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Determining the relative resistance of selected *Pinus* species to fire damage

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ABSTRACT: In Southern Africa, a high percentage of suitable timber plantation sites have to be set aside for unplanted fire breaks. These fire prevention systems are normally in the form of (dynamic) montane grasslands, which cure before the dry winter season, and are then prescribed-burned yearly or two-yearly as soon as the dry biomass can carry a continuous fire. An experiment was established during 1998, in the northeastern Cape region of the Eastern Cape Province of South Africa, using a randomized split-plot design, with prescribed burning as the main treatment, and species as sub-treatments. The experiment had four replicates, and seven Pinus species (sub-treatments) were used, namely Pinus elliottii, Pinus patula, Pinus greggii var. greggi, Pinus greggii var. australis, Pinus leyophylla, Pinus arizonica and Pinus teocotina. Highly significant differences were recorded between relative height growth of the species used, with Pinus elliottii, Pinus patula and Pinus greggii (var. greggii and var. australis) producing economically acceptable height growth rates, and Pinus leyophylla, Pinus arizonica and Pinus teocotina under-performing. Three months after burning, no significant differences were recorded between tree mortality/survival of species and replicates. This pattern was caused by a significantly higher fire intensity recorded in the 4th replicate. However, species survival recorded for the four economically viable species were: 90.3% for Pinus elliottii, 80.4% for Pinus greggii var. greggii, 71.8% for Pinus patula and 55.1% for Pinus greggii var. australis. No cambium damage was recorded, while surviving trees re-sprouted in abundance with all species. The outcome of this experiment has far reaching implications for the Southern African Forestry Industry because:

- Prescribed burning can now be applied inside *Pinus* stand as early as at three years stand age.
- Fire breaks can now be utilized for both fire protection and timber production purposes.
- Fire protection systems (such as fire breaks and buffer zones), can be strengthened significantly by adding even-aged prescribed-burned fire resistant *Pinus* stands, with species such as *Pinus elliottii* or *Pinus greggii var. greggii*.

1 BACKGROUND

In Southern African Plantations, a high percentage of suitable plantation sites have to be set aside for the maintenance of fire breaks. In the summer rainfall region, these breaks are normally situated in dynamic grasslands, which "cure" before the dry winter season, and are then prescribed-burned yearly or two-yearly, as soon as an adequate percentage of the grassland biomass has been converted to dry (burnable) biomass, and can carry a continuous fire front.

One of the questions raised by forest managers, is whether it is possible to establish fire resistant *Pinus* trees in plantation-form within these fire break sites, and if it is feasible to prescribe-burn these stands at *e.g.* a two-year rotation, to satisfy the following objectives:

- Multiple use of land allocated to fire protection.
- Improved fire protection.
- Increased timber productivity per unit area of land.

The use of fire resistant *Pinus* species to strengthen selected fire protection lines (such as main, regional, fire protection buffer zones), can also be considered as a viable option if a species can provide (i) acceptable resistance to fire damage and (ii) an acceptable growth rate and timber quality. To investigate this issue, we will have to consider any *Pinus* species that might qualify for this purpose, and not only known Southern African commercial species.

One of the most crucial problems the Southern African forestry industry is faced with in the application of prescribed burning inside even-aged *Pinus* stands, is that all commercial *Pinus* species have to reach a specific tree height/age before prescribed burning can safely be applied within these stands. This is because if fire is applied at a too young stage, serious crown scorch or even mortality can be experienced. In the case of *e.g. Pinus patula*, this qualifying age may not be before ten years stand age is reached, or when crown canopy closure is adequate. Qualification for prescribed burning also depends on the silvicultural regime applied inside plantations, such as thinning and pruning, and can even depend on factors such as poor tree growth and subsequent lack of crown canopy closure. All these restricting factors can further delay fire application, even if applied to a stand with an age of more than fifteen years (own experience).

It has to be accepted that not all grassland fire breaks can be planted up with trees, as some of these protection lines are situated in sensitive wetlands, wildlife corridors or riparian zones, or on land which may be unsuitable for tree growth. However, many times there is a need to strengthen strategic plantation boundaries where a high fire hazard is experienced, and chains of stands adjoining these areas can then be planted up with fire resistant species, to provide additional fire protection. The need for this has already been identified in some forestry regions, particularly along certain strategic boundaries.

