# Emission of carbon dioxide from soil

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*Carbon dioxide ($CO_2$) is an important greenhouse gas accounting for 60% of the total greenhouse effect. Soil is a major source for atmospheric $CO_2$. In the event of growing threats of global warming due to greenhouse gas emissions, reducing $CO_2$ emission by sequestering C in the soil is of prime importance. Soil management practices like increasing soil organic carbon content, reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro-aggregation and mulching can play an important role in sequestering C in soil.*

IN the last few decades there has been an increase in the emission of naturally occurring, radiatively active gases like carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$); popularly known as 'greenhouse gases'. These gases trap the outgoing infrared radiation from the earth's surface. This process, generally referred to as the greenhouse effect, adds to the net energy input of the lower atmosphere, and leads to regional and global changes in climatic parameters like temperature and rainfall. Human health, terrestrial and aquatic ecological systems, agriculture, forestry, fisheries, and water resources are sensitive to changes in climate. Amongst the greenhouse gases, $CO_2$ is the most important, accounting for 60% of global warming. The concentration of $CO_2$ in the atmosphere has increased from 280 ppmv at the beginning of the industrial revolution to the present-day value of 366 ppmv[1]. This increase is attributed to the anthropogenic activities, including fossil-fuel burning, deforestation, emission from automobiles, forest fires, etc.

Scientists working on global warming and climate change have recently focused attention on soil as a major source and sink for atmospheric $CO_2$ (ref. 2). Soil contributes 20% of the total emission of $CO_2$ to the atmosphere through soil respiration[3–5]. Besides disturbing the earth's heat budget, emission of $CO_2$ from the soil results in diminution of soil organic C pool, soil fertility and productivity. The objectives of this article are to review the research on (1) emission of $CO_2$ from the soil and the effect of various factors regulating the emission, (2) emission of $CO_2$ from different ecosystems, and (3) to suggest measures to increase the sink of $CO_2$ through C sequestration in the soil.

## Carbon reserves in the earth

The world's soils hold about twice (1400 1500 Gt C) as much carbon as the atmosphere. Carbon stored in agricultural soil is 170 Gt, while the entire vegetation contains 550 Gt C (ref. 6). Emission of $CO_2$ due to deforestation is considered to be a major source for atmospheric $CO_2$ (refs 7 and 8). Soils and vegetation together exchange 100 Gt C per year with the atmosphere and soil respiration alone contributes 50–75 Gt C per year[9]. The total C lost as a result of bringing land under crop cultivation the world over has been estimated at 54 Gt, in which the contributions of temperate grassland and tropical forest soils were substantial[10] (Table 1). In India, the amount of carbon stored in the soil is 23.4–27.1 Gt, which is 1.6 to 1.8% of the carbon stored in the world's soils[11].

## $CO_2$ emission from soil

Carbon dioxide is released from the soil through soil respiration, which includes three biological processes, namely microbial respiration, root respiration and faunal respiration primarily at the soil surface or within a thin upper layer where the bulk of plant residue is concentrated[12–14], and one non-biological process, i.e. chemical oxidation which could be pronounced at higher temperatures[15]. Processes affecting dynamics of soil carbon are presented in Figure 1. Soil microflora contributes 99% of the $CO_2$ arising as a result of decomposition of organic matter[16], while the contribution of soil fauna is much less[17]. Root respiration, however, contributes 50% of the total soil respiration[18].

Several studies have shown that factors such as soil texture, temperature, moisture, pH, available C (labile and non-labile components of soil organic matter), and N content of the soil influence $CO_2$ production and emission from the soil[19,20]. For root respiration, the source of C is photosynthates and its translocation to the root; while litter fall, root mortality, application of manures and crop residues provide carbon for microbial respiration in the soil. Soil organic matter includes a wide variety of organic substances ranging from freshly added leaves or manures to substances at varying stages of decomposition.

