Radiata Pine Young Age Fertiliser Response Prediction Tool for the Green Triangle Region.

December 2010

This report was prepared by
ForestrySA
for
Primary Industries and Resources South Australia.

For further information please contact

Information Officer
PIRSA Forestry
Email pirsaforestry@sa.gov.au
Phone (08) 8735 1232
Fax (08) 8723 1941

Government of South Australia
Primary Industries and Resources SA

ForestrySA

Radiata Pine Young Age Fertiliser Response Prediction Tool for the Green Triangle Region.

December 2010

SUMMARY

AIM

To produce a fertiliser response prediction tool for young age radiata pine plantations in the Green Triangle Region of South Australia and Western Victoria based on soil type, stand density and rainfall zone.

BACKGROUND

ForestrySA aims to grow all of its plantations in the Green Triangle region to a minimum productivity standard of Site Quality (SQ) III (Lewis *et al* 1976). As part of achieving this aim fertiliser is applied to selected plantations at age 3 and 4 years based upon the results from a young age growth monitoring program (Cameron 1993-1995) (Richardson 1996-2009). The young age growth plot monitoring program began in 1985 with measurements of areas in the Caroline fire replant.

Since 1985 the growth model used to assess young age growth performance has been revised and refined three times using data from the growth plots themselves and research trials such as LT145 *Long-term Growth Response to Patterns of Weed Control in Radiata Pine* (Shaw, Mattay, and Adams, 2002). The model uses the inputs of basal area /ha (BA/HA) and predominant height (PDH, 75 tallest/ha) to produce a minimum SQ III growth curve which is plotted against plantation age. By combining these data inputs and using a simple conic volume equation (0.35 X BA/HA X PDH) it is possible to present the data as a single Total Stem Volume (TSV) (m^3/ha) figure which can be compared to a minimum SQ III TSV for the given age. Plantation areas which fall below the minimum SQ III line at age 2.5 and 3.5 years are given priority for young age fertiliser treatment. While the young age growth plot program is very effective in identifying plantation areas which are below the minimum growth standard it can not predict if the application of fertiliser will produce the required growth response.

EM188A was an investigation study using data from the ForestrySA young age growth plot measurement program, fertiliser records, the bureau of meteorology 30 year average rainfall isohyets and the ForestrySA GIS soils and site productivity geographic data bases aimed at producing a young age fertiliser response prediction tool.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations contained within this report are based upon the best information available at the time of its drafting and form a baseline from which the model for young age fertiliser response in radiata pine can be further developed. Predicting if an economic fertiliser response will be achieved can be a very imprecise science due to the large number of potential inputs and their interactions. What is clear is that the productivity of plantations in the Green Triangle Region is driven by planting stock survival and young age getaway growth.

If radiata pine and Tasmanian blue gum plantations have favourable growing conditions during the establishment phase up until the time of canopy closure they will continue to grow strongly until the limit of growth potential based upon the site factors of climate, soil water availability, drainage, rooting depth and nutrient availability is reached. This is particularly critical with Tasmanian blue

gum which has not proven to have the ability to grow on strongly if retarded during the first six months following planting. Radiata pine has the ability to respond if site conditions improve and can react favourably to the removal of site limiting factors. Any growth response will be dependent upon what the key limiting factor is. If the primary limiting factor is removed or ameliorated the next most limiting factor will become the new primary limiting factor and dictate the level of productivity achievable.

The key factors which impact on seedling survival and early growth in South Eastern Australia are as follows:

- **Rainfall**: Drives soil moisture availability which is the number one factor influencing growth.
- **Weed Control**: Is essential to optimise soil moisture availability and reduce competition for light and nutrients.
- **Planting Quality & Timing**: Poor planting technique or timing can significantly impact on tree survival as seen in the results of the ForestrySA research trial EP240 (Thomas 2009).
- **Soil Depth**: A key factor for determining water holding capacity/availability, rooting depth, drainage and potential nutrient availability.
- **Drainage**: Impacts on soil moisture relations. Excessive drainage and soil moisture availability can be reduced during the critical drought months and too little will impact on fine root survival (drowning) and nutrient availability (cold soil conditions restricting nutrient mobility and uptake).
- **Soil Temperature**: Linked to plant growth and both micro and macro nutrient mobility.
- **Inherent soil fertility**: pH, cation exchange capacity, soil carbon etc.
- **Plant Genetics**: To the extent that genotype by environment (GxE) interactions are both important and understood, planting the wrong genotypes in a particular soil type or climatic zone may lead to poorer growth and survival.

The addition of supplementary nutrition in the form of granular fertiliser will not economically improve productivity if:

- Low nutrition is not the primary limiting factor to growth
- There is inadequate rainfall to drive an economic fertiliser response.
- There is inadequate soil depth to hold enough soil moisture to promote tree growth.
- Soil drainage is impeded to the extent that it restricts fine root growth (and, or reduces soil temperature impacting on nutrient mobility) or is so free that soil moisture cannot be retained within rooting depth.

All of these soil and site characteristics have been considered for each identified soil type and incorporated into the recommendations of the fertiliser prediction tool.

Radiata Pine Young Age Fertiliser Response Prediction Tool for the Green Triangle Region.

AIM

To produce a fertiliser response prediction tool for young age radiata pine plantations in the Green Triangle Region of South Australia and Western Victoria based on soil type, stand density and rainfall zone.

BACKGROUND

ForestrySA aims to grow all of its plantations in the Green Triangle region to a minimum productivity standard of Site Quality (SQ) III (Lewis *et al,* 1976). As part of achieving this aim fertiliser is applied to selected plantations at age 3 and 4 years based upon the results from a young age growth monitoring program (Cameron 1993-1995) (Richardson 1996-2009). The young age growth plot monitoring program began in 1985 with measurements of areas in the Caroline fire replant.

Since 1985 the growth model used to assess young age growth performance has been revised and refined three times using data from the growth plots themselves and research trials such as LT145 *Long-term Growth Response to Patterns of Weed Control in Radiata Pine* (Shaw *et al*., 2002). The model uses the inputs of basal area /ha (BA/HA) and predominant height (PDH, 75 tallest/ha) to produce a minimum SQ III growth curve which is plotted against plantation age. By combining these data inputs and using a simple conic volume equation (0.35 X BA/HA X PDH) it is possible to present the data as a single Total Stem Volume (TSV) (m3/ha) figure which can be compared to a minimum SQ III TSV for the given age. Plantation areas which fall below the minimum SQ III line at age 2.5 and 3.5 years are given priority for young age fertiliser treatment. While the young age growth plot program is very effective in identifying plantation areas which are below the minimum growth standard it can not predict if the application of fertiliser will produce the required growth response.

EM188A is an investigation study using data from the ForestrySA young age growth plot measurement program, fertiliser records, the bureau of meteorology 30 year average rainfall isohyets and the ForestrySA GIS soils and site productivity geographic data bases aimed at producing a young age fertiliser response prediction tool.

FORMULATING THE FERTILISER RESPONSE PREDICTION MODEL

The conclusions and recommendations contained within this report are based upon the best information available at the time of its drafting and form a baseline from which the model for young age fertiliser response in radiata pine can be further developed. Predicting if an economic fertiliser response will be achieved can be a very imprecise science due to the large number of potential inputs and their interactions. What is clear is that the productivity of plantations in the Green Triangle Region is driven by planting stock survival and young age getaway growth. If radiata pine and Tasmanian blue gum plantations have favourable growing conditions during the establishment phase up until the time of canopy closure they will continue to grow strongly until the limit of growth potential based upon the site factors of climate, soil water availability, drainage, rooting depth and nutrient availability is reached. This is particularly critical with Tasmanian blue gum which has not proven to have the ability to grow on strongly if retarded during the first six months following planting. Radiata pine has the ability to respond if site conditions improve and can react favourably to the removal of site limiting factors. Any growth response will be dependent upon what the key limiting factor is. If the primary limiting factor is removed or ameliorated the next most limiting factor will become the new primary limiting factor and dictate the level of productivity achievable.

The key factors which impact on seedling survival and early growth in South Eastern Australia are as follows:

- **Rainfall**: Drives soil moisture availability which is the number one factor influencing growth.
- **Weed Control**: Is essential to optimise soil moisture availability and reduce competition for light and nutrients.
- **Planting Quality & Timing**: Poor planting technique or timing can significantly impact on tree survival as seen in the results of the ForestrySA research trial EP240 (Thomas 2009).
- **Soil Depth**: A key factor for determining water holding capacity/availability, rooting depth, drainage and potential nutrient availability.
- **Drainage**: Impacts on soil moisture relations. Excessive drainage and soil moisture availability can be reduced during the critical drought months and too little will impact on fine root survival (drowning) and nutrient availability (cold soil conditions restricting nutrient mobility and uptake).
- **Soil Temperature**: Linked to plant growth and both micro and macro nutrient mobility.
- **Inherent soil fertility**: pH, cation exchange capacity, soil carbon etc.
- **Plant Genetics**: To the extent that genotype by environment (GxE) interactions are both important and understood, planting the wrong genotypes in a particular soil type or climatic zone may lead to poorer growth and survival.

The addition of supplementary nutrition in the form of granular fertiliser will not economically improve productivity if;

- Low nutrition is not the primary limiting factor to growth
- There is inadequate rainfall to drive an economic fertiliser response.
- There is inadequate soil depth to hold enough soil moisture to promote tree growth.
- Soil drainage is impeded to the extent that it restricts fine root growth (and, or reduces soil temperature impacting on nutrient mobility) or is so free that soil moisture can not be retained within rooting depth.

All of these soil and site characteristics have been considered for each identified soil type and incorporated into the recommendations of the fertiliser prediction tool.

LIMITATIONS OF THE TOOL

The Young Age Fertiliser Response Prediction Tool is designed to be an aid to forest managers when considering young age fertiliser decisions and **should not be considered an absolute or definitive response predictor**. The information used to compile this report has not been taken from purpose designed young age fertiliser trials though the results from 7 young age fertiliser trials with Tasmanian blue gum and 5 young age fertiliser trials with radiata pine conducted since 1990 have been incorporated. The use of only two consecutive years measurements from growth plots (plus where possible stand based age 9.5 year site quality assessments), the range of fertiliser products used from ammonium sulphate based Forest Starter Mix (FSM) and Forest Mix 4 (FM4) with trace elements to DAP Urea as 32:10:0 or 38:6:0 N & P without trace elements and the impacts of sustained drought during the period over which the growth plot data has been collected, all put considerable noise into the data analysis and **would limit the robustness of the conclusions if based purely on results from growth plot data**. In order to increase the robustness of the model extensive knowledge and experience gathered since the first radiata pine plantings in the 1870s in the Green Triangle region of the impacts of soil characteristics in conjunction with rainfall on potential growth responses, with or without the addition of fertiliser have been included in the modelling process. The Young Age Fertiliser Response Prediction Tool incorporates the cumulative knowledge of over 130 years of continuous radiata pine plantation management by a single entity which has a dedicated scientific research program to formulate and maintain worlds best practice plantation management.

The tool does not distinguish between the type of granular fertiliser used, the rate or the timing of application whether it is at age 2 years, 2.5, 3.5 or 4 years of age.

The tool does not consider the effectiveness of foliar applications of Cu, Zn or B to remediate form problems and is not designed to be used post thinning.

The tool does not provide advice on the type of fertiliser required as the young age growth plot program which it is designed to support does not target specific nutrient deficiencies but is a current best practice N & P based fertiliser program which relies on the recommendations from the ForestrySA Plantation Forestry Manual, 2007 (*Chapter 4 Nutrition*).

STRENGTHS OF THE TOOL

The growth plot data used to compile this tool have been collected over a 13 year period and cover all soil types, rainfall zones and plantation forest districts in South Australia and Western Victoria where ForestrySA has a presence. Data has been used from 1649 individual growth plots designed specifically to measure young age growth and gauge potential growth responses to the application of granular fertiliser. This data has been combined with a robust soil identification and classification system which has been the standard for the radiata pine industry in the Green Triangle Region since 1941 and is used by ForestrySA, Green Triangle Forest Products and Gunns (Auspine). This is backed up by a comprehensive GIS based soils layer which incorporates both the original Stephens 1941 soils data and all current era soil surveys which have been ground truthed and checked between 2007 and 2010 using the latest GPS technology and aerial photos. Readily identifiable soil characteristics and mean rainfall associated with specific soils have been incorporated into the model as an adjunct to the growth plot measurement results. This adds a significant level of robustness to the model to help compensate for the noise in the data set from the limitations associated with the growth plot data.

SOUTH AUSTRALIAN RADIATA PINE SITE QUALITY ASSESSMENT

The site quality assessment system as used in South Australia rates the productivity of a site in terms of the wood produced. South Australia uses seven site quality assessment classes to stratify radiata pine stands. Each site quality (SQ), from I to VII encompasses stands whose growth trends in wood volume are, and will remain similar for the length of the rotation. The relationships of the site qualities and their trends are shown in Figure 1 which shows the yield curves for total wood production volume (m3/ha) to 10 cm log assortment to specific ages.

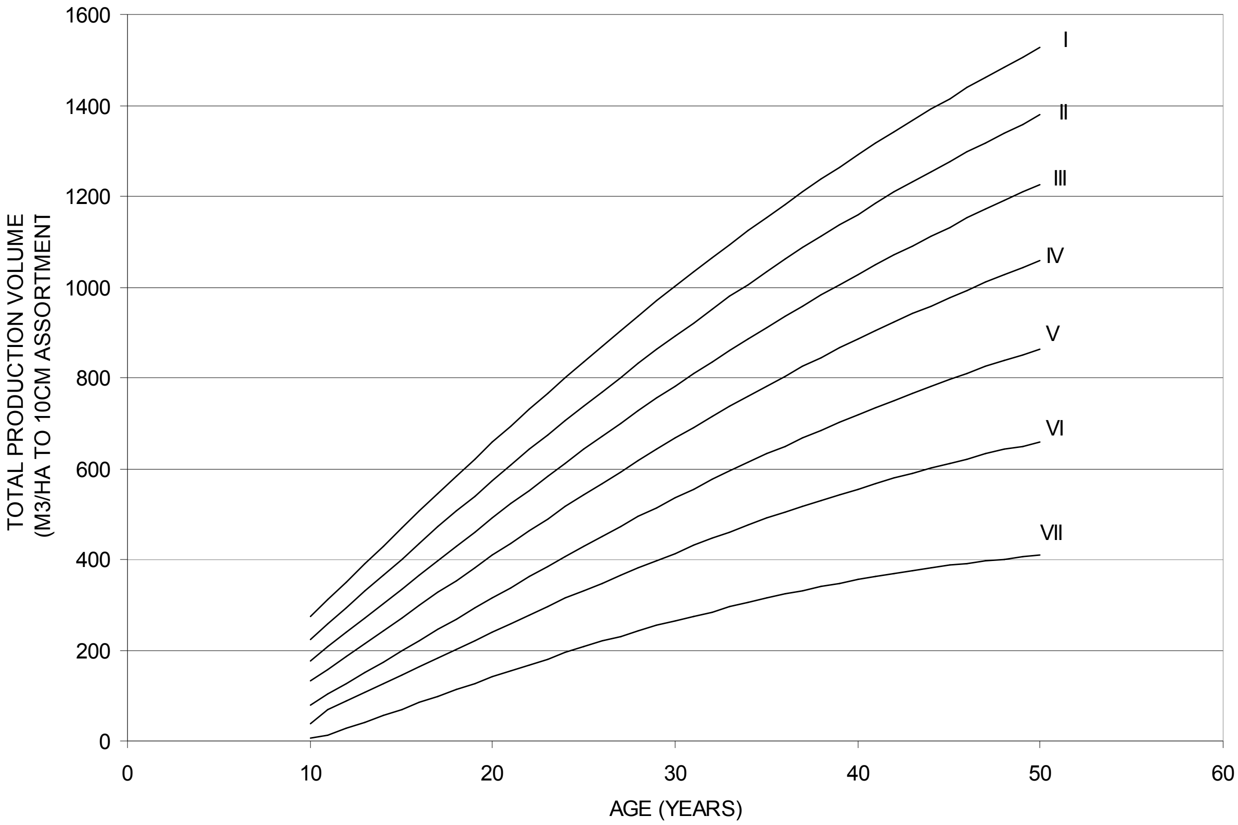

Figure 1. **Radiata pine total production volume (m3/ha) to 10 cm log assortment site quality curves.**

DATA USED

Plot Measurement Data

Prior to 1993 young age growth plots were managed by individual forest districts. Measurements were collected, analysed and interpreted by district staff with minimal input from the Research Section. Few recoverable records exist from this period. ForestrySA has very good records from 1995 onwards (1993 – 2006 plantations) and therefore data collected prior to 1995 has been excluded from this report. Since 1993 the Research Section has actively managed the collection, analysis, storage and interpretation of data for the young age growth plot program, as well as providing software, hardware, training and quality control checks for the measurement process. Data collected from 1993 onwards has been subjected to a series of quality checks starting from field collection through to the production of the annual growth plot report.

Growth plots are established at a rate of 1 per 10 – 20 ha depending upon a number of factors including weed control and soil type. In practice they are established at a rate of 1 - 2 per compartment with the exception of very small planting areas (generally 5 ha or less) which may have no plots established. Quality checks on field measurements are conducted at a minimum rate of 1 plot per forest locality[1] per plantation year which provides for an average checking rate of 15% of all plots established. Plot measurement data collected includes plot dimensions (area), stand density (live stocking/ha), BA/HA[2] and PDH[3]. The location of each individual measurement plot is surveyed and recorded on the ForestrySA GIS corporate spatial data base. Since the 2008/2009

[1] A forest locality is a plantation unit of approximately 200 to 300 ha with defined boundaries based upon historical land purchases, road boundaries or effective management units. Each forest locality has a unique name and number for operational identification. A forest locality may be of a single age class or contain compartments of various ages.

[2] BA/HA the area in m^2 of the cross-section of tree stems, including bark measured at 1.3 metres above ground level (breast height), over 1 hectare of land.

[3] Predominant height, or PDH, is a measure of stand height calculated as the mean height of the 75 tallest trees per hectare

measurement season soil identification (a single soil hole per growth plot) and soil pH and EC (ds/m) have also been recorded. This soil data is being used to confirm the accuracy of the ForestrySA GIS soils spatial data base, to assist with the fertiliser response model development and to assess the potential fertiliser response probability.

Fertiliser Records

Records of all ForestrySA fertiliser applications in the Green Triangle Region from 1993 to 2009 have been accessed and used in this analysis. Fertiliser records include the fertiliser type, rate, method and timing of application at the compartment level.

Rainfall Data

The Australian Bureau of Meteorology (2008) 30 Year Average Rainfall Isohyets have been used in combination with the ForestrySA GIS spatial data base to allocate a rainfall index to each individual measured young age growth plot. As the Bureau of Meteorology data supplied is of a course nature rainfall zones of 50 mm per annum range e.g. 750 – 800 mm have been used.

Soil Data

Soil type for each individual growth plot has been allocated from the ForestrySA GIS soils data base or from soil identification holes in individual measurement plots. The ForestrySA GIS soils data base is a composite of the Stephens *et al* 1941 soil survey (CSIRO Bulletin No 142) and soil surveys conducted by the ForestrySA Research Section. Almost the entire ForestrySA land base in the Green Triangle Region has been field checked for soil identification and boundaries between 2007 and 2010 to confirm the validity of both the original Stephens soil survey and subsequent ForestrySA soil surveys. Stephens used the international Great Soil Groups to identify and classify soils and this methodology has been maintained for continuity rather than convert the soil data to the Australian Soils Classification System (Isbell 1996) which is not in common use for forestry in the Green Triangle Region. Soils have been identified using three regionally specific references, these being; CSIRO Bulletin No 142, A study of the Land in South Western Victoria (Gibbons and Downs 1964) and Green Triangle Forest Soil Profiles (Winkley and Richardson 2003).

A summary of the current identified soil types on ForestrySA land in the Green Triangle by area and percentage of the estate is listed in *Table 1.*

METHODOLOGY

A total of 1771 growth plots were reviewed during this investigation. A total of 1649 have been used to develop the Fertiliser Prediction Tool. Measurement plots excluded (129), due to a lack of data, include those that were destroyed in a wildfire, discontinued after their initial measurement (not representative, well above the SQ III aiming point at age 2.5 years, abandoned due to excessive drought or drowning deaths) or have yet to receive an age 3.5 measurement (2006 plantations). The methodology for compiling and assessing the data collected is listed below. A summary of the results is presented in *Tables 2 and 3*.

