“Wood production in agroforestry and in short-rotation forestry systems – synergies for rural development”

Proceedings of the IUFRO:s conference (session 12, 128) held in Brisbane, August 8 - 13, 2005

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Uppsala 2006

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Lars Christersson, Theo Verwijst and Swoyambhu Man Amatya (eds.)
Report from the Department of Crop Production Ecology (VPE) No.4
Swedish University of Agricultural Sciences (SLU)
Uppsala 2006
ISSN 1653-5375
ISBN ISBN: 91-576-7177-X

Cover picture: 16- year old poplar plantation at Kadesjö,Skåne, Sweden. Mean height is 25 m and mean diameter 23 cm, the planting density is 650 trees per ha. Photo: Lars Christersson

Editor: Birgitta Båth

Content

Introduction

Sessions (12, 128): "Wood production in agroforestry and in short-rotation forestry systems – synergies for rural development".

Every fifth year forest scientists of all kinds within IUFRO (International Union of Forest Research Organizations) gather together at a World Conference. In August 2005, this conference was located in Brisbane, Australia. The conference was very well-organized and executed. Forestry study tours in different parts of Australia and New Zealand were included within the programme, mainly after the conference itself.

Following recommendations of the conference organizers, contacts between scientists from IUFRO's sessions for Short Rotation Forestry (1.09.00) and for Agroforestry (1.14.00) were made some years before the conference with the aim of organizing a joint session. Two sessions at the conference were organised, with excellent lectures by all the speakers. The speakers were required to send their manuscripts in advance to chosen reviewers for comments. After every lecture, this reviewer initiated the debate, sometimes with new and interesting angles of approach to the subject. After the conference the speakers were able to take these ideas into consideration. All the manuscripts have now been reviewed and put together in the following proceedings.

Using up-to-date physiological knowledge for increasing biomass production in forestry. National and international aspects.

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Abstract

Most tree breeding programmes and today's genetic engineering activities have the aim of making the plants more effective in transforming the radiation energy of the sunlight into chemical energy in the form of desired wood and at the same time making the trees resistant and hardy. Limiting factors for high biomass production, that could be influenced by man, include the choice of tree species, provenances and clones, together with the nutrient and water supply. The crucial point for high biomass production is the amount of intercepted light and avoidance of water and nutrient as the limiting factors together with good resistance to insects, fungus, virus and browsing animals and hardiness to frost and drought. In this context it is important to use trees species, proveniences and clones that have the potential for a rapid and dense canopy development. For this reason the design of the plantation is of great importance.

On the other hand, high demands for water and nutrients by some tree species can also be utilized in modern society by utilizing tree plantations as vegetation filters. Waste products from the society can be used for irrigation and fertilisation of woody biomass plantations. The main product of such vegetation filters is drinkable water with biomass production merely as a bonus.

New knowledge indicates that a peaceful revolution is taking place within forestry. In Sweden even politicians have realized that. The tools for this are: choice of fast-growing species, breeding programmes, effective methods of cultivation and weeding and techniques and tools to avoid nutrient and water as limiting factors. It is predicted that this change, together with improved hardiness and resistance, will reform the potential of forestry to supply the forest industries with enough wood and to eliminate too much competition between demands for wood for paper on the one hand and wood for energy purposes, heat, electricity and biofuels, on the other.

Introduction

Energy-effective harvesting of the sun's energy, through chlorophyll via carbohydrates to heat and/or electricity or biofuels, has assumed enormous importance in these days of soaring energy deficit (Commission on Oil Independency, 2006). The energy input to earth by the insolation from the sun is enormous but only a tiny percentage is used by plants. Most tree breeding programmes (Eriksson, 1991), and today genetic engineering activities (Sundberg *et al.*, 1997), are aimed at making the plants more effective in transforming the radiation energy of the sun into chemical energy in the form of the desired wood and at the same time making the trees resistant and hardy. The crucial point for high biomass production is the amount of intercepted light (Linder, 1985) and avoidance of water and nutrient as limiting factors (Christersson, 1987; Linder,

1987) together with good resistance to insects, fungus, virus and browsing animals and hardiness to frost and drought (Christersson *et al*., 1992). In this context it is important to use trees that have the potential for a rapid and dense canopy development. For that reason the design of the plantation is of great importance (Verwijst, 2001). Even if the Leaf Area Index (LAI) is the same, the interception of light is more effective if a closed canopy is made up of many small leaves rather than of fewer large ones (Jarvis & Leverenz, 1983, Hällgren, 1983;).

Some tree species, for example of the genus Eucalyptus and Salix, use a lot of water (Lindroth & Båth, 1999; Wildy *et al*., 2000) and for that reason water is the limiting factor for high biomass production in many places. But the most common limiting factor is the nutrient supply, particularly of nitrogen and phosphorus (Ericsson, 1994). However, the high demand for water and nutrient of some tree species can also be utilized in the modern society by utilizing tree plantations as vegetation filters (Christersson, 1994 a and b, Elowson & Christersson, 1994; Perttu & Obarska-Pempkowiak, 1998; Verwijst, 2001). In such plantations, waste products from society such as sewage sludge, run-off water from agriculture and from rubbish dumps etc, can be used for irrigation and fertilisation of woody biomass plantations (Aronsson, 2000). Biomass is then a by-product, drinkable water the main product.

The potential of green plants

Plants with green chlorophyll molecules have the unique ability to absorb the radiant energy of the sun, to convert it to chemical energy and to store it in the form of a large number of organic compounds, such as cellulose, different types of sugar, starch, proteins and fat and others. This process, photosynthesis (assimilation of carbon dioxide), is a process on which all living organisms are dependent for their energy provision (see, Appendix).

Modern research has tried to identify the species which are most efficient in this process of photosynthesis, expressing efficiency in tonnes or cubic metres of biomass produced above-ground per hectare and year (Earl, 1975; Cannell, 1989). In the Proceedings from an IEA-meeting in Ontario, Canada, Morgan *et al*. (1983) stated that “Wood energy plantations have a large production potential; in experimental plots in Canada and Sweden, yields up to 40 oven-dry tonnes per ha and year have been obtained. With genetically engineered planting stock and intensive technology, such production could be obtained on a large scale”.

For theoretical reasons (Doherty *et al*., 2002) and for a more applied discussion of energy efficiency (Börjesson, 1998) it is sometime more constructive to express the efficiency as a percentage of the absorbed, converted and stored radiant energy. A figure which is useful to bear in mind is that an annual production above ground of 10 tonnes of dry biomass, or 25 m^3 of wood per hectare, corresponds to approximately 1% of the energy of the incoming solar radiation. A comparison of the production potential of different biotopes and ecosystems in northern Europe shows that the most common forest types - either pure stands or mixed spruce and pine with some birch - have a conversion capacity of between 0.2 and 2.0% of the incoming solar radiation. The figure of 2% is from 30-year-old spruce on fertile agricultural land in northern Europe: the corresponding figure for various agricultural crops is between 1 and 3%, the latter for sugar beet. For fast-growing deciduous trees grown on agricultural land, the figure is between 1 and 4%. The conversion depends on the species and the initial methods of cultivation, on availability of water and nutrients and on the biological knowledge and technical skill of the growers.

A recent observation is that the optimal above-ground production of woody biomass on a large scale in Scandinavia is between 10 and 12 tonnes per hectare per year for a number of different tree species (Figure 1).

The difference between species lies in the time it takes to achieve that rate of production (Christersson, 1999). It is interesting that the total above-ground biomass production of many well-established and well-managed agricultural crops reaches approximately the same rate. Take wheat as an example: most farmers in northern Europe would consider 7 to 8 tonnes of dry grain per hectare as a good yield. Adding a straw yield of 4 to 5 tonnes again gives a figure of 10 to 12 tonnes. However, the best sugar beet farmers achieve a 25% better result. These yields are achieved without optimizing water availability. In a willow plantation irrigated with nutrient solution, wood production can easily be doubled (Christersson, 1987) (Table 1) compared with non-irrigated plantations.

Table 1. *Optimising the growth rates of Salix dasyclados and S. viminalis clones with very dense spacing and heavy and different type of fertilization and irrigation.*

Clone	**Standing woody biomass in tonnes DM per ha**		
	year one	**year two**	**year three**
77081 S.v.	8	24	41
77081 S.v	8	26 replaced	
77075 S.d.	12	32	68
77075 S.d.	--	26	54
77075 S.d.	--	12	42
78206 S.d.	10	33 replaced	

Table 1 shows some of the fastest-growing plots (after Christersson, 1987). The size of most of the plots was a quarter of a hectare. All edge effects were excluded. The same production results were obtained for irrigated and fertilized poplar plantations in the south of Sweden, but the plots were much smaller (Christersson, 2006a).

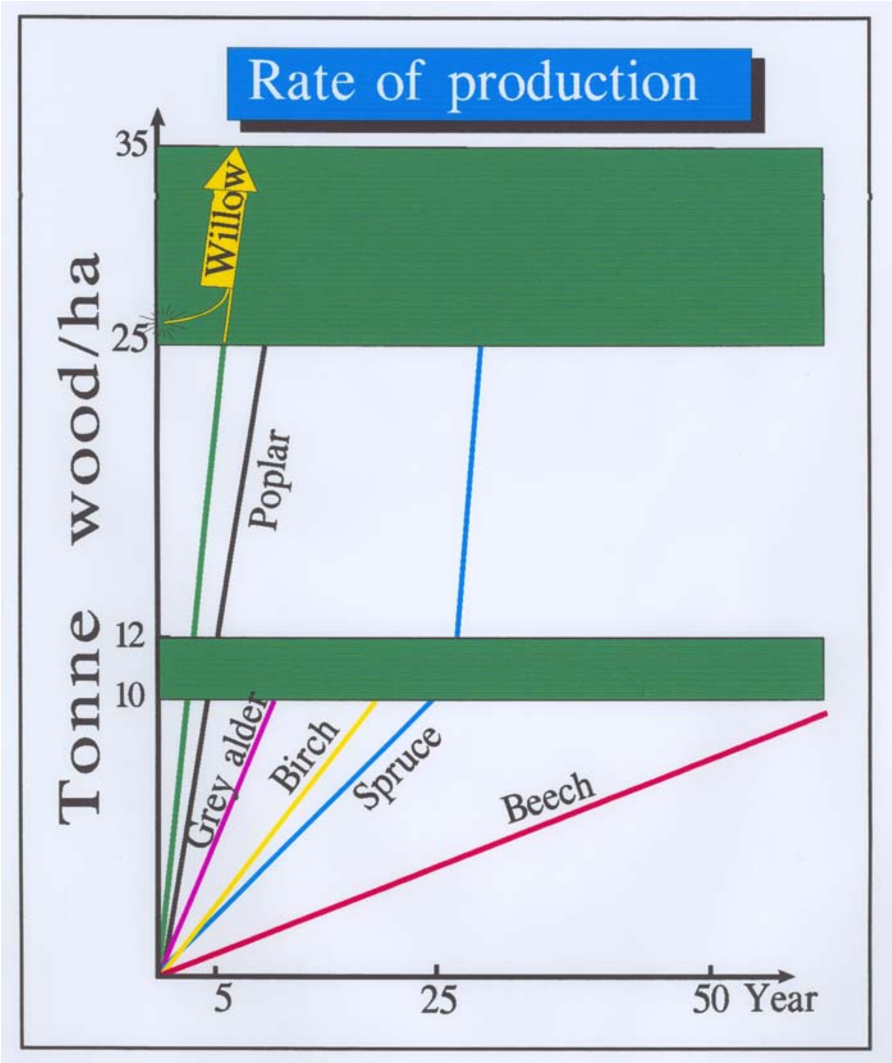

Figure 1. The diagram shows how quickly different tree species reach their optimal wood production, up to 10-12 tonnes of dry matter per ha and year, which is assumed to be ceiling production in natural conditions. Irrigation with fertilisation and early weed control increases this biological production ceiling considerably. The results of experiments (Långa-Veka, Karinslund, Table 1) show that the optimal ceiling lies somewhere between 25 and 35 tonnes of dry matter per ha per year for willow and poplars. Fertilizer and irrigation experiments are being undertaken by the Forest Faculty, SLU, Uppsala, Sweden to determine if the biological production ceiling for spruce and pine lies in the same range. But note that for these very high production figures the risk increases dramatically for all kinds of damage. This route is fraught with difficulties.

A biomass production of 10-12 tonnes DM per ha and year can also be obtained in planted poplar stands without irrigation and fertilisation, but it will take a few years longer to achieve (Christersson, 2001). Results from experiments in the south of Sweden indicate (Bergh *et al*., 1999) that Norway spruce has the same growth potential, but it will take even longer to achieve than in poplar stands. Very high biomass production can also be achieved if wheat or sugar beet is irrigated with nutrient solution, but unfortunately the yield of grain or sugar is almost unchanged while that of straw and sugar beet tops increases dramatically (Van Koninckxloo, 1991).

Eight important processes

It is evident that different plants have a different capacity to convert solar energy to biomass. The obvious question is: what factors and processes determine the production capacity of a particular species, provenance or clone? The short answer is: the rate of leaf development, the ratio of photosynthesis to respiration, how and where the products from the leaves are transported in the plant (the so-called allocation pattern), the turnover rate of fine roots, how efficiently water and nutrients are used (especially nitrogen and phosphorus), and the resistance and hardiness of the plants.

Leaf development

Since almost all the energy conversion of the radiant energy of sunlight to chemical energy takes place in the leaves, the rate of development of leaf area, and the amount, is a very significant feature of plants with high productivity. The amount of leaf area is often expressed as leaf area index, LAI, in square metres of projected leaf area per square metre of ground surface area. The highest values measured for tree stands and for agricultural crops lie between 6 and 10 m^2 per m^2

It is not only the amount of leaf that is important, but also how long the leaves are active. The earlier the leaf area develops in the spring, and the later the leaf falls in the autumn, the better for the biomass production. Linder & Lohammar, 1982 estimated that one-day-earlier bud break in a deciduous tree stand in southern Sweden increases annual production by 1%. However, this is true only if the phenology of the stand is adapted to the prevailing climate, so that bud break is not too early, or bud set not too late, which would result in irreparable frost damage (von Fircks, 1994).

Also relevant is the canopy structure and capacity of some species to arrange their leaves in three dimensions for maximum absorption of solar radiation, together with the size of the leaves (Jarvis & Leverenz, 1983; Cannell, 1989; Ceulemans *et al*., 1993). It has also been shown that it is more effective for a stand to have many small leaves rather than fewer larger ones, even if the total leaf area is the same (Hällgren, 1983). This is related to the extinction coefficient.

Ratio of photosynthesis to respiration

Not all the energy absorbed by a tree is stored in the form of organic substances. Quite a lot is used more or less directly for growth processes, for ion uptake, for pollination and the genetic mechanism and other development processes of trees via the ongoing processes of respiration. The rest, which can be stored, is equivalent to photosynthesis minus respiration. To attain a high production a species must have a high photosynthetic rate and a low respiration rate. With this in mind, one can to some extent explain why production in southern Swedish or Danish beech woods is approximately the same as production in tropical rain forests (Muller & Nielsen, 1965). The growing season is certainly much longer and the solar radiation is much higher in the tropical rain forest. However, the mean temperature is also much higher and since the rate of respiration is mainly temperature-dependent, while photosynthesis is not, much more of the assimilates is consumed in a rain forest than in a Scandinavian beech forest. These conditions will result in a biomass production that is about the same. The fact that irrigated and fertilized hybrid poplar plantations in southern Sweden (Christersson, 1987, 2006a) produce almost as much as *Eucalyptus* plantations in Australia (Baker *et al*., 2005) and Brazil (R. Penchel, pers.com) can be explained in the same way.

The allocation of assimilates

The word ‘allocation’ in this context means the transport of assimilates (mainly sugars) from the leaves in which they are formed to different parts of the plant. Different tree species use completely different strategies for this. The allocation of the assimilates, and the time schedule for this, to stems, leaves and roots is of particular interest in energy forestry, because it is the stems which are harvested. Many young coniferous trees invest a lot in the roots and relatively little in shoot development to start with, whereas the so-called pioneer tree species do the opposite. A number of willow species are extreme in this respect and have a relatively shallow and sparsely spread root system while much of the assimilate transport is directed to the growing points of the shoots. However, this pattern only applies in the young stages and after a number of years the willows invest more and more in the root systems. This phenomenon is one of the reasons why willows are harvested after three to four years so that the juvenile stages are maintained. This will result in a situation in which the translocation of sugars from the leaves is directed to shoots rather than to roots. As a consequence there is a high woody biomass production in the stems.

The turnover of fine roots

The development and turnover of the root systems is a relatively complicated process and our knowledge about it is particularly limited (Rytter, 1997). It has always been much simpler and quicker to achieve research results working with the above-ground parts of a plant. Besides, it is usually the above-ground parts which are harvested and so are most interesting in practice.

The root system of the tree penetrates through practically all the available soil volume over and over again in its search for water and nutrients. Since most of the uptake of nutrients and water is by the root tips this penetration of the soil must be ongoing. Thus the formation and the death of the fine roots (diameter 1 mm or less) are of particular importance. A rapid turnover of fine roots and root hairs gives a significant competitive advantage to plants with high productivity, because it allows rapid and efficient uptake of the ions made newly available by weathering and by humification. The same applies to precipitation.

In some willow species the formation of fine roots and root hairs is so rapid that the total growth of the root system in the growing season is equal to that of the stems, and the length of life of the fine roots and of the root tips is calculated to be only a few weeks (Rytter, 1997). In this context we can point out the enormous importance of mykorrhiza fungi for the effective uptake of nutrients and indirectly of water (Arveby & Granhall, 1998). We know very little about the turnover of the hyphae of these fungi during the growing season. We really know only that this occurs and that it is of greatest importance.

Water use efficiency (WUE)

In many parts of the world, water is the limiting factor for biomass production (Falkenmark, 1986). Presumably this is also true for the biomass production of woody species (Lindroth & Båth, 1999). Cereals use about 400 to 600 liters of water in order to produce 1 kg of dry biomass. The same is true for sugar beet and potatoes, whereas deciduous trees and coniferous trees in Europe use about half of this (Jörgensen, pers.com.). An example of water availability governing the choice of species is that in Australia eucalypt species are planted on areas with at least 700 mm annual rainfall and *Pinus pinaster* on areas with at least 450 mm (J.Bartle, pers.com.).

There are very large differences of WUE between different species and between different clones. The figures do not distinguish between the actual requirement and luxury consumption. To determine the efficiency of water use by a species, provenance or clone in the absence of luxury consumption, plants must be subjected to controlled and measurable stress, which is technically difficult to achieve. However, most investigations so far show that there is a lot of variation between different clones of willow.

