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Energy efficiency of large cardamom grown under Himalayan alder and natural forest

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Abstract

Energy efficiency of agroforestry systems of large cardamom grown under N_2-fixing Himalayan alder (alder-cardamom) and natural forest (forest-cardamom) was studied in the Sikkim Himalaya. Large cardamom (*Amomum subulatum*), the most important perennial cash crop of the region, is widely cultivated with Himalayan alder (*Alnus nepalensis*) as shade tree. Energy fixation, storage, net allocation in agronomic yield, and heat release and exit from the system were respectively 1.57, 1.44, 2.24 and 2.22 times higher in the alder-cardamom compared to the forest-cardamom system. Energy conversion efficiency and net ecosystem energy increment were also higher in the alder-cardamom than the forest-cardamom system. Energy fixation efficiency and energy conversion efficiency of large cardamom increased under the influence of Himalayan alder. Energy efficiency in N_2-fixation of Himalayan alder was also high (67.5 g N_2 fixed 10^4 kJ^{-1} energy). Quantum and flux of energy increased in the alder-cardamom compared to the forest-cardamom system that optimized the production potential of the cash crop under the influence of the Himalayan alder. Climatic sympatry of the large cardamom and Himalayan alder, and their synergetic energy efficiency makes this association ecologically and economically viable for the mountain regions.

Introduction

Large cardamom (*Amomum subulatum* Roxb.), a native plant of the Sikkim Himalaya, is a perennial low-volume, high-value and non-perishable cash crop grown beneath tree cover on marginal lands. Its cultivation is a unique example of ecological and economic viability of a traditional farming system based on indigenously evolved agroforestry practices (Sharma et al. 2000). Himalayan alder (*Alnus nepalensis* D. Don) is cultivated widely as shade tree in large cardamom based agroforestry systems. The altitudinal range of the Himalayan alder is sympatric with the agroclimatic range of large cardamom farming. Himalayan alder is nodulated and capable of nitrogen fixation (Sharma and Ambasht 1988).

Intensive studies have been carried out on alders with emphasis on various aspects on nitrogen fixation (Schubert and Evans 1976; Huss-Danell 1978) and with some emphasis on nitrogen accretion (Akkermans and VanDijk 1976; Binkley 1981; Sharma and Ambasht 1988; Binkley et al. 1992). Studies have been carried out on biomass production, nutrient dynamics, nitrogen fixation and its accretion in an age series of monocultures of Himalayan alder in the region (Sharma 1993; Sharma and Ambasht (1988, 1991)). Productivity and biogeochemical effects of red alder in forestry (Binkley et al. 1992) and Himalayan alder in large cardamom agroforestry (Sharma et al. (1994, 1997a, 1997b)) have been investigated. Information on energetics of nitrogen accretion in an age series of Himalayan alder is also available (Sharma and Ambasht 1988). However, information on the influence of nitrogen fixing trees on the associates and ecosystem energetics is lacking given that rates of nitrogen fixation and net annual production are not constant and energy requirements differ in stands with or without N_2-fixing trees.

A large amount of energy is consumed during N_2-fixation (Sharma and Ambasht 1988), substantially more than is required for nitrogen assimilation from soil (Silsbury 1977). But, the information on energy efficiency of nitrogen fixation with respect to associates is lacking. The present study investigates the energy efficiency of large cardamom agroforestry systems with and without N_2-fixing Himalayan alder as shade trees. The specific objectives of the study were to determine: (a) differences in component energy values, storage pattern and flow rates; (b) energy output and input ratio, and cost-benefit analysis; (c) net ecosystem energy increment, energy conversion efficiency, energy fixation efficiency and energy accumulation ratio; and (d) energy efficiency in N_2-fixation with respect to agroforestry systems as a function of Himalayan alder as shade tree.

Methods

Large cardamom based agroforestry systems located within the Mamlay watershed of the Sikkim Himalaya were selected for the study. Sharma et al. (1994) presented the location and climate of the study sites and descriptions of these agroforestry stands. Two agroforestry systems selected for this study were: (i) large cardamom with N_2-fixing Himalayan alder as shade tree (alder-cardamom stand) and (ii) large cardamom with non-N_2-fixing mix tree species (forest-cardamom stand). Biomass, yield, litterfall, floor-litter and decomposition values of the same stands reported by Sharma et al. (1994, 1997a) were used for calculation.

