Journal of Scientific & Industrial Research
Vol. 70, August 2011, pp. 577-582

Potential for rainfed woody biomass production for energy conversion in drought and salinity affected areas of Northern India

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Received 04 May 2011; revised 10 May 2011; accepted 11May 2011

This paper presents production of woody biomass using waste or saline water for irrigation and rainfed biomass production on land with low food crop potential. Woody biomass can be harvested sustainably from indigenous or naturalised vegetation, existing stands can be improved or tree plantations can be established, matching appropriate species to prevailing conditions. Rainfed productivity of woody species in dry areas is limited by soil salinity and water availability and assumptions on biomass productivity and land areas required for energy conversion should be based on yield estimates realistic for local soil and climate, which can be very low. Development of woody biomass production in rural communities needs to be cost effective, have good institutional support and governance, and comprise appropriate technologies and approaches. Woody biomass production potentially raises the issue of competition over land resources with other users and uses of wasteland. Some woody biomass species may also have adverse impacts on biodiversity.

Keywords: Energy conversion, Rainfed woody biomass production, Saline water

Introduction

One and a half billion people in developing countries derive more than 90% of their energy requirements from wood and charcoal, another billion or so meet around 50% from these sources[1]. Woody biomass (WB) is a renewable resource and close to carbon neutral if replanted or regenerated. As a biomass resource, trees and shrubs are perennial, deep rooted, often tolerant to adverse soil and climatic conditions, and generally require low input and management. WB can be harvested sustainably from indigenous or naturalised vegetation growing on extensive wastelands, existing stands can be improved or tree plantations can be established using low cost equipment and interventions, and matching appropriate species to the prevailing conditions. WB may be used for direct combustion, pre-processed as briquettes or charcoal, or used in more complex systems of pyrolysis or gasification involving internal or external combustion engines. This paper highlights potential rainfed production of WB in areas of low rainfall or with high levels of soil salinity.

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Woody Biomass (WB) Production

Species Selection for Plantation

Biomass species for energy production should ideally to be resistant to browsing, nitrogen fixing, coppicing, fast growing and produce wood of high calorific value. Such species need to survive and thrive under adverse abiotic conditions; perennial deep-rooted plants are able to be tolerant of poor soils, low rainfall, and generally require low management input. Tree species with potential of producing large volumes of straight branches and trunks are regarded as important fuel sources for local populations[2]. WB species used in farm forestry and agroforestry systems[3] are characterised by being multi-purpose, easy for coppicing and often nitrogen fixing. Coote[4] suggests that vital factors for trees as an energy source are biomass growth rate, calorific value of wood, suitability of species to local climate, competition of land for other uses, and extent of local expertise. In terms of calorific value, little difference is reported between species or between trees and shrubs[5]. A study of 22 commonly used tree species showed that three quarters had calorific values between 14-19 MJ kg^{-1} of oven-dry wood[6]. Twigs, branches, roots, shrubs, climbers and brushwood are more important sources of woodfuel than cut logs which involve felling trees, and several species provide these resources[5]. Although cutting trees for fuel

Table 1—Fuelwood species used by households in village Sar, Rajasthan 1998-99[15]

Species	Estimated use, t	As fuelwood, %	Household users, %
Prosopis juliflora	905.7	68.6	100
P. cineraria	375.7	28.5	83
Acacia senegal	5.8	0.4	44
Capparis decidua	12.2	0.9	39
Zizyphus nummularia	2.2	0.2	37
Salvadora oleoides	4.4	0.3	17
Tecomella undulata	6.6	0.5	11
Azadirachta indica	7.6	0.6	10

can cause deforestation, for rural communities, only 12% of fuelwood came from logs that involved the felling of trees, and 88% was from the cutting of branches[7].

Biomass from Natural Stands

Methods for converting natural woody stands to biomass production systems have been evaluated with *Prosopis glandulosa* in USA[8]. Conversion requires mainly thinning, pruning and treatment of understory. Following initial systematic thinning to a stand density of 500-1000 trees ha^{-1}, a secondary selective thinning is required to create desired final density of 100-625 trees ha^{-1} or less. Selected trees are then pruned to improve form. Stands can also be improved by grafting thornless high yielding varieties of *Prosopis* onto wild rootstocks[9].

