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TRIGENERATION FOR SUSTAINABLE RURAL INDUSTRIALISATION

Padma Vasudevan Sen[1], P.K. Sen[2] and Phillip Davies[3]

[1]Centre for Rural Development and Technology
[2]Department of Applied Mechanics, Indian Institute of Technology, Delhi, India
[3]Aston University, Birmingham, U.K.

ABSTRACT

In countries like India, a large population resides in rural areas and depends on agriculture for subsistence. The land holding of majority of farmers, however, is of the order of 1-2 acres. They also face the problem of poor quality of soil and water and drought conditions. A significant percentage of this population must find employment in secondary and tertiary sectors, but this has to be achieved through structured transitions sustaining the people based on the local assets, rather than aim at quantum jumps which are not feasible. Energy is a key input for rural industrialization and this has to be derived from local resources for ensuring availability and accessibility to the people. Biomass, a renewable resource, is best suited for this since biomass production, conversion and utilization can be done locally with value addition for the benefit of small farmers. However, new technical inputs are needed for profitable exploitation of biomass within the constraints related to land, water and skill availability and provide higher quality of energy needed for the possible rural industries. This paper presents the concept of "Trigeneration with appropriate technologies for using the energy in micro enterprises". Specifically the boiler route and bio-oil route are considered. Such systems could form the basis of sustainable rural industrialization.

Keywords: Trigeneration, Rural industrialisation, Sustainable development

1. INTRODUCTION

Over the last two decades, it has become clear that development in terms of purely economic growth is not sustainable. Rather sustainable development has to be based on economic growth with social equity and conservation of environment. An additional dimension is conservation of human values and the ethical fabric of the society. All activities envisaged, especially rural industrialization, must be planned within this framework assessing technologies holistically on this basis. Many countries like India have registered high economic growth, but have inequitable distribution of wealth and employment opportunities. For example, in India about 60% of the families depend on agriculture and about 80% of them are small and marginal farmers with 1-2 acres of land. They also face the problem of degraded soil, poor quality of water and inadequate sources for irrigation. They barely subsist on their land, getting a small additional income by participating in labour oriented work in nearby towns. Clearly such a large chunk of population cannot be sustained on agricultural land and the solution lies in not only enhancing agricultural production but also providing employment opportunities in secondary and tertiary sectors. However, such a transition has to be well planned, setting up small industries preferably utilizing locally available materials and skill.

Biomass which is a renewable resource is traditionally used in villages essentially for heating and lighting. This resource has to be made useful for providing "higher forms" of energy which can support micro enterprises. This way benefits would reach directly to the small farmers because they will be involved in the production of biomass and utilize the same locally. A conceptual framework has been developed for generating "sustainable livelihoods" using locally accessible biomass such as agro-residue, weeds and biomass grown specifically in the form of energy plantation. The process of "trigeneration" is at the heart of this system. These issues are discussed in this paper.

Electricity from Biomass

Biomass is available in the rural areas in the following forms:

- Agro-residues – eg. straw, rice husk, groundnut shell
- Non-edible oils – eg. Karanj (*Pongamia pinnata*), Jatropha (*Jatropha curcas*)
- Weeds – eg. *Lantana camara*, *Ipomea fistulosa*

- Specially raised energy plantations: eg. Subabul (*Leucena leucocephala*)

Since most plant biomass (leaf, stem, wood etc.) is lignocellulosic, the energy content in this is in the range 4,000-5,000 kcal/kg depending on the source. In the case of vegetable oils, which are triglycerides of long chain fatty acids, the energy content is typically 8,000 kcal/kg. Energy thus stored in biomass can be released by burning and the heat generated can be used to produce electricity through the following pathways:

1. *The boiler route*: Combustion in a boiler for raising steam and running a back-pressure steam turbine for electric power generation. Subsequently, utilize the thermal energy of the exhaust steam for multifarious applications.
2. *The gasifier route*: Gasifying the biomass to obtain producer gas and using this to substitute diesel in internal combustion engines for generating electricity. Subsequently, utilize the thermal energy of the exhaust gases.
3. *The bio-oil route*: Use oils from seeds, neat (as such) or after tranesterification, in internal combustion engines for producing electricity. Again use the thermal energy of the exhaust gases.
4. *The biomethanation route*: Gases (like biogas with ~ 60% methane) may be produced by anaerobic digestion of soft biomass and used in micro turbines or engines or in thermal applications.