Photosynthetically active radiation (PAR) during the study period was recorded using dataloger-based Campbell Scientific Inc. (USA) automatic weather station. Each plant component was sampled in replicates of five from both the agroforestry systems, oven-dried at 80 °C for 48 hours, milled to pass a 2-mm sieve, and used for estimating ash and energy contents. Per cent ash content of different plant components was estimated by burning samples in muffle furnace at 550 °C for 2 hours. All energy estimations were made on ash-free mass basis. Energy value of plant materials was estimated by using the oxygen bomb calorimeter (Lieth 1975). The energy contents in each of the plant components of shade trees and large cardamom crop were calculated by taking the product of mean energy value and biomass. Energy flow from tree leaf and twig, and cardamom leaf and pseudo-stem to floor-litter was estimated through litterfall and slashed leaf and pseudo-stem, and their energy values. The mean energy value of floor-litter was determined by analyzing samples at several places (n = 10) in different layers. The component energy contents of each tree in the sample plots were estimated and expanded to stand values. The sum of the energy contents of trees, understorey cardamom and floor-litter represented stand energy content. Net annual energy fixation in trees and understorey cardamom was calculated similarly as biomass production (Sharma and Ambasht 1991; Sharma et al. 1994). Energy efficiency in N_2-fixation by alder was calculated following Schubert (1982) and Sharma and Ambasht (1988, 1991).

Decomposition of different litter fractions and annual mass loss reported by Sharma et al. (1997a) were used to estimate the total heat release from the floor-litter. The energy loss from the root-nodules of alder was estimated using root-nodule turnover and decomposition rate conversion factor (Sharma and Ambasht 1986) and energy values in root-nodules.

Inputs and outputs of energy and cash were estimated in both the alder-cardamom and forest-cardamom agroforestry systems. The inputs were mainly in the form of farm labour and firewood used for cardamom curing. Energy in the form of farm labour was calculated using 0.15×10^4 kJ energy hour^{-1} following Freedman (1982). Energy content of firewood was estimated from total dry mass and its energy value. Energy output in the form of agronomic yield, and firewood and fodder extractions from the agroforestry systems were calculated as a product of dry biomass and energy values. Cash expenditure and income in each of the systems was evaluated for cost-benefit analysis.

Results and discussion

The energy value of component parts of the alder ranged between 18–21 kJ g^{-1} and mix tree species 15–20 kJ g^{-1} (Table 1). It was higher in each of the components of the alder than that of the mix tree species. Large cardamom crop components under the alder-cardamom and forest-cardamom systems did not

Table 1. Ash content and energy value of plant components in alder-cardamom and forest-cardamom agroforestry systems in Sikkim Himalaya, India

Plant components	Alder-cardamom		Forest-cardamom*	
	Ash (%)	Energy value (kJ g^{-1} ash-free dry mass)	Ash (%)	Energy value (kJ g^{-1} ash-free dry mass)
Tree				
Leaf and twig	2.25	21.36 ± 1.06	6.65	19.88 ± 0.34
Branch	2.50	19.51 ± 0.73	4.35	16.41 ± 0.21
Bole	1.95	21.29 ± 0.32	1.22	18.58 ± 0.08
Root	4.95	17.96 ± 0.39	5.30	14.68 ± 0.39
Root-nodule	12.48	21.02 ± 0.80	---	---
Cardamom				
Leaf	5.73	21.17 ± 0.21	5.65	21.16 ± 0.19
Pseudo-stem	3.61	17.39 ± 0.68	3.55	17.37 ± 0.71
Root/rhizome	11.10	19.72 ± 0.53	10.95	19.69 ± 0.49
Fruit (capsule)	11.95	20.26 ± 0.44	11.80	20.06 ± 0.39
Floor-litter	13.65	21.42 ± 0.16	7.35	17.91 ± 0.31

*Mix tree species without N_2-fixing alder. Energy values are mean ± SE; n = 5.

show much difference in energy values. However, floor-litter under the alder-cardamom contained much higher energy value than under the forest-cardamom system (Table 1).

