A Review of Site-Preparation, Fertilizer and Weeding Practices for Tropical Plantation Species with Recommendations for Whitewood (*Endospermum medullosum*) in Vanuatu

Author(s): R.G.B. Smith, K. Glencross, J.D. Nichols, J.C. Grant and M. Sethy
Source: International Forestry Review, 14(4):433-441. 2012.
Published By: Commonwealth Forestry Association
URL: http://www.bioone.org/doi/full/10.1505/146554812804715829

A review of site-preparation, fertilizer and weeding practices for tropical plantation species with recommendations for whitewood (*Endospermum medullosum*) in Vanuatu

R.G.B. SMITH[1], K. GLENCROSS[1], J.D. NICHOLS[1], J.C. GRANT[1] and M. SETHY[2]

[1]*Forest Research Centre, School of Environment, Science and Engineering, Southern Cross University, Lismore NSW Australia*
[2]*Department of Forests Vanuatu, Luganville, Santo, Vanuatu*

Email: smith.rgb@gmail.com

SUMMARY

The development of plantations with a new species, such as is occurring with the endemic tree *Endospermum medullosum* (whitewood) in Vanuatu, requires the resolution of appropriate establishment techniques. Site preparation, fertilisation and weed control have a very large impact on plantation productivity and represent major risks to plantation success. Establishment techniques for tropical species are reviewed and preliminary site preparation and fertilisation trials for whitewood reported. Trials were established at a site on Espiritu Santo island using available general purpose fertiliser with and without micronutrients at two rates. There was no effect of fertiliser over various rates of complete fertiliser with and without micronutrients, designed to provide adequate phosphorus in volcanic ash soils. Ripping had no significant effect on growth, however insufficient hand clearing of vegetation resulted in lower growth due to competition and complete machine clearing of vines results in high temperatures and decreased survival. A serious issue for whitewood establishment in single species plantations is weed management, especially vine control (*Merremia* spp). The time needed for weed control is influenced by initial planting density and spacing. When inter-planted with mixed gardens of food crops, weed control is not an issue due to more regular tending.

Keywords: plantation establishment, nutrition, ripping, Merremia peltata, seedling survival

Examen de la préparation des sites, des pratiques de fertilisation et de désherbage pour le essences de plantations tropicales, avec des recommendations pour le bois blanc (*Endospermum medullosum*) à Vanuatu

R.G.B. SMITH, K. GLENCROSS, J.D. NICHOLS, J.C. GRANT et M. SETHY

Le développement de plantations de nouvelles espèces, comme est la cas pour l'arbre endémique Endospermum Medullosum (bois blanc) à Vanuatu, nécessite une résolution de techniques d'établissement approppriées. La prépatation du site, la fertilisation et le contrôle des mauvaises herbes ont un impact important sur la production de la plantation et présentent des risques majeurs pour son succès. Les techniques d'établissement pour les essences tropicales sont examinées et des préparations de sites préliminaires ainsi que des essais de fertilisation pour le bois blanc sont notées. Les essais étaient établis sur un site sur l'île d'Espiritu Santo en utilisant les fertilisateurs généralement disponibles avec ou sans micro nutrients, créés pour fournir un phosphore adéquat dans les sols de cendres volcaniques. L'arrachement n'avait pas d'effet significatifs sur la croissance, mais un désherbage manuel insuffisant de la végétation résultait en une croissance plus faible dûe à la compétition; alors qu'un désherbage mécanique complet des vignes résultait en des températures trop élevées et une survie décrue. La gestion des mauvaises herbes, tout particulièrement le contrôle des vignes (Merremia spp) pose une question sérieuse pour l'établissement du bois blanc en plantations à espèce unique. Le temps requis pour le contrôle des mauvaises herbes est influencé par la densité et l'espacement initiaux de la plantation. Quant l'essence est plantée dans des jardins mixtes avec des récoltes alimentaires, le contrôle des mauvaises herbes n'est plus un problème du fait de la surveillance plus régulière.

