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Seasonal pattern of total soil respiration in an age series of Eucalypt plantation and mixed broad-leaved forest in tarai belt of Kumaun Himalaya

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Abstract. Rates of CO_2 efflux under plantations of 1-yr to 8-yr-old *Eucalyptus* (the hybrid *E. tereticornis* Sm.) and in adjacent natural mixed broadleaved forest were measured by alkali absorption method. The seasonal pattern of soil respiration was similar in natural forest and the plantations with a maximum during the the rainy season, intermediate during the summer season and a minimum during the winter season. Soil respiration and various soil physical characteristics decreased as a result of reafforestation with *Eucalyptus* and there was a further decrease with increasing age of the plantation. Among the edaphic conditions, soil organic C, total N, P, K, soil moisture and porosity positively affected total soil respiration,while bulk density inversely affected the same.

Key words: Metabolic activity, plantation development, *Eucalyptus tereticornis*, edaphic conditions

Introduction

Under the afforestation scheme, monocultures of fast growing trees, such as Eucalypts and Populars are introduced after clear felling the uneven-aged natural mixed broadleaf forests in the tarai belt (the exposed zone with a pronounced deposition of finer materials and abundant surface water) of Central Himalaya. This is to cope with an increasing demand of pulpwood and other wood products. The composition and productivity of such ecosystems is markedly affected by the physical and chemical properties of its soil and soil properties vary across the landscape, due to the modifying affect of microbial activity on soil-formation and geomorphic processes (Coleman *et al.* 1983).

Few studies on changes in soil metabolic activity following tree plantation have been conducted in the humid tropics (Stewart and Kellman 1982; Kadeba and Aduayi 1985). Total soil respiration accounts for the metabolic activities in and on the soil surface due to microbes, roots and fauna, as a result of which CO_2 is released (Tewary *et al.* 1982). Thus soil respiration is a major index of total metabolic activity in the soil (Edwards 1982; Teuben 1991). However, CO_2 evolution from mineral soil should also be taken into account (Cropper *et al.* 1985).

In the present investigation, dealing with total soil respiration under indigenous natural mixed broad leaf forest and 1 to 8-yr-old *Eucalyptus* hybrid (*E. tereticornis* Sm.) plantations, the objectives were:
(i) To determine the dependence of soil respiration on selected edaphic conditions and seasonal variations when the starting conditions of all the plantations were the same (Bargali 1990).
(ii) To show whether the soil metabolism in terms of soil respiration (i.e. CO_2 output) changes following establishment of pure *Eucalyptus* in subtropical natural forests in the tarai belt.

Material and Methods

Study sites

The study was conducted in the tarai belt of Kumaun Himalaya, India (29°3' to 29°12' N and 79°20' - 79°23' E) at an altitude of 280 m. The total basal cover, that is the ground surface occupied by stems of trees ($50.8\ m^2.\ ha^{-1}$), in the natural broadleaf forest was comparable with that of other similar forests of the region.

The climate of the region is subtropical monsoon, with a long dry season from early October to mid-June and a wet season from mid-June to early October. The monthly rainfall and temperature are indicated in Fig. 1. Of the annual rainfall (1593 mm average for 1985-1989), about 86% occurs from mid-June to September. The mean monthly temperature ranges from 14.4° (January) to 31.3° C (June).

Geologically, tarai is characterized by tertiary sediments consisting of lower sandstones of old tarai deposits washed from the Himalayan mountains. The soil is deep and fertile, moist alluvial loam conspicuously free from boulders and gravels.

Immediately after clear felling of the natural forest the site preparation techniques were followed (Bargali and Singh 1991, Bargali *et al.* 1993) and plantations were raised with stocking density of 2,000 individuals ha^{-1}.

