J. W. GOTTSTEIN MEMORIAL TRUST FUND

The National Educational Trust of the Australian Forest Products Industries

GOTTSTEIN
TRUST

PLANTATION NUTRITION MANAGEMENT - LESSONS FROM SOUTH-EASTERN USA

PAUL ADAMS

2008 GOTTSTEIN FELLOWSHIP REPORT

Joseph William Gottstein Memorial Trust Fund

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are:

1. Fellowships and Awards - each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

Further information may be obtained by writing to:

The Secretary

J.W. Gottstein Memorial Trust Fund

Private Bag 10

Clayton South VIC 3169

Australia

Dr Paul Adams has been a forest researcher for 20 years, focusing on plantation nutrition, weed management, and silviculture in both pines and eucalypts. His experience in these disciplines includes seven years in South Australia with the Woods and Forests Dept. and the last 10 nine years with Forestry Tasmania. Soil and nutrition related research is his passion, especially sustaining long-term productivity, inter-rotation management and weed interactions. He is currently the Principal Research Scientist and Manager of the Plantations branch, Division of Forest Research and Development, Forestry Tasmania.





Executive summary

A study tour was undertaken to south-eastern USA in June / July 2008 in one of the largest and most important forest regions in the world. The aim was to learn about plantation nutrition management and research. The tour included attendance at the 11th North American Forest Soils Conference and post-conference tour across Virginia, a visit to the Forest Nutrition Cooperative (FNC) and some important field trials along with visits to a number of forest companies in the region.

The 11th North American Forest Soils conference was attended by more than 100 soil scientists and specialists, mainly from USA and Canada. Many good papers were presented by leading scientists in the industry. My presentation of a joint paper on the development of a phosphorus decision guide for *Pinus radiata* in Tasmania (Neilsen and Adams) was well received.

The post-conference tour provided a valuable insight to the region, the history of land use, forest distribution, development and management on a wide range of soils and environments. The tour started in the ridge and valley geography of western Virginia and travelled through the Piedmont and down on to the coastal plains some 400 km from Blacksburg. It was clearly demonstrated that forest managers have good knowledge and understanding of the linkage between soil and forest productivity and other factors that influence tree growth. This has been the key to improving productivity - understanding the relationships between soils, forest health and productivity along with management techniques that are available to optimize growth. This is due in large part to the collaborative research that has been undertaken by the FNC.

The Forest Nutrition Cooperative has nodes in North Carolina State University, VirginiaTech and University of Concepcion in Chile. It has industry-wide recognition for providing valuable and practical research outcomes on nutrition and productivity in SE USA. I visited the NC State University as a guest of Dr Lee Allen, FNC CEO (now retired) and used this as the base for wide ranging visits to a field experiments and three forest companies (Resource Management Services LLC, Weyerhaeuser and Arborgen LLC). Discussions with these companies demonstrated a high degree of operational management and a strong relationship to the staff and students at the FNC. There were many interesting and valuable lessons from the study tour and I have listed the main take-home messages on the next page.

This study tour was valuable both professionally and personally and gave me a much greater appreciation and understanding of nutrition research practices and management in the region. My hosts were very generous with their time, sharing and friendship. I am now in a good position to review the current Forestry Tasmania Nutrition Research Program and to develop the next 5 year strategy for improving the productivity and value of eucalypt plantations in Tasmania.

Some key observations and take home messages:

It is important to know your soils and understand the relationships between soil characteristics and land use capability and to incorporate this information with tree performance and tree health. It is also important to understand site limitations and find methods to ameliorate these. Plantation silviculture is species related and site related. These are basic requirements for managing nutrition and productivity.

The utility of remote sensing to estimate leaf area index (LAI). The widely recognised phrase ‘leaves grow trees, resources grow leaves’ underscores the philosophy of this approach. Let the trees tell you what they need / require nutritionally.

Early intensive silviculture is needed to maintain growth and effective weed management is an essential part of this. Weed control in combination with fertiliser a better investment than either alone

Mid-rotation silviculture e.g. post-thinning fertilisation can be a very good investment.

Significant savings can be achieved by targeting the correct stands that can and will respond to fertiliser.

Long-term studies on productivity are expensive and difficult to carry out. However, such studies do provide very useful information to forest owners, managers and scientists. The principles can be determined from a single site but this should be applied to other sites with other environment / site combinations. Process-based models are being developed using information from long-term trials along with nutrition decision tools.

Significant and rapid gains in tree growth and quality are achievable through clonal or varietal forestry (e.g. AborGen tree improvement).

The influence of man and the history of land use coupled with the resilience of nature and the regeneration of forests in the region was impressive.

Acknowledgments

The Gottstein trip to SE USA was valuable and enjoyable due to my very helpful and friendly hosts. Dr Tom Fox and Dr Lee Allen (FNC Co-directors) were very generous with their time and shared their knowledge and wisdom freely. Through these two men I was able to visit a range of field experiments and met with many interesting forest soil practitioners. Tom Fox was also largely responsible for the successful Forest Soils Conference and he hosted the very enjoyable post-conference tour.

A very special thank you goes to Tim Albaugh (FNC), who spent the most time with me, travelling to and discussing many interesting field experiments. Tim also accompanied me to visit three forest companies in the region: Resource Management Service LLC, Weyerhaeuser and ArborGen LLC. We had many good and enthusiastic discussions on a wide range of issues, not just limited to forestry. Tim and his wife Janine also invited me into their home.

Other people who contributed to a very enjoyable trip were:

Prof Jim Burger (Virginia Polytechnic Institute and State University), Dr Dan Neary (Rocky Mountain Research Station), Dr Ron Taskey (California Polytechnic) and Dr Craig Ross and Dr Haydon Jones (Landcare Research and Scion, New Zealand) and Dr Peter Hopmans (Timberlands Research Pty Ltd, Australia). All were participants of the Post-conference Tour.

Dr Tom Bailey (US Forest Service Soil Scientist) and Tom Collins (US Forest Service Geologist) for explaining the soils and geology of sites during the Conference Field Day and the Post-conference Tour.

Dr Jerre Creighton and Mr John Scrivoni (Virginia Department of Forestry) for hosting a visit to local plantations and forests, including an example of the ‘old growth’ oak forest.

Students and staff at the Forest Nutrition Cooperative (NC State University): Jose Zerpa (PhD candidate - nitrogen nutrition), Jose Alvarez (PhD candidate – remote sensing) and Mrs Leandra Belvins (Data Manager, FNC).

Dr Jeff Pallin at the Duke University FACE experiment.

Mr Gerald Hansen (Resource Management Service LLC), Dr Robert Campbell (Weyerhaeuser) and Mr Phil Dougherty (ArborGen LLC) were very helpful and shared their knowledge and experiences. Their honesty and passion were appreciated.

Bill Neilsen (previously with Forestry Tasmania) for his help and collaboration on the joint paper that was presented at the North American Forest Soils Conference.

Forestry Tasmania for financial support and time to undertake the study tour.

Finally, I wish to thank the J.W. Gottstein Memorial Trust for their assistance and support which allowed me to undertake this very useful and enjoyable study tour. Particular thanks goes to Dr Adrian Wallis for his support and patience during the writing of this report.

Dr Tom Fox and Dr Lee Allan

Tim Albaugh and Jose Zerpa

Dr Jim Burger

Contents

Study tour objectives

South eastern USA (Figure 1) contains a very large and important forest industry that is based on pine and hardwood forests covering some 20 million hectares. The forests in the region represent some 40% of the commercial forests in the country. The current trend in the industry in the region is for increasing management intensity which is resulting in significant improvements in forest productivity across the region. A major driver for these improvements is the research that has been carried out by the Forest Nutrition Cooperative (FNC) based in Virginia (VirginiaTech) and North Carolina (NC State University). The cooperative has been operating since the 1970’s with wide industry support across most of the forest sector. An extensive network of field experiments has been installed across the region, addressing many aspects of nutrition management and silviculture, including long-term productivity studies, and the impact of weeds on fertiliser responses. This work has been pulled together to assist the development of decision making tools (nutrient management systems) that are in use within the industry. This work of the FNC is directly applicable to forestry in Tasmania and the broader Australian forest industry and so a study tour was arranged to find out more.

The study tour coincided with the 50th anniversary North American Forest Soils Conference in Virginia in June 2008. The conference theme was “forest soils research over the last 50 years, how technology has changed our understanding of forest soils processes and how do we continue to maintain functioning healthy soils”. This was an ideal forum to present a paper on phosphorus nutrition of *P. radiata* in Tasmania, which was the culmination of research that had been carried out by Forestry Tasmania over more than four decades (initiated by WA Neilsen). The conference also provided an excellent opportunity meet other forest soil and nutrition specialists.

In addition, I wanted to visit some forest companies to understand how they use research to manage their forests.

Therefore, the main objectives of the tour were:

Attend the 11th North American Forest Soils Conference, and present a paper on long-term phosphorus nutrition research in Tasmania.

Visit the Forest Nutrition Cooperative discuss plantation nutrition management, decision support systems (NMS), and long-term research sites.

Visit several major forest companies (Resource Management Services LLC, Weyerhaeuser LLC and ArborGen LLC) to discuss management, research methods and application of research findings from the Forest Nutrition Cooperative.

The general location of the study tour is shown in Figure 2.