Una revisión de las prácticas de preparación del sitio, fertilización y control de malezas para especies de plantaciones tropicales, con recomendaciones para madera blanca (*Endospermum medullosum*) en Vanuatu

R.G.B. SMITH, K. GLENCROSS, J.D. NICHOLS, J.C. GRANT y M. SETHY

El desarrollo de plantaciones con una nueva especie, como las del árbol endémico *Endospermum medullosum* (madera blanca) en Vanuatu, requiere técnicas de establecimiento adecuadas. La preparación del terreno, fertilización y control de malezas tienen un gran impacto en la productividad de las plantaciones y presentan riesgos importantes para su éxito. Se revisan diferentes técnicas de establecimiento de especies tropicales y se presentan resultados de ensayos preliminares de preparación del sitio y fertilización para madera blanca. Los ensayos se establecieron en un sitio en la isla de Espíritu Santo utilizando fertilizante genérico con y sin micronutrientes a dos niveles. No se encontró efecto alguno del fertilizante sobre las diferentes tasas de fertilizante completo con y sin micronutrientes, diseñado para proporcionar el fósforo adecuado en suelos de cenizas volcánicas. El uso de un escarificador no tuvo un efecto significativo sobre el crecimiento, mientras que una limpieza manual deficiente de la vegetación resultó en un menor crecimiento debido a la competencia y una limpieza mecanizada total de trepadoras se tradujo en altas temperaturas y menor supervivencia. Un grave problema en el establecimiento de plantaciones monoespecíficas de madera blanca es el control de malezas, y en particular de trepadoras *(Merremia* spp). El tiempo requerido para el control de malezas está relacionado con la densidad de plantación inicial y el espaciamiento. Cuando se planta en intercultivos de huertos mixtos de productos alimenticios, el control de malezas deja de ser un problema debido a recibir atención más regularmente.

INTRODUCTION

The first step in the establishment of a planted forest or plantation is ensuring the survival of the seedlings when transplanted into the field. This stage usually represents the greatest risk and requires large management inputs representing the majority of costs during a rotation. Tropical climates and landscapes are highly varied and tropical species have different requirements. Establishment silviculture must address species-specific requirements on particular site types. For species that have not previously been grown in plantations this requires development of silviculture protocols.

Establishment typically involves site preparation (cultivation), weed control and fertilisation, all of which can have a significant effect on successful establishment of planted forests. Whitewood (*Endospermum medullosum* L.S. Smith) is a species that requires adequate drainage and friable soils to grow very rapidly (Thompson 2006). Given these requirements for fertile and friable tropical sites, whitewood may be responsive to site preparation techniques, particularly cultivation and fertilisation.

Ripping is a mechanical cultivation technique that opens narrow channels into the subsoil to a depth of up to 1 m. Ripping to various depths has been demonstrated to greatly enhance survival rate, and more than double growth to age 19 months (Lacey *et al.* 2001, Graham *et al.* 2009). However ripping and cultivation may have little effect if existing uncultivated soil conditions are adequate (Smith *et al*. 2001, du Toit *et al*. 2010).

Two important and interrelated factors for plantation establishment are weed control and fertilisation. Most tropical soils are highly weathered, resulting in low levels of available nutrients (Lal 1997) and nutrient deficiencies can be asymptomatic (Webb *et al*. 2001). The application of fertilisers is the simplest method of ensuring an optimum supply of nutrients to plantations (Evans and Turnbull 2004). However different species responses to fertilisation can be complex and depend on soil fertility (Cameron *et al*. 1981, Webb *et al.* 2000).

Weed competition can develop rapidly and persistently in the tropics (Lowery *et al.* 1993,Graham *et al.* 2009). Control of weeds has been demonstrated to increase survival rates by up to 90% and volume growth by over 50% (Lowery *et al.* 1993). A review of long term studies in South Africa and Brazil showed increases in wood volume of 122% and 179% at harvest age of 29 and 10 years respectively, as a result of effective vegetation management (Wagner *et al*. 2006). The dominant weed species of most concern for plantation establishment in Vanuatu is *Merremia peltata*, a vigourous vine that covers large areas of potential plantation land and can cause significant damage to trees if not controlled.

We review literature on plantation establishment practices for tropical species relevant to whitewood and report preliminary results of silvicultural establishment trials undertaken in Vanuatu. We present results of ripping and fertiliser trials and discuss observations and literature relevant to establishment practices for planted whitewood forests in Vanuatu.

