Sustainable Agriculture Decision Support Tool

Dual Purpose Cowpea and Millet with and without Farmer-Managed Natural Regeneration in Senegal

Soil health, water availability, air quality, and climate change all influence crop productivity. Agriculture in turn drives deforestation, biodiversity loss, soil erosion, and soil and water pollution, producing over one-quarter of total greenhouse gas (GHG) emissions. This Decision Support Tool (DST) allows fuller accounting of benefits and costs of agricultural innovations by considering GHG emissions from agricultural technologies.
Viewing results and instructions

The Decision Support Tool allows users to select different parameter assumptions and view results for several outcomes of interest such as GHG emissions, crop yield, biomass yield, and the associated financial and economic returns for the improved technology as compared to business as usual (BAU). This guidance document outlines the key steps in using the DST and its application to dual-purpose cowpea and millet with and without Farmer Manager Natural Regeneration in Senegal.

Please visit senegaldst-dev.ags.io/ to access the tool.
The first step to develop an application for the DST is to define landscapes that you want to consider technology options for. For this application we selected the millet and cowpea growing regions of Senegal. We further sub-divided the landscapes into agro-ecologically distinct sub-regions.

**User-defined scenarios**

The DST will define the landscape at the beginning of each study, which will stay fixed for the remainder of the analysis.

**Role of this parameter in analysis:**

- Choice of landscape influences the total area that is used to calculate total costs, benefits and net returns.
- Choice of landscape affects the soil type used in the GHG estimation, and the climate – precipitation and temperature forecasts.
- Choice of landscape may also influence the business-as-usual scenarios and the extent to which adoption of new technologies may occur.
In Senegal, the DST evaluates agricultural technologies for the cowpea and millet growing regions that are sub-divided based on cropping patterns.
In the DST application for dual purpose crops, users can select the region to view results by specific sub-regions within the landscape.
Users can select the crop to view results by sub-regions that grow cowpea or millet or both.
Next, the users have to define prevalent technology in the landscape or the Business-as-Usual (BAU) and the technology options being considered to achieve the program outcomes.

User-defined scenarios
The DST will fix the BAU and technology options at the beginning of each study. Typically the BAU should not change but if there is uncertainty about what BAU is then the DST can be programmed to allow the BAU options to be changed.

Role of this parameter in analysis:
- The entire analysis is focused on understanding the difference in the outcomes between the BAU and alternative scenarios.
- The choice of technology may influence the time period of analysis so that it covers the expected time period when costs and benefits accrue.
- The choice of technology also influences the types of costs and benefits that are accounted for in the analysis.
For this application, we selected improved dual-purpose millet and cowpea that are expected to have better crop yields and better fodder yields. The second technology we consider is dual-purpose crops in combination with Farmer Managed Natural Regeneration (FMNR), which allows natural regrowth of trees in the farmland. The BAU crops are the current varieties being used, which are different based on sub-regions. While some sub-regions have only cowpea or only millet cultivation, others have both.
Based on the landscape and technology options the users define the following study parameters:

- **Time period of analysis.** This can range from 10 years to 100 years depending on the technology and the types of associated benefits or costs.

- **Discount rate.** USAID recommends using a discount rate of 10 percent or 12 percent. The choice of this factor determines the extent to which the future returns and costs are discounted.

**User-defined scenarios**

While the time period of analysis remains fixed within the DST, the users can change the discount rates and assess the difference in net returns.

**Role of this parameter in analysis:**

- The time period of analysis determines the numbers of years for which the analysis estimates the costs and returns for the technology. Longer time periods are needed for technologies that have a longer lifespan and those that give returns only in the later years (such as trees).

- Discount rate determines the extent to which future returns are valued. A high discount rate will value technologies that give returns in the earlier years more than technologies that give returns in later years.
Given the USAID recommendation, in the DST, users can select either 10 percent or 12 percent discount rate.
To evaluate the dual-purpose crops with FMNR, we use 20 years as the time period since it takes 10-15 years for trees to mature for the FMNR technology.

Users can view the results for the entire time periods in the Map View and the Chart View. To view results for another time period, users can adjust the sliders in the year. To see annual results, users should move both sliders to the same year.
Several factors determine GHG emissions from agricultural technologies that users need to specify. These vary by the type of technology being considered but may include:

- Agronomic practices
  - Tillage depth
  - Organic and inorganic fertilizer use per hectare
  - Crop residue left in the field
  - Plant density
  - Irrigation
  - Grazing
- Soil-type – texture, pH, organic matter, bulk density
- Daily minimum and maximum temperature and total daily precipitation forecasts

- Number of livestock per hectare
- Total fodder quantity needed per livestock
- Type of tree and density of trees planted

**User-defined scenarios**

Soil type remain fixed once the landscape is selected but users can define different climate forecast scenarios. User can also select different agronomic practices as long as they are consistent with each other. For dual-purpose crops, users can either specify the total livestock per area or they can let that be determined based on fodder quantity available and the crop residue left in the field.