The results of this burning experiment will provide the first indication of which species will be the most promising with regard to acceptable tree growth performance, and which species also has acceptable fire survival qualities.

2 METHODS

The experiment was established in typical dynamic montane grassland of the NE Cape, which completely cures before the dry winter season, because of the combined effect of frost and moisture stress. The site is situated in the Chillingly plantation unit, belonging to NE Cape Forests, which can be regarded as representative for that forestry region and probably beyond, well into the Kwazulu-Natal province. All plantings in this area are now still in the first rotation stage, and no history of longer-term, site-specific tree growth performance, is available.

The trial was demarcated during 1997, and trees were planted early during 1998, from stock raised in the local NECF nursery, only a few km west of the experimental site. The grassland fuel was not manipulated in any way (*i.e.* not slashed), and blanking was applied once, approximately one year after tree establishment. No further silvicultural treatments were applied within the trial area, apart from a 1.5 m pruning at three years of age, which was executed selectively before the burning treatment was applied to the trees, where adequate tree height made this possible.

The following *Pinus* species were used in this trial as sub-treatments:

Pinus elliottii	*Pinus leyophylla*
Pinus patula	*Pinus arizonica*
Pinus greggii var. greggii	*Pinus teocotina*
Pinus greggii var. australis	

Trees were planted in two rows of 20 trees each, thus 7 x 2 x 20 trees per sub-block, without provision for any surrounds between sub-plots (because of the short-term objectives of the trial). Two sub-blocks (one to be burned and one unburned) formed one replication, and the experiment had a total of four replications. The statistical design used was that of a randomized split-plot experiment, where the burning formed the main treatment, with species as sub-treatments.

Trees were measured during May 2000 (approximately two years and three months after planting) and an attempt to apply the burning treatment soon thereafter, before the 2000 fire season, failed because of adverse weather conditions. The second attempt to apply the burn during May 2001 (approximately three years and three months after planting) was successful. A mortality survey was conducted during August 2001. The tree height data for the whole experiment was statistically analysed to determine the relative growth performance of the trees up to the age of 2.25 years, one year before prescribed burning was applied.

The prescribed burning treatment that was applied during May 2001, was executed in the form of (mostly) back burning, which is known to produce the least crown scorch, because the flame profile is kept as low as possible (own experience of previous burning experiments in the NE Cape). One possible disadvantage of this burning method, however, is the slow fire rate of spread, which exposes the tree bark surface longer to the fire temperatures than would have been the case with a head fire application, with the wind/slope. No fire behaviour measurements were collected during the burning treatment application, because of the known significant contrasts within such areas burned, and even from one tree to the next (de Ronde, 1999).

During August 2001, three months after the burning application in 50% of the trial area (at 3.25 years), all burned trees were evaluated for survival, degrade and mortality. During the damage assessment, trees were graded for the following categories:

Surviving or most probably surviving (Survival class)

- Crowns partly scorched, remaining crown alive and healthy.
- High percentage or total crown scorch but re-sprouting, and most (if not all) growing points alive and healthy.

Mortality or probably dying (Mortality class)

- Trees already dead.
- Complete crown scorch, with no signs of re-sprouting.
- Total crown scorch and no prominent signs of re-sprouting. However, future re-sprouting cannot be ruled out completely, although it is highly unlikely.

Because it was observed that the fourth replication did experience a generally higher fire intensity when the burning was applied than the other three replications, statistical analyses was conducted for the first three replications only, as well as for all four replications, to determine if this variation did significantly contribute to the results of the analysis. The statistical analyses of the % survival, was also done for the four most promising species that were identified in the tree growth analysis.