Literature review

Site preparation

Establishment of plantations requires some degree of site preparation and early maintenance to ensure high survival and rapid initial growth rates. Two operations in site preparation are clearing of existing vegetation and subsequent soil cultivation. The clearing of vegetation is undertaken by hand or by machinery. The aim is to remove sufficient existing vegetation to allow subsequent operations and reduce competition.

After planting areas are cleared, cultivation of soils is the next operation. Cultivation can reduce the bulk density of the soil and break up impermeable barriers (Goncalves *et al*. 2008) or high strength clay layers (Espinoza 2004), improving soil drainage and aeration and increasing downward penetration of juvenile roots (Goncalves *et al*. 2008, Evans and Turnbull 2004). Ripping is a mechanical cultivation technique that opens narrow channels into the subsoil to a depth of up to 1 m, but can also be used to shatter hard subsoil layers with the use of wings (Espinoza 2004). Ripping to various depths has been demonstrated to greatly enhance survival rate, and more than double growth to age 19 months (Lacey *et al.* 2001, Graham *et al*. 2009). However ripping and cultivation may have little effect if existing uncultivated soil conditions are adequate (Smith *et al*. 2001, du Toit *et al.* 2010). For instance, Costantini *et al*. (1995) reported a highly significant soil type by cultivation interaction. Improved growth response due to ripping was observed in hardsetting soils, but not in non-hardsetting soils. Evans and Turnbull (2004) also reported varied results due to cultivation on sites with differing initial characteristics. Where soils are heterogeneous within management units the decision to rip will depend on the area of each soil type. Lacey *et al.* (2001) found that on a site with heterogeneous soil types where ripping was both beneficial and not, the logistics of delineating the different soils and treating the areas as separate management units was more difficult and costly than applying a single ripping prescription across the whole area. On sites where soils are free draining and friable, conditions may be conducive to root development in young seedlings without the need for cultivation.

Weed control

Two important and interrelated factors of early plantation maintenance are (i) management of competing vegetation, and (ii) ensuring an optimum supply of nutrients (du Toit *et al*. 2010). Vegetation management is critical within those tropical plantations that demand an efficiency of wood production because weed competition can develop rapidly and persistently in the tropics (Lowery *et al.* 1993, Espinoza 2004, Otsamo *et al*. 1995). Early control of weeds in tropical plantations has been demonstrated to increase survival rates by up to 90% and volume growth by over 50% (as measured 2 years short of rotation length) (Lowery *et al.* 1993). A review of long term studies in South Africa and Brazil showed increases in wood volume of 122% and 179% at harvest age of 29 and 10 years respectively, as a result of effective vegetation management (Wagner *et al*. 2006). Weed competition can also influence wood properties (Watt 2009).

Within the tropics, weed control is commonly performed either manually or chemically. Manual weeding, using a machete or bushknife, can be performed with minimal training and requires minimal initial capital outlay, however ongoing labour costs can be high, and cutting weeds may provide only temporary control due to vigorous regrowth (see below for discussion of whitewood, Evans and Turnbull 2004). Chemical weed control with herbicides, if used effectively, may be superior to manual weeding (Lowery *et al.* 1993). For example, one chemical can be equal to three manual weeding operations (Anon 2001 cited in Evans and Turnbull 2004), and spot herbicide treatment increased the stem volume of *Eucalyptus grandis* by almost 50% when compared to manual weeding, but little difference between the two treatments was observed for *Pinus oocarpa* or *Gmelina arborea* (Lowery *et al.* 1993). Chemical treatments can be hazardous to health, and can damage crop trees or the surrounding environment if used inappropriately (Evans and Turnbull 2004). The problems of herbicide application are exacerbated in the tropics because the performance of some herbicides can be erratic and suitable application conditions may not occur for long periods (e.g. long periods of consistent wind or rain) (O'Gara 2010).

The use of chemical weed control may also result in high costs associated with training and supervision, to ensure appropriate use. Training and safety are particularly difficult for transfer to smallholders in the developing world. There are risks associated with use of imported chemicals: capital and equipment required may be unavailable, prices of chemicals and safety equipment may be much higher than in developed countries, and well developed supply chains to ensure chemicals are readily available may not be in place.