1. All of the ForestrySA young age growth plots established between 1995/1996 (1993 plantations) and 2008/2009 (2005 plantations) were geographically located on the ForestrySA GIS data base and rainfall zone, soil type and site quality (stand productivity) where assessed were allocated to each plot.
2. Fertiliser records for each individual compartment in the Green Triangle Region were reviewed and a fertiliser history by age, rate (tons/ha or grams/tree) and form (Forest Starter Mix, Forest Mix 4, DAP Urea 38:6:0 or 32:10:0.) was assigned to each growth plot.

Table 1. **Summary of ForestrySA soils (GT) by area (ha) and percentage of land base.**

SOIL IDENTIFICATION	**AREA (ha)**	**PERCENTAGE OF ESTATE**
MOUNT BURR SAND	13780.4	13.810%
CAROLINE SAND	11856.9	11.882%
YOUNG SAND	9836.7	9.858%
NANGWARRY SAND	7720.0	7.737%
HINDMARSH SANDY LOAM	6640.4	6.655%
NOOLOOK YELLOW SAND	5081.9	5.093%
KILBRIDE SAND	5079.8	5.091%
WARROLONG SAND	3437.1	3.413%
TANTANOOLA FLINTY SAND	3389.0	3.396%
KALANGADOO SAND	3233.6	3.241%
SWAMP SOIL	3038.9	3.045%
COMAUM YELLOW SAND	2911.2	2.917%
SHORT SAND	2619.2	2.625%
FURNER YELLOW SAND	2553.8	2.559%
WANDILO SAND	2161.3	2.166%
MOUNT MUIR SAND	2026.9	2.031%
NOOLOOK RED SAND	1882.2	1.886%
MYORA SAND	1501.2	1.504%
LOWAN SAND	1329.5	1.332%
COMAUM GREY SAND	1261.7	1.264%
DERGHOLM SOLODIC	1211.8	1.214%
RED BASALTIC	925.6	0.928%
RIDDOCH SAND	797.3	0.799%
SWAMP	665.0	0.666%
COMAUM BROWN SAND	622.5	0.624%
KROMELITE SAND	604.8	0.606%
COONAWARRA SAND	447.0	0.448%
STONE	407.8	0.409%
RICHMOND SAND	389.6	0.390%
UNCLASSIFIED	376.0	0.377%
COARSE VALLEY SAND	300.6	0.301%
REEDY CREEK BROWN SAND	247.3	0.248%
COONAWARRA CLAY	246.7	0.247%
DERGHOLM IRON LEPTOPODSOL	230.6	0.231%
NOOLOOK GREY SAND	222.3	0.223%
BROWN RENDZINA	168.1	0.168%
COONAWARA LOAM	157.7	0.158%
FURNER RED SAND	121.2	0.122%
FOLLET SOLODIC	111.7	0.112%
MILLICENT CLAY	87.0	0.087%
DERGHOLM SOLONETZ	35.6	0.036%
KILLARA SOLODIC SAND	29.2	0.029%
LAKE EDWARD PEAT	18.1	0.018%
KENTBRUCK LOAMY SAND	16.7	0.017%
BRAY REGNOSOL	1.8	0.002%
MINGBOOL SAND	1.3	0.001%
TOTAL	**99785.1**	**100%**

3. Measurement records of growth (TSV m^3/ha) at age 2.5 and 3.5 years for each individual growth plot were examined and compared against the SQ III young age growth model. Based upon the growth rate between age 2.5 and 3.5 years (and reference to assessed site quality as allocated by the GIS data base) each individual plot which was below the SQ III aiming point at age 2.5 years was allocated a positive or negative (yes or no) growth response (reached the SQIII aiming point or provided a significant response which was likely to put the growth plot above the aiming point after the 3.5 year measurement).

4. All of the above data was combined in Microsoft Excel and sorted firstly by soil type and then rainfall zone and stand density (stocking at measurement).

Amongst the questions that arise from the results of this study two important ones are:
- Is the measured growth response recorded a result of the application of additional nutrition or have the growth plots responded to other factors such as improved soil moisture conditions?
- Could or have the fertilised plots reached the minimum site productivity level without the assistance of additional young age nutrition?

A definitive answer to these questions based upon the growth plot data alone can not be achieved because of the range of site and climate impact variables that can and do limit young age radiata pine growth. In order to draw conclusions and formulate recommendations on the probability of an effective fertiliser response, that meets the requirements of increasing productivity up to or above the required SQ III aiming point, soil characteristics and rainfall trends which are associated with specific soil types have to be included in the modelling process.

On some soil types there was insufficient growth plot data to form a reasonable conclusion of the probability of a fertiliser driven growth response which could increase productivity above the required minimum SQ III aiming point (*Table* 2). The reasons why there is insufficient data are;

- Shallow Terra Rosa soils such as the Coonawarra Clay and Coonawarra Loam have been purposely excluded from the young age growth plot program as their shallow depth to parent material (Miocene limestone) is the primary limiting factor to growth potential which can not be remediated by silvicultural practice or the addition of fertiliser. As such the number of growth plots located on these soils is too low to draw a sound conclusion based upon the growth plot data alone.

- Soils such as the Lowan Sand are not generally found in large continuous expanses of the plantation resource. As such this soil type is rarely the major soil type within any single plantation compartment and hence will not have a growth plot established on it unless it is a significant area and is representative of the growth within the plantation compartment. As such the number of growth plots located on these soils is too low to draw a sound conclusion.

On soil types where there is insufficient growth plot data recommendations of potential fertiliser response have been formulated based upon a number of additional inputs. These include soil characteristics such as depth to water retentive /root restrictive layer, inherent fertility and water holding capacity as well as the rainfall zone associated with the specific soil type. Fertiliser responses of soils with similar structural and fertility characteristics located in the same rainfall zone have been used as a bench marker to the likely fertiliser response. In addition the results from purpose designed young age fertiliser trials on known soil types have also been included in the modelling process when available.

GENERAL RESULTS

Of the 1649 young age growth plots included in this study a total of 1040 received an application of granular fertiliser between the ages of 2 and 4 years (*Table 2*). Of the 1040 plots fertilised, 878 or 84% were below the ForestrySA SQ III trigger point for consideration of young age fertiliser treatment. Of the 688 plots that were identified as being below the SQ III trigger point, and received a fertiliser treatment 356 plots or 52% have had a measured growth response which has pushed them above the SQ III growth line at either age 3.5 years and/or at the age 9.5 year site quality assessment.

A total of 190 growth plots that were identified as being below the SQ III trigger point for consideration of young age fertiliser application were not fertilised. Of these 190 plots that did not receive a granular fertiliser application between the ages of 2 and 4 years, 111 (58%) reached the SQ III growth line at either 3.5 years and/or at the age 9.5 year site quality assessment. The decision not to treat growth plots that were below the SQ III aiming point at young age was based upon an assessment of the probability of an effective fertiliser driven growth response. Soil type, stand density and how far below the SQ III growth line individual plots were at the time of measurement were considered as part of the assessment process.

- If a growth plot was below the SQ III line on a high fertility soil, such as a Tantanoola Flinty Sand, where nutrition is not the primary limiting factor to growth it may not be treated.
- If a growth plot was marginally below the SQ III aiming point and was surrounded by other growth plots of the same age, at the same locality that were at or above the SQ III aiming point it may have been excluded based on the probability of it reaching the SQ III aiming point without the assistance of additional nutrition.
- Growth plots that were below the SQ III aiming point due to excessively low stand density (<1200 stems /ha) because of tree losses from drought, poor weed control, drowning or insect attack may have been excluded from fertiliser application.

<u>Soil</u>

The level of measured growth response by individual soil type ranged from no measured growth response to a 100% growth response above the SQ III aiming point. On soil types which routinely produce high growth rates such as the Warrolong Sand (average measured SQ across the entire plantation resource of SQ 1.9) the measured growth response was very high (90%). On soil types such as the Kalangadoo Sand which has an average site productivity of SQ 3.4 across the ForestrySA plantation resource the growth response was low at 17%. Shallow soil types with low water holding capacity and growth limiting rooting depth, wet soil types such as solodic soils that suffer seasonal inundation and soils in low rainfall zones had a low probability of a growth response above the SQ III aiming point with the addition of young age fertiliser. Soils with a low water holding capacity due to their shallow depth to parent material located in low rainfall zones such as the Comaum Yellow Sand had a low probability of a growth response above the SQ III aiming point with the addition of young age fertiliser.

<u>Stand Density (Stocking)</u>

One of the key factors to optimising productivity on any plantation site within the Green Triangle Region is silvicultural practice. Growth and form of individual trees within any stand can be manipulated by effective management of competition for site resources via weed control at establishment and by the management of stand density (planting stocking / spacing and thinning practice). If stocking levels are too high competition for the site resources between individual trees will impact negatively on harvesting piece size and stand survival (Lewis *et al* 1976). If stocking levels are too low site productivity potential will not be reached and individual tree form can degrade as extra growing space and light is utilised for larger branch production (McGuire 2005). If weed control is inadequate at establishment competition from weed species can significantly impact on tree survival and growth, slowing canopy closure and impacting on tree form. On low rainfall sites where soil moisture availability is the primary limiting factor to growth, failure to achieve canopy closure as soon as practical following planting can extend the time period during which soil moisture losses from weed competition as well as sun and wind evaporation can significantly limit growth potential (Richardson, 2009). In the Green Triangle Region ForestrySA aims to establish plantations at 1600 stems / ha in higher rainfall zones, > 650mm and at 1330 stems / ha in rainfall zones of 650mm and lower (ForestrySA Plantation Forestry Manual Chapter 2 Establishment). Other major radiata pine plantation growers in the Green Triangle are currently using initial stocking rates of 1600, 1400 and 1150 stems / ha on selected sites[4].

A summary of the impact of stand density on the probability of a young age fertiliser growth response above the SQ III aiming point by individual soil type is shown in *Table 3*. At stand densities of 1400 stems / ha and above the probability (53-54%) of a young age growth response above the SQ III aiming point was marginally greater than the mean Green Triangle probability of a growth response of 52% (for growth plots that were identified as being below the SQ III aiming point and received a fertiliser application). At a stand density of 1300 – 1399 stems / ha the probability of a growth response above the SQ III aiming point was below the mean at 45%. At stocking rates of 1200 – 1299 stems / ha the probability of a growth response above the SQ III aiming point further reduced to only 33% and at stockings less than 1200 stems / ha no growth responses were recorded above the SQ III aiming point (*Figure* 2).

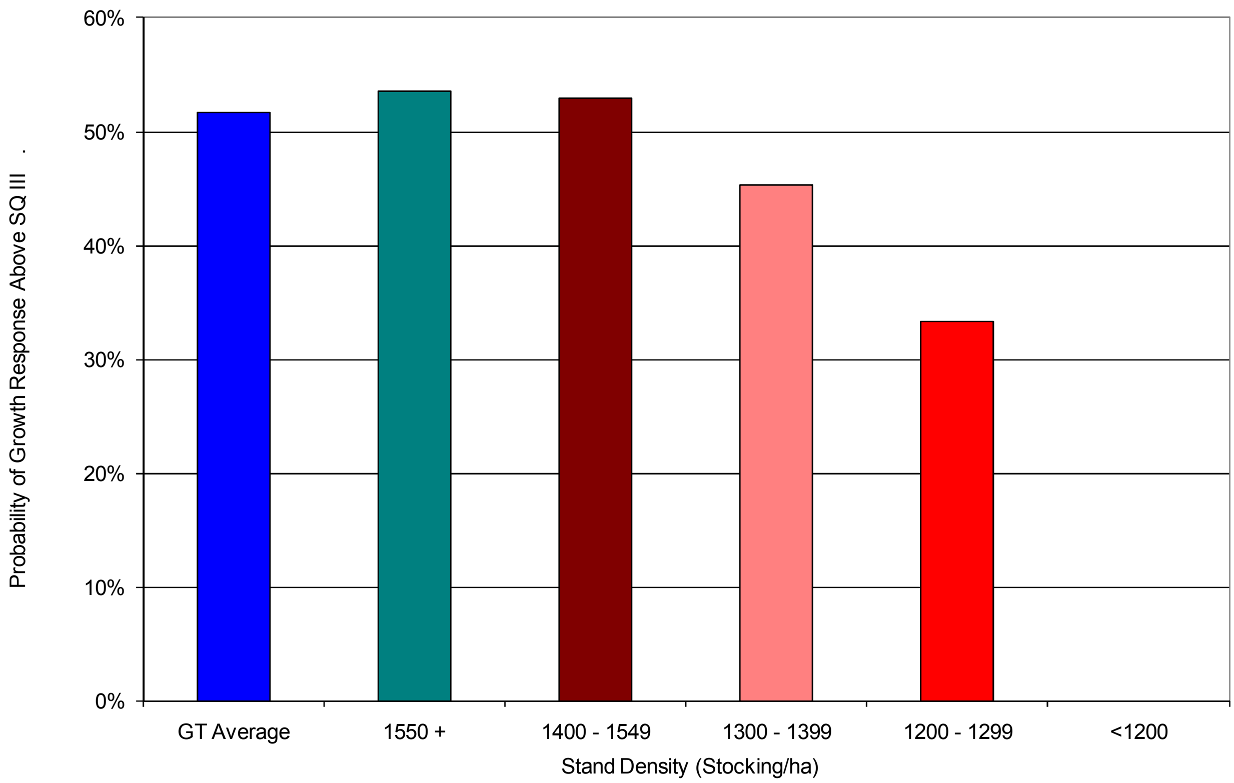

***Figure 2.* Probability of a young age fertiliser growth response above the SQ III aiming point across the Green Triangle Region and by Stand Density (Stocking).**

Figure 3 shows the growth response for a total of 190 growth plots that were identified as being below the SQ III trigger point for consideration of young age fertiliser application and were not fertilised between the ages of 2 and 4 years. Of these 190 plots, 111 (58%) reached the SQ III growth line at either 3.5 years and/or at the age 9.5 year site quality assessment. The growth response pattern resembles that of the growth plots that did receive a young age fertiliser application in that at stand densities of 1400 stems / ha and above the probability of a young age growth response above the SQ III aiming point was greater than the mean Green Triangle probability of a growth response of 58% (for growth plots that were identified as being below the

[4] Stocking density standards have been sourced from joint research projects and discussions with other forest managers within the Green Triangle Region. The stocking regimes employed by individual forest mangers can not be identified in this document due to commercial in confidence requirements.

SQ III aiming point and did not receive a fertiliser application). At a stand density of 1300 – 1399 stems / ha the probability of a growth response above the SQ III aiming point was below the mean at 54%. At stocking rates of 1200 – 1299 stems / ha the probability of a growth response above the SQ III aiming point further reduced to only 20% and at stockings less than 1200 stems / ha no growth responses were recorded above the SQ III aiming point. There were only 4 growth plots with a stocking of less than 1200 stems/ha that were below the SQ III aiming point and did not receive an application of granular fertiliser between the ages of 2 and 4 years. As such the results for this low stocking rate (<1200 stems/ha) are not statistically sound. While these results closely mirror the growth response pattern of the fertilised plots they are probably more reflective of the assessment process used to select plantation areas to be excluded from fertiliser application than just the impact of stand density on the potential site productivity.

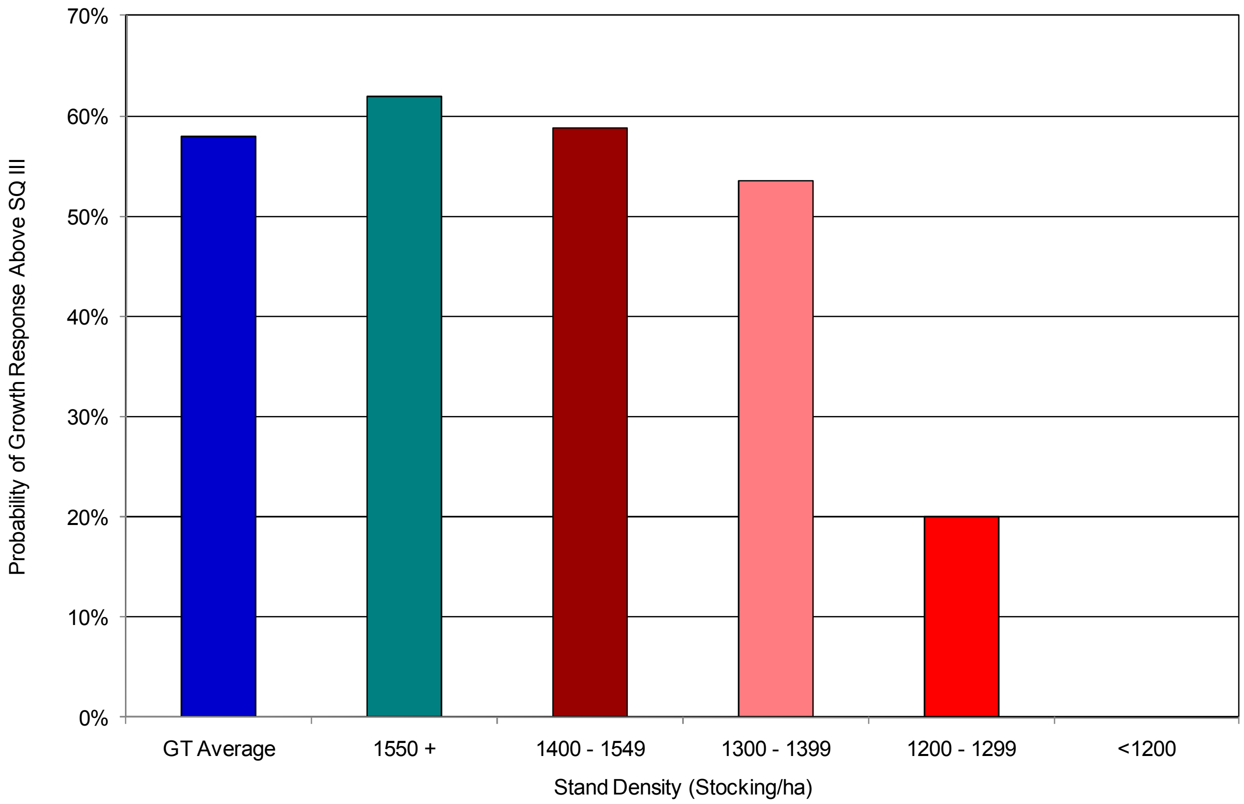

***Figure* 3. . Young age growth response (190 plots) without the addition of fertiliser above the SQ III aiming point by Stand Density (Stocking).**

<u>Rainfall Zone</u>

Rainfall is the primary factor driving plantation productivity in southern Australia as it is for broad acre cropping and livestock production, horticulture and viticulture. A summary of the impact of rainfall zone on the probability of a young age fertiliser growth response above the SQ III aiming point by rainfall zone (50 mm increments) is also shown in *Table 3*. In plantation areas with a mean annual rainfall of 750 mm and above the probability of a young age growth response above the SQ III aiming point was significantly greater at 78% than the mean Green Triangle probability of a growth response of 52% (for growth plots that were identified as being below the SQ III aiming point and received a fertiliser application). In a 700 – 750 mm rainfall zone the probability of a growth response above the SQ III aiming point was below the mean at 45%. In a 650 – 700 mm rainfall zone the probability of a growth response above the SQ III aiming point further reduced to only 39% and in rainfall areas of 650 mm or less no growth responses were recorded above the SQ III aiming point (*Figure* 4). The sample size of young age growth plots in a 600 – 650 mm rainfall zone that were below the SQ III aiming point and received a fertiliser application between the ages of 2 and 4 years is only a total of 7 plots and as such is too small to draw a statistically sound conclusion from. Compounding the small sample size is the impact of survival stocking in this rainfall zone with the average stand density (stocking) being 1142 stems /ha at age 2.5 years. This again highlights the impact of rainfall on survival and stand productivity which impacts on any potential economic response to the application of fertiliser.