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**Table 1.** Mass of C present in different soils and its loss due to cultivation

| Soil type | Area ($10^6$ ha) | Organic C content (kg $m^{-2}$) | Mass of C in virgin soil (Gt) | Mass of C in cultivated soil (Gt) | Loss of C due to cultivation (Gt) |
|---|---|---|---|---|---|
| Temperate forest soil | 308 | 6.9–14.2 | 24.4 | 18.1 | 6.3 |
| Temperate grassland soil | 325 | 12.5–18.4 | 49.8 | 36.9 | 12.9 |
| Tropical forest soil | 439 | 7.1–14.5 | 47.3 | 35.1 | 12.2 |
| Tropical grassland | 161 | 9.4–17.8 | 21.4 | 15.9 | 5.5 |
| Saline sodic arid soil | 308 | 2.6–7.1 | 17.7 | 13.1 | 4.6 |
| Wetlands/Paddy soil | 89 | 11.9 | 10.6 | 7.8 | 2.8 |
| Histosol | 39 | 112 | 43.6 | 35.6 | 8.0 |
| Andosol | 31 | 23.7 | 7.3 | 5.4 | 1.9 |
| Total | 1727 | – | 222 | 168 | 54 |

Source, ref. 10.

Changes in agricultural practices can result in changes in both the pool size and turnover rates of soil organic matter. Jenkinson and Rayner[21] identified different carbon pools ranging from a decomposable pool with a radiocarbon age of less than 1 year, biomass pool (radiocarbon age of 25.9 years) and chemically stabilized pool (radiocarbon age of 2565 years). The decomposable and the biomass pools of carbon constitute labile carbon, which declines faster and is restored faster than the non-labile carbon and, therefore, is a more sensitive indicator of carbon dynamics of the system[22].

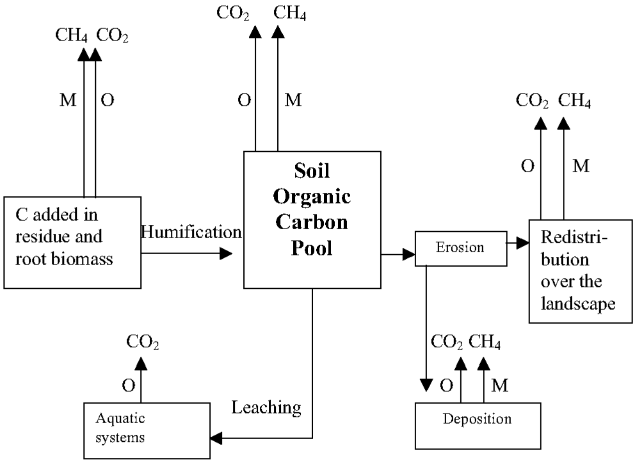

**Figure 1.** Processes affecting soil carbon dynamics. M, Methanogenesis; O, Oxidation. (source, ref. 89).

## Factors affecting $CO_2$ emission from soil

### *Temperature*

Temperature has a marked effect on $CO_2$ evolution from the soil. Edward[14] found a strong relationship between $CO_2$ evolution and mean daily litter temperature. Wiant[23] observed no $CO_2$ evolution at 10°C followed by a logarithmic increase in $CO_2$ evolution between 20 and 40°C; above 50°C, it declined rapidly. At higher temperatures partial inhibition of microbial respiration occurs, which is attributed to inactivation of biological oxidation systems. But Bunt and Rovira[15] found increased $CO_2$ evolution with a rise in temperature above 50°C also. Maximum $CO_2$ evolution rate was noted in mid-July (190 kg $CO_2$ $ha^{-1}d^{-1}$), which is attributed to the increasing role of root activity and organic matter decomposition with the increase in temperature. Increase in $CO_2$ emission with temperature is a matter of concern, as the possible global warming would increase $CO_2$ evolution from the soil that would accelerate the depletion of soil carbon and soil fertility. The $Q_{10}$ of 2.03 from 15 to 25°C for $CO_2$ emission in forest floor suggested that $CO_2$ emission was controlled primarily by soil biological activity[24]. Bouma *et al.*[25] reported that root respiration is affected by diurnal fluctuation in temperature ($Q_{10} = 2$). Sato and Seto[26] found that the rates of $CO_2$ evolution increased exponentially with increase in the incubation temperature from 4 to 40°C, the temperature coefficients ($Q_{10}$) were 2.0 for the forest soil and 1.9 for the arable soil. Chapman and Thurlow[27] also observed that rise in mean annual temperature of 5°C could potentially increase $CO_2$ emission by a factor of 2 to 4. It is estimated that 1°C increase in temperature could lead to a loss of 10% of soil organic carbon in the regions of the world with annual mean temperature of 5°C (ref. 28). While in the regions having a mean temperature of 30°C, 1°C increase in temperature would lead to 3% loss of soil organic carbon.

