PATTERNS OF SOIL RESPIRATION IN A TEMPERATE GRASSLAND OF KUMAUN HIMALAYA, INDIA

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JOSHI, M. 1995. Patterns of soil respiration in a temperate grassland of Kumaun Himalaya, India. Soil respiration throughout an annual cycle was measured in a temperate grassland of Kumaun Himalaya (29°7' to 29°26' N and 79°15' to 79°38' E) at an average elevation of 1800 m. The CO_2 evolution was significantly higher during the rainy season (101 - 159 mg CO_2 m^{-2} h^{-1}) than during the winter and summer seasons (35 - 101 mg CO_2 m^{-2} h^{-1}). The proportion of root respiration to total soil respiration was significantly higher during the winter and summer (29 - 35%) than during the rainy seasons (25-26%). A significant ($p<0.01$) relation existed between soil respiration and soil moisture, soil temperature, total nitrogen, organic carbon and root biomass. This paper also highlights the changes in soil metabolic activity due to deforestation and grazing.

Key words: Soil respiration - temperate grassland - root respiration-metabolic activity - Kumaun Himalaya - deforestation

JOSHI, M. 1995. Pola-pola respirasi tanah di sebuah padang rumput beriklim sederhana di Kumaun Himalaya, India. Respirasi tanah sepanjang satu kitaran tahunan telah disukat di sebuah padang rumput beriklim sederhana di Kumaun Himalaya (29°7' to 29°26' N and 79°15' to 79°38 E) pada ketinggian purata 1800 m. Pembebasan CO_2 semasa musim hujan (101 - 159 mg CO_2 m^{-2} h^{-1}) adalah lebih tinggi daripada musim-musim sejuk dan panas (35 - 101 mg CO_2 m^{-2} h^{-1}). Nisbah respirasi akar kepada jumlah respirasi tanah adalah lebih tinggi semasa musim-musim sejuk dan panas (29 - 35%) berbanding dengan musim hujan (25 - 26%). Terdapat hubungan ketara ($p < 0.01$) di antara respirasi tanah dengan kelembapan tanah, suhu tanah, jumlah nitrogen, karbon organik dan biojisim tanah. Kertas ini juga menunjukkan perubahan dalam aktiviti metabolik tanah disebabkan oleh pembasmian hutan dan peragutan.

Introduction

The vegetation in the Himalaya ranges from tropical dry deciduous forests at the foot-hills to alpine meadows (generally between 3000 and 4000 m elevations) above the timber line. The grasslands below 3000 m elevation have resulted from lopping of trees, clear cutting and burning of forests which represent the natural vegetation (Singh 1991). Such grasslands have developed around human settlements and these areas are increasing with the receding forest boundaries (Joshi 1991). All these grasslands constitute grazing grounds for livestock of the inhabitants of the adjacent villages.

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Efforts to understand site productivity problems, where necessary, can be aided by the study of ecosystem processes. One of these processes is soil respiration (Weber 1985, Weber *et al.* 1985). Soil respiration accounts for the metabolic activities in and on soil surface due to microbes, roots and fauna, as a result of which CO_2 is released (Tewary *et al.* 1982). Attempts to partition soil respiration (i.e. CO_2 evolution) into microbial, mycorrhizal and root respiration for the purpose of estimating ecosystem carbon balance have been problematic (Minderman & Vulto 1973). However, CO_2 evolution measurement as a diagnostic tool for the overall assessment of relative biological activities has enjoyed continued attention over the years (Reiners 1968, Tewary *et al.* 1982, Joshi *et al.* 1991, Tuben 1991, Bargali *et al.* 1992).

Few studies on soil metabolic activity have been conducted in the Himalayan region (Tewary *et al.* 1982, Joshi *et al.* 1991, Joshi 1994) and most of the reports are from forest ecosystems. This study quantifies *in-situ* soil respiration with the objective of depicting the rate of soil respiration and its relationship with related edaphic conditions in a grassland of Kumaun Himalaya that has resulted from deforestation.

