Carbon Sequestration and Fuel wood Assessment of Kahinure Plantation Forest in Rural Area of District Mau, Uttar Pradesh, India

SUMMARY
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Afforestation or forest plantation is one of the best strategies for the mitigation of global climate change. Role of forest ecosystem in the total balance of terrestrial carbon stock and its dynamics for mitigating climate change has highlighted the need for developing knowledge of different tree species for their carbon stocks that can act as a potential measure for mitigation of climate change. The most practical way to remove excess of CO_2 from atmosphere is storing of CO_2 into the physiological system of plants and finally to store in the soil as soil organic carbon stock. Therefore, there is no doubt that the forest act as a strong CO_2 sink and a cheaper mitigating option. Increase in afforestation or forest plantation rate may further be an incentive for sequestration of carbon and protection of natural forests from the degradation. Presently, the Plantation forests have small contribution in the total balancing of terrestrial ecosystem's carbon at both global and national level, but their contribution to store or absorb atmospheric carbon plays an important role for the future climate change mitigation.

The plantation forests are responsible for the productive and protective growth of plants. The protective plantations are predominantly intended for provision of various services such as protection of soil, rehabilitation of degraded land and carbon sequestration, whereas, the productive plantations are predominantly intended for the provisions of fuel wood, fibre, timber and non-wood products. Consumption of fuel wood is one of the most traditional activities which contribute to forest degradation in the event of people adopting an unsustainable use of forest for these activities. In fact, the demand for firewood is likely to continue to be the most important source of energy for rural areas in many countries. Wood-based energy has been viewed as a means to carbon emissions however it can be reduced, if biomass resources are consumed sustainably with efficient technology systems. Inefficiently burning of

firewood creates number of adverse consequences on health, social and economics. Improved cook stoves over commonly using tradition inefficient mud chulha have been disseminated as an alternative to reduce these impacts. Numbers of studies have been conducted on the consumption of biomass energy in India, but research on the strategies to be adopted for the fuel wood needs of the rural households focused to develop mass scale afforestation of suitable tree species to meet the energy demand is still limited. On the other hand, associated impacts due to the consumption of fuel wood and emission of CO_2 due to the burning of fuel wood without precise management are still a scare.

The present study was conducted in Kahinure plantation forest of district Mau, Uttar Pradesh, India to study the characterization of mix plantation forest for soil quality and carbon sequestration, fuel wood consumption pattern of Kahinure village and emission potential from firewood burning. The developments of energy efficient metal chulha for solid biomass fuel burning to cook food and evaluation of its performance have also been investigated. Very limited number of case studies is available on southeast Uttar Pradesh in India. Most of the literature available on these aspects mainly deals to Himalayan region. The study area adopted is untouched till the study was started.

Characterization of mix plantation forest for soil quality and carbon sequestration potential

Role of forest in soil organic carbon stock and there dynamics for mitigation of GHGs has highlighted the need for more knowledge on effect of tree species on soil organic carbon stock and other soil properties. Management of forest that include afforestation or forest plantation is acceptable measure for mitigation of atmospheric CO_2 in national greenhouse gases budgets. However, quantitative estimates of the

effect of tree species on the organic carbon stock of soil are still rare. In addition, the scientific basis for identifying more suitable tree species for better carbon sequestration is also limited to relatively few studies. Therefore, objective of this study was to study the impact of forest plantation on tree biomass and soil organic carbon stock and its comparison with non-forest areas (Waste land) in its surroundings, Inter relationship between different soil parameters at different soil depth and variability in carbon sequestration potential of different tree species in the plantation forest to evaluate tree species that have a better potential for carbon sequestration.

In the present study, soil in the plantation forest possessed higher soil organic carbon stock and other important soil fertility parameter than the adjacent non forest area (waste land) soil. However, with the increasing soil depth, these parameters decreased which increasing soil depth and bulk density in both plantation forest and waste land. The soil microbial biomass carbon (SMBC), soil enzyme activities like soil dehydrogenase activity, acidic and alkaline phosphates and soil respiration were higher in the plantation forest soil as compared to the waste land soil. Further, soil dehydrogenase activity was also higher in plantation forest soil. Therefore, conversion of degraded land or waste land under plantation cover is an important factor influencing the soil fertility related properties. Among the studied tree species, maximum carbon accumulation in different components (stem, branch, leaf) of certain species like *Prosopis juliflora, Putranjiva roxburghii, Pithecellobium dulce* and *Artocarpus heterophyllus* depict that these tree species can be recommended as atmospheric carbon reducers for their better potential to sequester and store carbon. The study indicated that afforestation or forest plantation enhanced SOC, nutrient stock and improved other soil properties as compared to non-forest soil i.e., waste

land. Biomass studies of the plantation forest stands revealed that the stand areas still have potential for re-growth and can be developed into good plantation forest if proper protection measures are taken. The participation of local communities in the management process can yielded better results than managing them without such participation. Among the studied tree species better atmospheric carbon reducer should be given priority in plantation drive in future for their role in long term climate change mitigation.