### *Moisture*

Soil moisture affects soil respiration and hence $CO_2$ evolution[29–31]. In general, increasing soil moisture would increase $CO_2$ evolution up to an optimum level, above which it would reduce $CO_2$ evolution. Periodic drying and wetting of soil has a pronounced influence on $CO_2$ evolution. When the soil is rewetted the activity of the microbes, which were in a latent state in the dry soil, increases accompanied by release of air trapped in the soil pores contributing to an increase in $CO_2$ evolution[32].

According to Casals *et al.*[33], rewetting a dry soil resulted in large increase in $CO_2$ efflux only at high temperatures. Borken *et al.*[34] observed that drought reduced soil respiration, while rewetting increased it by 48% to 144%. Drainage has been shown to increase annual $CO_2$ emission from forests soils[35]. In another study, $CO_2$ emission doubled when a rice field was subjected to drying[36].

Apart from the direct effects of temperature and moisture, the interaction of these two assumes great significance in view of the global warming and likely disturbance in precipitation pattern. However, Kowalenko[37] observed that temperature was the most dominant factor in determining $CO_2$ evolution from the soil. Moore and Dalva[38] simulated soil temperature and water table position to determine their influence on $CO_2$ emission. At 23°C emission of $CO_2$ was 2.4 times larger than that at 10°C and $CO_2$ emission showed a positive, linear relation with water content of the soil. Bijracharya *et al.*[39] also observed a significant correlation of C flux from the soil with soil temperature ($R^2 = 0.8$) and air temperature ($R^2 = 0.8$), but not with soil moisture. Grahammer *et al.*[40] observed that under dry soil condition soil respiration was greater during the day than at night, while day and night soil respiration rates were similar when the soil was wet. This is attributed to a reduction in the variability in soil temperature when the soil is wet.

### *Diurnal, seasonal and spatial variability*

There are considerable variations in $CO_2$ emission during different periods during the day and night. Medina and Zelwer[41] observed that soil respiration values at night were always higher than the day values due to the presence of higher relative humidity at night, which favours the activity of microbiota, and to high soil temperature at the beginning of night. Harris and van Bavel[42] found maximum rate of root respiration in tobacco, corn and cotton plants at 4 p.m. and minimum rate between 2 and 10 a.m., while Makarov[43] reported highest value for soil respiration between 9 a.m. and 3 p.m. Bijracharya *et al.*[39] also observed peak C flux during the mid-afternoon. All these suggest that soil temperature, which accounts for most of the temporal variability of $CO_2$ efflux, is by far the most influential factor controlling soil respiration rate[44].

Soil respiration is maximum during the growing season coinciding with the period of maximum growth of crops[45]. Seasonal $CO_2$ flux is maximum in spring followed by summer, autumn and winter. In spring, neither temperature nor moisture is limiting, resulting in better crop growth and higher soil respiration. In summer, moisture becomes limiting and in winter the limiting factor is temperature, hindering crop growth and soil respiration. On comparing summer and winter $CO_2$ fluxes, Piao *et al.*[46] and Bajracharya *et al.*[39] concluded that $CO_2$ evolution was generally higher in summer than in winter, while in autumn it was intermediate[44]. Flux of $CO_2$ from bare soil of Rothamsted, England varied from 15 kg $ha^{-1}$ $d^{-1}$ in winter to 60 to 70 kg $ha^{-1}$ $d^{-1}$ in summer[47]. Buyanovsky[48] calculated evolution of $CO_2$ from the surface of a soil cultivated with wheat. The values varied from 40 to 80 kg $ha^{-1}$ $d^{-1}$ in spring, but in winter when soil temperature was below 5°C, $CO_2$ evolution was less than 10 kg $ha^{-1}$ $d^{-1}$. In spring, as the ambient temperature increased, $CO_2$ production in the soil profile increased rapidly by 2.0 to 3.2 fold. Higher $CO_2$ emission observed in maize crop (61.7 kg $CO_2$ $ha^{-1}$ $d^{-1}$) was attributed to favourable temperature and moisture conditions during its growth (July to October), while lower emission for the wheat crop (36.7 kg $CO_2$ $ha^{-1}$ $d^{-1}$) was due to lower temperature during November to January[49].

