-Natal Midlands was survival of the dry-planted seedlings significantly lower than that of the seedlings planted with water from 90d after planting. This may have been due to low rainfall during the week before and two weeks after planting, or the small size of the seedlings. Application of 0.5l of water to the planting pit at this trial was sufficient to increase survival to a level equivalent to that where 2 or 4l of water was used, yet only increased soil moisture in the area immediately surrounding the seedling. Future research should aim to investigate the importance of seedling quality as well as the method of application of water to the planting hole on post-planting survival.

Keywords: ecophysiology, establishment, microclimate

Introduction

In South Africa, high post-planting mortality of *Pinus patula*, the predominant softwood species planted at higher altitudes in the summer rainfall region, is a major problem and research to increase post-planting survival is ongoing (Morris, 1990; Bayley and Kietzka, 1997; Allan and Higgs, 2000; Mitchell *et al.*, 2004; Crous, 2005; Rolando and Little, 2005). The planting of these sites with *P. patula* is predominantly carried out between September and March, when most of the annual rainfall occurs. Intensive planting schedules, combined with unpredictable rainfall, often forces foresters to plant during hot and dry periods that occur during these months, or alternatively to extend planting into autumn (late season) when soil water availability is decreasing. Planting with water is currently used by some commercial forestry companies to reduce post-planting water stress as well as to buffer against potentially adverse weather conditions (Morris, 1994; Nelson, 1995; Viero *et al.*, 2000). A number of factors complicate an assessment of the viability of planting with water. Firstly, the use of and/or method of application of the water varies widely between regions and commercial forestry companies. Some companies have a 'no water' policy, others always plant with water, while some only apply water when planting conditions are considered poor (hot weather, dry conditions). Company practices also vary in terms of the quantity of water used (1–5l), as well as the method of application (before planting, after planting or as a split application) (ICFR, 1995; 1996a; 1996b; Atkinson and Govender, 1997; Viero *et al.*, 2000). Research results show that the application of water to *P. patula* seedlings at planting does not always increase survival over that of planting without water (dry planting) (Atkinson and Govender, 1997; ICFR and Mondi Forests, 1997; Allan *et.al.*, 2000; Rolando and Little, 2004), raising questions as to the role of water in the planting operation.

To understand the effects water may have in the planting operation four trials were initiated to determine:

- the effect of the quantity of water applied at planting on survival and growth
- the impact of planting with water on pit soil moisture and temperature
- the effect of air temperature and rainfall on survival (up to one year)
- the impact of planting with water on planting depth.

Materials and methods

Two trials each were situated in the KwaZulu-Natal Midlands and Mpumalanga escarpment at the Linwood and Hebron plantations, respectively (Table 1). These sites differed in terms of mean annual temperature (MAT) and mean annual precipitation (MAP) as well as soil type, with the soil at Linwood having higher clay and organic carbon contents. The first trial at each site was planted in spring (October) and the second in summer (February). Based on current, regional

Table 1: Details of the four *Pinus patula* water planting trials planted in spring and summer in the summer rainfall region of South Africa. MAP = mean annual precipitation, MAT = mean annual temperature, OC = organic content of soil

			Soil physical properties (%)				Site characteristics			
Plantation and region	Season	Date planted	Sand	Clay	Silt	OC	Altitude (m asl)	MAT (°C)	MAP (mm)	Harvest residues
Linwood, KwaZulu-Natal Midlands	Spring	22/10/2003	6	67	27	7	930	15.7	1 300	Chopper-rolled
	Summer	03/02/2004								
Hebron, Mpumalanga	Spring	16/10/2003	48	38	14	3	1 200	17.6	1 200	Broadcast
	Summer	10/02/2004								

local and long-range weather forecasts (South African Weather Service[1]) the timing of planting was scheduled to coincide with a period when rainfall was unlikely to occur. Seedlings for all four trials were obtained from local nurseries. Planting pits were prepared with picks and the trees at Hebron planted at a 3.5 x 3.5m spacing (816 stems ha^{-1}) and those at Linwood at a 2 x 3m spacing (1667 stems ha^{-1}).

Each trial had four treatments replicated five times and arranged in a randomised complete blocks design. The treatments included the application of 0.5l, 2l and 4l of water, and no water (dry plant). Where 0.5l water was used, the water was poured into the planting hole before placing the seedling and covering the root plug with soil. Where 2l or 4l of water was used, half of the water was poured into the planting hole before placing the seedling and half poured onto the area around the base of the seedling immediately after covering the root plug with soil. Five labourers (planters) were used at each trial with the seedlings planted by each individual tracked to determine the impact of each planter on initial seedling height and subsequent survival. Each treatment plot consisted of 5 x 5 trees. Prior to planting, a chemical weeding with glyphosate was carried out, after which the experimental areas were weeded as per the commercial schedule for the compartment. Rainfall, air temperature (1.3m above ground) and relative humidity were recorded at each site prior to, at and subsequent to planting. Vapour pressure deficit was derived from air temperature and relative humidity (Unwin, 1980).

