# ENERGY PRODUCTION STUDIES OF A SIX YEAR OLD PLANTATION STAND OF *ACACIA AURICULIFORMIS* AT VARANASI

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## Introduction

The exponential growth of population and civilization exercise pressure on the limited land under green cover for meeting energy needs of mankind. This green cover acts as an important sink of the green house gas $CO_2$ and oxygenating system of the atmosphere. Ever increasing demand of energy is accelerating the consumption of natural biomass as energy sources. Over-exploitation is creating serious problems of floods, siltation, desertification and decrease in availability of energy rich biomass.

The forest biomass distribution and its estimation provides a basis for determination of energy flow (Turner and Cole, 1973). According to the Forest Survey of India Report 1995, only 11.5 per cent of the total land area has remained under cover of thick forest, which is far behind the target setup by the national forest policy. The country has only 2% forest area of the world but support 15% of the world population with the decreasing per capita forest area of 0.11 ha in 1991.

Uttar Pradesh has only 17.5% of the total geographical area of the State under forest cover. The official estimate (CFC, 1990) for Indian forest cover is around 74.8 million hectare (22.7% of the total land area). The National Remote Sensing Agency (NRSA) revealed degradation of forest cover over last twenty years (NRSA, 1984). This continuous reduction in the forest area is resulting in deterioration of the quality of the soil which in turn has led to the formation of wastelands.

Land use statistics place 305 million hectares of the land mass of India as usable land, of which 87 million hectares is lying unusable in the form of cultural waste and unproductive waste (Puri *et al.*, 1989). This unproductive land is liable to soil and water erosion. And so, the total demand on forests for fodder and fuelwood is far beyond the total capacity of the forests.

Wood has a high specific gravity and caloric value (Rierink, 1983). Biomass and caloric value when considered together provide a basis for categorization of trees for fuelwood.

To overcome the situation, countrywide reforestation of high-yielding species has been initiated to replace the low-yielding natural forest and to cope with the energy demand. For optimizing the productivity of fuelwood on successful selection and plantation of leguminous fast growing tree species (Brewbaker *et al.*, 1984).

Leguminous trees are potential source of fuel, hardwood and other uses which equals that of fast growing non-leguminous trees (Brewbaker *et al.*, 1982). The nitrogen fixing tree species are of particular interest due to their ability to support by $N_2$-fixation to raise the fertility and nutrient pool of poor or impoverished soil (Falker and Banduraski, 1979). For these reasons, woody legumes such as *Acacia auriculiformis* are receiving interest for energy generating agroforestry and reafforestation programmes.

Researches on energy plantation have been carried out by several workers (Saucier *et al.*, 1972; Schimidt and De Bell, 1973; Srivastava and Ambasht, 1995). Ribe (1974) has worked out the various advantages of such energy plantations.

## Material and Methods

*Energy Value Determination* : Biomass samples of different components collected at regular intervals were oven dried at 80°C for over 24 hours for energy estimation have been found to be most satisfactory (Paine, 1971). Plant material dried to constant weight were powdered and stored in plastic bags. About 0.6g of finally powdered plant material was pressed to make a pellet. The pellet was again dried at 80°C for 10-15 minutes, cooled and weighed. A fuse wire of 10cm length was bound around the pellet to suspend it inside the Parr oxygen bomb calorimeter (Lieth, 1975). The bomb was capped, filled with 10-15 atmospheric pressure of oxygen, and immersed in water (of known volume) contained in the calorimeter. The calorimeter lid was closed, and the pellet was electrically ignited while the water was continuously stirred. The rise in water temperature was noted. A correction factor of 2.3 cal $cm^{-1}$ of fuse wire was used.

Acid correction was estimated by assuming that all acid formed during combustion of organic compound was $HNO_3$, as the amount of sulphur in plant material was insignificant. About 5ml of water was poured into the bottom of the bomb before combustion and later when the pellet had burnt out the resultant solution was titrated against 0.07N Sodium carbonate. One ml titrate is equivalent to one calorie. The correction for acid was substracted from the calculated caloric value.