Spatial variability of soil respiration may occur at a scale smaller than 15 cm, which is attributed to the contribution of plant roots as maximum soil respiration during the growing season coincided with the period of maximum root growth[50]. However, in another study, $CO_2$ emission exhibited spatial variability at a scale of more than 50 m (ref. 51).

### *Soil texture*

Soil texture affects the spread of microbial propagules and the growth of bacteria and fungi through the supply of air and moisture, and thus affects formation of $CO_2$. Water infiltration and gas diffusion rates are also greatly influenced by soil texture and thereby $CO_2$ formation and emission. Kowalenko and Ivarson[37] observed that $CO_2$ evolution was greater from clay loam soil (6.2 kg $CO_2$ $ha^{-1}$ $d^{-1}$) than sandy soil (3.3 $CO_2$ kg $ha^{-1}$ $d^{-1}$).

### *Soil pH*

Hydrogen ion activity (pH) of soil has a marked effect on the growth and proliferation of soil microbes. In soils with pH 3.0, 2 to 12-fold less $CO_2$ efflux has been observed than the soils at pH 4.0 (ref. 52). This is attributed to adverse effect of low pH on soil microbial activity, which contributes to lower respiration rate and consequently lower $CO_2$ evolution. Kowalenko and Ivarson[37] have reported an increase in $CO_2$ evolution with pH. However, soil pH beyond 7.0 adversely affected $CO_2$ emission[53]. At pH 8.7, $CO_2$ emission reduced by 18% compared to that at pH 7.0 and when the pH was increased to 10.0 the extent of reduction in $CO_2$ emission was 83%.

### *Salinity*

Excess amounts of salt have adverse effects on physical, chemical and microbiological processes in soil, including C and N mineralization and enzyme activities, which are crucial for decomposition of organic matter. Pathak and Rao[54] recorded a progressive decrease in $CO_2$ evolution with increase in soil salinity. Organic manure amendment, however, increased biologically evolved $CO_2$ from these soils, except at a very high salinity (ECe 70 and 97 d S $m^{-1}$) where the emission remained low.

### Atmospheric pressure

Baldocchi and Meyers[55] noted that low atmospheric pressure increased $CO_2$ emission from a deciduous forest soil indicating that decrease in atmospheric pressure triggered the escape of $CO_2$ stored in the peat profile to the atmosphere. Some other studies[56] have also shown that atmospheric pressure is inversely related to the emission of $CO_2$.

### Organic manure application

Application of organic manure in soil can increase $CO_2$ emission[53,56–58]. McGill *et al.*[59] proposed that soluble organic C in the soil is an immediate source of C for soil microorganisms, which in turn emit $CO_2$. Large quantities of organic manure that are added to agricultural soils every year for supplying nutrients to crops may contribute significantly to $CO_2$ emission. Application of sewage sludge can also enhance $CO_2$ emission[60]. Alvarez *et al.*[61] found that increase of $CO_2$ emission from the soil represented 21% of C applied through sludge. Incorporation of straw increased $CO_2$ flux from 0.3 to 1.3 kg $CO_2$ $ha^{-1}$ $d^{-1}$ (ref. 62). The application of straw on the soil surface increased $CO_2$ fluxes, but the effect was small when straw was incorporated in the soil. Unlike straw, there was no significant difference in $CO_2$ production between the injected and surface-applied pig slurry treatments in a loamy soil[63].

### Fertilizer application

Application of nitrogenous fertilizer affects $CO_2$ emission (1) directly by providing nitrogen to crops and microbes, and (2) indirectly by influencing soil pH, which influences microbial activity[64]. There was 30–40% reduction in $CO_2$ emission with the addition of $NH_4NO_3$ fertilizer, which was due to reduced microbial respiration by increased acidity[52]. Bowden *et al.*[65] also showed reduced $CO_2$ emission with N fertilization. Aerts and Toet[66] suggested that increase in the supply of $NH_4^+$–N leads to reduction in the decay of organic matter and loss of C. The addition of nitrogenous fertilizer leads to a decrease in $CO_2$ evolution, but phosphatic fertilizer had no effect when compared with unfertilized control. Conversely, Rochette and Gregorich[67] observed that application of inorganic N had little effect on $CO_2$ emission, while manure amendment increased soil respiration by a factor of 2 to 3.