Measurements

Seedlings

To characterise the seedlings planted at each site, measurements of seedling height (from the top of the root plug to the growing tip) and root collar diameter were made on 30 randomly selected seedlings before planting. Samples of seedlings from each batch were also sent to a pathology laboratory[2] for the detection of the pathogen *Fusarium circinatum*. Seedling survival was assessed at 30, 60, 180 and 365 days (d) after planting and seedling height (cm, from the ground to the growing tip) and groundline diameter (mm) were measured immediately after planting (time 0) and then at 90, 180 and 365d after planting.

Pit soil moisture

A Delta-T Theta Probe type ML2 (Delta-T Devices Ltd) was used to measure pit soil moisture content in the top 6cm, initially on the day of planting and then every 2–3d thereafter for the first 14d. The Theta Probe data recorded at all trials were calibrated using the method described by Little *et al.* (1996). To determine changes in soil moisture content across the pit, readings were taken at distances of 5, 10 and 15cm from the seedling in the first five pits of each treatment plot.

Soil and air temperature measurements

Soil temperature measurements were made at a depth of 10cm below the soil surface (in the root plug zone) in four pits of each treatment in the summer-planted Linwood trial. These temperature measurements were taken with copper-constantan (Type T) thermocouples connected to a Campbell Scientific CR10x datalogger, which used an AM416 Multiplexer to increase the number of thermocouples that could be measured (Campbell Scientific, 1997). A 10TCRT thermocouple was used for the reference temperature with a maximum measurement error of 1.66°C (Campbell Scientific, 1997). One thermocouple was placed at each measurement point and the temperatures that were logged every hour were an average of measurements taken every 2min.

Air temperature at a height of 5cm above the soil surface and adjacent to the seedling (10–15cm from seedling) were measured on seedlings (n = 16) at the summer-planted Linwood trial. The measurements were made with H8 Onset Hobo® temperature loggers (Onset Computer Corporation) housed, one each, in gill radiation shields.

Analysis

Analyses of variance (ANOVA) were used to detect differences in survival and growth following planting. Only if the F-test was significant were the means further investigated using the least significant difference statistic. Bartlett's test was used to check the assumption for homogeneity of variance required for a valid ANOVA to be performed (Mead and Curnow, 1983). Where necessary percentage survival data were arcsine transformed before analysis, and detransformed percentage survival is shown in the text and tables. To test the effect of individual planters on initial seedling height (measured on the day of planting), each seedling was scored for the planter (1–5) and this score was used as a covariate in the analysis. Unfortunately, herbicide applied during a weeding operation affected survival in both the spring and summer plantings at Hebron and as such these trials had to be abandoned at 60 and 90d after planting, respectively. Results up to the time of herbicide damage are presented.

Results and discussion

Early growth and survival

There were significant differences between treatments at all four trials in terms of seedling height when measured immediately after planting, indicating that the planting treatment affected the depth at which the seedlings were planted (Tables 2 and 3). Seedlings planted with 2l or 4l of water were generally planted deeper than those planted with 0.5l or dry planted (Table 3). Besides this, no further significant differences in measures of height or groundline diameter were detected. On average, seedlings were planted with the root collar diameter 3.5cm below ground, with the smallest seedlings (in terms of shoot length before planting) planted at the Linwood trial in spring (Table 3). When used as a covariate, the planter was significant for height at planting at all trials, indicating that each planter played an important role in terms of the depth at which the seedlings were planted (Tables 2 and 4). However, the covariate planter was no longer significant from the second measurement onwards. In a trial to determine factors affecting survival during late-season planting of *P. patula*, Morris (1994) found that individual planter skill was one of the main determinants of post-planting survival. No *F. circinatum* was detected in any of the samples sent to the pathology laboratory.