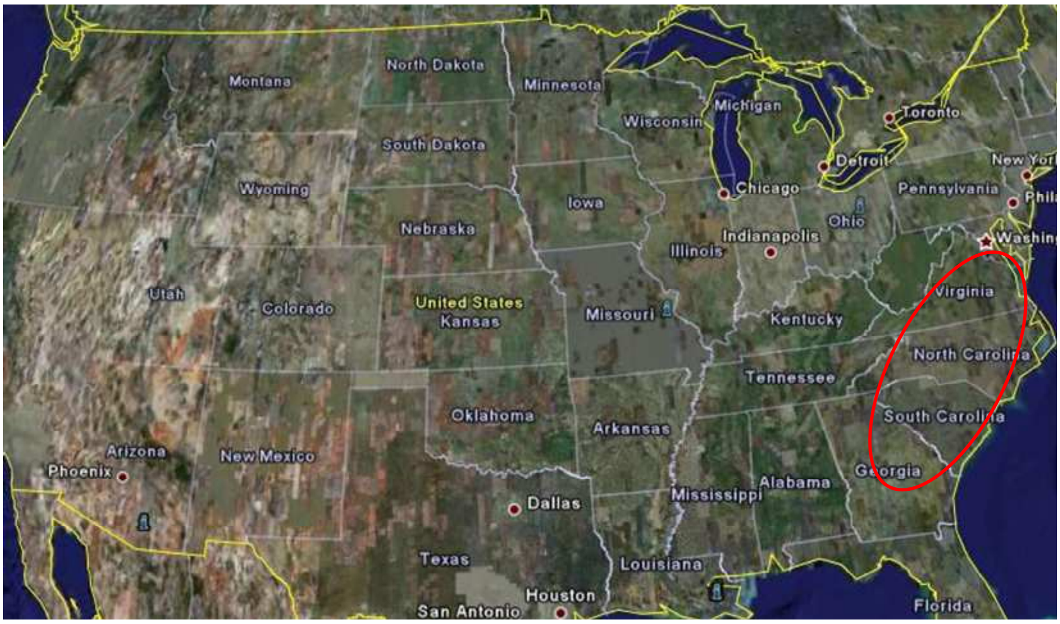


Figure 1. SE USA and the states visited (Virginia, North Carolina, South Carolina and Georgia)

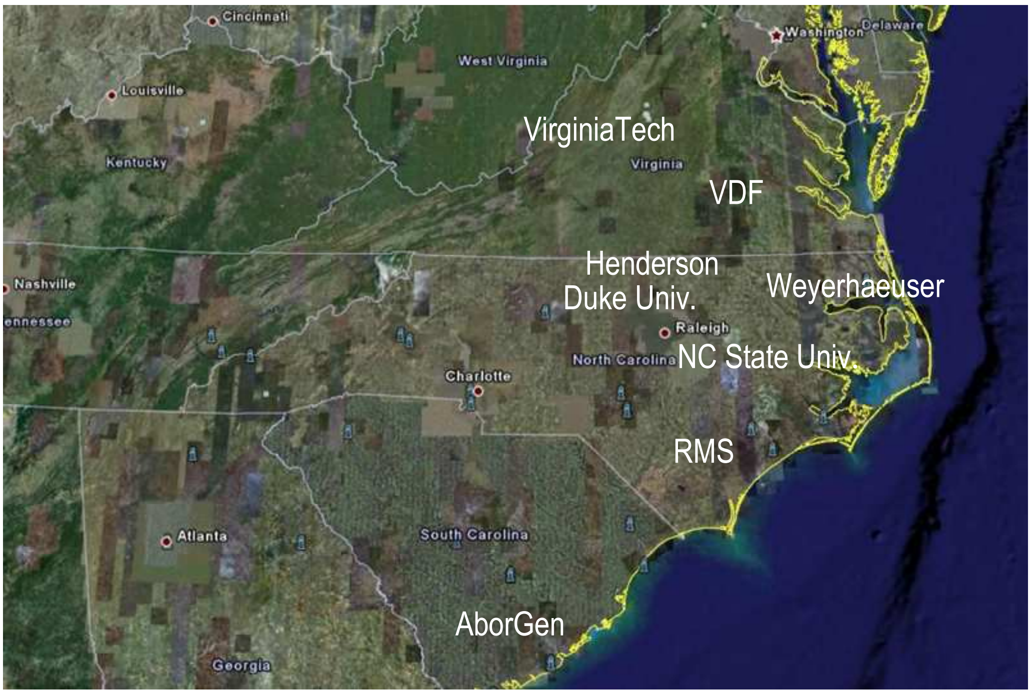


Figure 2. Location of main site visits in SE USA

Tour itinerary (June 21 – July 8)

Date	Activity	Contacts
Sun 21 – Thur 26 June	North American Forest Soils Conference Blacksburg, Virginia	Tom Fox, Ken Van Rees
Thur 26 – Sun 29	Post-conference tour Virginia	Tom Fox, Jim Burger
Mon 30	North Carolina State University Forest Nutrition Cooperative	Lee Allen, Tim Albaugh Jose Zerpa Jose Alvarez Leandra Belvin
Tues 1 July	Mid-rotation fertilisation and vegetation control SETRES nutrients and water study	Tim Albaugh
Wed 2	Resource Management Service LLC North Carolina	Gerald Hansen Tim Albaugh
Thur 3	FACE experiment: Duke University North Carolina	Jeff Pippen Tim Albaugh
Fri 4	Henderson site productivity project North Carolina	Lee Allan
Sat 5 – Sun 6		
Mon 7	Weyerhaeuser North Carolina	Bob Campbell Tim Albaugh
Tues 8	ArborGen LLC South Carolina	Phil Dougherty Tim Albaugh

Forestry in South Eastern USA – overview

The forests of SE USA consist of several important *Pinus* species e.g. *P. taeda* (Loblolly pine), *P. elliotii* (slash pine) and *P. palustris* (Longleaf pine), and *P. strobus* (white pine) and deciduous hardwoods e.g. *Quercus* (oak), *Carya* (hickory), *Acer* (maple) and *Populus* (poplar). These forests cover more than 20 million hectares and represent more than 40% of the production forests in the USA. A large forest industry has been built on these forests, particularly the pines, both natural and plantations. Two thirds of the forests are managed for pulpwood production and one third for sawn timber. Approximately 70% of the forests are owned in private holdings.

Natural growth rates for pines in the region range from 8 – 12 m^3/ha/yr (MAI) however, increased productivity through fertiliser application has been widely demonstrated and each year hundreds of thousands of hectares are routinely fertilised by forest companies (Figure 3). There is a trend towards more intensive management with significant efforts to increase productivity (Figure 4). This has occurred in tandem with increasing environmental protection and social issues, especially public demand for wildlife management and recreation. There is no Forest Practices Code in SE USA however other mechanisms such as forest certification and state environmental protection laws are used to protect environmental values. The national Sustainable Forest Initiative program is also an important influence on management practices.

As in Australia, the cost and complexity of managing forests is increasing. This is directly related to increasing land values, and inputs, such as fertiliser and decreasing stumpages. Until recent times fertiliser applications across the region were widespread but now operations are necessarily more targeted and focused on maximizing outcomes and efficiencies. The use of leaf area index, remote sensing and decision support tools have been an important part of this and the FNC has been a driving force behind these systems.

There is constant change of forest and land ownership in the region. Structural change is also occurring with TIMO's and REIT's where the land itself is viewed as having more value than the forests. Wall Street investors are now a major factor in the forest industry. A TIMO is a management group that aids institutional investors in managing their timberland investments. A TIMO acts as a broker for institutional clients with the primary responsibility to find, analyze and acquire investment properties that best suit their clients. When an investment property is chosen, the TIMO is responsible for actively managing the forests to achieve adequate returns for the investors. An example of a TIMO is Resource Management Service LLC (RMS) which manages forest land on behalf of its investors. A REIT is a Real Estate Investment Trust that owns and manages a pool of commercial properties and other real estate assets. REIT's therefore have a high focus on real estate value with purchase and sales being a big part of their business. Some land in the region is valued at up to $6250 / ha. An example of a REIT is Rayonier. TIMO's and REIT's make for interesting times. Ownership and organisational changes also impact on the Forest Nutrition Cooperative with respect to management of experiments and lines of communication with members.

Forest ownership changes have also meant a change in silviculture over time as each company has its own philosophy and management objectives. It has not been uncommon for the same stand to have had three or more different owners, with consequent changes in objective and management inputs. While there has been a trend for convergence of plantation silviculture, including increasing interest in growing forests for solid wood production, the different company objectives, philosophy and resources mean there will continue to be significant differences between the plantation estates within the industry.

Weyerhaeuser is one of the few vertically integrated forest companies in SE USA. It produces solid, high quality wood and is regarded as an innovative industry leader. However, the company is now also coming under increasing pressure to break up and some of this is occurring already, with the sale of some non-core manufacturing plants.

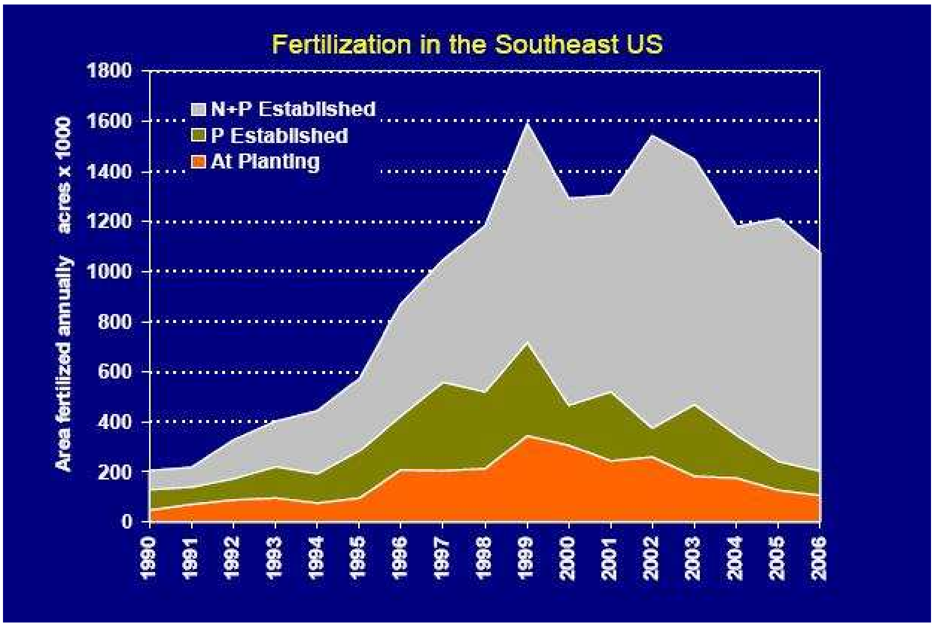


Figure 3 Annual forest fertilisation program in south east US (1990 – 2006). The area fertilised in 2006 was approximately 485,000 ha.