Weed control has two phases: control of ground weeds and clean and release operations (Evans and Turnbull 2004). Herbaceous and shrubby ground weeds will compete directly for sunlight, moisture and nutrients from time of planting. Control of ground weeds is required until the trees achieve site dominance at or near to canopy closure. Clean and release operations remove perennial vines, creepers and woody weeds that are likely to smother and kill young trees through their cumulative weight, shading and/or growth habit. Clean and release operations are particularly important for whitewood plantations in Vanuatu as fast growing exotic vine species, particularly *Merremia peltata*, can quickly smother young trees (Thomson 2006a), and can damage leaders beyond repair easily. Weed control within whitewood plantations must be performed for approximately the first 3 years, at a frequency of as little as every few weeks during the wet season (Thomson 2006a). Higher planting densities (closer spacing) can reduce weed control to shorter time frames. Four species tested in *Imperata* grasslands in Indonesia varied in the ability to suppress ground vegetation, but for all species there were significant linear relationships between closer tree spacing and reduced ground vegetation biomass (Otsamo 2002).

Initial spacing has been recommended at rates of 667–800 (Thomson 2006a), however higher rates may have advantages for lower cost and risks of establishment by reducing the long time of three years needed for tending. Some trials planted at 833 trees per hectare had achieved site capture by 2 years compared to 3 years at lower spacings. Some trial plots planted at 417 trees per hectare (a commonly used spacing on Santo, 8m × 3m) still required some tending at 3 years due to the very wide inter-row.

Higher stocking causes problems with unwillingness to thin (Glencross *et al* 2012). Successful alternatives to higher stockings of whitewood may be the use of interplanting with species for which there is a short term market. A preferred species for this purpose in many Pacific countries is *Flueggea flexuosa,* a tree that can be harvested as durable poles at an appropriate thinning age for whitewood (Thomson 2006a, b). This may also be effective in larger scale plantings.

Disruption to growth by weeds such as shrubs and grasses, in contrast to the case of vines, can be temporary if vegetation control is later restored. The risk of permanent damage from vines remains until canopy closure shades the vine growth. The amount of time to canopy closure is dependent on growth and spacing. As tree growth is relatively unaffected by spacing until trees approach canopy closure, spacing is the main determinant of the time to canopy closure. When evaluating the cost of extra trees against the cost of extra weed control events at wider spacings, consideration must also be given to the risk of damage from vines, risk from wind, as well as the wood quality benefits of closer spacing (see Glencross *et al.* 2012).

Cover crops

Weed control may be economically achieved using cover crops although this is not a commonly used technique (Lowery *et al.* 1993). Cover crops have been trialled for

Merremia control (Neil 1982), and have been trialled on Espiritu Santo island in whitewood (Vira 1992). Cover crops can be more economic than hand weeding where weeds that present different management problems take over after initial clearing. For example, after clearing of *Merremia* at Lorum, piko (*Solanum torvum*) became widely established across the site, presenting access and safety issues (due to thorns and wasps). When used as cover crops, particular families such as grasses and legumes have the advantage of being controllable with a selective herbicide. An alternative to cover cropping is a single species cash crop such as peanut. Intercropping can improve the growth of trees (Haggar *et al*. 2003, Dhyani and Tripathi 1999) as well as other economic and operational advantages; it allows wider initial spacing and so alleviates the need for thinning in the short term, provides short term returns to landholders or investors, and these early returns can offset costs of, and integrate operations needed for weed control and stand tending during the early years of plantation establishment. In contrast, if a forage cover crop were utilised, grazing would not be possible (due to possible tree damage from cattle) until approximately the time productivity (and weed problems) began to decline due to shading. Fencing would also be a major cost for some sites. Use of shade tolerant pastures later in the rotation may be another method to increase cash flow and control weed build-up, however light levels under whitewood at various stockings are unknown, and therefore the suitability for various pasture species are also currently unknown.

Merremia peltata

During the first year after planting of whitewood in Vanuatu, the hand tending of weeds at very productive sites was required at intervals as short as two weeks to ensure control of *Merremia* vine during the very active growing season. Even at such high frequencies of manual weed control there was damage from *Merremia* in some experimental plantings. This occurred where vines deformed tree leaders and tree boles became severely distorted. Once vines are in trees and near tree foliage, vine control is best achieved by manual methods, as spray drift can easily damage trees and represents a high risk. *Merremia* is shade intolerant so once site capture is achieved or trees are tall enough risk is reduced. In fact forestry has been suggested as a strategy for managing *Merremia* by shading it out (Kirkham 2004).