3 RESULTS

3.1 *Relative tree performance*

For a tree species to be considered for planting inside fire breaks, or along prescribed-burned fire protection lines, selected species will have to provide acceptable tree growth, both in terms of quality (including tree form) and quantity (mean annual increment). For this reason it was important to consider these aspects first, to determine which tree species would qualify economically, and which should be regarded as being uneconomical, regardless there fire tolerance performance. At 2.25 years after tree establishment, it was only possible to consider tree height, because some species still had not reached a suitable size to measure collar diameter. The results of this enumeration has been summarized as follows (Fig. 1):

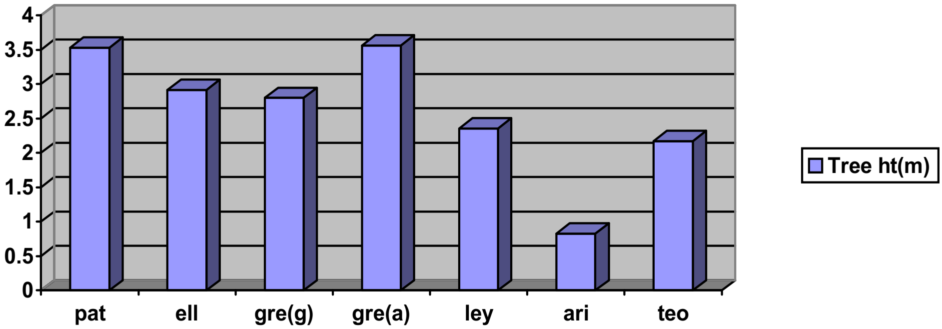

Figure 1. Average tree height at 2.25 years stand age before the prescribed burning treatment was applied.

Although tree growth is at an early stage, it appears that *Pinus patula* and *Pinus greggii var. australis* are performing equally well, both producing a yearly height increment of 1.58 m. *Pinus elliottii* and *Pinus greggii var. greggii*, were not far behind these two species, with an yearly average tree height increment of 1.27 m. No obvious problems with the stem form were observed for these four species. The yearly height increment of *Pinus leyophylla* and *Pinus teocotina* were on average only 1.00 m, which is probably below acceptable standards. The stem forms of these two species were also found to be not as good as that of the first four species, with *Pinus leyophylla* showing common "butt sweep". However, this problem can probably be corrected with tree breeding procedures, should this be required. The tree growth performance of *Pinus arizonica* was not acceptable, with the species only producing an average yearly tree height increment of 0.37 m (Figure 1). Statistically, differences between average tree heights between the treatments (species) were highly significant (F = 124.73**), with differences between replications (sites) being not significant.

3.2 *Tree Survival after a single prescribed burn*

3.2.1 *Considering four replications*

Using survival and mortality categories, calculated from the data collected during the damage assessment survey, provided the following results (Fig. 2):

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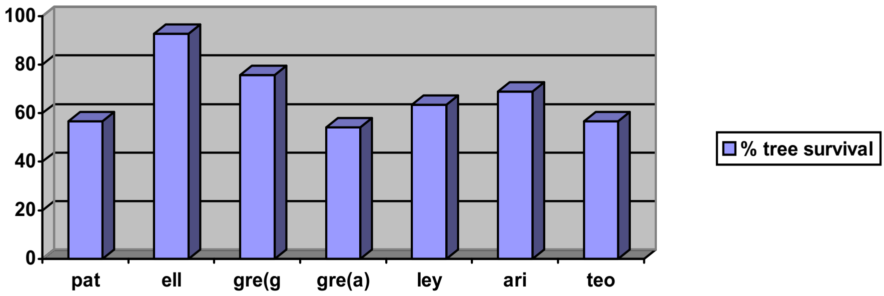

Figure 2. Illustration of tree survival for four replications, after prescribed burning application at 3.25 years stand age, applied when the grass was completely cured.

There were no significant differences between treatments (species) and neither between replications. Of the faster growing species, *P. elliottii* performed best with a survival of 92.0%, with *P. greggii var. greggii* second best, with a survival of 75.8%. Then *P. patula* followed with a 56.7% survival, and *P. greggii var. australis* with a 54.2% survival. The slower growing species showed a surprising 69.0% survival for *P. arizonica*, followed by a 63.5% survival for *P. leyophylla* and 56.7% for *Pinus teocotina.*

3.2.2 *Considering three replications*

The analyses of tree mortality/survival for the first three replications also provided no significant differences between treatments (species) or for replications, and the results are illustrated in Figure 3. Survival of *P. elliottii* is still the best at 90.3%, but is now followed by *P. leyophylla* with 84.7%, *P. greggii var. greggii* 80.4%, *P. teocotina* with 75.6% and *P. patula* with a surprising survival of 71.8%. The two species now showing the lowest survival were *P. arizonica* with 61.4% and *P. greggii var. australis* with 55.1%.