The calibration of calorimeter was done by the igniting known weight of benzoic acid. The water value of the calorimeter was calculated by the following formula (Anon., 1968) :

$$W = \frac{Hm + e_1 + e_2}{t}$$

where :

W = Water equivalent of the calorimeter (Cal $°C^{-1}$).

H = Heat of combustion of benzoic acid (6318 C $g^{-1}$)

m = Wt. Of benzoic acid pellet (g)

$e_1$ = Acid correction $HNO_3$ (C)

$e_2$ = Fuse wire correction (C)

t = Rise in temperature (°C)

The caloric value per gram (or the gross heat of combustion) of the dry plant material was calculated by using the formula given by Parr Instrument Company Manual 130 (Anon., 1968) :

$$Hg = \frac{tw - e_1 - e_2 - e_3}{m}$$

where :

Hg is gross heat of combustion,

$t$ is rise in temperature.

$w$ is water equivalent of the bomb,

$e_1$ is fuse wire correction (C )

$e_2$, $e_3$ is acid correction (C), and

$m$ is the weight of pellet (g)

Samples of plant component parts were burnt in replicates for energy value determination by using above mentioned method. For each diameter class sample harvested tree, the mean caloric value of a particular component was estimated (Table 1). The component energy content was obtained by taking the product of mean energy value and component dry weight. Individual sample tree energy content was obtained by adding the components energy contents (Table 2).

*Computation of Stand Caloric Content* : In all eleven trees were harvested. Component caloric contents of all the harvested samples trees were calculated from component dry weight values representing each diameter class. Thus, caloric contents in different components of all the eleven harvested sample trees were calculated, multiple linear regression equation was developed for each component from data of the harvested sample trees, taking component biomass ($x_1$) and energy ($x_2$) value as independent variables and energy content as dependent variable (y). The total energy content of individual tree component of the census plot was then obtained by the following regression equation :

$$Y = a + b_1 x_1 + b_2 x_2$$

where :

Y = energy content;

$x_1$ = biomass

**Table 1**

*Caloric value (cal $g^{-1}$) of components parts of the harvested sample trees of different diameter classes*

| Tree No. | dbh | Bole | Branch | Phyllode | Root |
|---|---|---|---|---|---|
| 1. | 4.20 | 4706 ± 224 | 4654 ± 98 | 4762 ± 144 | 4495 ± 172 |
| 2. | 4.84 | 4752 ± 165 | 4620 ± 126 | 4816 ± 135 | 4512 ± 208 |
| 3. | 5.19 | 4810 ± 98 | 4749 ± 160 | 4735 ± 111 | 4536 ± 126 |
| 4. | 5.80 | 4805 ± 82 | 4791 ± 148 | 4628 ± 124 | 4558 ± 146 |
| 5. | 5.99 | 4650 ± 122 | 4712 ± 135 | 4617 ± 162 | 4526 ± 94 |
| 6. | 7.49 | 4430 ± 236 | 4648 ± 195 | 4760 ± 98 | 4530 ± 117 |
| 7. | 8.16 | 4667 ± 132 | 4827 ± 125 | 4744 ± 126 | 4562 ± 165 |
| 8. | 9.98 | 4296 ± 209 | 4762 ± 182 | 4875 ± 204 | 4575 ± 128 |
| 9. | 12.34 | 4782 ± 163 | 4864 ± 97 | 4872 ± 159 | 4632 ± 155 |
| 10. | 14.19 | 4376 ± 142 | 4854 ± 137 | 4723 ± 124 | 4597 ± 144 |
| 11. | 15.42 | 4562 ± 118 | 4862 ± 128 | 4865 ± 182 | 4635 ± 184 |

(Values of mean ± standard error).

$x_2$ = energy value,
a and b = constant for a given component.

The standard error of Y, the dependent variable, was estimated for each of the multiple regressions of components. The relationship of the actual and predicted component energy content was also established using the values obtained in harvested sample trees (Table 3).

Regression equations for each component were used for determining the total energy content of component of individual tree in the census plot. The energy contents of the components were added together to get energy content of individual trees. From this, the energy content of the stand was determined which ultimately could be expressed in terms of kJ $ha^{-1}$.

