Use of Plants for Ground Bioengineering and Erosion & Sediment Control in New Zealand

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Abstract

Knowledge of the use of plants, particularly native plants, in New Zealand for ground bioengineering and erosion and sediment control is outlined in a brief review of unpublished and published information. In general, our level of knowledge about what makes any plant useful for these purposes is poor, particularly in regard to performance or effectiveness of individual plants or plant systems. Much of the knowledge is experiential rather than tacit, and what has been recorded is often in the grey literature. Limited data exist for some New Zealand native plants, but most are for a few species, of a limited age range and sample number, and have only been collected in the last 10 years or so. This paucity of quantitative data is set in the context of a resurgent interest in bringing more native plants into New Zealand's managed or cultural landscapes coupled with a desire to remove exotic plants such as willows, which are currently performing many functional ground bioengineering roles. Much of this recent focus has been to enhance indigenous biodiversity and to improve water quality in streams. However, opportunities to redress our shortfall in knowledge are beginning to appear in association with development industries such as roading, mining, and construction where the use of plant materials to perform functional roles is only now being recognised.

Keywords

native plants, erosion, sediment control, root growth, root morphology, soil reinforcement.

Introduction – ground bioengineering and erosion and sediment control

Ground bioengineering is a general term for all categories of application of plant materials for soil protection and slope stabilisation either on their own or in combination with mechanical methods (Schiechtl & Stern 1996). Historically, these technologies can be traced to ancient peoples of Asia and Europe where riverbanks and slopes were stabilised by combinations of live plant materials and "harder" structures. Much of the development and documentation of modern soil bioengineering techniques was done in relation to the mountainous areas of Austria and southern Germany. Unlike other technologies in which plants are chiefly an aesthetic component of the project, in ground bioengineering systems, plants are an important structural component. Bioengineering techniques tend to be more creative and environmentally sensitive as they aim to utilise natural elements of the site such as rock, trees, and other native vegetation to stabilise slopes and banks as opposed to man-made structures constructed of synthetic materials such as steel and concrete.

Various terms have been used to describe the use of plant materials in structural design and while there may be subtle differences between them they all tend to use plant materials for an engineering function. These include:

- Ground bioengineering
- Soil bioengineering
- Biotechnical stabilisation
- Bioengineering
- Ecological engineering
- Water bioengineering
- Green construction
- Living construction
- Green engineering
- Natural construction
- Biogeotechnology
- Biotechnical soil stabilisation
- Biotechnical erosion control
- Erosion and sediment control (E&SC) – in its widest sense.

Both ecological and ground bioengineering fall within the framework of 'ecological engineering'.

The role of vegetation: how it works

How do we control erosion? Mechanical methods have an immediate effect and operate more or less at maximum design efficiency but are costly to construct and maintain. Biological methods such as the use of live vegetation established from seeds and cuttings are generally cheaper but their immediate effect is smaller. However, once established, vegetation provides a self-perpetuating and increasingly effective permanent control (Coppin & Richards 1990).

How does vegetation control erosion? The canopy, stem and roots of plants interact with the erosion processes of soil detachment and transport. The canopy changes the raindrop size distribution and reduces the fall velocities thus reducing the kinetic energy available for erosion via raindrop impact. Plant stems disrupt overland flow paths and impart roughness to the flow thereby reducing flow velocity and energy to detach and transport soil particles. Plant roots tend to change the physical characteristics of the surface soil, promoting infiltration and thus reducing the incidence of overland flow. In addition, plant roots also increase the shear resistance of surface soil against the shearing forces of overland flow. In larger woody vegetation roots may penetrate to considerable depth increasing the shear strength of the soil and reducing the likelihood of mass movement. Vegetation may also enrich the soil by fixing nitrogen in its roots, and it may act as a filter or barrier to sediment-laden runoff (Greenway 1987; Table 1).

