Forestry Department

Food and Agriculture Organization of the United Nations

Forest Plantations Thematic Papers

PLANTATIONS AND WOOD ENERGY

Based on the work of

Donald J. Mead
Consultant

March 2001

Forest Resources Development Service
Forest Resources Division
Forestry Department

Working Paper FP/5
FAO, Rome (Italy)

Disclaimer

The Forest Plantation Thematic Papers report on issues and activities in forest plantations as prepared for FRA 2000. These working papers do not reflect any official position of FAO. Please refer to the FAO website (http://www.fao.org/forestry) for official information.

The purpose of these papers is to provide early information on on-going activities and programmes, and to stimulate discussion.

Comments and feedback are welcome.

For further information please contact:

Mr. Jim Carle, Senior Forestry Officer (Plantations and Protection),
Forest Resources Development Service
Forest Resources Division
Forestry Department
FAO
Viale delle Terme di Caracalla
I-00100 Rome (Italy)
e-mail: Jim.Carle@fao.org

For quotation:

FAO (2001). Plantations and wood energy. Report based on the work of D. J. Mead. Forest Plantation Thematic Papers, Working Paper 5. Forest Resources Development Service, Forest Resources Division. FAO, Rome (*unpublished*).

Please Note: The figures in this paper are estimated forest plantation areas in **1995**, based on a revision to the statistics collected in the **1990** forest resources assessment. More up-to-date forest plantation statistics will be published when the **2000** forest resources assessment is published in **2001**.

CONTENTS

1. INTRODUCTION

Forests and trees provide a significant share of the world's energy use, accounting for about 7 percent of the total energy used. For developing countries, wood energy is of considerably greater importance than in industrialised countries – about 15 percent of their energy needs come from woodfuel, with about 80 percent of all their wood being used for this purpose (WEC 1999). The industrialised countries depend much more heavily on fossil fuels with only 2 percent of their energy demand coming from wood. Woodfuel production is overwhelmingly concentrated in the developing world with over three-quarters of annual production located there.

Most bioenergy comes from natural or semi-natural forests or woodlands, agricultural sources or other by-products, rather than from planted trees and shrubs. Despite this there is growing recognition that planted woody species are an important means of providing energy in a wide range of specific situations.

The word plantation has been variously defined. According to FAO, for tropical and subtropical regions, plantations consist of forest stands established by planting or seeding with introduced or indigenous species (FAO 2000). They exclude stands, which although they may have been planted, are without intensive management and are better regarded as semi-natural and they also exclude tree-crops like oil palm and rubber. However, in this report, particularly the latter sections, we will cover planted woody species (both trees and shrubs) grown both as forest stands and outside forests.

This paper reviews the current situation and future for trees planted for energy in developing countries. As most of these developing countries, as defined in the World Energy Council report (WEC 1999) are located in the tropics, the emphasis is on the tropical situation.

2. PRESENT STATUS OF WOODFUEL

2.1 *Current woodfuel[1] use*

Woodfuel is a broad term covering both the direct use of wood in cooking and heating, the use of charcoal (both for households and for industrial uses) and also recovered wastes in wood-using industries. While all are important in particular situations in developing countries, the use of wood and charcoal in heating and cooking predominate and are the main energy sources for more than two billion people (Nogueira, *et al.* 1998; Mather 1990; WEC 1999). However, substantial quantities are used in small and large-scale industrial processes – in Brazil, for example, about four million tonnes of woodfuel, as charcoal, are used in the steel and cement making industries each year, much of this being derived from eucalypt plantations (Foley 1986; Turnbull 1999). Furthermore, there is widespread use of wood wastes to provide energy for wood processing in Brazil.

The production and use of woodfuel is heavily concentrated in developing countries and in particular in the tropical countries (Table 1). Asia accounts for about 44 percent of all wood

[1] The term woodfuel is a generic term used here to cover direct use of woody material (eg twigs, branches and stems used as fuel or charcoal); indirect use such as in wood processing residues; recovered woodfuels (used wood); wood-derived fuels (eg methanol). Wood-based fuels are generally less important in developing than in developed countries.

fuel use, Africa about 21 percent and South America and the Caribbean about 12 percent. These figures hide the variability between individual countries. Indeed there are 34 countries where woodfuel provide more than 70 percent of their energy needs and 11 African and two other countries where woodfuels provide over 90 percent (WEC 1999). In developing countries woodfuel makes up about 80 percent of total wood use; in Africa it averages 89 percent (Table1) and in a few countries it is almost the sole use of wood. The per capita woodfuel use also varies widely, being highest in African countries and tropical Oceania. Again, usage varies widely between countries, with 19 developing countries and four industrialised countries averaging greater than one cubic meter per person per annum (WEC 1999).

Table 1: Woodfuel use summarised by region (based on WEC, 1999)

Region	Woodfuel demand $m^3/yr \times 10^6$	% of total energy used	% of wood used for energy	% world's woodfuel use	Woodfuel per capita m^3/yr
Developing countries	1 763	15	80	77	0.40
Tropical	1 368	26	84	59	0.51
Non tropical	395	6	65	17	0.23
Africa	486	35	89	21	0.67
Asia	1 003	12	81	44	0.29
Oceania	1	52	56	<1	0.88
Latin America	268	12	66	12	0.56
Developed countries	537	2	31	23	0.41
World	2 300	7	59	100	0.40

Notes:
1) Totals may not tally due to rounding
2) Oceania excludes Australia, New Zealand; Asia excludes Japan, Turkey and Israel; all these countries are included in the developed countries. Latin America includes the Caribbean. The limitations of this data have been discussed by WEC, 1999.