**Table 2**

*Component caloric content (x $10^3$ k cal) of the harvested sample trees of different dbh classes of six years old plantation stand of A. auriculiformis.*

| Tree No. | dbh (cm) | Bole | Branch | Phyllode | Root | Total |
|---|---|---|---|---|---|---|
| 1. | 4.20 | 17.39 | 3.22 | 4.76 | 4.61 | 29.98 |
| 2. | 4.84 | 22.22 | 3.97 | 6.24 | 5.63 | 38.16 |
| 3. | 5.19 | 25.66 | 5.34 | 7.22 | 7.00 | 45.22 |
| 4. | 5.80 | 26.24 | 5.71 | 7.35 | 7.69 | 46.99 |
| 5. | 5.99 | 31.06 | 8.28 | 9.20 | 5.84 | 54.38 |
| 6. | 7.49 | 60.67 | 19.33 | 17.46 | 5.59 | 103.05 |
| 7. | 8.16 | 73.47 | 20.01 | 20.97 | 15.12 | 129.57 |
| 8. | 9.98 | 78.35 | 27.92 | 23.82 | 16.39 | 146.48 |
| 9. | 12.34 | 207.91 | 60.16 | 49.30 | 41.67 | 359.04 |
| 10. | 14.19 | 221.03 | 68.33 | 46.93 | 38.06 | 374.35 |
| 11. | 15.54 | 30.16 | 98.43 | 79.34 | 46.92 | 524.85 |

**Table 3**

*Allometric relationships between independent variables and the predicted (dependent variables) component total energy content of the sample harvested trees.*

| Components | Regression Equations | $R^2$ | F | P< | SE |
|---|---|---|---|---|---|
| Bole | TEC = -70.729 + 0.0046CB + 0.0149CEC | 0.99 | 8556.38 | 0.005 | 12.03 |
| Branch | TEC = 1.92490+ 0.0048CB - 0.0004CEC | 0.99 | 56519.51 | 0.005 | 3.89 |
| Phyllode | TEC = -1.1156 + 0.0048CB + 0.0002CEC | 0.99 | 32042.71 | 0.005 | 2.96 |
| Root | TEC = 11.6167 + 0.0047CB + 0.0027CEC | 0.99 | 465.03 | 0.005 | 2.00 |

TEC = Total energy content (k cal); CB = Component biomass (g); CEC = Component energy concentration (k cal $g^{-1}$).

## Results

*Energy Concentration* : The energy or caloric value per gram ranged from 4,296 cal $g^{-1}$ to 4,875 cal $g^{-1}$.The component mean caloric value ranged from 4,296 cal $g^{-1}$ to 4,810cal $g^{-1}$ in bole, 4,620 cal $g^{-1}$ to 4,864 cal $g^{-1}$ in branch, 4,617 cal $g^{-1}$ to 4,875 cal $g^{-1}$ in phyllodes and 4,495 cal $g^{-1}$ to 4,635 cal $g^{-1}$ in root (Table 1). The energy value of different component increased in the order of root < bole < phyllode < branch.

*Energy Content* : The energy content of sample harvested trees increased with the increase in different diameter classes. It ranged from 29.98 x $10^3$ k cal to 524.85 x $10^3$ k cal. The caloric content of component parts of the sample harvested trees increased with increment in diameter classes from 4.2 cm to 15.4 cm. These are: 17.39 x $10^3$ k cal to 300.16 x $10^3$ k cal in bole followed by 3.22 x $10^3$ k cal to 98.43 x $10^3$ k cal in branch, 4.76 x $10^3$ k cal to 79.34 x $10^3$ k cal in phyllode, and 4.61 x $10^3$ k cal to 46.92 x $10^3$ k cal in root (Table 2).

*Stand Energy Content* : Multiple regression equations have been developed on establishing relationship between independent variable (biomass, component energy concentration) and predicted (dependent variable) component total energy content of the sample harvested tree (Table 3). The relationship of each component was highly significant at $P < 0.05$ with low relative error.