Although the results were not statistically significant between treatments (species) nor between replications (sites), it is important to note that the average percentage mortality for replications I – III was ranging between 19.21 and 30.07%, while that of the fourth replication (which experienced the observed higher fire intensity) was 54.79%, illustrating the importance of maintaining an as low as possible flame height profile, when executing this kind of prescribed burning.

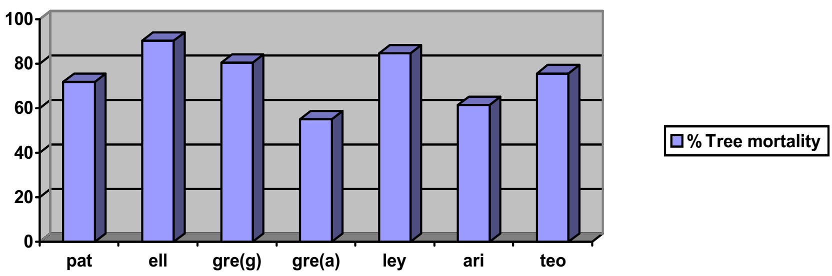

Figure 3. Illustration of tree survival for three replications, after prescribed burning application at 3.25 years stand age, when the grass was completely cured.

3.3 *Considering the four fastest growing Pinus species*

It is also important to determine if some species are more susceptible for higher fire intensity than others, particularly if we keep in mind that a high variability of fire behaviour was experienced (also observed during the survey) within the experimental area. Statistical analyses for the four most potential commercial species also showed no significant difference between species, but it is useful to compare the table of results (Table 1).

Table 1. Percentage tree mortality recorded for the four fastest growing *Pinus* species used in the experiment.

Replication	P. patula	P. elliottii	P. greggii (var. greggii)	P. greggii (var. austral.)
I	2.7	23.7	23.7	21.0
II	2.6	2.6	35.1	62.5
III	79.4	2.7	1.0	51.3
IV	88.6	1.0	38.2	48.6
Average	43.3	7.5	15.9	45.8

From the above table it is clear that *P. elliottii*, and to a lesser extent *P. greggii var. greggii*), are highly resistant to fire temperatures, regardless the fire intensity/crown scorch height experienced. In contrast, *P. patula* had a very low mortality rate in replications I and II (2.6 to 2.7%) and a very high mortality in replications III and IV (79.4 to 88.6%). This indicates that the latter performs well under a relatively low crown scorch height with a low mortality rate, but that the species is more susceptible to fire damage when crown scorch height is high. *P. greggii var. australis*, although found to be the best tree height growth performer (Fig.1), experienced a more constant mortality (ranging from 21.0 to 62.5%), and recorded the highest average mortality of the four species (45.8%, Table 1).

3.4 *Type of tree damage*

3.4.1 *Cambium damage*

Although the resistance of species, such as *P. elliottii*, to cambium damage is well known (*e.g.* de Ronde, 1982; Johansen and Wade, 1987) and that of some of the other species used in this experiment were expected to have a relatively high resistance against this kind of damage, species such as *P. patula* have (until recently) been regarded as being highly susceptible to fire damage, particularly to cambium damage. In this experiment, no cambium damage was recorded for any of the tree species subjected to the grassland fire at 3.25 years of age, which confirms results from related prescribed burning in the NE Cape, in *P. patula* growing in similar (cured) grasslands (de Ronde, 1999). The experiment confirms that this species can survive these controlled burns, without any damage to the cambium. The cambium below the layers of the thicker, “flaky” structure of the bark layer of *P. greggii var. greggii* withstood the slow moving, low profile, flames of the high intensity fire as well as the thinner *P. patula* bark layer (Figure 2). This indicates that cambium damage to trees does not have to be considered as important when prescribed burning is applied, even at this early age.