Survival of the seedlings in the dry-planted treatment at the Linwood (spring) trial was significantly lower than that in all water treatments (Figure 1a). This difference was significant from 90d after planting (Table 2), when the average difference in survival between the trees planted with water versus the dry-planted trees was 12%. Survival of all three treatments planted with water were similar (>90%) 365d after planting (Figure 1a). The Linwood (spring) trial was planted on a very hot day (maximum air temperature 29.1°C) with a number of hot, dry days during the 14d following planting (Table 5). In addition, there was very little rain 7d prior to, and immediately after, the planting of the trial (Table 5). At the Linwood (summer) trial (Figure 1b) there were no significant differences in survival between treatments during the first 90d after planting, with survival greater than 90% for all treatments at 365d after planting (Figure 1b). Post-planting temperature and rainfall were similar to that which occurred during the spring trial, with more rainfall occurring during the 7–14d following planting (Table 5). Vapour pressure deficit was higher during the 7d after planting at the spring trial than that during summer, and very little rainfall occurred. Although the vapour pressure deficit was higher during the 7–14d after planting at the summer trial, 56mm of rainfall occurred during the second week (Figure 2). The lower vapour pressure deficits during the first week of the summer trial, as well as the higher rainfall during the second week, may have alleviated severe water stress in the dry-planted treatment. It is also possible that the slightly larger, more robust seedlings planted during summer were better able to tolerate the hot and dry conditions. Seedling quality at the time of planting has been positively related to survival (Morris, 1994; Généré and Garriou, 1999; Bayley and Kietzka, 1997; Mitchell *et al.*, 2005). Morris (1994) found that when planting at the end of the summer season (April to May) in

Table 2: Summary ANOVA of mean squares for initial height (Ht) and survival at four *Pinus patula* water planting trials established in spring and summer in the KwaZulu-Natal Midlands (Linwood) and Mpumalanga (Hebron)

Source of variation	df	Linwood: spring Ht (cm)	Linwood: spring Survival (%) 30d	Linwood: spring Survival (%) 90d	Linwood: summer Ht (cm)	Linwood: summer Survival (%) 30d	Linwood: summer Survival (%) 90d	Hebron: spring Ht (cm)	Hebron: spring Survival (%) 30d	Hebron: spring Survival (%) 60d	Hebron: summer Ht (cm)	Hebron: summer Survival (%) 60d	Hebron: summer Survival (%) 90d
Replicate	4	85.4	70.6	78.0	173.4	10.0	33.6	19.9	0	25.9	29.8	39	10.0
Treat	3	689.7**	37.3^{ns}	163.2*	196.4**	8.9^{ns}	165.9^{ns}	555.7**	0^{ns}	44.2^{ns}	20.4**	143.1*	187.9**
Covariate	(1)	90.8**			97.3**			144.3**			15.6*		
Residual	12 (491)	18.7	33.44	49.6	5.3	14.4	57.4	7.4	0	25.2	2.8	31.2	18.5
Total	19 (499)												
Grand mean		3.8	99.3	95.9	10.3	99.9	98.6	12.8	100	99.8	9.0	97.2	96.0
CV (%)		30.0	6.8	9.0	22.0	4.3	5.1	20.2	0	2.2	18.7	7.2	5.0

^{ns} Not significant

* Significant at $p < 0.05$

** Significant $p < 0.01$

Table 3: Seedling height measured before and after planting at four *Pinus patula* water planting trials established in spring and summer in the KwaZulu-Natal Midlands (Linwood) and Mpumalanga (Hebron)

Trial	Height[1] before planting (cm)	Height[2] after planting[3] (cm)					
		Dry	0.5l	2l	4l	Mean	Standard error of mean
Linwood: spring	7.1	4.0[b]	4.8[c]	3.1[a]	3.5[a]	3.8	0.46
Linwood: summer	14.6	10.4[b]	12.1[c]	9.8[b]	9.2[a]	10.4	0.53
Hebron: spring	14.9	12.2[b]	14.4[c]	14.6[c]	10.1[a]	12.8	1.10
Hebron: summer	13.1	9.6[b]	8.9[a]	8.9[a]	8.6[a]	8.9	0.46

[1] Height measured from top of root plug to growing tip
[2] Height measured from ground to growing tip
[3] Within each row, numbers followed by different letters are significantly different at $p < 0.05$, using the least significant difference statistic

Table 4: Ranking of different planters used at each of the four trials according to average height (cm) of seedlings after planting. Values in parentheses range from 1 = planted the deepest to 5 = planted the shallowest

Trial	Planter 1	Planter 2	Planter 3	Planter 4	Planter 5
Linwood: spring	4.4 (5)	4.3 (3)	2.8 (1)	3.4 (2)	4.4 (4)
Linwood: summer	11.0 (5)	10.5 (4)	10.1 (3)	9.9 (1)	10.0 (2)
Hebron: spring	11.9 (1)	12.9 (3)	12.6 (2)	13.0 (4)	13.7 (5)
Hebron: summer	9.3 (5)	9.2 (4)	8.6 (1)	9.1 (3)	8.7 (2)

Swaziland on sandy, clay loam soils, acceptable survival of *P. patula* could be achieved by the planting of good quality seedlings without the addition of water.