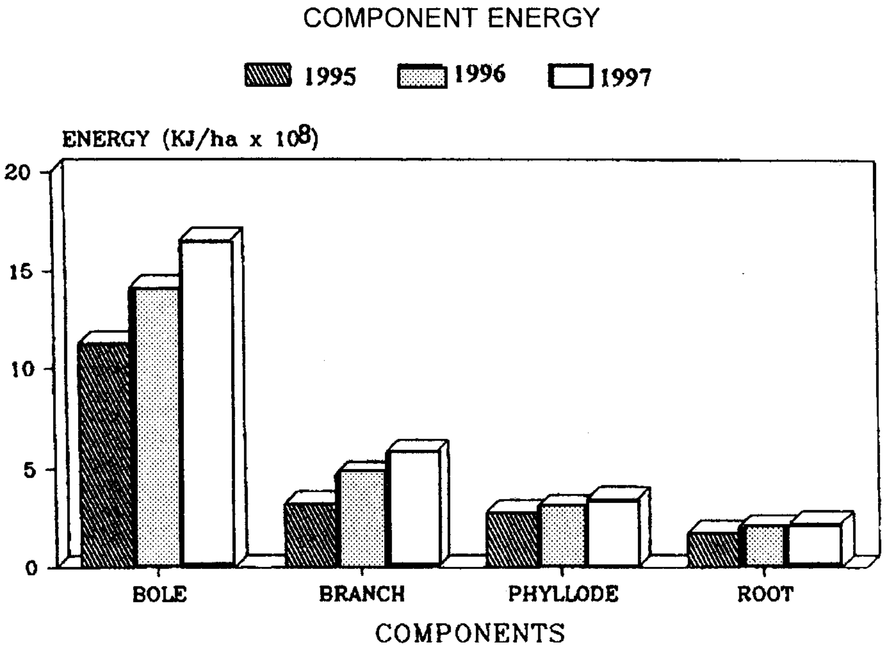
The standard error calculated for each of the regression equation for each component was 12.03 for bole, 3.89 for branch, 2.96 for phyllode, and 2.00 for root. The coefficient of correlation estimated for all the component (bole, branch, phyllode and root) were 99%. The square multiple correlation coefficient was also highly significant at $R^2 = 0.99$ for each of the components (Table 3). The energy content of each component of individual tree of the stand was added and then converted it into stand energy content.

The total energy content of the plantation stand ranged from 19.18 x $10^8$ kJ $ha^{-1}$ in 1995 (6 years age) to 28.19 x $10^8$ kJ $ha^{-1}$ in the 1997 (8 years age). The variation in component energy content with increase in stand age ranged 11.27 x $10^8$ kJ $ha^{-1}$ to 16.57 x $10^8$ kJ $ha^{-1}$ in bole, 3.28 x $10^8$ k J $ha^{-1}$ to 5.82 x $10^8$ k J $ha^{-1}$ in branch, 1.80 x $10^8$kJ $ha^{-1}$ to 2.29 x $10^8$ kJ $ha^{-1}$ in root and 2.83 x $10^8$ kJ $ha^{-1}$ to 3.51 x $10^8$ kJ $ha^{-1}$ in phyllode. The variation in total energy content with increase in stand age have also been calculated for successive years and given in Fig. 1.

The bole component contributed 58.75 - 58.87% of energy content to the total energy content of plantation stand followed by branch of 17.10 - 20.65%, root of 8.12 - 9.38% and phyllode of 12.45 - 14.75%, approximately.

*Net Energy Production* : The rate of total net energy production in six years old plantation stand of *A. auriculiformis* was also estimated for the year 1995-96 and 1996-97. The total net production in terms of energy ranged from 4.87 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in 1995-96 to 4.14 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in 1996-97. On increasing the age of the plantation stand, the variation in component net energy fixation ranged from 2.89 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ to 2.41 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in bole, 1.43 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ to 1.11 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in branch followed by 0.26 x $10^8$ kJ $ha^{-1}\cdot yr^{-1}$ to 0.42 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in phyllode and 0.29 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ to 0.20 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in root.

Fig. 1



Energy content distribution in different components of *Acacia auriculiformis*

## Discussion

In the present study, the component mean caloric value ranged as 4,296 to 4,810 cal g$^{-1}$ in bole, 4,620 to 4,864 cal g$^{-1}$ in branch, 4,617 to 4,875 cal g$^{-1}$ in phyllode and lastly 4,495 to 4,635 cal g$^{-1}$ in root. Net energy fixation is also a measure of net primary production. It has a good biomass yield potential, fuel value and susceptibility of combustion (Khanduja and Goel, 1986).

