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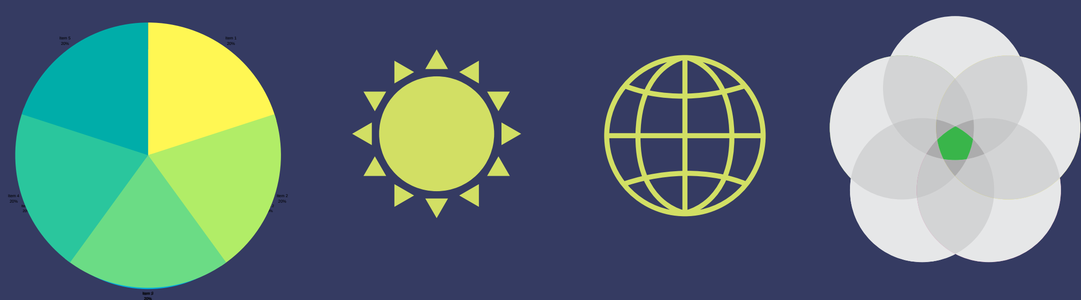

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# CO2FIX model: A tool for estimating carbon sequestration potential of any agroforestry systems

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**Summary**: The CO2FIX model is a tool or software, which is extensively used for assessing baseline carbon as well as estimating carbon sequestration potential (CSP) of any land-use systems, more particularly the potentiality of every individual component (*i.e.,* trees, shrubs, agricultural crops or pastures, soil, *etc.*). This tool is not only can quantify the carbon stock, but also can quantify the C-fluxes in the biomass of any land-use systems, soil organic matter and also can quantify the C-fluxes in wood products chain. Moreover, this model can simulate the result for "n" numbers of years and can estimate the prediction values. Hence, this tool can be a very useful to the forester, scientists, researchers and academician in estimating the CSP of any system and it's future predictions in terms of carbon stock and fluxes.

## INTRODUCTION

Growing woody perennials under agroforestry systems can be considered to be the most effective means through which mitigation of climate change can be ascertained. Hence, estimation of tree biomass (above and below ground) and biomass carbon are the most important parameters to be studied in general which can elicit their importance, mostly of the ecosystem services rendered by the trees under agroforestry system. Moreover, it is having higher potential in sequestering carbon under the climate change mitigations strategies (Watson *et al.*, 2000). It was also reported that agroforestry can sequester an average of 25 Mg C $ha^{-1}$ (Sathaye and Ravindranath, 1998), but there are differences in biomass production in different regions of the country and hence variations do exist in carbon sequestration too (Ramnewaj and Dhyani, 2008 and Dhyani *et al.,* 2009).

The CO2FIX model is a tool or software, which is known to be used for assessing baseline carbon as well as estimating carbon sequestration potential of any land-use systems which can simulate at the hectare scale with time steps of one year with a simulation period of "n" number of years (say, n= 20 or 30 or 50 years). This model can extensively be used for all plants (*i.e.,* trees, shrubs, agricultural crops, *etc*.) and all types of land-use systems, provided that, the user must have enough knowledge in handling and using. Even one can use this model for estimating biomass and changes in soil carbon stocks for forestry, agriculture and agroforestry projects since the estimates do consider soil, climate and any other biological factors like crop residues *etc.* (Ajit *et al.,* 2013). Many literatures (Lal and Singh, 2000; Swamy *et al.,* 2003; Swamy and Puri, 2005; Naik *et al.,* 2018) revealed that, in most of the cases, the scientists or researchers do analyze the carbon sequestration potential (CSP) of forest or multipurpose trees species (MPTs) individually and generally neglect the non-woody crops/ agricultural crops or herbs/ grasses. Hence, there is still very less information available on the CSP of the total system (e.g., forest ecosystem). But on the other hand, many literatures (Ajit *et al.,* 2013; Sarkar *et al.,* 2017; Das *et al.,* 2018) revealed that, there is ample scope to work with this CO2FIX model of any compatible version (*i.e.,* dynamic carbon accounting model CO2FIX v3.1 for assessing the baseline tree biomass and biomass carbon as developed as a part of the CASFOR II project (Namburs and Schelhaas, 2002), which was described by Masera *et al.,* 2003 and Schelhaas *et al.,* 2004. This model also has included soil module known as YASOO (Liski *et al.*, 2005), which takes into account the initial litter quality and the effect of climate on decomposition. Hence, this CO2FIX model can be useful to temperate and tropical climates, to estimate biomass and soil carbon (Namburs and Schelhaas, 2002; Masera *et al.,* 2003) and to coniferous or deciduous forests or to monocultures or mixed tree stands as well as for a variety of ecosystem around the world (Schelhaas *et al.,* 2004). De Jong *et al.* (2004) had used CO2FIX model for estimating the carbon sequestration potential of live fenced pasture lands.

**Input parameters for running the CO2FIX model**

The main input parameters relevant to CO2FIX model are the cohort-wise values for the stem-CAI (current annual increment in $m^3$ $ha^{-1}$ $year^{-1}$) over years; relative growth of the foliage, branches, leaf and root with respect to the stem growth over years; turnover rates for foliage, branches and roots; and climate data of the site (annual precipitation in mm and monthly values of minimum and maximum temperatures in °C). Other inputs to the model includes initial surface soil organic carbon (Mg C $ha^{-1}$), rotation length for the tree species, per cent carbon contents in different tree parts, wood density and initial values of baseline carbon (Mg C $ha^{-1}$) in different tree parts (Ajit *et al.,* 2013; Sarkar *et al.,* 2017; Das *et al.,* 2018). In case of estimating average tree volume (V) of the particular standing tree species and Current Annual Increment (CAI), one can either use volume equations or can calculate by averaging the tree volumes ($V_1$ and $V_2$) after considering trees as average of cylindrical and conical shape (Sarkar *et al.,* 2017; Das *et al.,* 2019).