Initial survival was good at Hebron (spring and summer) with an average of 98.5% survival at 60d for the spring and summer planted trials (Table 2 and Figure 1c–d). No significant differences in survival were detected in the spring trial, whereas survival of the dry-planted treatment was significantly better than that of the three treatments planted with water in the summer trial (Table 2 and Figure 1c–d). There were three cool (air temperatures below 10°C) days and 45mm of rainfall during the 7d following the planting of the Hebron (spring) trial, with higher air temperatures occurring only 7–14d after planting (Table 5). The 14d following the planting of the Hebron (summer) trial were all very hot, but high rainfall, typical for this region during summer, occurred and the initial good survival was likely related to the high soil moisture availability (Table 5). Excessive herbicide-induced seedling mortality occurred at both trials (at 60 and 90d) after routine weed control operations and consequently these trials had to be terminated.

Pit soil moisture

A lateral gradient in surface soil moisture content was recorded within all treatments at all four trials (data shown for Linwood only; Figures 3 and 4). In comparison to the dry plant, the use of 0.5l water increased soil moisture in the area immediately surrounding the seedling (0–5cm), whereas 4l increased soil moisture laterally throughout the pit (Figures 3 and 4). Low-intensity rainfall events (<15–20mm) increased the soil moisture contents recorded for all treatments, but this increase remained relative to the initial values (Figures 3 and 4). After more intense rainfall events (>40–60mm), especially at the Hebron site, soil moisture contents between the treatments equalised. This extended period of soil moisture differences between treatments, even after low-intensity rainfall events, was unexpected and may reflect the effect of watering during planting on pit soil bulk density.

Although the soil water retention characteristics at Linwood were not determined, it is possible to get an indication of changes in plant-available soil water from studies conducted on similar soil types at low bulk densities (similar to that of disturbed pit soil). The permanent wilting point (which generally occurs at a soil matric potential of –1.5MPa) for clay-textured soils at low bulk densities will occur when the volumetric soil moisture content ($m^3\ m^{-3}$) drops below 0.28 (or 28%) (Smith *et al.*, 2001). Field capacity (generally accepted to be the soil moisture content at a matric potential of –10KPa) will be attained at a volumetric soil moisture content of about $0.39 m^3\ m^{-3}$ (or 39%) (Smith *et al.*, 2001). When the seedlings were planted at the Linwood (spring) trial, the soil moisture recorded in the dry pits was near to wilting point for the first 9d after planting (20–25%) (Figure 3). While soil moisture was near to wilting point during the Linwood (summer) trial, rainfall 2d after planting and during the second week increased soil moisture to above wilting point. At both planting dates application of only 0.5l water to the soil immediately surrounding the seedling was sufficient to increase soil moisture in the zone around the seedling (0–5cm) to above wilting point. In addition, this increase in soil moisture persisted for up to two weeks after planting (Figures 3 and 4).

At the Linwood (spring) trial, survival of the seedlings in the dry-planted treatment diverged from the water planted treatments from approximately 30d after planting, but was only significant at 90d (Figure 1a). This delayed response in survival to a stress experienced from planting may highlight some of the difficulties associated with identifying the point at which pine seedlings die. It seems unlikely that low soil moisture at the time of planting in the dry-planted treatment may have been the direct cause of mortality 60–90d later and therefore the cause and timing of mortality remains unknown. Application of 0.5l to the seedlings at the spring trial increased survival to a level equivalent to that where 2 or 4l water was used, yet only increased soil moisture in the