Knowledge of the WUE is also essential because many willow clones are used in plantations close to city dumps or as vegetation filters to remove as much water as possible (Perttu & Obarska-Pempkowiak, 1998). The more water they transpire the better. For that reason tests should be initiated to select the willow clones which have the highest Luxury Water Consumption (LWC). The same is valid for the oil mallee plantation in Western Australia, where they try to lower the salty ground water table by planting belts of deep-rooted eucalypt tree species with a high LWC (Bartle & Giles, 2001).

Nutrient use efficiency (NUE)

In order to utilize the total growth potential of a species in the prevailing conditions of climate and of water availability, it is usually necessary to apply fertilizers. Different species vary in the efficiency with which they utilize the available plant nutrients. However, our knowledge of this variation is particularly limited because of the difficulty of finding adequate methods to measure the efficiency. The problem with luxury consumption also arises here. The more effective and competitive a species is in taking up nutrients, particularly nitrogen, phosphorus and potassium, and then making use of them, the higher the biomass production that can be obtained in the prevailing conditions. There are some published results from Croatia in which the uptake of nitrogen of some fast-growing Salix hybrids varied between 14.0 g to 21.1 g per kg of dry matter woody biomass produced (Kajba, 1999). These results demonstrate the great economic and ecological benefits of using effective clones. The ecological benefit will came from the decreased leakage to ground water, streams and lakes. It is also important to take NUE into consideration as one of the most important characteristics in any future breeding programmes.

The efficiency of utilization of nitrogen and phosphorus in conditions of good water availability

It is assumed that the efficiency of utilization of the nutrients that are mobile in water, for example nitrogen, phosphorus and potassium, will be affected by good availability of water. This means that proteins and phosphorus compounds in older, dying leaves would be broken down rapidly in a tree to which water is readily available. Then the products of the breakdown, in the form of nitrate and phosphate ions, will be transported rapidly to the meristems, the growing points of the shoots and roots. It may be possible that these processes can occur several times per growing season so that the same nitrate and phosphorus ions might be used more than once in a year. This hypothesis has been put forward because biomass growth is sometimes so large that some of the nitrogen in the current budget calculations is "missing".

Resistance and hardiness

In the same way as respiration decreases total net production, biological damage caused by insects, fungi, bacteria or viruses, for example, and non-biological damage, such as that caused by frost and drought, reduces or sometimes completely eliminates high biomass production. Thus it is not sufficient for a tree species to have a high growth potential; it must also have a high degree of resistance and hardiness. As an example of the possible magnitude of damage, we can mention the reduction of the biomass production of a willow stand by 60% by a single night of frost in Halland (in the south west of Sweden) at the beginning of June, during which the temperature dropped to -4 °C (Verwijst *et al*., 1996). In the same way, infestation by pests (beetles or Hymenoptera), or leaf rusts can wipe out stands of hybrid poplar clones in some years (Newcombe, 1996). A synergistic effect of frost and fungus attacks, for example, would be expected but has not yet been demonstrated to be significant (Najad, 2005).

Tree farming, a peaceful “revolution” in forestry

As stated above collected biological knowledge indicates that the growth potential of many tree species is much greater than is utilized in forestry today. But change is on its way (Sirén & Zsuffa, cited to in Morgan *et al*., 1983; Christersson, 1987, 2006a,b; Sundberg *et al*., 1997; Bradshaw & Strauss, 2001; Brunner & Nilsson, 2004; Bergh *et al*., 1999, 2005). The reasons why a tree species’ full growth potential cannot be utilized is often a harsh climate, but not infrequently the production is limited by shortage of water and nutrients. Damage of various kinds, both biotic and abiotic, also contributes to reducing production.

For centuries, developments in forestry and agriculture have followed each other closely. During the most recent decades, however, agriculture has evolved much more rapidly. The "green revolution" seen in agriculture has not yet occurred in forestry. Seeds of new varieties of corn and rice came onto the market in the 1960s. These new varieties were improved considerably by fully utilizing up-to-date physiological knowledge in advanced breeding programmes. This, plus the development of effective methods for weeding and utilization of fertilizers and irrigation, creates conditions for increasing cereal yields, in some cases up to four-fold. There is nothing comparable within forestry, yet. But there are signs that something is now happening in forestry with respect to increasing woody biomass production for different purposes on an ecologically acceptable and economically sound basis.

In Swedish forestry the new ideas are built on earlier findings of Emeritus Professors Carl-Olof Tamm, Gustaf Sirén and Torsten Ingestad and forest officer Paul Widén. Active professors like Sune Linder, Göran Sandberg and Ove Nilsson are contributing significantly to the rapid development of much more efficient and sustainable forestry in Sweden. The goals for the new ideas are t*o create tree provenances, varieties and clones with high biomass production potential and to establish growing conditions by effective utilization of improved methods for irrigation and fertilization to avoid nutrient and water as limiting factors. By better understanding of the ecophysiological background and by breeding and gene techniques resistance and hardiness should be highly improved*.

In other countries, the same lines of thought are being followed (Christersson & Verma, 2006). In Brazil, for example, they are growing eucalypt hybrids, imported from Australia and bred and developed in Brazil, with a production of 300-350 m^3 in a 7 years rotation, which in the future they will try to reduce to 5 years (Lorenzen, 2001). In the Pacific Northwest in North America, hybrid poplars are grown for paper, and now also for construction, with an annual production of 20 tonnes dry matter per ha (Stanton *et al*., 2002). In the semi-desert around the lower part of the Columbia river, with irrigation and fertilisation, they are growing hybrid poplars with the same result, (Stettler *et al*., 1988). In Australia, in a plantation of Pinus radiata for purifying wastewater production is up to 40 tonnes woody dry matter per ha and year (Baker *et al*., 2005). In Punjab in India, carefully selected hybrid poplar clones grow up to 6 m in the first year after planting 25 cm cuttings (Sanjeev Chauhan, per.com).

In Sweden, fertilized and irrigated dense willow plantations in Långa-Veka, Halland (Table 1) have produced up to 30 tonnes dry matter per ha in some years (Christersson, 1987). In a small clone trial on sandy soil in the south of Sweden, some pure Populus trichocarpa-clones have produced 3 kg DM per m^2 and year (Christersson, 2006a). Conifers also have a much higher production potential than previously believed (Bergh *et al*., 1999, 2005). However, leading scientists are becoming concerned about shortage of ground water (Falkenmark, 1986) and leaching of nutrients, particularly of nitrogen, to streams and lakes (Gustafsson, 1983; Jonsson & Mårtensson, 2002).

The above production results, though unfortunately few in number, show that the growth rate of many species is much higher than is normally utilized. In Sweden even politicians are aware of this and suggest, among other things, cultivation of very fast-growing deciduous tree species on abandoned farming land and on fertile forest areas in order to achieve a long term 15-20 % increase in the production of wood for biofuels, electricity and heat (Commission of Oil Independence 2006). In this way politicians hope that the very insecure and economically risky dependence in Sweden on imported oil can be avoided.

Sweden today

Sweden has no oil-, coal- or gas-resources, which means that there is complete dependence on imports of these resources (Aleklett, 2003). However, Sweden does have well-developed forestry (23 million ha of managed forest) and a forest industry with pulp, paper and timber as the main products. Further, it was already 1993 necessary to import 4 million m^3 of wood from the east to cover the total requirement of the industry for wood (Berggren et al., 1994). Today this figure is 8 million m^3 (VMR, 2006). Sweden has also established district heating systems in almost all towns and villages, with boilers for oil and electricity but also for wood, in combined power and heating plants. So there is already a functional system for using wood for energy. Today's high oil prices mean that there is competition for wood between the forest industry and the energy market and there is a common worry within the industry about future shortage of wood .

On the other hand, the economic situation is worrying for many farmers. All crops in Sweden are subsidised and with a new EU economic farming policy expected from 2008-2009, many farmers fear for their future. Sweden has 2.6 million ha of agriculture land. Today we have given up our demand of self-sufficiency and rely on a free flow of goods and foods within EU. In an international study Helmfrid and Haden (2006) have tried to estimate the area needed for farming on a global scale to produce both food and biofuels at different levels of the global population of man. They used the estimation of Wolf et al. (2003) and found that if we continue with the so called high input farming 55 % of the farming land is needed for food production and 45 % can be used for production of biofuels. By applying the same percentage in Swedish agriculture and with the cultivation techniques currently available, ideas exist that only farming areas for a little more than half those existing 2.6 million ha is required to feed the population of nine million people. This means that up to one million ha of agricultural land can be used for crops other than cereals and milk.

Looking to the future, it is exciting to make the following calculation. Currently, 22 TWh of oil (2.2 million m^3) are used for heating houses in Sweden (Board of Energy, 2005). The same amount of heat energy is found in about 5.5 million tonnes of wood. With a production capacity of 8 tonnes dry wood per ha and year, as in Sångletorp and Johannesholm (Christersson, 2006 b), and with up to one million hectare agricultural land available, all the oil for heating houses could be replaced by cultivation of wood on abandoned farmland in the future.

Further more by replacing 2,2 million m^3 of oil with wood from our farming land we will not only decrease the bill of the import to Sweden, we will also considerably contribute to decreasing the carbon dioxide emission to the atmosphere. As matter of fact by doing so we fulfil to about 40 % the Swedish commitment by ratification of the Kyoto protocol to decrease the emission of carbon dioxide to the atmosphere until year 2012 with 5.2 % in comparison with the level of carbon dioxide emission of year 1990.

In many countries like Sweden a future shortage of wood is expected to become the next big issue for the forest industries in the Western World (Thuresson, 2002). In Fennobaltoscandia "the forest revolution" means among other things that much more attention must be given to fast-growing deciduous tree species in comparison with the current situation in which almost all the focus is on conifers. However, the forest industry is, to say the least, very doubtful about this.

The Future

The requirement for successful further development of "a peaceful revolution in forestry" is that the scientific results achieved in growth chamber experiments and in small-scale experiments outdoors can be demonstrated on a large, economic, scale in practical forestry. A small beginning can be seen in the plantation results from Sångletorp (33 ha), Johannesholm (15 ha), Kadesjö (8 ha) and Näsbyholm (2 ha) (Christersson, 2006 b). To counteract the understandable doubts and hesitation within many areas of society about the "forest revolution", particularly within the forestry industries themselves, full scale demonstrations of the real growth potential and the economical and environmental consequences of growing some non-traditional tree species both deciduous and conifers, is the most effective way to proceed.

It is therefore suggested that Sweden takes the lead in this "revolution" and that the Government and scientific foundations should support two large-scale tree plantations for optimization of biomass production for energy and paper on large areas of agriculture land of 100 ha each, for example. The plantations should have a unified cultivation strategy and be located such that they fit in well in the landscape and that the effect of different types of soils will be demonstrated. One plantation should be located in the valley of Mälaren (lat 60^{o} N) and the other in Skåne (lat 56^{o} N). The responsible scientists should be from the Uppsala-Stockholm region and the Lund-Malmö region, respectively.

The steering committee of the two plantations should include theoretical and practical scientists from the biological, technical and economic areas, together with private foresters and farmers. The main objectives should be to demonstrate on a full scale the growth potential of some very peculiar and non-traditional tree species and the environmental, economic, social and cultural consequences of such plantations. The produced biomass should be used for paper and energy. All approved existing advanced techniques should be employed for weeding, fertilisation, irrigation, and harvesting. This project should be a real multi-disciplinary activity with focus not only on ecology and economy but also on social and cultural aspects. This type of cultivation, a so called *scitech tree plantations*, will contrast sharply with the tendency within some groups of the society, often politicians or greenies, that recommend farmers and foresters to revert to traditional labour-intensive and low-productivity cultivation methods, so-called ecological farming and forestry.

This suggestion is well in line with the proposal of Emanuelsson (2006) in the report of the Commission on Oil Independence of the Swedish Government, in which it is recommended that in the future there should be much more effective landscape planning, in which some areas are intended for maintenance of high biological diversity and others are designed for advanced biomass production.

By utilizing the most effective production methods Sweden will be in the forefront of advanced forestry and also contribute to the fulfilment of the EU-agenda of Lisbon, in which Europe is presupposed to be the world leader for knowledge-based competitive power and the most dynamic economy of the world. In a newly introduced programme for future activities within Swedish forestry the Swedish Government is saying that "The vision is clear. Sweden is to be Europe´s most competitive, dynamic and knowledge-based economy and Swedish forest-products industry is to be the most competitive in Europe" (Messing & Östros, 2006). But it is to be noted that special attention should be paid to the environmental consequences, particularly on the greenhouse effect, a chemical-loaded society, pollution of water, air and soil, biodiversity and eutrophication of water courses and lakes in the vicinity.

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Appendix

In the process of photosynthesis two reactions are commonly distinguished: a light reaction and a dark reaction. The light reaction describes the absorption of solar photoactive radiation PAR (hν) by the chloroplasts, the use of the absorbed light energy to split water into an oxygen molecule and active hydrogen, out of which the reduction equivalents $NADPH_2$ (P_i = inorganic phosphate group) are formed, while at the same time chemical energy in the form of ATP becomes available.

$$2\ H_2O + 8\ h\nu + 2\ NADP + 3\ ADP + 3\ P_i \Leftrightarrow 2\ NADPH_2 + O_2 + 3\ ATP \quad (1)$$

Both ATP and $NADPH_2$ are needed in the dark reaction, commonly called the Calvin cycle, to reduce the carbon atom in CO_2 from its oxidation state +4 (the oxidation states of hydrogen are commonly +1; of oxygen –2; for the neutral molecule CO_2 the carbon oxidation number is therefore +4) to the oxidation state zero in sugars (e.g. glucose $C_6\ H_{12}\ O_6$, (6 x 0) + 12 x (+1) +6 x (-2) = 0, results consequently in a zero charge for carbon) and other hydrocarbons. The reaction can be summarized:

$$CO_2 + 2\ NADPH_2 + 3\ ATP \Leftrightarrow [CH_2O] + 2\ NADP + 3\ ADP + 3\ P_i \quad (2)$$

The first step of the Calvin Cycle is to couple CO_2 with a 5-carbon-sugar ribulose in an enzymatic process using the most abundant plant enzyme ribulose-bisphosphate-carbolase. The resulting carbon compound with six carbon atoms is unstable to yield two stable carbon compounds with three atoms; for this reason this most common metabolism for plants is also called the C-3 plant-metabolism. Six CO_2 molecules attached to 6 ribulose molecules finally yield, in a series of reactions within the Calvin cycle, one glucose molecule $C_6H_{12}O_6$, while at the same time six new ribulose molecules are formed, from which the cycle can begin again. All secondary plant metabolisms are built on these first two reactions of photosynthesis. The two above reactions can be summarized as follows:

$$CO_2 + 8\ h\nu + 2\ H_2O \Leftrightarrow [CH_2O] + O_2 + H_2O \quad (3a)$$

where the carbohydrate unit $[CH_2O]$ stands for 1/6 $C_6H_{12}O_6$. Often the above reaction is even more simplified, by omitting the energy considerations and also by cancelling out one water molecule on each side of the equation:

$$CO_2 + H_2O \Leftrightarrow [CH_2O] + O_2 \quad (3b)$$

which shows the formation of molecular oxygen in photosynthesis as the main feature. Sometimes one other form is common, which shows directly the first product of the Calvin cycle, glucose, which is simply obtained by multiplication by the factor 6.

$$6\ CO_2 + 6\ H_2O \Leftrightarrow C_6H_{12}O_6 + 6O_2 \qquad (3c)$$

Respiration is simply the reverse of the above reactions and is an exothermic process with liberation of energy. The oxidation from carbohydrates to CO_2 is coupled to the ADP/ATP system and thus yields chemical energy in a useful form for the plant or animal organism. The energy can be transformed into the physical or mental work we do, or can be utilized as heat, which is the simplest form of energy and the last step in the energy chain.

ASEAN-Korea Environmental Cooperation Project (AKECOP) Agroforestry regional research

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Abstract

AKECOP showcases creative regional collaboration in research and development initiatives for forest restoration and rehabilitation in the ASEAN region. Through action-research participatory agroforestry was found to be a promising strategy for enhancing the productivity and sustainability of degraded forest ecosystems as well as the economic well being of forest dependent local communities in the region. Sustainability of agroforestry systems can be enhanced through the participation of local people and the provision of land tenure security and other incentives, as shown by the experiences in Indonesia and in the Philippines. Preliminary results of agroforestry field experiments in the Philippines and Vietnam tend to validate the protective value of agroforestry systems, in that they enhance the condition of degraded forest soils. Depending on the objectives of agroforestry system design, farmers should take tree species and spacing as critical decision criteria.

Introduction: Environmental Crisis and the AKECOP Challenge

Several years of global assessments have shown that the area of the world's forests is shrinking. Global forest area is almost 30 percent of the total land area. The United Nations Food and Agriculture Organization (FAO) estimated that 0.38 percent of the world's forests were converted to other land uses every year in the 1990s. Large areas have also been reverted to forest, but still there is a net annual forest loss of 0.23 percent per year (FAO 2003). Showing the highest rates of deforestation among the tropical regions was Southeast Asia with 1.04 percent or an average of 23,260 km^2 of forests destroyed per year from 1990 to 2000 (Table 1). This is more than four times faster than the global average of 0.23 percent per year (UNEP, 2003).

A primary reason identified by FAO for the current situation of the world's forests is agricultural expansion due to increasing population and growing per capita consumption. Preliminary studies showed that agricultural land is expanding in about 70 percent of the countries of the world, declining in 25 percent and with generally no change in 5 percent. Increasing food production to address the rising global population has been at the expense of hundreds of millions of hectares of forest. Agricultural expansion in two-thirds of the countries has shown a decrease in forest area with only one-third of the countries showing an expanding forest area. And more land will be cleared in the future (FAO, 2003).

Adverse ecological and social conditions in several parts of the world particularly tropical Asia, have also contributed to deforestation and forest degradation. Low rainfall, shifting cultivation, uncontrolled livestock grazing and indiscriminate gathering of fuel wood have slowed down regeneration and reforestation. Forest productivity and biological diversity in natural and planted forests in developing countries are likewise being threatened by poor rural communities who depend entirely on these forests for their livelihood and way of life. The unregulated hunting of wildlife for meat and other products and the consequences of forest fires are also alarming, particularly in tropical forests (FAO, 2003).

Southeast Asia is considered one of earth's most diverse areas, with Indonesia, Malaysia and the Philippines among the world's 17 megadiversity countries. However, several socioeconomic and biophysical factors mentioned above had contributed to the fast rate of deforestation and forest degradation in these countries that could result to habitat loss and disappearance of plant and animal life (UNEP, 2003). In the face of this environmental crisis that threatens tropical biological and social systems integrity and sustainability including that of Southeast Asia, there is a need for a concerted effort at the regional level to develop programs that could address this problem. The ASEAN-Korea Environmental Cooperation Project (AKECOP) is a timely and fitting respond to this need.