Measurement of total soil respiration

Soil respiration was determined *in situ* by using the alkali absorption technique (Gupta and Singh 1977). The rates of soil respiration were measured within the intact litter layer using aluminium cylinders (13 x 23 cm) inserted 10 cm into the ground and a 1:20 ratio of alkali absorption to soil area, as recommended by Kirita (1971). Three replicates of the experimental cylinders were set up, and one set of three control cylinders (13 x 13 cm, equivalent to the aboveground part of the experimental cylinders), capped with airtight lids at both ends. Before each cylinder was fixed, the green vegetation within the cylinder was clipped. A 50-ml beaker containing 20 ml 0.5 N NaOH (determined as given in Gupta and Singh 1977) was hung on a thin wire in each cylinder. The alkali was titrated against N HCl after a 24h absorption period to avoid diurnal variations (Harris and Van Bavel 1957). The cylinders were placed randomly, and on each sampling date the soil temperature was measured with a soil thermometer. The CO_2 evolved during the experiment was calculated by the following formula (Misra 1968).

$$\text{mg } CO_2 = V \times N \times 22$$

where V represents titration of the blank minus the samples titration and N is the normal acid value.

After the soil respiration measurements had been taken, the soil cores were removed and immediately taken to the laboratory for further soil analyses. Soil texture, bulk density, water holding capacity and porosity were determined according to Misra (1968). The pH of soil was determined by a digital pH-meter; total nitrogen by micro-Kjeldahl technique (Peach and Tracey 1956); total phosphorus with a spectrophotometer, total potassium with a flame photometer, and organic carbon by the wet oxidation method (Jackson 1958).

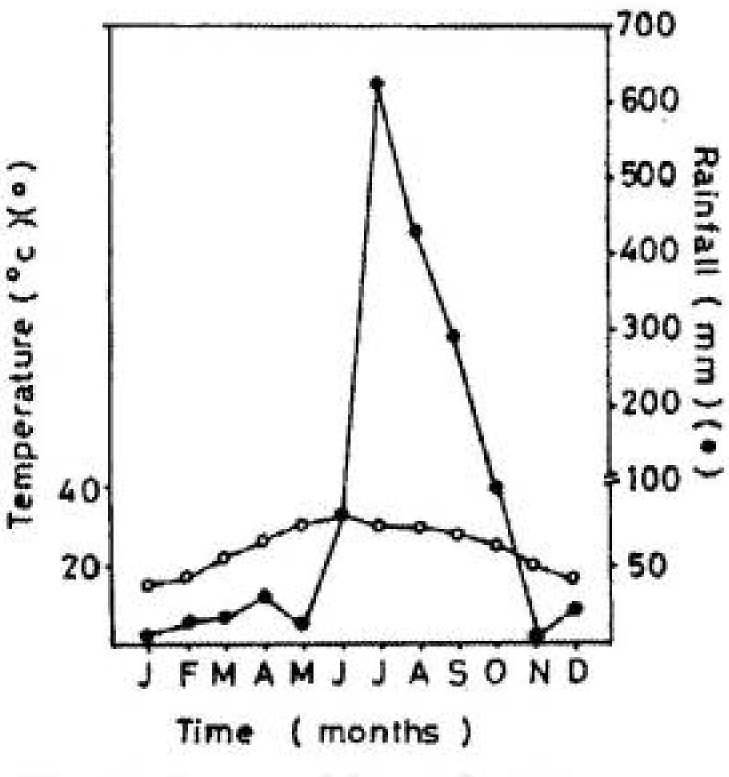

Fig. 1. Climatic diagram of the study area

Statistical analyses

The seasonal mean respiration rates, expressed as the production of CO_2 per square meter per hour, were subjected to linear regression analysis to relate the soil respiration (dependent variable, Y) to the soil characteristics (independent variables, X) across the plantation age. The linear regression equations used was of the type $Y = a + bX$, where a is the Y-intercept, and b is the slope or regression coefficient. Data of natural broad-leaf forest and different ages of the plantations were compared by using analysis of variance (ANOVA) and Student's t-test following Snedecor and Cochran (1968).