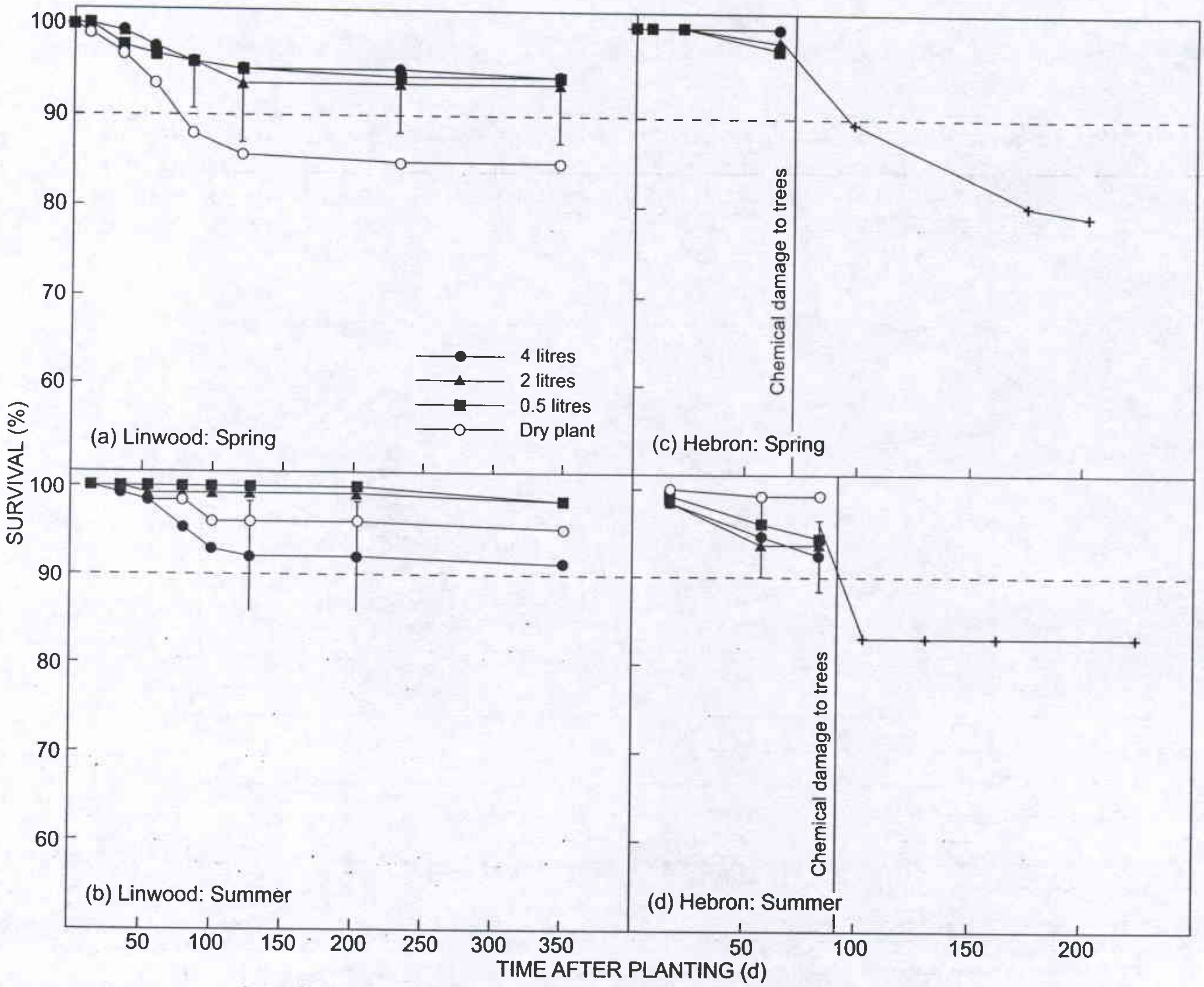


Figure 1: Survival of *Pinus patula* seedlings in response to the application of water (0, 0.5l, 2l, 4l) at planting in four trials established during spring and summer in the KwaZulu-Natal Midlands (Linwood) and Mpumalanga (Hebron). The solid single line following chemical damage at the Hebron trials indicates an average of survival in all treatments. Bars indicate the least significant difference between treatments. The dotted line at 90% represents commercially acceptable survival at 90d after planting

Table 5: Temperature and rainfall in the week preceding (7d before) and two weeks after (0– and 7–14d) planting at four *Pinus patula* water planting trials established in spring and summer in the KwaZulu-Natal Midlands (Linwood) and Mpumalanga (Hebron)

Trial	Temperature (°C)			Rainfall (mm)		
	No. days > 24°C	Average maximum				
	0–14d	0–7d	7–14d	7d before	0–7d	7–14d
Linwood: spring	10	28.0	25.5	0	6	15.5
Linwood: summer	12	25.4	28.3	ND	6	56.0
Hebron: spring	9	18.1	22.8	0	45	7.0
Hebron: summer	14	26.5	26.7	65	144	63.0

ND = No data were obtained

area immediately surrounding the seedling. This could reflect that (1) water (either 0.5l, 2l or 4l) increased soil moisture in the pit for only a short period and was therefore only available to the seedlings in the region immediately surrounding the root plug (and any soil water beyond this zone was unavailable to the seedlings and evaporated by the time the roots had penetrated that far); and/or (2) the use of water increased root to soil contact at planting, thus improving any subsequent root and soil water interaction.

