

Bioenergy crops: Soil and crop management practices

to reverse climate change

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Atmospheric carbon dioxide (CO₂) has considerably increased from about 280 in 1750 to 400 parts per million (ppm) in current situation. There are several negative consequences of rising CO₂ concentration. Soil is a major reservoir of carbon. There are certain soils and crop management practices by which we can sequester atmospheric CO₂ in soil, out of which growing bioenergy crops in soil is one of the most promising option. Bioenergy crops sequester atmospheric CO₂ in soil through their profuse and deep rooting systems and their above ground biomass can be utilized for production of green energy. This article discusses various strategies of soil carbon sequestration and how to achieve it through growing bioenergy crops.

Key words: Bioenergy crop, Carbon pools, Carbon sequestration

SINCE industrial revolution, the human activities, especially the burning of fossil fuels and land use changes, have caused a considerable increase in the atmospheric CO₂ concentration. This increase in atmospheric CO₂ from about 280 ppm in 1750 (IPCC, 2001) to 400 ppm in current situation is causing substantial global warming. Potential adverse impacts of global warming include rise in sea level, increased frequency and intensity of wildfire, flood, drought, and tropical storm; changes in the amount, timing, distribution of rain, snow, and runoff and disturbance of coastal, marine and other ecosystems. To offset these adverse impacts, we need technically and economically feasible strategies. The strategy should be aimed at decreasing atmospheric CO₂, which is the main factor for climate change. For formulating effective strategies, knowledge of global carbon pool is

imperative by which we can identify the source and sink of carbon (C).

Global carbon pools

Basically there are five global carbon pools, the oceanic pool being

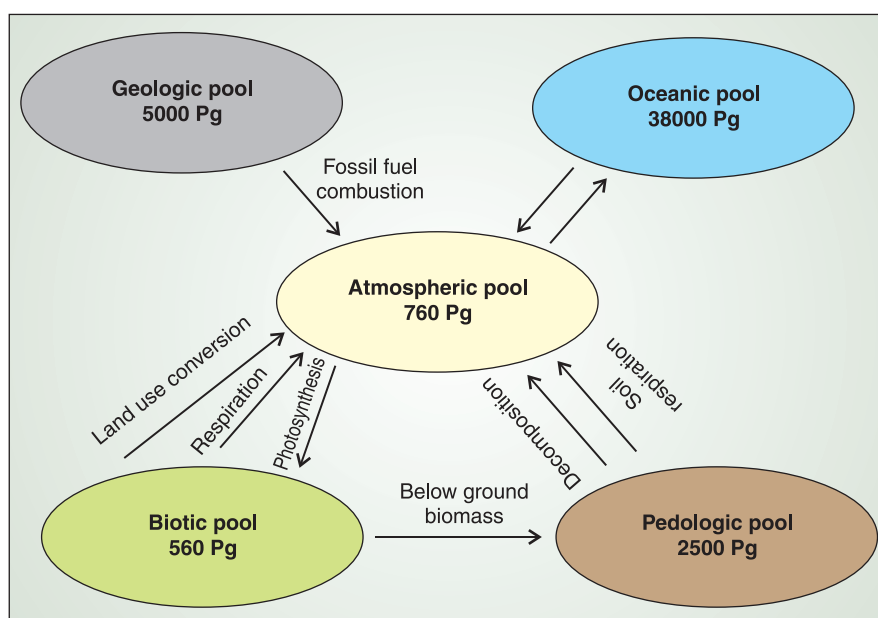


Fig. 1. Global carbon pool (Pg= Petagram)
Source: Adapted and modified from Lal et al. (2004)