There is often great variation within a country depending on the availability of wood. Use is much greater in rural areas than in larger towns, with at least half of gross energy consumption in most developing countries occurring in rural areas, primarily for cooking and heating of households (WEC 1999). The breakdown for India shows that 152 million tonnes of woodfuel was used in the rural sector while 49 million tonnes was used in urban areas, with most of this going to hotels, restaurants and cottage industries (Ahmed 1997). One Indian study found that the distance of the village from the forest was an important factor in woodfuel use, but an even more important factor was household income level (Ahmed 1997). Thus high-income people prefer to replace woodfuel with cleaner, more convenient fuels, particularly in urban areas. Other studies suggest that the greatest use is in the middle income range (Mather 1990).

Less obvious when looking at percentages of wood used as woodfuel for individual countries, is that the scale of production can be quite high compared to forest resources. Large volumes of woodfuel are produced from savannah woodlands of African countries, for example. As already pointed out for India large quantities come from trees grown on farms, along roadways or around the village. Furthermore, woodfuel is regularly available where fallow systems of agriculture (shifting cultivation) are used. Thus the supply of woodfuel depends not only on the forest resource, but also on the nature and condition of agriculture (Mather 1990).

In developing countries charcoal is often an important, although a small component of woodfuels (Foley 1986; WEC 1999). Limited data given by WEC (1999) suggest that about 7 percent of all woodfuel in developing countries is used as charcoal. Where it is used, then individual consumption is 100 -150 kg yr^{-1} (Foley 1986). Charcoal is relatively more important in Africa and Latin America than Asia. Wood residues and black liquor are generally less important in developing countries than developed countries (WEC 1999).

In addition to woodfuel there are other biomass alternatives that need to be recognised when considering woodfuel use and the potential for woodfuel. These include agrofuels in rural areas and municipal by-products in urban areas[2]. Agrofuels such as straw, husks, dung etc., are readily substituted for woodfuel and thus make estimation of true demands more complex. For example, in India it was estimated that 22 percent of bioenergy comes from dried dung (Vergara 997).

2.1.1 The ‘woodfuel crisis’

The ‘woodfuel crisis’ of developing countries, propounded in the 1970’s and often accepted until more recently, was based largely on looking at supply and demand from forests and did not take into account the complexities of the situation (Leach and Mearus 1988; WEC 1999). Deforestation was seen as one consequence of this theory because it was found that consumption exceeded annual forest growth rates. Furthermore, this problem was seen as often being aggravated by population growth. The remedy was to plant trees. Leach and Maerus (1988) identified four factors that tended to negate this theory:

- The imprecision of estimates about resources and consumption – a small initial difference, which may not be real, may suggest disaster in the longer-term.
- Estimates often ignored trees outside forests
- The gap calculations did not always allow for re-growth
- The switch to other fuels was ignored.

The underlying belief in a woodfuel crisis and the reaction to plant trees for this purpose, often in the form of traditional plantations, has led to many programme failures (WEC 1999). Nevertheless there are instances where intense local use, for example near large urban centres has lead to forest depletion (Mather 1990). Vergara (1997) also points to increasing difficulties in heavily populated areas like India and Bangladesh. Here, tree planting, both as plantations and outside forest areas, are likely to be important. Nogueira *et al.* (1998) suggested that, in general, there is little conflict with industrial use of wood (including for industrial energy) and that being used for household use.

There has been a steady increase in woodfuel demand in the developing countries over the last 50 years while demand has been relatively constant in the developed countries (Mather 1990[3]; WEC 1999). In the early 1950s woodfuel production was estimated to be about 866 million m^3 worldwide (Mather 1990). By 1970 the estimate for developing countries was

[2] Agrofuels cover material of agricultural origin such as crop, animal and agro-industrial by-products and fuel crops. The third broad category is municipal by-products.
[3] Mather (1990) warns that these upward trends may be overestimated as they could arise in part from changes in procedures and more comprehensive coverage.

about 1000 M m^3 and this has risen steadily so that by 1995 it was estimated that 1763 million m^3 was being used annually (WEC 1999). Globally there has been an annual growth of 1.75 percent in total woodfuel demand. Woodfuel demand and growth has been linked to both population growth and to income level, with low incomes generally indicating higher consumption (WEC 1999). Thus between 1975 and 1985 population increased by 19 percent while woodfuel increased by 28 percent (Mather 1990). However, while it is anticipated that by 2030 the world's population will grow by a further 45 percent and that most of this will be in developing countries, the majority of this growth will not be in rural areas (WEC 1999). The impacts of future population growth on woodfuel use are, therefore, less easy to predict.

2.2 Woodfuel production systems

Figures and studies like those described above hide what actually happens. In practice most of the woody biomass is collected from a wide range of sources – natural and degraded forests, savanah and shrub lands and from trees planted in plantations, on farmlands, in villages, along roads etc. Furthermore, a wide range of products is used from leaves under trees, dead and live branch windfalls and loppings, logs, logging residues and wastes from wood using industries. Bhattarai (1998) has described this as a 'residue and by-product woody based system'. In many situations woodfuel is not the main product of the forests. Often many of these contributions to woodfuel were poorly accounted for in earlier studies so that much of the past data is unreliable.

The importance of planted trees in farmland, villages, homesteads or along roads, waterways etc., can vary widely but often have a large impact on woodfuel supply. Asian studies for example, show that forest based supply can range from 13 percent in the Philippines to as high as 73 percent in Nepal and that in many countries it is less than 50 percent (Bhattarai 1998; Vergara 1997). On average only 5 percent comes from plantations (Table 2).