Energy distribution and flow rates in components of the alder-cardamom and forest-cardamom agroforestry systems are presented in Figure 1. Photosynthetically active radiation that reached the agroforestry systems was 11822 × 10^6 kJ ha^{-1} $year^{-1}$. Net annual energy fixation was higher by 1.57 times in the alder-cardamom (221.45 × 10^6 kJ ha^{-1} $year^{-1}$) compared to the forest cardamom (141.16 × 10^6 kJ ha^{-1} $year^{-1}$). The annual allocation of net energy fixation in different components of the alder-cardamom system (Tree – twig and leaf 27.5%, branch 4.3%, bole 14.5%, root 4.8%, root-nodule 3.6%: Large cardamom – leaf 9.6%, pseudo-stem 26.8%, root/rhizome 4.7%, and capsule 4.2%) was different from that of the forest-cardamom system (Tree – twig and leaf 40.9%, branch 2.8%, bole 20.7%, root 5.1%: Large cardamom – leaf 6.8%, pseudo-stem 15.0%, root/rhizome 5.8%, and capsule 2.9%). Net energy allocation in the understorey large cardamom crop was much higher in the alder-cardamom (45.3%) than the forest-cardamom (30.5%) system. This showed that Himalayan alder is better associate/shade tree than mix tree species providing conditions for higher allocation of energy in the cash-crop system. In absolute terms, net energy allocation in cardamom crop was 2.3 times and in capsule 2.2 times higher under the alder-cardamom than the forest-cardamom agroforestry system. Floor-litter energy build-up was conspicuous due to more litter production and accumulation in the alder-cardamom system and was 1.6 times more than the forest-cardamom (Figure 1). Energy release from the floor-litter was higher by 2.1 times in the alder-cardamom and in this stand 5.35 × 10^6 kJ ha^{-1} $year^{-1}$ of energy from the alder root nodules was recorded. The total energy storage in the perennial live components was 1.41 times higher in alder-cardamom system than forest-cardamom system (Figure 1). Of the total energy, 79% was in the plant components and 21% as floor-litter in the alder-cardamom, and 81% in plant components and 19% as floor-litter in the forest-cardamom system. The energy exit from the system was in the form of firewood and cardamom capsule which was more than double in the alder-cardamom (cardamom capsule 9.20 and firewood 30.87 × 10^6 kJ ha^{-1} $year^{-1}$) compared to the forest-cardamom (cardamom capsule 4.11 and firewood + fodder 14.86 × 10^6 kJ ha^{-1} $year^{-1}$). The heat release value of 93.90 × 10^6 kJ ha^{-1} $year^{-1}$ in the alder-cardamom was 2.3 times higher than that of the forest-cardamom system.

Large cardamom is a less labour intensive cash crop. The main inputs were labour and firewood used in cardamom curing. The outputs include agronomic yield, firewood from the agroforestry systems and also fodder from the forest-cardamom system (Table 2). Quantum of energy input and output was almost double in the alder-cardamom than the forest-cardamom system. However, the output:input ratio in the alder-cardamom (3.55) was lower than the forest-cardamom (4.98) system. Cash valuations of input