In pastoral systems *Merremia* can be controlled by cattle and herbicides (Anon 1993). Good palatability means grazing can be used as an economic technique in reducing cover in pasture cover crop or tree establishment (Anon 1993). In sites where fencing is not established this may not be economic. Biocontrol of *Merremia* may be another possibility. There are issues concerning the status of Merremia as an exotic or native species in different countries. Ecological studies of *Merremia* suggest it plays a role in maintaining diversity after disturbance events such as cyclones (Kirkham 2004). However a fungicide biocontrol agent developed from a naturally occurring fungus would be neither invasive nor detrimental (to *Merremia*) in non-target areas (Paynter *et al.* 2006).

Fertilisation

Most tropical soils are highly weathered, resulting in low levels of available nutrients (Lal 1997) and nutrient deficiencies can be asymptomatic (Webb *et al*. 2001). The problem is exacerbated in intensively managed plantations that lose nutrients to each successive rotation (Powers 1999, Mackensen and Folster 2000, Gonçalves *et al*. 2008). This is less of a problem with longer rotations for solid wood products such as whitewood compared to short rotations of less than 10 years (Goncalves *et al.* 2008, Smethurst 2010). The application of fertilisers is the simplest method of ensuring an optimum supply of nutrients to plantations (Evans and Turnbull 2004), although there is a risk that fertiliser, if applied incorrectly can benefit weeds rather than crop trees and therefore actually be detrimental to plantation establishment.

For long rotation crops overall productivity will be largely determined by inherent site quality (West 2006, Grant *et al*. 2012a), but nutrient additions can be useful at establishment to accelerate growth of seedlings that are not yet able to exploit site soil resources efficiently (du Toit *et al*. 2010). Rapid early growth is important in competing with weeds up until canopy closure, after which nutrients are recycled (Binkley *et al*. 1997) and competing vegetation is shaded out. In some cases small additions of nutrients can dramatically increase growth.

Growth responses to the addition of nutrients will vary depending on inherent soil fertility and the nutrient requirements of different species (Evans and Turnbull 2004, Webb *et al*. 2000, Ogbonnaya and Kinako 1999, Otsamo *et al*. 1997, du Toit *et al*. 2010). Species responses to fertilisation can be complex. For example, in Australia, improved growth of *Pinus caribaea* var. *hondurensis* due to the addition of several nutrients was only observed if the requirements for phosphorous had been satisfied, with some nutrients causing negative growth response when applied without phosphorous (Cameron *et al*. 1981). In a study on the growth response of four tropical plantation timber species to the addition of phosphorous, Webb *et al*. (2000) observed a strong growth response in two of the species (*Cedrela odorata* and *Agathis robusta*), but little or no response in the other two species (*Flindersia breyleyana* and *Castanospermum australe*). Similarly, Otsamo (1997) observed response in only some of four species when NPK fertiliser was applied at 1 month and 1 year after planting in Imperata grasslands. Boron is often deficient in soils derived from volcanic ash (Ladrach 1992, Grant *et al* this volume), as is the case in Vanuatu. Boron is important in structural aspects of plant growth and has been shown to be important in disease resistance in eucalypts (Smith 2007).

Supply of nutrients through the use of fertiliser treatments is costly (Evans and Turnbull 2004, Mackensen *et al.* 2000), and may result in neutral or even negative growth response (Dell *et al.* 2001). Multiple field trials are required to determine growth responses to particular nutrients, and whether these growth responses render fertilising economically worthwhile (Webb *et al.* 2001, Evans and Turnbull 2004, Smethurst 2010). As with herbicides, fertiliser may not be available in some countries or areas and laboratory facilities for soil and foliar analysis are even less available, making diagnostic tests difficult.