Soil and air temperature

No differences were detected in pit soil temperature

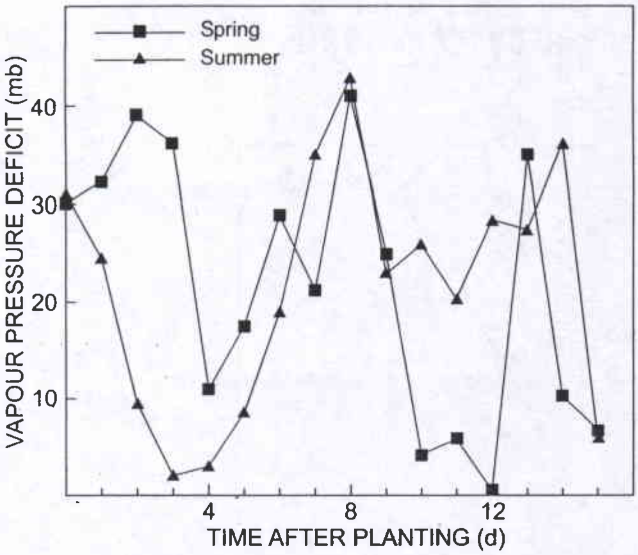


Figure 2: Changes in the vapour pressure deficit (millibars) associated with daily maximum temperatures at the Linwood trial planted in spring (October) and summer (February)

between treatments when measured at the Linwood (summer) trial (data not shown). This may be due to the variability in temperature measurements within treatments as well the small sample size used (n = 4 measurements per treatment). The variability in soil temperature measurements within treatments may be a function of the measuring equipment and/or microenvironmental differences between different pits where factors such as organic matter, soil friability, soil moisture and position of the pit in the landscape may affect the temperature of the soil to a larger extent than the quantity of water that has been artificially added to the soil. Average maximum pit soil temperatures ranged between 18 and 25°C and minimum temperatures were around 18°C during the first two weeks after planting (Figure 5). Maximum air temperature at 5cm in the zone of the shoots at the summer-planted Linwood trial was 3–4°C higher than those measured at 1.3m and reached 35°C or higher on four occasions during the first week after planting (Figure 5).

While no effect of watering on pit soil temperature in the root zone was recorded, data provide an indication of the relationship between ambient air temperature and that of pit soil during the peak summer period. The increased production of primary lateral roots and new root tips by *Pinus* species is strongly influenced by root zone temperature, water availability and their interaction (Nambiar *et al.*, 1979; Brissette and Chambers, 1992; Sword, 1996). The negative effect of water stress on new root growth for *P. palustris* has been found to increase at higher root-zone temperatures (>20°C) (Sword, 1996). Carlson *et al.* (2004) found that daily exposure of *P. patula* seedlings to soil temperatures above 24°C, for at least 1h over a period of 10d, significantly reduced the development of new roots. However, despite the potentially negative impacts of high temperatures on seedling root growth, these data indicate that provided sufficient water is available, high temperature