Table 1. *Forest area and area change in Southeast Asia. Source::FAO, 2003*

COUNTRY	LAND AREA ('000 HA)	FOREST AREA, 2000		FOREST COVER CHANGE 1990 - 2000	
		TOTAL FOREST ('000 HA)	% OF LAND AREA	ANNUAL CHANGE ('000 HA)	ANNUAL RATE OF CHANGE (%)
Brunei Darussalam	527	442	83.9	-1	-0.2
Cambodia	17652	9335	52.9	-56	-0.6
Indonesia	181157	104986	58.0	-1312	-1.2
Lao PDR	23080	12561	54.4	-53	-0.4
Malaysia	32855	19292	58.7	-237	-1.2
Myanmar	65755	34419	52.3	-517	-1.4
Philippines	29817	5789	19.4	-89	-1.4
Thailand	51089	14762	28.9	-112	-0.7
Vietnam	32550	9819	30.2	52	0.5

What is ASEAN-Korea Environmental Cooperation Project (AKECOP) ?

The ASEAN-Korea Environmental Cooperation Project (AKECOP) is a regional initiative responding to the challenge of restoring degraded tropical forest ecosystems particularly in Southeast Asia. It was launched in July 2000 as an off-shoot of the ASEAN-Korea Summit Meeting in 1997 in Bali, Indonesia where environmental challenges were identified as a priority area of collaboration between ASEAN member countries and Korea.

The goal of AKECOP is to contribute to the sustainable and equitable forest management and rehabilitation of deforested areas in the tropical forest ecosystems of ASEAN member countries through creative partnership between Korea and ASEAN member countries.

The first ever collaboration between the Republic of Korea and ASEAN, the project is aimed towards the following specific objectives:

To provide ASEAN countries with the opportunity to share in Korea's practical knowledge and experiences on addressing deforestation;

To establish partnership between Korea and the ASEAN in the conduct of basic and applied researches on biodiversity, sustainable forest management, and agroforestry in the tropics;

To develop and implement technologies for the restoration of degraded forest ecosystems and for sustainable forest management in selected areas within the ASEAN member countries;

To help advanced professional and technical expertise of the ASEAN member countries to deal with forest degradation problems;

To enable Korean scientists to better understand tropical forest ecosystems and enhance their capacity to undertake field researches in such areas;

To achieve the above goal and objectives AKECOP adopts three complementary strategies. These are research, advanced education and training, and information exchange.

Research

The conduct of research is the primary vehicle in operationalizing the cooperative endeavor. The sustainable management of the ASEAN forests and the various resources within these ecologically diverse and important ecosystems will never be a reality unless a scientific understanding of the various processes and functions that occur in them exists.

Appropriate interventions to address the urgent need to restore degraded tropical forests and stop the further decimation of biodiversity in the region need to be developed, tested and validated through time and varying ecological conditions.

AKECOP conducts two types of research in the context of cooperation -- the on-site research by Korean scientist and the regional researches of the ASEAN scientists in their respective countries. On-site experiments on forest restoration, agroforestry and biodiversity conservation and management are carried out by the Korean scientists in the Philippines. These experiments are designed to generate information on the fundamental changes in structure and functions of tropical forest ecosystems as affected by various disturbance factors. The basic information obtained will be used in developing technologies for the ecological restoration of degraded tropical forests and the sustainable management of biodiversity.

The regional researches are undertaken by the participating ASEAN countries on the issues and concerns on forest restoration, agroforestry and biodiversity that are existing in their respective countries. Research topics in the individual countries are harmonized with the research themes espoused by the AKECOP, which also provides the funds for the implementation of these researches.

Major findings of these researches would provide sound scientific bases for improved management of forests, and contribute to effective restoration and rehabilitation of highly degraded forest environments in ASEAN countries. All technical information and experiences would be shared between ASEAN and Korean researchers for further improvement of techniques.

Advanced Education and Training

AKECOP also provides opportunities for post graduate scholarships and fellowships for short term trainings on fields of studies relevant to its mandate. The Project offers scholarships at the Seoul National University to qualified professional staff and researchers of the ASEAN participating countries to enable them to obtain a masteral or doctoral degree in forestry, agriculture, environmental sciences and any other related fields. The success of the AKECOP also rests on its capacity to provide short term training in research methods and operational techniques related to forest restoration, agroforestry and biodiversity conservation and management. A highlight of the short training programs is the opportunity for ASEAN researchers and scientists to acquire skills in the operation of modern equipment for environmental research and obtain learning experiences and practical knowledge on forest restoration and management from Korea.

Information Exchange

The great Swiss zoologist and geologist, Louis Agassiz once proclaimed, "Time has come when scientific truth must cease to be the property of the few, when it must be woven into the common life of the world; for we have reached the point when the results of science touch the very problem of existence." AKECOP recognizes the wisdom in these very elegant and powerful words of the Swiss scientist. In the context of the AKECOP cooperation, the forest crisis in the ASEAN region is best addressed when scientists, researchers and professional staff working on forest restoration, agroforestry and biodiversity conservation and management engage in a free exchange of research results and information, when data and hard facts of research findings and observations are made known and questions on them debated in open and frank discussions. This is one best way for the sciences of forest restoration, agroforestry and biodiversity conservation and management to advance.

Along this line of thought, AKECOP has organized and will continue to hold conferences, workshops, symposia and similar gatherings to foster and/or encourage active interactions among scientists and researchers participating in the project. By design, these activities are held annually in both Korea and the ASEAN countries. Results of both the on-site and regional researches are presented, and constructive discussions are made on the implications of the findings and observations of the studies made. The same gatherings also make possible the learning and/or further improvement of specific research skills and the discovery of more in-depth knowledge of the tropical forests.

Collaborating Countries and Institutions

With Korea as main proponent and lead implementer, AKECOP originally started with only six participating countries, Indonesia, Philippines, Vietnam, Malaysia, Laos and Cambodia. In view of the demand for a wider Project coverage in the ASEAN region the number of participating countries has now increased from six to nine with the recent addition of Thailand, Myanmar, and Brunei Darussalam. The collaborating institutions in Korea and in the nine participating countries are as follows:

Korea**;** Department of Forest Resources and Forest Products and the National Instrumentation Center for Environmental Management, The College of Agriculture and Life Sciences, Seoul National University; The National Institute of Environmental Research; and Korea Forest Research Institute;
Brunei; The University Brunei Darussalam; and the Forestry Department;
Cambodia; Department of Forestry and Wildlife, Ministry of Agriculture, Forestry and Fisheries; and Nature Conservation and Protection Department, Ministry of Environment;
Indonesia; Institute Pertanian Bogor (Bogor Agricultural University);
Lao PDR; Forestry Research Center, National Agriculture and Forestry Research Institute;
Malaysia; Forest Research Institute of Malaysia;
Myanmar; Forest Research Institute;
Thailand; Faculty of Forestry, Kasetsart University;
Philippines; College of Forestry and Natural Resources, University of the Philippines, Los Banos; and Bantay Kalikasan, ABS-CBN Foundation, Inc.;
Vietnam; Forest Science Institute of Vietnam.

AKECOP Agroforestry Research

Agroforestry has over the years been considered a suitable approach towards reversing the forestland degradation process. As a land-use, it is a dynamic ecologically-based, natural resources management system that diversifies and sustains smallholder production for increased social, economic and environmental benefits through the integration of trees into farm and rangeland (Leakey, 1996). Having been known as an ancient practice worldwide, particularly by most farmers in the tropics, agroforestry has gained recognition as a land use system because of its potential in improving the productivity and sustainability of a given piece of land. Nair (1993) classified four types of agroforestry systems based on composition:

Agrisilvicultural system - combination of agricultural crops with woody perennials.
Silvipastoral system - combination of woody perennials with livestock production.
Agrisilvipastoral system - combination of agricultural crops, woody perennials and livestock.

Integrated or complex agroforestry systems- could include all the above and other complementing elements.

Among the nine ASEAN member countries that are participating in AKECOP only Indonesia, Lao PDR, Philippines, and Vietnam are conducting research in agroforestry. In addition to the regional agro-forestry research being conducted by Filipino scientists, Korean scientists also conduct an on-site agro-forestry research in the Philippines. Basically, there are two types of agroforestry research being conducted; experimental research in the Philippines, Lao PDR and Vietnam and action-research or development-oriented research in Indonesia and in the Philippines.

Goals and Objectives

The goals and objectives of agroforestry vary in the four participating countries (Table 2). The bottom line however, is that all of these researches hopefully would redound to the development of agroforestry technology or system that is most appropriate in the respective countries, site specific-wise (AKECU 2003; AKECU 2004; OACP 2005)

Table 2. *Agroforestry Research in Indonesia, Lao PDR, Philippines, and Vietnam*

Country	Research Title	Research Objectives
Indonesia	Restoration of degraded forests through establishment of sustainable agroforestry system with high ecological and economic values using people's participation in Gunung Walat, Indonesia	-Development of agroforestry system -To maintain agroforestry systems with appropriate technology and practices. -To evaluate and strengthen extension technology and practices. -To evaluate and strengthen local farming institutions and income generating activities. -Research on agroforestry -To conduct research on the socioeconomics of agroforestry. -To conduct biological studies towards the improvement of agroforestry system
Lao PDR	Study of an agroforestry in degraded forest land after shifting cultivation in northern Lao PDR	-To determine agroforestry techniques suitable for geographical zone, local and socio-economic conditions. -To identify suitable species of commercial timber trees, fruit trees and crop species
Philippines	Rehabilitation of degraded lands through forest tree-based agroforestry system	-To determine growth performance of 2 forest tree species (Gmelina arborea or yemane; and Swietenia macrophylla or large-leaf mahogany) planted under 3 different initial spacings (2 x

		2m; 2 x 3m; and 2 x 4m) -To determine the effect of spacing on growth and yield of intercropped corn and mungbeans; -To determine the soil and light dynamics under different spacings of each forest tree species and their correlation to growth and yield of intercrops. -To determine the best initial spacing for each forest tree species.
	Rehabilitation of degraded lands through nurse tree-climax species (NTCS) strategy	-To evaluate the effect of planting nurse species on the growth and development of climax species in a degraded area. Specifically it aims to: -Determine the growth performance of two trees (Gliricidia sepium or kakawate and Erythrina orientalis or dapdap) serving as nurse trees; -Evaluate the survival and growth of two climax species (Parashorea malaanonan or bagtikan and Durio zibethinus or durian) planted under dapdap and kakawate nurse trees; and assess the cost-effectiveness of the nurse tree-climax species approach.
	Studies on the development of tropical agroforestry system based on local people's participation: The case of Mt. Makiling in the Philippines	-To diagnose problems and constraints of the present land-use systems and agroforestry technologies; -To propose improved land-use system and agroforestry technology based on local people's participation. -To undertake experiments that could improve agroforestry systems based on locally identified problems.
Vietnam	Restoration of degraded forest by agroforestry system in the northern mountainous region of Vietnam	-To determine the best agroforestry practices for restoration of degraded natural forests.

Source: AKECU 2003, AKECU 2004, OACP 2005

Preliminary results

The preliminary results of the agroforestry researches conducted in the Indonesia, Philippines and Vietnam are reported below. Research results in Lao PDR are not available.

Indonesia (Darusman and Sundawati 2005; Darusman 2003)

Three agroforestry system designs based on initial forest stand condition and people's interest was recommended. First is a combination of Agathis lorathifolia and Paraserianthes falcataria as tree components with banana, pineapple, chili and rice/corn/peanuts as agriculture crop components in areas where almost no trees were present. Second, is the same tree and agricultural crop combination but established in area where about 25 until 100 trees per hectare were present. And third, is a combination of Agathis lorathifolia (tree crop) and banana, cardamon and coffee (agricultural crops) in area where more than 100 trees per hectare were present.

Local people's participation has been integrated into the agroforestry system development. Total number of local people participants to the AKECOP project were 22 farmer groups in five forest blocks with total membership of 213 households covering a total occupied/encroached area of 74 778 hectares. Through participatory rural appraisal techniques (PRA) regular meetings, local interests and plant species preferences were discussed.

Security of tenure has been provided to the farmer project participants through a legal contract entered into between them and Gunung Walat Educational Forest (GWEF) Manager on behalf of the Institut Pertanian Bogor (IPB). The farmer participants are allowed to cultivate the forest land according to the planned agroforestry design for about ten (10) years. The farmers are secured to get all the agricultural crops, with 50 percent of the wood volume from Paraserianthes falcataria and resin from Agathis lorathifolia.

Eleven (11) research support activities, four socioeconomic and 7 biophysical are being conducted. The socioeconomic research includes agroforestry products marketing, agroforestry labour allocation and income effect, socioeconomic assessment of GWEF communities and factors affecting farmers' participation in forest rehabilitation project. The biophysical studies include diversity of plant species in local people's garden, seed yield of Agathis lorathifolia in agroforestry stand, pest and diseases commonly found in agroforestry system, vertical and horizontal space allocation of intensive and less intensive agroforestry systems in relation to yields, mykorrhiza field inoculation and production techniques, and erosion rates and slope variation and vegetation composition in agroforestry site

After four years researchers observed the following at the research site.
-No more occurrence of illegal cutting.
-No further encroachment by local people
-Increased farmers' cash income
-Agroforestry has given a certain level of staple food security in the area
-Farmers expect to get more/additional income when the trees (Paraserianthes falcataria) are harvested
-Agroforestry in the degraded forest area of GWEF has increased the diversity of plant species in the areas

Based on the experience of Indonesia, development of appropriate agroforestry systems through people's participation and provision of land tenure security can be an effective strategy for promoting forest rehabilitation and people's welfare. Community-based forest management appears to be the better approach to forest establishment or rehabilitation especially where there is high population pressure on the forest for agricultural land.

Philippines

On-site action-research (Lee, 2005 and Lee & Kim, 2003)
Using the diagnosis and design (D & D) methodology, a participatory action research approach, on-site research on agroforestry being conducted by Korean scientists in collaboration with Filipino academic researchers have so far achieved the following results.

Three broad categories of farming/agroforestry systems were found in the Mt. Makiling Forest Reserve: kaingin (slash and burn), home gardens, and plantation-based. The most dominant farming system is the plantation-based type consisting of farms planted with agricultural crops in combination with fruit or plantation crops and tree crops.

Within the forest reserve, formerly citrus orchard monoculture and coconut-based multi-storey system were generally found. However, virus infestation of citrus in 1990 resulted to abandonment of most of the citrus farmlands. Today only coconut-based multi-storey systems (with fruit tree or coffee) are cultivated inside the forest reserve.

In the study area in Sitio Jordan, San Vicente, Sto. Tomas, Batangas, coconut-based multi-storey system along with fruit tree or coffee is commonly practiced. However, many farmers prefer mahogany planting along the boundary and within their farm lots.

There are several reasons why farmers prefer mahogany (Swietenia macrophylla) as a tree component in their agroforestry system. Primarily, mahogany is perceived as a source of raw material for house construction in the future. Other reasons are its potential for erosion control, income source, and as farm boundary. More specifically, farmers prefer mahogany + coconut + fruit trees as the best combination of crops in terms of income generation as well as environmental protection. In addition, farmers also claimed that mahogany + fruit trees + annuals combination of planting is also profitable and is environmentally protective. Many farmers are shifting to mahogany-coconut-mixed multi-storey system from the coconut, fruit-tree or coffee-based multi-storey system due to the decreasing price of agricultural products in the long run. However, change is so slow and mahogany plantations are not well maintained. Limited investments on mahogany plantation was also observed because of uncertainty of mahogany timber market, lack of farmers skill in growing and managing mahogany, no guarantee of seed quality, and labor difficulty due to competing new jobs in the industry.

The socioeconomic conditions in the project site are generally characterized as follows:
Economy is dominated by commercial and medium scale agriculture and agroforestry operations. Main products are coconut (including copra), timber (coconut and mahogany), ginger, taro, coffee, and other fruits. The household income level ranges from US$70 to US$1000 per month. Farm size lies generally between 1.5 to 8 hectares. Land ownership pattern indicate that 80 percent of the farmers claimed to have security over their land. Age classes (reflecting manpower availability) range from 51 to 70 years old.

In support of the agroforestry development activities in the individual farmer participants farms, three field experiments are being conducted, namely: 1) effects of thinning on the growth of eight year old mahogany and intercropped with gabi, edible fern, rattan and ubi; 2) effect of organic fertilizer and mulching treatments on growth of 3-year old mahogany plantation intercropped with gabi and papaya; and 3) effect of coconut frond pruning treatments on the growth and yield of interplanted mahogany. Perhaps because of the recency of the experiments, based on available data so far there has been no significant effect of the different treatments introduced in the three experiments.

During the last four years the research team was able to characterize the land use system in area, to investigate problems and constraints, to propose agroforestry development strategy at the farm level, and to undertake some field experiments. Based on the team's experience so far, the following conclusion can be drawn: Most farmers appear to prefer the mahogany-based agroforestry system because of economic and environmental reasons. However, investment in mahogany plantation based agroforestry system leaves much to be desired because of some socioeconomic constraints.

Based on the D & D approach, farmer participants were found to be good partners, good record keepers and "local scientists".

Experimental Research

Rehabilitation of degraded lands through forest tree-based agroforestry system (OACP 2005)

Under this study two experiments were conducted. The first experiment is on the growth performance of yemane (Gmelina arborea) and mahogany (Swietenia macrophylla) under different tree spacing. Preliminary results showed that the mean height (261 cm) and diameter growth (47 mm) increment of yemane was comparatively higher than that of mahogany, respectively (72 cm and 13 mm height and diameter increment, respectively). For mahogany there were no significant differences observed in height and diameter growth under three different spacing treatments. However, for yemane, diameter growth was significantly lower at closer plant spacing (2 x 2m).

Another experiment was on the effects of tree species and spacing on the growth and yield of intercropped corn and mungbean. Preliminary results showed that the dry matter yield of mungbean was significantly affected by tree species and spacing. Mungbean intercropped with mahogany had higher dry biomass compared to those grown with yemane. This may be attributed to better light environment afforded by mahogany because of its relatively open canopy compared to yemane. In terms of tree spacing, dry matter production was highest for mungbean grown under trees planted at 2 x 4m spacing.

Grain yield of mungbean was not significantly different when intercropped with either yemane or mahogany. However, effect of spacing on grain yield was significant.Yield was significantly higher at 2 x 3m and 2 x 4m spacing. Mungbean mean yield (64 kg/ha) at 2 x 2m tree spacing is only half as much the mean yield (114 kg/ha) obtained across all treatments.