Table 1 How vegetation affects slope stability and erosion (modified from Greenway 1987). A – Adverse to stability, B – Beneficial to stability

	Influence
Hydrological mechanisms	
Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce rainfall available for infiltration.	B
Foliage intercepts rainfall protecting the soil surface from rain splash erosion.	B
Roots and stems increase the roughness of the ground surface and the permeability of the soil, leading to increased infiltration capacity.	A
Roots extract soil moisture from the soil, which is lost to the atmosphere via transpiration, leading to lower pore-water pressures.	B
Depletion of soil moisture may accentuate desiccation cracking in the soil, resulting in higher infiltration capacity.	A
Mechanical mechanisms	
Roots reinforce the soil, increasing soil shear strength.	B
Tree roots may anchor into firm strata, providing support to the upslope soil mantle through buttressing and arching.	B
Weight of trees surcharges the slope, increasing the normal and downhill force components.	A/B
Vegetation exposed to the wind transmits dynamic forces into the slope.	A
Roots bind soil particles at the ground surface, reducing their susceptibility to erosion.	B
Low-growing vegetation may filter and trap sediment from runoff	B

Common bioengineering techniques

The classification system introduced by Schiechtl (1973) divides ground bioengineering techniques into four groups each with their corresponding construction types that have definite functions and special areas of application (Schiechtl & Stern 1996).

1. **Soil protection techniques**

Rapidly protect the soil from surface erosion and degradation by means of their covering action. They improve water capacity and promote biological soil activity.

2. **Ground stabilising techniques**

Designed to reduce or eliminate mechanical disturbing forces. Stabilise and secure slopes by means of root penetration and decreased pore pressure. Generally involve linear or single-point systems of trees, shrubs, or cuttings and often supplemented by soil protection works.

3. **Combined construction techniques**

Combine the use of live plants and inert materials such as stone, concrete, steel, to secure unstable slopes and embankments.

4. **Supplementary construction techniques**

Comprises seeding and plantings in the widest sense to secure the transition from the construction stage to the completed project.

Traditional erosion and sediment control (E&SC) technologies such as those associated with the stormwater industry are largely found in groups 1 and 3 as these techniques tend to focus on reducing or mitigating surface erosion processes. However, on occasions, typical E&SC projects will use some techniques of all the bioengineering groups outlined above.

In terms of groups 2 and 3 there is a range of different techniques other than individual planting where vegetation is used to "engineer" soils. These include any one of or a combination of: fascines, fascine drains, grassed channels, live stakes, brush layering, wattle fences, hydro-seeding, hydro-mulching, erosion control mats/geotextiles, vegetated crib walls, live gabions and so on (Gray & Sotir 1996).

Many of these techniques have limitations on where they can be used and what type of erosion they can control. In most cases the key to successful ground bioengineering projects is the timing. It is important to "plant/deploy" materials when soils are moist, materials are "green" and not susceptible to drying out, and when plants are dormant. A further consideration for some techniques is "keying in" or tying a structure into the bank or hillslope.

Plant materials may also perform a contaminant or sediment-stripping function (sediment control) such as in swales or filter strips. Here the focus is less on stabilising the soil (though this is still important) but more on slowing down and capturing contaminants from runoff before they enter streams, lakes or estuaries.

Several considerations govern the choice of a particular species for ground bioengineering and E&SC (van Kraayenoord & Hathaway 1986). These include factors such as:

- Ecological considerations
- Adaptability
- Ease of propagation and availability
- Ease of establishment
- Growth habits and growth rate
- Root habit
- Soil improvement
- Resistance to mechanical damage
- Resistance to pests and diseases
- Undesirable features, such as a propensity to turn into a weed.

In contrast to ground bioengineering and E&SC where plants are used to provide a functional engineering role, most current rehabilitation or revegetation projects seen in many parts of New Zealand and Australia aim to speed up the natural regenerative process or plant succession, largely with the aim of enhancing local biodiversity. The aim here is to “fast-track” the succession by either intervening with a mix of different plant materials from different successional stages or to provide ways to promote growth, particularly in the early stages. In the former situation the focus is on the function and the ability to perform that role and not on the concept of providing any form of succession or enhancement of biodiversity.

In contrast to ground bioengineering, ecological engineering has largely been devoted to the sustainability of wetlands, wastewater and aquaculture (Painter 2003). Focusing more on the restoration or protection of sites, eco-engineering has recently been defined as the long-term strategy to manage a site with regards to natural or man-made hazards (Stokes et al. 2004, 2005).