**Tree volume, $V_1$ ($m^3$ $tree^{-1}$) = (π x $DBH^2$ x H)/4 (for cylindrical shape) ………… (1)**
**Tree volume, $V_2$ ($m^3$ $tree^{-1}$) = (π x $DBH^2$ x H)/12 (for conical shape) ………… (2)**
**Thus, V ($m^3$ $tree^{-1}$) = ($V_1$ + $V_2$)/2 ………… (3)**

**Basic data required for running the CO2FIX model**

The CO2FIX model (Fig. 1), requires primary as well as secondary data on tree and crop components (called 'cohorts'). The primary data includes name of the existing tree species along with their number, diameter at breast height (DBH), tree height, crops grown on farmlands or in the alleys along with their productivity, area coverage *etc*., whereas the secondary data includes the growth rates of tree biomass components (stem, branch, foliage, root) for various species on annual basis as well as the productivity of different crops grown in that area (Ajit *et al.,* 2013; Sarkar *et al.,* 2017). Soil data particularly soil organic carbon (t ha$^{-1}$) needs to be analyzed following standard procedure as used by Naik *et al.* (2017), Das *et al.* (2017) and Das *et al.* (2019).


**Fig. 1: CO2FIX model**

**Biomass validation of the model**

For validating the tree biomass estimated by using model, an independent data set containing sequential annual harvesting of trees of particular period need to be recorded and analyzed. This methodology was already tried for a period of 9 years by Ajit *et al.* (2013) in poplar trees (*Populus deltoides*) and reported that for validating the tree biomass. In this, a minimum of three numbers of trees need to be regularly harvested every year for biomass measurements. The observed variables like DBH, Height, above ground biomass components (stem, branches, leaf and twigs) and below ground biomass components (primary, secondary, tertiary and fine roots) need to be measured, calculated statistically and compared with the predicted biomass about its significance.

**The bias/error in prediction**

The estimation of bias/ error in prediction is very crucial for validating the output result of the model which is to be more accurate statistically. Kaonga and Smith (2012) had reported the percent bias values from CO2FIX model ranged from 2 to 19 % for the total above ground C-stocks, 22 to 40 % for branches and 22 to 62 % for leaves.

**Sensitivity analysis of the model**

Sensitivity analysis refers to investigating the influence of perturbation of certain parameters or model outputs (Ajit *et al.,* 2013). The two important site specific factors *viz*., annual precipitation and monthly temperatures are reported as the main factors of simulation. The CO2FIX model, by default, considers them as unchanged throughout the simulation period and thus is source of uncertainty in model output. In one of the study carried out by Ajit *et al.* (2013) reported that a change of 0.5 $^{0}$ C in monthly temperature may result in 0.7-2.46 % change in per cent rate of C-sequestered, whereas a change of 20 % in annual precipitation may lead to 5.39-10.88 % change in per cent rate of C-sequestered. Thus, it is more cleared from their study that the rate of C-sequestration is more sensitive to precipitation than temperature.

**Significance over other available tools**

The CO2FIX is preferred over others (*viz.,* PROCOMAP, CENTURY and ROTH), since only CO2FIX can simulate the carbon dynamics of single or multiple species simultaneously, and can handle trees with varied ages and agroforestry systems (Ajit *et al.,* 2013). In order to run this model, Current Annual Increment (CAI) of the species is very important. But on the other hand, PROCOMAP is generally used for project level carbon stocks (biomass and soil) for forestry projects and both the CENTURY and ROTH model concentrate more particularly on dynamics of soil carbon stocks for agriculture and forestry projects (Ajit *et al.,* 2013). Hence, CO2FIX has been extensively used for estimating biomass and changes in soil carbon stocks for forestry, agriculture and agroforestry projects.

**Key points to be remembered while using the CO2FIX model**

Various key points are to be considered by the users while using the model:

1) Before running the model, one must confirm it's compatibility with the system

2) Both the primary as well as secondary data to be analyzed properly and convert them in accordance with the measurement units that the model accepts and made ready just before running the model.

3) Users must have enough knowledge while estimating the Current Annual Increment (CAI) which is the most important parameter to be used while running the model.

4) For validating the predicted versus observed values, the user must have the annual total harvesting data including biomass of root, bole, branches, leaves, *etc*.

5) One must know the age of the plantation, otherwise, age of the individual trees to be determined from volume equations.

6) Sensitivity analysis needs to be run to cross check the percent change in the predicted estimates by changing the values of temperature and rainfall in the model while running.

**Conclusion**

The CO2FIX model is extensively used for estimation of CSP (Carbon sequestration potential) of any land-use systems, more particularly the potentiality of every individual component (*i.e.,* trees, shrubs, agricultural crops or pastures, *etc.*). This tool is not only can quantify the carbon stock, but also can quantify the C-fluxes in the biomass of any land-use systems, soil organic matter and also can quantify the C-fluxes in wood products chain. The users will feel very easy and quick in processing and analyzing the data in this model. Moreover, this model can simulate the result for "n" numbers of years and can estimate the prediction values.

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