Soil - Plant Interactions and Establishment of Woody Perennials on Hostile Soils

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ABSTRACT

Woody perennials exist in diverse conditions across arid and semi-arid regions and they bring enormous ecological, environmental and economic benefits – yet their establishment remains unreliable and expensive. A great deal of research has gone into cultural methods to improve establishment yet the edaphic factors have been largely ignored, and this is seen as a serious limitation. Without a good understanding of the interactions between plants and (often hostile) soil conditions, improved cultural methods can generate only limited progress. This study reviewed the literature associated with establishing woody perennial species on hostile soils in arid and semi-arid regions (Chapter 2, published in *Plant and Soil* as a review paper) and concluded that two of the most important soil properties limiting woody plant growth were high soil strength and low soil aeration. It also concluded that because some species grow well in hard soils while others grow well in waterlogged soils, there must be considerable genetic variation among woody perennials in the way they adapt to edaphic conditions.

On this basis, the research reported in this thesis was conducted in four separate studies (each published or submitted for publication) to understand the variation in inherent root growth pressures that different woody species can exert on the soil (Chapter 3), the response of different species to compaction (Chapter 4), the response of different species to poor soil aeration (Chapter 5), and the response of different species to these conditions in the field (Chapter 6). Cultural methods were included as variables, and model crops (either *Pisum sativum* or *Hordium vulgare*) were included for comparison.

The establishment and survival of woody perennials on hard, dry soil was postulated to depend *inter alia* upon their ability to exert high maximum axial root growth pressures, σ_{max} (Pa), which enable them to establish deep root systems. Values of σ_{max} have been published for crop plants in the past but not for a wide range of woody perennials. In Chapter 3, six small-seeded *Eucalyptus* species from two different habitats were grown in a glasshouse for 3-4 months until their root systems developed into a root-bound 'plug'. They were then re-potted into larger vessels to reproduce a new set of lateral roots over 3-4 days. The maximum axial root growth force, F_{max} (N), was then measured on lateral root axes using a recognized apparatus (Misra 1997, Plant Soil 188,161-170). F_{max} was also measured on the primary root

axes of 3-4-day old seedlings of the large-seeded woody perennial, *Acacia salicina*, and the crop plant, *Pisum sativum*. Values of σ_{max} were calculated from F_{max} and the corresponding root diameter (d, m) using the relation: $\sigma_{max} = \frac{4F_{max}}{\pi d^2}$. The primary and lateral roots of all woody perennials were found to be considerably smaller than the primary roots of *P. sativum* yet they exerted a similar mean F_{max}. The mean σ_{max} varied between 0.15 and 0.25 MPa and the species: *E. leucoxylon*, *E. loxophleba* and *A. salicina* exerted the greatest pressures among the woody perennials, which were comparable to those exerted by the crop plant, *P. sativum*. Seedling age appear to influence the value of σ_{max} for primary roots of the trees, so a separate experiment was conducted to measure F_{max} for *A. salicina* and *P. sativum* over a period of 2-10 days after germination. The value of σ_{max} for the primary roots of *A. salicina* seedlings increased with time such that it became greater than that for *P. sativum*. The value of *P. sativum* did not change with time.

In Chapter 4, four species that exerted low, medium, or high σ_{max} in Chapter 3 were selected to evaluate their performance in compacted soils containing no cracks or biopores. All species were grown by direct seeding in a loamy sand compacted to obtain a range of soil penetration resistance, SR, ranging between 0.3 and 5 MPa. The seedlings of the *Eucalyptus* species were too small to be handled so they were grown for 3-months then transplanted into soil having the same range of SR values. Root diameter, elongation rate, total length and distribution of roots with the soil depth were measured. The SR value at which the rate of root elongation was halved, $SR_{0.5}$, was determined from a plot of elongation rate versus soil resistance. The diameter of the primary roots of *A. salicina* increased more consistently and this species maintained higher rate of root elongation and had higher $SR_{0.5}$ value than those of the direct seeded eucalyptus species and *P. sativum*. However, the lateral roots of transplanted *Eucalyptus* species elongated faster and had greater values of $SR_{0.5}$ than the primary roots of all species. The lateral roots of transplanted *E. camaldulensis* were more strongly negatively affected by compaction than those of the other transplanted eucalyptus species. Irrespective of compaction, *P. sativum* grew most its roots in the top 5 cm of soil, whereas tree roots were more uniformly distributed with depth. These variations in root growth behaviour in response to varying compaction were only found to moderately correlate (R^2 = 0.79 and P = 0.11) with the ability of their roots to exert σ_{max} (measured in earlier experiments) when the soil was severely compacted.