In summary then, ground bio-engineering and E&SC methods integrate civil engineering techniques with natural materials to obtain fast, effective and economic methods of protecting, restoring and maintaining the environment (Schiechtl 1980; Coppin & Richards 1990; Gray & Sotir 1996).

The New Zealand situation

Much of New Zealand’s indigenous vegetation has been cleared for human uses since European settlement in the 1800s. The loss of this vegetation has led to a decline in indigenous biodiversity and to degradation of waterways through increased sedimentation and nutrient pollution (Phillips et al. 2001). Further, vegetation removal created accelerated erosion in many hill country areas with concomittant losses of soil and site productivity (Phillips & Marden 2005). A need for both flood control and revegetation strategies to deal with these problems began to be increasingly recognised from about the 1940s and culminated in the Soil Conservation and Rivers Control Act 1941. This led to the establishment of catchment authorities that had specific functions for soil conservation and river and flood control. Subsequent legislation such as the Water and Soil Conservation Act 1967 and its various amendments continued the responsibilities for these functions by catchment boards through to 1991 when the Resource Management Act 1991 saw their demise and the establishment of regional and district councils.

More recently, following major floods in the Manawatu, Bay of Plenty, Coromandel, and Tauranga regions, attention has refocused on the role of catchment vegetation, particularly in steeplands, for mitigating natural hazards. In addition, the introduced willow sawfly (*Nematus oligospilus*) has caused widespread defoliation of New Zealand’s willow trees since 1997, particularly in the Hawke’s Bay, posing a threat to riverbank protection programmes (Charles et al. 1999). River engineers are currently seeking alternative plant species to exotic willows that provide this riverbank protection function.

Increasingly, societal considerations have also become an integral part of bringing native vegetation back into New Zealand’s landscapes. These may include incorporating the aspirations of Māori in plant selection for use in traditional medicine, as fibre for weaving, and for other uses. There is also now an increasing movement by grass-roots communities to undertake restoration, largely to improve biodiversity but also to improve water quality in streams and rivers (Ministry for the Environment 2000; Parliamentary Commissioner for the Environment 2002; NZERN – the New Zealand Ecological Restoration Network 2004 (http://www.bush.org.nz/)).

Lastly, while there has been renewed interest in revegetation of New Zealand's managed landscapes driven largely by the biodiversity lobby, many former plantings of exotic species used for river and slope protection have now become an issue for landowners as these reach the end of their useful lives. In many cases lack of active management over the last two to four decades has created a potential problem for many locations around the country. Poplars are now so tall they are falling over or their tops are snapping out on slopes, and willows on river banks are also toppling and blocking stream channels. The question many landowners and local authorities are now facing is what to do with these trees. With their having no or little economic value, landowners are poisoning, ringbarking or felling these old stands of poplars in particular. What the effect on hillslope protection will be is unknown.

Use of ground bioengineering in New Zealand

In New Zealand vegetation has, and still does, play a major role in the stabilisation and rehabilitation of eroded lands, and in stream and river control works (van Kraayenoord & Hathaway 1986). However, other than seeding and planting of individual plants, the most commonly used ground bioengineering technique in New Zealand is live staking using poles. This is generally done with species of willow for river control or poplar species for hillslope stabilisation. While a range of traditional ground bioengineering techniques may have been used to a limited degree in the past, the use of these more labour-intensive techniques has long gone out of favour. However, there appears to be some level of renewed interest in some of these "old" techniques (Robert Coulson, pers. comm.).

Willows have long been used for edge protection on gravel-bed rivers. They have been used as individual pole plantings, integrated into structures, and layered. An exotic species, they were introduced from about 1840 on, and there are many varieties in New Zealand. Willows and poplars were bred specifically for river protection and soil conservation purposes by river boards and government agencies from about the 1930s on. The total depreciated book value of live willow protection in New Zealand is estimated to be at least $50 and more likely $100 million dollars (Brent Cowie, pers. comm.). They form a very important part of river control works protecting many billions of dollars of assets on the often intensively populated and fertile flood plains where over half of our population live. Edge protection is a critical component of flood protection. Willows slow water velocities close to stopbanks, and, through their deep and strong rooting abilities, prevent river channels eroding laterally. In the absence of live protection, stopbanks are vulnerable to attack and breaching by floodwaters in relatively minor events. The alternatives to live willow protection – such as the use of spur groynes – are much more expensive to construct and maintain.