3.4.2 *Crown damage and re-sprouting features*

Various researchers have observed that tree mortality is more closely related to crown damage than to cambium damage (*e.g.* Cooper and Altobellis, 1969; Crow and Shilling, 1980;de Ronde, 1983). It is also known that most Pine trees show little mortality until crown scorch approaches 100%; but if (in contrast) tree crowns are consumed by a fire, dramatic increases in mortality will occur (*e.g.* Van Loon, 1967; Wade 1985; Wade and Ward, 1975). In this experiment very little needle consumption was recorded, but up to 100% crown scorch was commonly observed during the August 2001 survey, three months after having been exposed to fire. At that stage, re-sprouting trees and trees that experienced mortality, could easily be identified in most plots, particularly in *P. patula*.

All seven species of the experiment showed some degree of new bud development after experiencing some degree of crown scorch, but mortality and survival were not always as clear at that stage, as is illustrated in Figure 3. In some species, such as in *P. patula* and *P. leyophylla* with 100% crown scorch, a relatively high percentage of the trees could still go either way, and the final results will only become known at a later stage. With other species, such as *P.elliottii* and *P. greggii var. greggii*, the difference between dead and surviving trees could clearly be observed three months after the burn, by the abundance (or a total lack) of re-sprouting. *P. elliiotti* in particular, again illustrated its ability to survive and re-sprout, even when exposed to the higher fire intensity in Replication IV.

Although Figure 1 illustrates that *P. greggii var. greggii* was clearly outgrown by *P. greggii var. australis*, the first species survived the prescribed fire consistently better than the latter (Figs. 2 and 3), regardless the fire intensity experienced. With a mortality range of 1.0 to 38.2% (average of 24.2%) the species could be used as a supplement to *P. elliottii*, particularly in regions where it outperforms the latter species in terms of growth rate.

3.5 *Effect of fire damage on future tree growth performance*

Although it has been observed that serious crown scorch in mature trees can result in losses of tree height growth increment for up to two years (de Ronde, 1983), this possible loss of growth is not expected to be more than part of one growing season, or more probably, none at all (own observations in NE Cape and in other regions). Where phosphate deficiencies occur in some regions, a single fire can even provide significant tree growth improvements, *e.g.* in *P. elliottii* (de Ronde and Zwolinski, 2000).

4 DISCUSSION AND RECOMMENDATIONS

Although the outstanding survival rate of *P. elliottii* has now been confirmed, it is important to note that *P. greggii var. greggii* is a good second best, and the species is recommended in regions where it has a faster growth rate than *P. elliottii*. Depending on confirmed variation in tree growth rate performance in the various forestry regions, both species can be established for fire protection purposes, and can be prescribed-burned on a two-year rotation, from the age of three years onwards. Average tree height, however, should be the norm.

It is also clear that it is important to keep the flame height of a prescribed burn as low as possible, by applying a back burn (backing fire). Applying a head fire instead, will result in unacceptable crown scorch height and subsequent higher rate of mortality.

The experiment also confirmed that the high within-plot, between plots and between replications variation in fire intensity experienced, makes it difficult to arrive at any meaningful correlation between tree and fire parameters. The non-significance of all results recorded after the burning confirm this, in contrast to the highly significant differences recorded between average tree heights, before burning.

The use of *P. patula* for prescribed burning can still be considered at early age, provided only a low-profile back burn is applied, and also if burning before grassland curing is considered (as a “wet” season burn). The latter method can produce a significantly lower fire intensity than that of a fire applied after grassland curing (de Ronde, 1999). Sometimes the forest manager has no option but to consider prescribed burning of *P. patula*, because the species has already been established on the site. This experiment proved that it is possible to burn three-year old *P. patula* with a mortality rate of as low as 2.6%, if the correct burning procedures are followed. However, if burning is applied when the average tree height is exceeding five to six metres with a substantial degree of crown canopy closure, burning will be possible with a higher safety margin.

The experiment confirmed that *P. elliottii* is the most fire resistant species, and that it can easily survive light to moderate fire intensities, at a stand age of three to four years. Even if exposed to a slow moving back burn in completely cured grassland, no cambium damage should be experienced, and a survival rate of more than 93% can be expected. Similar results can be expected when burning three to four-year old *P. greggii var. greggii*. If any of these two species are thus established *in tandem* in two strips, during two consecutive years, and the grassland (or slash after clearfelling a previous tree rotation) was burned prior to tree establishment, there will consequently only be a period of one to two years without prescribed fire application along these lines. These "fire protection strips" should thereafter be burned alternatively on a two-year rotation.