### Use of nitrification inhibitors

Nitrification inhibitors, viz. dicyandiamide, nitrapyrin, thiosulphate and acetylene inhibit nitrification, a microbially mediated process[68]. Therefore, they may act on microbes engaged in the oxidation of organic carbon. In a greenhouse study, encapsulated calcium carbide (a slow release source of acetylene) reduced $CO_2$ emission and appeared to be effective in minimizing emission of this greenhouse gas from flooded rice[69]. However, studies on the effect of nitrification inhibitors on $CO_2$ emission are limited and need further investigation.

### Crops

Presence of crops influences $CO_2$ production and emission from the soil. Production of $CO_2$ is approximately 2 to 3-fold greater in cropped soil compared to bare soil[70]. Within different crops also there is variability in $CO_2$ production.

### Tillage

More $CO_2$ emission can occur from a tilled than from an undisturbed soil (no tillage) as tillage produces a soil microenvironment favourable for accelerated microbial decomposition of plant and animal residues[45,71–73]. Tillage breaks down soil aggregates, helps in mixing soil and organic particles, improves infiltration and water-holding capacity and thereby increases $CO_2$ production, while reduced tillage is reported to reduce emission of $CO_2$ due to less ploughing of soil and keeping the soil organic C unexposed. According to Ball *et al.*[74], low or zero $CO_2$ fluxes under no-tillage are associated with reduced gas diffusivity and air-filled porosity, while increased $CO_2$ emission with ploughing is due to degassing of soil $CO_2$. Ellert and Janzen[75], however, observed that immediately after tillage, $CO_2$ fluxes along the tilled transects increased from 2 to 4-fold above pre-tillage fluxes, but the increase was short-lived and fluxes along undisturbed and tilled transects were similar within 24 h of cultivation. The effect of tillage is confined not only to diffusibility, but also higher $CO_2$ production. Dao[76] observed that the proportion of soil organic C respired in the 60-day period was twice as great under mould-board plowing than under no tillage. Tillage enhanced C mineralization and atmospheric fluxes, suggesting that tillage intensity should be decreased to reduce C loss from the soil.

## $CO_2$ emission from different ecosystems

Emission of $CO_2$ from different ecosystems has been discussed below. It may be noted that an ecosystem may have low rate of $CO_2$ emission but a large areal extent, and therefore, total $CO_2$ flux could be more. Effluxes of $CO_2$ from different biomes vary markedly with the taiga biome having the highest amount of $CO_2$ emission and the polar desert, the least (Table 2).

### *Peat lands*

Peat lands and other wetlands play a major role in the regulation of the atmospheric $CO_2$. Peat lands of northern latitudes represent an enormous store of organic C and are primarily sinks of $CO_2$, as assimilation of carbon through photosynthesis generally exceeds the release through the decomposition of plant litter[77]. Efflux of $CO_2$ from peat land to the atmosphere is a function of plant root respiration and decomposition of plant material and peat in the soil profile. The rate of carbon dioxide production is greatest in the upper part of the peat profile and is related to the botanical origin of the peat[41] and also to temperature, water content and availability of $O_2$ (refs 78–80). Glenn *et al.*[81] measured $CO_2$ fluxes of 16.4–127.4 kg $ha^{-1} d^{-1}$ from drained horticulture peat soils in southern Quebec. On the contrary, large boreal peat land ecosystems sequester C from the atmosphere due to a low oxygen pressure in waterlogged peat. However, when such soils are brought under cultivation they become large emitters of $CO_2$ (ref. 82). In response to global climate change resulting in elevated temperatures and lower water table, peat lands may become a net source rather than a sink of $CO_2$ (refs 77 and 83).

### *Forests*

In boreal aspen forest, the soil $CO_2$ efflux ranged from 6.3 to 96.8 kg $CO_2$–C $ha^{-1} d^{-1}$ and soil temperature was the most effective variable to predict soil $CO_2$ efflux[84], but in acidic forest soil flux of $CO_2$ was much lower[85]. At a productive temperate deciduous forest in USA, the $CO_2$ flux was 13.9 kg C $ha^{-1} d^{-1}$ (ref. 65). Forest is also a major sink of atmospheric $CO_2$. According to Lal and Singh[86], Indian forest and plantations remove about 0.13 Gt of $CO_2$ per annum from the atmosphere.