2. CONCEPT OF TRIGENERATION

In all these cases cited above, initially energy is released by burning of biomass and this is transformed into electricity. Generally the electric power generated is of the order of 10-30% of the total energy stored in the biomass. Thus if we focus only on electric power, a large percentage of the energy potential of the biomass is wasted as heat. The scheme developed by the authors envisages conversion of all chemical energy into thermal energy at high temperature. Some illustrative examples are shown in table 1.

Table 1: Energy utilization in micro enterprises

Activity	Heating/Steaming	Cooling	Electricity
Mushroom cultivation	Composting, pasteurization	Maintaining suitable temperature in mushroom hut	Running machinery
Water purification	Multi Effect distillation	-	Running feed water pump
Milk based	Pasteurization	Refrigeration for storage	Testing packaging and other machinery
Poultry farming	Composting hatchery	Storage of produce	Running machinery
Vegetable & fruits processing	Steaming cooking for jelly, jam, pickle etc.	Storage	Running machinery
Herbs	Room temperature drying steam extraction	Cooling storage	Juicers, grinder, running machinery

Part of the heat generated is converted into electric power and utilized, and the rest of the thermal energy is used for heating and cooling purposes in appropriately selected micro enterprises. When, along with electricity generation, heating and cooling applications are also combined the process is termed “trigeneration”. In this high efficiency can be achieved in the utilization of the stored energy in biomass, and, except for frictional losses in running moving parts, all the energy is utlised in some form or other.

The envisaged trigeneration systems are discussed below.

2.1 The Boiler Route

The system is shown schematically in figure 1. Generation of steam from agro-residues for running turbines to generate electricity at MW levels is already in practice in several industries. For example, the sugarcane industry extensively uses bagasse for co-generation. However, for typical village level consumption for sustaining micro enterprises, considering the energy load that can be absorbed, it would be expedient to have generation of power at the level of 100 kW or below. Scaling down to these levels is the most important task. One of the few companies which is able to supply boiler and steam turbine for this, is Industrial Boiler Ltd., India. In the system high pressure steam generated in a boiler at 20-25 bar gauge pressure is sent to a back pressure turbine. The output of electric power from the steam turbine is ~ 100 kW. The low (back) pressure steam (of the order of 1 bar gauge pressure) exhaust can be used in a variety of micro-enterprises, as illustrated in figure 1. Additionally as per need some steam at high pressure can be bled into a thermal vapour compressor system, combining it with low pressure steam from the turbine to produce steam at 3-5 bg pressure. This steam can be used to produce distilled water through a multi effect distillation unit [1], and, also for food processing industries. The co-generated steam at different pressures can be used for heating as well as cooling. Cooling and refrigeration can be done by phase change or sorption or desorption processes, e.g. by use of Lithium Bromide based, or carbon ammonia based, systems. The cooling system may be for air conditioning of cool rooms kept at 10-15^{o}C, or for refrigeration upto 0^{o}C, depending on the types of the cooling system. Steam can be used for heating purposes in drying, pasteurization, sterilization, cooking etc. typically useful in food processing. Roughly 1 kg biomass raises 3-4 kg steam. The water per hour requirement for 20% make-up water is 0.6 tons/hr in a 100 kW system, since circulating steam in the system is 3 tons per hour. The biomass required is 1 ton (1,000 kg)/hr.

2.2 The Bio-Oil Route

All vegetable oils are basically triglycerides of long chain fatty acids, whereas fossil fuels like diesel and petrol mostly consist of hydro carbons. If the bio-oils are to be converted to bio-diesel, one needs to go through a “transesterification” process [2]. This is necessary to run a mobile engine, like an automobile, although blending of ‘neat’ vegetable oil is also being tried. However, for a stationary engine, it has been shown that any raw bio oil, including kitchen waste oil after frying etc., can be used directly in a diesel engine [3], provided such oils are