Materials and methods

Study site

The study was conducted at Kailakhan near Nainital town in Kumaun Himalaya (Figure 1), India (29° 7' to 29° 26' N and 79°15' to 79° 38' E) at an average elevation of 1800 m. The soil (0-30 cm) with a pH of 5.9 consisted mainly of sand particles (sand 76%, silt 14% and clay 10%), the water holding capacity was 40% and the bulk density 1.21 g cm^{-3} (Joshi *et al.* 1994).

The rocks present in the study area are commonly black carbonaceous and pyritous, locally oxidized to an ash grey colour, with characteristic oxidization rings on primary planes. Light-green- and grey-banded slates intercalated with thin layers of silt stone is another typical element of the lithology (Valdiya 1980).

The vegetation of the study site (open grassland with a few scattered trees of original banj-oak, *Quercus leucotrichophora,* forest) consisted of grasses and forbs such as *Cymbopogon distans* (dominant grass), *Arthraxon lanceolatus, Arundinella nepalensis, Gnaphalium hypoleucum, Dicliptera roxburghiana, Oxalis corniculata,* etc. The grassland has been subjected to grazing by livestock (cattle and goats) throughout the year, according to the nearby villagers. The continual removal of ground vegetation by livestock has prevented the establishment of trees and shrubs (Singh 1991). The species richness and primary productivity of the ground vegetation were 12 and 554 g m^{-2} respectively (Joshi 1991, Joshi 1995).

Climate

The climate is temperate monsoonal with a dry and warm summer season (March to May), a wet and warm rainy season (June to September) and a dry and cold winter season (October to February). More than 75% of the total annual rainfall of 2441 mm occurs between mid-June and mid-September. The mean daily

maximum temperature varies from 12.5 °C (February) to 23.8 °C (May) and the mean minimum from 7.2 °C (February) to 17.0 °C (June) (Figure 2).

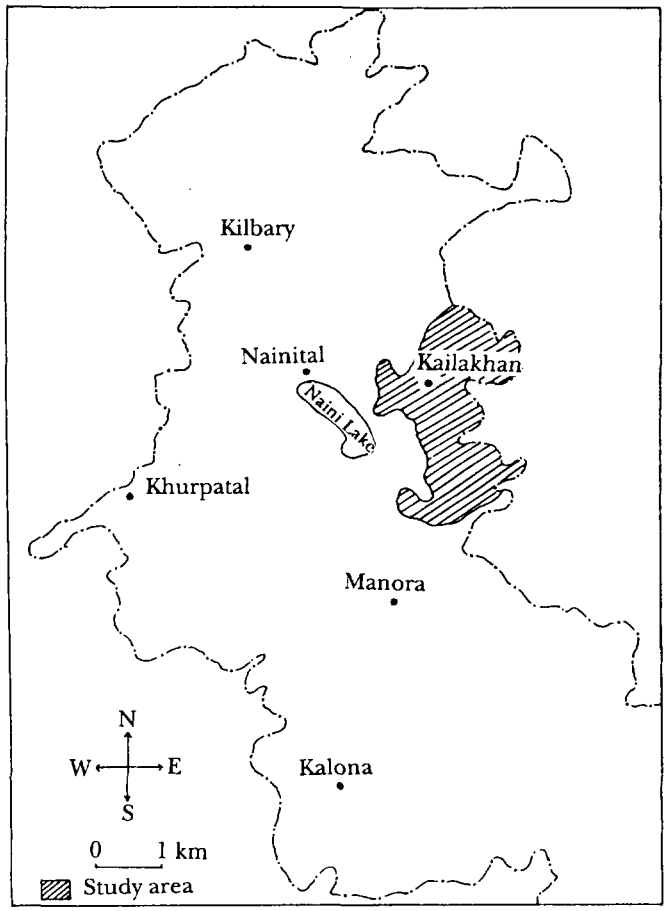

Figure 1. Location of study area

Data collection

Soil respiration was measured *in-situ* using an alkali absorption method (Gupta & Singh 1977) by inserting aluminium cylinders (13 × 23 cm) 10 cm into the ground and permitting a 1: 20 ratio of alkali absorption to soil area, as recommended by Kirita (1971). Nine replicates of experimental cylinders were set up with one set of three control cylinders (13×13 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 falling within the cylinder was clipped. A 50-ml beaker containing 20 ml 0.5 N NaOH (determined as given by Gupta and Singh 1977) was hung on a thin wire in each cylinder. The alkali was titrated against N HCl after a 24-h absorption period to avoid diurnal variations (Harris & van Bavel 1957). The cylinders were placed randomly, and on each sampling date (once a month) the soil temperature was measured with a soil thermometer.