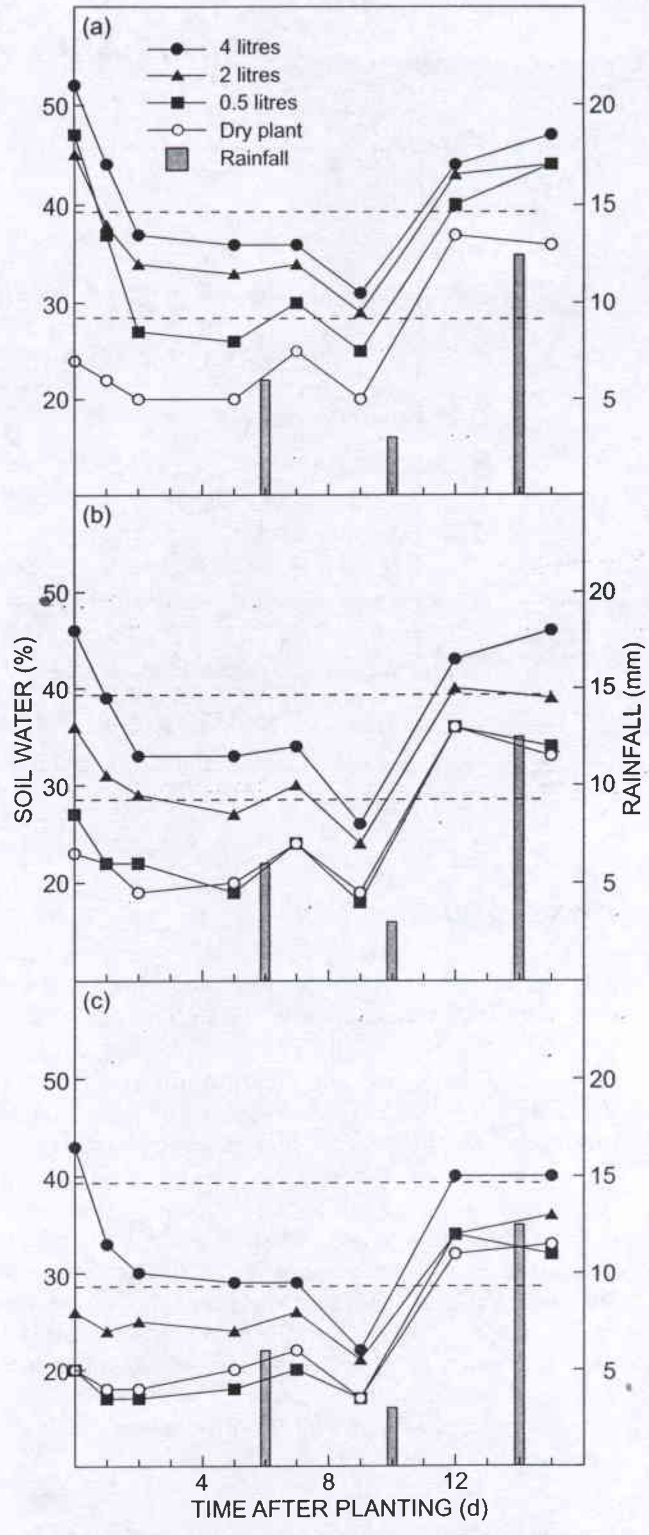
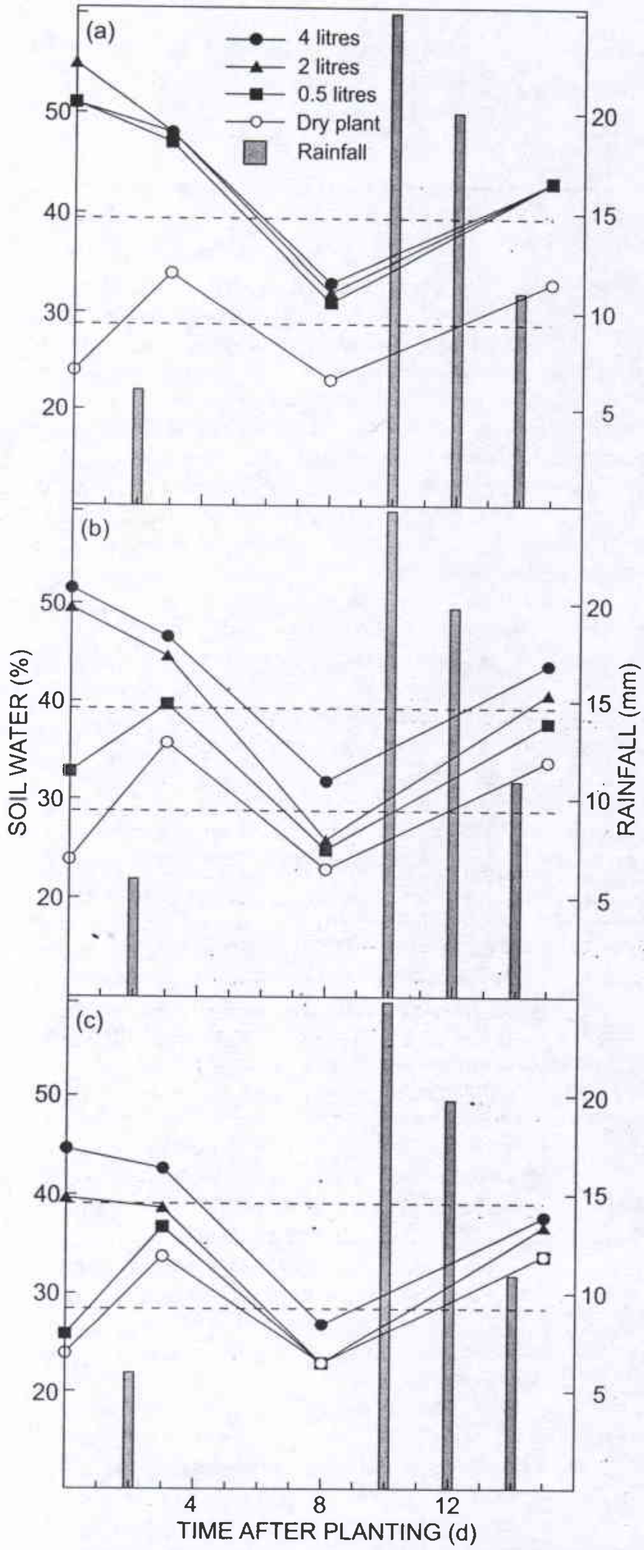


