should be incorporated into the model (rule-set). The final rule-set, or ecological-niche model, is then projected onto a digital map as the species' potential geographic distribution, exported as an ASCII raster grid and imported into ArcView 3.1 (© ESRI, USA, 1998) using the Spatial Analyst Extension for visualization (http://biodi. sdsc.edu).

8. *DIVA*-GIS: The program generally uses a set of 15 of the available 24 climatic variables loaded with the program and most of these variables are those that are likely to affect the ecological domain of the organism (www.diva-gis.org). In this sense *DIVA*-GIS also is a niche modelling program but uses BIOCLIM (Nix, H. A., In *Atlas of Elapid Snakes* (ed. Longmore, R.), 1986, pp. 4–15, Australian Flora and Fauna series #7, Australian Government Publishing Service, Canberra) model for predicting the distribution.
9. In GARP, we performed 1000 iterations (program stop condition) and applied 0.01 convergence factor for 20 tasks. That is, within each task, 1000 iterations of the rules were tested and the best rule was stored for projection. The analysis was performed using climatic data for the period from 1961 to 1990. The layers used were annual minimum temperature, annual maximum temperature, mean minimum temperature, mean maximum temperature, vapour pressure, wetness, relative humidity, wind flow accumulation, aspect, DEM, slope and topography. After obtaining the output from each of the 20 tasks, we combined them to arrive at the final image of possible spread of Sugarcane Woolly Aphid in Southern Peninsular area; the probability of occurrence was assigned based on the number of tasks that predicted the occurrence of the pests in a given pixel. The categories accordingly were: 5–8 (tasks), very low probability of occurrence (yellow); 9–12 (tasks), low probability of occurrence; 13–16 (tasks), moderately high probability of occurrence; 17–20 (tasks), very high probability of occurrence (purple).
10. *DIVA*-GIS model was implemented with 14 variables, viz. annual mean temperature, hottest month maximum temperature, coolest month minimum temperature, annual temperature range, wettest quarter temperature, driest quarter temperature, minimum monthly diurnal temperature, average monthly diurnal temperature, annual mean precipitation, wettest month precipitation, driest month precipitation, annual precipitation range, wettest quarter mean precipitation and driest quarter mean precipitation to identify the potential geographical distribution of the woolly aphid. The program was run with the option Bioclim Classic (four groups) for identifying the optimum, sub-optimal, marginally suitable and not suitable areas. The algorithm attaches 0 to areas that are beyond 0–100 percentile for one or more variables, 1 for those within 0–100 percentile, 2 for those within 2.5 to 97.5 percentile and 3 for those within 5–95 percentile. Interestingly, even without using the mask of the sugarcane cultivating area, the model predictions were quite similar to those given by GARP. The program generated four categories of suitability, viz. not suitable (0), less suitable (1), marginally suitable (2) and optimum (3), for the organism.

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Carbon allocation in different components of some tree species of India: A new approach for carbon estimation

Vegetation plays an important role for carbon sink or source of atmospheric CO_2. During the process of photosynthesis, the atmospheric CO_2 is utilized by the leaves for the manufacture of food in the form of glucose. Later on, it gets converted to other forms of food material, i.e. starch, lignin, hemicelluloses, amino acids, protein, etc. and is diverted to other tree components for storage. It is a well-established fact that food is stored either in the roots or bole. Generally, the plants allocate more of the energy in the root system under stress conditions and in the aboveground components in normal conditions. However, different species respond in different ways for carbon utilization[1]. Here we have made an attempt to categorize the ranking responses to CO_2 by the different life forms.

In the present day scenario, the enhancement of atmospheric CO_2 coupled with the rise in temperature is the main reason behind the global climate change which has evidently raised the global mean temperature by 0.5°C during the last hundred years[2] and 0.4°C in the last 70 years for the Indian sub-continent[3]. Under such changing pattern of climatic condition there is need to classify the plant species for their efficient responses to enhanced CO_2 to climate change.

Nutrient concentration in various tree components varies in accordance to their utilization for regulating different physiological processes. These nutrients are also translocated to various components as and when required. Most of the macronutrients (N, P, K, Mg, S and Na) are highly mobile and leachable except for Ca. Ca being an immobile element, can be used as indicator of carbon content in different tree components.

The present study was undertaken (i) to find out the methodology to provide carbon content of different plant species in different components and (ii) to classify the species responses to enhanced CO_2. The first objective was taken into consideration because most of the information for carbon estimation described in the literature suggests that carbon constitutes between 45 (ref. 4) and 50% of dry matter[5] or it is assured to be 50% of dry matter[6]. The second objective was aimed to understand the efficiency of species for carbon sequestration.