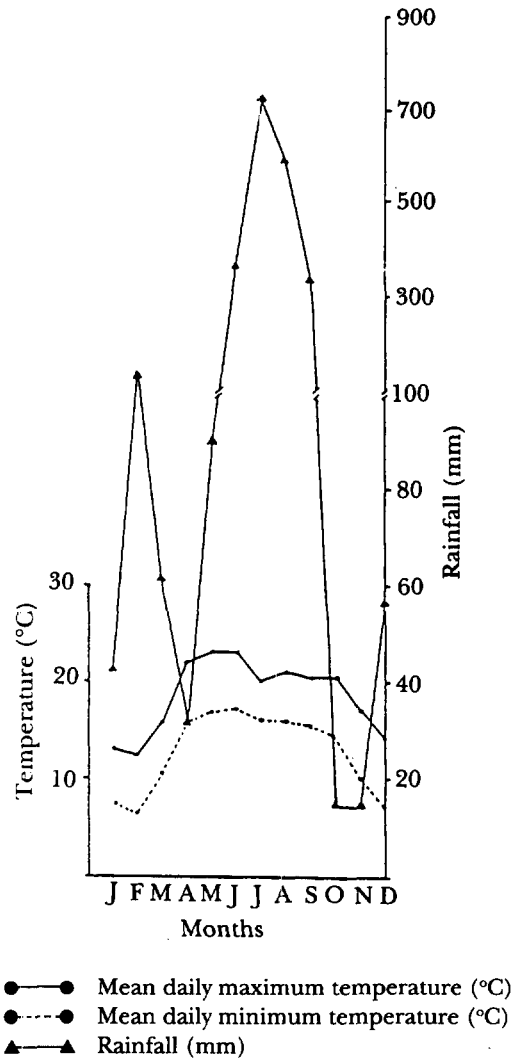

Figure 2. Climatic diagram (average of three years, i.e. 1988 - 1990) for the study area

The CO_2 evolved during the experiment was calculated by the following formula (Misra 1968):

$$mg\ CO_2 = V \times N\ 22$$

where V represents titration of the blank minus sample 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. Roots were collected separately from each soil core and the adhering soil particles were brushed off. Root

respiration was measured using cylinders (13 × 13 cm) capped at both ends. After measuring the root respiration, the root samples were weighed (fresh weight), oven dried and re-weighed for the quantification of root biomass and root moisture.

The soil samples (0-10 cm) were ground in a Wiley mill for nutrient analyses. Total N (%) was determined by the micro-Kjeldhal technique and organic C (%) by the wet oxidation method (Jackson 1958).

Statistical analyses

Mean respiration rates, expressed as the production of CO_2 m^{-2} h^{-1}, were subjected to regression analysis to relate the soil root respiration (dependent variable, y) to the soil root characteristics (independent variables). The linear regression equation used was of the type $y = a + bx$, where a is the y-intercept, and b the slope of regression coefficient (r) (Snedecor & Cochran 1967).

Results and discussion

The most commonly used abiotic variables explaining observed respiration pattern are temperature and moisture (Singh & Gupta 1977, Orchard & Cook 1983, Salonius 1983, Joshi *et al.* 1991). These two variables have a direct effect on CO_2 evolution by indirectly altering other abiotic parameters such as gaseous diffusion (Weber 1985). Furthermore, these abiotic variables often interact with each other (Boddy 1983). The overall role of temperature, however, is to set a general level of respiratory activity, while moisture acts as a secondary modifier, bringing substrate moisture variations above and below the optimal level for CO_2 evolution (Cowling & MacLean 1981, Weber 1985).

Seasonal pattern showed that the rate of soil respiration (Figure 3) was significantly higher ($p < 0.01$) during the rainy season (125-159 mg CO_2 $m^{-2}h^{-1}$) compared to other seasons (34 - 101 mg CO_2 m^{-2} h^{-1}). The higher respiration rates during the rainy season reflect the favourable effect of soil moisture and optimal temperature (Figure 4) on microbial activity and root metabolism, while low temperature decreases soil metabolic activities during the winter season. A linear regression analysis based on monthly data indicated that soil moisture, soil temperature and root biomass affected soil respiration positively ($p<0.01$ in all the cases) and showed 49, 70 and 60% variability respectively (Figures 5a,b,c).