Figure 3: Changes in volumetric soil water content of the top 6cm of pit soil as measured with the Theta Probe at a distance of (a) 5cm, (b) 10cm and (c) 15cm from the seedling in the Linwood (spring) trial. Bars represent rainfall during the first two weeks following planting. Dotted lines at 39% and 28% soil water represent estimated soil water content at field capacity and wilting point, respectively



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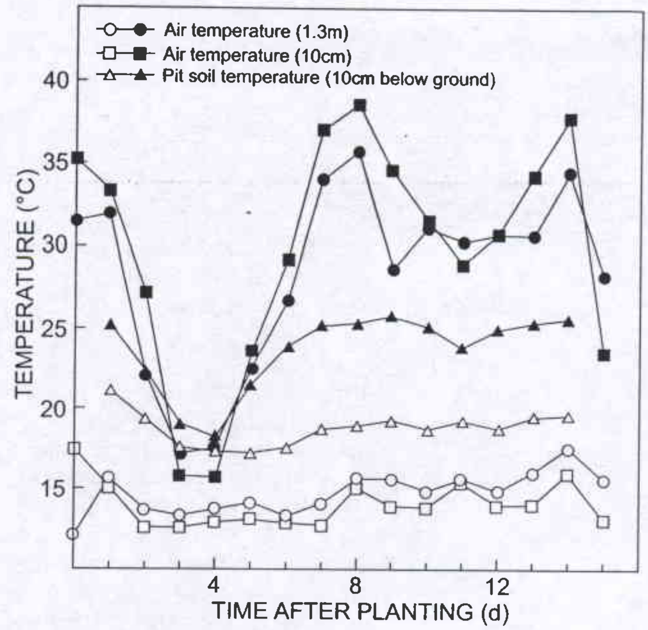

Figure 5: Measurements of pit soil temperature (10cm below ground) and air temperature (10cm; 1.3 m) made at the Linwood trial planted in summer. Closed symbols indicate maximum values and open symbols indicate minimum values

stress is not a primary determinant of mortality in *P. patula*.

The results obtained in these four trials are consistent with several other local studies where planting with water has been shown to increase survival when planting during early spring or late autumn (Morris, 1994; Rolando *et al.*, 2006). Besides these studies, however, little literature could be found on the practice of planting with water in forestry worldwide (Evans, 1992), making it difficult to contextualise these results with that of international studies. This is contrary to the agricultural sector where the application of water to the soil surrounding the roots of plants immediately after planting is common practice (McKee, 1981; Cox, 1984). According to McKee (1981) re-establishment of vegetable seedlings is improved by (1) making water readily available to the root system, (2) reducing water loss to the soil from the roots should the soil be dry at the time of planting, and (3) by improving root to soil contact. Cox (1984) investigated the combined effects of root-plug moisture content at planting and watering immediately after planting on establishment of lettuce and leeks. While watering at planting (with no further irrigation) was found to improve root growth during the first week after planting, it was unable to keep the seedlings supplied with water for more than a few days following planting during summer (Cox, 1984). Cox (1984) emphasised the importance of new root growth for subsequent seedling survival and yield.

Conclusions

These trials were implemented during periods within the commercial pine planting season when either sporadic rainfall and/or high air temperatures were likely to occur. Measurements of rainfall, air temperature and changes in pit soil moisture (both spatially and temporally) at all trials, as well as intensive measurements of pit soil temperature at one trial, were carried out to increase the understanding with which the data could be interpreted. While additional measurements provided some insight into the micro-environment in response to planting treatment, it was not possible to determine the actual cause of seedling mortality. More datasets combined with measures of seedling physiology following planting may increase our understanding in future trials. The results from the treatments and conditions that prevailed in these trials have indicated that when planting *P. patula* seedlings:

- planting with water has the potential to improve survival when soil water availability is low and rainfall sporadic (but cannot reduce mortality during prolonged drought)
- the amount of water used in the planting operation, on soils similar to that tested in this study, is not critical and either 1 or 2l is sufficient, provided some is applied into the planting hole prior to planting. The method of application of the water to the seedling and the effect of this on survival will need further investigation
- seedling quality may play an important role in the requirement for water during planting and may require further investigation
- planting depth is affected by individual planters as well as planting method. The effect of planting depth on survival has not been investigated locally.

Notes

[1] www.weathersa.co.za
[2] Tree Diagnostic Clicnic, FABI, University of Pretoria, Pretoria 2000, South Africa

Acknowledgements — The authors would like to thank Gavin Higgs and David Borain for their help with the implementation and monitoring of these trials. Thanks must also be extended to the relevant sponsor companies for the support they provided during the implementation and maintenance of the trials.

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