The effect of tree species and spacing on biomass yield of corn was not significant

Aside from the experiments on the effect of spacing on growth of two forest tree species in an agroforestry system and on the effect of trees and spacing on crop yields, the study also sought to assess the impact of the agroforestry system on soil properties. Results showed that the soil pH in all the plots sampled both at 0-15 cm and 15-20 cm depths generally increased or improved (from 4.97 to 5.33 for 0-15 cm depth and from 4.91 to 5.30 for 15-30 cm depth).

In topsoil, highest increase from 4.8 to 5.5 was recorded for plot planted with yemane and agricultural crops with 2 x 4m spacing. At 15-30 cm depth, highest increase was for plots with yemane and spacing of 2 x 2m. Across all plots however, there was greater increase in mean pH at the yemane than in the mahogany plots both at the two depths. Comparing the effect of spacing revealed higher increase in pH at 2 x 4m spacing for the topsoil and for both 2 x 2m and 2 x 3m spacing in the subsoil.

Based on the experiments and studies conducted on tree based agroforestry system the following conclusions can be drawn: Under experimental site conditions yemane appeared to grow faster apically (height) and laterally (diameter) than mahogany. Yemane’s diameter growth is affected by spacing. Dry matter yield was significantly affected by tree species and spacing while grain yield was only affected by spacing. Tree-based agroforestry system improved soil condition as a result increasing pH in all sample plots.

Rehabilitation of degraded lands through nurse tree-climax species (NTCS) strategy (OACP 2005)

Data showed that both dapdap (Erythrina orientalis) and kakawate (Gliricidia sepium) are exhibiting relatively fast growth rate with mean height and diameter (across treatment combinations) of 3.46 m and 35 mm, respectively, after two years. But analysis revealed that there was no significant difference in the mean height of the nurse trees, dapdap (3.54 m) and kakawate (3.39 m). However, kakawate had developed significantly smaller diameter (29 mm) compared to dapdap (42 mm). This could imply that the lateral growth rate of dapdap is faster than kakawate.

The initial average height and diameter of climax species, bagtikan (Parashorea malaanonan) and durian (Durio zibethinus) were 0.63 m and 9 mm, respectively. Since the climax species have only been recently planted, statistical comparison between the different crop combinations cannot be conducted yet. Observations on the survival rate of the climax species 90 days after planting indicate that the survival of bagtikan and durian were relatively higher when planted either as pure crop or when interplanted under kakawate. This implies that kakawate can serve as good nurse trees for durian and bagtikan.

Vietnam (AKECU 2004)

In Tu Ne commune, Cinamomum cassia (a cash tree crop) has been tested in three different treatments: C. cassia plus cassava plus Tephrosia candida; C. cassia plus cassava; and C. caasia plus Tephrosia candida. Analysis of the height growth of Cinamomum cassia showed that there is no difference in its height growth in the three treatments. Average yield of cassava was 10 tons/ha (wet). Tephrosia candida could provide 3,500 kg of green manure equivalent to 50 kg $(NH_4)_2SO_4$.

Combination of N-fixing trees, agricultural crops and indigenous tree species for restoration of degraded land offers a great potential because of its multipurpose benefits.

Agroforestry Research Implications

Research strategy and research utilization

Either action-research or field experiments were used as agroforestry research strategies by the participating countries. As experienced in Indonesia and in the Philippines, action research provides the logic for an integrated research and development approach that enables researchers to directly deal with the environmental and social problems related to forest degradation and at the same time exploring the best technological solutions or most appropriate social interventions. Thus the application of technological and social innovations developed through action research is accelerated. On the other side, as applied in Lao PDR, Vietnam and also in the Philippines, experimental research is assumed to follow the traditional sequential model of research generation, research validation, and research utilization thus application of research results takes a longer time. In the context of the ASEAN region where the expected beneficiaries of agroforestry research are poor communities which can not afford the luxury of waiting too long for the results of long gestation research, action research seem to be the most appropriate strategy. But action research needs an interdisciplinary team of experts who can work together in a collaborative manner in addressing a common problem. This capability has yet to be developed in many if not most of the ASEAN countries.

The apparent advantage of action-research in the context of ASEAN does not all negate the importance and usefulness of experimental research by virtue of its longer research application and utilization pathway. In fact the speed at which the results of experimental research that follows the sequential model of research generation, validation, and application can also be accelerated through the active involvement of research clienteles or expected beneficiaries in the research planning and development process as in action-research.

Action-research results and the need for institutional change

Based on the action-research experience in Indonesia and in the Philippines participatory agroforestry development with the active participation of local communities and provision of land tenure security appear to be an effective strategy for faster forest rehabilitation and restoration and social amelioration. However, for participatory agroforestry development or community-based forest management to be promoted and sustained in a wider scale beyond the action-research site some institutional changes are necessary. Policies legitimizing participatory or community-based agroforestry development and insuring land tenure security and other incentives for active local people participation must be formulated by national forestry development agencies. A bold step towards organizational re-structuring to enable forestry bureaucracies to more effectively respond to the challenges of participatory forest management must also be taken.

In the Philippines, much has been done towards these needed institutional changes. In Indonesia and other ASEAN countries the process of policy and organizational change are also underway.

Experimental research results and agroforestry system design

The result of these experiments provide empirical support or justification to farmers preference for agroforestry because of their protective value as observed in the on-site research area in Mt. Makiling in the Philippines.

In the design of agroforestry systems, if farmers are more interested in grain yield, they should take more consideration about spacing. On the other hand, if they are more interested in dry matter yield (biomass) they should take both species type and spacing serious consideration. Farmers can also consider kakauate as a possible shade tree when designing agroforestry system involving durian (a high value fruit tree) and bagtikan (a commercial tree species) which are light intolerant at their early stages of growth development.

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Agroforestry and SRF in Southeast Asia

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Abstract

This paper describes the potential and benefits of agroforestry and short rotation forestry (SRF) for diversification and improving economic status of millions of people in Southeast Asia in general and Hindu-Kush Mountain Himalayas in particular. Planting short rotation timber, fuel and fodder tree species in combination with high value cash crops (HVCC) such as medicinal and aromatic herbs will benefit farmers with limited income and land. Diversification of existing cropping pattern by adopting agroforestry and short rotation forestry, seems to be the need of the day, to cope with the ever increasing imbalances between demand and supply for basic products. Multipurpose tree species outside the forest have played very important role in catering to the day to day requirements of the rural population in Asian countries. Different agroforestry systems developed for the upland regions of northwestern Indian Himalayas have yielded encouraging results. Agri-silviculture system integrating fuel, fodder and timber tree species with agricultural, medicinal and aromatic crops; agri-horticulture combining fruit trees; agri-horti-silviculture consisting crops combined with fruit trees and SRF trees on the farmland; silvi-pastoral system containing SRF tree species in combination with improved grasses on the sloppy degraded land have not only helped diversification but enhanced productivity of land per unit area. The suitable management of tree canopies, permitting adequate transmission of photosynthetically active radiation beneath canopies, has been found critical for improving the productivity of associated arable crops. The suitable tree management practices not only regulate biomass production ability and maintain vigour for extended period but also help agricultural crops to perform better under agroforestry intervention. Diversification of farming systems by growing short rotation timber, paper, pulp, fuel and fodder tree species with high value cash crops on the farmland is a viable option for increasing income of the farmers.

Introduction

The continuous degradation of upland mountain watersheds in the Asian region is increasingly becoming a serious problem. It is severely undermining the economic, social and environmental security of large population living in this part of the world. The Himalayas is a vast and diverse mountain system, spreading through eight developing countries of Southeast Asia, including Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Myanmar and Pakistan. The rising human and livestock population coupled with falling productivity, land degradation, wind erosion, shrinking of cultivable land, and lesser availability of water and lack of biodiversity are some of the major constraints for a sustainable development in Asian mountain regions. Today, there is a huge shortfall of basic needs, besides an enormous damage to the resources, renewable as well as non-renewable on account of their abuse and overuse. So, to meet the gap between supply and demand, efficient management of natural resources is the key issue. The existing allocation to agriculture and forestry are inadequate to meet the demands for food, timber, fuel, fodder and other minor products. There is approximately 140 million hectare of land in Asia, which is wooded land other than forest. The area contains bushes or lesser-known tree species. This is the right time to exercise option to convert this huge low productive and less exploited land into a productive gold mine by adopting agroforestry and SRF for diversification and sustainable biomass production. However, in order to transform present day practices into high-tech scientific adventure, there is an urgent need to formulate hypothesis through conductive reasoning, test and validate the hypothesis through deductive experimentation and strive to attain predictable understanding that will have a wide applicability. The inclusion of trees on the farmland paves the way for the improvement and diversification of existing systems but creates complex biological interactions (Lawson & Kang, 1990; Ong *et al*., 1991; Khybri *et al*., 1992; Rao *et al*., 1998; Gillespie *et al*., 2000; Thakur & Singh, 2003; Thakur & Dutt, 2004). The integration of traditional knowledge with scientific research is required for the development of improved technologies. The selection of proper multipurpose tree species for agroforestry and SRF, followed by suitable management practices, are the key factors for improving overall productivity per unit of land. While pursuing to achieve such tall targets, the efforts must be made to educate the farming community regarding tangible and intangible benefits of agroforestry and SRF.

Why agroforestry and SRF?

The exponential growth in human and livestock population over the years coupled with the declining production, soil erosion and declining cultivable land have increased gaps between supply and demand for timber, fuel and fodder. The growing appetite for trees for fuel, fodder and construction in both rural and urban areas has largely been responsible for much of the deforestation. The existing traditional land use systems with separate allocation to agriculture and forest are inadequate to meet the demands for food, fuel, fodder, timber, paper and pulp. The scenario on fuel, fodder and timber production is not satisfactory. There is a chronic deficiency of timber, fuel wood and fodder in the Southeast Asian countries. For example in India, according to the available estimates the annual consumption and production of fuel wood, timber and forage is as shown in Table 1.

Table 1. *Fuel wood, timber and fodder production and consumption status in India*

	Consumption	Production	Deficiency
Fuel wood	235 million m^3	90 million m^3	62 %
Timber	28 million m^3	12 million m^3	57 %
Fodder	900 million tones (dry)	441 million tones	51 %
Fodder	1100 million tones (green)	250 million tones	77 %

Table 1 shows imbalances between the demand and supply for fuel, forage-fodder and timber. The gap is being met from the farmland and other lands outside the forests. The situation likewise is no better in the remaining Southeast Asian countries. Therefore, agroforestry, which is an intersectoral intervention spanning two important and at times competitive land use systems i.e. agriculture and forestry seems to be panacea for overcoming most of the problems related to the alleviation of poverty and socio-economic instability in the Asian regions. Agroforestry and SRF hold potential for increased availability of on-farm wood products, energy sources and improved carbon sequestration (Semwal *et al*., 2002; Thakur & Sehgal, 2003; Shively *et al*., 2004). Agroforestry is being promoted and popularized by the Government and wood based industries in India in order to address the crisis of food, timber, fuel wood and fodder. After eucalypt species poplar based agroforestry has become very popular and remunerative. Acacia mangium plantation in Southeast Asia, particularly in Indonesia and Paulownia and Populus based agroforestry systems in East Asia, particularly in China, can be reasonably mirrored in the remaining Southeast Asian countries. Short rotation plantations consisting eucalyptus, poplars, acacias and pines will go a long way in improving the socio-economic status of smallholders in Southeast Asia.

The Southeast Asian countries encompass two peculiar situations, i) hilly terran and ii) plain areas with contrasting agroclimatic conditions. The main agroforestry systems existing on the farmer’s field are as under:

Agri-silviculture
Agri-horticulture
Agri-silvi-horticulture
Silvi-pastoral
Horti-pastoral
Horti-silvi-pastoral
Home gardens
Energy plantation (Fuel-fodder banks)
Commercial plantation

The components of agroforestry systems differ greatly in size, texture and nature depending on the necessity of rural population. The fuel, fodder and timber tree species dominate in the hilly regions, whereas commercial species like poplar, teak, eucalyptus, sandalwood, rubber etc., constitute the major component of agroforestry systems in the plains.

Poplar for short rotation forestry

The burgeoning demand and a steady increase in the per capita consumption of building materials, pulp, paper and other wood products is intensifying the loss of increasingly scarce natural forests. The improved hybrid clones of poplar are excellent multipurpose tree species for SRF. Our experience is that poplar planted at 8x3m and 6x4m proved suitable spacing for successfully growing medicinal and aromatic crops under agroforestry systems. There were no or little adverse effects on the performance and production of medicinal crops. The total income from diversified systems (medicinal crops combined with poplar) was substantially higher than monocropping. Table 2 shows the impact of poplar canopies on herb yield of medicinal and aromatic crops during two consecutive experimental years. The presence of poplar trees were not observed to adversely affect herb yield between 1-2 m distance from the tree line, especially under tree spacing of 8x3m and 6x4m. The herb yield reduction under closer spacing (5x5m and 4x6m) varied between 33-46% over the control up to 1m distance from the tree rows. Many workers have suggested use of poplar in agroforestry and SRF for higher economic returns (Mohsin *et al*., 1999; Dutt & Thakur, 2004).

Table 2. *Influence of poplar tree spacing on the total dry herb yield (t/ha/yr) of intercrops under mid-hills sub-temperate conditions of North-West Indian Himalayas. D_1 (1 m) and D_2 (2 m) distances from tree rows*

Tree Herb species spacings	Ocimum sanctum D_1	Ocimum sanctum D_2	*Spilanthes acmella* D_1	*Spilanthes acmella* D_2	*Tagetes minuta* D_1	*Tagetes minuta* D_2	*Withania somnifera* D_1	*Withania somnifera* D_2
Year 2001								
8 x 3 m	5.78	7.38	4.03	4.94	1.87	2.46	0.116	0.117
6 x 4 m	5.70	7.09	3.74	4.72	1.78	2.27	0.117	0.166
5 x 5 m	5.34	6.77	3.55	4.44	1.63	2.06	0.112	0.157
4 x 6 m	4.89	6.53	3.29	4.19	1.54	1.92	0.108	0.152
Control (no trees)	8.09		5.43		2.86		0.195	
$CD_{0.05}$ to								
Compare spp	0.08							
Compare distances	0.03							
Year 2002								
8 x 3 m	7.13	9.07	4.69	5.88	2.24	2.81	0.147	0.194
6 x 4 m	6.81	8.85	4.54	5.64	2.03	2.70	0.144	0.178
5 x 5 m	6.65	8.70	4.19	5.29	1.87	2.43	0.142	0.166
4 x 6 m	6.34	8.28	3.78	4.99	1.81	2.31	0.129	0.156
Control (no trees)	10.58		6.24		3.37		0.203	
$CD_{0.05}$ to								
Compare spp	0.06							
Compare distances	0.05							

Canopy management and biomass production

The management of multipurpose tree species, especially agroforestry and short rotation forestry tree species, integrated on the farmland with crops, is essential for two reasons, i) canopy size decides the transmission of photosynthetically active radiation to the understorey crops and ii) the impact of canopy management practices some times have drastic implications. The removal of the aboveground portion of trees results in enormous decrease in photosynthesis and vigour of the trees, which is not desirable. Our experience with canopy management of some of the important agroforestry and SRF tree species indicate enormous influence of management option on the vigour and biomass production potential.

Table 3 shows the impact of different cutting heights on foliage and branchwood production in Grewia optiva, an important fuel and fodder agroforestry tree species of Asian region, growing in combination with the agricultural crops. Grewia trees, cut at 3.0 m and 4.5 m in comparison to that at 1.5 m cutting height produced substantially higher foliage and branchwood biomass. Trees cut at higher heights attained larger canopy size and exhibited better biomass production potential for longer duration.

Table 3. *Impact of canopy management (cutting heights) on wet biomass yield (t/ha/yr) in Grewia optiva for two years after treatments*

Cutting heights	First year		Second year	
	Foliage	Branch	Foliage	Branch
1.50 m	1.01	5.32	0.99	5.24
3.00 m	1.47	7.97	1.25	7.69
4.50 m	1.53	7.88	1.39	7.65
Unmanaged	1.15	7.63	1.09	7.50
$LSD_{0.05}$	0.01	0.12	0.14	0.10

Four canopy management options in Morus alba, another important fodder and fuel tree species for short rotation forestry, namely i) no crown removal, ii) 25% crown removal, 50% crown removal and iv) 75% crown removal not only affected radiation climate in the system but also influenced biomass productivity. No crown removal option in Morus produced higher annual foliage and branchwood biomass; whereas considerable decline in biomass production with decreasing canopy size was observed (Table 4). Out of the four tree canopy management options tried; 25% crown removal causing least adverse effects on the growth and yield of associated agricultural crops and may be adopted as a compromised crown management practice.

Table 4. *Wet biomass production (t/ ha/yr) and canopy management in Morus alba (250 plants ha^{-1})*

Treatments	Foliage	Branch
No crown removal	0.293	0.851
25% crown removal	0.233	0.445
50% crown removal	0.094	0.028
75% crown removal	0.074	0.176
$LSD_{0.05}$	0.011	0.052

Table 5 shows the effect of coppicing and pollarding canopy management options on the biomass production in Grewia optiva, Celtis australis, Bauhinia variegata and Morus alba, group of important species suitable for agroforestry and SRF. Out of the four tree species; Grewia optiva and Morus alba, when pollarded at 1.5 and 2.0 m, responded better to canopy management practice in comparison to Celtis australis, and Bauhinia variegata. Morus alba, followed by Grewia optiva produced greater foliage and branchwood biomass at 2.0 m cutting height during the entire experimentation period, which may be adopted for better foliage and branchwood biomass production for longer period under the rainfed conditions.

Table 5. *Canopy management influence on leaf plus wood production on fresh weight basis (t/ha/yr) in important agroforestry tree species up to three years after treatments*

Cutting heights	First year	Second year	Third year
Grewia optiva			
0.5 m	3.73	2.99	1.88
1.0 m	4.22	3.38	2.23
1.5 m	5.99	5.08	3.66
2.0 m	10.29	8.90	6.59
$LSD_{0.05}$	1.01	0.90	0.16
Celtis australis			
0.5 m	2.72	1.94	0.82
1.0 m	3.61	2.85	1.37
1.5 m	2.95	1.61	0.64
2.0 m	2.78	1.41	0.53
$LSD_{0.05}$	0.11	0.08	0.03
Bauhinia variegata			
0.5 m	4.13	3.02	1.75
1.0 m	6.26	5.14	3.56
1.5 m	6.14	4.84	3.05
2.0 m	5.08	3.12	1.66
$LSD_{0.05}$	0.14	0.12	0.04
Morus alba			
0.5 m	7.97	6.88	4.88
1.0 m	8.06	6.95	4.95
1.5 m	9.57	8.55	6.96
2.0 m	13.22	12.10	10.09
$LSD_{0.05}$	1.11	0.81	0.19

Table 6 indicates biomass production behavior of Leucaena leucocephala and Morus alba grown as hedgerows on the farmland along with the agricultural and herbal crops under short rotation agroforestry systems. Leucaena, as well as Morus, produced higher foliage and branch biomass per tree, when grown at wider plant spacing in the hedgerows. Leucaena hedgerows with 0.5, 0.75 and 1.5 m spacing of plants in the hedgerows produced different quantity of biomass with lower production per tree at a closer plant spacing in the hedgerows. It was true for Morus hedgerows also. The hedgerows with a closer spacing, exerted comparatively greater adverse effect on the performance of associated understorey crops.