Selected substrate characteristics such as organic matter and nitrogen concentration can also be used to interpret observed respiration pattern (Weber 1985). Over the months, soil respiration increased ($p<0.01$) in response to increase in total N and organic C (Figures 5d,e). The total N increases the rate of soil respiration by providing a source of protein for microbial growth (Tewary *et al.* 1982), and organic matter (mass of potential energy for microbial activity) prevents soil compaction and maintains pore space for microbial growth (Elliott *et al.* 1980, Coleman *et al.* 1988, Elliott & Coleman 1988). The available pore space also influences the trophic structure of soil microbes hence the rate of decomposition and mineralization (Elliott *et al.* 1980, Tewary *et al.* 1982).

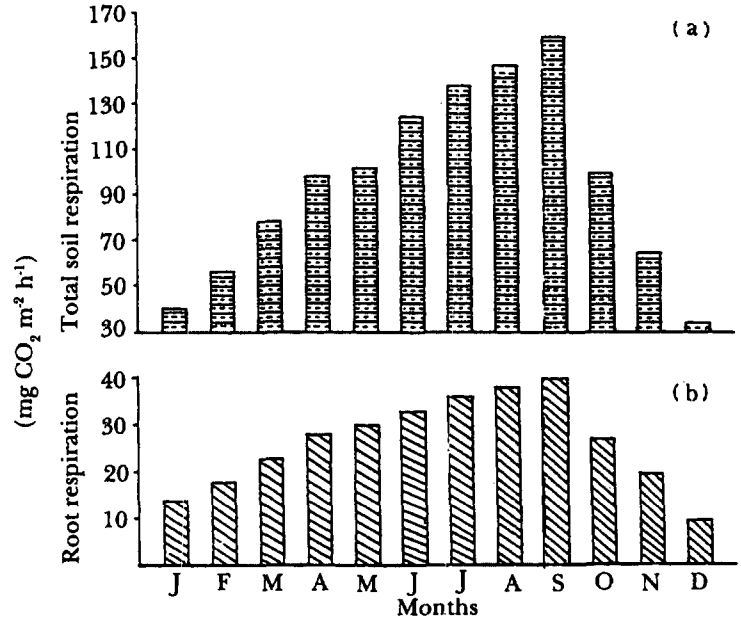

Figure 3. (a & b): Seasonal variation in (a) total soil respiration and (b) root respiration

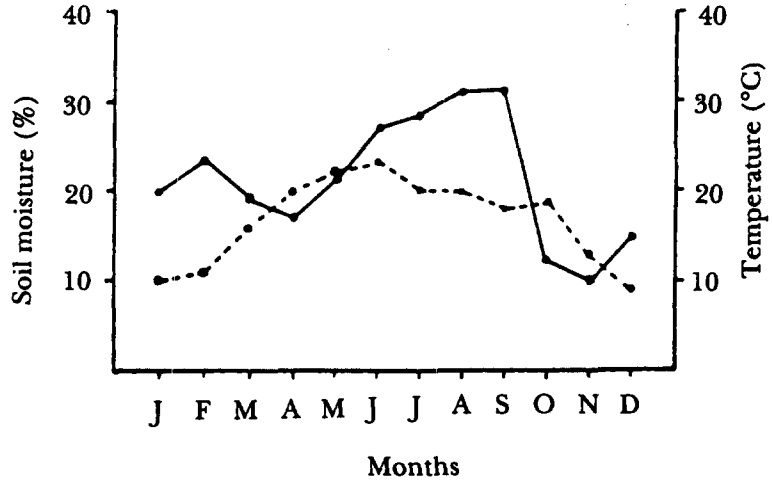

Figure 4. Soil moisture and soil temperature at different months
—— Soil moisture
---- Soil temperature

Seasonal pattern of root respiration (mg CO_2 m^{-2} h^{-1}) followed the same trend as the soil respiration, i.e. a maximum during the rainy season (Figure 3). The rate of root respiration is governed by factors such as age of the tissues, phenologic stage of the plants, proportion of live tissues, and their moisture content (Singh & Gupta 1977). In the present study, root respiration was positively related ($p<0.01$) to root biomass and root moisture (Figure 5f,g).