The use of poplars for erosion control particularly in hill country is also widespread throughout New Zealand. Poplars are used to control landslide-prone slopes and stabilise gullies or earthflows; like willows, significant effort went into breeding a range of varieties for these different purposes. In addition, other exotic species such as alders and acacias were used for gully control (Van Kraayenoord & Hathaway 1986).

Extensive afforestation has also been used to combat soil erosion and reduce sediment generation in many parts of the country. This is most important in the East Coast of the North Island where a Government-funded initiative – the East Coast Forestry Project – has subsidised the planting of trees (mostly radiata pine but more recently including poplars) to control regional landslide erosion and reduce sediment input into rivers (Phillips et al. 2000; Phillips & Marden 2005). The effect of vegetation on specific erosion processes has also been investigated (O'Loughlin & Zhang 1986; Zhang et al. 1993; Marden et al. 2005b).

In urban development and road construction, exotic grasses are usually preferred in hydro-seeding mixes, though in some areas such as at mining sites native mosses and seeds have been used (Coulson 2005; Phillips 2005; Simcock et al. 2005).

What we know about NZ native plants for ground bioengineering E&SC

Information on the nature, and more importantly on the performance, of New Zealand's indigenous species for ground bioengineering and erosion and sediment control is poor. What is available is generally descriptive, with much of our knowledge anecdotal.

In terms of ground bioengineering, the use of natives has virtually been ignored largely because they have, or are perceived to have, slow growth rates and are often slow to get established compared to exotic plants such as willows and poplars mentioned above. Brush layering with mānuka and kānuka (*Leptospermum scoparium* and *Kunzea ericoides*) is about the extent of the use of natives in traditional bioengineering. In addition, there is virtually no quantitative data on the role of native vegetation such as native grasses, sedges or tussocks to filter sediment from runoff (and also very little on exotic vegetation for that matter). Nor is there much information on the rates of spread of groundcover or canopy of native plants (as a surrogate for cover of bare ground).

Further, research and investigation on the use of indigenous vegetation specifically for erosion and sediment control has, in general, received little attention in New Zealand. The most significant contribution to knowledge of native plants for soil conservation (E&SC in its widest context) was in a volume of the *Plant Materials Handbook for Soil Conservation* series published in 1986 (Pollock 1986). This publication discusses the selection of suitable native plants, sources of plant materials, their propagation, field establishment and maintenance, followed by specific comment on, and the requirements of, some 70 individual species when used for soil conservation. Companion handbooks deal with the use of exotic plants such as willows and poplars (Van Kraayenoord & Hathaway 1986).

Up to the 1980s (and even through to today), the use of native plants in soil conservation focused on the restoration of natural communities or impoverished remnants and the revegetation of areas near indigenous vegetation so as to prevent the onset of soil erosion. The use of native plants specifically for E&SC was largely restricted to those used in windbreaks where some species showed proven success. The lack of native plants used in E&SC relates to the fact that relatively few species were identified as able to rapidly colonise bare soil even though native vegetation has kept most of the soil in place in New Zealand over many centuries.

The introduction of exotic species that grew faster and colonised bare areas quicker became the preferred option for many revegetation projects and saw native plants relegated to those areas where there was a specific conservation or aesthetic value. Even though few native plants are suited to rapid recolonisation of severely eroded land and few can be used to protect rapidly eroding surfaces, there are a number that can be used to revegetate denuded but generally stable surfaces or prevent potential erosion situations from becoming active. Many of the 70 species outlined in the 1986 handbook have uses for the prevention of sheet and rill erosion, with a much smaller number recommended for mass movement or gully erosion.

In the case of below-ground growth performance and functionality, there are few published studies on root system architecture and biomass of individual tree species be they exotic or native. Studies mostly involve one or a few specimens usually of a limited age range (e.g. Cameron 1963; Wardle 1991; Phillips & Watson 1994; Watson et al. 1995, 1999; Marden et al. 2005b; McIvor et al. 2005; Watson & Marden 2005; Czernin & Phillips 2006). This paucity of data is a reflection of the time-consuming nature of root system extraction, particularly for large shrubs and trees, as well as the fact that root systems are often influenced by soil conditions, making statistical comparisons difficult. Phillips (2005) provides a brief summary of the current state of knowledge of the below-ground characteristics of New Zealand's native plants. The current knowledge base contains limited information on parameters such as plant growth, root architecture, root depth, root spread, root biomass, root:shoot ratio, root strength, and root site occupancy (Phillips & Watson 1994; Marden et al. 2005b; Phillips 2005).