Table 6. *Wet biomass yield of Leucaena and Morus (kg/tree/yr) grown as hedgerows under short rotation agroforestry systems.*

Plant spacing	No. plants (ha^{-1})	Foliage ($kg\ tree^{-1}$)	Branch ($kg\ tree^{-1}$)
Leucaena leucocephala			
0.50 m	2857	1.00	2.50
0.75 m	1904	1.50	3.00
1.50 m	952	1.80	4.50
$LSD_{0.05}$		0.03	0.14
Morus alba			
1.50 m	952	1.40	3.50
2.00 m	714	2.00	5.80
2.50 m	571	2.90	6.70
$LSD_{0.05}$		0.66	0.21

Our findings indicate that the suitable tree management options not only regulate biomass production ability and maintain vigor for extended period but also help agricultural crops to perform better under agroforestry interventions.

Water as constraint for biomass production

Water is one of the major critical resources, which will remain a decisive constraint not only for the establishment of short rotation forestry tree species but also for the subsequent growth and biomass production on the stress sites, predominant in south east Asia. The performance and productivity of trees depend on the maintenance of higher physiological status, especially ability of tree species to register relatively higher photosynthetic rate and utilization of resources (Thakur & Sehgal, 2003). Drought is reported to cause decrease in water potential, osmotic potential and growth (Thakur *et al*., 2000; Correia *et al*., 2001; Pane & Goldstein, 2001; Thakur & Dutt, 2003).

The aim of one experiment was to select suitable drought tolerant short rotation agroforestry tree species for stress sites. The drought tolerance of Grewia optiva, Morus alba, Dalbergia sissoo, Acacia catechu and Populus deltoides was tested through various growth and physiological parameters. It was found that out of the five tree species; Morus alba and Dalbergia sissoo exhibited relatively higher drought tolerance in comparison to Acacia catechu, Grewia optiva and Populus deltoids, when subjected to two consecutive summer droughts after transplanting. Table 7 shows the impact of summer droughts on wood biomass production. Adverse effects of summer droughts were minimum in D. sissoo and M. alba.

Table 7. *Aboveground wood biomass (g/plant) on fresh weight basis as influenced by summer droughts after transplanting*

Tree species Duration	G. optiva		M. alba		D.sissoo		A.catechu		P. deltoides	
	Un stressed	Stressed	Un stressed	Stressed	Un stressed	Stressed	Un stressed	Stressed	Un stressed	Stressed
First summer drought										
25th day	11.1	7.8	33.5	25.6	14.7	11.4	13.4	11.2	42.5	29.9
50th day	14.7	9.5	41.3	29.1	20.6	13.3	17.4	12.3	49.7	30.9
75th day	18.4	10.1	53.6	31.1	26.1	14.1	19.8	14.5	59.1	31.2
$LSD_{0.05}$	0.21		1.15		0.72		0.55		0.36	
Second summer drought										
25th day	56.8	31.6	112.1	96.5	152.7	127.0	23.7	16.0	102.4	76.4
50th day	62.9	33.9	119.1	101.3	161.5	131.4	28.0	17.5	111.8	78.9
75th day	69.0	36.7	122.9	102.4	166.3	133.5	31.9	19.1	122.2	80.4
$LSD_{0.05}$	1.06		1.42		1.09		1.03		1.92	

Conclusions

There has been great progress in which agroforestry and short rotation forestry have played a justly proud role. But the coming decades will be more critical for the Southeast Asian countries in order to transform present day agroforestry and SRF into high tech scientific adventure, basically to reduce the imbalances between the demand and supply. Investment in developing the suitable germplasms of fast growing agroforestry and SRF tree species, capable of sequestering higher carbon and coping with the fast changing climate (global warming), cannot be lessened, nor can new technological possibilities be ignored. Besides, the participation of rural people cannot be overlooked in this process. Hopefully, diversification of farming systems combining fuel, fodder and commercial timber tree species under short rotation agroforestry with high value cash crops seems to be a viable option for boosting income of farmers.

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Use of willow crops for phytoremediation of wastewater, sewage sludge, landfill leachate, and farm land

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Abstract

Willows (Salix sp.) have been extensively studied as tools for phytoremediation purposes. This plant genus exhibits genetically large variability, are easy to propagate, thus enabling specific clones/varieties to be used, and have capacities to grow extremely rapidly under certain environmental conditions. In this review paper, we are going to discuss results when using willow plantations for phytoremediation of domestic wastewater, sewage sludge, landfill leachate, and farm land in terms of i) nitrogen (N) and phosphorus (P) retention in the soil-plant system, ii) N and P concentrations in harvestable biomass, and removal of these elements at harvest, iii) high chloride and N concentrations of landfill leachate, and iv) uptake and concentration of heavy metals in harvestable biomass.

Introduction

Willows are suitable for treatment of municipal wastewater and sludge, for irrigation using landfill leachate, and for soil remediation (Aronsson & Perttu, 2001). The interest of techniques based on phytoremediation instead of hardware engineering is continuously increasing, not at least because of economic reasons (Rosenqvist, *et al*., 1997). Willows have an efficient water and nutrient uptake (Perttu, 1998; Elowson, 1999; Aronsson, 2000), and have furthermore also shown a high, selective uptake of heavy metals (Riddell-Black, 1994). The crop is non-edible, and the techniques for establishment, management and harvest are well developed (Ledin, 1992).

Since construction of conventional wastewater treatment plants is very costly, it is necessary to find less expensive and more "natural" methods (Rosenqvist, *et al*., 1997). Willows can be used to treat most types of municipal wastewater and sewage sludge. However, the crop must be harvested regularly to off-load the soil-plant-system from unwanted compounds (Aronsson & Perttu, 2001). Drip irrigation or low-pressure, near-ground sprinklers can be recommended. Municipal sludge, as a result of sedimentation, can be applied to the crop after each harvest. Because of presence of pathogens in municipal wastes, attention must be paid to the storing and distribution methods (Perttu, 1999).

Landfill leachate is mainly the result of surplus precipitation. More or less hazardous compounds are dissolved inside the landfill, thus leaching into the environment. Often, the ambition is not to filter the leachate or remedy the landfill area, but rather to prevent pollutions reaching the surrounding water bodies. For this it is necessary to keep the leachate within the landfill area by collecting it in ponds, from where it can be re circulated to willow plantations within or close to the landfill area. Using intermittent irrigation, the evaporation rates can be optimised (unpublished data).

Several willow clones used until now have shown a high capacity to take up and accumulate different heavy metals, especially cadmium. Since cadmium is a toxic metal and a pronounced risk for human health, a possibility to neutralise its effect is highly desirable. During the 20th century, the Cd-content of agricultural topsoil in Sweden has increased by 100-150 g ha^{-1}, i.e. more than one gram per year. One rotation of willow crops (25 years) can easily remove this amount (Perttu *et al.*, 2003; Göransson & Perttu, 2004). During the last 5-10 years, however, the annual increase is stabilised at about 0.2 g ha^{-1}.

Examples of use of phytoremediation

Species of willows are frequently used for wastewater treatment, soil remediation, etc. This type of vegetation is regularly harvested and a large part of the biomass including different polluting compounds is thus removed from the soil-plant-system. Nutrients together with water and light are necessary for efficient plant growth. Solar energy can therefore in a large scale be converted into storable biomass at the same time as bothering pollutants can be taken up and neutralised. If the compounds, for instance, consist of nutrients in polluted waters or heavy metals in soils, plants with large requirements of nutrients and water or high uptake and storage of metals can be used for treatment purposes. The benefit is a combination of removal of pollutants and producing of biomass for various purposes. Improvement of the environment by re-circulating necessary (but otherwise polluting) compounds is of great importance. However, the most positive outcome is probably the fact that this type of biomass in many respects can replace fossil fuels, thereby counteracting many of their negative effects.

Municipal wastewater and landfill leachate treatment using willow coppice crops

A short rotation willow coppice crop can often be used to treat both municipal wastewater and landfill leachate. The plant community acts as an efficient filter by taking up and thus hindering the pollutants (nutrients, chloride, heavy metals, etc.) to pollute the surrounding water courses and/or groundwater. Because plants always need water and nutrients for satisfactory growth, irrigation with this type of waters is an attractive way to combine remediation with irrigation/fertilisation. The dose applied must, however, be adapted to match the plant community and the environmental conditions. Since vegetation normally does not take up more water and nutrients than they need for maximal growth in a certain climate, it is risky to apply more than that. Surplus irrigation can lead to leaching beyond the root zone, which might result in polluted groundwater and/or water courses.

Irrigation with landfill leachate can tolerate larger doses, if the leachate is aerated in ponds and if the willow cultivation is applied inside the landfill area. In this case, the surplus water circulates within the landfill area and does not reach the surroundings. Using suitable intermittent sprinkler irrigation above the canopy, an increased evaporation effect can be reached when the wet leaves are drying. The aim is to keep the leachate under control and to minimise the negative effects of high ionic strength of chlorides (often about 1 000 mg l^{-1}) and the ammonium (Dimitriou & Aronsson, 2005). The latter is at the same time a positive factor for willow growth.

In areas where the Köppen climate classification code (e.g. Huschke, 1995) is denoted as warm and cold temperate humid climate (Cfb and Dfb respectively), it is possible to positively treat 30-40 PE (person equivalents) of wastewater per hectare of stand. On every hectare, an amount of biomass corresponding to 3-4 m^3 of mineral oil can be produced. However, in areas with more optimal climate conditions, considerably higher production levels can be reached, and so the irrigation doses (and treatment capacity) can be correspondingly larger.

Treatment of municipal sludges

Normally, wastewater treatment plants produce large amounts of sludges which have to be handled in an environmentally safe way. In most cases, the sludge is pre-treated so that the hygienic risks are minimised. In most countries, there are strict regulations how this should be handled and used in a safe way and even more strict if the sludge is going to be used on land for food or fodder crop production. From the nutrient view point, municipal sludges have an unbalanced nutrient composition compared with corresponding wastewater. An optimal composition of the macro nutrients N, P, K for almost all green plants is 100, 14, 72 in relation to each other (Ericsson ?????). For municipal wastewater, the composition is near perfect (100, 18, 65), but for municipal sludge, the corresponding relation is about 100, 75, 10. This means that the sludge doses should be based on phosphorus, but then additional nitrogen is necessary for optimal growth. If the dose on the other hand is based on nitrogen, the amount of phosphorus is several times too high compared with the plant requirement. However, it is still better to use the sludge in non-food crops than to depose it on landfills from where it can also pollute the surroundings by leaching. After every harvest of the willow stands, it is possible to apply municipal sludge on the area with a positive increase of the nutrient status and humus content.

Soil remediation

Several clones of willow (Salix spp.) are able to accumulate large amounts of cadmium (Cd), and consequently the Cd-balance for these crops is positively affected. Therefore, this can be used to reduce the amounts of Cd that otherwise could be taken up by ordinary food crops. A comprehensive study was performed in Sweden during a four-year period (Perttu *et al*., 2003), and the main objective was to give answers to the following questions:

Will re-translocation of cadmium from subsoil to topsoil, for example by leaf shed, be a problem for future cultivation of food or fodder crops?

The conclusion was that the risk of increase of Cd-concentrations in the topsoil deriving from the subsoil is very small, as long as the part of the subsoil Cd uptake is less than 55-60 % of the total uptake. The present knowledge shows that the subsoil roots constitute 30 % or less of the total root mass. Since the efficiency of the subsoil roots is almost the same as those of the topsoil, this means that it is likely that considerably less than half of the total uptake occurs in the subsoil.

Can an increased biomass production increase the cadmium uptake and thereby improve the soil remediation?

The conclusion was that it is possible to increase the Cd-uptake by optimisation of the stem production. However, when choosing a certain willow clone, both the production and the uptake ability must be optimised to receive the best remediation effect.

What is the significance of cadmium accumulation in the leaves for removal and for re-translocation from subsoil to topsoil?

The conclusion was that, by choosing suitable willow clones, it is possible to control the uptake and, thus, maximise the concentrations in the shoots. It is also possible to find clones that store relatively more in the stems than in the leaves. Furthermore, it is possible to choose clones with a low uptake in the shoots, thereby avoiding producing bio fuels with high Cd-contents.

Will the cadmium concentration in the stumps be a problem implying that they cannot be milled down in the soil after the final harvest but must be dug up and removed?

The conclusion was that removal of stumps in most cases is not necessary in normal, commercial cultivations of willows for energy purposes (Table 1). They should instead be milled down into the soil to be decomposed and, thus, leaving their Cd evenly spread over the area. In some cases, however, it can be necessary to remove the stumps, but then it is important to point out that they must be treated in the same way as the corresponding stem biomass to avoid negative environmental consequences.

Table 1. *Removal of Cd by willow stumps and stems calculated at the end of a 24-year rotation period (After Perttu et al., 2003).*

Cd-removal by stumps	Cd-removal by stems
Average (range) in g ha^{-1}	Average (range) in g ha^{-1}
60.3 (16–125)	202.1 (32–318)
Average (range) in %	Average (range) in %
23 (9-35)	77 (65-91)

Log-yard runoff treatment

Sprinkling with water of stored wood at sawmills and at pulp mills during summer time is a normal procedure to protect the timber from being damaged by insects, fungi and drying. A medium-sized sawmill can annually consume 10^5 m^3 of water for the sprinkling. The content of the runoff water varies with the wood material stored and with the log-yard conditions. The main problems are caused by release of phenolic acids, organic carbon, heavy metals and phosphorus.

A large-scale study was performed in central Sweden at a sawmill, where 60000 m^3 of sprinkled water per year were recycled in a one hectare willow coppice crop (Dimitriou & Aronsson, 2005). The initial doses of water distributed were almost 40 mm per day. This high amount did, however, saturate the soils with a reduction of the willow growth. After reduction of the volume to 10-20 mm per day, the vigour and the efficiency of nutrient uptake were improved.

Economical considerations

In a temperate climate with the growing season length restricted by the temperature, it is not recommended to irrigate year round. Since wastewater normally is produced relatively evenly every month of a year, it is therefore necessary to combine a phytoremediation system with other treatment methods. Storage of the wastewater during the non-growing season to be handled during the growing season is one alternative. This is acceptable when the amount to be stored is not too large, which in turn is depending on number of persons (PE) connected to the wastewater treatment plant and on the lengths of the non-growing season. In the areas mentioned above with a non-growing season length of 160-180 days, this use of storage is possible in municipalities of up to 10 000 PE.

Rosenqvist *et al*. (1997) based their economic calculations on nitrogen, which economically is the main problem at most wastewater treatment plants. The results showed that the costs for a conventional technical system for removal of nitrogen and phosphorus in wastewater could allow a good margin for investment, operation and management of an irrigation system for wastewater treatment using willow cultivation.

Conclusions

Phytoremediation is suitable for treatment of municipal wastewaters and sludges. In the latter case it is necessary to use doses based on the component with the highest value per unit dry matter in order to avoid leaching. Therefore, it might be necessary with additional fertilisation to make the sludge fertilisation more efficient. A pronounced advantage with the phytoremediation method is that treatment of municipal waste products can be combined with production of biomass in a re-use system, thus replacing a considerable part of polluting fossil energy. It is also possible to use this method for soil remediation. As shown by Perttu *et al*. (2003), one rotation of willow (25 years) can remove the whole cadmium increase in the topsoil during the last 100 years. The economic calculations (Rosenqvist *et al*., 1997) show that the phytoremediation method even in areas with considerably long non-growing seasons can positively compete with more traditional treatment techniques.

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NABARD's initiatives in funding clonal eucalypts under short rotation forestry.

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Abstract

NABARD provides credit for sustainable agriculture, including forestry development, both on forest and non-forest wastelands. It has recently sanctioned a forestry project to Andhra Pradesh Forest Development Corporation for raising clonal eucalypts in 5530 ha degraded forests in Rangareddy, Medak, West Godavari, Krishna and Khammam districts for 7 years with credit from Bank of India. The clonal plantations will have better growth as compared to seedling plantations, besides, special soil moisture conservation technology will be used to boost productivity. The eucalyptus species are: E.camaldulensis and E. tereticornis. Total financial outlay of the project is Rs. 264.92 million (1 US $= Rs. 44), out of which the Corporation's share is Rs.74.73 million and bank loan of Rs.190.19 million. Against present average yields of 20 ADMT (Air Dry Metric Tone) per 7 or 13 or 19 years per ha from seedling plantations, clonal plantations will yield 50 ADMT, which will be sold as props, chocks, pulpwood and firewood. The cultivation cost is Rs.35.000 per ha, and harvesting will be in 7th, 13th and 19th year with average income of Rs. 80.000 per harvest. The plantations will be used for grazing purposes after average growth of the trees. There will be no displacement of local population and the village community will benefit by the NTFP (Non Timber Forest Producing) trees developed in rows in the periphery of the plantation.

Key words:
Clonal eucalypts, SRF, NABARD, Wasteland, Bank credit

Introduction

National Bank for Agriculture and Rural Development (NABARD) is an apex developmental bank with a mandate to promote sustainable and equitable agriculture and rural prosperity through effective credit support, related services, institutional development and other innovative initiatives. It's main objective is to facilitate credit flow for agriculture and rural development, promote and support policies, practices and innovations conducive to rural development and strengthening rural credit delivery system through institutional development measures and effective supervision.