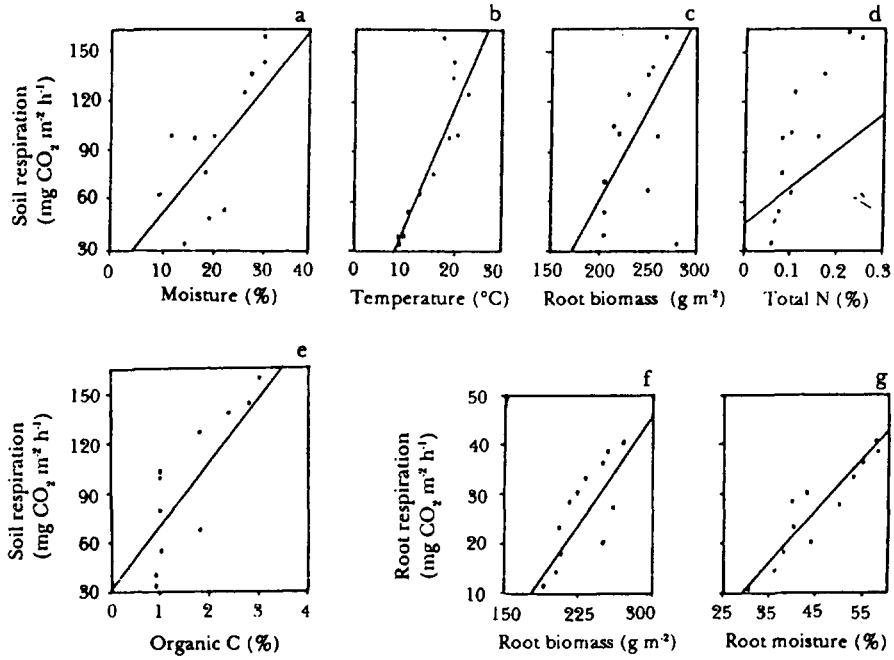

Figure 5. Relationship between total soil respiration and (a) soil moisture, (b) soil temperature, (c) root biomass, (d) total N, and (e) organic C (%); relationship between root respiration and (f) root biomass and (g) root moisture

Crapo and Coleman (1972), while studying the broom-sedge old field community in south Carolina, suggested that root respiration was proportional to root biomass. For any one sampling date, it can be assumed that the rate of respiration per unit area (m^{-2}) has a positive relation with the root biomass present. However, the same quantity of root biomass may respire at different rates under different environmental conditions (Gupta & Singh 1981). This was clearly reflected when the weight specific root respiration (mg CO_2 g $root^{-1}$ h^{-1}) was calculated (Figure 6). These estimates of respiration were significantly higher during the rainy season (0.14 - 0.149 mg CO_2 g $root^{-1}$ h^{-1}), when herb biomass attained its peak (Joshi 1995), compared to the winter and summer seasons (0.056 - 0.135 mg CO_2 g $root^{-2}$ h^{-1}). Since, the proportions of functional and non-functional root biomass also affect the rate of root respiration (Gupta & Singh 1981), a higher proportion of functional

biomass during the growing season (rainy season) seems to have affected root respiration per unit mass. However, it is not easy to separate functional and non-functional biomass components (Singh & Coleman 1973, 1974).