Its excellent quality as a firewood is that it burns without smoke or spark and with high caloric value in fuelwood and in charcoal (Chandra Siri, 1988) is now well recognized.

The energy value of 20.48 kJ g$^{-1}$ for needles and 18.93 kJ g$^{-1}$ for bole wood were reported by Madgwick *et al.* (1977) for *Pinus radiata* in New Zealand. Sharma and Ambasht (1991) observed 16.32 kJ g$^{-1}$ energy value for trunk wood and 15.45 kJ g$^{-1}$ for leaf of *Alnus nepalensis* in Eastern Himalayas. Sinha (1991) has also reported 17.8 kJ g$^{-1}$ mean energy value for *Leucaena leucocephala* leaf. Golley (1969) reported that on the average, caloric values were greater for stem and fruit in four types of tropical forests. These values were exemplified for the same component in the tropical moist forest 4,185 - 4,310 cal g$^{-1}$, Premontane 4,167 - 4,073 cal g$^{-1}$, Gallery 4,248 - 3,845 cal g$^{-1}$, Mangrove 4,337 - 4,360 cal g$^{-1}$ and combined 4,220 - 4,102 cal g$^{-1}$. The total energy content of the plant components in six years old plantation stand has the same trend as of biomass buildup.

## Conclusion

Lastly, it is concluded that the *Acacia auriculiformis* is rich in energy conserving value, content and efficiency, and can meet the challenge of fuelwood demand and supply on proper management, both under social and natural forestry systems. The species introduced in Gangetic belt is highly successful and its growth is thick.

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## SUMMARY

**The present study is comprised of energy value, component energy, total energy content and net annual energy production of 6 years old monoculture plantation stand of *Acacia auriculiformis* A. Cunn. ex. Benth at Saresar Forest Range situated in the South-East outskirts of Varanasi city. The caloric value and content of different component of sample harvested trees are analyzed. Multiple linear regression equation was developed for each component. The energy content of different component increased with increment in diameter classes. The energy value of different component increased in the order of root < bole< phyllode < branch. The rate of total net energy production of the six year old plantation stand was 4.87 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in 1995-96 to 4.14 x $10^8$ kJ $ha^{-1}$ $yr^{-1}$ in 1996-97. On increasing the age of the plantation stand, the variation in component net energy fixation was observed.**

*Key words* : ***Acacia auriculiformis*, Plantation, Energy production, Varanasi, Uttar Pradesh.**

## वाराणसी में *अकेसिया औरिकुलिफौर्मिस* की छह वर्षीय रोपवन संनिधि की ऊर्जा उत्पादकता का अध्ययन

जितेन्द्र कुमार

### सारांश

प्रस्तुत अध्ययन में वाराणसी नगर के दक्षिण.पूर्वी उपनगरीय भाग में अवस्थित सरेसर वन परिक्षेत्र में लगी हुई *अकेसिया औरिकुलिफौर्मिस* ए० कनि० पूर्व बेन्थ० की छह वर्षीय एकजाति रोपवन संनिधि की ऊर्जा अर्हा, संघटक ऊर्जा, कुल ऊर्जा तत्व और शुद्ध वार्षिक ऊर्जा उत्पादन को समाविष्ट किया गया है। नमूना स्वरूप काटे गए वृक्षों के विभिन्न संघटकों की कैलोरी अर्हा और तत्व विश्लेषित किए गए हैं। प्रत्येक संघटक के बहुल रेखीय प्रतीपायन समीकरण तैयार किए गए हैं। विभिन्न संघटकों का ऊर्जा तत्व उनकी व्यास श्रेणियों में संवृद्धि होने के साथ बढ़ता गया है। विभिन्न संघटकों की ऊर्जा अर्हा में जड़ें < तना < वृन्तफलक < शाखा अनुक्रम से वृद्धि हुई। छह वर्षीय रोपवन संनिधि के कुल शुद्ध ऊर्जा उत्पादन की दर 1995–96 में 4.87 X $10^8$ kJ प्रति हेक्टे० प्रतिवर्ष और 1996–97 में 4.14 X $18^8$ kJ प्रति हेक्टे० प्रतिवर्ष रही। रोपवन संनिधि की उम्र बढ़ने के साथ संघटकों में शुद्ध ऊर्जा स्थिर बनने में अंतर पड़ता देखा गया।

## References

Anon. (1968). Oxygen Bomb Calorimetry and Combustion Methods. Parr Instrument Co., *Manual No. 130*. 56 p.