Species of the genus Eucalyptus were first introduced in India as early as in 1790, in Nandi hills in Karnataka State and after this about 170 species of eucalypts have been tested. Of these, about a dozen species have been successful in different parts of India. However, only two species viz, E. tereticornis and E. camaldulensis and their hybrids have been commercially cultivated and today more than a million ha is under eucalypt plantation both on forest and non-forest wastelands. These species were also brought under Farm Forestry by the tree farmers in the states of Punjab, Haryana, Gujarat, Uttaranchal, Uttar Pradesh, Andhra Pradesh etc. The main reasons for successful cultivation of eucalypts under Farm Forestry are their exceptionally fast growth with a rotation of 8 to 10 years, multipurpose uses viz. poles, pulp, furniture and firewood, their strong coppicing ability, not browsed or grazed by cattle, fairly good survival even with little or no care and their high degree of adaptability to varying soil conditions including highly degraded lands. On suitable sites very good yield has been achieved in comparison to many other Farm Forestry species. Because of their capability to produce more under short rotation, NABARD/ Banks have financed eucalypt projects and substantial credit has been disbursed under such plantations. Besides, due to their high promise, a number of hybrids were produced by Forest Research Institute, Dehra Dun for enhancing productivity. Of these, few combinations displayed pronounced degree of hybrid vigor both in respect of height and diameter growth. The recent trend is however in favor of clonal propagation of selected genotypes. NABARD has recently sanctioned a large clonal eucalypt project to Andhra Pradesh State Forest Development Corporation (APFDC).

The clonal eucalypt project.

The project envisages raising 5530 ha of eucalypt clonal plantations over a period of 7 years at a moderate target of 790 ha/year. The Corporation had already developed the required infrastructures like mist chambers, clonal multiplication areas and selected candidate plus trees through their long term silvicultural research for mass production of clonal plants. The total financial outlay of the project was Rs.264.92 million, of which the Corporation was to invest Rs. 74.73 million as equity. It had made a tie up arrangement with M/S Singerenni Coallieries Ltd. for supply of props and chocks for a period of 10 years and which can be extended further, because these are required by the company for coal mining.

Unit cost, suitability of area and species

The unit cost proposed by the corporation was Rs.41,496 per ha for raising and maintaining the eucalypt clonal plantations up to 6th year with a design of 3 x 3 m. In addition to this, the Corporation has proposed to raise the important indigenous Non Timber Forest Producing (NTFP’s) trees, mainly fruit bearing at a design of 5 x 5 to 7 x 7 m in the periphery of the plantations in 3 - 4 rows for use by the local community. The land proposed for raising eucalypt clonal plantations are forest wastelands under the control of the State Forest Department and are considered suitable for raising the plantations. Besides, the introduction of Soil Moisture Conservation (SMC) technology, where various measures like gully plugging with rock fill dams, masonry check dams, individual soil working measures as per requirement, ploughing with septum bunds etc. will further boost the suitability of the area and bring in higher productivity. For establishment charges, the

Corporation made provision for salary, overhead expenses, allowances, vehicle, and road maintenance etc. which is inbuilt in the unit cost @ 20% on the cost of the plantation. Further, the required staff will be redeployed from the existing strength.

Yield and rotation

The Corporation has estimated biomass yield and returns per rotation, which is provided in table I.

Table 1. *The proposed yield estimates by APFDC*

Rotation	Yields per Ha			
	Props Nos.	Chocks – m^3	Pulpwood –ADMT (Air Dry Metric Tone)	Faggot wood - m^3
First	40	14	35	35
Second	40	14	30	30
Third	40	14	25	25

Field studies by NABARD

In a field visit undertaken by the authors with other officials of NABARD, besides the Bank of Maharashtra to APFDC plantations in Medak and West Godavari districts of Andhra Pradesh, it was observed that exceptional eucalypt clonal plantations were raised with uniform growth in height and diameter. In fact a 1993 clonal plantation when harvested had given yield two times more than the seedling plantation on wastelands. It may be mentioned in this connection that since eucalypts are strong coppicers, at least 2 more commercially viable rotational yield will be available. Table II gives the details of expenditure incurred and income generated based on actual yield obtained in a 1993 clonal eucalypt plantation of 4.74 ha without introduction of SMC technology.

Table 2. *Expenditure and income obtained by APFDC- both actual and estimated*

Rotation	Year	Expenditure per ha (Rs.)	Income per ha (Rs.)	Profit per ha (Rs.)
I (Actuals)	7	76,040 (incl. interests)	90,888	14,848
II (Estimated)	14	9,367	137,658	128,291
III (Estimated)	21	12,156	125,422	113,266
Total		97,563	353,968	256,405
Rotation	Yields from 4.74 Ha			
	Props Nos.	Chocks m^3	Pulpwood ADMT	Faggot wood m^3
First (Actuals)	1,092	1,014	202.4	24
Second (Estimated)	1,200	1,500	250	50

Another clonal plantation raised by APFDC in 1998 in 53.75 ha area in Paloncha Division at Mulkalpalli with SMC technology had promised higher returns. Here the design was 3 x 3 m accomodating 1111 plants per ha and the clones used were nos. 3,4,7,10 ,27,71 and 99. The total per ha expenditure up to 1st rotation including 14.5% interest on bank loan (today it varies from 8.5 to 10.0%) up to 7th year was estimated at Rs.74.600. With 93% survival and average girth of 46 cm, total per ha yield has been estimated at 92.60 ADMT. Based on the prevailing price of Rs. 1370 /ADMT, the expected revenue will be Rs.127.000 per ha, thus giving a profit of Rs.52.400 per ha.

Other observations

Nurseries were established by APFDC for raising the plantations and also for selling to interested farmers at no profit no loss basis. The team visited eucalypt clonal plantations raised by APFDC from the year 1996-2001 spanning over a period of 6 years. It was observed that very high quality plantations were raised by APFDC with a design of 3 x 3 m. In this area, the rainfall varied from 500 - 700 mm per year. By adopting the clonal technology and SMC, excellent plantations were raised which were not only of good growth but also uniform in height and girth. However, for raising the plantations under watershed approach, 50 g of SSP (Single Super Phosphate) had been put in the pits per plant and later on 50 g urea per pit per plant was also put after 3 months. For soil preparing, a new method of uprootal of weeds through tractors was used which had also helped the tree crops to grow uniformly. Besides, 2-3 rows of fruit trees under NTFP have been planted on the roadsides of the plantations, which will be available free to the local people. The Corporation expected to get more than 100 ADMT of pulpwood from these eucalypt clonal plantations on maturity.

The team also visited a plantation where harvesting was going on which was raised in the year 1993 by the clonal method. This was raised in an experimental plot of 1.5 ha but without adopting the SMC technology. The actual yield obtained was: Pulpwood of 60 ADMT for supply to paper mills, 345 nos. props for supply to Singerenni coallieries, 98 chocks for supply to collieries and 9 ADMT faggot for supply to Nagarjuna Power / Green Power Companies.

From the above it could be observed that the Corporation could get a return of more than Rs. 100,000 per ha from the clonal plantations thus yielding a very high return.

Economics of clonal eucalypt plantations

Based on the above parameters of cost and income, with IRR of 22.83%, the project was considered both technically feasible and financially viable, the details of which are provided below in Table 3.

Table 3.*Economics of clonal Eucalypts*

	Years														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	36318	1980	690	600	1260	288	360	690	690	690	690	690	690	690	690
Benefit	0	0	0	0	0	0	103250	0	0	0	0	0	0	0	180000
Net Benefit	-36318	-1980	-690	-600	-1260	-288	102890	-690	-690	-690	-690	-690	-690	-690	179310

PWC (Present Worth of Cost) @15% 35925.06
PWB (Present Worth of Benefit) @15% 60936.51
BCR (Benefit Cost Ratio) 1.70
IRR (Internal Rate of Return) 22.83%

Assumptions :

Produces	**I Rotation**	**II Rotation**
Props	200 @ Rs.175 per piece	250 @ Rs.250
Chocks	200 @ Rs.40 per m^3	300 @ Rs.55
Pulp	40 @ Rs.1500 per ADMT	50 @ Rs.2000
Faggot	5 @ Rs.50 per cm3	10 @ Rs.100

Sanctioning of the project

The management committee of NABARD sanctioned for the first time the above project in the year 2003 under co-financing in collaboration with Bank of Maharashtra. The total cost estimated at Rs.35.000 per ha was spread over a period of 7 years. The rate of interest was fixed at 10.5% p.a. simple. Harvests in the 7^{th},13^{th} and 19^{th} year are expected to yield approximately Rs.80.000 per ha per harvest. The project will prevent displacement of local people while generating an annual employment of nearly 100 man days per ha. Besides, after 2-3 years of maintenance, the plantations can be used for grazing. Also the non-timber forest produces will benefit the villagers around the plantations. The disbursement of loans will be in stages as per progress of plantation and the repayment will start from the year 2009-10 which will be completed by the year 2016-17. As per security requirements, the plantation and the book debts will be hypothecated and APFDC will provide guarantee from the Government of Andhra Pradesh. The Corporation will insure the plantation for full value during the currency of loan period. Results of sensitivity analysis indicated that with risk variables, namely lower sale price and lower yields, the financial indicators were satisfactory. Although sanctioned by NABARD, the project is being funded by Bank of India.

APFDC has now more than 10 000 ha of clonal eucalypt plantations, which are likely to give a windfall gain to the Corporation in the years to come. A brochure published by ITC (India Tobacco Company)--Limited, a public Limited Company in Andhra Pradesh promises the following returns to the farmers through eucalypt clonal routes in comparison to seedling route. The details are provided in Table 4.

Table 4. *Cost/Returns per hectare for 7 years rotation of ITC Brochure*

Particulars	**Seedlings**	**Bhadrachalam clones**
Cost of Planting Stock	2,670	10,992
Cost of Planting and Maintenance for 7 years	11,891	11,891
Supervision & Extension Costs	1,456	1,456
Insurance	1,085	1,779
Total Expenditure	17,102	26,118
Gross Income for First Harvest after 7 years @Rs.1000/T	70,000	120,000
Net Returns	52,989	93,882
Gross Income from Second Rotation in 15th Year @2000/T	140,000	240,000
Maintenance Cost for Second Rotation	10,000	10,000
Net Returns	130,000	230,000
Total Net Returns for Two Rotations	182,898	323,882

Planting stock required per hectare, seedlings - 2670 @ Re.1.00 per plant including replacement of casualties or 1832 clonal plants @ Rs.6/- per plant ex-nurseries. Net additional income from clonal plantations for first rotation Rs.49984/ha

Net additional income from clonal plantations for second rotation Rs.100000/ha The above calculations are exclusive of interest costs.

Results and Discussion

Trees are among the few natural resources that can be renewed and the need for trees and the wood that they provide is continuing to increase with increases in world population and the striving of people to maintain or increase their standard of living. The supply of wood is threatened by over cutting and over grazing in many countries and in some areas forests have been totally destructed. Hence, more intensive and aggressive forest management is necessary to improve the supply of wood and other forest products on existing forest lands that can be reforested, and on marginal and wastelands that can be afforested under Farm Forestry. Besides trees can be planted on agricultural lands under agroforestry.

Clonal forestry especially with eucalypts has just begun in India. In the years to come large scale plantations are likely to come up both on forest and non-forest wastelands. ITC Limited, which manufactures speciality paper and paper boards in Andhra Pradesh state is the pioneer in eucalypts clonal technology in India and now offers site specific genetically superior "Bhadrachalam" clones for planting under farm or agroforestry conditions. These clones are high yielding, disease resistant and adapted to different site conditions.

Their current thrust under R&D is to develop second generation hybrid clones and selection of clones tolerant to high pH and saline soils. They are also offering best quality superior eucalypt seeds from clonal seed orchards established by them. In fact demand for planting stock of “Bhadrachalam” clones far exceeds the current production level of 7 million plantlets per annum.

Their future programmes include to develop 0.1 million ha land with 600 million plants (ITC Limited, 2004). Further, they have initiated research on Casuarina, Leucaena and Bamboo clonal forestry. Similarly, JK Paper Ltd. at Rayagada, Orissa state introduced clonal technology and produced 11 proven and tested high yielding, disease resistant clones of eucalypt suitable for wastelands and rain fed areas of Orissa and adjoining states. So far the Paper Mill distributed 2.4 million clonal plants for planting on farmer’s fields. Likewise, Orient paper Mill at Amlai in Shahdol District of Madhya Pradesh state tested 89 candidate plus trees of eucalypt and selected 7 promising clones well suited for arid and semi-arid areas of the state.

Other trees which have been successfully cloned in India and are being used for large scale planting under clonal forestry are poplar (Populus deltoides) for North Indian agricultural lands, Acacia hybrid clones produced by Mysore Paper Mills in Karnataka state and Casuarina equisetifolia by Ballarpur Industries Ltd. in Orissa State. In near future many more clones of different trees might be commercially used. Special mention may be made of teak (Tectona grandis), Shisam (Dalbergia sissoo), Bamboos, Subabul (Leucaena leucocephala) etc. For the present Eucalyptus, Casuarina, Leucaena and Acacia clones have been very successful not only in developing India's wastelands but also in augmenting the pulpwood requirements of wood based industries. Similarly poplar clones have been highly successful under agroforestry for higher wood production in north Indian states. A recent visit to Hara farms in Haryana state showed that the farm had reached clonal wood yields of 50 MTGreen/ha/year and aiming at 62.5 MTGreen/ha/year, which might be a world record. In fact the most successful clonal technology under forestry in India has been with poplar clones (Haque & Kannapiran, 2003).

The Planning Commission, Govt. of India in its report of the task force on greening India for livelihood security and sustainable development (July 2001) had set a target of covering 43 million ha degraded land under watershed approach, out of which 15 million ha under Joint Forest Management, 10 million ha of irrigated area under commercial agroforestry, and 18 million ha of rainfed areas under subsistence agroforestry to be brought by 2012. It had identified only six trees viz. Populus deltoides, Acacia nilotica, Casuarina equisetifolia, Eucalyptus sp., Prosopis cineraria and Bamboo sp. for planting. It had also recommended the use of clonal materials for higher productivity. Before this, National Agriculture Policy (July, 2000) had identified agroforestry and social forestry as prime requisites for maintaining ecological balance and augmentation of biomass production in the agricultural systems. If more and more Indian wood based industries adopt clonal forestry using successfully cloned trees on commercial scale, then Farm Forestry will get a real boost with substantially high returns to the rural farmers. This will also help in poverty alleviation and all round rural prosperity including achieving the target of bringing 33% of land under tree cover as envisaged in National Forest Policy 1988 .

With the Kyoto Protocol coming into force from February, 2005, the introduction of CDM (Clean Development Mechanism) establishes a framework within which the industrialized countries can meet a part of their CO_2-emission reduction requirements by purchasing CERs (Certified Emission Reductions) from developing countries like India (Rawat & Kumar, 2005). Under such situation clonal forestry is destined to play a greater role in the near future in improving the productivity of large forestry plantations for carbon trading with industrialized nations. By the use of clonal technology and it's commercial application, The Government of India can also save foreign exchange for import of wood pulp.

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Hybrid poplar in North America: plantation management for multiple goods and services.

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Abstract

The North American poplar plantation industry was largely commercialized as source of low-cost fiber for the domestic pulp and paper industry between 1950 and 1990. Whether the poplar plantation industry is able to increase its importance and contribution to the domestic forest products industry will depend on: 1) Increasing profitability through sustained yield improvement through ongoing hybridization and varietal selection and 2) Development of more cost-efficient methods of plantation silviculture, and lowering of harvesting and processing costs. Equally important will be the success with which the plantation industry can expand into solid wood markets and the extent to which markets in tradable pollution credits associated with carbon sequestration materialize. Both will improve financial analyses of sustainable poplar rotations thereby ensuring long-term growth of the North American plantation industry.

Introduction

The cultivation of hybrid poplar in North America encompasses approximately 45,000 hectares in the United States and 14,000 hectares in Canada (FAO, 2004). Poplars and their hybrids were among the first trees domesticated in North America. Between 1925 and 1927, the Oxford Paper Company participated in the first poplar hybridization project in the United States to develop improved varieties for plantation cultivation (Stout & Schreiner, 1933). Controlled hybridization of American aspen (P. tremuloides, P. grandidentata) and white poplar (P. alba, P. x canescens) began soon thereafter at the Petawawa Forest Experiment Station in Ontario, Canada (Heimburger, 1936). Originally intended to supply logs for both the pulp and paper and match stock industries, nearly all large-scale, industrial plantations have been established and managed primarily for wood chips for pulping fibers (Stanton, 2005). These plantations currently make a relatively small contribution to the overall fiber supply of the North American pulp and paper industry, partly as a consequence of a trend to shift domestic wood supplies to hardwood plantations of the Southern Hemisphere (Kellison, 2000).

Today poplar plantation management has begun to diversify, focusing on a multiplicity of markets. For instance, as the cost of fossil fuels continues to rise and methanol and ethanol conversion technologies continue to be developed for lignocellulosic feedstock, opportunities for poplar energy plantations may soon become economical for large-scale commercial development (Thorp, 2005). Moreover, poplar plantations in the Pacific Northwest are now being managed for more profitable veneer and lumber markets in view of declining red alder (Alnus rubra) supply. Finally, poplars are being increasingly used in environmental and pollution control projects and in the restoration of ecologically important floodplain and riparian habitats.

Industrial Plantations

All large-scale poplar plantations in the United States have been developed by the forest products industry in three regions: the Pacific Northwest, the North Central, and the Mississippi River Valley. Similar plantation developments are underway in Canada's western prairie region of the Province of Alberta. Nearly all of these plantations have been established on agricultural land of marginal crop quality and are managed using an intensive, agronomic-style of site preparation and tending to strictly limit herbaceous weed competition (Stanturf *et al*., 2000). Clean cultivation ensures rapid stand establishment and high rates of survival; when successful, intensive use of both mechanical and chemical weed control can be discontinued after the two- to four-year establishment stage when weeds are eliminated by shading under closed canopies.

Pacific Northwest

Poplar is grown both on the mesic west side and the arid east side of the Cascade Mountains along the Columbia River (Heilman *et al*., 1995). Growth of west side plantations is optimized on the silt-loam alluvial soils of the lower Columbia River floodplain. The climate is relatively mild and ample rainfall (1,000 to 1,500 mm annually) supports growth rates of merchantable stem wood approximating 9.0 to 11.2 dry Mg ha^{-1} yr^{-1} after eight years. Average winter minimum and average summer maximum temperatures are, 0.9^0 C and 22.8^0 C respectively. Growing degree days (5^0 C base temperature) in this area approximate 1 541^o C. Plantations are stocked with superior varieties of the predominant hybrid taxon, P. x generosa (P. deltoides x P. trichocarpa). More recently, the Asian species, P. maximowiczii has been used in F_1 hybrid breeding with both P. deltoides and P. trichocarpa. Insect problems are mostly lacking in west side plantations although sporadic outbreaks of sawfly (Nematis sp.) and leaf beetle (Phratora californica) have occurred. Pathogen pressure is more serious, primarily with leaf rust (Melampsora x columbiana and Melampsora medusae) and, secondarily, with shoot blight (Venturia populina) and leaf spot (Septoria populicola and Marssonina brunnea) (Newcombe & Bradshaw, 1996; Newcombe & van Oosten, 1997; Newcombe *et al*., 1994). Disease-resistance breeding has been effective in alleviating pathogen pressure although continuous varietal development has been necessary to counter evolving pathogen virulence in Melampsora leaf rust.