These studies, together with the few published reports on the root depth of some of New Zealand's tallest podocarp forest species (Cameron 1963), indicate the rooting depth for most of New Zealand's indigenous species rarely exceeds 2 m. The conclusions from all of these root studies indicate that, in general, native species have higher tensile root strengths than exotic species, tend to be slower growing, and have shallower root systems.

In studies of colonising riparian native species Czernin & Phillips (2006) and Marden et al. (2005b) make reference to the use of native plants for streambank stabilisation and conclude that the effectiveness of riparian restoration programmes using indigenous species, though potentially high for low-order streams, will be limited by their relatively shallow-rooted habit for bank stabilisation on larger rivers without the prior installation of structural protection works.

Some species such as the cabbage tree (*Cordyline australis*) showed some promise, as root development occurs at different depths in the soil profile (Czernin & Phillips 2006), a pre-requisite for efficient stabilisation (Schiechtl & Stern 1996). However, based only upon the parameters assessed, it appeared that the cabbage tree could not serve as a primary substitute to presently used willow species for river protection across a range of river sizes. The cabbage tree may still play an important role in the protection of riverbanks, as its natural occurrence and persistence in these environments testifies. The study recommended that young cabbage trees should generally not be planted directly on the lower banks of larger rivers where large hydrodynamic stresses can be expected, but on smaller streams this may be less of an issue. Above the age of 10 years, however, cabbage trees may well afford a high level of protection for riverbanks, though two issues are worthy of note. Firstly, the rhizome, while significantly increasing its volume as the tree grows, still represents only a local level of protection. In many ways it acts like a localised slope nail. To enhance the protection value, trees may have to be planted at spacings of around 2 m to ensure a dense network of fine roots develops between neighbouring trees. Alternatively, if planting is required closer to the riverbank, sufficient surface coverage has to be ensured in order to protect the ground surface from erosion, perhaps with another species such as the New Zealand flax (*Phormium tenax* or *P. cookianum*).

The limitations of root depth aside, New Zealand's indigenous riparian vegetation is sufficiently diverse to meet most of the requirements for slope and bank restoration, particularly of lower-order streams. The selection of suitable plants must take into account the degree of overbank inundation contemplated and the ability of plant materials to provide year-round protection, have the capacity to become well-established under adverse soil conditions, be long lived, develop a root system that will withstand the drag of stream flow on the above-ground portion, have multistem and branch characteristics with many stems emerging from the boundary surface, have tough, resilient stems and branches, and require minimum maintenance.

Where stability is required to a known depth, such as to a potential failure plane that lies within the rooting depth of plants being considered to restore stability, the species selection must include sufficient numbers of those with root systems capable of reaching the specified depth. Failure to meet this goal will undoubtedly be the result of insufficient roots crossing the failure plane, as it is below the vertical limit of root growth of the species selected. For many restoration sites the strategy should be to select a mix of species with different rooting habits. However, to fully appreciate the potential use of indigenous vegetation for the stabilisation of riparian slopes and streambanks in New Zealand, further studies are needed for other plant species that may better meet the slope and bank stability requirements for drainage systems in a range of different soil types, geology, and with differing hydraulic characteristics (Marden et al. 2005a).

The use of native plants for erosion and sediment control and revegetation in a range of environments including mine sites, roadsides, construction sites and in coastal dunes was also briefly reviewed by Phillips (2005). In general though, the use of native plants in many of these situations is low in comparison to the use of exotic plant materials and natives tend to be used only in special circumstances such as in conservation lands or where the project client specifically requests native planting. However, there are some signs that demand for native plants in E&SC roles is increasing (Robert Coulson, pers. comm.)