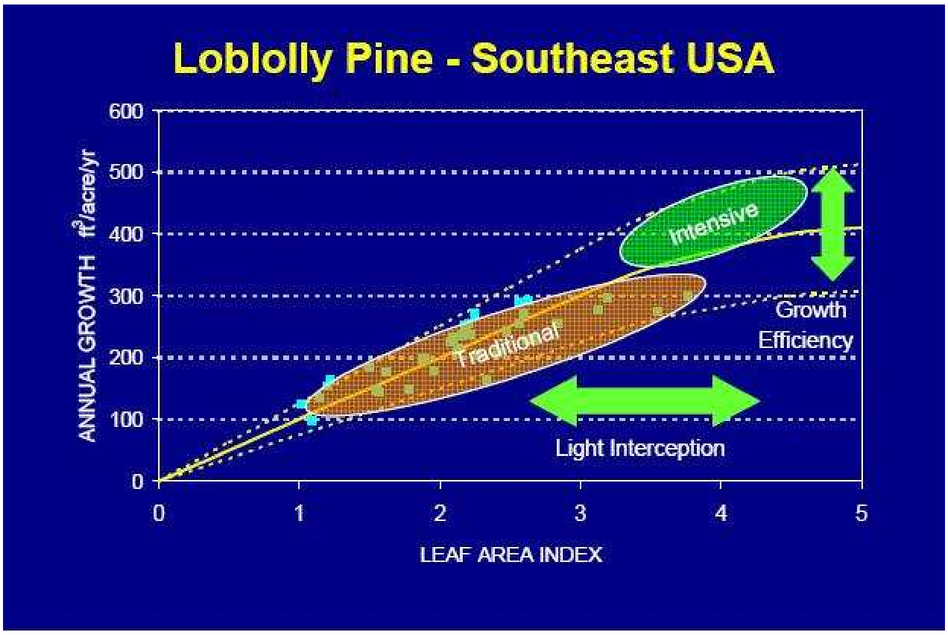


Figure 4. Productivity of Loblolly pine using traditional management compared to intensive nutrition management with increases in light interception (LAI) and growth efficiency. The natural range for this species is 8 – 12 MAI (150 – 250 ft^3 / acre / yr).

11th North American Forest Soils Conference

I attended the 50th anniversary of the first North American Forest Soils Conference held at VirginiaTech in Blacksburg, Virginia. The theme was “forest soils research over the last 50 years, how technology has changed our understanding of forest soils processes and how do we continue to maintain functioning healthy soils”. There were more than 100 delegates, with the bulk from within the US and Canada. Around 20 delegates were from overseas (including 4 from Australia and New Zealand).

The conference was very well organised and structured. There were two hour breaks between sessions allowing plenty of time for discussion and posters. Attendance at the conference was very worthwhile, and I made some very good contacts with other scientists. It was also a very good introduction to the region and the industry.

The conference also provided an opportunity to present the joint paper on phosphorus nutrition research in Tasmania. This paper represented the culmination of very important research that was carried out by Forestry Tasmania (initiated by WA Neilsen) over more than four decades. This work fitted the conference theme, demonstrating a significant contribution to advancing the knowledge and management of phosphorus in Tasmanian *P. radiata* forests. The paper was entitled: Management of Phosphorus nutrition in radiata pine: 45 years of research and experience in Tasmania, Australia (Neilsen and Adams). The abstract is provided in Appendix 1.

Many excellent papers and reviews were presented on a range of topics, including, site preparation and cultivation (Morris), forest fertilisation (Burger), history of significant contributors to soil science (Helga), and resilience of forest soils and sustainability (Hopmans).

It was apparent from discussions with many of the delegates that a number of Australian scientists have studied at universities in the region over the last four decades and have worked alongside many of the ‘fathers’ of modern soil science. Australian scientists include Dr David Boomsma, Dr Phil Smethurst and Dr Phil Polglase.

The proceedings of the conference are worth reading and selected papers from the conference are to be published in a special edition of Forest Ecology and Management.

Conference field tour

The conference field tour visited five sites within several hours of the conference venue in Blacksburg. Presentations included the importance of soil information and forest management along the use of ground penetrating radar, discussions on gypsy moth damage, streamside management zones, and the role of stumps in nutrient cycling. Figure 5 shows the line up of vehicles at lunch time at Jefferson National Forest.

Figure 5. Line-up of tour vehicles at old-field location during conference field tour.

Highlights

The use of soil information

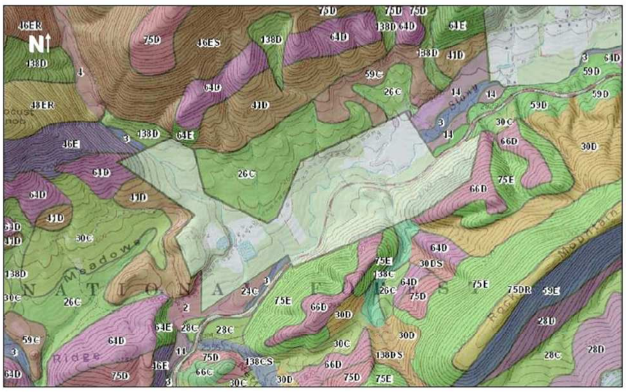
Forest land managers in the region have significant information on soils and land use capability through comprehensive geology and soil maps. This information includes details on soil formation, past land use and implications for forest productivity, current forest composition and management constraints. Figure 6 shows an example of soil, geology and forest map in the ridge and valley landscape in Virginia.

Excellent soil pits were prepared for the field day and located within a range of forest types and positions in the landscape. (Figures 7 and 8). Each were described in detail by local scientists and then implications for forest management described by local managers.

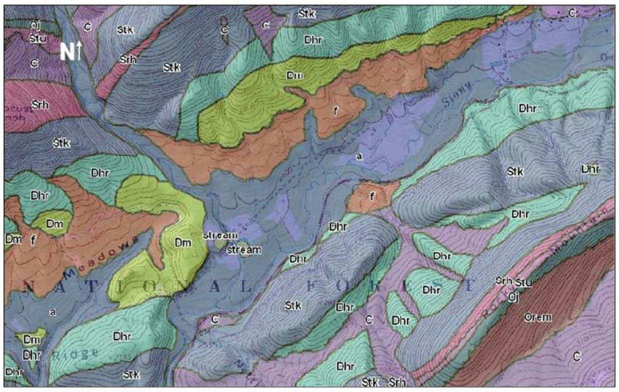
Importance of stumps in nutrient recycling

(Eric Sucre, Post grad student at VirginiaTech)

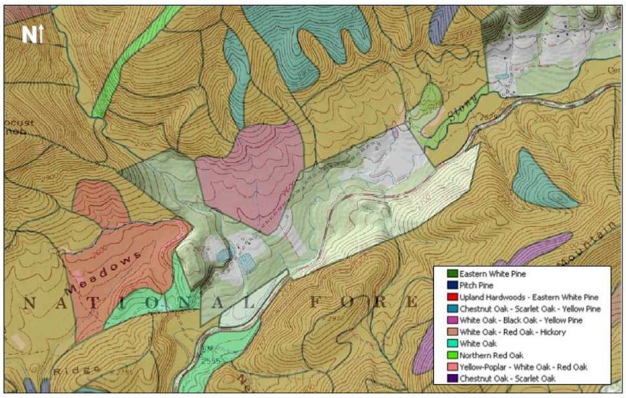
Decomposing stumps and coarse fragments contain appreciable amounts of carbon, nitrogen and macronutrients. In order to study nutrient cycling dynamics in forest ecosystems these components need to be sampled.



USFS Forest Soils of Glen Alton Farm Area
1:17,658
(Legend on back)



USGS Geology of Glen Alton Farm Area
1:17,658
(Legend on back)



USFS Stands and Forest Types of Glen Alton Farm Area
1:17,658

Figure 6. Examples of a soil, geology and forest type map.

Figure 7. Soil pit in mixed hardwood species woodland

Figure 8. Soil pit under a white pine plantation (*P. strobus*)

Ground-penetrating radar

(Wes Tuttle, USDA Natural Resource Conservation Service)

Figure 9. Ground-penetrating radar being pulled across the surface of the ground.