A 1996 example of the breakdown by woodfuel source from the Philippines illustrates the diversity possible (source RWEDP database):

	%
▪ Natural Forest	7
▪ Forest plantations	4
▪ Processing residues	3
▪ Home gardens	26
▪ Crop lands	19
▪ Rubber plantations	7
▪ Coconut plantations	19
▪ Other	15
Total	100

These figures also indicate the considerable variation in the ownership of the forest resources from which woodfuel is derived; government, private companies, communities and farmers. We see this also in Indian figures where in rural areas where 62 percent of woodfuel is collected from forest and public lands, 23 percent is collected from private lands and 15 percent is purchased (Ahmed 1997).

Other Indian estimates suggested a breakdown of woodfuel, based on ownership and source, as follows (based on RWEDP 1997):

	%
▪ Natural forests (state)	32.2
▪ State & community plantations	7.0
▪ Farm forestry (plantations)	11.3
▪ Farm trees (planted)	21.1
▪ Homestead gardens	7.3
▪ Degraded lands	12.1
▪ Shrub lands	9.0
Total	100

In contrast to these patterns South America has a greater emphasis on privately owned woodfuel plantations, some of which, as in Brazil, are large-scale to supply industries. In Minas Gerais State, the center of Brazil’s iron and steel industry, there are several private companies with 150 000 to 200 000 hectares eucalypt plantations being grown for charcoal (Turnbull 1999). Some of these are also encouraging small landowners to plant eucalypts.

Another source of woodfuel is from extensive rubber and palm plantations. There are almost 10 million hectares of rubber plantations, of which about 64 percent are overmature (IRSG 1997). Similarly, about 20 percent of the12 million hectares of coconut plantations are senescent (APCC 1998). India has about 2.3 million hectares in these types of plantations. Bamboo is also an important in some countries.

2.3 Current energy plantations

Globally, non-industrial forest plantations are estimated to cover about 20 million hectares (FAO 2000). This was almost 17 percent of the world’s total plantation area in 1995. Most of these had been planted for woodfuel and 98 percent are in developing countries. Other major reasons for establishing non-industrial plantations include land rehabilitation and erosion control, watershed protection and production of non-woody forest products. These plantation figures do not account for trees planted outside forests on farms or villages etc; nor do they consider agricultural plantations like rubber or palm trees. Furthermore, they do not consider forest residues that are used by industries, nor where rural people collect fuel from industrial plantations. FAO (2000) suggested that as a first approximation, the roundwood volumes for non-industrial plantations might be used as conservative estimates for woodfuel plantation production.

In developing countries about one third of the plantation estate was being primarily grown for woodfuel in 1995 (Table 2). Three quarters of these plantations were in Asia (which in this analysis excludes Japan), where they accounted for 60 percent of total plantation production. In Latin America more than half of plantation production went to woodfuel; in Africa and Oceania a larger proportion of plantation production was as industrial wood. However, plantations, in general, provided only a small proportion of total woodfuel used (Table 2). Uruguay is an interesting exception.

Table 2: Estimated areas and production of non-industrial forest plantations in developing countries by region, and for the largest producers in each main region (Based on FAO 2000).

Region	Area woodfuel estate* ha x 10^3	% total plantation estate	1995 estimates		
			Plantation woodfuel* m^3 x 10^6	% of plantation production	% of total woodfuel use**
Africa	2 154	37	12.2	34	3
Ethiopia	135	88	1.5	93	3
Madagascar	122	52	1.5	84	16
Sudan	233	78	1.1	76	7
Asia*	15 090	33	53.8	60	5
China	3 854	18	5.5	20	2
India	8 308	67	30.2	92	11
Indonesia	399	13	4.2	52	5
Oceania**	14	10	<0.1	12	<1
Latin America	3 123	35	20.4	55	8
Brazil	1 946	47	12.6	51	12
Peru	210	72	1.5	70	9
Uruguay	232	67	2.1	71	95
Developing countries	20 380	33	86.4	47	5

Notes:
* Assumes non-industrial plantations are primarily for woodfuel.
** Based on estimates in WEC (1999) and FAO (2000).
*** Asia includes Turkey but excludes Japan.
**** Oceania excludes Australia and New Zealand.

There are large differences between countries and within countries. Brazil, India and China, partly as a result of their size, dominate world production (Table 2). Brazil, for example, had 4.2 million hectares of plantations in 1995 of which about half (47 percent) were considered as being grown for woodfuel; they provided about 12 percent of all woodfuel used. China had 3.9 million hectares of woodfuel plantations, largely planted by communities, but this was only 18 percent of their total plantation estate and supplied about 2 percent of woodfuel used. India’s 8.3 million hectares of woodfuel plantations made up 67 percent of their estate and supplied 11 percent of their woodfuel. Most of this was used non-industrially and a large proportion was planted on degraded lands with state assistance (Ahmed 1997); there are also good examples of plantings by private owners (Mather 1990).

While these three countries dominate the world scene, it is also important to recognise that woodfuel plantations will vary in their importance depending on location, climate, socio-economic and historic factors. For example in Ethiopia, over 87 percent of plantations are grown for bioenergy (FAO 2000). Yet they provided only 3 percent of the woodfuel used, which is about the African average (Table 2). Ethiopia has a long history of planting eucalypts for fuel and poles, having introduced them in 1895. Madagascar’s 122 000 hectares of woodfuel plantations provide 16 percent of their woodfuel demand or 13 percent of their total energy demand. In contrast, South African production has been dominated by industrial wood, with only 1 percent of their plantation production going to woodfuel in 1995 (FAO 2000); they made very little input to their woodfuel use (0.02 percent).