the largest one, followed by the geologic, pedologic (soil), biotic and the atmospheric pool (Fig.1). These carbon pools are inter-connected and carbon circulates among them. The soil C pool consists of two sub-pools: soil organic carbon (SOC) and the soil inorganic carbon (SIC) pool. The SIC pool comprises calcium and magnesium carbonates in soil, thus have importance in soil of the dry regions and calcareous soil. The SOC is present in soil organic matter (SOM) and constitute approximately 58 % of SOM. The concentration of SOC ranges from low level in soil of the arid regions to high in soil of the temperate regions, and extremely high in organic or peat soil. It also varies widely among eco-regions, being higher in cool and moist than warm and dry regions. According to the estimate, the total soil C pool is about four times of biotic pool (trees, etc.) and about three times of atmospheric pool. Historic estimate of C loss indicates that from 1850 to 1998, 270 ± 30 Pg (Pg = petagram = 10^{15} g) of C were emitted from fossil fuel burning and cement production. Out of this, 176 ± 10 Pg C found its way to atmosphere and the remainder was absorbed by the ocean and the terrestrial sinks. Simultaneously, land use changes caused emission of 136 ± 55 Pg C. Hence, it can be interpreted that considerable amount (about 50 % of fossil fuel burning and cement production) of carbon is emitted due to land-use changes. In context of C emission, land-use changes mainly include decomposition of vegetation arising out of deforestation and SOC mineralization resulting from conversion of forest and undisturbed land to arable land.

Depending on management conditions, soil acts as both sink and source to atmospheric C. Though soil constitutes a large pool of carbon, it can act as a potential sink for atmospheric C. The term carbon sequestration in context of soil implies to the removal of atmospheric CO_2 by plants and storage of fixed C as soil organic matter. Realization of the sink capacity of soil requires adoption of some recommended management

practices (RMPs) that increase SOC content.

RMPs for enhancing SOC content

Soil and crop management practices that enrich carbon in soil are described below-

Conservation tillage: Organic carbon in soil remains protected inside soil aggregates from microbial decomposition because inside these aggregates it remains out of reach of microbes. In conservation tillage, there is minimum disturbance of soil leading to least SOC decomposition. In reverse, in conventional tillage, there is breakage of aggregates resulting in exposure of protected SOC inside aggregates for microbial degradation.

Crop residue retention: Crop residue retention implies retention of a portion of annual crop biomass on soil itself after harvesting a crop. It acts in two ways, firstly, it adds carbon to soil through crop biomass, and secondly it moderates the soil biological activity by producing cooling effect by covering the soil surface. In addition, conservation tillage along with crop residue retention slows down the decomposition rate of added residue increasing SOC concentration.

Growing cover crops: In many annual cropping systems, soil remains fallow for a large part of the year. During this period, decomposition of SOC continues without crop biomass addition resulting in net flux of carbon to atmosphere. Growing cover crops, especially leguminous cover crops adds some crop biomass to such soil. Moreover, growing leguminous cover crops enhances biodiversity and quality of residue input, which in turn enhances the SOC pool. Ecosystems with high biodiversity absorb and sequester more C than those with low biodiversity. Legume cover crops contain carbon compounds that are likely to be more resistant to microbial metabolism and could also increase the complexity and diversity of soil carbon, making it more stable.

Judicious nutrient management: In general, addition of organic manure and compost improves SOC more than use of the same amount of

inorganic fertilizer. The effect of fertilizer on SOC is linked to the amount of crop biomass C produced/ returned to soil and its subsequent stabilization. There is synergistic effect of conservation tillage and use of organic manure in enhancing SOC pools. Use of biofertilizers also greatly enhances SOC status. Nevertheless, adoption of integrated nutrient management strategy that makes use of balanced application of inorganic fertilizer, organic sources of fertilizers and legume crops in rotation can enrich SOC and improves sustainability of the system.

Irrigation management: Similar to nutrient application, judicious use of irrigation water in drought prone areas can enhance both above ground and below ground biomass production and in turn enhance SOC concentration after its incorporation.

Restoration of degraded land: Restoring degraded land have great potential of sequestering carbon. These soils have lost a large proportion of antecedent organic carbon, which can be restored through adoption of appropriate land use. The major causes of land degradation are deforestation, over grazing and intensive agriculture. Degraded lands can be restored through afforestation, cultivation of pastures and perennial crops. Here, henceforth, we will discuss about cultivation of perennial crops like bioenergy crop in degraded and marginal land.

Bioenergy crop: Bioenergy crop is a crop, used to produce bioenergy that has capacity to produce large volume of biomass, has high energy potential, and is adapted to marginal soil. The bioenergy crops include perennial herbaceous crops and short rotation woody crops.