East of the Cascades large-scale industrial plantations have been established on coarse, loamy fine sands in the mid-Columbia River basin. Drip irrigation of up to 1,200 mm per growing season for mature stands is required under the extremely arid conditions (250-300 mm annual precipitation). Growing degree days average

2 530^0 C. Average winter minimum and average summer maximum temperatures are, - 0.3^0 C and 30.0^0 C respectively. Nitrogen, phosphorus, and zinc fertilizers are applied at rates of 90 kg ha^{-1} yr^{-1}, 11 kg ha^{-1} yr^{-1}, and 1 kg ha^{-1} yr^{-1} for mature stands. Compared with the west side's alluvial plantations, those of the mid-Columbia River basin achieve superior growth rates of merchantable wood of 13.5 dry Mg ha^{-1} yr^{-1} on seven-year rotations due to warmer temperatures and virtually cloudless days during the growing season, and the precise control over irrigation and fertilization. The standard hybrid taxon is P. x canadensis although other types are used. Pest concerns are nearly exclusively limited to insects of which the more important include the defoliating cottonwood leaf beetle (Chrysomela scripta) and several stem borers including western poplar clearwing moth (Paranthrene tabaniformis), poplar and willow borer (Cryptorhynchus lapathi), and carpenterworm (Prionxystus robiniae). Leaf beetles are controlled with systemic inorganic insecticides delivered through the drip irrigation system. Control of the western poplar clearwing moth is achieved using aerially applied synthetic pheromones to disrupt mating. No cost-effective control strategy has yet been implemented for other boring insects although select varieties of P. x canadensis exhibit some degree of resistance (Johnson & Johnson, 2003).

Establishment of both west and east side plantations utilizes dormant cuttings 23 to 35 cm in length. Most are produced by serial propagation using one-year-old branches taken from two-year-old plantation trees. Originally, plantations were established with approximately 1,550 trees per hectare (2.1 x 3.0 meter spacing) and managed for the production of wood chips on rotations of seven or eight years for pulping fibers for paper manufacturing. However, approximately 70% of the acreage in the Pacific Northwest has been converted to the production of higher-value saw and veneer logs due to the continuing low market price for hardwood pulp chips in the region. Typical markets now include paneling, molding, cabinetry, doors, furniture, and plywood. The conversion has involved thinning of existing pulpwood stands and re-planting of new stands to a density of 675 to 750 trees per hectare (3.0 x 4.9 meter spacing or 3.6 square meter spacing). Poplar logs are grown on rotations of 12 to 15 years, the longest cycles allowed for crops receiving an agricultural designation under current state regulations.

North Central USA

Poplar research and development has a very lengthy history in the North Central and upper Midwest regions of the United States. Both pulpwood and, more recently, energy plantations have now been developed in the state of Minnesota. Average winter minimum and average summer maximum temperatures are, - 14.1^0 C and 25.9^0 C respectively with growing degree days approximating 1 960 ^{0}C. Annual precipitation averages 575 mm. Pulpwood plantations are stocked at a density of 1,700 trees per hectare (2.4 meter square spacing) and managed on 10 to 12 year rotations. Growth rates of merchantable stem wood vary between 5.6 and 9.0 dry Mg ha^{-1} yr^{-1}. Over 6,800 hectares of pulpwood plantations have been established with an additional 3,200 hectares to be brought into production within the next five years. Energy plantations are stocked at a rate of 3,400 trees per hectare and will be harvested after 5 years. Over 12,000 hectares will be needed to provide feedstock to area co-generation plants.

Establishment is by dormant cuttings 23 cm in length although the success is more dependent upon genotype and soil temperature than in the Pacific Northwest (Zalesny *et al*., 2004). Cuttings are produced by coppice in local nurseries. Nitrogen fertilizer is applied at periodic intervals during the rotation beginning at the conclusion of the establishment phase at rates of 56 to 140 kg ha^{-1}. Select varieties of the P. x canadensis taxon (e.g. DN2, DN5, DN182, I 45/51) perform well but are exceeded in growth rate by a single P. nigra x P. maximowiczii variety (NM6) (Hansen *et al*., 1994). Hybridization efforts are focused on enlarging the base of the P. nigra x P. maximowiczi taxon as well as breeding improved varieties of local sources of P. deltoides, although the establishment of pure P. deltoides varieties from unrooted, dormant cuttings is oftentimes difficult. The major pest problems are leaf beetle (Chrysomela scripta) and Septoria musiva stem canker. The former is held in checked with aerially applied insecticides while varietal selection within the P. x canadensis taxon has effectively controlled the latter (Netzer *et al*., 2002).

Mississippi River Valley

Poplar plantations in the southern part of the United States are managed solely for the production of pulpwood. Two large plantations have been established on the alluvial floodplain of the Mississippi River, one near the confluence of the Ohio and Mississippi Rivers (6,000 hectares) and one further south near Vicksburg, Mississippi (4,800 hectares). Average winter minimum and average summer maximum temperatures are, - 0.7^0 C and 32.9^0 C respectively. The growing degree days vary between $3,528^0$ C (Wickliffe, Kentucky) and $4,567^0$ C (Vicksburg, Mississippi). Annual precipitation averages about 1200 mm. Plantations are stocked at a rate of 750 trees per hectare and are managed for eight to ten years (3.7 m square spacing). Establishment is by dormant cuttings 60 cm in length produced by coppice in nursery beds. Nitrogen is applied at rates of 100 kg ha^{-1}. Growth rates of merchantable stem wood vary between 6.75 and 7.50 dry Mg ha^{-1} yr^{-1}. Select varieties of P. deltoides (e.g. ST66, ST75, S7C8, S7C15) are used exclusively (Land, 1974; Mohn *et al*., 1970). Susceptibility to stem canker (Septoria musiva) and the lack of adaptability to the southern photoperiod may account for the poor performance of inter-specific hybrid varieties bred using parents from more northerly-adapted species. Cottonwood leaf beetle (Chrysomela scripta), cottonwood twig borer (Gypsonoma haimbachiana) and cottonwood borer (Plectrodera scalator) are key insects pests, the control of which requires applications of chemical insecticides. Varietal selection for leaf rust resistance is effective in countering infection and defoliation by Melampsora medusae (Cooper & Filer, 1977).

Canada

The most active industrial poplar plantation program in Canada is being developed in the arid prairie region of the province of Alberta. One pulp and paper company has taken the lead although others are involved (Kryzanowski, 2005). Average winter minimum and average summer maximum temperatures are, - 21.1^0 C and 21.7^0 C respectively.

Growing degree days are about 1,180^0 C. Annual precipitation averages 300-400 mm. Two thousand, six hundred (2,600) hectares have been planted to date. Ultimately 25,000 hectares will be brought under cultivation and managed on 18-year rotations. Conservative growth rates of merchantable stem wood approximating 5 dry Mg ha^{-1} yr^{-1} are anticipated. Stands are established at a density of 1 111 stems per hectare using a 3 m square spacing. Select varieties of both the P. x canadensis (e.g. Walker) and P. x jackii (e.g. Northwest) hybrid taxa are featured in the planting program. Bareroot planting stock is grown in nurseries under contract and used because establishment from dormant cuttings is not always reliable in the typically cool soils and dry conditions on the western prairie. It is likely that the future will also involve hybrid aspen (P. tremuloides x P. tremula) varieties propagated using rooted stock.

Environmental Applications

Poplar culture has more lately been employed in a number of environmental and site-remediation applications (Isebrands & Karnosky, 2001). A principal use involves recycling municipal and industrial effluent. Land application of treated municipal sewage and vegetable-processing wastes has proven to be more cost effective than alternative treatment methods. A related use is row plantings established along the periphery of agricultural fields that act as living filters in the interception and recycling of nutrient flows in subsurface runoff.

Poplar plantings are also being used to uptake and sequester toxic substances from landfills and contaminated industrial sites (Gordon *et al.*, 1997). Plantings have also been used to reclaim mine tailings. These projects are only locally important for wood supply but offer considerable cost savings relative to alternative methods of site amelioration and/or soil removal and decontamination. Poplar plantings managed for extended and sustained rotations may also figure as efficient carbon sinks in efforts to combat global warming (Tuskan & Walsh, 2001).

Agro-forestry

The use of poplars in agro-forestry has been mostly limited to shelterbelt plantings to control wind erosion and to provide protection for crops and livestock in Canada's prairie regions and the Great Plains of the United States. Approximately 700 000 hectares in Canada alone are protected by poplar shelterbelts. Shelterbelts are planted using varietal mixes to maintain genetic diversity to lessen the chance of stand decline due to cold, drought, and insects. Most shelterbelts are established as line plantings with trees separated by 2 meters. Occasional multiple-row shelterbelts are planted with rows separated by 4 meters. Lifespan is generally 40-

50 years. One kilometer of poplar shelterbelts contains a total aboveground biomass of 175 Mg.

Ecological Uses

Poplars have recently been put to use in the restoration plantings along degraded rivers and floodplains. Such plantings are restricted to native (i.e. non hybrid or exotic) materials. In the United States, P. deltoides stands have been established in combination with other hardwood species along the Mississippi River to improve wildlife habitat. The planting density of poplar in mixed stands is approximately 250 trees ha^{-1}. In the United States, the program has qualified for government support programs such as the Conservation and Wetland Reserve Programs. In the Pacific Northwest, locally adapted selections of P. trichocarpa are planted along many coastal rivers to improve water quality and safeguard endangered salmon runs.

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Development of tree plantations in Australia.

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Abstract

Australia's forest plantation estate is expanding, exceeding 1.7 million ha in 2004. In a global context, most of these plantations are managed on short rotations (10 to 40 years). Most plantation development until the 1980s used exotic softwood species for sawlog production. Most of the recent expansion has been in hardwood plantations, mainly eucalypts, which now exceed 0.7 million ha. The market and government policy factors and major sources of finance supporting plantation expansion are outlined.

Most of the hardwood plantations established recently are planned to be grown on 10-15 year rotations and intended for pulpwood production. There is some interest, mainly from governments, in growing eucalypt plantations to supply sawlogs to replace supplies from natural eucalypt forests. However, only a small proportion of eucalypt plantations are thinned and pruned to enable sawlog production. There is also interest in the potential for tree plantations in low rainfall areas for wood production and environmental benefits, especially salinity control.

Recent development of tree plantations has been mainly on agricultural land with species previously little used for plantation forestry in Australia. This has led to a range of technical, social and economic issues. Plantation development has therefore depended on research into genetic selection and breeding, matching species with climate and sites, silvicultural management, nutrition, and pest and disease management.

There is significant concern in some rural areas about the real or perceived social, economic and environmental impacts of plantations. Water use by plantations and the impact of reforestation on catchment water yield has recently become a major issue. These issues are discussed briefly with respect to the potential impact on further substantial plantation expansion.

Introduction

Plantations of tree species selected for their timber production potential have been established in Australia since the 1870s. That was about 100 years after European settlement started and clearing of forests and woodlands for farmland began. There were two major factors that prompted the first plantations. First, there was concern in some regions that the native forests could not supply sufficient timber for construction and fuel to support settlement. Second, the mining industry that began in the 1850s had a voracious demand for timber and left large areas denuded. Reforestation with plantation timber species rehabilitated the land while also providing a future timber resource.

Some native species, mainly eucalypts, and many introduced species were tried at various times before those that best suited the soils and climates in each region, and which also suited market needs, were identified.

Pinus radiata (radiata pine) was first planted for forestry in 1876 in South Australia and in Victoria, in 1880. By 1900 it was evident that it was the best softwood species for plantation forestry in southern regions of southern Australia. It is now the single most commonly used softwood species, providing a majority of the structural timber used by Australians for building and other purposes. The ‘southern pines’ P. elliottii (slash pine), P. caribaea (Caribbean pine) and P. taeda (loblolly pine) were found suitable for the sub-tropical and tropical regions of northern Australia. Araucaria cunninghamii (hoop pine) was the only native conifer found to be suitable as a plantation tree.

The rate of new softwood planting peaked briefly in the 1930s before declining to negligible levels until the 1960s. From 1967 through the 1970s, the Australian Government provided finance to the State Governments to develop plantations. There was an implicit policy shared by the Australian Government and most State Governments to aim for self sufficiency in forest products (Carron, 1990). Most of the current softwood plantation estate dates from the late 1960s to the late 1980s.

Eucalypts were also tried in the first era of planting and there are still some small areas of eucalypt plantation dating from the late 19th and early 20th centuries. Eucalypt planting was negligible for many years. Up to 1960 the total area was only about 12,000 hectares. The area increased slowly but steadily until the late 1980s when the potential of Tasmanian blue gum (Eucalyptus globulus) plantations to grow fibre for the Japanese pulp and paper industry was realised. The rate of planting soared during the 1990s. Over 130,000 hectares of new plantations were established in 2000. The rate then declined until picking up again in 2004.

The general trends in plantation expansion outlined above are shown in Figures 1 and 2 and the total areas to 2004 are shown in Table 1. A more detailed chronology is provided by Catton et al. (2004).

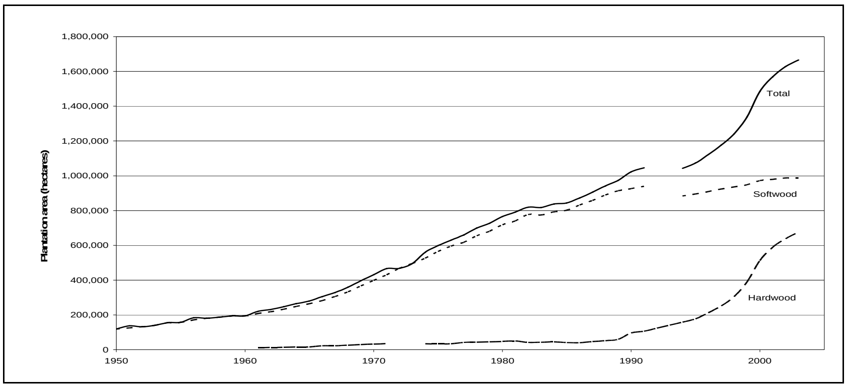

Figure 1. Hardwood and softwood plantation establishment 1950-2004.
Source: National Forest Inventory data

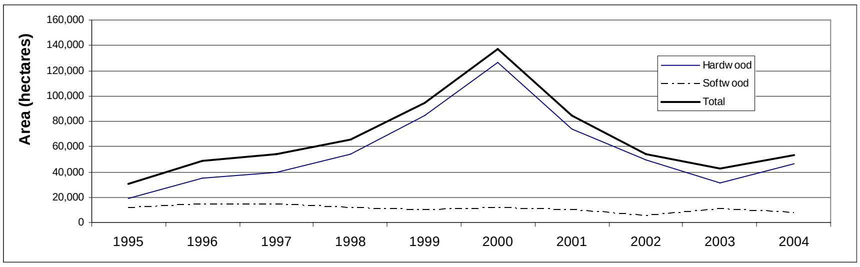

Figure 2. New hardwood and softwood plantation establishment 1995-2004.
Source: National Forest Inventory Note: these are the areas established on land not previously used for plantation.

Table 1. *Total Hardwood and Softwood Plantations 2004 (hectares).*

State/Territory	**Hardwoods**	**Softwoods**	**Total**
Western Australia	259,371	110,395	369,766
Northern Territory	8,437	3,817	12,254
South Australia	39,438	124,313	163,751
Queensland	34,427	180,158	214,585
New South Wales	54,060	287,302	341,362
Australian Capital Territory	65	5,363	5,428
Victoria	168,461	214,874	383,335
Tasmania	151,272	74,420	225,692
Australia Proportion of total	715,531 42%	1,000,642 58%	1,716,172

Source: National Forest Inventory 2005.

Even after the substantial increase in plantation area in the past ten years, plantations are still a small land use in Australia (Table 2).

Table 2. *Land use, Australia*

Land use	**Area (million hectares)**	**Proportion of total land area**
Plantations	1.7	0.2%
Public native forest where timber production is permitted	11.4	1.5%
Forests in nature conservation reserves	21.5	2.8%
Agricultural and horticultural crops	23.6	3.1%
Native forests and woodlands	161.5	21.1%
Total land area	766.0	100.0%

Sources: National Forest Inventory 2005; Thackway et al. 2004; Bureau of Rural Sciences unpublished data. Integrated vegetation cover 2003, version 1.

Table 3. *Plantation species, primary products and regions.*

Region	**Product**	**Hardwoods**	**Softwoods**
Tropical – medium to high rainfall [1]	Sawlogs	Eucalyptus pellita, Flindersia brayleyana, Khaya senegalensis, Tectona grandis	Pinus caribaea, Araucaria cunninghamii
	Pulpwood	Acacia mangium	None
	Biomass	None	None
Sub-tropical – medium to high rainfall	Sawlogs	E. grandis, E. pilularis, E. saligna, E. dunnii, E. cloeziana, Corymbia henryii	P. elliottii, P. caribaea, P. taeda, hybrid pine [2], Araucaria cunninghamii
	Pulpwood	E. grandis	None
	Biomass	None	None
Temperate – medium to high rainfall	Sawlogs	E. nitens, E. regnans, E. grandis, E. saligna,	P. radiata
	Pulpwood	E. globulus, E. nitens	None
	Biomass	None	None
Temperate – low to medium rainfall	Sawlogs	E. cladocalyx, C. maculata, E. occidentalis, E. camaldulensis, E. astringens [3]	P. pinaster [4]
	Pulpwood	None	None
	Biomass	E. kochii, E. loxophleba	None

1. As a guide, 'high rainfall' is over 900 mm average annual rainfall; 'medium rainfall is 650 to 900 mm and 'low rainfall' is less than 650 mm.
2. A cultivated hybrid between P. elliottii and P. caribaea has for some years been the favoured plantation softwood in sub-tropical regions on new sites and after harvesting mature stands of exotic pines.
3. E. astringens (brown mallet) plantations were established in Western Australia between 1927 and 1960 primarily for tannin production (Forests Department Western Australia 1971). They are no longer used for tannin but some timber is harvested.
4. Pinus pinaster (maritime pine) was planted extensively around south east Australia in the early 20th century. The only significant areas of new planting currently are in Western Australian, where a government program – the Maritime Pine Project – is using this species for reforestation to help combat increasing soil salinisation in agricultural areas caused by water tables rising following the clearing of native vegetation.

The major species planted in each climatic region for each type of product (sawlogs, pulpwood and biomass) are listed in Table 2. Note that only small areas of some of these, especially the hardwood sawlog species, have been established. There is currently no significant planting for pulpwood in some regions and only in Western Australia is there any significant planting specifically for biomass production.