Results

Edaphic conditions

In all the *Eucalyptus* plantations the proportion of sand was higher than in natural mixed broadleaf forests which is considered as a base line. The proportion of sand increased from 21% in natural forest to 24% in the 1-yr-old plantation and with a further increase to 33% as the plantation aged. Soil bulk density increased significantly ($P<0.05$) from 1.12 to 1.45 with plantation development. Water holding capacity, soil moisture content and porosity showed trends opposite to that of bulk density. The water holding capacity decreased only slightly ($P<0.05$) from 84% (1-yr-old plantation) to 82% (8-yr-old plantation). Porosity changed more drastically ($P<0.01$) from 61% in the 1-yr-old plantation to 44% in the 8-yr-old one. Soil moisture (averaged across all seasons) decreased significantly from 30% in natural forest to 26% in the 1-yr-old plantation ($P<0.05$) and with a further decrease to 19% in the oldest plantation age ($P<0.01$). Soil moisture was significantly ($P<0.01$) higher in the rainy season than during other seasons (Fig. 2).

The natural forest soil was alkaline, with a pH of 7.2. The pH value of the soil under the 1-yr-old to 3-yr-old plantations were slightly lower than those of the natural forests but still above 7. In the older plantations the soil had become slightly acidic with a tendency to a further decrease with increasing plantation age.

Organic carbon (averaged across three season) was slightly higher in the eutrophic soil of the natural forest viz., 4.0% against 3.7% in the youngest *Eucalyptus* plantation. In the older plantations there was a steady decrease to 2.2%. As to the nutrients (averaged across the seasons) values for total nitrogen, phosphorus and potassium were all lower in the plantations as compared to the natural forest. For P the corresponding figures are 0.009-0.005 against 0.012%, and for K 0.16 to 0.10 against 0.17%. Seasonal pattern showed that the values for organic carbon and all the nutrients were highest in the rainy season and lowest in the winter season (Fig. 2).

Soil respiration

Total soil respiration (mg CO_2 m^{-2} h^{-1}) followed a similar seasonal pattern (Fig. 2) in all the plantations and natural forest, the values being highest during the rainy season (459 mg CO_2 m^{-2} h^{-1} in natural forest to 247-426 mg CO_2 m^{-2} h^{-1} in plantantions) and lowest during the winter season (91 mg CO_2 m^{-2} h^{-1} in natural forest to 129-222 mg CO_2 m^{-2} h^{-1} in plantantions). The rainy season value was approximately twice the summer value at all sites, and five to eight times higher than the winter value. The difference between the rainy season and the winter season was greater in older plantations.

In all the *Eucalyptus* plantations soil respiration (averaged across the seasons) was lower than in the natural forest and it declined from 247 mg CO_2 $m^{-2}h^{-1}$ in natural forest to 222 mg CO_2 m^{-2} h^{-1} in the