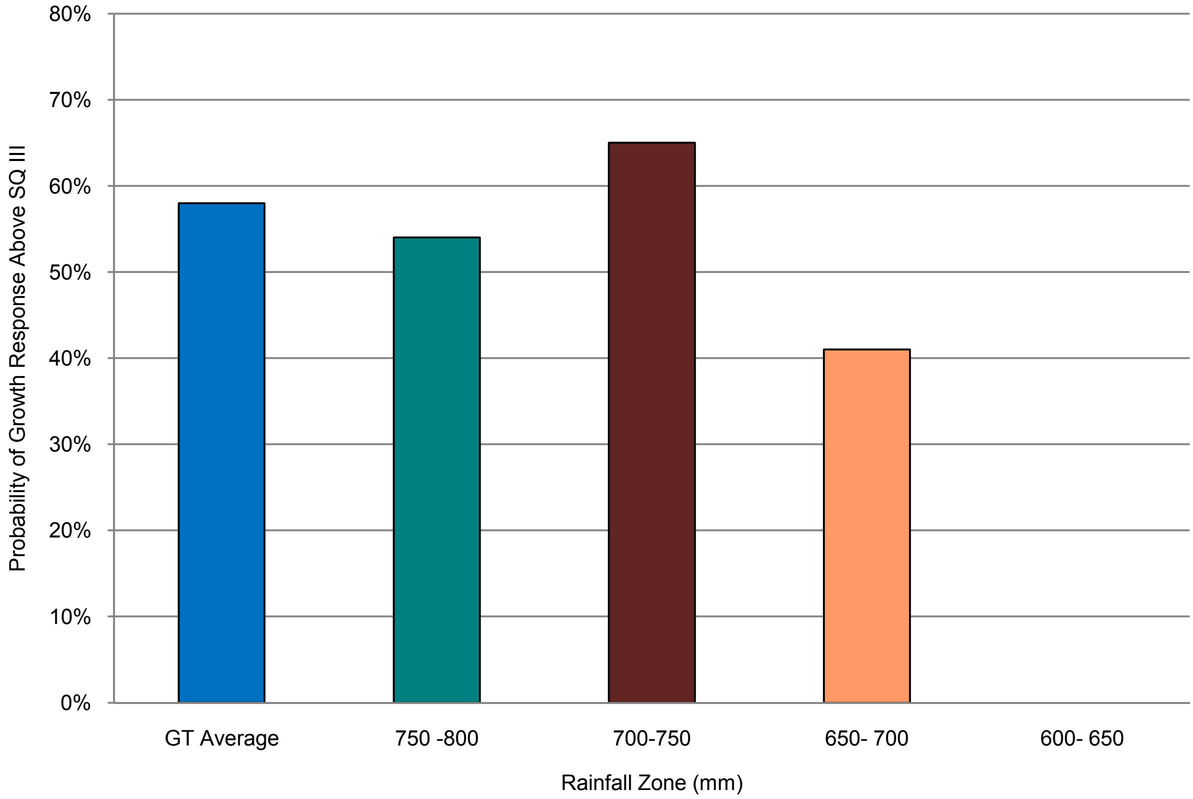

***Figure 4.* Probability of a young age fertiliser growth response above the SQ III aiming point across the Green Triangle Region by Rainfall Zone (mm).**

Figure 5 shows the growth response for a total of 190 growth plots that were identified as being below the SQ III trigger point for consideration of young age fertiliser application and were not fertilised. Of these 190 plots that did not receive a granular fertiliser application between the ages of 2 and 4 years, 111 (58%) reached the SQ III growth line at either 3.5 years and/or at the age 9.5 year site quality assessment. Unlike the growth plots that were fertilised between ages 2 – 4 years there is not a pattern of a reducing growth response from highest to lowest rainfall zone. In plantation areas with a mean annual rainfall of 750 mm and above the probability of growth response above the SQ III aiming point was lower than the mean Green Triangle growth response at 54% (for growth plots that were identified as being below the SQ III aiming point and did not receive a fertiliser application). In a 700 – 750 mm rainfall zone the growth response above the SQ III aiming point was above the mean at 65%. In a 650 – 700 mm rainfall zone the growth response above the SQ III aiming point reduced to only 41% and in rainfall areas of 650 mm or less no growth responses were recorded above the SQ III aiming point. These results are probably more reflective of the assessment process used to select plantation areas to be excluded from fertiliser application than just the impact of rainfall on the potential site productivity.

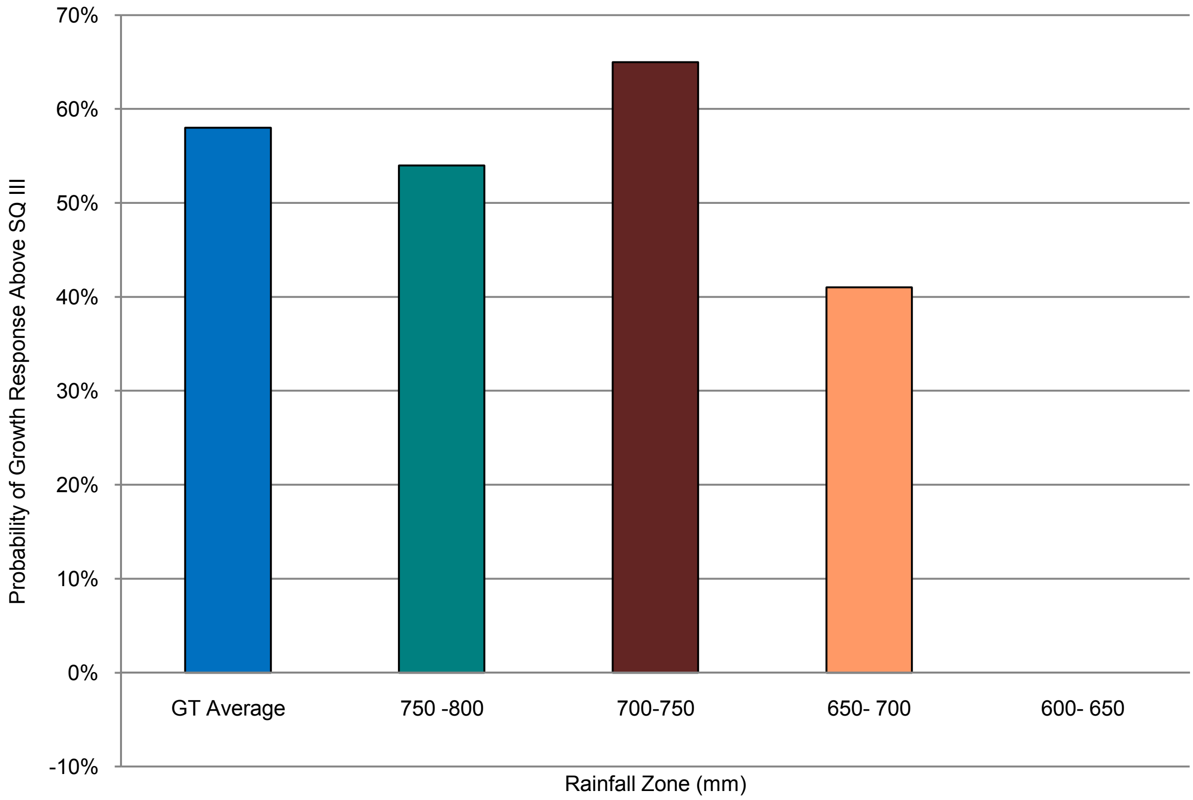

Figure 5. **Young age growth response (190 plots) without the addition of fertiliser above the SQ III aiming point by Rainfall Zone (mm).**

***Table 2.* Summary of young age growth plots (1993 – 2005 plantations) growth response + or – fertiliser application by soil type.** Figures and soil types in red indicate that there is insufficient data to draw a reasonable conclusion based upon the growth plot data.

Soil ID	Plots	Ave SQ	Number Fertilised	Below SQ III @ Age 2.5 Years	Probability of Below SQ III @ Age 2.5	Number Below SQ III Fertilised	Number Responded to Fert Application	Fert Response %	Responded Without Fert Application	No Fert Application Response %
CAROLINE SAND	216	2.2	138	77	36%	65	49	75%	10	83%
COARSE VALLEY SAND	13	1.5	6	6	46%	5	4	80%	0	0%
COMAUM BROWN SAND	25	4.3	16	13	52%	10	1	10%	0	0%
COMAUM GREY SAND	30	4	24	24	80%	21	5	24%	0	0%
COMAUM YELLOW SAND	88	3.6	58	44	50%	40	7	18%	3	75%
COONAWARRA SAND	6	3.3	6	3	50%	3	2	67%		
COONAWARRA CLAY	2	4	1	1	50%	1	1	100%		
COONAWARRA LOAM	3		2	2	67%	2	0	0%		
FOLLET SOLODIC	4	1.2	0	1	25%	0				
FURNER YELLOW SAND	50	1.9	26	19	38%	11	8	73%	4	50%
HINDMARSH SANDY LOAM	59	2.5	33	30	51%	23	12	52%	2	44%
KALANGADOO SAND	41	3.2	24	25	61%	12	2	17%	8	62%
KILBRIDE SAND	69	3.1	59	44	64%	34	10	29%	8	80%
KROMELITE SAND	18	1.5	7	6	33%	2	2	100%	4	100%
LOWAN SAND	11	3.3	6	10	91%	6	0	0%	4	100%
MT BURR SAND	270	2.6	190	181	67%	151	97	64%	21	70%
MOUNT MUIR SAND	38	2.3	22	25	66%	17	12	71%	5	62%
MYORA SAND	45	2.4	43	17	38%	17	12	71%		
NANGWARRY SAND	88	3.1	70	55	63%	39	19	49%	10	62%
NOOLOOK GREY SAND	2	2.5	0	2	100%	0			0	0%
NOOLOOK RED SAND	16	3.4	11	12	75%	10	4	40%	0	0%
NOOLOOK YELLOW SAND	37	3.6	30	28	76%	27	5	19%	0	0%
REEDY CREEK BROWN SAND	7	1.0	0	0	0%	0%				
RED BASALTIC	18	2.1	8	7	39%	6	6	100%	0	0%
RICHMOND SAND	2	1.5	0	0	0%	0				
RIDDOCH SAND	16	1.8	7	7	44%	4	3	75%	0	0%
SHORT SAND	65	2.1	21	27	42%	19	10	53%	6	75%
TANTANOOLA FLINTY SAND	92	2.0	17	30	33%	11	5	45%	11	58%
WANDILO SAND	58	2.5	45	31	53%	27	14	52%	3	75%
WARROLONG SAND	89	1.9	36	27	30%	20	18	90%	6	86%
YOUNG SAND	141	3.3	110	103	73%	87	40	46%	5	31%
Total (Average)	**1649**		**1040**	**878**	**53%**	**688**	**356**	**52%**	**111**	**58%**

Table 3. **Summary of young age growth plots (1993 – 2005 plantations) growth response + or – fertiliser application by stand density (stocking/ha) and rainfall zone (mm).** Figures and soil types in red indicate that there is insufficient data to draw a reasonable conclusion.

Soil ID	**Fert Response %**	**Fertiliser Response Probability X Stocking Range**					**Fertiliser Response Probability X Rainfall Zone**			
		1550 +	1400 - 1550	1300 - 1400	1200 - 1300	<1200	750 - 800	700 -750	650 - 700	600 - 650
CAROLINE SAND	75%	81%	84%	30%	0%		75%			
COARSE VALLEY SAND	80%	100%		75%			80%			
COMAUM BROWN SAND	10%	0%	0%	**100%**					**10%**	
COMAUM GREY SAND	24%	14%	30%	0%	50%				24%	
COMAUM YELLOW SAND	18%	12%	23%	14%	0%				18%	0%
COONAWARRA SAND	**67%**	**100%**			**0%**				**100%**	**0%**
COONAWARRA CLAY	**100%**		**100%**						**100%**	
COONAWARRA LOAM	**0%**	**0%**	**0%**						**0%**	
FOLLET SOLODIC										
FURNER YELLOW SAND	73%	80%	100%				73%			
HINDMARSH SANDY LOAM	52%	40%	66%	100%	100%	0%				
KALANGADOO SAND	17%	20%	0%	30%	0%		100%	0%		
KILBRIDE SAND	29%	40%	31%	0%	0%	0%		10%	39%	
KILLARA SOLODIC SAND										
KROMELITE SAND	**100%**	**100%**					**100%**			
LOWAN SAND	**0%**	**0%**	**0%**	**0%**					**0%**	
MT BURR SAND	64%	72%	49%	71%	50%	0%	62%	71%		
MOUNT MUIR SAND	71%	82%	75%	**0%**	**100%**		78%	75%		
MYORA SAND	71%	69%	**100%**	**0%**	**100%**		71%			
NANGWARRY SAND	49%	64%	50%	42%	**0%**			35%	63%	
NOOLOOK GREY SAND										
NOOLOOK RED SAND	40%	40%	**100%**					40%		
NOOLOOK YELLOW SAND	19%	22%			**0%**			19%		
REEDY CREEK BROWN SAND										
RED BASALTIC	100%	**100%**	**100%**	**100%**			**100%**	**100%**		
RICHMOND SAND										
RIDDOCH SAND	**75%**		**66%**		**100%**					
SHORT SAND	53%	78%	**50%**	**40%**	**0%**	**0%**		38%	100%	
TANTANOOLA FLINTY SAND	45%	43%	**0%**	**100%**	**100%**	**0%**	**45%**			
WANDILO SAND	52%	67%	45%	75%	**0%**	**0%**	54%	50%		
WARROLONG SAND	90%	78%	100%	**100%**			100%	88%		
YOUNG SAND	46%	49%	52%	29%	**0%**	**0%**	36%	66%	20%	
Average	**52%**	**54%**	**53%**	**45%**	**33%**	**0%**	**78%**	**45%**	**39%**	**0%**

INDIVIDUAL SOIL RESULTS

Bray Regosol

Soil Description:

A shallow, well drained single grain structured un-consolidated sand derived from coastal sand dunes. The Bray Regosol has a loamy A1 horizon overlying an A2 horizon of leached sand containing shells and shell grit. ForestrySA does not have any young age growth plots on this soil type so it is not included in *Tables* 2 & 3 of this report. This soil is unsuitable for economically viable plantation forestry due to its high inherent soil pH.

Young Age Fertiliser Response:

ForestrySA has only 1.8 ha of Bray Regosol in its plantation estate which is 0.0002% of the plantation area. No growth plot data is available to draw any conclusions about the fertiliser response potential on this soil type but given its inherently high soil pH which makes it unsuitable for effective plantation establishment fertiliser application is not recommended for this soil type.

Brown Rendzina

Soil Description:

A poorly drained, wet soil often associated with swamps, swamp margins and areas of seasonal inundation. Characterised by its shallow grey brown loamy sand surface over a nodular brown clay. It is seldom more than 30cm above its parent material of Miocene limestone. This soil requires ripping and mounding if plantation establishment is to be attempted though it is generally too wet and has too high an inherent soil pH for effective plantation establishment. ForestrySA does not have any young age growth plots on this soil type so it is not included in *Tables* 2 & 3 of this report.

Young Age Fertiliser Response:

ForestrySA has 0.17% (168ha) of its total forest estate (both plantation and native forest reserve) in the Green Triangle Region identified as Brown Rendzina. No growth plot data is available to draw any conclusions about the fertiliser response potential on this soil type but given its soil characteristics and unsuitability for effective plantation establishment fertiliser application is not recommended for this soil type.

Caroline Sand

Soil Description:

The Caroline Sand is a well drained, fertile iron nomopodsol whose parent material is aeolian sand. Caroline sand is characterised by its grey sand A1 horizon overlying up to 30 cm of light grey sand A2 with a light yellow to yellow sand A3 up to 180 cm deep which overlays a B1 horizon (approximately 30 cm) containing brown organic cemented and ironstone gravel in yellow sand. It is part of the Caroline sand complex and is associated with dune ranges. Caroline sand will normally grow site quality II radiata pine but can produce site quality I as a transitional soil (transition between Caroline Sand and Warrolong Sand) provided adequate weed control is undertaken at establishment.

Young Age Fertiliser Response:

There is a high probability that Caroline Sand will grow site quality III and above radiata pine without young age fertiliser application. Results from 216 young age growth plots established on Caroline Sand indicate that there was a 36% probability of being below the SQ III aiming point at age 2.5 years and a 75% probability of a fertiliser response raising site productivity above the SQ

III threshold. A total of 88 of the 216 growth plots assessed have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 6*. The results indicate that average site productivity increased from age 2.5 years to age 9.5 years. No additional increase in the number of fertilised plots which were above the SQ III aiming point was achieved after the 3.5 year measurement. This would indicate that nutrition was not the primary limiting factor to tree growth in these plots. Fertiliser application is recommended especially on ex bracken sites and following drought years.

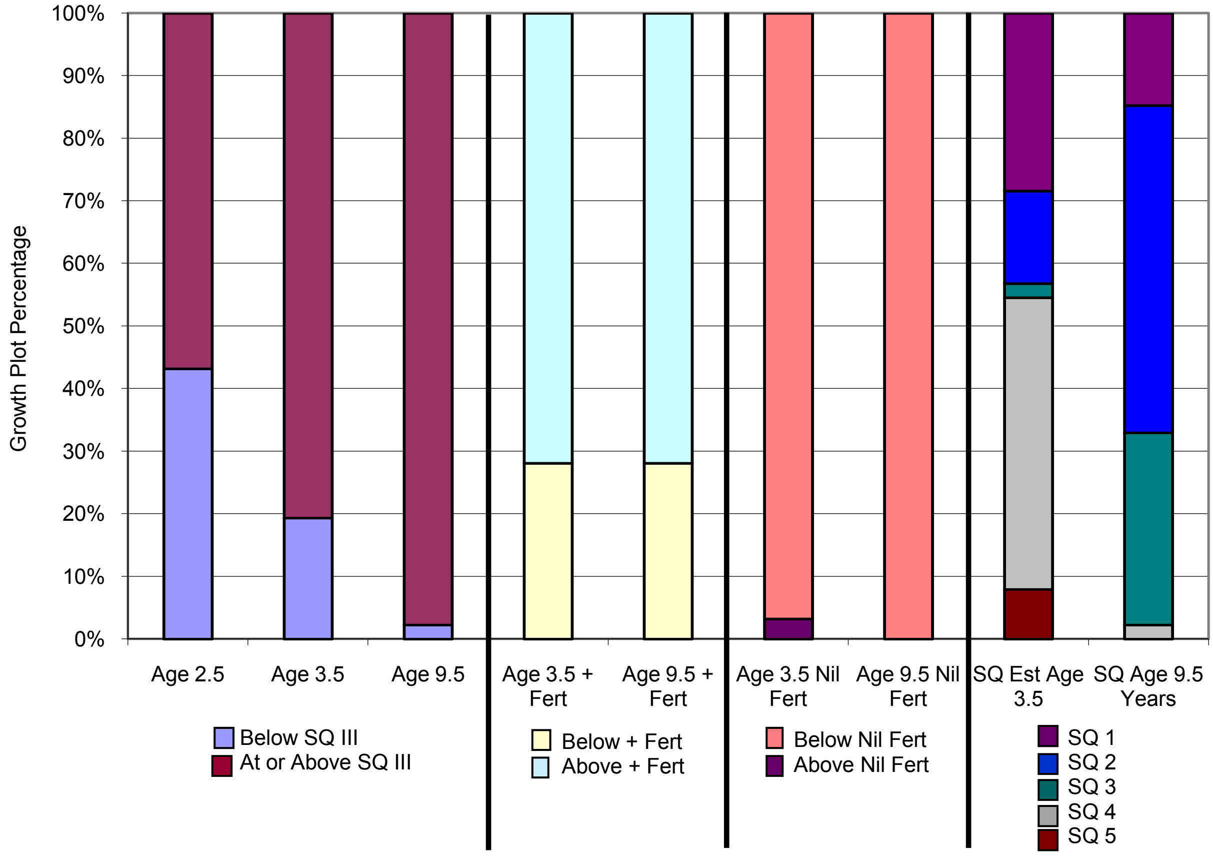

***Figure 6.* Caroline Sand growth response (88 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

<u>Coarse Valley Sand</u>

Soil Description:

The Coarse Valley Sand is an alluvial soil that has been derived from volcanic ash that has had the more soluble, finer and looser material removed by the movement of water. It consists of layers of undifferentiated coarse sand grains which vary in depth depending upon the speed of deposition at the time of soil formation. The Coarse valley sand has varying degrees of podsolization with the soil colour ranging from a dull brown to a lighter brownish grey. It is a soil of high inherent fertility that is associated with the dry valleys of the Mt Burr and Glencoe districts of the Green Triangle Region. Coarse Valley Sand will produce SQ I – II radiata pine plantations.