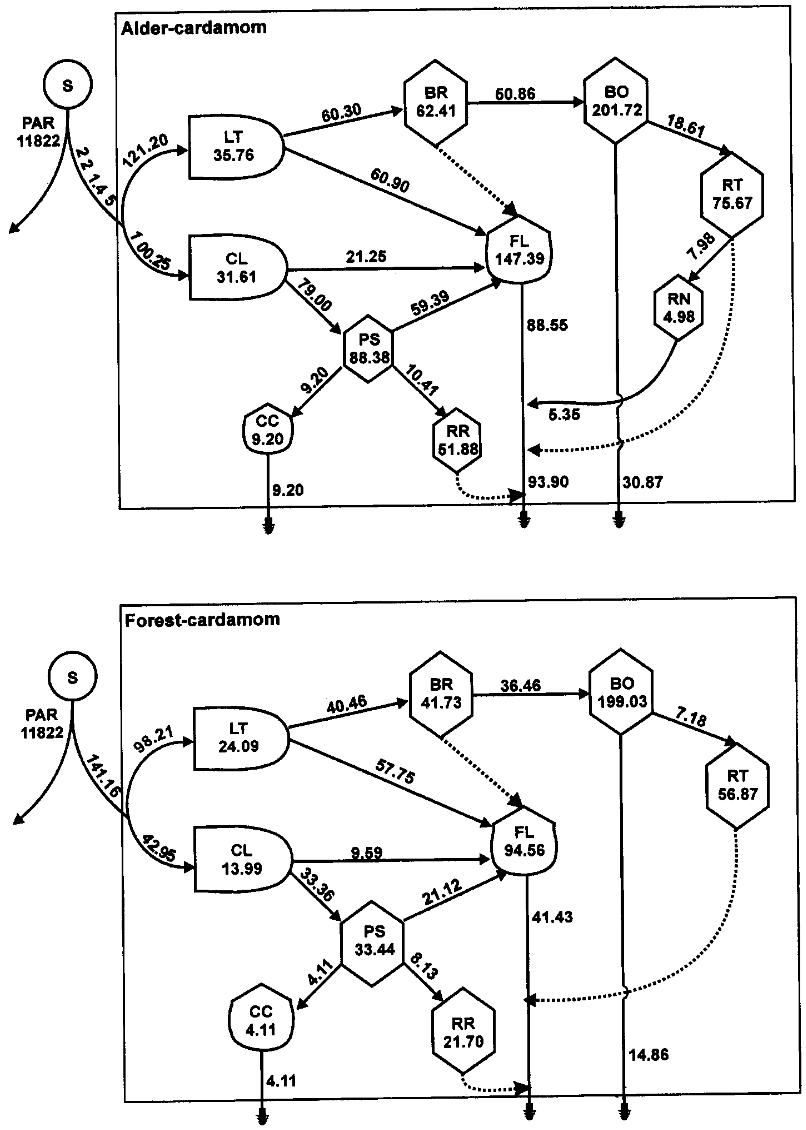

Figure 1. Distribution of energy storage in components, net energy flow and heat release in the alder-cardamom and forest-cardamom agroforestry systems in Sikkim Himalaya, India. Units are $\times 10^6$ kJ ha^{-1} for compartments and $\times 10^6$ kJ ha^{-1} year^{-1} for flows. Broken lines indicate that values are not estimated. S = sun; PAR = photosynthetically active radiation; LT = leaf and twig; BR = branch; BO = bole; RT = root; RN = root-nodule; FL = floor-litter; CL = cardamom leaf; PS = pseudo-stem; RR = root and rhizome; and CC = cardamom capsule. This figure is drawn using the symbols given by Odum and Odum (1976).

and output have been made and presented in Table 2. Cash income from the alder-cardamom system was more than double to that of the forest-cardamom system. The cost benefit analysis showed 18.23 times cash income in the alder-cardamom and 15.67 times in the forest-cardamom system. Both, the quanta of energy and higher cash return from the alder-carda-

Table 2. Annual input and output of energy and cash in alder-cardamom and forest-cardamom agroforestry systems in Sikkim Himalaya, India

Input/Output	Alder-cardamom		Forest-cardamom	
	Energy ($\times10^4$ kJ ha^{-1})	Cash (US \$ ha^{-1})	Energy ($\times10^4$ kJ ha^{-1})	Cash (US \$ ha^{-1})
Input				
Labour*				
Weeding	2.1	2.8	4.2	5.6
Harvest	8.4	11.2	4.2	5.6
Post-harvest	42.0	55.8	21	27.9
Fire-wood collection	12.6	16.7	6.3	8.4
Fire-wood used in curing	1064.0	34.9	465	17.4
Total	1129.1	121.4	500.7	64.9
Output				
Agronomic yield	920	2112**	411	954**
Fire-wood extraction	3087	101	1486	56
Fodder	---	---	596	7
Total	4007	2213	2493	1017
Output:Input ratio	3.55	18.23	4.98	15.67

*Human labour hour^{-1} = 0.15 × 10^4 kJ (Freedman 1982). **Calculated at US $ 4.65 per kilogram of cardamom as per 1999 average rate. Cash conversion @ US $ 1 = Rupees 43.