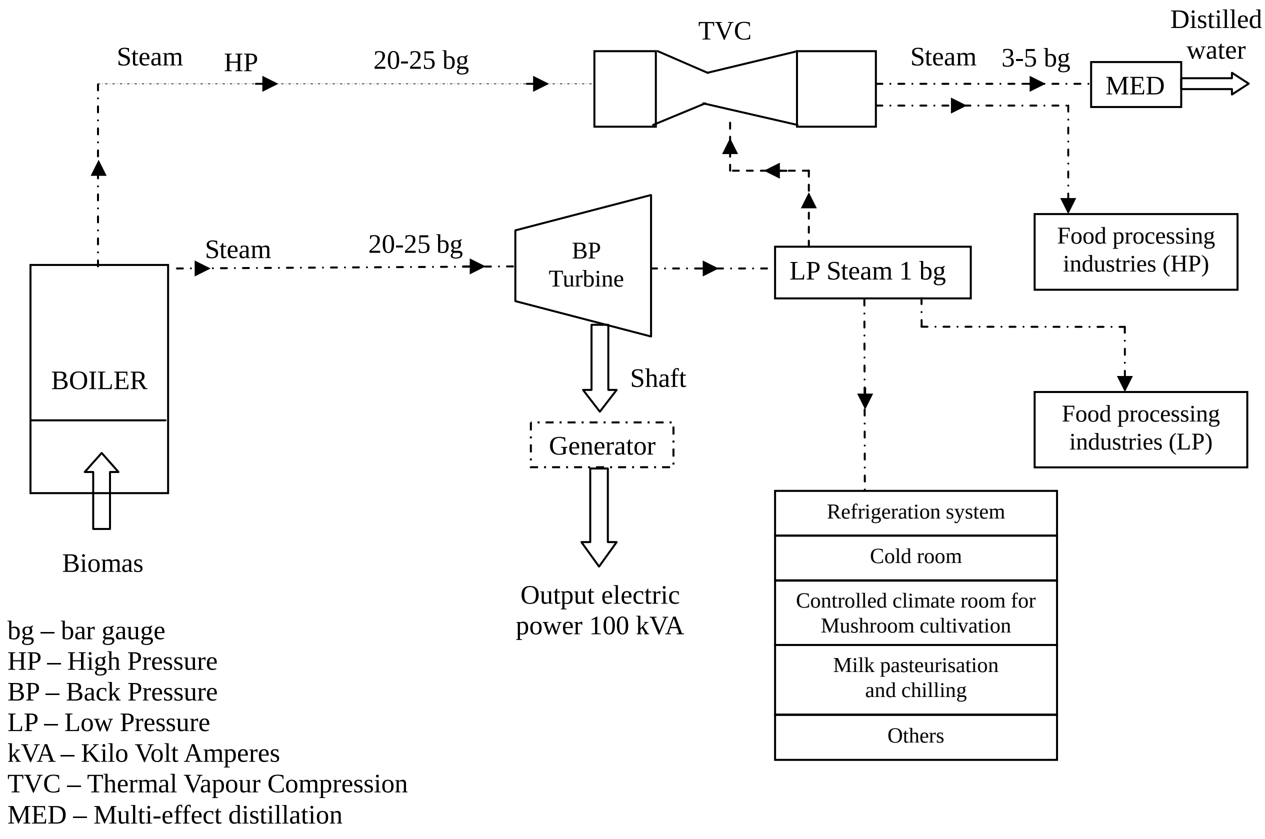

Fig 1: Trigeneration system based on steam production

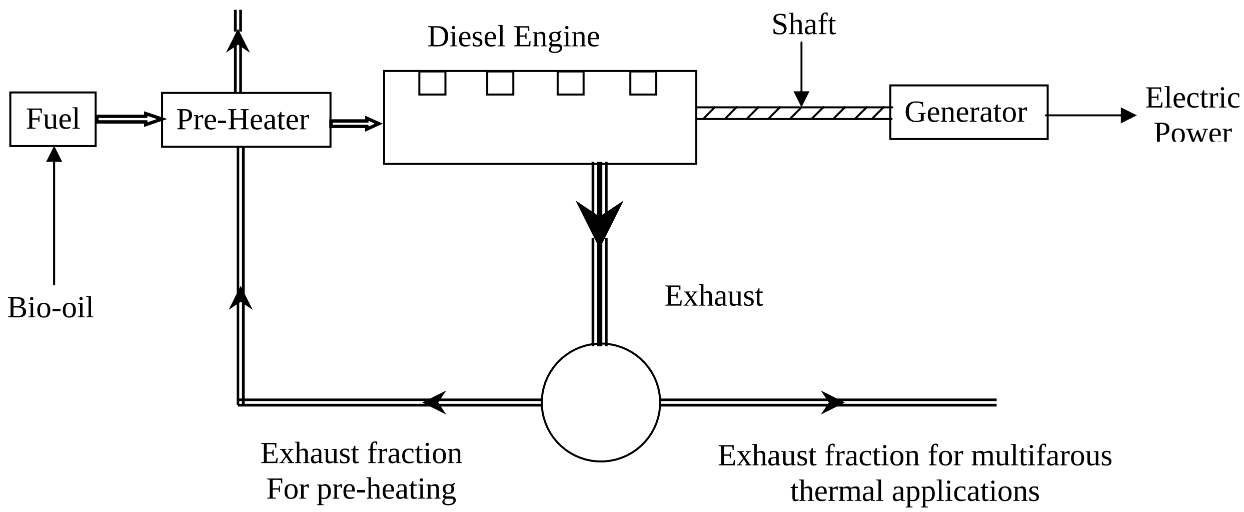

Fig 2: System based on bio-oil route

initially heated to about 160-170°C which reduces their viscosity. After heating, these oils can be used 'neat' in any conventional diesel engine. The initial heating of bio-oil can be done by diverting a fraction of the exhaust heat in an oil pre-heater. Thus, almost the entire exhaust heat energy is available for other uses, including refrigeration, or distillation, or heating applications. The system is shown schematically in fig. 2. A rough estimate is that a genset of 100 kW output of electric power would require a capital cost of Rs. 20.0 lakhs. It would use ~ 300 kg/day (10 hrs) of oil which works out to about 100 tons per year. This amount of oil would require 25-30 ha of land for seed production. It needs to be said in common, both for the bio-oil route and the gasifier route (described below), that, the final combustion of the fuel takes place in a diesel engine.

The characteristic of such internal combustion engines is that, out of the total chemical energy released