Much of domestic fuelwood use in rural India is sourced from indigenous or naturalised stands. In India, a household study[5,10] on fuelwood in 1985 found that dominant sources of fuelwood were 26% each from forests and own farms, 17% from roadside collections and other sources including neighbours' farms, and the rest purchased. According to a National Sample Survey[11], private homegardens and trees around houses contribute 30 Mt of fuelwood annually. Village commons and degraded land are also important sources of WB. A study of 12 semi-arid districts of rural India showed that 66-88% of total domestic fuel needs of marginal farmers (with < 2 ha land) and landless poor were derived from village commons, and 8-32% of large farmers also obtained their domestic fuel from village commons[12]. Two multi-village studies indicated that thin tree branches were the main type of fuelwood gathered as larger branches have a market value and are sold[13,14]. A study of fuel use in an arid village in Rajasthan[15] showed that 356 households used 1320 t of fuel in one year, more than two thirds of it coming from *P. juliflora*, widely naturalised on wastelands (Table 1).

Limits to Biomass Production

Assuming suitable soil and climate, under rainfed conditions, total rainfall and its annual distribution are factors limiting biomass production. Where soil salinity is the limiting factor, physiological stress tolerance of trees becomes the overriding control of productivity. There are many salt tolerant woody species[1] (*Prosopis*, *Eucalyptus*, *Casuarina*, *Rhizophora*, *Melaleuca*, *Tamarix* and *Acacia*). Some key levels of salinity and salinity required to reduce crop and tree growth by 50% are as follows: Good quality irrigation water[1], 0-1; Marginal to poor irrigation water[1], 1-4; Limit recommended for potable water[16], 3; Saline crop production in Negev Desert[17], 4-7; 50% reduction in yield of barley[18], 14.8; 50% reduction in yield of *Eucalyptus microtheca*[18], 27.9; 50% reduction in yield of *Prosopis juliflora*[18], 35.3; 50% reduction in yield of *Atriplex nummularia*[18], 38.0; and Seawater[1], 46 dS m^{-1}.

Crop water productivity[19], often described as water use efficiency (WUE), expressed as the amount of water used by plants to produce a unit of dry matter, sets a theoretical maximum to biomass productivity in arid areas. Polster[20] reported values of 169 to 344 kg H_2O per kg of biomass for a range of tree species, while Cernusak *et al*[21] reported values of 938 for *Tectona grandis* (teak) and 375 for *Platymiscium pinnatum.* Felker *et al*[22] reviewed WUE values for a range of annual and perennial species and used 579-935 kg H_2O per kg of biomass in their calculations of productivity of *Prosopis* sp. in semi-arid ecosystems. This is reflected in low biomass production values for wastelands and forests assumed in the Biomass Resource Atlas of India (BRAI)[23]. Theoretical biomass production in Rajasthan with 300 mm annual rainfall, even with 100% rainfall use, with a WUE of 500 kg H_2O per kg biomass would be 6 t ha^{-1} y^{-1}, and would clearly be much less when evaporation and ground water recharge are taken into consideration.

Table 2— Land area, biomass generation from forests (dense forest, open forest, scrub forest) and wastelands, and potential power generation for four dry states of northwest India, 2000-2004[23]

State	Area kha		Biomass generation kt y^{-1}		Biomass surplus kt y^{-1}		Potential power MWe	
	Forest	Waste	Forest	Waste	Forest	Waste	Forest	Waste
Punjab	178	51	283	115	187	76	26	11
Haryana	51	244	59	335	39	221	5	31
Rajasthan	3160	10975	2839	6703	1874	4424	262	619
Gujarat	1302	7729	1520	10676	1073	7179	150	1005

Biomass production of wastelands, forests and crops in Rajasthan estimated by BRAI[23] are reported as follows: wastelands, 0.61; forests, 0.90; all crops - crop component, 1.04; all crops - residue, 1.92; wheat - crop component, 2.56; and wheat – residue, 1.80 t ha^{-1} y^{-1}.