2.4 Have plantings for energy been successful?

Recent studies have concluded that there was mixed success with large-scale programmes designed to meet chronic rural woodfuel shortages. In Asia large-scale woodfuel plantations were established in India, China, Pakistan, Indonesia, Myanmar, Vietnam and South Korea. Many of these were planted under government programmes either by the state itself or as community programmes; their success has been mixed. Sudan, Ethiopia and Rwanda are African countries with relatively large areas of forest plantations used for woodfuel (FAO 2000) while Brasil, Peru, Uruguay, Cuba and Mexico are the main Latin America countries. Brazil is notable for its large area of industrial woodfuel plantations. However, in general, WEC (1999) concluded that large-scale plantations have been the least successful method of providing woodfuel.

Problems associated with past efforts have been:

- Woodfuel plantations sometimes ended up being used for more profitable purposes (e.g. in South Korea) and not for energy.
- Sometimes farmers became discouraged with tree planting because woodfuel has low market value. For example, some Indian farmers were encouraged to plant for industrial uses that never eventuated and subsequently firewood gave poor returns.
- Subsidies on prices of woodfuel from Government forests (e.g. in India) discouraged private tree planting (Saxena 1997).
- Using a ‘top-down’ approach, where ‘community participation’ involved experts telling the people what was planned.
- Lack of participation by local communities – the planting programme was ignored or in rarer cases was hindered.
- Ignoring social structural aspects such as, who has the power, who has the land, who has the need and who does the work.
- Projects failed to define and establish rights to the trees and procedures for allocating benefits. This led to indifference by the people being assisted.
- Not recognising that woodfuel is only one need among many. This led to incorrect choice of species and practices – often the focus was too narrow.
- Lack of adequate assistance and follow-up to ensure trees were correctly planted, tended and protected.
- Targeted areas associated with villages were not actually available because of encroachment or competition from other uses.
- Large-scale reforestation schemes, often on previous agricultural land, reduced grazing, food production and employment (Long and Nair 1999).

On the other hand planting on private farms was more successful (Long and Nair 1999).

3. PLANTING FOR WOODFUEL

3.1 *Woodfuel production trends*

FAO (2000) modelled three scenarios to study future trends in woodfuel plantations and a summary of these results, to 2020, is presented here (Table 3). All three only consider developing countries and assume that non-industrial use of wood is the same as woodfuel production. As they consider only stem volumes, the figures are probably conservative (FAO

2000). They do not take woodfuel derived from industrial plantations or agricultural tree crops like rubber or oil palm. Care is therefore needed in interpreting these results. It is also possible that some of these plantations might not be used for bioenergy, but go to other markets.

The key assumptions of the scenarios were:

Scenario 1: No expansion in planted area; replanting of harvested areas.
Scenario 2: New planting at a fixed annual rate of 1 percent of current forest area (plus replanting).
Scenario 3: New planting at current planting rates for the next 10 years, followed by a 20 percent decline each 10 year interval (plus replanting).

All three scenarios indicate there has been a sizeable increase in production from woodfuel plantations in the last five years (Tables 2, 3). This was because the estimates were based on trees already in the ground. Differences between the scenarios appear in 2010 and 2020, but in all cases, even where no new land is being planted (scenario 1), substantial increases in woodfuel production are predicted (Table 3). By year 2020 these increases are 190, 220 and 350 percent for scenarios 1, 2, 3, respectively. If the trends prove correct, this should help the expanding rural population in developing countries.

Asia and particularly India, dominate the scene (Tables 2, 3). The estimates suggest that India should account for about 45 percent of all the plantation woodfuel production in developing countries and it will have the greatest expansion in potentially available woodfuel from plantations. The situation is not so positive for Africa where, even under the optimistic scenario 3, the expansion in absolute terms is relatively small. Indeed for a few countries, e.g. Ethiopia, the prediction is that there will be a drop from current plantation woodfuel production over the next 10 to 20 years (Tables 2 and 3). A positive, modest expansion is predicted for Latin America.

On top of these potential production increases from non-industrial plantations, there will be increased possibilities to utilise wood wastes from factories based around industrial plantations; productivity of these plantations are predicted to expand rapidly (FAO 2000). The increase in woodfuel from this source between 1995 and 2020 for developing countries could be about half that predicted from non-industrial plantations (assuming medium scenario 2, with 20 to 25 percent of industrial roundwood volumes being used as fuel). The potential of the timber industry for energy production has been discussed in more detail by Gowen *et al.* (1994). They suggested that the biggest potential was in Asia and then Latin America, with more limited and concentrated options for Africa.

3.2 Planting systems

3.2.1 Forest plantations

The woodfuel production trends from ‘non-industrial plantations’, that are discussed above, cover plantations which may range in size from woodlots, grown by individuals or communities, to larger forests usually under government or industry management. At the smaller scale they can be appropriate for supplying local needs of urban people. Larger scale

Table 3: Projected production of plantation woodfuel between 2000 and 2020 under three scenarios* (from FAO 2000). Projections are given by region and for the largest producers in each region. The base year for projections was 1995.