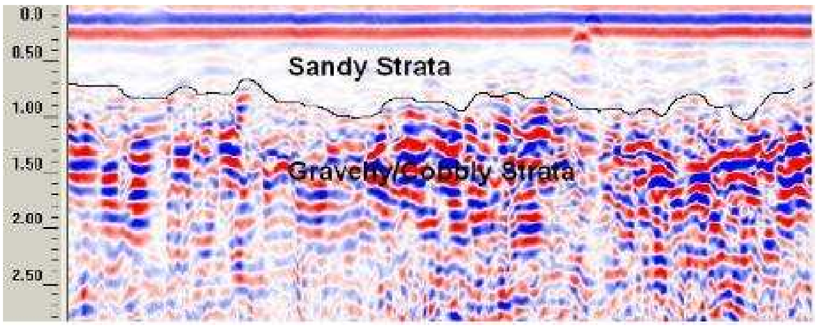


Figure 10. Print out from GPR showing boundary between soil and bedrock

Streamside management zones research project

(Bill Lakel, Virginia Department of Forestry)

Current status of SMZs

Numerous studies have shown the positive effects of forestry FMZs

Few studies have studied the actual efficacy of different widths and harvest levels

Current state BMP guidelines vary from 25 to 200 feet for width

SMZ Study showed for water quality

Increasing SMZ widths was not beneficial

Decreasing SMZ width (or thinning) was not detrimental

N and P in water were low and unaffected by SMZ width or harvest level

SMZ width and thinning did not affect water temperature, DO or TOC

Forestry SMZ width specifications are largely speculative

Costs to landowners should be considered

Several other studies had similar results

Hardwood forest management

(Tom Fox, VirginiaTech)

There are many challenges in regeneration of oak in the forests in the region. Fire perpetuates oak but there is less fire now compared to 200 years ago. The problem is not one of regeneration but of species composition. On good (fertile) sites oak is easily replaced by maple and poplar species. Planting oak seedlings is futile. The light regime is very important as oak seedlings cannot compete with more vigorous shade intolerant species. In contrast, on poorer sites, where maple and poplar grow less vigorously, regeneration of oak is much more acceptable. Figure 11 shows a typical site quality gradient for hardwood forests in the Appalachian region. Figure 12 shows examples of these forest types.

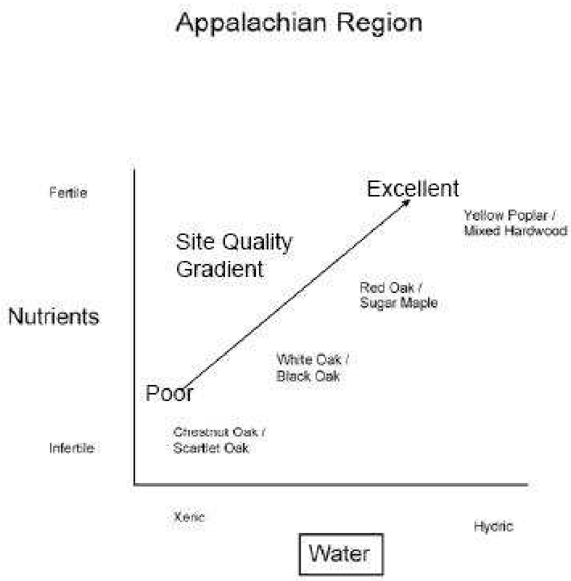
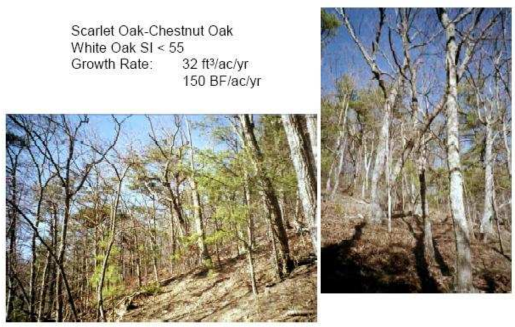
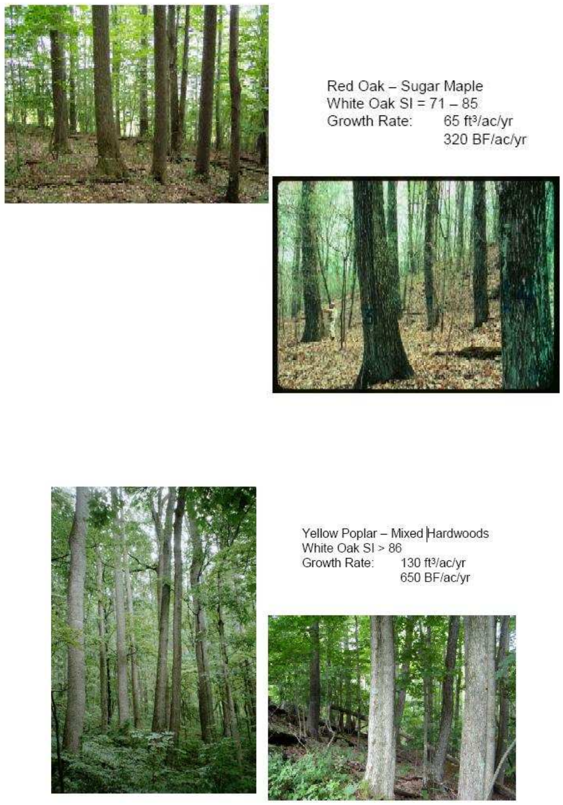


Figure 11. Diagram of forest type by nutrient and water gradient



2 – 3 MAI

3 – 4 MAI



4 – 5 MAI

9 – 10 MAI

Figure 12. Forest class with equivalent MAI figures (m^3/ha/yr)

Gypsy moth devastation

(Ed Leonard, Jefferson National Forest)

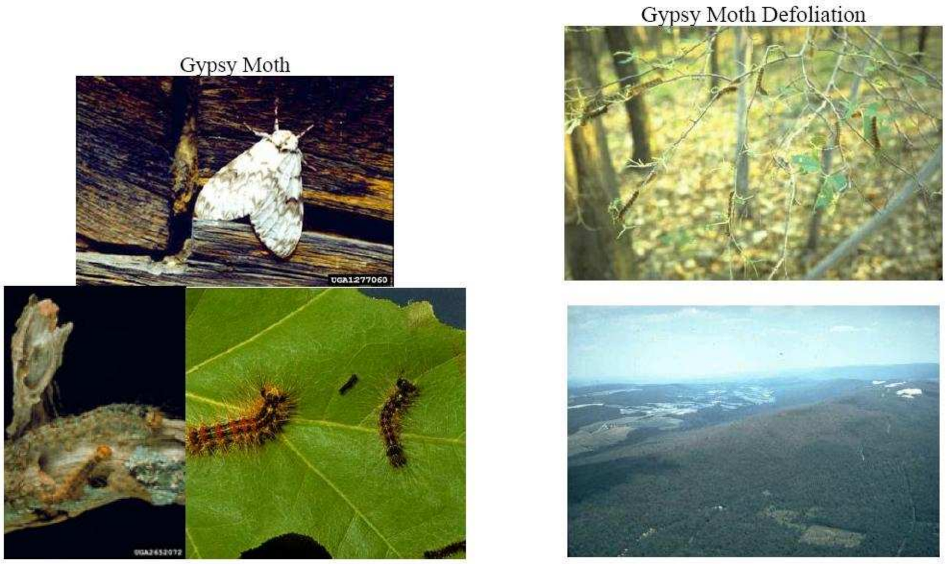


Figure 13. Gypsy moth

There has been very severe damage from Gypsy moth infestation in NE USA over the past decade and it is rapidly spreading south and west. Figure 13 shows the damage associated with gypsy moth in the region.

Silvicultural options for dealing with the pest problem include:

Pre salvage and sanitation thinning to reduce the vulnerability of the stand by removing oaks with poor crowns and to utilize the reproduction system that favours non-susceptible species.

Salvage thinning to recover economic value of trees that are killed and to reduce susceptibility of the residual stand and regenerate the stand.

The Table below shows species that are preferred by the moth, those that are resistant and those that are ‘immune’.

Preferred species	Resistant species	"Immune" species
Oak species	Beech	Yellow poplar
Basswood	Birch	Ash
Sweetgum	Black gum	Fir
Serviceberry	Black cherry	Sycamore
Hornbeam	Buckeye	Black locust
Willow	Chestnut	Dogwood
Apple	Cucumbertree	Holly
Aspen	Elm	Striped maple
Birches	Red and Sugar maple	Mountain Laurel
	Sourwood	Grap
	Hickory	
	Walnut	
	Hemlock	
	Pine	

Post-conference Field tour

Following the conference, there was a three-day field tour. The tour started on June 27 in Blacksburg, Virginia, and travelled through the Blue Ridge Mountains, across the Piedmont and down to the Coastal Plains (Figure 14). The aim was to observe a range of soils and vegetation communities and discuss how these impacted on forest and plantation productivity and management. The region contains hardwood and pine forests and plantations, all of which supply a very large and diverse wood products industry.