Carbon content of 54 plant species was estimated by two methods, first by ash content method and secondly by regression equation derived between carbon and Ca content (%). In the first method, oven-dried plant components (leaves, bark and wood) were burnt in electric furnace at 400°C temperature, ash content (inorganic elements in the form of oxides) left after burning was weighed and carbon was calculated by using the following equation:

Carbon % = 100 – (Ash weight + molecular weight of O_2 (53.3) in $C_6H_{12}O_6$).

Values of carbon (total 850) were calculated and regression equations were developed between carbon and calcium (Ca was estimated by EEL Flame Photometer[7]).

Bark
$y = -2.1049x + 43.319$ $r = 0.73$

Leaf
$y = -2.2933x + 43.464$ $r = 0.75$

Wood
$y = -2.5368x + 46.358$ $r = 0.89$

where y is carbon percentage, x is Ca content (%) and r is correlation (%) between the carbon content and Ca.

The models or equations developed have been compared with actual carbon content (t) and 0.50 factor (Table 1). The results were well comparable.

Data since 1968 were available with the Forest Ecology and Environment Division, Forest Research Institute, Dehra Dun on ash and Ca content of different components of various species. So back calculations as described above were made to estimate the carbon and also an attempt was made to develop a model to estimate the carbon through the Ca content of components.

Leaf: A total of 289 observations were made for developing a prediction equation between Ca and carbon content. Most of the observed values were scattered and attributed to (i) time of sampling, (ii) age of the tree as well as leaf, and (iii) nature of the leaves, i.e. sclerophyllous or calcareous or smooth. The model developed showed 75% accuracy (Figure 1).

Bark: A total of 278 observations were made for prediction equation (Figure 2). Bark being a storage part for the nutrients, most of the observation falls close to the prediction line.

Table 1. Validation table for the actual (ash content method), predicted and 0.5 factor[6]

Species	Calcium (%)	Carbon (%)	Biomass (t)	Carbon (t) by ash content method	Carbon (t) by Prediction equation	Carbon (t) by 0.5 factor[6]
Bark						
Dalbergia sissoo	2.63	37.78	6.35	2.29	2.40	3.18
Araucaria spp.	1.49	40.18	32.49	13.28	13.06	16.25
Eucalyptus hybrid	2.63	37.78	15.90	6.09	6.01	7.95
Pinus roxburghii	1.00	41.21	11.85	5.22	4.88	5.93
*Shorea robusta**	1.19	40.81	50.62	21.55	20.66	25.31
*Shorea robusta***	1.96	39.19	56.95	20.76	22.32	28.48
Tectona grandis	4.26	34.35	13.71	5.00	4.71	6.86
Leaf						
Dalbergia sissoo	1.49	46.88	3.33	1.30	1.56	1.67
Araucaria spp.	1.73	47.43	5.95	2.51	2.82	2.98
Dendrocalamus strictus	0.56	44.75	3.21	0.96	1.44	1.61
Eucalyptus hybrid	1.27	46.38	3.90	1.50	1.81	1.95
Pinus roxburghii	0.60	44.84	7.00	3.04	3.14	3.50
*Shorea robusta**	0.87	45.46	8.65	3.61	3.93	4.33
*Shorea robusta***	1.06	45.89	5.02	1.81	2.30	2.51
Tectona grandis	2.34	48.83	5.33	1.92	2.60	2.67
Wood						
Dalbergia sissoo	0.47	47.55	33.35	14.82	15.86	16.68
Araucaria spp.	0.16	46.76	141.71	65.38	66.27	70.86
Dendrocalamus strictus	0.14	46.71	269.02	115.76	125.67	134.51
Eucalyptus hybrid	0.07	46.54	161.00	73.58	74.92	80.50
Pinus roxburghii	0.36	47.27	214.93	99.30	101.60	107.47
*Shorea robusta**	1.12	49.20	253.90	115.93	124.92	126.95
*Shorea robusta***	0.25	46.99	157.42	69.40	73.98	78.71
Tectona grandis	0.23	46.94	67.50	29.76	31.69	33.75

*and **, sampled from two different localities.

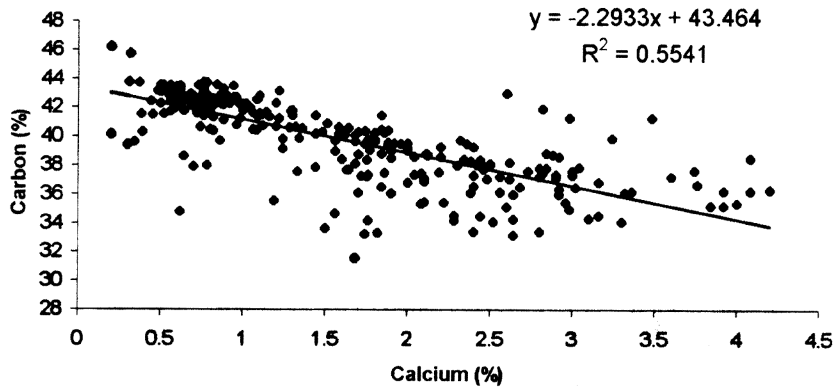

Figure 1. Regression equation for leaves.