Young Age Fertiliser Response:

A total of 13 growth plots were available for this study of which 46% (6 plots) were below the SQ III aiming point at age 2.5 years. A total of 5 of these plots were fertilised with 80% realising a growth response following fertiliser application raising site productivity above the SQ III threshold. It is recommended that young age fertiliser application be a high priority for this soil type.

Comaum Brown Sand

Soil Description:

The Comaum Brown sand is an iron leptopodsol from the Comaum soil association. Characterised by a dark grey sand A1 (0-20cm) overlying a grey-brown to brown sand to loamy sand A2 of 20 – 80 cm in depth and yellowish brown sandy clay to mottled yellow and brown medium clay with red inclusions B horizon. Some ironstone gravel may be present in the lower portions of the A2 horizon and the upper B1. This is a soil of moderate to high fertility which can produce SQ III radiata pine provided there is adequate soil depth and rainfall but on average produces SQ IV radiata pine due to a lack of soil depth and associated low water holding capacity.

Young Age Fertiliser Response:

A total of 25 growth plots were available for this study of which 52% (13 plots) were below the SQ III aiming point at age 2.5 years. A total of 10 of these plots were fertilised with 10% realising a growth response following fertiliser application raising site productivity above the SQ III threshold. Nutrition is not the limiting factor to plantation growth on this soil type, rainfall zone (650 mm) and soil depth are the primary growth limiting factors. Young age fertiliser application is not recommended with this soil type.

Comaum Grey Sand

Soil Description:

The Comaum Grey Sand is a humus nomopodsol from the Comaum soil association which has a poorly drained hardpan/swampy variant associated with areas of impeded drainage on the fringes of the dune range and a dry phase variant which is a very deep, heavily leached very well drained very coarse sand associated with the dune range. The Comaum Grey Sand (normal or dry phase) is characterised by its dark grey coarse sand A1 (0-40cm) overlying a leached grey coarse sand A2 of approximately 70 cm, a grey-brown coarse sand A3 of approximately 100 cm overlying a brown and yellow brown, organic stained layer of accumulation of approximately 75 cm. This is a relatively low fertility soil with low water holding capacity due to its depth and coarse sand structure in its dry phase and prone to seasonal inundation in its wet phase. It can produce SQ IV radiata pine provided it has adequate weed control at establishment.

Young Age Fertiliser Response:

A total of 30 growth plots were available for this study of which 80% (24 plots) were below the SQ III aiming point at age 2.5 years. A total of 21 of these plots were fertilised with 24% realising a growth response following fertiliser application raising site productivity above the SQ III threshold. Nutrition is a limiting factor to plantation growth on this soil type, but rainfall zone (650 mm) and soil moisture holding capacity (excessive drainage in the normal/dry phase and limited drainage in the hardpan/swampy phase) are the primary growth limiting factors. The Comaum Grey Sand (normal/dry phase) is likely to respond to young age fertiliser application in an above average rainfall year but has a low probability of response in a normal to low rainfall year. Fertiliser application on this soil type is recommended as a low priority.

Comaum Yellow Sand

Soil Description:

The Comaum Yellow Sand is an iron nomopodsol from the Comaum soil association which can be found from the dune ranges of Comaum to as far north as Bangham and east as far as Padthaway and Khayyam at East Avenue Range. A well-drained, often 200 cm + deep iron nomopodsol of moderate fertility that will grow site quality III- IV radiata pine provided there is adequate rainfall.

This sand is characterised by its very coarse single grain sand structure and poor water holding capacity during the summer months.

Young Age Fertiliser Response:

A total of 88 growth plots were available for this study of which 50% (44 plots) were below the SQ III aiming point at age 2.5 years. A total of 40 of these plots were fertilised with 18% realising a growth response following fertiliser application raising site productivity above the SQ III threshold. Primary limiting factor to growth is rainfall zone (600 - 650mm). Very likely to respond to fertiliser in an above average rainfall year. Probability of response in an average to below average rainfall year very low due to its high drainage rate and associated poor water holding capacity.

<u>Coonawarra Clay</u>

Soil Description:

A member of the terra-rossa soil group Coonawarra Clay is characterised by its brown - dark brown clay surface horizons overlying Miocene limestone. Often very shallow (less than 10 cm) with limestone protruding through the soil surface it rarely exceeds 40 cm in depth. Soil depth is the primary limiting factor to site productivity on this soil which has limiting water holding capacity and rooting depth.

Young Age Fertiliser Response:

A total of only 2 growth plots on Coonawarra Clay were available for this study with an average site quality of SQ IV. This is an inadequate sample size to draw any conclusions based on the data available. Fertiliser is not recommended for this shallow terra rossa soils because soil depth and a low water holding capacity is the primary growth limiting factor not inherent fertility.

<u>Coonawarra Loam & Hindmarsh Sandy Loam</u>

Soil Description:

The Coonawarra Loam and the Hindmarsh Sandy Loam are for all practical operational purposes the same soil with the primary difference being that the Coonawarra Loam is marginally lighter in colour. Both the Coonawarra Loam and Hindmarsh Sandy Loam are characterised by their dark brown – red brown sandy loam – loam surface horizons overlying Miocene limestone. Often very shallow with limestone protruding through the soil surface they rarely exceed 90 cm in depth. Both can be expected to produce site quality I - II radiata pine where there is adequate soil depth and rainfall and to be unsuitable on the excessively stony flats and rises. The Coonawarra Loam is to be found north of the Tarpeena hundred line in South Australia to north of Naracoorte and east to Langkoop in Western Victoria. This soil is replaced by the Hindmarsh Sandy Loam as the primary terra rossa soil along the flats and low dunes of Wattle Range in the west.
The Hindmarsh Sandy Loam is found throughout the Caroline, Dartmoor, Kentbruck, Kongorong, Mt Burr, Mt Gambier, Myora, Puralka, Reedy Creek and Wattle Range forest regions of the Green Triangle.

Young Age Fertiliser Response:

A total of 59 growth plots on Hindmarsh Sandy Loam and 3 on Coonawarra Loam were available for this study of which 51% (32 plots) were below the SQ III aiming point at age 2.5 years. A total of 25 of these plots were fertilised with 48% of the combined total realising a growth response following fertiliser application raising site productivity above the SQ III threshold. Soil fertility is not the primary limiting factor to growth on these two soil types. Lack of soil depth which impacts on soil moisture holding capacity and rooting potential is the primary limiting factor to growth. For the Coonawarra Loam, the rainfall zone (600 - 650mm) in its northern range is also a major growth limiting factor. Fertiliser is not recommended for these shallow terra rossa soils because if soil depth is not limiting growth site productivity will be high. If soil depth is limiting growth the addition of supplementary nutrition will not increase productivity.

Coonawarra Sand

Soil Description:

A member of the terra-rossa soil group Coonawarra Sand is characterised by its brown – dark brown sandy or sandy loam A1 to 20cm in depth overlying 30 – 45 cm of brown sand or sandy loam A2 with very slight amounts of ironstone gravel in its lower portion above brown and yellow brown mottled friable clay with red inclusions. The Coonawarra Sand is located in the Kalangadoo/Nangwarry and Comaum areas of the Green Triangle. It is a soil of moderate to high productivity depending upon its depth and associated rainfall zone and can be expected to grow SQ III radiata pine in its higher rainfall range (750 – 700 mm) and SQ IV in the lower rainfall (650 – 600 mm) Comaum and Cave Range areas.

Young Age Fertiliser Response:

A total of only 6 growth plots were available for this study with an average site quality of SQ III-. This is an inadequate sample size to draw any conclusions based on the data available. A total of 50% (3 plots) were below the SQ III aiming point at age 2.5 years. All three of these plots were fertilised with 2 plots or 67% realising a growth response following fertiliser application raising site productivity above the SQ III threshold.
The Coonawarra Sand is most similar in soil characteristics (depth, texture, colour and drainage) to the Mt Muir Sand which is its equivalent in the Mt Burr soil complex. Like the Mt Muir Sand it has a high probability of responding to fertiliser application in its higher rainfall areas (Kalangadoo/Nangwarry) but a low probability of response in the lower rainfall areas of Comaum and Cave Range.

Dergholm Iron Leptopodsol

Soil Description:

The Dergholm Iron Leptopodsol is a soil from the Dergholm series of soils from the Lowan Land System of South Western Victoria and is characterised by having a brown gravely sandy loam A horizon approx 30cm deep containing variable amounts of ironstone inclusions, merging into a mottled brown with red sandy clay B horizon with clay content increasing with depth. This soil can be expected to have lower phosphorus availability due to the presence of ironstone gravel in it's A horizons which will bind phosphorus in the soil.

Young Age Fertiliser Response:

The Dergholm series of soils are not represented in *Tables* 2 & 3 of this report as they had not received an age 3.5 year growth plot measurement at the time of compilation of this report. Growth results from 5 young age growth plots established at Langkoop in the 2007 plantation and measured in 2010 show that all were above the site quality III minimum aiming point at age 2.5 years. Insufficient data is available to draw any definitive conclusions on the potential fertiliser responses that may be expected on this soil type. However based on its soil characteristics and the rainfall zone (600 - 650 mm) in which it is most prevalent it can be expected that there is a moderate probability that this soil type would respond to the application of fertiliser in an above average rainfall year.

Dergholm Solodic

Soil Description:

The Dergholm Solodic soil is a soil from the Dergholm series of soils from the Lowan Land System and is characterised by having a brown (fine) sandy loam A1 horizon of approx 30cm deep, greyish brown (fine) sand A2 horizon of approx 30cm, mottled brown with yellowish-brown, orange and red heavy clay B horizon. This soil has limited vertical drainage potential due to its shallow depth and heavy clay B horizon.

Young Age Fertiliser Response:

The Dergholm series of soils are not represented in *Tables* 2 & 3 of this report as they had not received an age 3.5 year growth plot measurement at the time of compilation of this report. Growth results from 60 young age growth plots established at Langkoop in the 2007 plantation and measured in 2010 showed that 35 plots (58%) were below the site quality III minimum aiming point at age 2.5 years. The measured plots from the 2007 plantation that were below the SQ III aiming point were primarily associated with areas of impeded drainage. The plots that were above the SQ III aiming point were associated with areas of slightly higher elevation and increased soil depth. At the time of completion of this report no data was available on any potential fertiliser response because no fertiliser applications had been made. The follow up age 3.5 measurement of these growth plots is not scheduled to occur until the summer of 2010 -11.

The Dergholm Solodic is a soil of moderate to high inherent fertility with nutrition not being the primary limiting factor to plantation growth. Rainfall zone (600- 650mm) and limited drainage causing excessive wet feet during wet years are the primary growth limiting factors. Fertiliser is not recommended for this soil because if soil depth and drainage is not limiting growth site productivity will be limited by available rainfall and not nutrition. If soil depth and impeded drainage is limiting growth the addition of supplementary nutrition will not increase productivity.

Dergholm Solonetz

Soil Description:

The Dergholm Solonetz soil is a soil from the Dergholm series of soils from the Lowan Land System and is a heavy brown clay (often cracking during summer) with mottled orange and red inclusions. It is either overlain by 0-10 cm of brown clay loam to sandy loam or protruding at the soil surface. This soil is unsuitable for a commercial radiata pine or Tasmanian blue gum plantation establishment.

Young Age Fertiliser Response:

The Dergholm series of soils are not represented in *Tables* 2 & 3 of this report as they had not received an age 3.5 year growth plot measurement at the time of compilation of this report. Limited rooting depth, poor drainage and a cracking surface which can expose fine roots to the sun during summer limit the growth potential on this soil. Fertiliser application is not recommended for this soil type.

Follet Brown Solodic

Soil Description:

The Follett Brown Solodic is a soil from the Follett series of soils from the Strathdownie Land System. It is characterised by having a greyish brown (coarse) sandy loam A1 horizon of approximately 20cm deep, brownish grey (coarse) sand A2 horizon of approx 30cm overlying a mottled brown heavy clay B horizon. This soil has limited vertical drainage potential due to its shallow depth and heavy clay B horizon. This soil will require ripping and mounding and can be expected to produce a SQ I - III radiata pine dependent on its rainfall zone.

Young Age Fertiliser Response:

A total of only 4 growth plots were available for this study with an average site quality of SQ I -. This is an inadequate sample size to draw any conclusions based on the data available. One of the four growth plots assessed was below the SQ III aiming point at age 2.5 years which reached a SQ II growth level at age 9.5 years without the addition of fertiliser. Based on the high productivity of the plantation resource currently growing on this soil type fertiliser application is not recommended.

<u>Furner Red Sand</u>

Soil Description:

The Furner Red Sand is a regional variant of the Coonawarra Loam and Hindmarsh Sandy Loam which is found in the Furner to Reedy Creek area associated with the exposed parent material of the eroded dune ranges. Characterised by its dark brown – red brown sand, sandy loam to loam surface horizons overlying Miocene limestone. Often very shallow with limestone protruding through the soil surface it rarely exceeds 50 cm in depth. Nutrition is not the primary limiting factor to plantation growth on this soil type. Shallow soil depth (lack of rooting depth) and low water holding capacity are the primary limiting factors to tree growth. The Furner Red Sand grows site quality III - V radiata pine depending upon the depth of soil.

Young Age Fertiliser Response:

Fertiliser is recommended as a low priority for this shallow terra rossa soil because if soil depth is not limiting growth site productivity will be moderate to high. If soil depth is limiting growth the addition of supplementary nutrition will not increase productivity.

<u>Furner Yellow Sand</u>

Soil Description:

The Furner Yellow Sand is a well drained, fertile iron nomopodsol whose parent material is aeolian sand. It is part of the Mt Burr sand complex and is a paler and often shorter variant of the Mt Burr Sand. It is found principally north of Mt Graham in the Mt Burr Range. The Furner Yellow Sand is characterised by its approximately 20 cm deep brown non coherent sand A1 horizon overlying a 20 - 100 cm of brownish yellow sand A2 which sits on top of a very distinct yellow sand A3 horizon over a brown to brownish yellow sandy clay to clay B horizon.
The Furner Yellow Sand will grow site quality II radiata pine.

Young Age Fertiliser Response:

A total of 50 growth plots were available for this study of which 38% (19 plots) were below the SQ III aiming point at age 2.5 years. A total of 11 of these plots were fertilised with 73% realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 4 out of 8 plots (50%) of those that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years. Fertiliser application is recommended for this soil type.

<u>Kalangadoo Sand</u>

Soil Description:

The Kalangadoo sand is a Solodic soil, often <1m in depth associated with the fringes of dune ranges and flat plains of impeded drainage. This soil has a dark grey loamy sand A1 horizon over a pale brown sandy A2 horizon which contains prominent pink grains. There is a sharp delineation between the sandy A horizons and the heavy textured clay B horizon that often contains red inclusions. The Kalangadoo sand has three main variants containing either a sandy surface, a loamy surface or a gravely subsoil containing abundant amounts of ironstone gravel. It is of moderate fertility and will grow SQ II - IV radiata pine depending on the level of drainage. Nutrition is not the primary limiting factor to plantation productivity; impeded drainage is the primary limiting factor to growth on this soil type.

Young Age Fertiliser Response:

A total of 41 growth plots were available for this study of which 61% (25 plots) were below the SQ III aiming point at age 2.5 years. A total of 12 of these plots were fertilised with 2 (17%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 8 out of 13 plots (62%) of those that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years. Fertiliser application is recommended as a low priority on this soil type. Where drainage is adequate site productivity will be high and where drainage is the primary limiting factor to growth the addition of supplementary nutrition will not increase productivity.

<u>Kentbruck Loamy Sand</u>

Soil Description:

The Kentbruck Sandy Loam is an iron Leptopodsol from Nelson Land System. It is a well drained dune sand associated with the coastal fringe. The Kentbruck Sandy Loam is an orange-brown sand characterised by its dark greyish brown loamy sand A1 horizon over a dark yellowish brown loamy sand A2 above a distinctly mottled (due to occlusions) dark yellowish brown, brown and strong brown loamy sand grading to sand with depth A3 horizon. Underlying the A3 is a further orange brown loamy sand of up to 50 cm in depth which gradually lightens in colour until it abruptly ends at strongly mottled grey and yellowish brown sandy clay. Fertility of this soil is very variable and is dependant upon its inherent soil pH which can vary from acid to alkaline depending upon its distance from the coast and hence it’s geological age. The closer this soil type is to the sea shore the higher its pH tends to be.

Young Age Fertiliser Response:

ForestrySA has only 16.7 ha of Kentbruck Loamy Sand in its plantation estate which is 0.017% of the plantation area and does not have any young age growth plots on this soil type so it is not included in *Tables* 2 & 3 of this report.. The Kentbruck Loamy Sand is however a significant soil type in the Kentbruck forest district of south western Victoria. Dependent on its distance from the coastal dunes soil pH will range greatly from within the acceptable acid range for optimum nutrient availability for radiata pine and Tasmanian blue gums (pH 4.5 - pH 6.7) to very alkaline (up to pH 8.7). Where in the acceptable pH range this soil can be expected to respond to fertiliser application especially on ex bracken areas. Where the inherent soil pH is above the acceptable pH range plantations will not responded to fertiliser application.

<u>Kilbride Sand</u>

Soil Description:

A low fertility, humus nomopodsol which has a very deep, heavily leached dry phase found in the dune ranges and a swampy phase often associated with areas of seasonal inundation and restricted drainage such as swamp margins and flood plains. The Kilbride Sand is characterised by its leached, pale A2 horizon often 150 cm plus deep overlying a black and brown accumulation of organic matter up to 60 cm thick which forms an organic cemented hardpan with gravel, penetrated with channels of leached sand in its swampy phase. This is sometimes underlain by a sand horizon which can range in colour from yellow to bleached almost white. Impeded drainage is the primary limiting factor to growth on the swampy phase soil which has a very low response probability. On the dry phase soil nutrition is a significant limiting factor to productivity especially on bracken sites.

Young Age Fertiliser Response:

A total of 69 growth plots were available for this study of which 64% (44 plots) were below the SQ III aiming point at age 2.5 years. A total of 34 of these plots were fertilised with 10 (29%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold.
A total of 45 of the 69 growth plots assessed have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 7*. The results indicate that average site productivity increased from age 2.5 years to age 9.5 years. The number of plots which received fertiliser and were below the SQ III aiming point after the 3.5 year measurement decreased by age 9.5 years while the number of plots that were below SQ III at age 3.5 years and did not receive fertiliser increased at age 9.5 years. This would indicate that nutrition was a significant limiting factor to tree growth in these plots. Fertiliser application is recommended for dry phase Kilbride Sand and the better drained wet phase soils, especially on ex bracken sites.