Time of planting

Tropical plantations are often established in climates with a dry season. In these climates planting is best undertaken at the start of the rainy season, allowing maximum opportunity for trees to become established under ideal growing conditions (Ladrach 1992). However, around the onset of the rain season can include periods of high temperatures in between patches of rain. If planting is undertaken at the start of the rainy season then seedlings are also most vulnerable at this time. Therefore there are risks of drought periods and high temperatures causing heat stress and transplant shock. High temperatures are exacerbated by dark organic surface soil layers, such as those on Santo, especially when areas are completely cleared. Partial clearing therefore provides some protection.

While the risk of dry periods and high temperatures are difficult to predict, survival can be enhanced by planting drought-hardened seedlings (Thomas 2009) or use of watering or gels to reduce transplant shock (Thomas 2008). The converse of rapid onset of rains can also present difficulties. Operations such as ripping and cultivation require soil moisture contents to be adequate (but not excessive) and therefore must take place after the onset of rainfall. Preparation and planting must be complete before site access becomes difficult due to excess rain.

METHODS

Site description: Lorum

The trial site was located at Shark Bay in north east Santo Island. It was a large contiguous area largely covered in *Merremia peltata*, with little woody vegetation or other weeds. The intention was that lines would be cleared by bulldozer but the presence of interconnecting vines meant that much of the site was almost completely cleared and windrowed. Ripping only took place in a very small area (see below the ripping trial). The site was cleared by bulldozer and trials were laid out and plots marked in September, and planted in October 2008 using containerised seedlings grown from locally collected unimproved seed. Weeding began two weeks after planting and continued at intervals of several weeks for two years. Infill planting necessary due to mortality (due to high temperatures) was undertaken in December 2008 using the same batch of plants that had been grown on to larger containers. Fertiliser treatments were applied in late January 2009. A representative soil was described and sampled from a soil pit (down to coral, Table 1) according to standards defined by the National Committee on Soil and Terrain (2009). Reaction to NaF (Fieldes and Perrot 1966) was recorded as an indicator of phosphorus sorption levels (Alves and Lavorenti 2004). Colour was Munsell (2000). More detailed site and soil descriptions are given in Grant *et al*. (2012b) and Glencross *et al*. (2012)

Site preparation trial

A trial comparing growth of ripped versus unripped plots (30 m by 30 m) in two replicate blocks at Lorum was established and height growth and survival compared after 1 and 2 years. The ripping treatments were arranged in a complete randomised block design with one plot in each pair randomly selected for ripping.

Several different techniques of site clearing were used to establish trial plantings at other locations during 2008 (Glencross *et al*. 2012). Observations revealed several important aspects for successful and efficient establishment of whitewood. Each of the following methods of site preparation was used in establishing different trials: a bulldozer cleared large areas at Lorum to establish a large plot silvicultural regime trial; bulldozer cleared 2 metre wide strips within scrub at 8 metre spacing between strips; hand cleared areas in gardens; and hand cleared areas in scrub.

Establishment fertiliser trial

Most soils suitable for whitewood on Santo were thought to be likely phosphorus deficient as they are commonly strongly phosphorus-fixing (Grant *et al*. 2012). Initial establishment of whitewood trials had been successful without fertiliser, and no information was available about whitewood nutrition, therefore establishment fertiliser treatments of a complete general purpose fertiliser with and without micronutrients were applied to test for accelerated early growth. Only one general purpose fertiliser was available locally. Laboratory facilities for soil and foliar analysis are even less available, making diagnostic tests difficult. Therefore an approach that

TABLE 1 *Lorum soil pit description*

Horizon; depth; colour; texture/structure; pH; reaction
A1, 0–3cm, very dark brown (7.5YR2.5/2) loam, with strong fine granular structure, field pH 6.0.
A3, 3–18, dark brown (7.5YR3/3) clay loam with moderate fine angular blocky structure, field pH 6.0, very weak reaction to NaF
B1, 18–38, dark brown (7.5YR3/4) clay loam with moderate fine angular blocky structure, field pH 6.0, very weak reaction to NaF
B2, 38–65, dark brown (7.5YR3/4) heavy clay loam with moderate fine angular blocky structure, field pH 6.0, weak reaction to NaF
BC, 65 90+, Coral substrate with some penetration by B2 material field pH 9.0.