Region and main countries	Woodfuel production $m^3 \times 10^6$		
	2000	2010	2020
Scenario 1 - Total	130.5	155.6	163.8
Africa	12.4	12.1	12.7
Ethiopia	1.4	1.2	1.2
Madagascar	1.3	1.2	1.3
Sudan	1.1	1.1	1.2
Asia + Oceania	94.4	119.7	118.3
China	13.1	25.4	23.4
India	62.4	73.7	72.6
Indonesia	4.5	3.2	4.0
Latin America	23.7	23.8	32.8
Brazil	15.0	13.2	21.0
Peru	1.7	2.0	1.8
Uruguay	1.8	2.0	2.7
Scenario 2 - Total	130.5	162.8	186.5
Africa	12.4	12.7	14.3
Ethiopia	1.4	1.3	1.3
Madagascar	1.3	1.2	1.5
Sudan	1.1	1.2	1.3
Asia + Oceania	94.4	125.5	136.2
China	13.1	26.6	27.2
India	62.4	77.6	84.1
Indonesia	4.5	3.3	4.5
Latin America	23.7	24.6	36.0
Brazil	15.0	13.7	22.8
Peru	1.7	2.0	2.1
Uruguay	1.8	2.1	3.0
Scenario 3 - Total	130.5	202.6	302.4
Africa	12.4	14.8	20.6
Ethiopia	1.4	1.4	1.6
Madagascar	1.3	1.3	1.7
Sudan	1.1	1.9	3.2
Asia + Oceania	94.4	160.2	234.8
China	13.1	36.7	56.7
India	62.4	97.0	137.7
Indonesia	4.5	4.7	8.2
Latin America	23.7	27.6	47.0
Brazil	15.0	14.4	25.1
Peru	1.7	2.3	3.6
Uruguay	1.8	2.7	5.9

Notes: see table 2.
* Scenario 1 – replant current areas; Scenario 2 – new annual planted area at 1 percent of current area; Scenario 3 – for 10 years new planted area at same as recent years, followed by a gradual decline

plantations are more appropriate for supplying wood for charcoal or small-scale industries (e.g. bakeries, brick, potteries) or for use in woodfuel-based power stations or perhaps conversion to liquid fuels.

Industrial plantations offer considerable potential to supply wood wastes to the woodfuel markets or for use in co-generation activities (Gowen, *et al*. 1994; WEC 1999). Further, better management of these forests, with participation of local peoples, offers good near-term prospects of increasing the supply of woodfuel (WEC 1999). This could entail greater utilisation of thinning, pruning or clearfelling slash. Alternatively, as is being done in Scandinavia and Europe, this latter material might be mechanically collected and used in centralised energy plants.

3.2.2 Systems outside forests

There are a wide variety of agroforestry, farm forestry or urban systems where trees are planted in non-forest conditions (Long and Nair 1999). With agroforestry and farm forestry, the general objective is to integrate tree growing with agricultural or fish production. As farmers and communities seldom plant for woodfuel as a primary goal, even where it is in short supply, agroforestry systems and the use of multipurpose trees (trees that provide a range of benefits) are often appropriate (Nair 1993, 1989). Rich farmers may use intensive silviculture which aim for maximum profit from their investment – it is unlikely that the highest value will be as woodfuel. Resource-poor farmers are more likely to want to use low-input approaches aiming for small, yet attractive, returns with minimum investment. It is often best to promote multiple-purpose tree species that have benefits other than fuel.

A wide variety of agroforestry systems are found in developing countries and their occurrence is often site specific (Long and Nair 1999; Nair 1993). Systems are characterised by environment, plant species and their arrangement, management and socio-economic functioning. Nair (1993) identified 18 different practices within the three main agroforestry systems:

- *Agrisilvicultural systems* – crops plus trees. These range from improved fallow to taungya, alley cropping, homegardens, shelterbelts etc.
- *Silvopastoral systems* – trees plus pastures and/or animals. They can include widely spaced trees over pastures and living fences to using trees as protein banks.
- *Agrosilvopastoral systems* – trees plus crops plus pastures and/or animals. This includes homegardens with animals, multipurpose woody hedgerows, woodlots and others.

As with agroforestry systems urban forests and tree planting have many forms and functions (Long and Nair 1999). Among these can be to provide significant quantities of woodfuel, either to individuals or to the wider community via municipal waste disposal facilities.

3.3 Species for energy

Useful criteria for selecting species for fuel-wood in developing countries are that they should be:

- Preferably coppicing hardwoods
- Adapt well to the site conditions

- Easy to establish and require minimum care, especially where the establishment is by farmers in agroforestry situations.
- Readily available as seed or plants
- Grow rapidly with early culmination of current annual increment
- Have nitrogen-fixing ability
- Produce high-calorific wood, which burns without sparks or toxic smoke, splits easily and dries quickly. Usually they are moderate to high-density species.
- Have resistance to goat and wildlife damage, unless grown also for fodder
- Multiple–use species.

Stem straightness is not a criterion *per se* for fuelwood especially for non-industrial users; nor is always desirable to grow large sized trees, as this can make manual handling difficult. There is a wide range of species that meet many of the above criteria (National Academy of Sciences 1980, 1983; Nair 1993). Some 1200 species have been identified of which 700 were highly ranked.

Good examples of tropical multiple-purpose species that make excellent woodfuel, for both plantations and outside forests, are given in table 4. Yields, given good sites without long dry seasons and careful management, can be high for some species such as some of the eucalypts and acacias. However, for arid regions without irrigation, productivity will be low. Many of the species suitable for these drier sites are either shrubs or small trees. Some potential species are aggressive pioneers and can become weeds (e.g. *Prosopis juliflora* and some acacias). Most of the species listed in table 4 are moderate to high density and have calorific values over 4000 Kcal/ kg. Often species used are those that have proved themselves and are sold as woodfuel in the area, rather than being newly introduced ones. Indeed some woodfuel plantings by state agencies in India have found difficulty in marketing exotics such as *Leucena, Casuarina and Eucalyptus* species.

3.4 Silvicultural aspects

Silviculture needs to be adapted to the situation, taking into account the species, biophysical aspects (climate, site, weeds) and social setting. For agroforestry-based plantings and small farmer woodlots, the actual silviculture should be simple and readily adopted by local people. The most important factors that need to be considered are species choice, seed or plant availability, perhaps local nursery production, spacing and layout, planting, initial weed control and animal control, if palatable. Big productivity gains can often be made if quality planting-stock are handled and planted carefully and subsequently kept weed-free in the early years. Subsequent management and biomass harvesting depends on the agroforestry system (Nair 1987, 1993).