Scaling up Biomass Use for Energy Conversion

Although wild harvesting of WB is already an extremely important source of fuelwood in dry areas of India, this remains a very significantly underutilised resource. Biomass generation from forests (dense, open and scrub forest) and wastelands estimated[23] to be surplus to current usage, and potential power generation are shown for four dry states of northwest India (Table 2). Harvested wood can be used for electricity generation by direct burning[24,25], carbonisation[26,27], gasification[28,29] or pulverisation[30]. Among highly suitable species for production of woody biomass, most important in dry areas is *Prosopis* sp., as it is already widespread on wastelands and depended on for fuelwood in arid zones. Because *Prosopis* is also seen as an invasive species, the best way to treat *Prosopis* is to manage it as a source for fodder and energy[31,32]. The Ministry of New and Renewable Energy Sources, Govt of India has sanctioned more than 30-40 projects on *P. juliflora* for generating electricity in Andra Pradesh, Tamil Nadu and Gujarat. Several small plants are in operation in northern India, producing 1-5 MW of electricity solely from *P. juliflora* biomass[25]. To generate 1 MW of electricity, Patel[24,33] observed that 6,169 t of fuelwood is required and for that, 300 ha area is required assuming a yield of 20 t ha^{-1} y^{-1} fuelwood. In USA, Felker[30] assumed a yield of 16 t ha^{-1} y^{-1} from *P. glandulosa* in calculating that a 500 MW generating facility could be fed with biomass from a farm with a 22 km radius. However, while high yields with *Prosopis* are reportedly attainable on good soils with adequate rainfall or irrigation (Kenya[34], 36; India[35], 11-20; Kenya[36], 6-12), Yields are usually lower (Sudan[37], 1.6; and Brazil[38], 1), and a yield of 0.6 t ha^{-1} y^{-1} is also reported for rainfed *Prosopis* growing on arid lands in India[39].

Socio-Economic and Environmental Implications of Using Wasteland for Woody Biomass (WB) Production

Consideration of socio-economic factors, when assessing potential for WB production on arid lands, including forest and wasteland, is very important especially if production is focussed at community rather than at industrial level. These issues include socio-economic conditions that drive increase in WB production, advantages and challenges of WB production, and factors required to scale up production. Key drivers for establishing plantations, as opposed to relying on native stands, include diminishing availability of indigenous timber, transport costs and logistics, and need for a constant fuel supply for specific activities[4]. In India, cost of wood production for fuel is cheaper than coal[40]; the former averages US$ 23 t^{-1} with an internal rate of return greater than 20%, and the latter US$ 40-75 t^{-1}. Some of the wider benefits of WB production have been identified as energy provision for rural areas, cost savings on synthetic fertiliser if using nitrogen fixing WB species, employment creation[41,42], carbon sequestration, and positive impact on land and water use[4]. In terms of employment, significantly more jobs are created if the production system is one of intensive biomass fuel production at a family level than if it is a more intensive one geared toward large scale energy forestry[43]. Although more challenging for rural communities to tap into the Clean Development Mechanism of the Kyoto Protocol may offer incentives for establishing energy plantations that sequester carbon. Having land under trees also helps to reduce or prevent soil erosion, supports rehabilitation of degraded and marginal land[42] and restores mining areas[44]. An overview of potential of biomass power for rural energy in India[43] described socio-economic benefits

emerging from community biomass projects funded by Indian Renewable Energy Development Agency Ltd (IREDA), New Delhi. These benefits include revenue generation, the emergence of small cooperatives for the supply and transportation of biomass, commercial establishments for trading in the byproducts, improved roads and bridges, improved local power, and entrepreneurial activities around machinery repair and supply provision. Some individuals have also taken up wasteland development for energy crop plantations. From $ 280 million invested in biomass power and co-generation projects up to 2007, around 87,000 jobs were created.