What we should know

While we have made significant advances in our understanding of the ecological aspects of many of our exotic and native plants systems, there is still a lack of fundamental information and understanding on the performance of both exotic and native species for functional uses outside of their ecological niches. In the case of exotic species such as willows and poplars, we do have a significant knowledge base built on the experience of decades of use. However there is little quantitative performance data available even for these species. Further, if we are to increasingly use native plants in roles that they may not be naturally adapted to, or wish them to grow in habitats that may be unfamiliar, then further research and investigation is required. However, the opportunities to use natives plants other than for aesthetic reasons or for biodiversity enhancement is significant, particularly in our urban environments.

Even though there are many hundreds if not thousands of community-based and private restoration/rehabilitation efforts underway in New Zealand that focus on "putting natives back into the landscape", most do not carry out any monitoring or evaluation of how they are performing. Collecting fundamental data such as mortality/survival, plant growth (size, dbh, height, spread), density, ground cover, regeneration, phenology etc. is crucial to ensuring that those efforts do contribute to the viability of our natural heritage, particularly in highly modified cultural landscapes.

In addition, if we are serious about restoring the balance and introducing more native plants into our landscapes then one of the things we need to do is begin to explore the possibilities of using native plants for specific roles in ground bioengineering and E&SC. To do that, we will need to invest more in research on understanding what plants are best for what roles (root reinforcement, sediment stripping from runoff, groundcover expansion, fast establishment etc.), in what combinations, and how they should be applied (Phillips 2005). In addition we should also capture and record the specific successes of local community groups who have managed to devise local solutions to growing and using native plants in their environments, e.g. Whaingaroa Harbour Care Group (Fred Lichtwark, pers. comm.).

Conclusions

For a relatively young country, New Zealand has lost a lot of its indigenous vegetation in a short space of time. Although large areas are now protected and administered as conservation lands, the value of New Zealand's indigenous flora in managed landscapes outside of national parks and reserves is only now beginning to be recognised and has gained some attention in the last decade or so. While the general ecology of many of our plant systems is relatively well known, the use of these plants for restoration and rehabilitation outside of their normal habitat, let alone for the varied functions of ground bioengineering and E&SC, is set against a paucity of quantitative information and knowledge. Further, although it is recognised that the use of exotic plant materials in these functional roles has contributed significantly to the economic development and protection of our lowlands (Cowie 2005) there currently exists a "tension" between those who traditionally favoured harder engineering approaches and those who are wanting to introduce more native plants into our managed landscapes.

To date, limited research resources have been focused on the use of our native plant materials for use in ground bioengineering and E&SC. Thus any knowledge about the performance of these plants or the ways in which they are used is largely anecdotal and often based on trial and error.

There are signs that this lack of data is beginning to be addressed, with mining, roading, and construction industries turning their attention to the use of more "natural' methods for land stabilisation and vegetation management. In addition, the significant groundswell of community action to bring more indigenous biodiversity into New Zealand's cultural landscapes through riparian planting programmes, wetland restoration, and forest restoration has seen the emergence of networks of knowledge sharing and the start of more quantitative data collection on the performance of many of our native plants in these roles. It is questionable in the short term, however, whether there will be a wholesale shift from the use of exotic plants in roles such as flood protection and riverbank stabilisation to native plants when the performance of these exotic ground-bioengineering systems have stood the test of time both in New Zealand and the countries in which they were invented.

As we move to address the reintroduction of native plants into our mangaged landscapes an issue that needs to be considered is that we do not continue to make the mistakes of the past and forget about the maintenance of the interventions we make. There has to be acceptance that there will be a requirement for weed and pest control, the possible culling of trees toppling towards stream channels, the possibility of thinning where plants are too close together, and also that suppression of podocarps by vigorous early-colonising plants is likely. The latter is critical if we wish to achieve a balanced mixture of shrubby and tall species, otherwise we could end up with native plantings that do not head on the expected natural trajectory that nature intends. We may need to devise planting systems that serve a range of functions rather than the "one-size-fits-all" approach that is currently focused largely on biodiversity enhancement. Ongoing maintenance becomes crucial in these systems to ensure the "trajectory is maintained towards the goal it is aiming for" (Fred Lichtwark, pers. comm.).

There is still a long way to go before we can reach into our toolbox and select a plant or a plant system to perform a particular bioengineering or E&SC function with any degree of confidence. For this to be realised, we will need to invest more in research and investigation, as well as find better ways to harness and share what we already know.

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