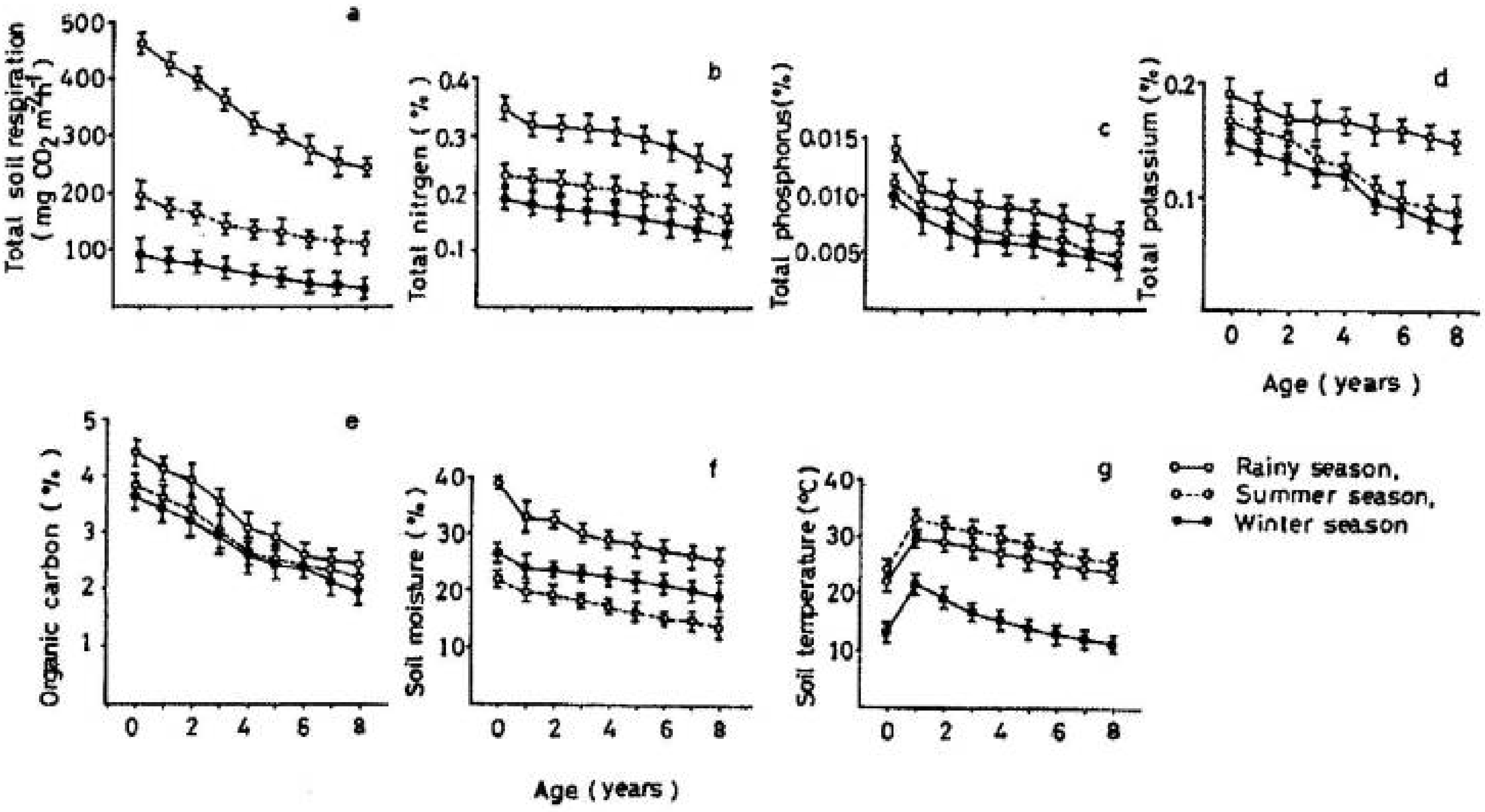

Fig. 2. Seasonal pattern of (a) total soil respiration (mg CO_2 m^{-2} h^{-1}), (b) nitrogen concentration (%), (c) phosphorus concentration (%), (d) potassium concentration (%), (e) organic carbon (%), (f) soil moisture (%) and (g) soil temperature (°C). Zero (0) indicates base line i.e., natural forest.