Fuel wood consumption pattern of Kahinure village and emission potential from fire wood burning

Fuel wood consumption is identified as the main source of energy in rural India for cooking purposes. Higher consumption of fuel wood is mainly due to lack of unconventional energy sources. In many developing countries fuel wood consumption is now one of the most important reasons for forest degradation. Shifting cultivation coupled with excessive deforestation for fuel wood has caused severe environmental degradation. In the present study, fuel wood consumption patterns of the plantation forest in rural area of Kahinure District Mau, Uttar Pradesh, India had been evaluated. A questionnaire survey of random sampling method was employed for 180 households to understand socio-economic conditions and energy consumption pattern for cooking purposes in the study area.

The study reveals that fuel wood was largely utilised as non-commercial and cheap source of energy, followed by dung cake and agriculture residue. About 65% of household's energy consumption was in the form of wood biomass fuel derived from the selected plantation forest. The cow dung was used by 22% households and agriculture residue by 12%. About 1.3% people used kerosene for cooking. Average cooking time was estimated at 4.46 h/day/family, and average value of fuel wood

consumption was estimated at 4.5 t/family/ year, whereas average market value of annual consumption of fuel wood had been calculated as Rs 8,700.00 per households. Due to poor socio-economic situations in the village, a significant amount of fixed carbon of plantation forest was used for cooking of food which could be saved by choose of enable tree species for future energy plantation and replacing the cooking method with alternative energy efficient cooking techniques.

Further, the present study investigate fuel wood characteristics on the basis of fuel wood value index (FVI), a proximate and ultimate analysis of 12 subtropical tree species to sort out the tree species commonly used by the rural communities and examine their energy properties. The FVI was determined on the basis of calorific value (CV), bulk density (BD), and ash content (AC). The highest CV was found in *Prosopis juliflora*, and the lowest CV was found in *Streblus asper*. The AC was found maximum in *Pithecellobium dulce* and minimum in *Streblus asper*. Moisture content was ranged between 38.70 and 58.67%. Investigation of elemental composition in fuel wood revealed that carbon, nitrogen, hydrogen (CHN), and sulfur value ranged from 40 to 46% C, 4.80 to 6.80% H, 0.03 to 1.40% N, and sulfur was defected only in some species and its maximum value (0.012) was found in species of *Tectona grandis*, *Terminalia arjuna*, and *Ficus benghalensis.* This study revealed that only the single basic parameter is not sufficient for identifying the suitable tree species for fuel wood. On the basis of FVI and other fuel wood properties species, *Prosopis juliflora, Tectona grandis, Ficus benghalensis, Alstonia scholaris,* and *Holopetelea integrifolia* are the most preferred fuel wood species among the 12 trees studied. To enable choice of plant species for future energy plantation program may help the local people to take maximum benefit to be used as bioenergy if electricity and alternative energy sources are not available in such remote areas.

In addition, the study elaborates the GHG emission rate and deforestation due to the burning of firewood by the rural households. The rate of CO_2 emission is directly proportional to consumption of fuel wood. However, efficient way of fuel wood combustion may reduce the rate of CO_2 emission. A traditional clay chulha commonly used in the study area for cooking that is thermally inefficient and a greater higher emission of smoke. Therefore, an effort should be made to reduce the emission as a result of fuel wood burning. This can be achieved by replacing the traditional cook stove with alternative energy-efficient improved cook stove that can reduce emission and better thermal performance.

Development of Improved metal chulha for low emission and better thermal efficiency

Biomass is one of the largest and important sources of fuel in domestic cooking of developing countries. Burning of biomass in the tradition cook stove is one of the widely used biomass based appliance from incanting time to till date. In India majority of the households living in a rural area depends on fuel wood, dung cake and crops residue to meet their domestic energy needs and these solid fuels accounts more than 80% of total fuel used for cooking purposes. Inefficient way of burning of solid biomass fuel releases large amount of air pollutants like CO, $PM_{2.5}$, PM_{10}, SO_X, and NO_X. Therefore, efficient way of combustion of biomass fuel reduce indoor emission with increases the thermal efficiency. In the present study we have developed an improved metal chulha over commonly available traditional mud chulha for rural households and evaluates the performance of a newly developed improved metal chulha (IMC) over available traditional mud chulha (TMC) as energy efficient non-smoking cooking appliance for the rural households.