### *Deserts*

There is substantial emission of $CO_2$ from desert soil because of the presence of calcium carbonate. For example, from Chihuahuan desert range-land soil, which contained 2.3% carbonates, emission ranged from 9.6 to 40.7 kg $CO_2$ $ha^{-1} d^{-1}$ (ref. 87) and was higher than most forest ecosystems[88]. The two major factors influencing $CO_2$ evolution from desert are moisture and temperature. Moisture not only limits microbial activity in the soil but also serves as a constraint for plant growth and hence, input of C to the soil[87].

## Sequestration of C in soil

Emission of greenhouse gases has become a matter of great concern because of the future projections of global warming and related effects on biological life. As mentioned earlier, $CO_2$ is the most important amongst the greenhouse gases. While nations struggle to lower the greenhouse gas emissions at source, complementary efforts must be made to enlarge the sinks of these gases. Increasing the net fixation of atmospheric $CO_2$ through C sequestration in the soil is one such option. Soil management strategies for C sequestration include three approaches (Figure 2). First, management of soil to maintain higher than existing levels of soil organic matter through reduced tillage and no tillage practices. Secondly, to manage carbon-degraded soils so as to restore soil organic matter levels. Wastelands in India cover more than 100 m ha, of which 70% is carbon-degraded. These soils

**Table 2.** Efflux of $CO_2$ (Tg C $yr^{-1}$) from different biomes

| Biome | Below ground mortmass decomposition | Litter decomposition | Soil organic matter decomposition | Root respiration |
|---|---|---|---|---|
| Polar desert | 0.2 | 0.2 | 0.1 | 0.2 |
| Tundra | 194.4 | 119.8 | 18.1 | 108.6 |
| Forest tundra/sparse taiga | 248.2 | 340 | 17.0 | 210.8 |
| Taiga | 476 | 996 | 42.0 | 672.7 |
| Mixed-deciduous forest | 168 | 246.4 | 11.2 | 243.0 |
| Forest-steppe | 341 | 233.2 | 11.0 | 221.7 |
| Steppe | 549 | 182.5 | 9.4 | 232.1 |
| Subtropical woodland | 2.6 | 2.2 | 0.1 | 2.3 |
| Desertsemi desert | 487 | 182.7 | 5.2 | 215.8 |
| Total | 2467 | 2273.1 | 114.0 | 1907.1 |

Source, ref. 91.