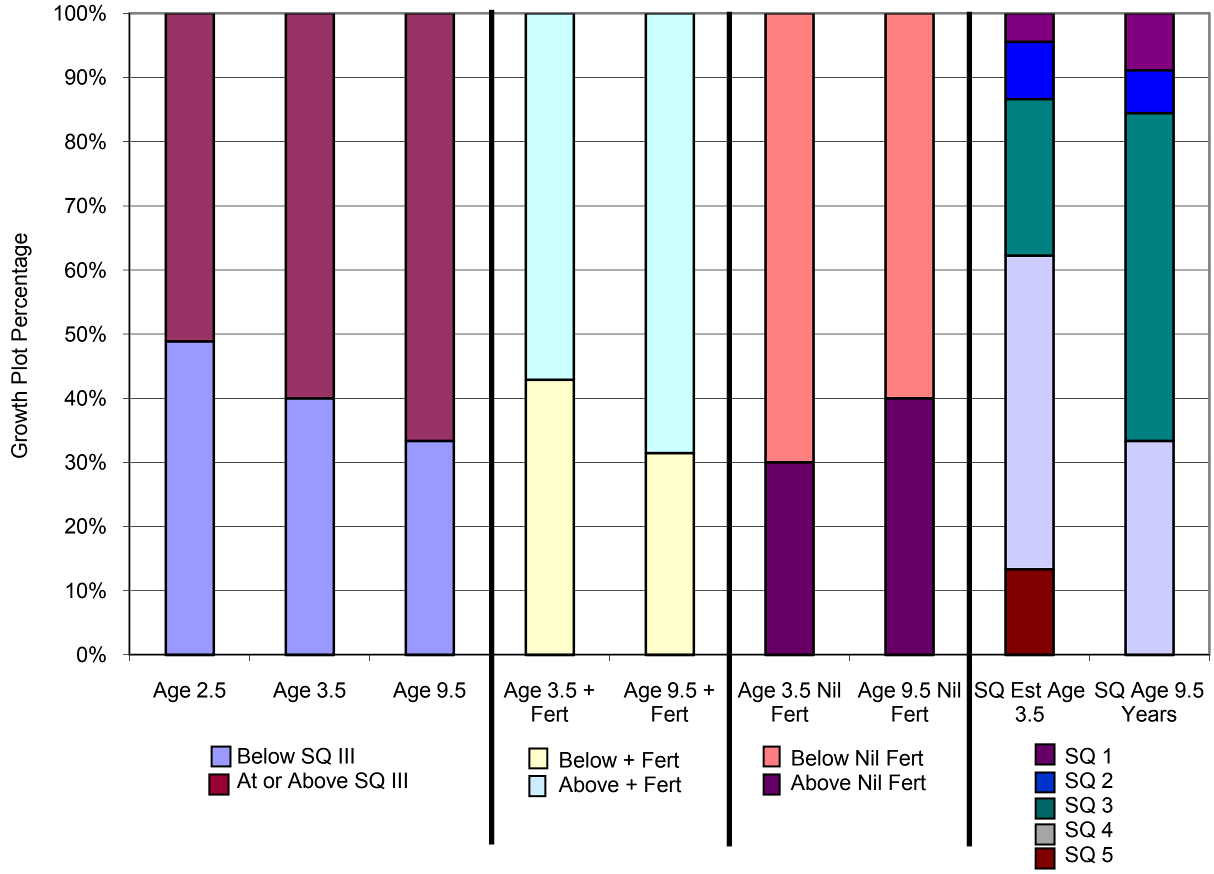

***Figure 7.* Kilbride Sand growth response (88 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

Killara Solodic Sand

Soil Description:

The Killara Solodic Sand is a soil from the Follett series of soils from the Killara sub system of the Follet Land System. It is characterised by having a dark grey (medium) sandy loam to sand A1 horizon of approx 10 – 20 cm deep, light grey sand A2 horizon of approx 20 - 30cm overlying a dark brown medium to heavy clay B horizon. This soil has limited vertical drainage potential due to its shallow depth and heavy clay B horizon. This soil will require ripping and mounding and can be expected to produce a SQ III - IV radiata pine provided optimal weed control options are utilised during the establishment phase.

Young Age Fertiliser Response:

ForestrySA has only 29.2 ha of Killara Solodic Sand in its plantation estate which is 0.029% of the plantation area and no young age growth plots have been established on this soil type at the time of the production of this report so it has not been included in Tables 2 & 3. No growth plot data is available to draw any conclusions about the fertiliser response potential on this soil type.

<u>Kromelite Sand</u>

Soil Description:

The Kromelite sand is a well drained, fertile iron nomopodsol whose parent material is aeolian sand. Kromelite sand is a truncated yellow dune sand characterised by its grey non coherent sand A1 horizon with a moderate content of fairly coarse organic matter overlying up to 90 cm of light grey sand A2 which overlays a B1 horizon of approximately 60 cm of grey sandy clay loam above a B2 of mottled yellow and grey structureless sandy clay to clay approximately 60 cm deep. It is part of the Caroline sand complex and is associated with dune ranges. Kromelite sand can be expected to produce SQ I radiata pine.

Young Age Fertiliser Response:

A total of 18 growth plots were available for this study of which 6 (33%) were below the SQ III aiming point at age 2.5 years. A total of 2 of these plots were fertilised with both realising a growth response following fertiliser application raising site productivity above the SQ III threshold. All of the remaining 4 plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser also reached the SQ III threshold at age 9.5 years. A total of 13 of the 18 growth plots in this study have reached site quality assessment age (9.5 years) and have an average SQ of I-. There is a very high probability that Kromelite Sand will reach SQ III and above without young age fert application. In ex bracken areas and following drought years' fert application is recommended.

<u>Lake Edward Peat</u>

Soil Description:

ForestrySA has 18.1 ha (0.018% of the total ForestrySA estate) of peat soil at Lake Edward which is under conservation management. Peat soils in the Green Triangle Region are unsuitable for plantation establishment to radiata pine or Tasmanian blue gums due to their very high inherent soil pH and saturated soil condition during winter.

<u>Lowan Sand</u>

Soil Description:

The Lowan sand is an eroded and degraded iron nomopodsol of the Nangwarry sand complex associated with low lying areas of impeded drainage in the Nangwarry and Kalangadoo areas of the Green Triangle. It is characterised by its grey non-coherent sand A1 horizon containing moderate amounts of organic matter of approximately 10 cm; overlying 15 – 45 cm of grey to light grey sand in the A2; above approximately 30 cm of yellowish grey sand with large amounts of organic cemented gravel which can form an impenetrable hardpan B1 horizon. The B2 consists of an unrelated clay 60 – 180cm deep of mottled yellow, yellow brown, light grey, grey and brown with abundant red inclusions. The Lowan sand is a wet soil that requires ripping (if the organic hardpan can be reached) and mounding for plantation establishment. It can be expected to grow site quality III – IV radiata pine.

Young Age Fertiliser Response:

A total of 11 growth plots were available for this study of which 10 (91%) were below the SQ III aiming point at age 2.5 years. A total of 6 of these plots were fertilised with none realising a large enough growth response following fertiliser application to raise site productivity above the SQ III threshold. All of the remaining 4 plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years. Insufficient growth plot data is available to draw conclusions on potential fertiliser responses. Fertiliser application is recommended on the elevated better drained Lowan sand sites. In the low lying Lowan sand areas with impeded drainage the addition of supplementary nutrition is unlikely to provide an economic growth response.

<u>Millicent Clay (Black Rendzina/ Unnamed Rendzina)</u>

Soil Description:

An often very shallow, black friable clay to clay loam overlying Miocene limestone. Characterised by its cracking surface during drought months this can vary greatly in depth from a few cm over limestone to 2 m in depth over heavy black clay. This soil often is too wet and shallow to support economic radiata pine or Tasmanian blue gum plantations and is subject to seasonal inundation during heavy winter rain. There are two distinctive Millicent Clay types these being the normal surface cracking Millicent Clay and the degraded grey surface Millicent Clay which is sometimes referred to as an unnamed Rendzina.

<u>Mingbool Sand</u>

Soil Description:

The Mingbool sand is a Solodic soil, often <1m in depth associated with the fringes of dune ranges and flat plains of impeded drainage. It is of moderate fertility and will grow SQ III radiata pine on the better drained sites. Nutrition is not the primary limiting factor to plantation productivity. Impeded drainage is the primary limiting factor to growth on this soil type.

Young Age Fertiliser Response:

ForestrySA has only 1.3 ha of Mingbool sand in its plantation estate which is 0.0001% of the plantation area and no young age growth plots have been established on this soil type at the time of the production of this report so it has not been included in Tables 2 & 3. No growth plot data is available to draw any conclusions about the fertiliser response potential on this soil type.

<u>Mount Burr Sand</u>

Soil Description:

The Mt Burr Sand is a deep (up to 6 m+ to clay on the Mt Burr dune range), well drained, fertile iron nomopodsol whose parent material is aeolian sand. It is part of the Mt Burr sand complex and will generally grow SQ II radiata pine provided adequate weed control is undertaken at establishment. The Mt Burr sand is characterised by its A1 horizon of approximately 20 cm of grey or brown non coherent sand; overlying up to 60 cm of leached light grey sand A2; above 30 – 150 cm (up to 5m on the deep phase dunes) of light yellow to yellow non coherent sand A3. The underlying B1 horizon contains approximately 30 cm of brown organic cemented gravel with some yellow sand above a B2 of approximately 30 cm of brown yellow brown structureless sandy clay-loam to sandy clay.

Young Age Fertiliser Response:

A total of 270 growth plots were available for this study of which 67% (181 plots) were below the SQ III aiming point at age 2.5 years. A total of 151 of these plots were fertilised with 97 (64%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 21 (70%) plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years.

Of the 270 growth plots in this study 152 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 8*. The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years. The number of plots which received fertiliser and were below the SQ III aiming point after the 3.5 year measurement decreased by age 9.5 years as did the number of plots that were below SQ III at age 3.5 years and did not receive fertiliser. This would indicate that that there is a high probability that radiata pine growing on a Mt Burr sand will reach the SQ III aiming point and above without young age fertiliser application. Fertiliser application is recommended for this soil type especially on ex bracken areas and following drought years.

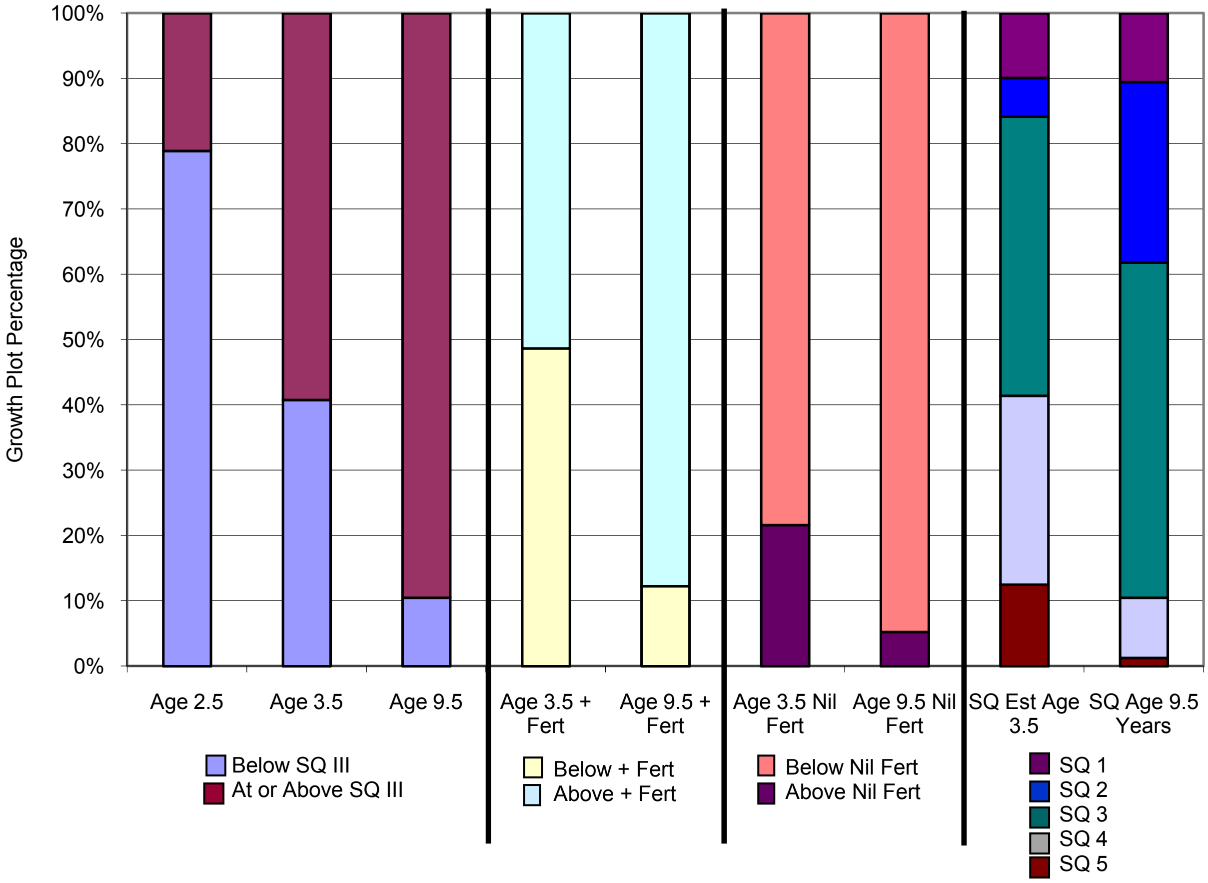

***Figure 8.* Mt Burr Sand growth response (152 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

<u>Mount Muir Sand</u>

Soil Description:

The Mt Muir sand is a well drained, fertile sandy soil whose parent material is aeolian sand mixed with eroded volcanic or terra-rossa soils. The Mt Muir sand forms part of the Mt Burr soil complex. Stephens et al (1941) classified the Mt Muir as a “weak podsol” but this classification has been revised to a terra-rossa in the ForestrySA 2003 publication Green Triangle Forest Soil Profiles (Winkley & Richardson, 2003). It is part of the Mt Burr sand complex and will generally grow site quality II radiata pine provided adequate weed control is undertaken at establishment. The Mt Muir sand is characterised by its grey-brown to grey non-coherent sand A1; brown to yellowish-brown non-coherent sand A2 of 30-60 cm in depth which can contain slight amounts of organic cemented gravel and ironstone in the lower few centimetres of the horizon; overlaying up to 60 cm of brown to red brown sandy clay-loam to sandy clay in the B1 horizon.

Young Age Fertiliser Response:

A total of 38 growth plots were available for this study of which 25 (66%) were below the SQ III aiming point at age 2.5 years. A total of 17 of these plots were fertilised with 12 (71%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 5 plots (62%) of those that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years. Fertiliser application is recommended on this soil type due to the recorded high growth response in this study. This may seem anomalous given the inherent fertility of this soil, its depth, drainage and the rainfall zone (750 – 800 mm) it is normally found in which indicate there is a high probability that this soil type will reach the SQ III threshold without the addition of young age fertiliser (provided optimal weed control and planting practices are utilised at plantation establishment). However as this is a high productivity soil type the economic return potential of increasing the growth response from 62% without the addition of young age nutrition to 71% with young age nutrition warrants a recommendation to fertilise based upon the data available in this study.

<u>Myora Sand</u>

Soil Description:

The Myora Sand is a humus nomopodsol which forms part of the Caroline Soil complex. It has two distinct variants a dry phase which is mostly associated with the dune ranges but can be found on the better drained flats of northern Myora extending across the South Australian / Victorian border and the swampy phase Myora which is associated with lower lying areas of impeded drainage and swamp edges in the Mingbool to Peweena (S.A) and Ardno to Puralka (Western Vic) areas. The dry phase Myora is characterised by its grey to light-grey sand A2 horizon (30 -120 cm), overlaying approximately 60cm of light yellowish grey sand (which is absent in the swampy phase), which overlays a dark organic stained B1 horizon of approximately 45 cm. The B1 layer can take the form of a dark brown/black softpan or hardpan which will often contain large amounts of organic compacted gravel (coffee rock). Where drainage is adequate it can be expected to grow site quality II – III radiata pine.

The swampy phase Myora is characterised by its dark grey non coherent sand A1 with moderate amounts of fairly coarse organic matter up to 50 cm overlying a leached grey to light-grey sand A2 horizon (30 -120 cm), overlaying a dark organic stained B1 horizon of approximately 45 cm. The B1 layer can take the form of a dark brown/black softpan or hardpan which will often contain large amounts of organic compacted gravel (coffee rock). The underlying B2 layer contains 60-90 cm of light yellowish grey structureless sandy clay-loam. The wet phase Myora sand can be expected to grow site quality VII - III dependent upon the level of drainage.

Young Age Fertiliser Response:

A total of 45 growth plots were available for this study of which 17 (38%) were below the SQ III aiming point at age 2.5 years. All of the 17 plots below the SQ III aiming point were fertilised with 12 (71%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. Fertiliser application is recommended for the dry phase Myora sand where soil drainage is not the primary limiting factor to site productivity. Fertiliser application is not recommended for the swampy phase Myora sand where impeded drainage is the primary limiting factor to site productivity.

Nangwarry Sand

Soil Description:

The Nangwarry sand is a low fertility iron nomopodsol whose parent material is resorted aeolian sand. Drainage of the Nangwarry sand varies considerably dependent upon the local topography. On the few dune rises in the Nangwarry forest area drainage will be good but in the majority of the flat Nangwarry range drainage in the lower lying areas can be impeded requiring the mounding of this soil type for plantation establishment. Nangwarry sand is characterised by its grey non coherent sand A1 of approximately 15 cm; up to 60 cm of light grey non coherent sand A2; overlaying 30 – 150 cm of light yellow to yellow sand A3; which overlays a B1 horizon of approximately 30 cm containing brown organic cemented gravel with some yellow sand. The B1 is sometimes underlain by another yellow sand layer. The B2 horizon contains 60 – 180 cm of mottled yellow, yellow brown, light grey, grey and brown clay with abundant red inclusions. It is part of the Nangwarry sand complex and is associated with the flat Nangwarry – Kalangadoo plain. Nangwarry sand can be expected to grow an average site quality III radiata pine provided adequate weed control and the appropriate site preparation is undertaken at establishment.

Young Age Fertiliser Response:

A total of 88 growth plots were available for this study of which 63% (55 plots) were below the SQ III aiming point at age 2.5 years. A total of 39 of these plots were fertilised with 19 (49%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 10 (62%) plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years.
Of the 88 growth plots in this study 71 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 9*. The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years. The number of plots which received fertiliser and were below the SQ III aiming point after the 3.5 year measurement increased slightly by age 9.5 years as did the number of plots that were below SQ III at age 3.5 years and did not receive fertiliser. This would indicate that while the addition of young age fertiliser between ages 2 – 4 years increased average site productivity across the plots included in this study it did not maintain the level of increased productivity on all sites up until age 9.5 years. A large number of factors including drought, essigella induced needle loss, poor drainage on some sites or unidentified nutrient deficiencies could be the cause in this reduction in growth.

Young age fertiliser application is recommended for this soil type.

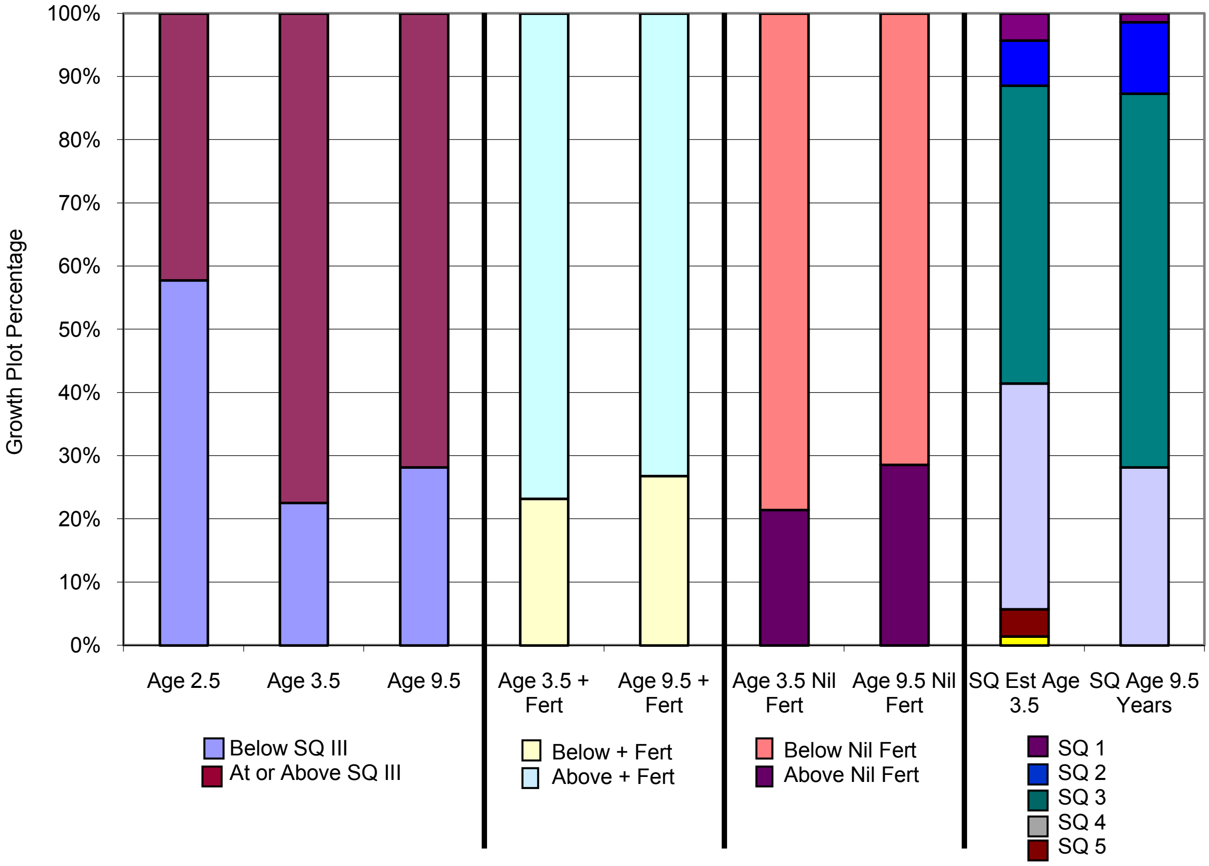

Figure 9. **Nangwarry Sand growth response (71 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

<u>Noolook Grey Sand</u>

Soil Description:

The Noolook Grey sand is a well drained, shallow iron nomopodsol or iron leptopodsol (depending upon depth) whose parent material is aeolian sand. The Noolook Grey sand is from the Noolook soil association and is characterised by its greyish brown sand A1 of 0-20 cm; light grey to brown non coherent sand A2 of between 20 -30 cm in depth overlying a B1 horizon of 30 – 40 cm of structureless brown to yellow brown clayey sand which sits on a C horizon of miocene limestone up to 100 cm deep. The Noolook Grey sand can be expected to grow site quality II – III radiata pine dependent upon the soil depth.