The results of this experiment now open the door for selective establishment of *P. elliottii*, *P. greggii var. greggii* or even *P. patula* under certain conditions for fire protection purposes, as discussed in this report. The following are some circumstances when the application of these methods can be considered:

- Planting of trees within existing grassland fire breaks (externally or internally), which are presently burned on a yearly or two-yearly rotation, and which are situated on sites with an acceptable tree growth potential*. Two-yearly prescribed burning under the trees will then replace the rotational grassland burning, as follows:
    - <u>Slash treatment prior to tree establishment within these fire breaks</u>: Burning of grassland prior to tree establishment.
    - <u>Planting rotation</u>: 50% established per year, during the first two consecutive years, in two adjoining strips.
    - <u>Species</u>: *P. elliottii* or *P. greggii var. greggii*, depending on which species provides the best tree increment.
    - <u>Stand age when first applying prescribed burning</u>: Three to four years stand age, provided tree height exceeds four metres.
- Within existing fynbos fire breaks, which are at present burned on a specific rotation, and which are situated on sites with acceptable tree growth potential*. Two-yearly prescribed burning will then be applied, with the same provisions as above.
- Within existing, yearly ploughed, fire breaks. Two-yearly prescribed burning under the trees will then be applied, with the same provisions as above.
- To form two strips of stands adjoining external fire breaks, to provide supplementary fire protection lines or buffer zones, which are situated on sites with acceptable tree growth potential. Two-yearly prescribed burning under the trees will then replace the previous stands' species, as follows:
    - <u>Slash treatment prior to tree establishment</u>: Burning of slash, after clearfelling the previous tree rotation.
    - <u>Planting rotation</u>: All trees to be established simultaneously, as soon possible after slash burning has been applied.
    - <u>Species</u>: *P.elliottii*, or *P. greggii var. greggii*, whichever species provides the best tree increment. Alternatively, where *P. patula* stands already exist, and if these stands are not going to be clearfelled within the foreseeable future.
    - <u>Stand age when first applying prescribed burning</u>: Three to four years in the case of *P. elliottii* or *P. greggii var. greggii*, provided tree height exceeds four metres. *P. patula* should have a tree height of five to six meters and a substantial degree of crown canopy closure, before the first prescribed burn is applied.

- = Provided these sites are not situated within special heritage areas, sensitive nature conservation land, wildlife corridors or riparian zones.
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REFERENCES

Cooper, R.W. and Altobellis, A.T., 1969. *Fire kill in young Loblolly Pine*. Fire. Cont. Notes 30(4): 14-15.

Crow, A.B. and Shilling, C.L., 1980. *Use of Prescribed Burning to enhance Southern Pine Timber Production*. So. J. Appl. For. 4(1): 15-18.

De Ronde, C., 1982. *The Resistance of Pinus Species to Fire Damage*. S. Afr. For. J. 122: 22-27.

De Ronde, C., 1983. *Controlled Burning in Pine Stands in the Cape: The Influence of Crown Scorch on Tree Growth and Litterfall.* S. Afr. For. J. 127: 39-41.

De Ronde, C., 1999. *Final report: Season and Stand Age of Prescribed Burning in Pinus patula*: 7 pp.

De Ronde, C. and Zwolinski, J., 2000. *Comparing the Impact of four Slash Treatments, applied after Clear-felling Mature Pinus pinaster on Sustainable Productivity (unpublished report).*

Johansen, R.W. and Wade, D.D., 1987. *Effect of Crown Scorch on Survival and Diameter Growth of Slash Pine*. So. J. Appl. For. 11(4): 180-184.

Van Loon, A.P., 1967. *Some Effects of a Wild fire on a Southern Pine Plantation*. Res. Note 21, For. Comm. NSW, Australia, 38pp.

Wade, D.D., 1985. *Survival in Young Loblolly Pine Plantations following Wildfire*. In: Proc. 8th Nat. Conf. On fire and forest meteorology, 1985 April29-May2: Detroit, MI, Washington DC: Soc. Am. For: 52-57.

Wade, D.D. and Ward, D.E., 1975. *Management Decisions in Severely Damaged Stands*. J. For. 73(9): 573-577.