Brewbaker, J.L., R. van den Beldt and K. Mac Dicken (1984). Fuelwood uses and properties of nitrogen-fixing trees. *Pesquisa Agropecuaria Brasileira* **19** (special) : 193-204.

Brewbaker, J.L., R. van de Delt and K. Mac Dicken (1982). Nitrogen Fixing tree Resource : Potentialities and limitation. *Workshop Biological Nitrogen Fixation Technology for Tropical Agriculture*, Coli, Columbia.

CFC (1990). *India's forests.* Central Forestry Commission, Ministry of Agriculture, Govt. of India, New Delhi.

Chandra Siri, S. (1988). Fast Growing Nitrogen fixing trees as MPTS for fuelwood and charcoal on small farms. *Multipurpose trees species for small form use – Proc. Intl. Workshop,* Pattaya Thailand. p. 272.

Falker, P. and R.S. Banduraski (1979). Uses and Potential uses of leguminous trees for minimal energy input agriculture, *Econ. Bot.*, **33**: 172-184.

Golley, F.B. (1969). Caloric value of wet tropical forest vegetation. *Ecology,* **50** : 577-579.

Khanduja, S.D. and V.L. Goel (1986). Pattern of variability in some fuelwood tree species grown on sodic soils. *Indian Forester,* **112**(2), 118-123.

Lieth, H. (1975). Modelling the primary productivity of the world. *Primary production of the biosphere* (Lieth, H. and R.H. Whittaker, eds.). Springer Verlag, New York. pp. 237-262.

Madgwick, H.A.I., D.S. Jackson and P.J. Knight (1977). Above-ground dry matter, energy and nutrient contents of trees in an age series of *Pinus radiata* plantation. *N.Z. J. For. Sci.,* **7** (3): 445-468.

NRSA (1984). *Project report on nation wide mapping of forest and non-forest area using Landsat false colour composites for the period 1972 and 1980-83, 1983*. NRSA.

Paine, R.T. (1971). The measurement and application of the caloric to ecological problems. *Ann. Rev. Ecol. and Systematics,* **2**: 145-164.

Puri, G.S., R.K. Gupta and V.M. Meher-Homji (1989). *Forest Ecology*, 2nd edn. Vol. 2 : Plant Form, Diversity, Communities and Succession.

Ribe, J.H. (1974). A Review of Short Rotation Forestry. Univ. of Maine at Orono, *Rep. 160*. pp.1-51.

Rierink, A. (1983). On the Caloric Value of the 60 Netherland-Indias wood species. *Tectona*, **31** : 400-418 (NL, en).

Saucier, J.R., A. Clark and R.G. Mac Alpine (1972). Above-ground biomass yield of short rotation Sycamore. *Wood Sci.*, **5**: 1-6.

Schmidt, P.L. and De bell (1973). Wood production and kraft pulping of short rotation hard woods in the pacific north-west. *IUFRO Biomass Studies* (Young, H.E., ed.). Orono, Univ. of Maine Press. pp. 507-576.

Sharma, E. and R.S. Ambasht (1991). Biomass, Productivity and energetic in Himalayan Alder plantation. *Ann. Bot.* (U.K.), **67** : 285-293.

Sinha, M. (1991). Primary Production, Nutrient dynamics and decomposition in a plantation stand of *Leucaena leucocephala* (Lam.) de Wit. *Ph.D. Thesis*, BHU, Varanasi, India.

Srivastava, A.K. and R.S. Ambasht (1995). Biomass Production decomposition and nitrogen release from root nodules in *Casuarina equisetifolia* plantation in Sonebhadra, India. *J. Appl. Ecol.*, **32**.

Turner, J. and D.W. Cole (1973). A review of forest biomass accumulation. US/IBP Coniferous Forest Biomass Programe, *Internal Report No.56*, Washington. pp. 1-15.