Short rotation crops?

The planned production period and potential growth rates for the major plantation species, products and regions are shown in Table 3.

Table 3. *Short rotation crops*

Region	**Species**	**Main Product**	**Rotation (years)**	**Growth rate (m^3/ha/year)**
Temperate low to medium rainfall	E. kochii, E. loxophleba [1]	biomass	2 – 4	10 – 12
Tropical high rainfall	Acacia mangium [2]	pulpwood	8	25 – 32
Temperate medium to high rainfall	E. globulus, E. nitens	pulpwood	10 – 15	15 – 25
Tropical high rainfall	Khaya senegalensis [2]	sawlogs	15	12
Tropical high rainfall	Tectona grandis [2]	sawlogs	20	16
All regions	Eucalypts	sawlogs	25 – 45	5 – 15
Temperate medium rainfall	Pinus radiata	sawlogs	28 – 35	14 – 25
Tropical, sub-tropical medium rainfall	Pinus caribaea	sawlogs	30	12 – 15
Temperate low to medium rainfall	Pinus pinaster	sawlogs	40 – 45	10
Tropical, sub-tropical high rainfall	Araucaria cunninghamii	sawlogs	50	13

1. These are two of the main species used in the Mallee Project in Western Australia. The growth rate shown is green weight of annual production of foliage. Biomass is foliage (leaves and stems) harvested using a coppice system. The plan is to use the biomass to produce activated carbon, charcoal, eucalyptus oil and electricity.
2. The rotation and growth rates shown for Acacia mangium, Khaya senegalensis and Tectona grandis are the objectives indicated by the providers of private investment schemes and have not yet been achieved in operational practice in Australia.

Who is establishing new plantations?

While there were some private investment schemes and companies involved, Australian State Governments were the major investors in new plantations for most of the first hundred years of plantation development. Public investment waned in the 1980s and private investment has now predominated for several years. The proportions of public and private plantation ownership were equal in 1999 but in 2004 privately owned plantations comprised 58%.

The current three main sources of investment in new plantations are private retail investment schemes, private company plantation projects and State Government schemes.

Private retail investment schemes raised over A$4 billion for plantations in the past eight years, including about A$500 million in 2004 from people with high incomes aiming to diversify their investment portfolios. These schemes established about two thirds of the new plantations in 2004. Investors in these schemes are treated as primary producers and receive the same taxation treatment as other primary producers. This means that establishment costs can be deducted against income from other (non-forestry) sources when assessing their tax liability. Tax is paid when income is received when the crop is harvested.

Few Australian timber processing companies are investing their own funds in plantations in Australia. In contrast, from the early 1990s Japanese companies and industry organisations have started 20 plantation projects. Together they aim to establish 201,500 hectares of plantations of a total 493,400 hectares of planned overseas plantation investments. The area established in Australia to 2003 was about 116,000 hectares (Japan Overseas Plantation Center n.d.). Several of the projects have reached or are nearing their target plantation areas, so that their rate of new plantation development is waning. There is also a Korean company, Hansol, which has established 16,000 hectares. Hansol started exporting woodchips from Bunbury, Western Australia, in 2003.

State government reforestation schemes are currently a less significant source of new plantation investment than the previous two categories. These are described further below. Some private landholders also establish commercial plantations, often in proximity to the markets created by larger corporate plantation growers.

In the 1990s interest rose in planting small woodlots of native and exotic hardwoods for sawlog production on farmland. Governments support this activity by providing advisory services and, in some cases, grants. Many different species have, or are being, tried. However, the total area established is only a few thousand hectares and this is dispersed over several regions so that it is difficult to make these forests commercially viable.

Why are plantations being established?

Timber production is still the main reason for establishing plantations. In the ten years to 2003-04, plantation logs increased from 48% to over 62% of the total volume of logs harvested. However, in recent years the reasons for establishing plantations have become more diverse and include production of biomass and carbon credits and to control salinity.

Pulpwood versus sawlog supply

Over 80% of the new plantations established in the past 10 years are short rotation crops designed to produce pulpwood. Potential pulpwood supply from 2010 onwards may exceed 12 million cubic metres per year compared with about 1.5 million cubic metres of pulpwood harvested from hardwood plantations in 2002-03. There is currently no domestic market for this surplus, although there are proposals to build new pulpmills. Most plantation managers are aiming for export markets, but only a small proportion of the potential supply is actually contracted to a buyer.

Australian consumption of softwood plantation sawlogs is nearly 11 million cubic metres per year, which is more than current domestic supply of around 9.3 million cubic metres per year. Consumption is increasing, so that the gap between consumption and domestic supply is also increasing. Imports of sawn timber are increasing to fill the gap. Despite this, only about 16% of the new plantations in the past 10 years are long rotation softwood crops designed to produce sawlogs. Australia therefore has the curious situation where most investment in new plantations will produce products for an export market which is not secured while domestic demand for sawn timber cannot be supplied from Australian plantations. A study into the impediments to investment in longer rotation plantations found that secondary markets, taxation and other issues were limiting factors (Kelly et al. 2005). A number of government policy changes were recommended to address those issues.

Since the mid 1990s, State Governments in New South Wales, Queensland and Victoria have funded hardwood plantations to produce sawlogs to offset reductions in supply from native forests that have been reserved from timber production. Some hardwood plantations established in New South Wales and Victoria in the 1960s and 1970s are also managed for sawlog production. The potential of these plantations to contribute to national hardwood sawlog production was assessed by Nolan et al. (2005). The conclusion was that the potential was much less than the amount by which sawlog supply from native forests has reduced.

Salinity control

Salinity currently affects 2 million hectares of farmland in Western Australia and 6 million hectares are considered to be at risk (Government of Western Australia 2002). Reforestation can lower the water table and reduce the amount of salt in sub-surface soils leaching into streams. For example, it has been shown that Eucalyptus globulus plantations established for pulpwood production have reduced salinity in the Denmark River in south west Western Australia (Bari et al., 2001). The private sector is establishing Eucalyptus globulus plantations in the mid to higher rainfall areas closer to the coast of Western Australia, but not further from the coast where salinity is also an issue. The State Government of Western Australia has therefore been promoting reforestation projects to control salinity in farmland in the mid to lower rainfall regions of that State.

The two main Western Australian government-funded reforestation projects are growing Pinus pinaster (maritime pine) and mallee eucalypts (mainly Eucalyptus kochii and E. loxophleba). P. pinaster plantations in Western Australia already supply logs to industries that produce sawn timber, laminated veneer lumber and other products. The rotation required exceeds 30 years, so this may not be considered a short rotation tree crop. The maritime pine project started in about 1997 and aims to expand the supply of logs to those industries by establishing P. pinaster on farmland where the trees will also help control salinity.

The mallee eucalypt project is currently the only significant short rotation tree crop aimed at biomass production in Australia. The plan is to use the biomass to produce charcoal, activated carbon, eucalyptus oil, electricity and carbon credits. One of the investors in mallee planting is Kansai, a Japanese power company, which is seeking to obtain carbon credits to offset carbon emissions from electricity generation.

Mallee eucalypts were first proposed for salinity control in the 1980s. The State Government Department of Conservation and Land Management provided research into genetics, seed production, establishment and management practice, harvest and handling and products. Farmers were attracted by the vigorous growth and tolerance of sheep grazing, which meant that fencing was unnecessary and belts of trees could be planted within standard agricultural practices.

An average of 3 million mallee trees in belts two trees wide (equivalent to 1,100 ha) were planted per year between 1994 and 2004 with more than 1,000 farmers participating. The Oil Mallee Company of Australia was formed in 1997 to commercialise the project. A plant to process 100,000 tonnes per year of chipped biomass is nearly operational (Harrison et al., 2005).

There is considerable discussion and research into plantations for salinity control in the catchments of the Murray and Darling Rivers in eastern Australia. Progress to date is limited to research and demonstration sites.

Other products and services

Many small plantations have been established in south eastern Australia for the treatment and disposal of municipal and industrial wastewater. The technology is well developed and includes selection of suitable species, silvicultural management, design of water reticulation systems, regulation of nutrient and pollutant application and tree growth in relation to salinity and pollutant levels (Baker et al., in press; Myers et al., 1999). While successful for wastewater treatment, the plantations are yet to be generally accepted as a means of wood production. Baker et al. (in press) concluded that irrigated plantation forestry cannot compete with agricultural use of the same irrigable land and wastewater.

Establishing plantations to earn ‘carbon credits’, that is, the rights to carbon captured from the atmosphere by the trees, has been discussed as an additional significant source of investment. A number of projects have been initiated for this purpose in Queensland (hardwood plantations) and New South Wales (hardwood and, more recently, softwood plantations). Plantations established specifically for carbon credits are still relatively few and small in area. However, a State-owned electricity company is proposing to pay for the establishment of 30,000 hectares of mallee eucalypts in southern New South Wales. Also in New South Wales, a private company has established a trial of Grevillea and Casuarina to assess the potential for an energy crop.

Plantations are sometimes referred to as having potential to provide ‘environmental services’, for which plantation owners may receive payment. Environmental services may include aesthetic values, habitat for native plant and animal species and soil erosion protection, as well as salinity control and carbon credits as described above. Except for carbon credits and salinity control, there seems little prospect of markets for these services to develop in the near future.

Does everyone like plantations?

Timber products industries that use pine products would prefer that more softwood plantations, rather than hardwood plantations, were established. However, in general, timber industry companies welcome plantation expansion. There are also many rural and regional communities whose economic viability relies on forestry and timber processing. While those communities support plantation forestry, other groups in the community are less sure of the benefits.

Some of the new plantations established in the 1980s and nearly all of the new plantations established since 1990 are on land previously used for agriculture. This has led to significant concerns in rural communities as the rural landscape changed. For example, it is argued that when farms are bought for plantations the farmers move to towns and regional centres and that this leads to reduced local access to social services, such as education and health care. These issues are currently being investigated by the Australian Government Bureau of Rural Sciences. Some concerns arguably come more from competition for land between forestry organisations and farmers who want to expand.

Water use is another perceived problem. It is ironic that reforestation was (and is still in some regions) promoted as a way of controlling catchment salinity caused by rising water tables. While salinity is a major problem in Western Australia and in the Murray-Darling River systems, much of eastern Australia is under prolonged drought conditions and urban communities and farmers are facing restrictions on water supply. This has led to pressure to control plantation establishment because trees use more water than the dryland pastures they are replacing.

Concerns over plantation expansion can influence the political process and can potentially lead to impediments to further plantation development. For example, in response to concerns over water use, regulations have been imposed to limit the area of additional plantations in south east South Australia.

Environmental non-government organisations (NGOs) appear to have mixed feelings about plantations. NGOs have frequently promoted plantations as an alternative to harvesting timber from native forests. However, the same NGOs have then complained about plantation establishment practices, such as use of pesticide and weedicides, and about perceived aesthetic affects, even for plantations established on cleared farmland where previous agricultural practises typically required far more chemical use.

Research and development

Exotic pines have been used in plantations in Australia for over one hundred years. The silvicultural requirements are therefore well understood and there has been considerable progress in genetic improvement. In contrast, Eucalyptus globulus and other species introduced to plantation forestry more recently are in the early stages of domestication. Considerable work is therefore continuing on genetic selection and breeding, matching species with climate and sites, silvicultural management, nutrition, and pest and disease management. Processing sawlogs from fast grown hardwood plantations is presenting challenges to a sawmilling industry used to larger, slow grown logs from native forests, providing scope for further research and development.

Conclusions

Short rotation plantations are now the major source of timber products in Australia, supplying over 62% of logs harvested. The area of hardwood plantations has increased rapidly in the past decade. These plantations are short rotation pulpwood crops (10 to 15 years) mainly intended to supply export woodchip markets. Investment in longer rotation plantations to produce sawlogs is low, and sawlog production is falling behind domestic demand.

The reasons for establishing plantations have broadened in the past decade to include salinity control, carbon credits, energy and other products or services. While the areas established for those purposes so far are small, there are proposals for considerably more.

Most new plantations are established on farmland. This is leading to social and resource use issues that are likely to constrain further plantation expansion.

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Records and observations at the IUFRO world conference in Brisbane, Australia.

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Abstract

Every fifth year forest scientists of all kinds within IUFRO (International Union of Forest Research Organizations) are gathered to a World Conference. In August 2005, the meeting was located to a conference centre in Brisbane, Australia. The Conference was eminently organized and very well carried out. Forestry study tours were included within the programme. They were mainly organized after the conference and directed to different parts of Australia and New Zealand.

Following recommendations of the conference organizers, contacts between scientists from IUFRO's sessions for Short Rotation Forestry (1.09.00) and for Agroforestry (1.14.00) were made some years before the conference with the aim of organizing a joint session. Two sessions at the conference were organised, with excellent lectures by all the speakers. The speakers were required to send their manuscripts in advance to chosen reviewers for comments. After every lecture, these reviewers initiated the debate, sometimes with new and interesting angles of approach to the subject. After the conference the speakers were able to take these ideas into consideration when they prepared their manuscripts for publication in the Proceedings.

Common remarks of the conference

Thousands of forest scientists from all over the world participated, and presented papers or posters. It is not possible to summarize a conference of this kind with up to 15 parallel sessions. However, a few remarks and observations should be given to a broader audience. The President of IUFRO, Professor Risto Seppälä from Finland, opened the conference by declaring that forest scientists in many countries have not kept up with the common development. He also concluded that foresters do not any longer participate in the common debate. Many of us were startled of this statement but of course it is of great importance for the forest politics of a country that foresters participate in the public debate.

From the perspective of Short Rotation Forestry and Agroforestry.

Different effects of the increased greenhouse effect and fears for the future development were often discussed. Most people agree about the fact that the temperature will increase in the future, but there were different opinions about how much. But then the opinions and ideas diverged. If the increased temperature at the same time means more or less precipitation, more or less cloudiness, higher or lower humidity, more or fewer strong winds, more forest fires or fewer, more or less flooding, cannot be predicted today. At the same time it was concluded that “climate change” would have such far-reaching effects and radical influences on almost all sectors of the society and human life that the term “climate change” ought to be replaced with “global change”.

Suggestions concerning up-to-date priorities and further broadening of the activities of IUFRO, particularly from an energy point of view, were discussed. So were the rapid change and in some cases the very frustrating development of the economy within the energy sector. As a matter of fact, the oil price rose from 60 to 67 US dollars per barrel during the Brisbane Conference.

It was noticed with some surprise that few foresters have taken account of the rapid change taking place in the world and broadened the use of forestry to include bioenergy in different forms. It was almost only in the sessions of Short-Rotation Forestry and Agriculture, that this very rapidly developing trend was recognised. At our session, we stated that access to energy in different forms governs and controls the world, and we put the question and formulated the situation like this: Do the foresters (we) really understand the power they (we) have in their (our) hands? The fact that forestry in general has hardly appreciated its possible role in bioenergy development proves Professor Seppäläs words when he opened the conference to be correct! Many business opportunities are lost as a result of the current neglect of the bioenergy business.

It was also amazing to hear some keynote speakers declare that now it is time to start to look at forestry for energy purposes. In some countries like Finland, Sweden, USA, The Netherlands, Canada, Ireland and others, this has been done so since the middle of the 1970s. For cooking and heating houses this has been going on all over the world since the beginning of human life.

In the next 5 years and at the next IUFRO conference in Seoul, it was hoped that the Executive Board of IUFRO will underline the possibilities and the duty that foresters have all over the world to act to help to create a sustainable and thereby much more peaceful world. Implementation of all forms of utilisation of biomass as a source of energy is a key question for a sustainable world.

Many lectures dealt with the tropical rain forest and its future. It was surprising and a little astonishing to learn that results and experiences from Costa Rica show that clear-felled and exploited areas after a while have considerably higher biodiversity than the original rain forests. It was concluded that the most important action is to ensure that a complete plant community will be established as soon as possible to prevent erosion of various kinds. Then a high biodiversity will develop by itself. In one presentation it was also concluded that however badly we human beings treat nature there will always be a new ecosystem. But this is a truth that perhaps demands some modifications.

In a seminar of forest politics, among other things, the organization of WWF (World Wide Fund for nature) and its activities was discussed. How representative is this organization?; in whose interests are the priorities chosen?; which scientific and emotional considerations are behind its standpoints?; and how democratic is the organization? These questions were put on the table but no answers were given. It was not clear whether anyone responsible from this organization was present. Because of security reasons no participation list from the conference was available. However, WWF did participate with an informative showcase in the exhibition hall. It was vaguely suggested in the discussion that foresters should participate in the work of WWF. This is particularly important now when WWF and the World Bank have renewed their Alliance for Forest Conservation and Sustainable Use for another five years.

Election of a new chairman

To the new president of the IUFRO, Professor Don Lee from South Korea was elected.

Next IUFRO conference

Next IUFRO worldwide conference will be in Seoul year 2010

Short Rotation Forestry Sessions

Two sessions of IUFRO:s Short Rotation Forestry section (1.09.00) and Agroforestry section (1.14.00) took place with excellent lectures by all the speakers. After every lecture, the chosen “opponent” started the debate with, in some cases, new and interesting angles of approach to the subject. All the manuscripts are now put together in a Proceeding after the ”opponents” have reviewed them.

Coordinator: Kartar Verma, India.
Deputy coordinator: Lucrecio Rebugo, The Philippine
Deputy coordinator: Theo Verwijst, Sweden

Theoretic SRF (1.03.01)	Applied, temperate SRF (I.03.02)	Applied, tropical SRF (1.03.03)
Coordinator: Gail Tailor, GB	Coordinator: Tim Volk, USA	Coordinator: Sanjeev Chauhan , India
Dep.co: Martin Weih, Sweden	Dep.co: Pathak, India,	Dep.co: de Sousa, Brasil
Dep.co: Dai Limin, China	Dep.co: Mark Parsons, Australia	Dep.co: Kasahun Embaye, Ethiopia
Dep.co: Larry Abrahamson,USA	Dep.co: Ian Nichols, New Zealand	Dep.co: ?
Education, information	Education, information, training	Education, information, training
Socio-ecology	Socioecologic aspects	Socioecologic aspects
Vegetation filters	Vegetation filters	Vegetation filters
Pest and diseases	Pest and Diseases	Pest and diseases
Climate change influence	Climate/soil/species connection	Climate/soil/species connection
Nutrient use efficiency	Utilisation	Utilisation
Soil fertility	Plantation and management	Plantation and management
Carbon sequestration	Harvest	Harvest
Water use efficiency	Economy	Economy
Energy efficient ratio	Marketing	Marketing
Wood quality	Design	Design
Stand development, competition		