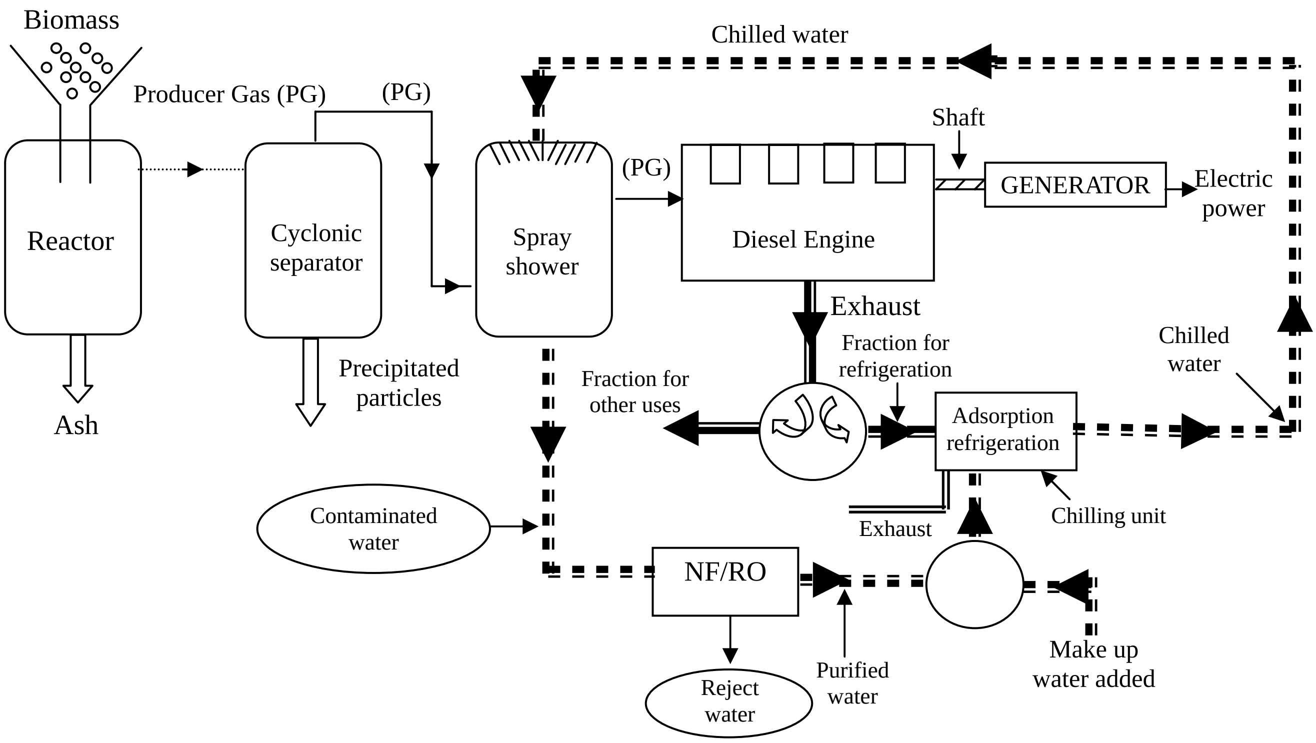

Fig 3: System based on gasifier route

from combustion of the fuel, roughly 1/3rd goes as shaft power, 1/3rd goes as frictional and other losses, and 1/3rd goes as energy lost in the exhaust gases. For example, if an engine is rated for 20 kW shaft power, then 20 kW is also available in the exhaust gases which are emitted at 400-500°C temperature. In fact it is the exhaust gases which can be utilized for cogeneration or trigeneration, for various applications, like making distilled water, or for raising steam with a view to heating or cooling as appropriate, for food processing, drying or refrigeration.

2.3 The Gasifier Route

This is shown schematically in fig. 3. Combustion, Gasification and Propulsion Laboratory (C.G.P.L.) in Indian Institute of Science, Bangalore, India have developed a highly efficient gasifier system. The first stage is the Reactor where gasification takes place, through a pyrolytic process like slow burning. CGPL has developed high quality reactors where the residual carbon and tar are relatively small in the Producer Gas formed. In the next stage the Producer Gas is taken to a Cyclonic Separator where most of the solid particles are precipitated. In the next, i.e. third stage, the gas is subjected to a cool water spray. Almost all the residual particles are then removed in the Producer Gas, which particles are now at ppb (parts per billion) levels. After this stage, the Producer Gas is ready for use straight in a diesel engine without mixing/blending with any additional fossil diesel fuel. The whole system requires two more ancillary units. Firstly, the dirty wash water, after scrubbing of the Producer Gas in the spray shower, is passed through a nano filtration unit, for recycling. (However some water is wasted for backwash of the nano filtration unit). The recycled water, along with some make up water added, is fed to the second ancillary unit, namely, a refrigeration unit for chilling. This refrigeration unit is based on an adsorption system working on energy derived from the exhaust heat.

The above system is efficient but quite elaborate. A 20 kW output electric energy system costs about Indian Rs. 20.0 lakhs and capital intensive. By comparison a diesel generator-set (genset) of the same rating costs 3-4 lakhs (20 kW diesel genset). However, gasifiers are viable at higher power ratings like 1 MW output energy and above. Such units are being manufactured and supplied by CGPL.