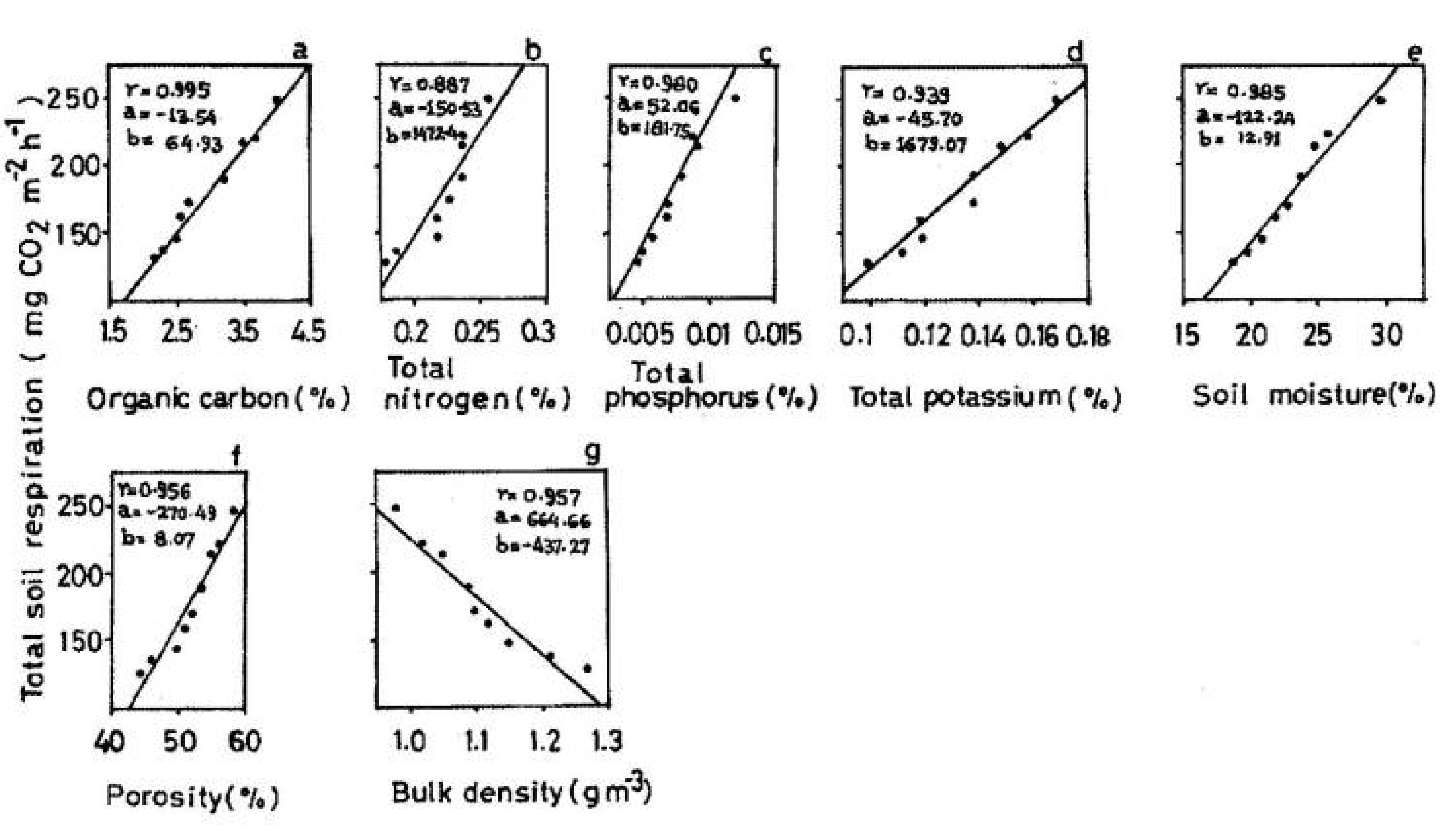

Fig. 3. Relationship between total soil respiration (mg CO_2 m^{-2} h^{-1}) and (a) organic carbon (%), (b) total N (%), (c) total P (%), (d) total K (%), (e) soil moisture (%), (f) porosity (%) and (g) bulk density (g.cm^{-3}). Correlation coefficients (r), intercepts (a), and slopes (b) are given. Values for regression, Y=a+bX, are given for statistically significant relationships (P<0.01). (All the values are averaged across the seasons).

youngest plantation, and there was a marked decrease ($P<0.01$) to 129 mg CO_2 m^{-2} h^{-1} with plantation age. ANOVA on total soil respiration data showed that the rate of respiration was significantly different for age series of plantations and among seasons. The interaction between plantations and seasons was also significant ($P<0.01$).