The major challenge of WB production is the issue of competition over land resources with other users and uses of this land. A socio-economic analysis of dendro power in Sri Lanka[4] confirmed that growing of short rotation coppice crops is a potentially viable activity for those farms and plantations with under-utilised land that is marginal for food crops, and particularly for those areas where rainfall is limiting and where there are large areas of scrub or degraded land. In the case of so-called scrub and wasteland however, land used for new WB plantations may already have an important community use such as livestock grazing or wild harvesting of resources[45]. Community-focused programmes for WB production at least afford the opportunity for communities to decide whether land proposed for development is of more importance to them for other usages such as food production. In the case of managed stands of *Prosopis* biomass, collection of *Prosopis* fuelwood in wild areas of Gujarat left thorny branches that reduced availability of grass for foraging by wild donkeys[46]. *Prosopis* can also have a negative impact on herbaceous diversity, owing to allelopathins in leaves that inhibit growth of other species[47], and on bird species in Gujarat ravines and wastelands[48,49].

Lack of secure tenure or ability to lease land for long periods, share cropping and other forms of tenancy have been assumed to inhibit tree growing. In Sri Lanka, lack of lease agreements with the Forestry Department led to limited interest by farmers in establishing woodlots as farmers were expected to plant trees without any legal assurance of tenure in a tree-planting scheme[45].

If a community managed biomass project is to supply a woodchip burner, then logistics may cause a challenge. Fuel chips have low density and the amount of space required for transport and storage of chips is more than that for coal and oil[3]. Consequently, distance from production areas and power plant should not be excessive. Further, there may be transport and economic challenges in collecting small quantities of wood from a large number of geographically dispersed and isolated farms.

The main barriers[40] facing expansion of bio-energy relate more to inadequate access for developers to promote setting up of small decentralised power units together with overall lack of a clear and consistent policy in promotion of different types of renewable energy. There is a need for clearer thinking on the levels of subsidies and state-level support that should be targeted on the renewable energy sector and at the same time better direction on defining the extent that each technology should be allowed to develop. The same area of wasteland is often targeted to develop wind farms, biomass plantations or *Jatropha* cultivation with no clear guidelines for apportioning available land for specific projects. Other challenges are the number of official clearances required for setting up projects, subsidies are re-introduced where market growth seems to be happening and are not required; subsidies are provided for unproven/untested/under-tested products and in general there is little public-private partnership. It has been recommended[40] that platforms be established at different levels to promote dialogue among energy consumers, entrepreneurs, and government agencies for promoting renewable energy development in an organised way.

At a farmer level, and as is the case with the introduction of any new crop or alternate method, there may be the need to overcome farmers' production inertia and their low level of willingness to change. For example, rural people in arid and semi-arid regions are apprehensive of some WB species such as *Prosopis* as they consider that the species adversely affects crop growth and production and are concerned that it may become a weed[50]. To counter this, demonstration projects and farmer-to-farmer exchanges may allow farmers to see for themselves the benefits of investing time into stand management[4]. Overall, and for community management, a participatory approach to development of any intervention is crucial in order to mitigate potential problems.

Conclusions

Dryland areas hold significant potential to produce WB on currently underutilised arid and semi-arid waste land. Fuelwood species need to be not only hardy to local agroclimatic conditions, but also be able to produce good

volumes of branches and trunks, to regrow rapidly after cutting, and ideally to have other uses for local populations. Particular species are recognised as highly suitable for the production of WB in arid areas of India and possibly the most important of these is *P. juliflora*. Rainfed productivity of woody species in dry areas is limited by soil salinity and water availability and assumptions on biomass productivity and land areas required for energy conversion should be based on yield estimates realistic for the local soil and climate, which can be very low. For rural communities, management approaches need to be low-cost. In the case of *Prosopis*, conversion of existing stands to managed systems may be the most appropriate, low-investment option. Development of WB production in rural communities is dependent on consideration of socio-economic factors. Any intervention needs to be cost effective, have good institutional support and governance, and comprise appropriate technologies and approaches. In terms of good governance, national policies in India are turning to the support of renewable energy development, although these appear to be focussed on private enterprise development and larger scale gasification programmes rather than provision of micro finance and support for smaller decentralised community power units. In particular, wasteland is being targeted for a broad range of schemes with little coordination or prioritisation. At the same time, there is little evidence that local communities are able to lead the development of appropriate biomass energy initiatives, and instead farmers are apprehensive about introduction of species that they have previously experienced as weedy pests.

Acknowledgement

Authors thank financial support under EPSRC, UK (grant reference EP/E044360/1).

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