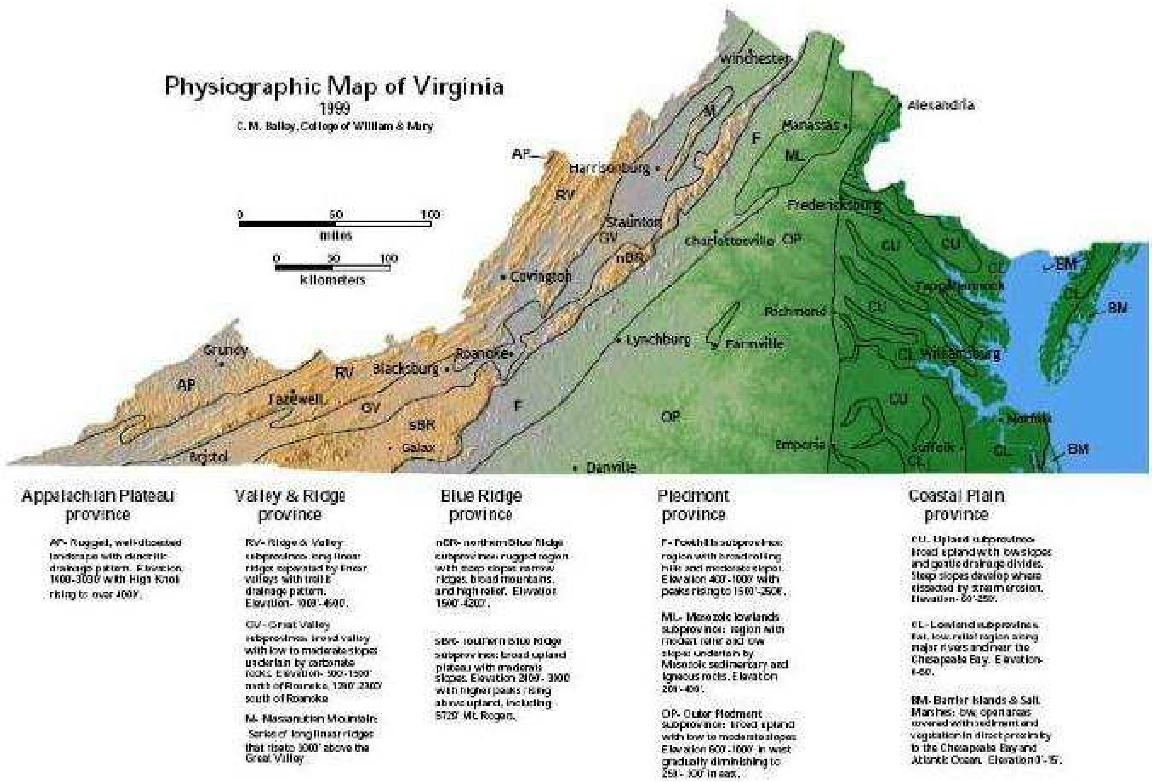
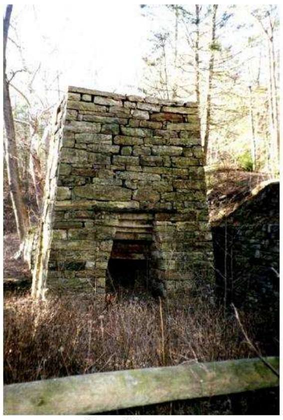


Figure 14. Map of Virginia and transect explored during the post-conference tour.

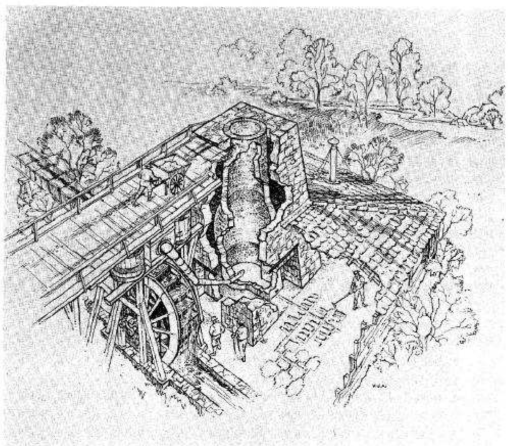
The typical Blue Ridge landscape is shown in Figure 15.

The history of land use and the impact of man was described by forest archeologists. Prior to the 1700's the forests were predominantly woodlands due to the impact of native Americans and their use of fire. When colonisation occurred the landscape was very rich and bio diverse which lead to massive exploitation with mining, logging and iron production (Figure 16). This led to widespread deforestation to fuel the furnaces. At the same time farming practices in many areas were poor which led widespread loss of topsoil and eventually large areas of farmland were abandoned. The resilience of nature was very apparent as many of the forests that dominate the landscape today occur on abandoned farmland and are 100 – 200 years old (Figure 17 and 18). These forests are viewed by the public as wilderness areas and are managed for multiple use purposes by the US Forest Service.

Figure 15. Landscape of the Blue Ridge mountains



Iron Furnace



Operation of Iron Furnace

Figure 16. Iron production in the Blue Ridge Mountains

Figure 17. Yellow poplar forest in the Blue Ridge Mountains

Figure 18. White pine and hardwood forest in the Blue ridge mountains on abandoned farmland

Once we left the Blue Ridge mountains we visited loblolly pine (*P. taeda*) and hardwood forests on soils derived from metamorphic and igneous parent materials on the Piedmont. There was much discussion about soil classification, soil formation and the management practices that could be used to optimise productivity (Figure 19, 20). It was very interesting to observe a buried profile in the plantation which highlighted the high degree of soil erosion due to poor farming practices (Figure 21). The tour included a visit to the Virginia Department of Forestry where we looked at 18-year-old thinned loblolly pine forests and the soils they were growing on (Figure 22). Much of the research undertaken at this site has been in collaboration with the Forest Nutrition Cooperative.

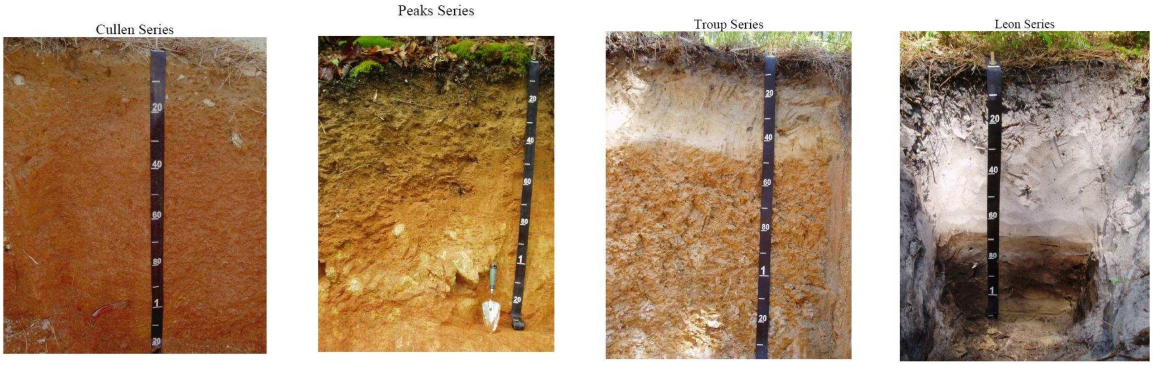


Figure 19. Typical soil profiles observed during the field tour.

Figure 20. Tom Fox and visiting scientists describing the soil profile in a thinned *P. taeda* plantation.

Figure 21. Example of a buried profile with the topsoil indicated by the two blue pins.

Figure 22. Thinned *P. taeda* on low fertility soils (abandoned farmland) on the Piedmont. Note the thin crowns (Virginia Department of Forestry).

A range of plantations and trials were observed on higher fertility soils and lower fertility sandy soils on the coastal plains (Figure 23, 24, 25).

Figure 23. Planting density x fertilisation on land owned by MeadWestvaco Corporation. Note the heavy branching.

Figure 24. Loblolly pine (*P. taeda*) on fertile soils on the Piedmont on Lynchburg series

Figure 25. Longleaf (*P. palustris*) and loblolly pine (*P. taeda*) on low fertility sandy soils

Forest Nutrition Cooperative

There is a very long and interesting history of research cooperation between Virginia Tech, North Carolina State University and the forest industry in south-eastern USA. There are more than 35 forest industry organisations participating in the Cooperative. It is one of the few cooperatives remaining in south-eastern USA and has a 40 year history and strong reputation for good research and industry uptake. In recent years the Universidad de Concepcion in Chile has become a node of the FNC where Dr Rafeal Rubilar is working on nutrition research for *P. radiata* and *E. nitens*.

The mission of the Forest Nutrition Cooperative is to integrate research, education and technology transfer to provide innovative solutions to enhance and sustain forest productivity through management of soil and site resources. Figure 26 shows the extent and distribution of series of trials covering a wide range of nutrition, productivity and silvicultural research. The success of the FNC is also due to a broader focus from nutrition research to include productivity and management systems.

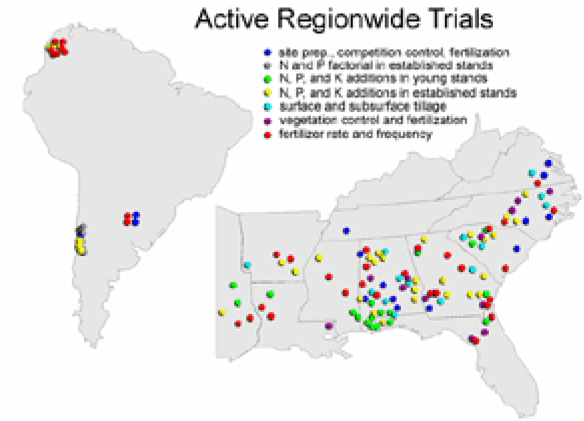


Figure 26. Location of active Regionwide trials across SE USA and South America

I visited the NC State University on Monday 30th June where I met with staff and students involved in FNC research programs: Dr Lee Allen (Director) and Tim Albaugh (Senior Researcher) and Leandra Blevins (Data Manager) on their wide ranging work on nutrition and management and the operational aspects of the FNC, and two PhD candidates: Jose Zerpa (Venezuela) on volatilisation of nitrogen fertilisers and Jose Alvarez (Chile) on his plans for research on remote sensing for nutrition management.

It was evident that there is a very strong relationship between the researchers and industry partners. A key strength of the FNC is the high quality students who study at the FNC working on many aspects of nutrition management and silviculture that are important to industry. Many of the students who have studied at the FNC now work for industry partners. This has obvious benefits for communication and operation of the FNC. The success of the student research program shows many similarities with the Forestry CRC (based in Hobart) in Australia.