Linear regressions

A linear regression analysis based on the data (averaged across three seasons from natural forest and the plantations) indicated that among edaphic conditions organic C, total N, P, K, soil moisture, water holding capacity and porosity positively affected total soil respiration explaining respectively 99, 79, 96, 88, 97 and 91% of the variability, while bulk density had a significant inverse relationship explaining 92% of the variability (Fig. 3).

Discussion

The changes that occured in the physico-chemical characteristics of the soil show the same trend as reported by Bargali *et al.* (1993). The decrease in the proportion of fine soil particles during the early stage of plantations may be explained as an effect of the eroding influence of the rains on fine soil particles. The loss of fine soil, and increase in the sand fraction, and soil compaction occur which reduce the pore space available for microbial activity and lowers the moisture retention capacity of the soil (Elliot *et al.* 1980; Coleman *et al.* 1988). The organic matter and nutrient levels tend to decline especially in the early stages of development and most probably, the site preparation techniques prior to the planting have induced some initial soil changes (Bargali *et al.* 1993). Most reports on the soil changes following the replacement of indigenous forest canopy with exotics in tropical environments, usually occur during the first 10 years of plantation development (Lundgren 1978; Chijoke 1980; Kadeba and Adauyi 1985). These soil changes are due to vigorous growth of the exotic trees and rapid nutrient uptake from the top soil as the canopy and root system of the young plantations develop.

The removal of natural vegatation cover is a major ecological change, since a considerable part of the nutrient capital of the ecosystem is kept in the vegetation. When the vegetation is removed the soil tend to rapidly losse the fertility (King and Tuo 1982). There is an evidence that when the land is cleared and replanted with fast growing exotic trees in mono-culture, changes in organic matter and soil properties occur (Babalola and Samie 1972, Lundgreen 1978).

The most commonly used abiotic variables explaining observed respiration patterns are temperature and moisture (Weber 1985; Joshi *et al.* 1991). In the present study high moisture and moderate temperature during the rainy season resulted in markedly higher soil respiration. As the plantations aged, soil respiration decreased with decreasing soil moisture ($P<0.01$). Lowered soil respiration as a result of lower soil moiture regimes in the presence of optimal temperature has been documented previously (Gupta and Singh 1977; Weber 1985; Joshi *et al.* 1991). The available soil moisture enhances soil respiration by increasing microbial activity and decomposition of organic matter (Gupta and Singh 1977; Tewary *et al.* 1982; Joshi *et al.* 1991).

Linear regression analysis indicated that total soil respiration declined with a decline in organic carbon and soil nutrients (total N, P and K). Soil N increases soil respiration by providing a source of protein for microbial growth (Tewary *et al.* 1982; Joshi *et al.* 1991). Organic matter prevents soil compaction and increases pore space (Misra 1968). An inverse relationship ($P<0.01$) of total soil respiration with bulk density and a positive relation with porosity indicates the importance of pore space for microbial activity and moisture retention capacity of the soil. The available pore space also influences the trophic structure of soil microbes hence the rate of decomposition and mineralization (Elliot *et al.* 1980; Coleman *et al.* 1989).

In conclusions, in this climate dominated by the monsoon pattern of rainfall, there are wide seasonal variations in soil respiration that correspond to variation in soil moisture. The significant relationship of edaphic conditions and soil respiration reflects the major role played by microorganisms such as, soil fungi and bacteria in soil respiratory activities. The habitat having greater organic carbon, nutrients, moisture and porosity and lesser bulk density showed greater respiration. Comparisons between plantations and natural forest suggest that the ecosystem properties (edaphic conditions) that develop subsequent to clear-cutting of a natural forest bring about marked variations in metabolism of soil subsystems. The decrease in organic matter, nutrient concentrations, soil moisture, porosity and soil respiration with increasing plantation age, suggest that *Eucalyptus* plantations may indeed lead to soil degradation in the present short rotation of eight years. Modifications in soil structure and soil nutrients as described in this study are likely to occur in connection with clear-cutting of natural forests (Bormann and Likens 1979).

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