It has been reported that many compacted and uncompacted soils in arid and semi-arid regions suffer from permanent or temporary waterlogging. Root zone of such soil lacks sufficient aeration and oxygen supply. In Chapter 5, the performance of woody perennials from previous experiments were evaluated under a range of soil aeration, ε_{air}, between totally waterlogged and highly aerated (i.e. $0 < \varepsilon_{air} < 0.20$ m^3m^{-3}). *Hordium vulgare* was included for comparison because it is known to survive temporary waterlogged soil conditions. All species were direct seeded and grown for 21 days. The concentration of soil oxygen was measured directly in each soil, and the diameter, total length of roots, mass of shoots and roots, as well as water use and water use efficiency were measured or calculated. The soil oxygen concentration was severely depressed in soil where $\varepsilon_{air} \leq 0.10$ m^3m^{-3} but there was considerable variation among plant species in their response. Root and shoot growth as well as the water use by the young seedlings of *E. camaldulensis* were virtually unaffected by soil aeration status, while the other four species showed different responses. *E. kochii*, for example, was highly sensitive to declining ε_{air}, while *H. vulgare* and *A. salicina* were somewhat less sensitive. In terms of water use efficiency, the two large seeded species, *A. salicina* and *H. vulgare*, were significantly more efficient than the eucalyptus species.

In Chapter 6, the above findings from the laboratory and glasshouse experiments, which suggested the ability of roots to either exert high σ_{max} or to maintain a high rate of root elongation might be important for establishment and survival of these woody perennials, were tested under field conditions. A field survey was conducted near Monarto, South Australia, where soil physical properties and the success of woody perennials were thought to be related to differences in land management. A planting experiment was also conducted nearby where several woody perennials were established using two different planting methods. The large-seeded acacias were more successful than the small-seeded eucalypts when both were planted from seeds. Among the small-seeded species, transplanting of 90 day-old-seedlings was more successful than direct-seeding. Differences in success rates of various tree species and planting methods in the field corroborated well with the performance of these woody perennial seedlings in the laboratory. The findings from this research can be used by land managers and revegetation agencies to select superior woody perennials and planting methods to maximize the outcomes of their revegetation efforts in arid and semi-arid regions.

The key findings from this research were:

i. There were significant differences between woody perennials in their ability to exert high root growth pressures; some tree roots exert comparable pressures to those of an annual species.

ii. Roots of older seedlings can exert higher pressures than those of younger seedlings, and when compacted conditions persist for up to 10 days, a woody perennial (i.e. *A. salicina*) can continue to exert root growth pressures that exceed those of an annual species (i.e. *P. sativum*).

iii. There are significant differences between woody perennial seedlings in their ability to penetrate soils by their roots under varying soil strength which can be justified by differences in their respective habitats. Among the direct seeded woody perennial, large-seeded species have comparatively higher $SR_{0.5}$ than those of small-seeded ones.

iv. There are significant differences in the ability of roots of young seedlings planted by different methods. The lateral roots of transplanted eucalyptus seedlings generally elongate faster at all levels of compaction and they have significantly greater $SR_{0.5}$ values than those of their direct-seeded counterparts.

v. In highly compacted soil (e.g. SR > 4 MPa) there is a strong correlation between the ability of species to exert high root growth pressures and their ability to continue to grow in very hard soils.

vi. The effect of soil aeration on plant growth varies widely among species. Some woody perennials are better able to grow and use water in poorly aerated soils than others (probably by moving oxygen from the shoots to the roots). There appears to be no single critical value of ε_{air} to which all woody perennials respond. Some decline as soon as $\varepsilon_{air} < 0.20$ m^3m^{-3}, while others either don’t respond at all or do not decline until $\varepsilon_{air} < 0.15$ m^3m^{-3}. Furthermore, no single plant response universally indicates plant performance under waterlogging conditions – in some cases only root or shoot growth is affected while in other cases a more integrated response occurs (e.g. water use efficiency).

vii. The laboratory and glasshouse observations can be used to predict the success of young woody perennial seedlings and planting methods in real field conditions.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma from any university or tertiary institution to Md Gausul Azam. To the best of my knowledge and belief, it contains no material previously published or written by any other person, except where due reference has been made in the text.

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Md Gausul Azam **Date:**

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