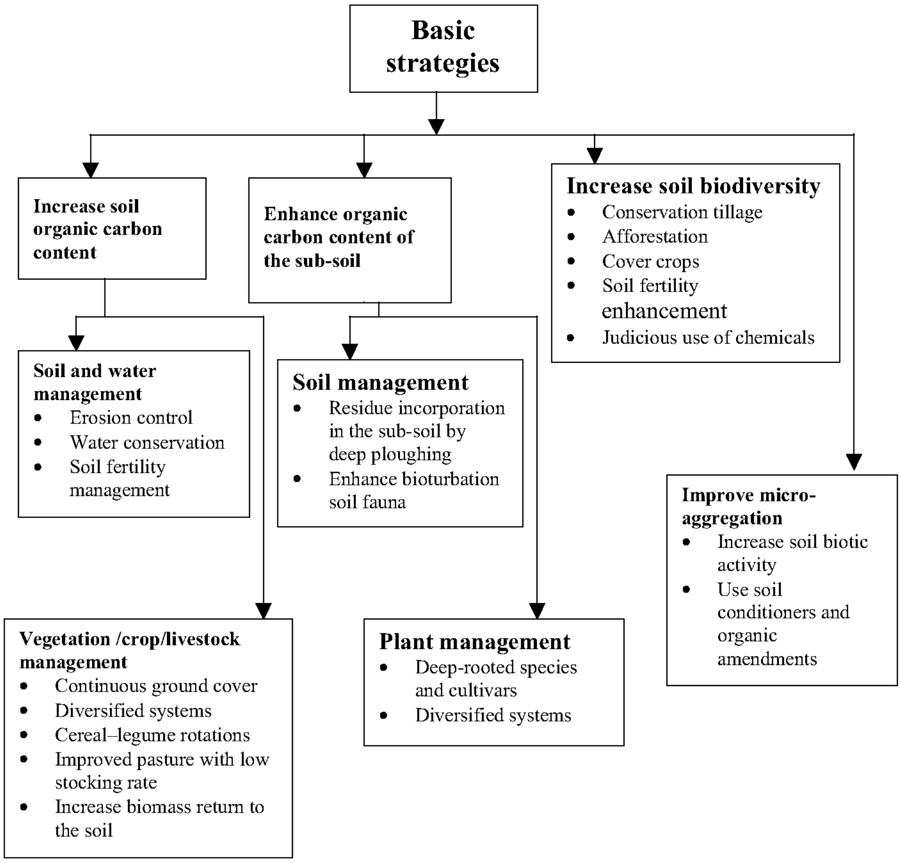

**Figure 2.** Strategies for carbon sequestration in soil (source, ref. 90).

have relatively high potential for accumulating organic carbon in vegetation and in soil, if suitable trees are grown along with proper soil conservation measures. Promoting agro-forestry in these lands is highly desirable. Thirdly, enlarging soil organic matter pools by improving soil fertility. Soil processes could be managed so that litter production exceeds decomposition. Such an approach of increasing carrying capacity of soils is difficult as it is determined by factors such as climate, that cannot be managed. Another approach could be to increase the passive or inert fraction of soil organic pool. This implies taking soil organic carbon out of the humification–mineralization cycle. This can be achieved through the increase of sub-soil organic carbon and micro-aggregation. Sub-soil organic carbon can be increased by growing deep-rooted plants and deep ploughing, while micro-aggregation can be increased by using soil conditioners, long-chain polymers and earthworms. Recently, eco-friendly farming practices like organic farming and precision farming are getting popular worldwide. Organic farming, where all the NPK requirement of crops is supplied through organic sources, has a great potential to enrich soil with organic carbon through sequestering C in soil. In precision farming site-specific crop management is done, keeping in account the variability in soil and micro-climatic conditions in the field, and wasteful use of inputs is avoided. All these farming practices are at their infancy in India and are being tested at various levels for their economic and environmental considerations. Research efforts should be made to quantify the C sequestration capacity and greenhouse gas emission potential of these practices. In India, the role of agroecosystem should be significant in terms of global greenhouse gas emission budget, since 45% of geographical area of the country is used for agriculture. Eco-friendly farming practices like organic farming, farming with reduced tillage and precision farming may play an important role in combating global warming.

## Conclusion

Soil is one of the major sources of atmospheric $CO_2$. However, it also serves as an important sink. There are several factors influencing $CO_2$ production and emission from the soil. These include inherent properties of the soil like texture, moisture, pH and salinity which influence $CO_2$ production through their effect on soil microbial activity and root respiration. Besides these, external factors (seasonal effect and atmospheric pressure) and manipulation of soil environmental conditions, viz. tillage, irrigation, fertilizer and manure application also have an effect on $CO_2$ production and emission. Adoption of C sequestration measures in the soil can considerably reduce the rise in atmospheric $CO_2$ level.

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Received 6 July 2001; revised accepted 4 January 2002

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# MEETINGS/SYMPOSIA/SEMINARS

### Eleventh National Symposium on Environment (NSE-11)

Date: 5–7 June 2002
Place: Udaipur

Topics include: Environmental pollution: Monitoring methods and pollution assessments; Environmental pollution remedial actions; Environmental radiological impact assessment; Regulatory aspects, pollution index; Aquatic, atmospheric, terrestrial and physico-chemical pollution; Use of agricultural wastes; Environmental pollution modeling.

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### International Seminar on Frontiers of Polymer Science and Engineering & Seventh National Conference of the Society for Polymer Science India

Date: 9–11 December 2002
Place: Kharagpur, India

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### 6th International Conference on Applications of Magnetic Resonance in Food Science

Date: 4–6 September 2002
Place: Paris, France

Topics include: Magnetic resonance – The developing scene; Food – The human aspect; Food structure and dynamics; Food quality control.

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