Plantations or woodlots designed for energy usually use the coppice system, providing that the species sprout reliably. The coppice with standards is useful where there is a desire to provide some larger logs for construction or other purposes, as well as woodfuel.

With wood-fuel woodlots on farms, spacing often range from 1 to 3 m, planted on a square pattern. Closer spacing generally will produce the largest biomass of small piece size in the shortest possible time; wider spacings have the ability to produce larger piece size and will give more flexibility with rotation length without risking suppression of some stools. Wider spacings also allow for some crops or animal grazing beneath and may be more suited to arid

Table 4: Useful woodfuel species for tropical developing countries (based on National Academy of Sciences 1980, 1983, Nair 1993, FAO 2000, FFRD, 1994).

Species	Zone	Use*	Yield m^3/ha/yr	Energy kcal/kg	Other major Uses**
Acacia auriculiformis	Humid	Pl, AF	6.5-10-20	4600-4800	Pw, C, Sc, Ta, Or, Nf
Acacia decurrens	Highland /subtrop.	Pl, AF	6–20	3500-3900	T, C, Ta
Acacia mangium	Humid	Pl, AF	8-19–40+	4800-4900	Pw, T, C, Nf, Sb
Acacia mearnsii	Highland/subtrop.	Pl, AF	10-25	4700-7800	Ta, C, Gm, Pw, Nf
Acacia nilotica	Arid/semi-arid	AF	5	4800-4950	T, G, B, Fo, Ta
Acacia saligna	Arid/semi-arid	AF	1-10		Sc, G, Fo
Acacia senegal	Arid/semi-arid	AF	4–7	3200	T, C, G, F, Nf, B, Sc
Acacia tortilis	Arid/semi-arid	AF		4400	T, C, Sc, Fo, B
Albizia lebbek	Arid/semi-arid	Af	5	5200	T, Or, Fo, Sc, B
Alnus nepalensis	Highland	AF		4600	T, C, Fo, Sc, Nf
Calliandra calothyrsus	Humid	Pl, AF	5–20	4500-4750	Pw, C, Fo, B, Sc, Nf
Casuarina equisetifolia	Humid	Pl, Af	6–18	4800-4950	T, C, Pw, Sc, Ta, Nf
Dalbergia sissoo	Humid	Pl, Af	3–5–8	4900-5200	T, C, Sc, Or, Nf
Derris indica	Arid/semiarid	Af		4600	T, O, Fo, P, Sc, Fi
Eucalyptus camaldulensis	Arid/semiarid	Pl, Af	15-25	4800	T, C, B, Pw
Eucalyptus grandis	Humid	Pl	24-55	4700-4800	T, Pw, C, B
Eucalyptus globulus	Sub-tropics	Pl	10-30	4800	T, C, Pw, B, O
Gliricidia sepium	Humid	Pl, Af	10-15	4700-4900	T, C, Fo, Gm B, Or, Nf
Gmelina arborea	Humid	Pl	12-19-30+	4800	T, Pw, C, B
Grevillia robusta	Highland/subtrop.	Pl, Af	10-15		T, C, Or, B
Leucaena leucocephala	Humid	Pl, Af	20-40	4200-4600	T, Fo, Gm, Sc, F, Nf
Mangroves	Humid	Pl, Af		4000-4300	T, C, Sc, Pw, Ta
Melia azedarach	Highland	Af	5-10	4600-5200	T, Sc, P, Fo, Or
Mimosa scabrella	Humid	Pl, Af			Pw, Gm, Nf
Paraserianthes falcataria	Humid	Pl, Af	20-40	2900-3400	Pw, C, T
Pinus caribaea	Humid	Pl	10-40	4200	Pw, T
Prosopis sp.	Arid/semi-arid	Af	2-9	~5000	T, C, B, Fo, Sc, Nf
Terminalia catappa	Humid	Af			Pw, T, Ta, Sc, F
Ziziphus mauritiana	Arid/semi-arid	Af		4900	T, C, Fo, Ta
Ziziphus spina-christi	Arid/semi-arid	Af			T, Fo, Sc

* Pl – plantation and woodlots; Af - agroforestry
** B – bees; C – good charcoal; G – gum; Gm – green manure; F – food; Fo – fodder; Nf - nitrogen fixing; O –oil; Or – ornamental; P – pest control; Pw – pulpwood; Sc – soil conservation; T – timber; Ta - tannin

regions. Occasionally irrigation is a possibility in some drier areas and if used along with weed control, will increase productivity substantially. Rotation length will vary with site and species and with coppicing species is related to ensuring stools are not suppressed. Typically rotation lengths range from 3 to 15 years.

For larger scale industrial plantings more intensive silviculture may be possible, provided it is economic. For example, for eucalypts it could follow those used in pulpwood plantations and aim to produce uniform high-producing crops (Turnbull 1999).
Practices could include:

- Active seed selection and breeding programmes.
- The use of advanced nursery techniques, including clonal systems.
- Intensive establishment with practices such as soil cultivation, good chemical weed control and fertilisers at planting.
- Control of pests and diseases.
- Rotation lengths of 5-10 years.
- Mechanised harvesting which, where sustainability is a priority, will leave behind nutrient-rich parts of the biomass and concentrate removal of woody biomass.

Such advanced practices offer the possibility of increasing productivity substantially. There has been considerable research in northern temperate countries that have illustrated this possibility with closely planted willows, poplars and alders grown on very short rotations (Christensson *et al.* 1993; Makeschin 1999). In a few situations irrigation may be a possibility, such as where waste water from sewage treatment plants is available.