I was very fortunate to visit the FNC at this time as Dr Lee Allen (FNC Co-Director) was in his final week of work before retiring after 18 years at the head of the cooperative. Another key figure in the FNC was Tim Albaugh who was very helpful and my host throughout the remainder of the trip.

Administration and communication by the FNC to members appears effective. This is achieved through an annual meeting to report on research programs and to set budgets, followed up by contact meetings (field-based) with individual members once per year to talk about the latest results and implementation options in their situation. Anything new can be raised with the FNC directors during these visits and it is important that directors attend these meetings so that there are no surprises. Once every 5 years a strategy meeting is held to refine the research program as a group and remind members of the priorities. This is then linked in with each of the work programs and fits with the annual goals. There was good technology transfer in action. The FNC motto is: keep contact, be consistent, be available, and be able to provide what they say in timely, useful way.

A characteristic of the business environment in the region (and elsewhere) is that there has been much change of ownership of forest estates and this is continuing. There are also many changes in company and organisation structure (e.g. TIMO and REIT) which can make management of the cooperative challenging.

The wide range of field trials (Figure 26) include topics such as site preparation, early age, mid-rotation, long-term trials, weed control, physiology, soil processes, and remote sensing. These trials have been the foundation for work on long-term trials and the development of decision support systems (DSS).

There have been many trials and sites and there were many instances where research did not go according to plan. Many were lost or compromised and it is now becoming more difficult to have trials successfully established and then maintained adequately by research partners. This has led to the recent practice of using contract labour for the installation and maintenance of new research trials. The series of trials is now up to Regionwide 19. New work that is being targeted by the FNC includes: ways to combat rising costs of fertiliser and determining priorities for fertiliser application. This includes further development of decision support systems.

The FNC has developed a very good understanding of the resource limitations in the region and has focused on fixing the limitations with silviculture. In early years there were chronic widespread nutrient limitations (especially N, P). Nutrient supply curve varies greatly. Trials in the 1980's with NP trials demonstrated very large growth responses following a huge effort by members. Rates of 200 kg N and 25 kg P was shown to pay off very well (IRR 15%+). In those times no diagnosis was necessary because most sites responded. However, due to increasing costs of fertiliser and application, decision support tools and leaf area index (LAI) are now used to target sites which will provide the best return on the fertiliser investment. Remote sensing using Landsat has been successfully applied to observe stand performance over time. Detection of stand LAI is relatively straightforward in the region due to the deciduous understorey species. Work is now underway to use LiDAR to discriminate between individual tree LAI in thinned stands.

Important ways to combat the historically high fertiliser prices are:

Prioritise stands to receive nutrients,

Reduce rates of application,

Manage volatilisation,

Use urease inhibitors,

Seek alternative sources of nutrients,

Manage costs with futures.

The standard fertiliser prescription for *P. taeda* in the region is based on LAI:

(a) If peak LAI <1.3 and P deficient, use 36N and 40P, repeat N later

(b) If peak LAI >1.3 and < 2.2 fertilise 120N+25P, repeat with N later

(c) If peak LAI > 2.2 and < 3.5 use 200N and 25P or (a)

(d) If peak LAI >3.5 don't fertilise unless thin (then use c.)

The management focus is to apply early and intensive silviculture to achieve good early growth and then to maintain growth rates through the rotation. *P. taeda* a very plastic species and if intensive management stops, then growth stops. It has been clearly demonstrated it is possible to drive the growth through fertiliser and weed control. Natural stands grow at rates of 5 – 8 MAI in the region. Managed stands grow at 8 – 10 MAI while intensive management can achieve 10 – 15 MAI and up to 20 – 25 MAI.

The philosophy is to focus on the process not the tool, that is, what is limiting productivity, and how to manage to minimize the limitations. The point was raised that gaining an understanding of the processes is important so as to be able to correctly interpret responses and much of the FNC research has been carried out to help understand nutrition processes. Long-term sites such as SETRES (South East Tree and Research Education Site) and the Henderson Long-term Productivity trial have provided a lot of information on these processes and limitations.

Due to the increasing economic pressures it is important to design for thinning operations. It has been shown that 75 tonnes / ha is required to make the operation pay. However, intensive management costs are in the order of $6 / tonne, while current pulpwood stumpage is in the order of $6 - $8 - $10 / tonne. This is very low and so the economics are marginal. In the past, pulpwood stumpages used to be $12 / tonne.

Regionwide 17 mid-rotation experiments

These trials followed RW 13 and RW 15 and were established on 13 sites across SE USA. Fertiliser treatments were 200 N, 50 P applied in mid-rotation. Several of these sites were compromised due to weed control issues, bark beetle infestation, root rot problems and fusiform rust problems. Weed control is a big factor (Imazapyr herbicide applied aerially to control hardwood weed understorey species, e.g. oak species.

The objectives of the trials are to determine the most effective way to ameliorate limiting resources in mid-rotation stands and quantify the magnitude and duration of responses in pines and competing hardwoods following one application of weed control, fertilisation and combination, on a variety of sites and competing vegetation levels. This has resulted in a range of responses due site variability and other problems and implementation.

Average response to treatment after 8 years for Loblolly pine and slash pine

ft/ ac/yr (m3/ha/yr)	Loblolly pine	Slash pine
Fertiliser	45 (3.1)	13 (0.9)
Vegetation control	35 (2.5)	23 (1.6)
Fertiliser+ Vegetation control	70 (4.9)	35 (2.5)

Outcomes

The importance of vegetation control in combination with fertiliser

Fertiliser + vegetation control > Fertiliser > Vegetation control

Fertiliser had the same response patterns as in RW13 and RW 15

However, vegetation re-growth was reducing responses over time

Economic responses to fertiliser – more response per $ application cost with vegetation control

Figure 27 and 28 show the weedy and weed-free treatments at one site for the RW17 series.

Long term effects of P fertilisation on P availability

Very big responses to applied phosphorus have occurred with a dominant and large change in Site Index. Fertilisation x weed control were applied with P applied at 56 kg / ha P (DAP 280 kg / ha). The main change was an 8 – 10 kg / ha increase in organic P. This means there was more phosphorus in the system and there was no change at depth except for fixing by iron at depth at clay layer. It was found that there was a carry over of P until the stand was 8 – 10 years old.

It is important to get the N:P ratio correct and a lot of work has been done on this. A lot of stands get treated with a large amount of nitrogen fertiliser; e.g. 100 – 150 kg / ha N. The importance of the O horizon in the soil for decomposition and for future soil P pools was highlighted.

Figure 27. Regionwide 17 trial. Weedy treatment

Figure 28. Regionwide 17 trial. Weed-free plot

South East Tree Research and Education Site (SETRES)

This study site was established in North Carolina in order to expand the understanding of relationships among forest productivity, resource availability and environmental stress using loblolly pine as the model.

Outcomes from this research:

The potential productivity is far above levels being realised today on many sites

Improved resource availability results in better growth due to higher leaf area and higher growth efficiency

Resource availability varies during the rotation and is manipulatable (i.e. Site index is not fixed)

Variations in response to treatments are expected due to variations in resource availability across sites and the treatment's effectiveness in ameliorating the resource limitation(s).

Variation in individual tree size is decreased – stand homogeneity is increased

Density dependant mortality is almost non-existent until carrying capacity is reached

Diameter and basal area growth is much higher than existing models predict – high basal areas are achieved before age 10 years.

Spatially available LAI and weather data can be used to predict growth.

Figure 29. SETRES site showing typical plot condition and litter traps (left).

Figure 30. SETRES site showing a distorted longleaf pine among loblolly pines located in a high nitrogen treatment

Figure 31. Loblolly pine genetics trial as part of SETRES 2

FACE Experiment (Duke University)

Host: Dr Jeff Pallin

The FACE facility consists of four free-air CO_2 enrichment (FACE) plots that provide elevated atmospheric CO_2 concentration and four plots that provide ambient CO_2 control. The system has been in operation since June 1994 in the prototype plot, and since August, 1996 in the three additional plots. The prototype plot and its reference were halved with a barrier inserted in the soil in 1998 to conduct, together with five additional plot pairs, CO_2 X soil nutrient enrichment experiments. The rest of the plots were partitioned in early 2005 and incorporated into the CO_2 X nutrient experiment. To increase statistical power, four additional ambient plots were established in January, 2005, halved, and one half of each fertilised.

It costs $2 million per year to operate including $1 million for maintenance / CO_2. Three truckloads of CO_2 are required every day (during the day time only). It has another 5 – 7 years to go including a 3 - year decommissioning phase. Each ring is 30 m in diameter

Outcomes

It has been shown that CO_2 is increasing faster than the trees can sequester it. Therefore, it is still important to cut emissions. Trees and carbon sequestration are only part of the answer to combating the increasing CO_2 levels.

It was demonstrated that tree growth increased with higher CO_2 via higher rates of photosynthesis.

Some treatments were applied to test the response to high nitrogen levels (100 kg N / ha / yr applied in the last 3 years). The trees showed a definite response to improved nitrogen nutrition.

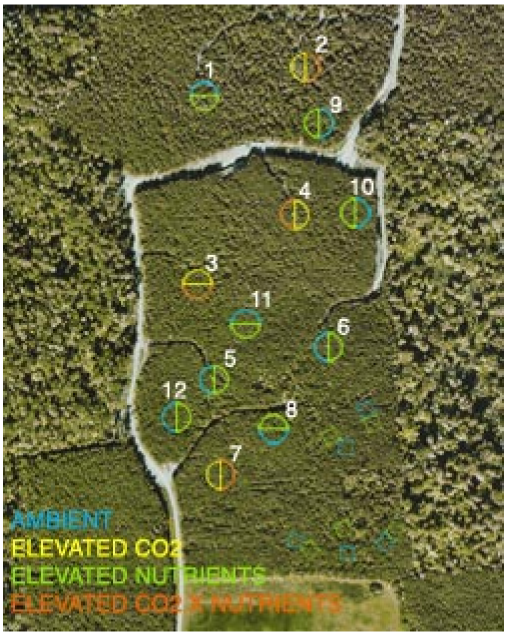


Figure 32. Overview of the FACE experiment

Figure 33. Face experiment from the top of one 30 m diameter ring.