Perennial herbaceous crops: Herbaceous crops are plants that have little or no woody tissue, and mostly consist of bunch-type grasses generally harvested like hay at the end of the growing season when important nutrients (especially nitrogen) have been translocated to roots. Different grasses, such as kleingrass (*Panicum coloratum*), elephantgrass (*Pennisetum purpureum*), buffalo grass (*Buchloed actyloides*), miscanthus (*Miscanthus*

Table 1. Total organic carbon concentration (g/Kg of soil) in soil under different bioenergy crops and adjacent arable field in different soil depth.

Soil depth (cm)	Woody crops			Herbaceous crops			Arable field	F	P
	Black locust	Willow	Poplar	Miscanthuss	Switchgrass	Giant reed			
0-10	12.2a	11.8ab	11.7abc	10.2bcd	9.9cde	8.9de	8.3e	18.07	<0.001
10-30	7.9	8.4	8.1	8.0	8.1	7.4	8.3	0.89	0.53
30-60	5.5	5.1	5.2	4.8	5.7	5.0	4.8	1.10	0.41
60-100	2.9	2.9	3.3	3.1	3.6	3.7	3.2	0.44	0.84

*Different letters within the same row indicate significant differences ($P < 0.05$) among crops, according to Tukey's test

Source: Chimento *et al.* (2016)

spp.), switchgrass (*Panicum virgatum*), reed canarygrass (*Phalaris arundeneacea*), eastern gamagrass (*Tripsacum dactyloides*), tall fescue (*Festuca arundinacea*) and big bluestem (*Andropogon gerardii*) have been identified as promising species for biofuel production. These grasses regrow from their roots and do not require replanting for long periods of time (>15 years).

Short-rotation woody crops:

The short-rotation woody crops are fast growing woody plants with a great range of adaptability and good disease resistance. These crops include hardwood species such as poplar (*Populus* sp.), cottonwood (*Populus fremontii*), willow (*Salix* spp.), sweetgum (*Liquidambar styraciflua*), black locust (*Robinia pseudoacacia*), sycamore (*Platanus occidentalis*), silver maple (*Acer saccharinum*), and eucalyptus. These crops can also be grown for paper production and the waste can be utilized for energy.

Why bioenergy crop?

Energy consumption and CO₂ emission has been increasing worldwide. Presently, there is no constraint of fossil fuels, but its long-term availability and desirability is questionable, since the ever growing world economy is anticipated to increase fossil fuel combustion. Hence, exploring an alternative green source of energy is imperative. Bioenergy crop is one of the desirable alternatives of fossil fuel for future energy production due to its renewable nature and its adaptability to grow in degraded soil. Currently, biomass supplies only 15% of the total primary energy used in the world compared to 85% supplied through fossil fuels (oil, coal, and natural gas). An efficient production

of bioenergy crops, along with modern conversion technologies has potential to supply substantial amount of energy at a large scale while minimizing the net CO₂ emissions and enhancing soil carbon sequestration. For instance, bioenergy crops emit about 7, 12, and 13 times lower CO₂ than gas, petroleum, and coal, respectively in process of energy production.

Carbon sequestration through bioenergy crops

Bioenergy crops can be used as a feasible option to sequester atmospheric CO₂ in soil due to their perenniality, high biomass production, deep rooting system and adaptability to grow in degraded soil. The advantage of bioenergy crops is that above ground biomass can be utilized in producing energy through combustion without increasing net CO₂ emissions because the CO₂ released during its utilization was recently removed from the atmosphere. The only CO₂ that is released from the fossil fuels is the amount used in the production process of biomass. On the other hand there is sequestration of atmospheric C through their prolific deep rooting system. The massive fibrous and deep rooting systems in perennial crops facilitate direct movement of C into the deep soil and make it less available for removal by harvesting, thereby aid in carbon sequestration in soil. Table 1 compares the total organic carbon (TOC) concentration under different bioenergy crops and arable crop in a six year experiment. After 6 years of experiment, TOC content in soil under bioenergy crops increased significantly in comparison to arable field only in top soil layer (0-10 cm). Greater increase in TOC content was

recorded under the woody crops and under miscanthus. In contrast to this, TOC under switch grass and giant reed were statistically at par with that of arable field.