*Well drained soils. Field texture is underestimating the clay content in these subplastic soils.

uses several levels of a general purpose complete fertiliser was considered most appropriate initially. Boron is often deficient in soils derived from volcanic ash (Ladrach 1992, Grant *et al* this volume). Boron is important in structural aspects of plant growth and has been shown to be important in disease resistance in eucalypts (Smith 2007). Also a soil analysis was undertaken at Lorum (Appendix A). Phosphorus was indicated as possibly low as well as B and Zn. The treatments used the only available fertiliser on Santo called Crop King. A micronutrient mix was also added that was imported for the trial.

Crop King is 12% N, 12% P, 17% K + 2.5% Mg + 0.3% B. It was applied at 50gm per tree (single fertiliser treatment) to get 6g P per tree, which is broadly recommended for plantations. Micronutrients were applied as 0.23gm elemental Zn (as zinc sulphate heptahydrate) and 0.06g of elemental B (as borate) per tree (plus the additional B in the Crop King). The double treatment used two times the Crop King rate, with or without the micronutrients (Table 2). Fertiliser was applied on the soil surface 15cm from the base of the tree on the downhill side after infill planting took place. The trial used a complete randomised design with 4 replicates of each treatment.

Statistical analysis

Differences in average tree height and average tree DBH per plot up to age 3 in the fertiliser trial were analysed using ANOVA. Differences in average tree height per plot in the ripping trial were assessed using a t-test.

RESULTS AND DISCUSSION

Site preparation

There was no significant effect of ripping on growth (mean height at age 1 was 1.44m ripped and 1.57m control; t_1 = –0.94, p=0.26) or survival (mean survival at age 1 was 84% ripped and 81% control; t_1 = –0.38, p=0.36). This is in accord with several authors who found ripping and cultivation may have little effect if existing uncultivated soil conditions are adequate (Smith *et al*. 2001, du Toit *et al*. 2010, Costantini *et al*. 1995, Evans and Turnbull 2004)

An additional consequence of mechanical clearing and ripping on sites where vines such as merremia are a common weed species, was that large areas of soil become exposed. At Lorum where large open areas were cleared using mechanical methods there was mortality, thought to be due to heat stress, particularly the exposure of the dark soils to intense sun, desiccation and the resulting high temperatures on young newly planted whitewood seedlings. It appears that some vegetation left between rows acts to protect seedlings from high temperatures and wind.

At the other extreme, at sites where very low impact site preparation techniques were applied, tree growth was observed to be adversely affected by high levels of competition from surrounding vegetation. One site that used hand clearing around young trees, suffered reduced growth and high mortality from competition as the weeds and remnant woody vegetation was not cleared sufficiently far from planted trees. These observations indicate that a balance needs to be struck during the establishment phase, between complete removal of vegetation resulting in excessive exposure and insufficient removal resulting in excessive competition.

TABLE 2 *TABLE 2 Fertiliser treatments* applied at Lorum trial site Shark Bay*

Code	Treatment
NoFert	No fertiliser
CK50	Crop King 50 gm/tree
CK50+	Crop King 50 gm/tree + micro
CK100+	Crop King 100 gm/tree + micro

* Crop King is 12% N, 12% P, 17% K + 2.5% Mg + 0.3% B.
Micro is 0.23 gm elemental Zn (as zinc sulphate heptahydrate) and 0.06g of elemental B (as borate) per tree.