Table 3. Energy fixation, storage and efficiency of alder-cardamom and forest-cardamom agroforestry systems in Sikkim Himalaya, India

Energy/efficiency parameters	Alder-cardamom	Forest-cardamom
Energy fixation ($\times10^6$ kJ ha^{-1} year^{-1})	221.45	141.16
Energy storage ($\times10^6$ kJ ha^{-1})	699.80	485.41
Net energy allocation in agronomic yield ($\times10^6$ kJ ha^{-1} year^{-1})	9.20	4.11
Energy release and exit ($\times10^6$ kJ ha^{-1} year^{-1})	133.97	60.40
Net ecosystem energy increment ($\times10^6$ kJ ha^{-1} year^{-1})	87.48	80.76
Energy conversion efficiency (%)	1.87	1.19
Energy fixation efficiency (GJ GJ^{-1} leaf energy year^{-1})	3.29	3.70
Energy accumulation ratio	3.16	3.44
Energy efficiency in N_2-fixation* (g N_2 fixed 10^4 kJ^{-1} energy)	67.50	---

*See Schubert (1982) and Sharma and Ambasht (1988, 1991) for calculation.

mom agroforestry support alder's association to be an efficient system for management.

Energy fixation, storage, net allocation in agronomic yield, and heat release and exit from the system were respectively 1.57, 1.44, 2.24 and 2.22 times higher in the alder-cardamom compared to the forest-cardamom system (Table 3). Energy conversion efficiency (ECE) at the autotrophic level is the ratio of energy captured by vegetation to the photosynthetically active radiation reaching an area over a period of time expressed as a percentage (Sharma and Ambasht 1991). The ECE of the alder-cardamom system (1.87%) was higher than that of the forest-cardamom system (1.19%). The range of 1.8– 3.5% ECE in age series of Himalayan alder (Sharma and Ambasht 1991) and 1.8–4.2% in red alder stands of Canada (Smith 1977) are indicative that 1.87% in the alder-cardamom system is within the expected range. Rawat and Singh (1988) reported 1.1% ECE in oak forests of the central Himalaya which is comparable to mix tree species forest-cardamom value of 1.19%. The ECE contribution of large cardamom was recorded much higher in the alder-cardamom (0.85%) than the forest-cardamom (0.36%) system.

Net primary production per unit weight leaf is the production efficiency (Johnson and Risser 1974). Using this concept energy fixation efficiency (EFE) was calculated as net energy fixation per unit energy of leaf. Energy accumulation ratio (EAR) is calculated as the ratio of energy storage in the system by net energy fixation. The EFE and EAR of the alder-cardamom system was slightly lower than the forest-cardamom system (Table 3). The EAR can be used in categorizing the production conditions of forest communities as has been done earlier using biomass (Whittaker and Woodwell 1969). The alder-cardamom system showed lower EAR resulting from less energy accumulation in perennial components of alder tree and greater annual turnover in the form of leaf & twigs of tree and cardamom components. This shows higher energy dynamics in the alder-cardamom than that of the forest-cardamom system. The EFE may be expected to drop when fixation increases because availability of some other resources (such as water or nutrients) limits production. The EFE in the cardamom based agroforestry systems were generally consistent with this hypothesis. It decreased as an influence of N_2-fixing alder in the alder-cardamom compared to the forest-cardamom system (Table 3), a pattern consistent with the expectation that efficiency should decrease with increasing rates of fixation. However, the EFE contribution of large cardamom was found higher in the alder-cardamom (3.20 GJ GJ^{-1} leaf energy $year^{-1}$) compared to the forest-cardamom (3.07 GJ GJ^{-1} leaf energy $year^{-1}$) system. Sharma and Ambasht (1991) reported that energy efficiency in N_2-fixation decreased with plantation age of the Himalayan alder and ranged between 58–103 g N_2 fixed 10^4 kJ^{-1} energy. The energy efficiency in N_2-fixation of the Himalayan alder in the alder-cardamom system was within this range (Table 3). Plantation of the alder with large cardamom did not show any adverse impact on the energy efficiency of N_2-fixation thereby complimenting it to be an excellent associate.

Conclusion

Large cardamom based agroforestry as a production option is perfectly compatible with the mountain specificity that fulfills the conditions to be sustainable, and more so when the Himalayan alder is the associate. The energy value was higher in each of the components of the alder tree compared to the mix tree species. Net annual energy fixation, storage, net allocation in the agronomic yield, heat release and exit from the system, and energy conversion efficiency of the alder-cardamom system was more than the forest-cardamom showing that plantation of N_2-fixing alder increased the quantum and energy flux optimizing the production potential of the system. Quantum of energy, energy allocation in the cardamom crop and cash return from the alder-cardamom agroforestry system being higher, support the alder to be an excellent associate. Energy efficiency in the N_2-fixation of the alder when planted with large cardamom based agroforestry remains equally beneficial as pure alder plantation in forestry. Climatic sympatry of the large cardamom and Himalayan alder, and their synergetic energy efficiency makes this association ecologically and economically viable for the mountain regions.