Table 2. Carbon content (%) of various plant species

Plant species	Carbon (%)		
	Bark	Leaf	Wood
Conifers			
Abies pindrow (Fir)	40.82 ± 0.76	42.34 ± 0.23	46.13 ± 0.07
Picea smithiana (Spruce)	40.05 ± 0.13	42.31 ± 0.12	46.11 ± 0.05
Pinus roxburghii	44.07 ± 0.35	43.46 ± 0.11	46.32 ± 0.14
Pinus wallichiana	42.06 ± 0.88	43.08 ± 0.75	46.18 ± 0.09
	41.75 ± 1.75	**42.80 ± 0.57**	**46.19 ± 0.09**
Dicotyledons, deciduous			
Amoora rhotica	39.70 ± 0.55	36.14 ± 0.46	45.46 ± 0.11
Amoora wallichii	40.15 ± 0.95	38.66 ± 0.44	45.67 ± 0.23
Anogeissus latifolia	34.55 ± 1.25	37.63 ± 1.00	44.86 ± 0.82
Aporosa dioca	30.46 ± 0.56	33.62 ± 0.16	43.74 ± 0.05
Artocarpus spp.	40.76 ± 0.87	39.86 ± 0.35	45.83 ± 0.14
Bauhinia retusa	33.90 ± 0.75	35.49 ± 0.35	44.60 ± 0.22
Boswellia serrata	35.86 ± 0.36	29.15 ± 0.29	45.02 ± 0.13
Careya arborea	41.72 ± 0.86	39.82 ± 0.40	45.77 ± 0.09
Dalbergia sissoo	36.00 ± 1.40	38.93 ± 1.05	44.45 ± 0.83
Dillenia indica	39.22 ± 0.39	37.93 ± 0.21	46.05 ± 0.11
Grewia elastica	36.95 ± 1.56	36.01 ± 0.77	45.24 ± 0.34
Heynea trifiga	38.76 ± 0.92	39.15 ± 0.74	45.08 ± 0.32
Phoebe lanceolata	35.91 ± 1.03	40.32 ± 0.54	44.94 ± 0.26
Pieris ovalifolia	40.02 ± 0.83	41.43 ± 0.41	46.21 ± 0.05
Primna bengalensis	30.55 ± 3.52	32.96 ± 1.23	42.97 ± 0.96
Pterocarpus marsupium	33.71 ± 3.26	38.11 ± 0.59	44.67 ± 1.22
Rhododendron arboreum	43.48 ± 0.98	42.83 ± 0.64	46.14 ± 0.51
Shorea robusta	41.72 ± 1.04	42.58 ± 0.42	45.66 ± 0.30
Tectona grandis	36.46 ± 1.36	35.98 ± 3.31	44.09 ± 1.17
Terminalia alata	26.40 ± 7.49	36.83 ± 2.21	44.20 ± 1.76
Terminalia bellerica	37.55 ± 0.63	40.27 ± 0.28	44.87 ± 0.17
	36.85 ± 4.25	**37.80 ± 3.30**	**45.02 ± 0.84**
Dicotyledons, Evergreen			
Bachnania latifolia	31.82 ± 0.59	35.11 ± 0.63	45.10 ± 0.07
Bischofia javanica	32.37 ± 0.63	37.54 ± 0.47	43.56 ± 0.05
Coriaria nepalensis	32.13 ± 0.13	34.30 ± 0.15	42.77 ± 0.08
Diospyrus melanoxylon	36.07 ± 1.87	38.34 ± 1.01	44.30 ± 0.06
Litsea khasyana	40.01 ± 0.89	41.56 ± 0.45	44.90 ± 0.31
Litsea glutinosa	42.28 ± 0.52	37.58 ± 0.22	45.45 ± 0.20
Litsea monopetela	41.94 ± 0.42	38.00 ± 0.36	45.21 ± 0.14
Mallotus philippenensis	39.92 ± 0.23	40.41 ± 0.56	45.13 ± 0.05
Quercus leucotrichophora	39.37 ± 0.99	41.34 ± 0.45	45.69 ± 0.15
Quercus semicarpifolia	42.70 ± 3.54	43.10 ± 0.95	46.14 ± 0.26
Sehima wallichii	43.62 ± 1.02	43.52 ± 0.88	45.05 ± 0.19
Syzygium cuminii	42.04 ± 0.04	41.92 ± 0.78	45.76 ± 0.30
Salix spp.	46.70 ± 0.74	39.73 ± 0.29	45.09 ± 0.33
Zyzyphus xylopira	25.94 ± 0.76	38.38 ± 0.52	44.57 ± 0.08
	38.35 ± 5.82	**39.35 ± 2.80**	**44.91 ± 0.89**
Monocotyledons			
Bambusa arundinacea	–	28.23 ± 0.49	43.28 ± 1.94
Bambusa tulda	–	31.25 ± 1.13	43.64 ± 1.75
Dendrocalamus hamiltonii	–	27.50 ± 2.85	42.28 ± 1.34
Dendrocalamus longispathus	–	28.41 ± 8.45	43.72 ± 4.12
Dendrocalamus strictus	–	29.87 ± 8.28	43.46 ± 2.65
Malocanai bambusa	–	26.93 ± 1.25	43.10 ± 1.94
Ochlandra rheedii	–	30.78 ± 0.35	41.49 ± 1.83
Coeheilinanthera nigrolata	–	31.83 ± 1.40	44.51 ± 1.64
	–	**29.35 ± 1.83**	**43.19 ± 0.93**
Exotic species			
Populus ciliata	41.07 ± 0.59	33.41 ± 1.80	45.36 ± 0.38
Populus alba	42.19 ± 0.52	37.36 ± 0.89	44.65 ± 0.22
Populus deltoides	40.44 ± 0.20	33.26 ± 1.47	45.29 ± 0.83
Populus nigra	40.99 ± 1.02	33.06 ± 0.42	45.79 ± 0.18
Eucalyptus hybrid	37.17 ± 2.45	39.19 ± 1.02	45.40 ± 0.95
Eucalyptus globulus	38.32 ± 0.90	38.39 ± 1.62	45.70 ± 0.22
	40.03 ± 1.89	**35.78 ± 2.84**	**45.37 ± 0.40**