Young Age Fertiliser Response:

Insufficient data is available to draw any conclusions about the fertiliser response potential on this soil type.

<u>Noolook Red Sand</u>

Soil Description:

The Noolook Red sand is a fertile, shallow, often less than 30cm to limestone, dark yellowish brown to red brown sand over limestone terra rossa whose parent material is Miocene limestone. It can have a very shallow layer of clayey sand – sandy clay immediately above the parent material in its deeper phases. The Noolook Red sand is from the Noolook soil association and is characterised by its red brown sandy surface with limestone floaters visible above the surface in its deeper phases. Site productivity on the Noolook Red sand varies from site quality I to unsuitable depending upon its depth and inherent pH which can range from within the optimal range for nutrient availability, pH 4.5 – pH 6.7 for radiata pine to pH 8.

Young Age Fertiliser Response:

A total of 16 growth plots were available for this study of which 12 (75%) were below the SQ III aiming point at age 2.5 years. A total of the 10 plots below the SQ III aiming point were fertilised with 4 (40%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. Neither of the 2 remaining plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold at age 9.5 years. Fertiliser application is not recommended for this soil type as shallow soil depth and in specific locations high inherent pH are the primary limiting factors to growth. The addition of supplementary nutrition will not remediate these limitations on growth.

Noolook Yellow Sand

Soil Description:

The Noolook Yellow sand is a well drained, iron nomopodsol whose parent material is aeolian sand. The Noolook Yellow sand is from the Noolook soil association and is characterised by its greyish brown to brownish yellow sand A1 of 0-20 cm; brownish yellow to pale yellow fine sand A2 up to 130 cm in depth overlying a B1 horizon of up to 50 cm of brownish yellow to strong brown sand clayey sand which sits on a C horizon of miocene limestone. The B1 horizon may be absent in some profiles. The Noolook Yellow sand grows site quality I – V radiata pine dependent upon soil depth and rainfall availability during the establishment phase. It can generally be expected to grow site quality III - IV radiata, with average performance on sites that have received a site quality assessment at age 9.5 years being SQ III.

Young Age Fertiliser Response:

A total of 37 growth plots were available for this study of which 28 (76%) were below the SQ III aiming point at age 2.5 years. A total of 27 plots below the SQ III aiming point were fertilised with 5 (19%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold.

Of the 37 growth plots in this study 26 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 10.* The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years.

Rainfall zone 600 – 650 mm is the primary limiting factor to growth on this soil type. The probability of a fertiliser response based upon the data available for this study is low. Given the characteristics of the Noolook Yellow sand of depth, water holding potential, drainage and inherent fertility there is a reasonable probability that it will respond to the addition of supplementary nutrition if it receives above average rainfall. Fertiliser application is recommended for the Noolook Yellow sand on a medium priority with the key decision factor being seasonal rainfall levels.

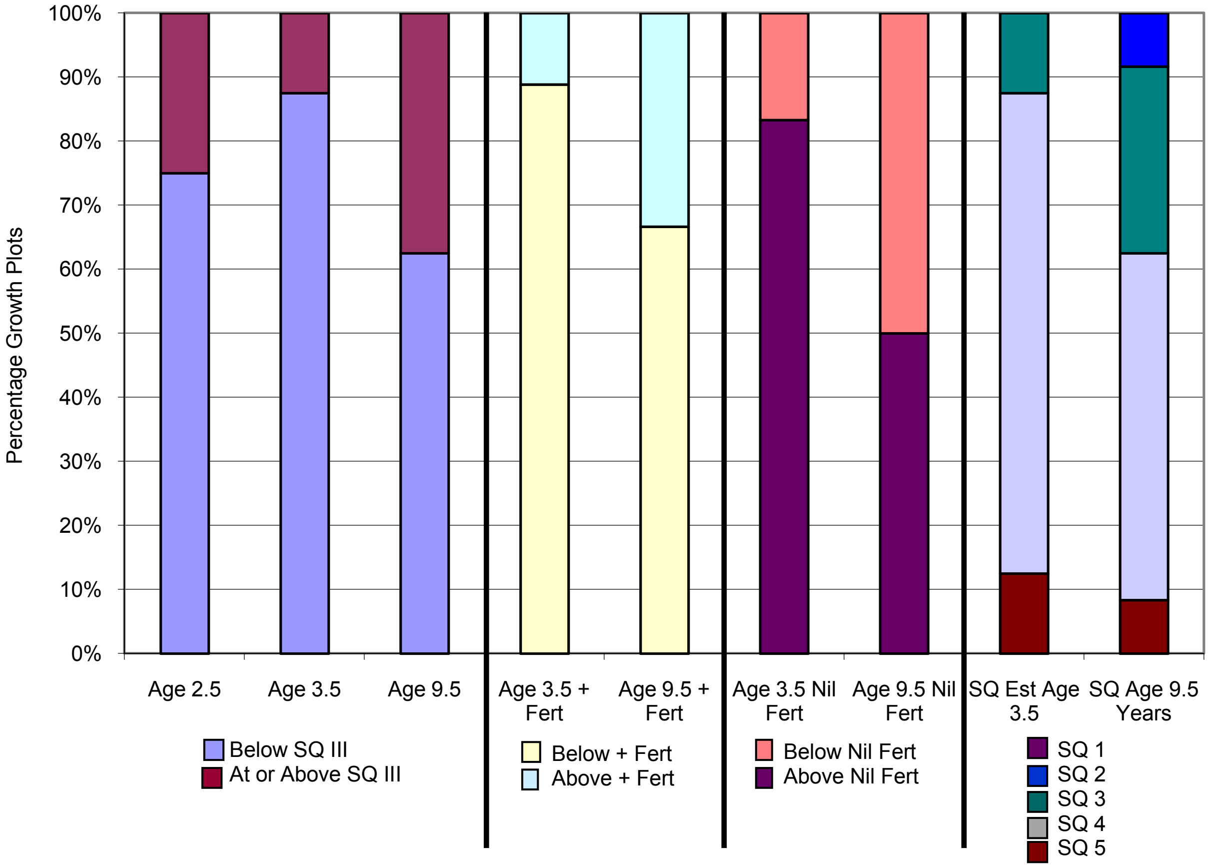

Figure 10. **Noolook Yellow Sand growth response (26 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

<u>Red Basaltic</u>

Soil Description:

The Red Basaltic is a transitional krasnozem which is associated with volcanic activity and has a known occurrence in the vicinity of the Mt Burr range, Mt Gambier and Mt Schank in the lower south east of South Australia. Red Basaltic soils will be encountered in Western Victoria also associated with previous volcanic flows. The Red Basaltic is well drained high productivity soil of volcanic origin. It is characterised by its dark brown loam A1 of approximately 40 cm; dark yellowish brown loam B1 of between 40 – 120 cm in depth with occasional large floaters or boulders of weathering basalt. The B1 horizon is sometimes underlain by a yellowish brown loamy B2 horizon. The C horizon which is often 120 cm+ in depth is made up of basaltic floaters and weathered basalt grains which increase in frequency with depth until the basalt hardpan parent material is reached,

Young Age Fertiliser Response:

A total of 18 growth plots were available for this study of which 7 (39%) were below the SQ III aiming point at age 2.5 years. A total of 6 plots below the SQ III aiming point were fertilised with all 6 (100%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. It is interesting to note that the single remaining growth plot below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached SQ I at age 9.5 years. Fertiliser application is not recommended for this soil type as it has the highest inherent fertility of any of the soil types included in this study and does not require supplementary nutrition to reach the SQ III aiming point.

Reedy Creek Brown Sand

Soil Description:

The Reedy Creek Brown Sand is a very fertile iron leptopodsol of up to 90 cm in depth to its water retentive clay layer that is part of the Reedy Creek soil association. It is characterised by its grey-brown loamy sand A1 horizon overlaying a pale brown to brown sand A2 of 10 – 30 cm in depth above a leached pale brown sand A3 of 10 – 50 cm in depth that transitions into a clayey sand to sandy clay B1. The Reedy Creek Brown Sand grows SQ I radiata pine.

Young Age Fertiliser Response:

A total of 7 young age growth plots were available for this study with all 7 (100%) being above the SQ III aiming point at age 2.5 and 3.5 years. None of these plots were fertilised. All 7 plots have reached SQ I at site quality assessment age (9.5 years). Radiata pine growing on the Reedy Creek Brown Sand has the highest stand productivity of any plantation on ForestrySA land. Fertiliser application is not recommended for this soil type.

Richmond Sand

Soil Description:

The Richmond Sand is a humus nomopodsol from the Follet Land System of south western Victoria. It is of moderate fertility and is characterised by its leached A2 horizon overlying an organic stained layer of accumulation (dark brown – black in colour) which can form a hardpan in its swampy phase and may contain varying amounts of organic compacted gravel (coffee rock) which can form a root impeding layer in its better drained dry phase. It is a soil which requires both ripping and mounding in its wet or swampy phase and may require ripping if a hard pan is present and within ripping depth in its dry phase. Given adequate weed control and high mounds in its wet phase Richmond sand can be expected to produce site quality III pinus radiata and in its dry phase it can produce site quality II –III.

Young Age Fertiliser Response:

No data is available to draw any conclusions on potential fertiliser response based upon the growth plot information available. Based upon the soil characteristics of the Richmond sand and the higher rainfall zones where it is normally found it can be expected to respond to fertiliser application in its dry phase, provided there is adequate rainfall but may not respond to young age fertiliser on excessively wet sites where impeded drainage is the primary limiting factor to growth.

Riddoch Sand

Soil Description:

A shallow, generally less than 0.5 m to water retentive layer deep solodic soil with sharply defined sand A and clay B horizons. Characterised by its pale grey A2 horizon and columnar clay in its B1 over limestone. Riddoch Sand is a wet soil that can grow site quality II - I radiata pine if mounded and well drained. If not adequately drained or if weed control is suboptimal it can struggle to produce site quality V radiata pine plantations. The Riddoch sand is associated with areas of impeded drainage with its shallow depth and poor drainage being the primary limiting factors to site productivity.

Young Age Fertiliser Response:

A total of 16 growth plots were available for this study of which 7 (44%) were below the SQ III aiming point at age 2.5 years. A total of 4 plots below the SQ III aiming point were fertilised with 3 (75%) realising a growth response following fertiliser application raising site productivity above the

SQ III threshold. This is insufficient growth plot data to draw conclusions about the fertiliser response potential of this soil.

Of the 16 growth plots in this study 11 have reached site quality assessment age (9.5 years). A total of 5 plots were below the SQ III aiming point at age 2.5 years and 6 plots were above the SQ III aiming point. None of these 11 growth plots are below the SQ III threshold with the average site quality being slightly better than SQ II. This is an unexpected result given the physical characteristics of this soil type. Impeded drainage is the primary limiting factor to plantation growth on this soil which in wet years can be inundated with ground water for extended periods. Where this soil is present at an elevated or well drained site it can be expected to respond to fertiliser application.

<u>Short Sand</u>

Soil Description:

Short sand is a fertile humus nomopodsol associated with the relatively flat but slightly undulating plains of Wattle Range area of South Australia. Its parent material is resorted aeolian sand spread over Miocene limestone and varies considerably in depth to clay and sub-soil horizon structure. It is characterised by a black or brown organic stain in its B1 horizon found at varying depths from 0.4 – 1.0 m. This organic stain layer mostly contains varying amounts of ironstone gravel and often forms an impenetrable hardpan. It is a soil associated with impeded drainage and will require ripping (If a hardpan is present and within ripping depth) and large mounds for the economic establishment of radiata pine and Tasmanian blue gum plantations. Short sand will routinely grow site quality I – II radiata pine provided it is adequately mounded on its wetter sites and adequate weed control is used on its drier sites.

Young Age Fertiliser Response:

A total of 65 growth plots were available for this study of which 42% (27 plots) were below the SQ III aiming point at age 2.5 years. A total of 19 of these plots were fertilised with 10 (53%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 6 (75%) of the 8 plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold. Included in the growth plots of this study were 7 established in the ForestrySA 2002 and 2003 plantations at Wattle Range on a previously flood irrigated site. The soil pH in these growth plots was well above the acceptable level for optimal nutrient availability (due to the impacts of irrigation which had deposited high levels of calcium bicarbonate on the soil surface) which has significantly impacted on tree survival and growth and negated any effective response to the fertiliser regime applied.

Of the 65 growth plots in this study 23 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 11*. The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years. The number of plots which received fertiliser and were below the SQ III aiming point after the 3.5 year measurement did not change by age 9.5 years. It is interesting to note that the single growth plot that was below SQ III at age 3.5 years and did not receive fertiliser reached SQ I at age 9.5 years.

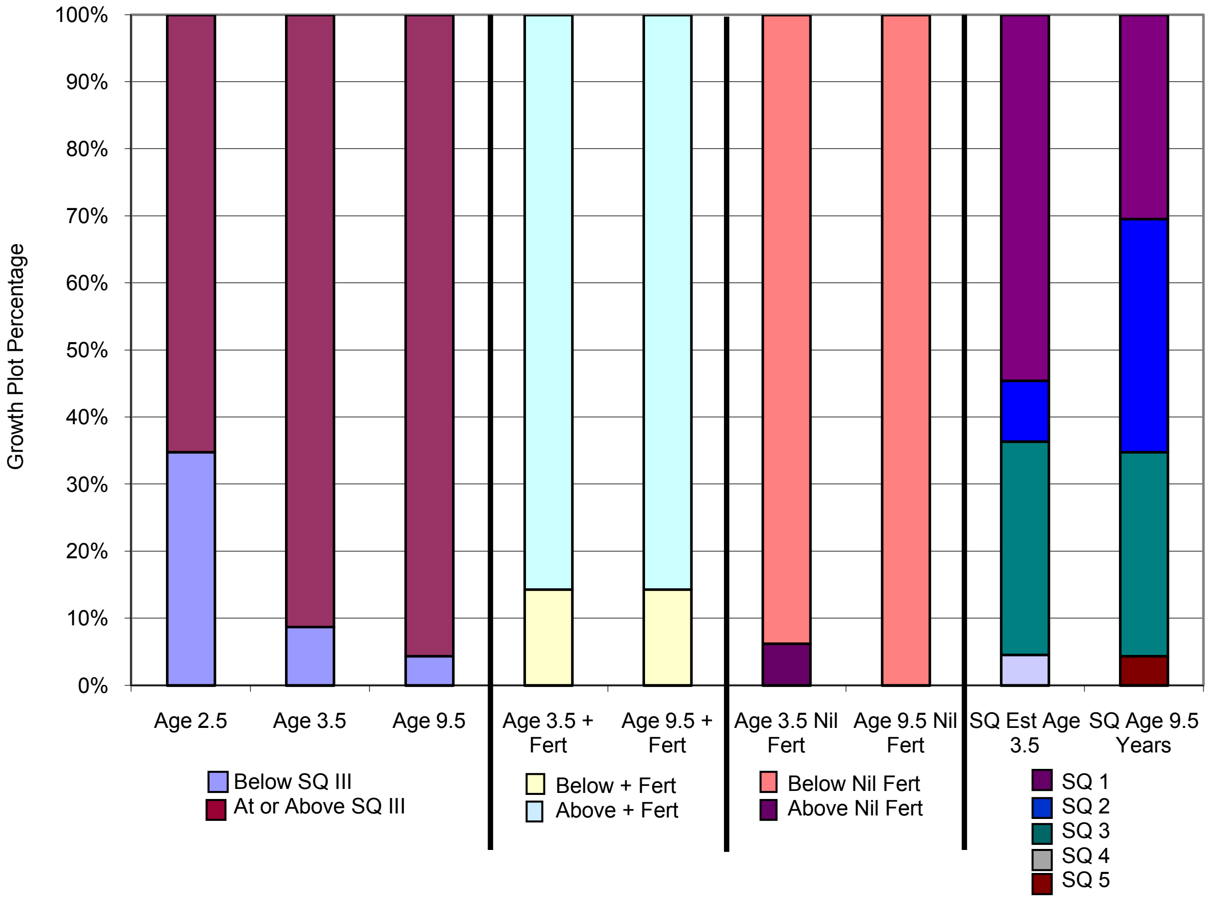

Figure 11. **Short Sand growth response (23 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

Results from the ForestrySA research trial LT236 (Richardson 2007) which was designed to investigate the effect of fertiliser applications at different ages on growth of *Eucalyptus globulus* plantations in the Wattle Range area show that Tasmanian blue gums can have an economic response to the application of young age fertiliser at age 2 years on a Short sand. No fertiliser response was measured following the application of fertiliser at age 1 year but a minimum 20% increase in total stem volume growth above the nil control was measured following the application of fertiliser at age 2 years (*Figure* 12).

While there is a very high probability that radiata pine growing on Short sand will reach the aiming point of a minimum of site quality III at age 9.5 years without the addition of supplementary nutrition, young age fertiliser application is recommended for this soil type based upon the confirmed fertiliser response recorded in LT236. Results from 7 young age fertiliser trials conducted with Tasmanian blue gums since 1990 on 17 sites and 10 different soil types within the Green Triangle Region have strongly indicated that the factors that limit or enable a young age fertiliser response in radiata pine are the same factors with Tasmanian blue gums.