2.4 The Biomethanation Route

Where there is enough soft biowaste such as cowdung, the technology of biomethanation to produce biogas (about 60% methane + 40% carbon dioxide) by anaerobic digestion of the feed stock is already a well established technology. As for digestion of alternate feed stock from plants using soft biomass, such as twigs etc. and oil cakes, a number of institutions in India and elsewhere are working on this. Thus there is a possibility of furthering this technology provided the biogas can be produced in sufficient quantities and utilized appropriately. Use of biogas, for cooking, lighting and running diesel pumps for water lifting etc. is already known. The main problem is availability of biogas, which is restricted due to limited availability of feed stock and high investments needed on the anaerobic digester. Daily feed of 25-50 kg fresh cowdung is needed per 2 m^3 of biogas digester volume. It may be noted that besides 40% carbon dioxide, the biogas from the digester has some hydrogen sulphide and water vapour also.

2.5 Biomass Availability

For running the trigeneration system for energizing micro enterprises, sustained availability of biomass in adequate quality and quantity is a prerequisite. For this, the right kind of plant species have to be selected ensuring the right mix of soil, plant nutrition, water and other inputs, for sustainable production. Also biomass production for energy use has to be integrated with biomass production for food, fodder, timber and other applications. The yield potential of agricultural crops, different kinds of trees as well as weeds have to be looked into, to evaluate the amount of biomass which can be obtained from agri-horticultural, silvipastural and wasteland systems for energy generation. The seasonality in the production of different kinds of biomass need to be matched with the continual requirement of biomass for the trigeneration system on a day to day basis. In table 2 and 3 below an estimate of yields from some representive plants are listed. The actual yields would vary with soil, water and other inputs. Concept such as "Fertigation" which involves judicious use of wastewater (which has plant nutrients) for irrigation of energy plants are useful in enhancing biomass production.