An extensive survey of 90 respondents revealed that majority of the households use firewood for cooking in energy inefficient TMCs. The TMC emitted considerable amount of toxic component, which can adversely affects the human health on direct exposure. To overcome this problem, we have developed an IMC, which significantly reduces energy loss and cooking time compared to TMC. In this study, we have measured the level of airborne pollutants emitted from fuelwood used for cooking purpose. In addition to this, we have also studied the thermal efficiency of IMC over TMC. A major reduction of indoor pollutants viz. PM_{10} (45%), $PM_{2.5}$ (73%), CO (51%), SO_X (22%), NO_X (36%) was recorded for IMC over the TMC. The water boiling test also indicate higher thermal efficiency during all the three phases; cold start (37%), hot start (41%) and simmering test (46%) for IMC over TMC. The fuel consumption rate (g/min) was recorded23, 16.6, 14 and 32.2, 25.1 and 20.6 for IMC and TMC respectively. Compared with TMC the IMC reduced specific fuel wood consumption, increased efficiencies and lower emissions of pollutants including PM_{10}, $PM_{2.5}$, NO_X, SO_X and CO. A social survey in the form of a questionnaire revealed that majority of households realised that IMC will be better than the traditional mud chulha in terms of handling, reduced emissions, easier cooking and efficiency. Therefore, the present study suggests that adoption of improved metal chulha reduces the indoor emission and trace metals associated with coarser fraction of the particulate matter significantly and help carbon economic by saving considerable amounts of fuel wood with lower CO_2 emission. Further, knowledge should be imparting more about the use of IMC and its benefits for the reason that societies progress only if their people are healthy, and the government should launch programs on the basis of a different scheme for adaptation of energy efficient improved chulha for poor rural households.

The overall studies presented in this thesis provide some new insights in understanding the characterization of mix plantation forest for soil quality and carbon sequestration potential, Fuel wood consumption pattern of Kahinure village and emission potential from fire wood burning and development of improved metal chulha for reduction in indoor emission and better thermal efficiency. Following are the specific conclusions from the present study.

- The current study reveal that afforestation or forest plantation even in degraded or waste land can enhance soil organic carbon (SOC) stock and improve the soil fertility in addition to provide a good sink for atmospheric carbon sequestration. Soil from plantation forest showed higher concentration of SOC, soil nutrient, soil microbial biomass carbon and soil enzyme activity as compared with non-forest area i.e. Waste land, though it reduces with increase in soil depth in both forest and non-forest areas. Increase in soil microbial biomass carbon reflects an increase in soil microbial population which is essential for long term soil productivity and fertility.
- Variability in carbon percentage in different tree species and in their components showed that certain species such as *Prosopis juliflora*, *Putranjiva roxburghii, Pithecellobium dulce and Artocarpus heterophyllus*have more potential in sequestration of atmospheric carbon over the other tree species studied. Priority should be given to the selected species in the region for future plantation due to their potential as atmospheric carbon sink.
- According to the results of survey, fuelwood consumption varies significantly from season to season. Daily fuel wood consumption from the forest was higher in winter as compared to summer seasons. The higher consumption of fuelwood explains possible reason for deforestation and emission of

greenhouse gases. Further, the rate of CO_2 emission is directly proportional to consumption of fuel wood. However, efficient way of fuel wood combustion may reduce the rate of CO_2 emission and strongly recommended that mass scale afforestation program of suitable tree species for future energy plantation in the study region bridge the gap between demand and supply.

- To investigate fuel wood characteristics on the basis of fuel wood value index (FVI), a proximate and ultimate analysis to sort out the tree species commonly used by the rural communities and examine their energy properties. On the basis of energy analysis only the single basic parameter is not sufficient for identifying the suitable tree species for fuel wood. On the basis of fuel wood value index (FVI) and other fuel wood properties species *Prosopis juliflora, Tectona grandis, Ficus benghalensis, Alstonia scholaris* and *Holopetelea integrifolia*are the most preferred fuel wood species and attention should be given on such tree species for large scale energy plantation in future, especially in this region of Uttar Pradesh, India to fulfil the future demand of rural communities.
- After the extensive survey, it was found that the majority of the households use traditional mud chulha for cooking in this area, which is thermally and environmentally inefficient. To overcome this drawback we have designed improved cook stoves with apparent modification in the conventional chulhas for rural people in view of their health care, economic concerns and climate benefits.
- After the installation of improved metal chulha enhances the thermal efficiency with the reduction of specific amount of fuelwood consumption in

the present investigation. This further reduced the duration of time and the amount of fuel to prepare a particular amount of food.

- ❖ Therefore, the national level program must be implemented by the government and the nongovernment organization to introduce this type of improved metal chulha. The improved metal chulha is not only beneficial to health and the environment, but also indirectly responsible for deforestation and the deterioration of ecosystem.

Finally, from the present study it is concluded that plantation forest is an asset towards mitigating global climate change. Increase in carbon stock within the studied tree species and soil of the plantation forest depicts that plantation forest as an efficient carbon sequester. Since, rural India is dependent upon forest fuel wood for their energy requirements, development and management of energy efficient plantation forest like that of Kahinure plantation forest can minimize the anthropogenic pressure on natural forests. Development and inclusion of an energy efficient and eco-friendly chulha (i.e., improved metal chulha) over traditional chulhas which are commonly used in rural households can minimize indoor air pollution to a large extent. Also improved metal chulha is thermally efficient, as analysed for the use in rural areas of India.

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