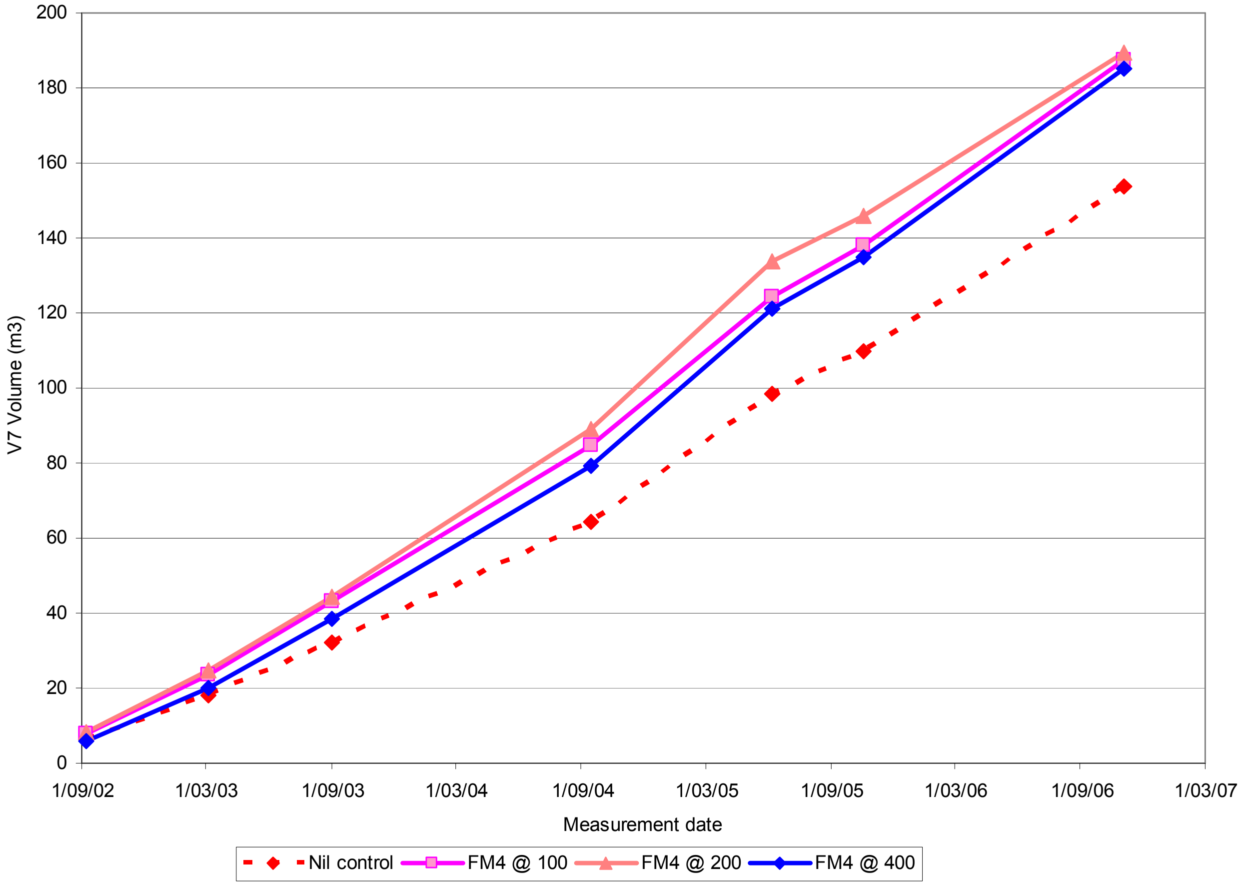

***Figure 12.* LT236C V7 volume (m^3/ha) at treatment + 49 months (age 6.3 years) showing the growth response of Tasmanian blue gum growing on a Short sand to the application of varying rates of FM4 fertiliser at age 2 years.**

Swamp Soil / Sandy Swamp Soil

Soil Description:

The Sandy Swamp Soil is a poorly drained, wet soil often associated with swamps, swamp margins and areas of seasonal inundation and will require large mounds for the establishment of radiata pine or Tasmanian blue gum plantations. Characterised by its dark grey sand A1 often up to 40 cm overlying leached grey sand A2 (40 - 70 cm thick approximately) which overlies a grey brown sand (layer of accumulation) A3.
The Swamp Soil is a very shallow <0.5m Solodic soil. This soil has a dark brown to black loamy A horizon that often contains organic matter, overlying a dark brown to black medium to heavy textured clay B horizon. The Swamp Soil is a poorly drained, wet soil often associated with swamps, swamp margins and areas of seasonal inundation and will require large mounds for the establishment of a Pinus radiata plantation.

ForestrySA has 3% of its total forest estate (both plantation and native forest reserve) in the Green Triangle Region identified as either Swamp Soil or Sandy Swamp Soil on its GIS soils coverage layer. Neither of these soil types are generally suitable for economic plantation establishment due to their level of impeded drainage and/or their value as designated wet lands of environmental significance.

Tantanoola Flinty Sand

Soil Description:

The Tantanoola Flinty Sand is a pediological oddity being a well drained iron leptopodsol to iron nomopodsol depending on depth which contains massive inclusions of flints varying in size from centimetre diameter fragments to boulders a metre plus in diameter. The Tantanoola Flinty Sand is an extremely fertile, high productivity soil type which is not generally limited by low soil nutrition. The primary limiting factor to plantation growth is depth of soil (rooting depth and water holding capacity). Effective rooting depth is very variable and ranges from 30cm to 200 cm +. The Tantanoola Flinty Sand is characterised by its dark grey to dark brown sand to sandy loam A1 of approximately 10 cm overlying a light grey to grey sand A2 of 10 – 200+ cm with massive flint gravel or flint inclusions overlaying approximately 30 cm of dark brown and grey brown mottled slightly structured clay with calcium carbonate in the last few centimetres. It will grow site quality I to VI radiata pine dependent upon the soil depth but averages SQ II.

Young Age Fertiliser Response:

A total of 92 growth plots were available for this study of which 30 (33%) were below the SQ III aiming point at age 2.5 years. A total of the 11 plots below the SQ III aiming point were fertilised with 5 (45%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 11 out of 19 (58%) plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold.
Of the 92 growth plots in this study 40 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 13.* The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years. A total of 10 plots were below the SQ III aiming point at age 3.5 years. A total of 3 of these plots received fertiliser with all reaching the minimum SQ III point at age 9.5 years. Of the remaining 7 plots 6 reached SQ III and above at age 9.5 years without young age fertiliser.

Young age fertiliser application is not recommended for this soil type. The primary limiting factor to growth on the Tantanoola Flinty Sand is soil depth and the application of supplementary nutrition will not remediate this factor.

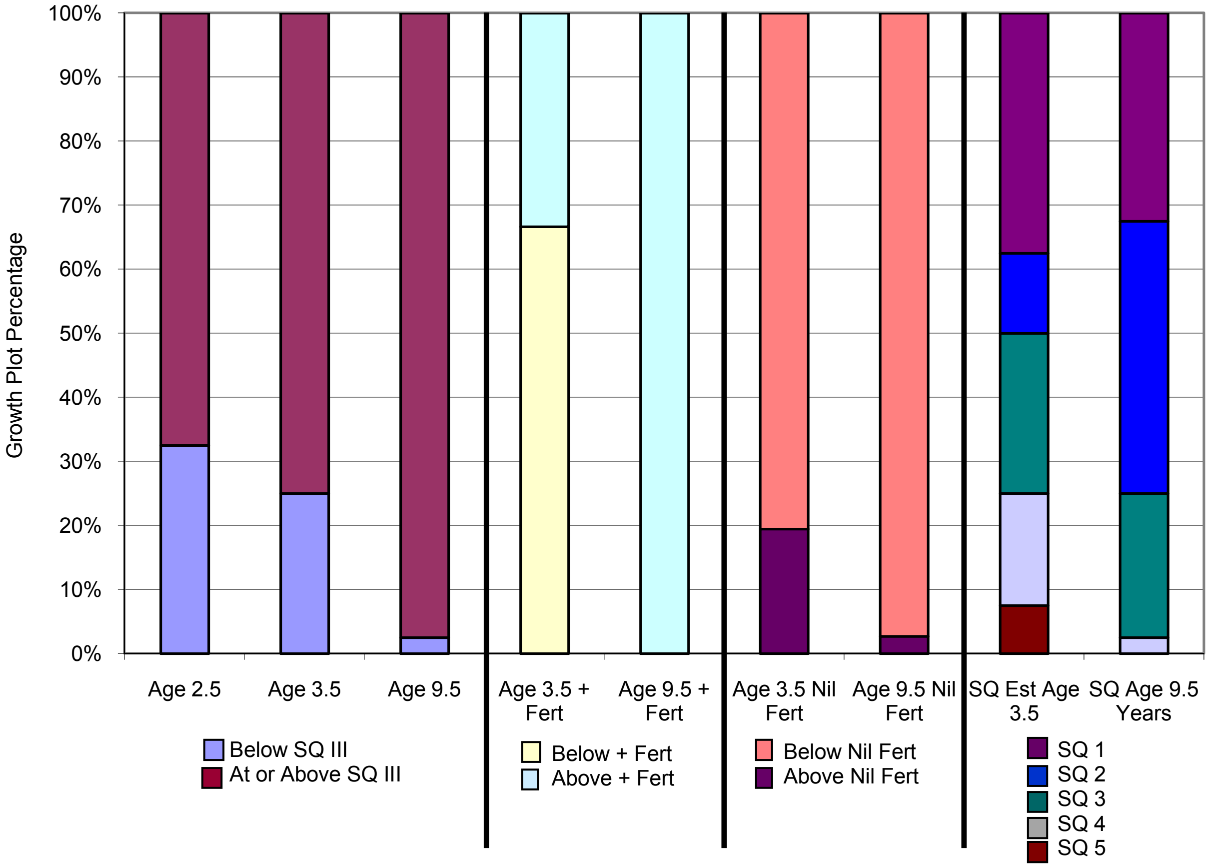

Figure 13. **Tantanoola Flinty Sand growth response (40 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

<u>Wandilo Sand</u>

Soil Description:

The Wandilo Sand is a humus nomopodsol which is primarily associated with the impeded drainage transition zone between the dune ranges of Mt Burr and Mt Gambier Forests and the flats of Wattle Range and Peweena/Mingbool in South Australia and the dunes of Myora (South Australia) and Rennick Forests and the flats of Ardno and Puralka in South Western Victoria. The Wandilo Sand is characterised by its dark grey to brown grey A1 horizon of approximately 25 cm; light brown-grey or yellowish brown-grey A2 horizon overlaying approximately 30cm of organic stained sand or hardpan B1, which will often contain large amounts of ironstone gravel. This layer or the ironstone gravel are occasionally absent from the soil profile. The B2 horizon contains up to 120 cm of yellow brown and grey clay with red inclusions This clay is somewhat structured and contains calcium carbonate in the last few centimetres. This is mostly a soil associated with impeded drainage and low phosphorus availability. It will grow site quality II – III radiata pine if adequately drained and mounded prior to planting.

Young Age Fertiliser Response:

A total of 58 growth plots were available for this study of which 31 (53%) were below the SQ III aiming point at age 2.5 years. A total of 27 plots below the SQ III aiming point were fertilised with 14 (52%) realising a growth response that raised site productivity above the SQ III threshold. A total of 3 out of 4 (75%) plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold.

Young age fertiliser application is recommended for the Wandilo Sand where adequately drained and mounded. Where associated with poor drainage the probability of a young age fertiliser response is low.

<u>Warrolong Sand</u>

Soil Description:

The Warrolong sand is a very fertile, well drained, sandy terra rossa whose parent material is Miocene limestone. The Warrolong sand is characterised by its dark brown slightly coherent sand A1 of approximately 15 cm, brown to red brown sand A2 of approximately 30 cm overlying a red brown to brown B1 horizon of 15 – 30 cm containing ironstone gravel which can range from a light scattering to a massive hardpan. The underlying B2 horizon is a yellowish brown coherent sand of very variable depth (20 – 120 cm) which sits on top of a B3 of 30 – 40 cm of yellow brown structureless sandy clay-loam to sandy clay. The Warrolong sand can be routinely expected to grow site quality I – II radiata pine.

Young Age Fertiliser Response:

A total of 89 growth plots were available for this study of which 27 (30%) were below the SQ III aiming point at age 2.5 years. A total of the 20 plots below the SQ III aiming point were fertilised with 18 (90%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 6 out of 7 (86%) plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold.
Of the 89 growth plots in this study 62 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 14.* The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years with all growth plots reaching SQ III and above at age 9.5 years with or without the application of young age fertiliser.

Young age fertiliser application is not recommended for this soil type as there is an extremely high probability that it will reach the SQ III aiming point without the addition of supplementary nutrition.

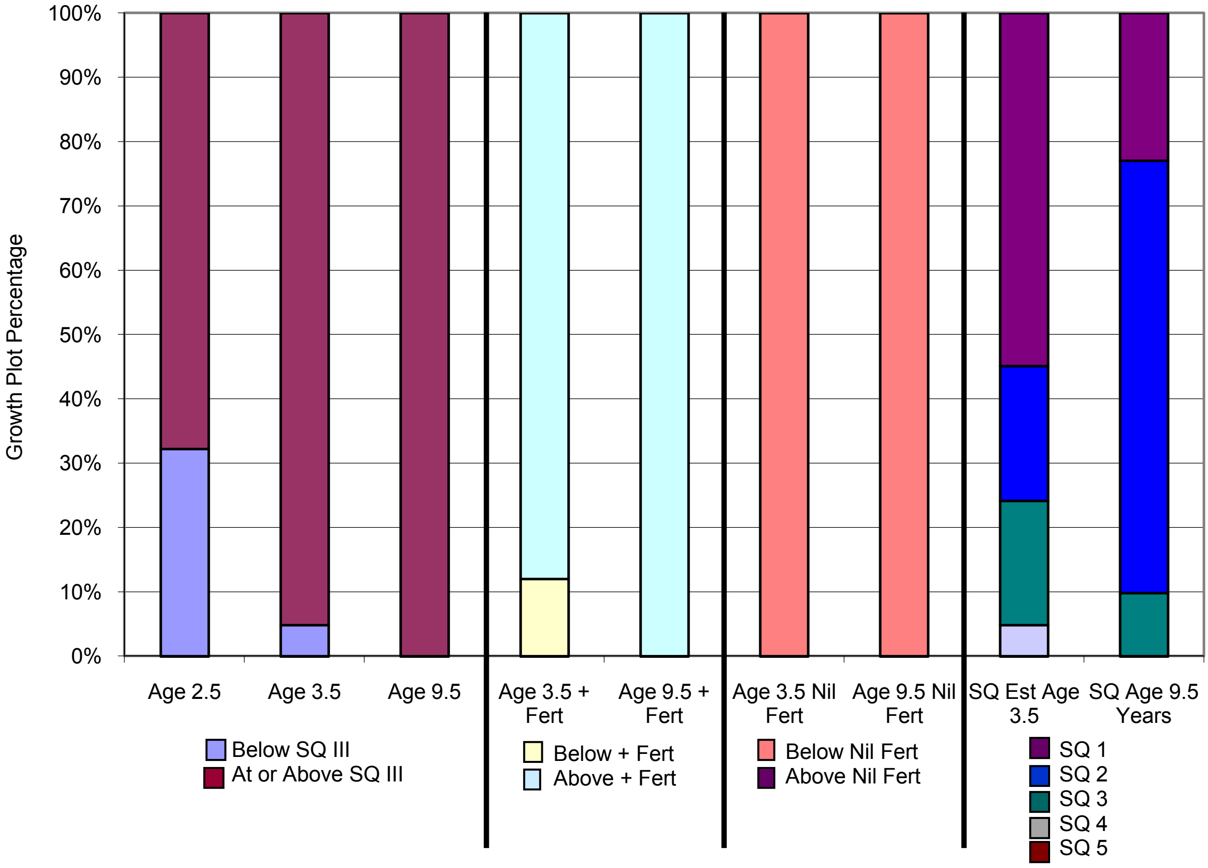

Figure 14. **Warrolong Sand growth response (62 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

<u>Young Sand</u>

Soil Description:

The Young sand is a low fertility humus nomopodsol whose parent material is aeolian sand. It is a low fertility soil which can be found in two distinct forms these being a dry phase deep soil of the dune ranges which is often associated with bracken fern and raised sand dunes, and a swampy phase associated with areas of seasonal inundation and impeded drainage such as swamp margins and flood plains. The Swampy phase is often unsuitable for economic plantation establishment. Young sand is characterised by its heavily leached, pale A2 horizon often 150 cm plus deep overlying a black and brown accumulation of organic matter which often forms a hardpan that is up to 60 cm thick. When bared off this soil has a tendency to “blow” resulting in the loss of surface organic matter and the sand blasting of seedlings. It can be expected to grow site quality IV - V P. radiata pine if the inherent low fertility is not supplemented.

Young Age Fertiliser Response:

A total of 141 growth plots were available for this study of which 103 (73%) were below the SQ III aiming point at age 2.5 years. A total of the 87 plots below the SQ III aiming point were fertilised with 40 (46%) realising a growth response following fertiliser application raising site productivity above the SQ III threshold. A total of 5 out of 16 (38%) plots that were below the SQ III aiming point at age 2.5 years that did not receive young age fertiliser reached the SQ III threshold.
Of the 141 growth plots in this study 91 have reached site quality assessment age (9.5 years). The growth responses from these plots, with and without the application of young age fertiliser are summarised in *Figure 15.* The results indicate that average site productivity significantly increased from age 2.5 years to age 9.5 years. A total of 54 plots were below the SQ III aiming point at age

3.5 years. A total of 45 of these plots received fertiliser with 18 (40%) reaching the minimum SQ III point at age 9.5 years. Of the remaining 9 plots 6 (66%) reached SQ III and above at age 9.5 years without young age fertiliser.

Young age fertiliser application is recommended for the dry phase Young sand since nutrition is a significant limiting factor to productivity, especially on previous bracken fern sites. Nutrition is also a significant limiting factor to growth on the swampy phase as was shown at the research trial EP117 (McGuire 1975) where a significant growth response was recorded following the application of phosphorus fertiliser. However if drainage is inadequate on the swampy phase the probability of an economic growth response is low.

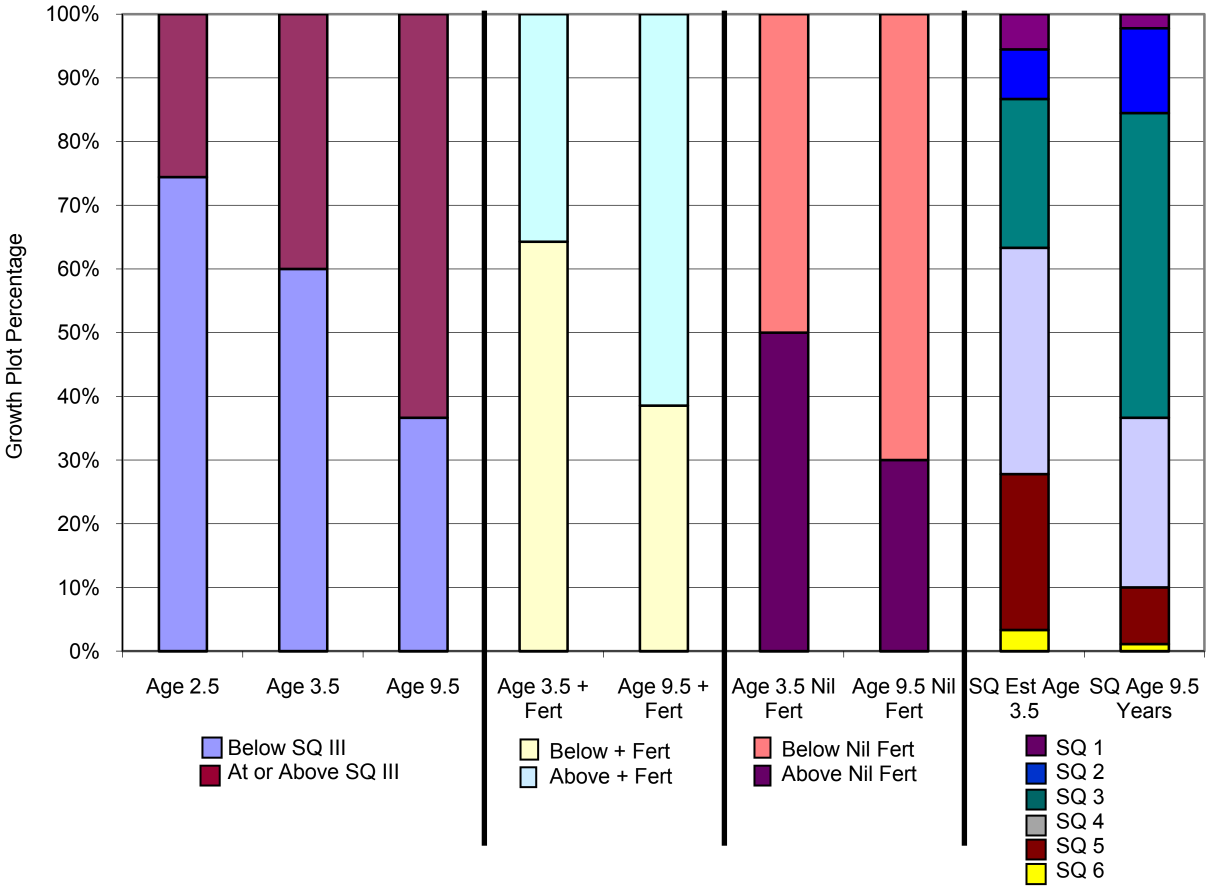

***Figure 15.* Young Sand growth response (91 young age growth plots that have had site quality assessment at age 9.5 years) and site quality at age 3.5 (young age SQ model estimate) and 9.5 years, plus or minus young age fertiliser application (age 2 to 4 years).**

RECOMMENDATIONS

The recommendations from EM188A are listed in Appendix I.