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References

Akkermans A.D.L. and VanDijk C. 1976. The formation and nitrogen-fixing activity of the root nodules of *Alnus glutinosa* under field conditions. In: Nutman P.S. (ed.), Symbiotic Nitrogen Fixation in Plants. Cambridge University Press, Cambridge, pp. 511–520.

Binkley D. 1981. Nodule biomass and acetylene reduction rates of red alder and sitka alder on Vancouver Island, B.C. Can J of For Res 11: 281–286.

Binkley D., Sollins P., Bell R., Sachs D. and Myrold D. 1992. Biogeochemistry of adjacent conifer and alder/conifer stands. Ecology 73: 2022–2033.

Freedman S.M. 1982. Human labour as an energy source for rice production in the developing world. Agroecosyst 8: 125–136.

Huss-Danell K. 1978. Nitrogenese activity measurement in intact plants of *Alnus incana*. Physiol Plant 43: 372–376.

Johnson F.L. and Risser P.G. 1974. Biomass, annual net primary production and dynamics of six mineral elements in a post oak-blackjack oak forest. Ecology 55: 1246–1258.

Lieth H. 1975. Measurement of caloric values. In: Lieth H. and Whittaker R.H. (eds), Primary Productivity of the Biosphere. Springer-Verlag, Berlin, pp. 119–129.

Odum H.T. and Odum E.C. 1976. Energy Basis for Man and Nature. McGraw-Hill Inc., New York.

Rawat Y.S. and Singh J.S. 1988. Structure and function of oak forests in central Himalaya. I. Dry matter dynamics. Ann of Bot 62: 397–411.

Schubert K.R. 1982. The Energetics of Biological Nitrogen Fixation. American Society of Plant Physiologists, Rockville, Maryland.

Schubert K.R. and Evans H.J. 1976. Hydrogen evolution: A major factor affecting the efficiency of nitrogen fixation in nodulated symbionts. Proceedings of the National Academy of Sciences. USA 73: 1207–1211.

Sharma E. 1993. Nutrient dynamics in Himalayan alder plantations. Ann of Bot 72: 329–336.

Sharma E. and Ambasht R.S. 1986. Root nodule age-class transition, production and decomposition in an age sequence of *Alnus nepalensis* plantation stands in the Eastern Himalayas. J of Appl Ecol 23: 689–701.

Sharma E. and Ambasht R.S. 1988. Nitrogen accretion and its energetics in Himalayan alder plantations. Func Ecol 2: 229–235.

Sharma E. and Ambasht R.S. 1991. Biomass, productivity and energetics in Himalayan alder plantations. Ann of Bot 67: 285–293.

Sharma E., Sharma R., Singh K.K. and Sharma G. 2000. A boon to the mountain populations: Large cardamom farming in the Sikkim Himalaya. Mount Res and Develop 20(2): 4–7.

Sharma R., Sharma E. and Purohit A.N. 1994. Dry matter production and nutrient cycling in agroforestry systems of cardamom grown under *Alnus* and natural forest. Agrofor Syst 27(3): 293–306.

Sharma R., Sharma E. and Purohit A.N. 1997a. Cardamom, mandarin and nitrogen-fixing trees in agroforestry systems in India's Himalayan region. I. Litterfall and decomposition. Agrofor Syst 35: 239–253.

Sharma R., Sharma E. and Purohit A.N. 1997b. Cardamom, mandarin and nitrogen-fixing trees in agroforestry systems in India's Himalayan region. II. Soil nutrient dynamics. Agrofor Syst 35: 255–268.

Silsbury J.H. 1977. Energy requirement for symbiotic nitrogen fixation. Nature 267: 149–150.

Smith N.J. 1977. Estimates of above-ground biomass, net primary production and energy flows in 8 to 10 year old red alder (*Alnus rubra* Bong.) ecosystems. Master of Forestry thesis, University of British Columbia, Vancouver, Canada.

Whittaker R.H. and Woodwell G.M. 1969. Structure, production and diversity of the oak-pine forest at Brookhaven, New York. J of Ecol 57: 155–174.