3.5 Social and environmental aspects

The problems that have arisen with woodfuel planting in the past, as discussed in section 2.4, suggest that to be successful greater attention needs to be given to social aspects. This is needed at all levels from policy development down to actual implementation of a programme (WEC 1999). In particular, biomass based rural energy development needs:

- Strong political commitment by government with clear energy policies
- People at the heart of planning and implementation
- Programmes that have a bottom-up approach and take account of social structures.
- Clearly defined responsibilities
- Integration with other needs and activities (e.g. agriculture, education, infrastructure) and methods of improving energy-use efficiency.

The economics of growing trees for woodfuel production are often clouded because it must compete with the high proportion of woodfuel collected and marketed from public lands without payment. In India woodfuel prices have been artificially low because prices of woodfuel from government land have often been fixed or subsidised (Ahmed 1997; Saxena 1997; Long and Nair 1999). The use of multi-purpose trees in agroforestry systems acknowledges that planting solely for woodfuel is uneconomic. Many countries have used subsidies to encourage new tree planting, both in plantations and on farms.

Tree planting for woodfuel may have positive environmental outcomes. Ahmed (1997), for example, stated that 35 percent of the natural forests of India have been badly degraded by woodfuel collection and that the country’s forests are being exploited in excess of their regenerative capacity; there is often a lack of regeneration. Nutrient cycling may also be interfered with, if the pressure of collection is too great, and in extreme cases the forest is destroyed. The increased production coming from tree planting (Table 3) can therefore be seen in a positive light, particularly if the planting programme continues, even if at the present time these new plantations have not stemmed forest degradation. In Brazil legislation requires that charcoal be produced from plantations rather than taken from natural forests (Turnbull 1999). Increased tree planting may thus act as a conservation tool.

Another benefit of using sustainable woodfuel plantations is that they do not add to the increasing atmospheric carbon dioxide level. Hence their use are preferable to fossil fuels. Other possible added environmental benefits include land rehabilitation, erosion control and watershed maintenance.

On the negative side there been criticism around the choice of species (e.g. eucalypts) and the impacts of forest monocultures. Some of this criticism was really about social, rather than environmental factors (Turnbull 1999). Cannell (1999) in his review of the effects of monocultural plantations on water use, acidification, wildlife conservation, and carbon storage, suggested that these are usually relatively minor, or of concern in specific situations. The continual collection of leaves and twigs, both of which tend to be high in nutrients, and the long-term use of short-rotation coppice poses a real risk of nutrient depletion. This will be particularly acute on low fertility sites. Currently, for example, very many eucalypt plantations have sub-optimal nutrition and there are particular concerns with the removal of P, K, Ca, and Mg, even with normal harvesting (Turnbull 1999). Returning the ash to the forest would assist. The use of N-fixing species, while important for the N status of the site, does not help the availability of other nutrients.

4. CONCLUSIONS

Current production of woodfuel from plantations makes only a small contribution to energy requirements, although it is very important in some localities and countries. Plantations currently supply 5 percent of woodfuel production and woodfuel are about 15 percent of total energy used in developing countries. In practice woodfuel is a residue and by-product system, as it includes leaves, twigs, branches as well as stems of both trees planted for industrial and non-industrial purposes, plus industrial wood waste. Woodfuel is only part of a larger bio-energy system that includes agrofuels and municipal by-products.

About a third of plantations in developing countries are devoted to non-industrial uses, mainly woodfuel. The bulk of these are in Asia. Production from these plantations are likely to double over the next 20 years, even with little expansion in area. In addition there will be increased woodfuel by-products coming from wood using industries. The situation is less positive in Africa; a few countries actually have projected declines in plantation-based woodfuel production.

Traditional plantations have been the least successful method of supplying bio-energy to the rural households. Agroforestry systems, which can include woodlots on farms or communal lands, have proved more useful because they integrate closer to the needs of the people. Multipurpose trees, for example, are able to produce a range of needed benefits, of which woodfuel is but one. Nevertheless, there are examples where the traditional plantations have been very successful, such as when providing charcoal to local industries or fuel to power plants.

Rural energy plantation programmes have suffered from a number of failures. Many failures have resulted from not appreciating of the complexities of bioenergy supply and demand, of not taking into account social aspects and people's needs, as well as poor programme structures. Occasionally market factors have also led to poor outcomes for woodfuel. Many of these could be overcome by more careful development of policies, by making local people the centre of planning and implementation, and by careful integration with other sectors and methods of providing bio-energy.

The environmental outcomes from planting trees for woodfuel should usually be positive or have minimal effects. Nutrient depletion from collection of leaves, twigs etc. or long-term coppicing, poses a risk, particularly on lower fertility soils. Planting nitrogen-fixing trees helps maintain the nitrogen status of the site.

In general hardwood species have greatest potential for woodfuel and they should preferably coppice readily, have nitrogen-fixing ability and be multi-purpose species. The fuels they provide also need to be easy to handle and dry, have a high calorific value and burn without toxic smoke or sparks. Many species, from shrubs to larger trees, fit these requirements. Actual selection depends on what can be grown easily on the site and being acceptable by the users. In agroforestry situations silviculture will tend to be simple and adapted to the skills and resources of the rural people. Care in the establishment phase is very important. Industrial users should be able to adopt more intensive silviculture.

REFERENCES

Ahmed, M.F. 1997. *In-depth country study – India.* FAO/APFSOS working paper 26. Also available at: www.fao.org/forestry/fon/fons/outlook/asia/apfsos/26/Apfsos26.htm

APCC (Asian and Pacific Coconut Community) 1998. Coconut Statistical Yearbook 1997, Jakarta.