Management of bioenergy crops for greater carbon sequestration

Species: Plant species vary in biomass production and in turn soil C storage. This is primarily regulated by net primary productivity (NPP) and decomposition. Higher NPP leads to increased C storage, whereas reverse is true in case of decomposition. Bioenergy crop species that have higher plant C content, greater root biomass development, faster growing rates, better nutrient use efficiency, more efficient microbial processes, and greater adaptation to highly degraded soils leads to greater soil carbon sequestration.

Fertilization: Fertilization stimulates biomass production and, thereby, enhances carbon sequestration. Degraded lands are usually deficient in N, biomass production of bioenergy crops grown in these soil can be increased through addition of N fertilizers.

Harvest management: Most short rotation woody energy crops grown as bioenergy crop are harvested on a 3–10-year rotation and are generally harvested during the dormant season (winter) when significant quantity of nutrients are translocated to the roots and most of the leaf deposition contributes to SOC sequestration. Rapid juvenile growth and high SOC sequestration rates can be sustained if the stands are harvested in short cycles.

Status of Bioenergy crop in India

In India, biodiesel can be obtained from three sources i.e. from

sugarcane, *Jatropha curcas* and *Pongamia pinnata*. In 2009, Indian government launched the National Biodiesel Mission (NBM) identifying *Jatropha* as most suitable for biodiesel production. But due to acute shortage of *Jatropha* seeds, the government plan did not work. According to a survey by Axelsson *et al.* (2012) in Andhra Pradesh and Tamil Nadu states, by 2010, 85% of farmers, who cultivated *Jatropha* in year 2004, had stopped growing it. The primary reasons for discontinuation in cultivation of *Jatropha* were limited knowledge about cultivation, lack of market structures i.e. purchase agreements and buyers, as well as low retail price for seeds. Thus, bioenergy crop cultivation in India still is not a successful venture. Biodiesel production from multiple feed stocks reported during the year 2016 was 140 million liters and estimated to increase by 10 million liter in 2017.

Future scope for *Jatropha* cultivation in India

As stated earlier, growing bioenergy crops in wasteland is considered as a means to address

concerns about climate change, alleviate energy crisis and improves livelihood security of farmers. A recent estimate stated that 16% of Indian land area (approximately 50 million hectare) is wasteland. *Jatropha* is considered to be drought tolerant and has potential to be grown in degraded lands with low nutrient content. Thus, India has vast potential of growing *Jatropha* and producing biofuel. Realization of higher production of *Jatropha* in India needs some strategies to be adopted which are described below :-

- Genetic improvement of *Jatropha* for higher yield
- Improvement of market structure for *Jatropha* procurement from farmers
- Easy availability of quality seeds to farmers
- Restructuring and proper implementation of policy
- Creating awareness for *Jatropha* cultivation among farmers.

SUMMARY

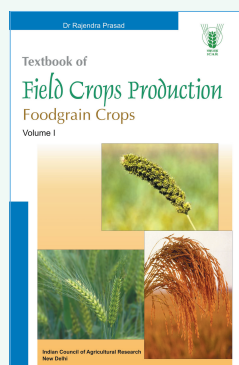
The rising concentration of atmospheric CO₂ is a major global concern from both climate change and soil fertility point of view. Soil

consists of a substantial portion of global carbon. Depending upon management practices soil acts both as source and sink to atmospheric CO₂. The recommended management practices for soil carbon sequestration are conservation tillage, crop residue retention, growing cover crop, judicious nutrient management, irrigation management and restoration of degraded land. Soil carbon sequestration through growing bioenergy crop is a win-win strategy, because along with soil carbon sequestration it alleviates world energy crisis through production of green energy out of its biomass. The bioenergy crops can achieve more soil carbon sequestration through its perenniality and profuse and deep rooting system in comparison to annual crops. Moreover, its potential to be grown in degraded soil widens its scope for its adoption as a viable strategy for soil carbon sequestration and production of green energy.

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TECHNICAL SPECIFICATIONS

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