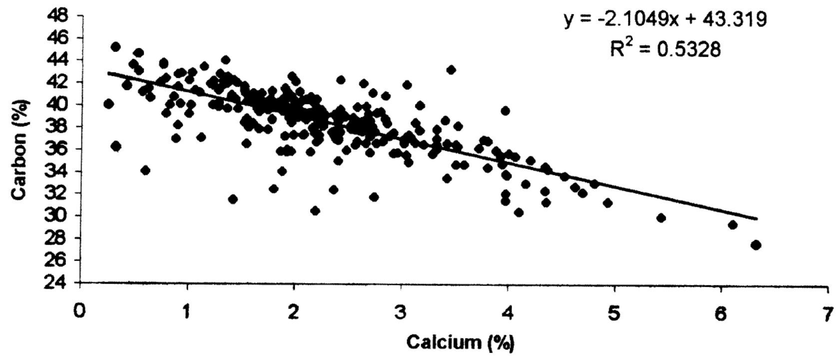

Figure 2. Regression equation for bark.

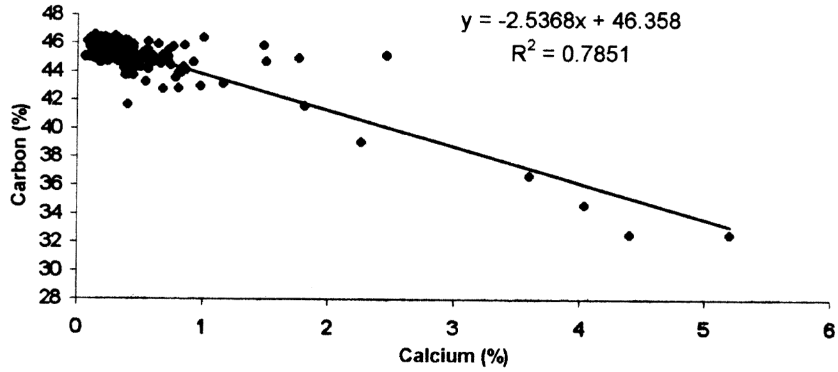

Figure 3. Regression equation for wood.

Wood: Prediction equation was developed between carbon content and Ca content by plotting 283 observations. Wood generally contains small amount of Ca. The points were close to the prediction line and the prediction equation gave 89% accuracy (Figure 3).

On an average, carbon content in different parts of various species depends upon the ash content and the ash content depends upon the amount of structural components. More the structural tissue higher will be the ash content and lower will be the carbon content. Thus ash and Ca content showed decreasing trend of bark < leaf < wood, whereas the carbon content showed the increasing trend of bark > leaf > wood (Table 2).

These observations reveal that the wood, which constitutes maximum portion of total biomass, stored maximum amount of carbon. While comparing the different life forms, it was observed that the maximum carbon is stored in the order of conifers > deciduous > evergreen > bamboos. Thus it can be said that the conifers are more efficient in carbon sequestration.

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