Bhattarai, T.N. 1998. Wood energy resources in RWEDP member countries. Annex 7, pp 84-89 *In Wood energy and forest education.* Expert consultation on the integration of wood energy into training curricula of forestry education. Cha-am Thailand, June 1998. Field document 56, FAO/RWEDP.

Cannell, M.G.R. 1999. Environmental impacts of forest monocultures: water use, acidification, wildlife conservation, and carbon storage. *New Forests* 17: 239-262.

Christensson, L., Sennerby-Forsse, L. & Zsuffa, L. 1993. The role and significance of woody biomass plantations in Swedish Agriculture. *Forestry Chronicle* 69: 687-693.

FAO 2000. *The global outlook for future wood supplies from forest plantations.* By C. Brown. FAO Working Paper GFPOS/WP/03. FAO, Rome, Italy. 129pp.

Foley, G. 1986. *Charcoal making in developing countries.* Technical Report 5, Energy Information Programme, Earthscan, London, G.B.

FFRD 1994. *Species Fact Sheets. Module 9, Growing multipurpose trees on small farms* (2nd ed.). Forestry/ Fuelwood Research and Development Project, Bangkok, Thailand. Winrock International. 320 pp.

Gowen, M. M., Bentley, W.R. & Stijfhoorn, E. 1994. Tropical forest management and wood-based biomass energy as development assests. Pp 27-63 *In* Bentley, W.R. and Gowen, M.M. (eds.) *Forest resources and wood-based biomass energy as rural development assets.* Winrock International, USA and Oxford & IBH Publishing Co, New Delhi, India.

IRSG (International Rubber Study Group) 1997. *World Rubber Statistics Handbook*, Vol. 5, 1975-95. Wembley, United Kingdom.

IRSG (International Rubber Study Group) 1999. *Rubber Statistical Bulletin*, Vol. 53 (9). Wembley, United Kingdom.

Leach, G. & Mearus, R. 1988. *Beyond the woodfuel crisis: people, land and trees in Africa.* Earthscan, London, G.B.

Long, A.J. & Nair, P.K.R. 1999. Trees outside forests: agro-, community, and urban forestry. *New Forests* 17: 145-174.

Makeschin, F. 1999. Short rotation forestry in Central and Northern Europe – introduction and conclusions. *Forest Ecology and Management* 121: 1-7.

Mather, A.S. 1990. *Global Forest Resources.* Timber Press, London, G.B. 341pp.

Nair, P.K.R. 1987. Agroforestry and fuelwood production. Pp 367-386 *In* Hall, D.O. and Overend, R.P. (eds.) *Biomass.* John Wiley and Sons, Chichester, G.B.

Nair, P. K. R. 1989. Agroforestry for biomass energy / fuelwood production. Pp 59-97. *In* P. K. R. Nair (ed). *Agroforestry systems in the tropics.* Kluwer Academic Publishers, Dordrecht, Netherlands.

Nair, P. K. R. 1993. *An introduction to agroforestry.* Kluwer Academic Publishers, Dordrecht, Netherlands.

National Academy of Sciences 1980. *Firewood crops.* National Academy of Sciences, Washington, USA.

National Academy of Sciences 1983. *Firewood crops II*. National Academy of Sciences, Washington, USA.

Nogueira, L.A.H., Trossero, M.A., Couto, L. & Couto, L.C. 1998. Wood fuels for household consumption and industrial energy in relation to global fibre supplies. *Unasylva* Vol 49, 193: 51-56.

RWEDP 1997. *Review of wood energy data in RWEDP member countries.* FAO/RWEDP field document 47. 104pp.

Saxena, N.C. 1997. The woodfuel scenario and policy issues in India. FAO/RWEDP Field Document 49.

Turnbull, J.W. 1999. Eucalypt plantations. *New Forests* 17: 37-52.

Vergara, N. 1997. Wood materials from non-forest areas. Working paper FAO/APFSOS/WP/19. Also available at: www.fao.org/forestry/fon/fons/outlook/asia/apfsos/19/Apfsos19.htm

WEC (World Energy Council) 1999. *The challenge of rural energy poverty in developing countries.* FAO, World Energy Council, London, U.K.

FAO - Forestry Department
List of Working Papers on forest plantation: Thematic Paper Series

Working Paper FP/1:	*Mean Annual Volume Increment of Selected Industrial Species*. Ugalde L. and Perez O. April 2001.
Working Paper FP/2:	*Biological Sustainability of Productivity in Successive Rotations*. Evans J. March 2001.
Working Paper FP/3:	*Plantation Productivity*. Libby W.J. March 2001.
Working Paper FP/4:	*Promotion of Valuable Hardwood Plantations in the Tropics. A Global Overview*. Odoom F.K. March 2001.
Working Paper FP/5:	*Plantations and Wood Energy*. Mead D.J. March 2001.
Working Paper FP/6:	*Non-Forest Tree Plantations*. Killmann W. March 2001.
Working Paper FP/7:	*Role of Plantations as Substitutes for Natural Forests in Wood Supply – Lessons learned from the Asia-Pacific Region.* Waggener T. March 2001.
Working Paper FP/8:	*Financial and Other Incentives for Plantation Establishment*. Williams J. March 2001.
Working Paper FP/9:	*The Impact of Forest Policies and Legislation on Forest Plantations*. Perley C.J.K. March 2001.
Working Paper FP/10:	*Protecting Polantations from Pests and Diseases*. Ciesla W.M. March 2001.
Working Paper FP/11:	*Forestry Out-Grower Schemes: A Global View*. Race D. and Desmond H. March 2001.
Working Paper FP/12:	*Plantations and Greenhouse Gas Mitigation: A Short Review*. Moura-Costa P. and Aukland L. March 2001.
Working Paper FP/13:	*Future Production from Forest Plantations*. Brown C. March 2001.