Table 2: Crop residue yield of selected crop produce in India

Crop	Grain & seed Production (t/ha)	Agro residue percentage	Utilization of crop residue
Wheat [4]	2.7	Straw – 25%	Animal feed, hard board and paper industry, energy
Rice [4]	1.9	Straw 63%	Animal feed, packaging
		Husk 15-20% of paddy milled	Fuel, pulverized husk as cattle feed
		Bran 4-9% of paddy milled	Vegetable oil, bio-fuel, food and fodder
Jatropha [5]	0.7-4.0	Oil 30-40% Seed cake 10-15%	Bio- fuel Feed, manure, fuel, insecticidal properties

Table 3: Biomass yield of energy plantations of some multipurpose tree sp.

Genus	Yield (t/ha/yr)	Ref.
Eucalyptus	31.0-58.0	[6]
Populus	4.0 -19.0	[6]
Acacia nilotica	30.8	[7]
Leucaena leucocephala	40.6	[7]
S24 (5 years)	32.1	[8]
Coppiced S24 (Ist year)	26.7	[9]
Coppiced S24 (IInd year)	45.4	[9]
Coppiced S24 (IIIrd year)	38.1	[9]

Note: Controlled coppicing increases overall yields

3. CONCLUSIONS

Trigeneration can help in fully utilizing the energy stored in biomass. Already such systems are in operation for generating power of the order of several MW in industrial applications. The challenge lies in scaling down to power a rural industrial complex comprising micro enterprises. This has been conceptualized especially through the boiler and bio-oil route for electricity generation as described above.

4. ACKNOWLEDGEMENT

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5. REFERENCES

1. Sen, P.K., Sen, P.V., and Vyas, S.K., 2002, "Water Purification by Multi-Effect Distillation for Rural Drinking Water Supply", Proceedings of Second International (29th National) Conference on Fluid Mechanics and Fluid Power, IIT Roorkee, December, Vol. 2, pp. 982-990.
2. Vasudevan, P., Sharma, S. and Kumar, A., 2005, "Liquid fuels from biomass: An overview". J. of Sci. & Ind. Res., Vol. 64, Nov., 822-831.
3. Prof. Udipi Srinivasan, Centre for Sustainable Development and Department of Mechanical Engineering, I.I.Sc, Bangalore, udipi@mecheng.iisc.ernet.in; Private Communication, 2007.
4. Schiere, J.B., Joshi, A. L., Seetharam, A., 1995, "Feeding value of fibrous crop residues and their economic implications for crop production strategies. In: *Crop improvement and its impact on the feeding value of straw and stovers of grain cereal in India*". edt. By- Seetharam, A., Subba Rao, A. Schiere, J.B. Pub. by -ICAR. pp. 1-15.
5. Biswas, S., Kaushik, N. Srikanth, G., 2003, "*Biodiesel: Technology & Business Opportunities- An insight*". Technology Information, Forecast, Assessment Council (TIFAC).
6. Anderson, J.E., William, J., Kriedemann, P., Austin, M.P. and Farquhar, G.D., 1983, "Correlation between carbon isotope discrimination and climate of native habitats for diverse eucalypttaxa growing in a common garden", Aust. J. Plant Physiol., 23:311-320.
7. Gurumurthy, K., Bhandari, H.C. S. and Dhawan, H., 1986, "Studies on yield, nutrients and energy conversion efficiency in energy plantations of *Acacia nilotica*". J. of Tree Science. 5(1):36-42.
8. Pathak, P.S. and Gupta, V.K., 1994, "Evaluation of some new selections of *Leucaena leucocephalsa* on dry degraded lands". In (Singh, P., Pathak, P.S. and Roy, M.M. eds.) Agroforestry Systems for Degraded Lands 1: 302-307. Oxford and IBH Publ. Co. Ltd., New Delhi.
9. Pathak, S., 1999, "Growth, Productivity and energy dynamics of *Leucaena leucocephala* on degraded land in semi-arid India". Ph. D. Thesis. Bundelkhand University.