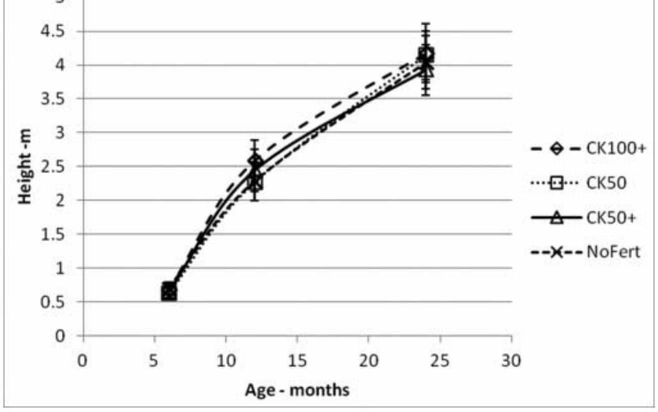
Fertiliser

There was no significant difference in growth between any fertiliser treatments up to 2 years old (Figure 1) (ANOVA: height 2 yrs - $F_{3,23}$ 0.191. p=0.901; DBH 2 yrs - $F_{3,23}$ 0.3845, p=0.765). It is possible that some fertiliser was washed away as it was placed on the soil surface, however the soils are very well structured and infiltration was very good. Soils have not been used for mechanised agriculture and the site had lain fallow for some time, therefore nutrient levels are unlikely to have been depleted. It is possible that competing vegetation took up some of the fertiliser applied, however growth rates were reasonable given the level of silviculture with unimproved seed and were similar across sites (Glencross *et al*. 2012).

CONCLUSIONS

Ripping and fertilisation had no impact on early survival or growth of whitewood. Soils fertility and structure appear

FIGURE 1 *Relative height growth for fertiliser treatments. Error bars are standard errors*



adequate for achieving moderate growth rates with no augmentation. The site quality of all available land for plantation development on Santo appears to be of a similar quality (Grant *et al*. 2012b) which is an advantage for the establishment of whitewood. Minimal costs for establishment will translate into profitable plantation development. More work is required to quantify the optimum level of vegetation removal and management under various site situations, especially Merremia, as this was observed to be important in plantation survival and growth.

ACKNOWLEDGEMENTS

This work was supported by ACIAR project FST/2005/089 Improved silvicultural management of *Endospermum medullosum* (whitewood) for enhanced plantation forestry outcomes in Vanuatu. We would like to thank all those who assisted with this work. Two anonymous referees made suggestions that helped to improve earlier drafts substantially.

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APPENDIX 1

	Nutrient		Units	*A1053/1*	*A1053/2*
Soluble Tests & Morgan 1 Extract	Calcium	Ca	ppm	1102	965
	Magnesium	Mg	ppm	162	114
	Potassium	K	ppm	350	247
	Phosphorus (Morgan)	P	ppm	0.2	0.1
	Phosphorus (Bray 1)	P	ppm	1	1
Soluble Tests & Colwell + Bray 2 Phoshorus Extract	Phosphorus (Colwell)	P	ppm	40	29
	Phosphorus (Bray 2)	P	ppm	13	5
	Sulphate Sulphur	S	ppm	30	31
	pH (1:5 water)		units	6.00	5.91
	Conductivity (1:5 water)		μS/cm	181	123
	Organic Matter		%	9.32	6.44
Ammonium Acetate Equiv. Extract	Calcium	Ca	$cmol^+/Kg$	18.98	10.64
	Magnesium	Mg	$cmol^+/Kg$	2.97	1.50
	Potassium	K	$cmol^+/Kg$	1.80	0.98
	Sodium	Na	$cmol^+/Kg$	0.10	0.08
	Aluminium	Al	$cmol^+/Kg$	0.01	0.00
Acidity Titration	Hydrogen	H^+	$cmol^+/Kg$	0.18	0.13
	Cation Exchange Capacity		$cmol^+/Kg$	24.04	13.33
Percent Base Saturation	Calcium	Ca	%	79.0	79.8
	Magnesium	Mg	%	12.4	11.2
	Potassium	K	%	7.5	7.4
	Sodium	Na	%	0.4	0.6
	Aluminium	Al	%	0.02	0.000
	Hydrogen	H+	%	0.7	1.0
	Calcium/ Magnesium Ratio		ratio	6.39	7.10
	K:Mg		ratio	0.60	
Micronutrients-DTPA +Hot $CaCl_2$ Extracts	Zinc	Zn	ppm	2.6	1.8
	Manganese	Mn	ppm	129.1	43.8
	Iron	Fe	ppm	69.5	40.6
	Copper	Cu	ppm	10.6	5.6
	Boron	B	ppm	0.22	0.13
$CaCl_2$ Extract	Silicon	Si	ppm	19.7	15.2
Total Nutrients	Total Carbon	C	%	5.33	3.68
	Total Nitrogen	N	%	0.60	0.41
	Carbon/ Nitrogen Ratio		ratio	8.8	9.0
	Approx clay content			32.5	40
	base status			73.4	33.0
	base status			Eutrophic	Eutrophic
	base saturation (with ECEC)			99.2	99.0