Figure 34. Face experiment at base of ring showing the range of monitoring equipment.

Henderson Long-term Site Productivity project

In the late 1970's the forest industry realised that they could enhance forest productivity on the coastal plains through the application of phosphorus and weed control. However, they did not have much research to lead this and there was little information on the long-term impact of forest management practices, for example whole tree harvesting. At this time there was concern over the potential for 2R decline. Therefore, in response to these questions, the Henderson Long-term Site Productivity project was established in 1980. This is one of the few studies in the world where the effects of plantation management practices have been intensively studied for a whole rotation. It is therefore a very important research site

The establishment of the trial followed detailed pre-harvest assessments in an existing *P. taeda* 2R stand, and then eight regeneration treatments were imposed on the third rotation crop – level of harvest utilisation, site preparation and weed control (vegetation management). In addition, many other processes have been intensively studied including soil chemical and physical properties, N-mineralisation, forest floor dynamics and plant community dynamics. Tree growth was used as an index of change in resource availability.

At the time of installation the standard practices were whole tree harvesting, nil fertiliser, and nil vegetation control for many non-industrial forest owners.

Outcomes

Control of vegetation (hardwoods) resulted in a doubling of plantation growth.

Harvest intensity had no effect on stand productivity

All but one of the plots exhibited higher site index values in the 3rd compared with the 2nd rotation.

Above-ground production in the pine plantation has been higher than in the mixed pine-hardwood stands.

Soil N-mineralisation rates peaked immediately after harvest on all treatments and dropped rapidly and have remained low since age 5 years (<30 kg / ha / yr).

Organic matter and nutrient displacement associated with piling at harvesting and site preparation had no effect on stand growth and little impact on N-mineralisation. Soil N availability appears to be more important than N capital.

Soil physical properties exhibited recovery in the surface of skid trails after 20 – 25 years

Intensive site preparation and vegetation control treatments resulted in early differences in the species composition of the plant communities, but by late in the rotation, these differences were no loner evident. However, there were strong differences in stand structure.

Carrying capacity: pines were much more efficient than the hardwood understorey due to differences in utilisation and growth. However, this depends on site type (fertile vs infertile).

Figure 35. Henderson Long-Term Site Productivity trial (weedy treatment)

Figure 36. Henderson Long-Term Site Productivity trial (Weed free)

Companies visited

Resource Management Service LLC (RMS)

Host: Gerald Hansen

RMS is the largest privately held forest management and consulting firm in the United States. The size of its forest estate is approximately 3.5 million ha in size, with 240,000 ha located in North Carolina. Much of the estate was previously owned by Union Carbide, then International Paper.

The company is known for its intensive and innovative management practices and the RMS philosophy is to add value to plantations to provide the best return for their investors. RMW is targeting value-adding through clonal or varietal forestry and fertilisation programs. In this region there are 10 staff to manage 100,000 ha of plantations across three districts.

General silviculture

General silviculture for the coastal plains involves growing *P. taeda* for pulpwood and solid wood on rotations 25 – 27 years in length and typically, have two thinning operations (see table bellow). Thinning is managed on the basis of basal area and involves a 5th row extraction row system. The table below shows a typical regime.

Typical stocking and timing of thinning operations for *P. taeda* on the coastal plain estate

	Per Acre	Per ha
Plant	550	1375
T1 age 9	300	750
T2 age 18	100	250
CF 23		

Plantation sites on the coastal plain generally have poor drainage therefore drainage and bedding (mound cultivation) are very important operations for re-establishment. An example of a young plantation (6 months old) is shown in Figure 37. Establishment practices use a fallow period of 2+ years between crops. The Sustainable Forestry Initiative requirement for fallow is 2 years. The site was very clean site (little residue) and therefore one pass bedding was able to be applied without the need for blade or chopper rolling. The beds were pulled one year earlier (2007) and then weed control (imazapyr / trychlopyr) applied as a pre plant spray. Planting was carried out in January 2008 at a stocking of 12 ft x 6.5 ft (approximately 1400 per ha), and then banded weed control was applied post-planting (imazapyr and sulfometuron methyl) over the top of the seedlings. Weed control is also practiced later in the rotation as understorey release treatments. In this case, if hardwoods species are present, for example maple and sweet gum, then imazapyr is applied over the top of the tree crop. Post-thinning understorey release may also be required (imazapyr and trychlopyr) and is applied beneath the tree canopy using a boomless sprayer on a skidder (Figure 39). This is the standard regime on the plains

Figures 37. 2R establishment (*P. taeda*) with mound and strip weed control.

Nutrition management

Nutrition management on the plains is based on a system of soil and site categorisation (CRIFF). Phosphorus is a vital requirement on these sites and P levels are determined from soil samples using the Melich 3 method. The amount of P that has been carried over between rotations can be determined by this method. This newly established plantation (Figure 37) contained 25 lb P per acre (30 kg P per ha) of residual P. The critical value for this region is 12 lb P per acre for establishment (14 kg P per ha) while the threshold is 16 lb P per acre (18 kg P per ha). This system is allowing cost savings through improved targeting of the correct areas to fertilise and this is currently running at about a 20% saving in fertiliser cost. Most of the estate is covered by soil maps which are crucial for nutrition management. At later ages the trees are used to indicate what nutrients are needed and this is based on leaf area index (determined by remote sensing).

A typical fertiliser regime:

Fertiliser at planting DAP

2. Juvenile 4 – 5 yrs Phosphorus (NP 100 , 25 kg per ha) (earlier if no P at planting)

3. Post thinning Mid rotation NP (DAP in summer at 125 lbs per acre (140 kg per ha) and urea in winter at 386 lbs per acre (440 kg per ha)

It is common for pre planting fertiliser (phosphorus) to be applied by air. FNC nutrition trials on the RMS estate, for example Regionwide 18, have helped to provided answers to post-thinning nutrition questions.

Innovation

Innovations that are being considering by RMS include new espacement opportunities. Wider rows involve lower stocking and are more suited to growing clonal forests and there are also spin-offs for other operations such as fertilisation. Other work is focusing on improving the use of LiDAR.

Figure 38. Significant drains on coastal plains sites. Note the retained habitat strip alongside.

Figure 39. *P. taeda* plantation aged 3 – 4 years old.
LAI is currently > 3 therefore secondary fertilisation is not yet required.

Figure 40. *P. taeda* mid rotation showing extraction row and dense understorey. Release treatments are often applied in these situations.

Other comments

Environmental issues are very important on the coastal plains and water management is part of this. Large drains are excavated through the plains to enable growth of productive pine plantations (Figure 38). Many of the large drains were in place before Clean Water Act 1972 was introduced. RMS is permitted to carry out management and maintenance of drains but is not permitted to cut them deeper. Access isn't always straightforward due to deep drains surrounding the plantations. Some drains have culverts, some have crossings as in Figure 38 and some contractors have portable bridges that are used to access the plantations.

Habitat diversity is also very important in the region for hunting purposes. Some areas are commonly left untreated, for diversity and encouragement of early successional species. There is also a requirement for vegetation to be retained along major drains for diversity / habitat purposes (Figure 38). The Sustainable Forestry Initiative sets conditions on diversity of the landscape including the mix of age classes and the size of clear-cut. The average clear cut is approximately 120 acres (50 ha) in size.

Weyerhaeuser

Host: Dr Robert Campbell

Weyerhaeuser is a fully integrated company with land, forests, mills, and manufacturing facilities. The Weyerhaeuser estate in North Carolina consists of 1 million acres (400,000 ha) plantations which are based on Loblolly pine (*P. taeda*) and are now in their 2nd rotation.

General silviculture

General silviculture involves thinning, pruning and an aggressive fertilisation strategy. Conservation of organic matter is given a very high priority and fire is no longer used. Espacement is wider than other plantation growers in the region with 20 ft rows (6m). This espacement allows Weyerhaeuser to put the organic matter in-between rows during site preparation. The *P. taeda* plantations are grown on 30 year rotations to produce large diameter sawlogs. The target is 14 – 16 inch (35 – 40 cm) which is limited by the debarking ring. Butt flare can be a problem sometimes. Many of these logs go to produce plywood. The large logs achieve a premium over smaller logs. Up to 80% of the sawlogs processed by Weyerhaeuser come from their own plantations. There are large benefits to owning the mills and being vertically integrated. Tree length harvesting systems are used.

However, Weyerhaeuser is now moving towards 22 – 25 year rotations. This is raising wood quality issues that need to be worked through. The premium product specifications are 2 x 12 inch boards. This is a premium product and a niche that Weyerhaeuser have captured. Locally Weyerhaeuser cannot compete with smaller dimension timber that comes in from overseas, e.g. Finland which produces very good quality material that is cheap. This type of material can be imported cheaper than it can be grown in the region. The strategy is to compete in the premium grade market. Therefore, management is directed towards this aim to get the most value rather than volume from their plantations.

Plantations are designed in an alley layout which is good for reducing costs. Pruning is carried out to 6 m. Over many years they gradually moved to wider rows 12, 14, 16, 18 ft widths without GPS, but it was difficult to keep damage down so it was eventually decided that wider rows would be better (20 ft row widths) and these are developed using GPS and V shearing with bedding.