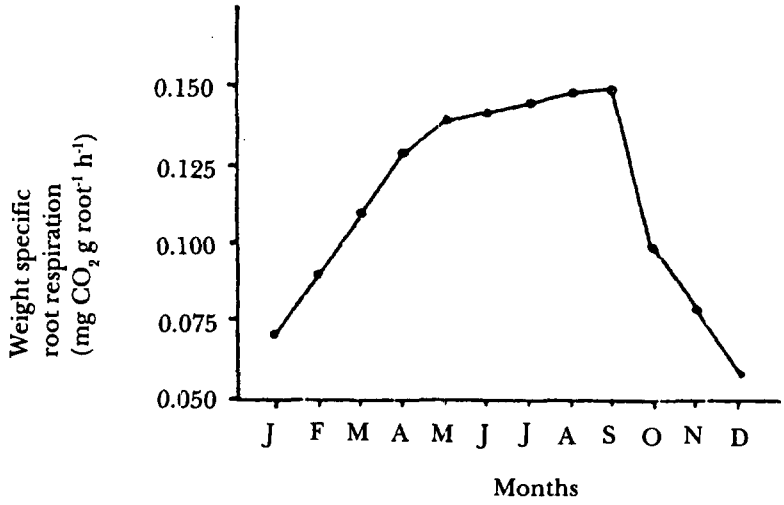

Figure 6. Weight specific root respiration at different months

Root respiration values represented a significantly ($p<0.05$) higher proportion of total soil respiration in the winter and summer seasons (29 - 35%) compared to the rainy season (25-26%) (Figure 7). This indicated that the winter conditions were less favourable to microbial respiration than to root respiration.

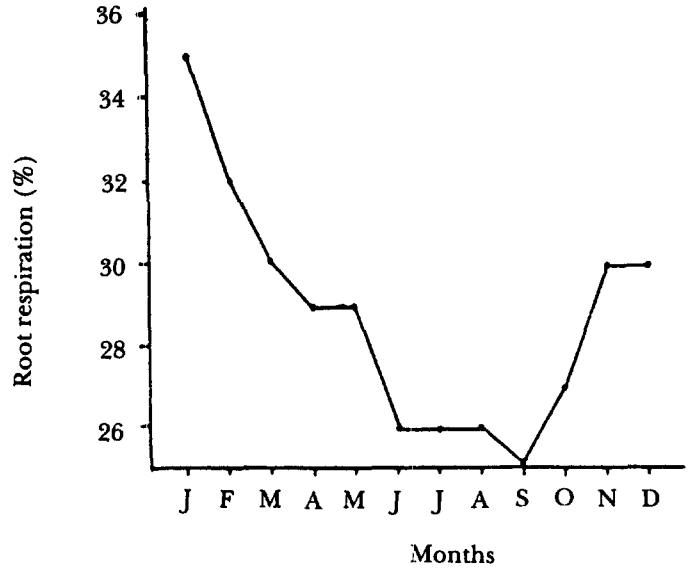

Figure 7. Contribution of root respiration to total soil respiration at different months

Conclusion

In this climate, dominated by the monsoon, there are great seasonal variations in soil respiration which is affected by soil moisture and temperature. The significant relationship between edaphic conditions and soil respiration reflects the major role played by microorganisms such as soil fungi and bacteria. Soil microorganisms play a key role in the decomposition of residue and the cycling of plant nutrients (Hutchinson & King 1982).

The temperate grasslands show great variability in the rate of CO_2 output from the soil. The method used may account for the variability (Singh & Gupta 1977). Most of the studies indicate a value in the range of 200-889 mg CO_2 $m^{-2}h^{-1}$. However, the studies of Coleman (1973), Redmann (1978) and Wildung *et al.* (1975) indicate similar or slightly higher rates of CO_2 output as observed in the present study (34-159 mg CO_2 m^{-2} h^{-1}).

The total soil respiration estimates of the present grassland are comparatively lower than the values for Central Himalayan forest ecosystems (38-362 mg CO_2 m^{-2} h^{-1}, Joshi *et al.* 1991), which represent the natural vegetation. This suggests that ecosystem properties (edaphic conditions) that develop subsequent to clear cutting and burning of natural forests bring about marked variations in the metabolism of soil subsystems. Joshi *et al.* (1994) reported that deforestation, grazing, burning, concomitant degradation of soil and changes in light and temperature regimes brought about marked changes in species composition, vegetation structure, organic production, microclimatic regime and soil properties. The removal of natural vegetation cover is a major ecological change, since a considerable part of the nutrient capital of ecosystem is kept in the vegetation. When vegetation is removed the soil metabolic activities tend to decrease (Bargali *et al.* 1992, Bargali *et al.* 1993), as evidenced by the low respiration rates in the present study. Modifications in soil structure and metabolic activity, as described in this study, are likely to occur after the removal of natural forests (Bormann & Likens 1979).

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