Wayne Richardson
Coordinator Research
December 2010

REFERENCES

Australian Bureau of Meteorology. (2008) *30 Year Average Rainfall Isohyets* (www.bom.gov.au/climate/map/rainfall/average-rainfall-metdata.pdf)

Cameron, A. (1993 - 1995) *Woods and Forests Annual Young Age Growth Plot Reports* (ForestrySA Research: Mount Gambier, Australia).

Gibbons, F. and Downes. R.G. (1964) *A study of the land in South West Victoria.* (Soil Conservation Authority Victoria, Australia)

Isbell, R.F. (1996) *The Australian Soil Classification* (CSIRO, Australia).

Lewis, N.B., Keeves, A. and Leech J.W. (1976) *Bulletin No 23 Yield Regulation in South Australian Pinus radiata Plantations* (Woods and Forests Department: Mount Gambier, Australia).

McGuire, D. (1975) EP117 *Pinus radiata and Pinus pinaster super phosphate fertiliser response trial.* (ForestrySA Research: Mount Gambier, Australia).

McGuire, D. (2005) EP204 *Influence of genotype and tree spacing on development of juvenile wood characteristics in radiata pine.* (ForestrySA Research: Mount Gambier, Australia).

Plantation Forestry Manual (2007) *Chapter 3 Nutrition* (ForestrySA: Mount Gambier, Australia).

Richardson, W. (1996 - 2009) *Annual GT Growth Plot Reports.* (ForestrySA Research: Mount Gambier, Australia).

Richardson, W. (2009) *EP235 Impact of initial stocking on P. radiata tree form, branch characteristics and wood quality in a low rainfall area of the Green Triangle, South Australia.* (ForestrySA Research: Mount Gambier, Australia).

Richardson, W. (2007) *LT236 Effect of fertiliser applications at different ages on growth of Eucalyptus globulus plantations in the Wattle Range area.* (ForestrySA Research: Mount Gambier, Australia).

Stephens, C.G., Crocker, R.L., Butler, B. and Smith, R. (1941) *A Soil and Land Use Survey of the hundreds of Riddoch, Hindmarsh, Grey, Young and Nangwarry, County Grey, South Australia.* (Bulletin No 142, CSIRO, Melbourne, Australia).

Shaw, S., Mattay, J. and Adams, P. (2002*) LT145 Long-term Growth Response to Patterns of Weed Control in Radiata Pine. .* (Proceedings of the 13th Australian Weeds Conference eds Spafford Jacobs, H., Dodd, J. and More, J.H., pp. 39-42 (Plant Protection Society of Western Australia, Perth).

Thomas, K. (2009) *EP240 Performance comparison of containerised Vs open rooted seedlings and cuttings radiata pine planting stock.* (ForestrySA Research: Mount Gambier, Australia).

Winkley, N., and Richardson, W. (2003) *Green Triangle Forest Soil Profiles.* (ForestrySA Research: Mount Gambier, Australia).

Appendix 1 - Young Age Fertiliser Response Prediction Tool. Probability of fertiliser response based upon soil type.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
BRAY REGNOSOL	Very High	NIL	No	None	Inherent soil pH too high for effective plantation growth or fert response.
BROWN RENDZINA	Very High	NIL	No	None	A poorly drained, wet soil often associated with swamps, swamp margins and areas of seasonal inundation. Generally soil is too shallow and wet for economic plantation growth. Inherent soil pH is often too high for effective plantation growth or fert response.
CAROLINE SAND	Low	High	Yes	High	High probability that Caroline Sand will reach SQ III and above without young age fert application. In ex bracken areas and following drought years fert application is recommended.
COARSE VALLEY SAND	Medium	High	Yes	High	High probability of young age fert response.
COMAUM BROWN SAND	High	Very Low	No	Low	High fertility soil. Nutrition is not the limiting factor to plantation growth, rainfall zone (650 mm) and soil depth are the primary growth limiting factors.
COMAUM GREY SAND	Very High	Low	Yes	Low	A poorly drained, often 200cm + deep humus nomopodsol of relatively low productivity that will grow site quality IV Pinus radiata provided there is adequate rainfall. Likely to respond to fertiliser in an above average rainfall year.
COMAUM YELLOW SAND	High	Very Low	Yes	Low	A well-drained, often 200cm + deep iron nomopodsol of moderate fertility that will grow site quality III Pinus radiata provided there is adequate rainfall. Primary limiting factor to growth is rainfall zone (600 - 650mm). Very likely to respond to fertiliser in an above average rainfall year. Probability of response in an average to below average rainfall year very low.
COONAWARRA CLAY	High	NIL	No	None	High fertility soil. Nutrition is not the limiting factor to plantation growth; rainfall zone (600 - 700mm) and soil depth are the primary growth limiting factors.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
COONAWARA LOAM	High	Very Low	No	None	High fertility soil. Nutrition is not the limiting factor to plantation growth; rainfall zone (600 - 700mm) and soil depth are the primary growth limiting factors.
COONAWARRA SAND	High	Medium	Yes	High 700 mm Low 650 - 600 mm.	High probability of responding to fertiliser application in its higher rainfall areas (Kalangadoo/Nangwarry) but a low probability of response in the lower rainfall areas of Comaum and Cave Range.
DERGHOLM IRON LEPTOPODSOL	Low	Medium	Yes	Medium	A shallow iron leptopodsol which can be expected to have lower phosphorus availability due to the presence of ironstone gravel which will bind phosphorus in the soil. Primary limiting factor to growth is soil depth and rainfall zone (650 mm).
DERGHOLM SOLODIC	High	Low	No	Low	High fertility soil. Nutrition is not the primary limiting factor to plantation growth, rainfall zone (600- 650mm) and limited drainage causing excessive wet feet during wet years are the primary growth limiting factors.
DERGHOLM SOLONETZ	Very High	Very Low	No	None	The Dergholm Solonetz soil is a soil from the Dergholm series of soils from the Lowan Land System; it is heavy clay at the surface. This soil is unsuitable for a commercial P. radiata plantation establishment.
FOLLET SOLODIC	Low	Unknown	No	Low	A high productivity soil with nutrition not being the primary limiting factor to growth. Shallow depth and limited vertical drainage are the primary limiting growth factors.
FURNER RED SAND	Very High	Low	Yes	Low	Moderate to high fertility soil. Nutrition is not the primary limiting factor to plantation growth. Shallow soil depth (lack of rooting depth) and low water holding capacity are the primary limiting factors to plantation growth. Grows SQ III - V radiata depending upon the depth of soil.
FURNER YELLOW SAND	Low	High	Yes	High	A variant of the Mt Burr Sand. High probability of a fertiliser response especially on ex bracken sites.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
HINDMARSH SANDY LOAM	High	Low	No	None	High fertility soil. Nutrition is not the limiting factor to plantation growth; soil depth is the primary growth limiting factor.
KALANGADOO SAND	High	Very Low	No	Low	The Kalangadoo sand is a Solodic soil, often <1m in depth associated with the fringes of dune ranges and flat plains of impeded drainage. It is of moderate fertility and will grow SQ III radiata on the better drained sites. Nutrition is not the primary limiting factor to plantation productivity. Impeded drainage ("Wet Feet") is the primary limiting factor to growth on this soil type.
KENTRBRUCK LOAMY SAND	Medium	Medium	Yes	Medium	The Kentbruck Loamy Sand is a soil from the Nelson Land System found in the Kentbruck and Bridgewater areas of South Western Victoria. Dependent on its distance from the coastal dunes soil pH will range greatly from within the acceptable acid range for optimum nutrient availability radiata pine and Tasmanian blue gums (pH 4.5 - pH 6.7) to very alkaline (up to pH 8.7). Where in the acceptable pH range this soil can respond to fertiliser application especially on ex bracken areas. Where the inherent soil pH is above the acceptable pH range plantations will not responded to fertiliser application.
KILBRIDE SAND	High	Low	Yes	Medium	Kilbride sand exists as a wet Swampy phase soil and a well drained, low fertility, deep Dry phase soil. Impeded drainage is the primary limiting factor to growth on the Swampy phase soil which has a very low response probability. On the Dry phase soil nutrition is the primary limiting factor to productivity especially on bracken sites. A fertiliser response can be expected on the Dry phase soil sites.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
KILLARA SOLODIC SAND	Unknown	Unknown	No	None	This soil has limited vertical drainage potential due to its shallow depth and heavy clay B horizon. Insufficient data is available on this soil type to draw any firm conclusions. The Killara Solodic Sand covers insufficient plantation area to be allocated a fertiliser priority at this time.
KROMELITE SAND	Low	High	Yes	Low	Very high probability that Kromelite Sand will reach SQ III and above without young age fert application. In ex bracken areas and following drought years fert application is recommended.
LAKE EDWARD PEAT	Very High	NIL	No	None	A very wet organic soil of high inherent pH. Unsuitable for economic plantation establishment.
LOWAN SAND	Very High	Medium	Yes	Medium	Lowan sand is primarily associated with low lying swamp areas where impeded drainage is the primary limiting factor to plantation growth. It is likely to respond to fertiliser application on elevated or well drained sites
MILLICENT CLAY (no data)	Very High	NIL	No	None	This soil is too wet and often too shallow to support economic Pinus radiata or Eucalyptus globulus plantations
MINGBOOL SAND	Very High	Very Low	No	Low	The Mingbool sand is a Solodic soil, often <1m in depth associated with the fringes of dune ranges and flat plains of impeded drainage. It is of moderate fertility and will grow SQ III radiata on the better drained sites. Nutrition is not the primary limiting factor to plantation productivity. Impeded drainage ("Wet Feet") is the primary limiting factor to growth on this soil type.
MOUNT BURR SAND	High	High	Yes	High	High probability that Mt Burr Sand will reach SQ III and above without young age fert application. In ex bracken areas and following drought years fert application is recommended.
MOUNT MUIR SAND	High	High	Yes	High	High probability that Mt Muir Sand will reach SQ III and above without young age fert application. In ex bracken areas and following drought years fert application is recommended.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
MYORA SAND	Low	High	Yes	High (dry phase) Low (swampy phase)	Myora sand exists as a wet Swampy phase soil and a well drained, moderate to high fertility, Dry phase soil. Impeded drainage is the primary limiting factor to growth on the Swampy phase soil which has a very low response probability. On the Dry phase soil there is a high probability that Myora Sand will reach SQ III without young age fertiliser application.
NANGWARRY SAND	High	Medium	Yes	High	A soil of low to moderate fertility which will respond to young age fertiliser application where it is adequately drained or has had successful woody weed (especially bracken) control.
NOOLOOK GREY SAND	Unknown	Unknown	Yes	Medium	A soil of moderate fertility which primary growth limiting factor is its relatively shallow soil depth.
NOOLOOK RED SAND	Very High	Very Low	No	None	A fertile, shallow, often less than 30cm to limestone, dark yellowish brown to red brown sand over limestone. It may have a very shallow layer of clayey sand – sandy clay immediately above the parent material in its deeper phases. Nutrition is not the limiting factor to growth, soil depth and at specific locations inherently high soil pH are the primary limiting factors to plantation growth.
NOOLOOK YELLOW SAND	Very High	Low	Yes	Medium	A soil of moderate fertility which has a low probability of responding to young age fertiliser. Rainfall is the primary limiting factor to growth on this soil type.
RED BASALTIC	Low	Very High	No	None	An extremely fertile high productivity soil type which is not limited by low soil nutrition.
REEDY CREEK BROWN SAND	Low	Very High	No	Low	An extremely fertile high productivity soil type which is not limited by low soil nutrition.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
RICHMOND SAND	Medium	High	Yes	High	Richmond Sand is a humus nomopodsol of moderate to relatively low fertility. Richmond sand exists a dry phase and wet phase soil with impeded drainage. Richmond sand can be expected to respond to fertiliser application in its dry phase provided there is adequate rainfall but may not respond to young age fertiliser on excessively wet sites where impeded drainage is the primary limiting factor to growth.
RIDDOCH SAND	Medium	Medium	Yes	Medium	Impeded drainage is the primary limiting factor to plantation growth on this soil which in wet years can be inundated with ground water for extended periods. Where this soil is present at an elevated or well drained site it can be expected to respond to fertiliser application.
SHORT SAND	Medium	Medium	Yes	Medium	A high fertility soil that is associated with the relatively flat but slightly undulating plains of Wattle Range. Inherent nutrition is not generally the primary growth limiting factors, soil drainage and rainfall zone (600 - 700 mm) are.
STONE	Very High	NIL	No	None	Unsuitable for plantation establishment.
SWAMP SOIL	Very High	NIL	No	None	Unsuitable for plantation establishment.
TANTANOOLA FLINTY SAND	Low	Low	No	Low	An extremely fertile high productivity soil type which is not limited by low soil nutrition. Primary limiting factor to plantation growth is depth of soil (rooting depth and water holding capacity). Effective rooting depth is very variable from 30cm to 200 cm +.

Soil Identification	Probability of Below SQ III @ Age 2.5	Probability of Young Age Growth Response to SQ III Following Fert	Young Age Fert Recommended	Fertiliser Priority	Comment
WANDILO SAND	High	Medium	Yes	Medium	The Wandilo Sand is a Humus Nomopodsol characterised by its light brown-grey or yellowish brown-grey A2 horizon overlaying approximately 30cm of organic stained sand or hardpan, which will often contain large amounts of ironstone gravel. This is mostly a soil associated with impeded drainage and low phosphorus availability. It will respond to young age fertiliser application where adequately drained. Where associated with poor drainage the probability of a young age fertiliser response is low.
WARROLONG SAND	Low	Very High	No	Low	An extremely fertile high productivity soil type which is not limited by low soil nutrition.
YOUNG SAND	Very High	Low	Yes	High	A low fertility soil which has a very well drained Dry phase (dune sand) and a Swampy phase wet soil associated with areas of impeded drainage. The Swampy phase soil has a very low probability of achieving a young age fertiliser response as "wet feet" is the primary growth limiting factor. The Dry phase soil is very often associated with bracken fern and will have a limited response potential if this weed is not controlled. On sites without bracken the Dry phase young sand can be expected to respond to fertiliser application provided there is adequate rainfall.

Appendix 2 - Green Triangle Forest Profiles. Soil Associations with Locality.

This is a guide to help identify soil types that may be found in different areas. This is not a definitive list nor does it restrict soil types to these areas exclusively. Use the Soil Association Zones map (Appendix III) as a guide for these areas.

Burrungule/Kongorong
- Caroline Sand (Iron Nomopodsol Section 5:1:2)
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Millicent Clay (Rendzina Section 7:3)
- Mount Burr Sand (Iron Nomopodsol Section 5:1:2)
- Red Basaltic (Transitional Krasnozem Section 7:1)
- Tantanoola Flinty Sand (Iron Nomopodsol Section 5:1:2)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Comaum
- Comaum Brown Sand (Iron Leptopodsol Section 5:2:1)
- Comaum Grey Sand (Humus Nomopodsol Section 5:1:1)
- Comaum Yellow Sand (Iron Nomopodsol Section 5:1:2)
- Coonawarra Clay (Terra-rossa Section 7:2)
- Coonawarra Loam (Terra-rossa Section 7:2)
- Coonawarra Sand (Terra-rossa Section 7:2)
- Sandy Swamp Soil (Solodic Section 6)
- Swamp Soil (Solodic Section 6)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Glencoe/Wandilo
- Coarse Valley Sand (Alluvial Section 3:4)
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Lake Edward Peat (Peat Section1)
- Mount Burr Sand (Iron Nomopodsol Section 5:1:2)
- Mount Muir Sand (Terra-rossa Section 7:2)
- Red Basaltic (Transitional Krasnozem Section 7:1)
- Sandy Swamp Soil (Solodic Section 6)
- Swamp Soil (Solodic Section 6)
- Wandilo Sand (Humus Nomopodsol Section 5:1:1)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Kalangadoo/Nangwarry
- Brown Rendzina (Rendzina Section 7:3)
- Coonawarra Clay (Terra-rossa Section 7:2)
- Coonawarra Loam (Terra-rossa Section 7:2)
- Coonawarra Sand (Terra-rossa Section 7:2)
- Kalangadoo Sand (Solodic Section 6)
- Kilbride Sand (Humus Nomopodsol Section 5:1:1)
- Lowan Sand (Iron Nomopodsol Section 5:1:2)
- Nangwarry Sand (Iron Nomopodsol Section 5:1:2)
- Riddoch Sand (Solodic Section 6)
- Sandy Swamp Soil (Solodic Section 6)
- Short Sand (Humus Nomopodsol Section 5:1:1)
- Swamp Soil (Solodic Section 6)
- Wandilo Sand (Humus Nomopodsol Section 5:1:1)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Millicent
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Millicent Clay (Rendzina Section 7:3)
- Riddoch Sand (Solodic Section 6)
- Tantanoola Flinty Sand (Iron Nomopodsol Section 5:1:2)

Mount Burr Ranges

- Brown Rendzina (Rendzina Section 7:3)
- Coarse Valley Sand (Alluvial Section 3:4)
- Furner Yellow Sand (Iron Nomopodsol Section 5:1:2)
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Mount Burr Sand (Iron Nomopodsol Section 5:1:2)
- Mount Muir Sand (Terra-rossa Section 7:2)
- Red Basaltic (Transitional Krasnozem Section 7:1)
- Riddoch Sand (Solodic Section 6)
- Sandy Swamp Soil (Solodic Section 6)
- Swamp Soil (Solodic Section 6)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Myora/Mingbool/Caroline

- Basaltic Soil (Transitional Krasnozem Section 7:1)
- Caroline Sand (Iron Nomopodsol Section 5:1:2)
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Kromelite Sand (Iron Nomopodsol Section 5:1:2)
- Myora Sand (Humus Nomopodsol Section 5:1:1)
- Sandy Swamp Soil (Solodic Section 6)
- Swamp Soil (Solodic Section 6)
- Wandilo Sand (Humus Nomopodsol Section 5:1:1)
- Warrolong Sand (Terra-rossa Section 7:2)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Noolook

- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Noolook Grey Sand (Iron Nomopodsol Section 5:1:2)
- Noolook Red Sand (Terra-rossa Section 7:2)
- Noolook Yellow Sand (Iron Nomopodsol Section 5:1:2)

Wattle Range

- Brown Rendzina (Rendzina Section 7:3)
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Kalangadoo Sand (Solodic Section 6)
- Millicent Clay (Rendzina Section 7:3)
- Riddoch Sand (Solodic Section 6)
- Sandy Swamp Soil (Solodic Section 6)
- Short Sand (Humus Nomopodsol Section 5:1:1)
- Swamp Soil (Solodic Section 6)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Western Victoria

- Brown Rendzina (Rendzina Section 7:3)
- Caroline Sand (Iron Nomopodsol Section 5:1:2)
- Comaum Brown Sand (Iron Leptopodsol Section 5:2:1)
- Comaum Grey Sand (Humus Nomopodsol Section 5:1:1)
- Comaum Yellow Sand (Iron Nomopodsol Section 5:1:2)
- Coonawarra Clay (Terra-rossa Section 7:2)
- Coonawarra Loam (Terra-rossa Section 7:2)
- Coonawarra Sand (Terra-rossa Section 7:2)
- Gorae Gravelly Loam (Clay Leptopodsol Section 5:2:2)
- Hindmarsh Sandy Loam (Terra-rossa Section 7:2)
- Peat (Peat Section1)
- Red Basaltic (Transitional Krasnozem Section 7:1)
- Richmond Sand (Palparra Sand)
- Sandy Swamp Soil (Solodic Section 6)
- Sherburn Loam (Transitional Krasnozem Section 7:1)
- Swamp Soil (Solodic Section 6)
- Warrolong Sand (Terra-rossa Section 7:2)
- Young Sand (Humus Nomopodsol Section 5:1:1)

Appendix 3 - Soil Association Zones from Green Triangle Forest Profiles.