Nutrition management

Nutrition and productivity are very important to the business. Fertiliser programs have been carried out in Weyerhaeuser plantations since 1979. Winter is the traditional time for fertilisation however, late summer / autumn is when the largest uptake by the crop occurs - a growing season response. Application is best done in the rain.

Nutrition management is tied to soils, then foliage development, then basal area. Land history and landform is also important. Landsat is used to help. There is a lot of data on LAI and this is used target sites for application. The overall fertiliser program is now cost constrained so prioritisation is very important. There are some operational constraints.

Weyerhaeuser has an applied research facility to help managers make decisions and a lot of work has been done on foliar micro nutrient application and dose rates.

Ground-based equipment is used for fertilisation where possible. Aerial application is more expensive and more fertiliser is applied due to broadcast. However, the decision depends upon topography.

An important consideration for nutrition management is the weed load. A pre plant then a release spray is usually carried out at age 2 – 3 years depending on the species. Herbicides are a lot cheaper than fertiliser. A release is also carried out at mid rotation and this is often achieved by mechanical methods. Weeds are also reduced through crushing during thinning operations.

Innovation

Weyerhaeuser has been at the forefront of developing fertiliser products for their own purposes over the years and some of these products have had patents applied and Weyerhaeuser is looking to market some of these to other plantation growers. They have developed a proprietary suspension (liquid) which is a blend of phosphorus and micro nutrients. MAP or phosphoric acid is combined in a suspension product which allows them to suspend the materials together. Micronutrients are in a chelated form so they are more available. Weyerhaeuser also have a proprietary product for a coated urea granule along with copper products and boron (Arborite). A spray binder containing B and Cu is applied to a urea granule which reduces volatility which is a concern (with up to 30 – 50% losses). Then there is powdered MAP on the surface. This provides a 39:9:0 ratio of N:P:K. Phosphorus and boron provides good control of volatilisation. This product has achieved 25 – 30% less losses through volatilisation, therefore Weyerhaeuser has been able to apply 25% less product, which saves maybe $10/acre maybe up to $20, which is a significant saving across a large estate. The per tonne price for coated products is high but when applied on a per acre price, it is a very good product.

There were many issues when developing the new coated products. There was some residue dust with product which was due to out of spec product. However, Weyerhaeuser were working with a good company and got it just right. The dust standards are now below 1 – 2 % for aerial and 5% for ground-based applications. They do not use augers but belts in their equipment, which helps handle the product more carefully. The big thing in the success of the fertiliser development was the relationship with fertiliser company and between the people. The driver was the fact that federal bodies and fertiliser companies are now not so much into research so no new products were available, except for some companies e.g. Scott. Therefore, agriculture and forestry have had to deal with commodity products. They were dealing with a commodity philosophy rather than a technical philosophy or expertise. So Weyerhaeuser decided to develop their own products. Laboratory testing is also very important. The raw material source is also very important because of problems with dust and chemicals and purity. Not all field trials worked either.

Other comments

Weyerhaeuser have recently sold their fine paper business and container board business. They intend to hold onto the Timberlands as their core business and it is yet to be decided whether the rest of the processing side will be sold. Certainly there is pressure from Weyerhaeuser stakeholders (Wall Street) to proceed towards a REIT to meet tax requirements.

The FNC has provided a lot of good research that could be applied and tailored to Weyerhaeuser operations. The field trials have helped to guide the development of their own silvicultural practices. Weyerhaeuser does more tillage than other companies and this is based on results from Region Wide 16 trials. Region Wide 18 trials give the dose rate for fertiliser application. There can be 3 – 5 applications through the rotation. But not all sites are broadcast applied. Leaf area development is more important than age and important work has been done on this by the FNC.

Figure 41. Typical 2R site preparation with shear blade pushing slash between the wide (6M) rows

Figure 42. A fallow is typically used to allow understorey species to recover before herbicide application.

Figure 43. A high quality sawlog regime to produce quality products.

ArborGen LLC

Host: Phil Doherty, Pine Development Manager

ArborGen is a leading tree improvement and production business with primary markets in the United States, Brazil, Australia and New Zealand. The Company operates from more than 20 locations, producing more than 350 million treestocks each year and employing more than 185 people.

Seedlings are produced in a most efficient manner with a focus on resources. The motto is ‘Seedlings with insight’. Phil’s job is to characterise the seedlings for the correct end use and what the requirements are. He recommends how to use the seedlings and how to get the best out of them. This is achieved through understanding silviculture, resource availability and limitations. ArborGen’s focus is to be more responsible and site specific with improved silviculture to extract the best worth of the genetics. This is very refreshing and pro-active. Phil discussed how the company uses information on the site, resource availability and limitations - what the site brings to the equation, where the pools of resources are and how to get the most of what you need from what you have (how to fully utilise the site, resources and genetics). This is a very good example of marrying the all the important components.

ArborGen is now working on the nutritional requirements through the rotation. Work with the FNC has been very important especially the Region Wide 18 trials. This has provided process level research and these trials have shown that productivity can be increased to 40 MAI. However hurricanes are a problem in the area with damage is proportional to LAI, i.e. influence of fertiliser.

On some soils a bigger response is achieved to managing stand density rather than nutritional inputs. Dry sandy soils need fertiliser as demonstrated in SETRES series of trials. However, as genetics are changed, other things may also change and this is different for nitrogen and phosphorus. These responses are also dependant on site and water regime.

Phosphorus carry over is monitored and used as a general guideline. If 70 lbs P per acre (80 kg P / ha) is applied in first rotation, then it will generally last until time of first thinning, before there is a need to reapply phosphorus. However, there is a need to keep in mind what is done to sites during site preparation.

The configuration of stands is also important. Trees of high genetic quality are not planted in extraction rows. Common configurations are 10 ft x 5 ft spacing. (3 x 1.5 m spacing = 2222 stems / ha). Now with improved genetics 60 – 65% of the stand trees are of sawlog quality. This is much better than before and inter row thinning is now being undertaken as well. Improved genetics have been shown to significantly increase growth / productivity in the next rotation. For example, 1R Site Index was 70 ft (21 m) but this is now in the mid 90’s (27 m) at age 7 years. It was mentioned that some plantations are heading towards a direct sawlog regime with a need to focus on the sawn timber outputs form the start. Most plantations are still managed for pulpwood only.

Branch control is a big issue and genetic control can help. ArborGen has gone clonal in a lot of places and have made significant gains. There are clones that have good growth and good branch quality, plus uniformity along with good branch control into the 2nd and 3rd log. This is only possible at the clonal level. There are cost differences with clonal material being 40c per seedling, compared to 12 – 15 c for MSP and 5 – 7 c for a standard seedling but the gains can be phenomenal.

Figure 44. Region wide 18 post thinning fertilisation trial (part of the series established by the Forest Nutrition Cooperative)

Figure 46. Clonal trial

The clonal trials that we visited were very impressive. They had a range of combinations of genotypes and phenotypes. The between row spacings are wide which allows big savings, with more strip or individual tree fertilisation which is row directed or tree directed. There is a move towards lower stocking. The main focus has been to find the best clone for the best use and this will depend very much on the management objective. It is all about finding the best match, which is a huge advance on previous approaches. ArborGen consider that the most important management decision is the initial stocking.

There are different stand dynamics between the clones. Total volume is the same but bigger trees, higher growth, higher percentage of sawn timber recoverable. This is seen as excellent value for anyone serious about forestry. Poles are very high value too and provide great returns.

ArborGen is also looking into pruning considerations, wildlife considerations and biofuel options with a new generation of trials planned. ArborGen is very focused and it was invigorating visiting and talking with them. They are “making every tree count”.

Appendix 1. Abstract of paper presented at conference

Management of Phosphorus nutrition in radiata pine: 45 years of research and experience in Tasmania, Australia

W.A. Neilsen[1] and P.R. Adams[2*]

[1]1 Bareena Rd, Taroona, TAS 7053

[2] Forestry Tasmania, G.P.O. Box 207, Hobart, TAS 7001

Low level of soil phosphorus is a major factor limiting productivity across significant parts of the Tasmanian plantation estate. Phosphorus nutrition has therefore been the focus of a significant research effort over almost five decades. Long-term fertiliser trials, dating from the 1960's are the foundation for predicting potential growth and responses to P-fertilisers across the estate. Long-term increases of at least 10 $m^3ha^{-1}yr^{-1}$ have been obtained in many of these experiments. Research has also investigated the interaction with other nutrients, root growth relationships and the effect of fertilisers on soils. Extensive aerial fertilizing was commenced in the early 1970’s based on this research. In conjunction with research, forest soil surveys, that have identified, named and mapped 185 individual soils with profiles described and full profile physical and chemical analyses, have been carried out. This work has recently culminated in the development of a P-fertiliser decision guide (PFertGuide). Using a GIS database, climatic factors (rainfall and temperature) are combined with the detailed soil profile data (topsoil depth, organic matter and rooting depth) and crop factors (growth, visual symptoms and foliar-P concentrations) to determine the requirement for, and likely responses to, the application of P-fertiliser. The P-fertiliser program is primarily targeted at young trees between age 4 and 8 years with the aim of overcoming limiting P and allowing the stands to achieve and maintain satisfactory growth. Recommendations include fertiliser products; rates and timing along with levels of confidence in predicted stand responses for a range of soil x stand combinations. The research demonstrates the value of extensive research combined with detailed soil survey information in developing fertiliser programs.

Theme Area: Management effects on growth, production and sustainability of forest ecosystems, or Fertility and Tree Nutrition