**Role of this parameter in analysis:**

- Tillage depth influences GHG emissions. For example, zero tillage reduces GHG emissions.
- Fertilizer use influences GHG. If fertilizer use is greater than what is needed by the plant, it can lead to higher GHG emissions through nitrous oxide emissions.
- Greater the crop residue left in the field, all else equal, carbon sequestration will be greater.
- Greater plant density can mean higher nitrogen use, but greater carbon sequestration. Sub optimal plant density can also reduce crop yield.
- Greater the total quantity of fodder available, the greater the number of livestock that can be sustained and greater the GHG emissions because of methane emissions resulting from enteric fermentation.
- Higher protein content in fodder also leads to greater GHG emissions.
- Agronomic parameters are also inputs for the cost-benefit analysis, which determine the cost of the technology in terms of fertilizer cost, water cost, and labor needs given the technology.
Agronomic parameters
Users can select variety of agronomic parameters to see how results change because of it.
Agronomic parameters

Users can select variety of agronomic parameters to see how results change because of it.

**Plant density.** Plant density is the number of saplings planted per land area. Higher plant density is recommended with improved dual-purpose crops. Higher plant density requires higher fertilizer use and needs to be consistent. Higher fertilizer use, if suboptimal for crops, increases GHG emissions.

For this application, the plant density choices that the users have are 24,792 seed hills per hectare or 12,396 seeds hill per hectare for millet, which is the plant density for which scientific trials were conducted to assess their impact on crop yield and biomass yield. For cowpea, the scientific trial did not vary plant density so users can select different plant densities only for millet.
Agronomic parameters

Users can select variety of agronomic parameters to see how results change because of it.

**Fertilizer use.** Higher fertilizer use, if suboptimal for crops, increases GHG emissions, For cowpea, users can choose low, medium, or high fertilizer use as follows

- **Low:** 0 kg/hectare urea
- **Medium:** 13 kg/hectare urea
- **High:** 150 kg/hectare N-P-K
Agronomic parameters

Users can select a variety of agronomic parameters to see how results change because of it.

Fertilizer use. Higher fertilizer use, if suboptimal for crops, increases GHG emissions.

Higher plant density requires higher fertilizer use and needs to be consistent. Since millet trial were done with different plant densities, users can choose low, medium, or high fertilizer use in combination with plant density as follows:

- **Low fertilizer (low plant density):** 140 kg/hectare urea
- **Medium fertilizer+organic (low plant density):** 140 kg/hectare urea + 270 kgC/hectare manure
- **High fertilizer (low plant density):** 200 kg/hectare urea
- **Low fertilizer (high plant density):** 200 kg/hectare urea
- **Medium fertilizer+organic (high plant density):** 200 kg/hectare urea + 460 kgC/hectare manure
- **High fertilizer (high plant density):** 300 kg/hectare urea

Define GHG estimation parameters
Agronomic parameters

Users can select a variety of agronomic parameters to see how results change because of:

Residue removal. Higher residue removal means less crop residue left on the field, which reduces GHG sequestration, but it also means greater returns from use of residue as fodder. Users can select to remove all residue in the field which is the total biomass generated based on the DNDC output. The lowest residue removal is the minimum fodder requirements for livestock, where the total number of livestock for BAU and improved is based on average ownership based on farmer interviews. Medium residue removal for improved cowpea is set as 65% of the total biomass generated and at 50% for improved millet. Depending on the residue removed, the model assumes that anything in excess of what the livestock will need is valued at the price of feed price.
In the current analysis we model GHG for dual-purpose crops but use existing emissions factors for FMNR.

All inputs for the GHG analysis on agronomic parameters, soil type, climate forecasts, and livestock assumptions are input into the Denitrification and Decomposition (DNDC) model, which has the following submodels:

- Climate submodel
- Soil biogeochemistry submodel
- Crop submodel

The DNDC model produces the following outputs for the entire time period of analysis and for each of the sub-regions in the landscape:

- Soil carbon and nitrogen pools
- Water leaching
- Emissions of nitrous oxide, nitric oxide, nitrogen, methane and carbon dioxide, which can be converted to GHG emissions in carbon dioxide equivalent tons
- Crop yields
- Biomass yields

**GHG output serves as input for cost-benefit analysis**

- GHG emissions from the DNDC model can be reported out separately but it is also input into the CBA analysis to assess technology's economic cost or benefit.
- DNDC model's crop yield and biomass yield are also inputs to the CBA model to estimate financial returns from the technology.
- Water leaching and nitrogen leaching can be presented as quantitative outputs but can also be inputs for the CBA if there is a reasonable way to monetize these impacts.
- If DNDC modeling is not feasible, expected impact of technology can be based on scientific trials or published literature. For this application, FMNR’s benefits came from published literature.
Environmental outcomes

DNDC model outputs 20-year stream of GHG emissions and nitrogen leaching for each scenario selected by the users. Users can view these in Map View or Chart View. These outcomes are available per hectare or for the region. The total value for the region is based on total area under the region with the improved technology, and total GHG in the region accounting for carbon sequestration because of plant growth (and sequestration from trees for FMNR) and crop residue left on the field and emissions because of nitrogen use.

- **Total GHG emissions** from DNDC model which is estimated based on selected technology choice, agronomic parameters, soil conditions and climate forecast. GHG emissions include GHG reduction from carbon sequestration because of plant growth (and sequestration from trees for FMNR) and crop residue left on the field and emissions increase because of nitrogen use.

- **Incremental GHG emissions** is the difference in total GHG emissions per hectare between user selected improved technology and BAU based on selected agronomic parameters, soil conditions and climate forecast.

- **Total nitrogen leaching** is the nitrogen leaching given user selected agronomic choice including rate of fertilizer use.

- **Incremental nitrogen leaching (kgN/hectare)** is the total nitrogen leaching for user selected region and user selected agronomic choice including rate of fertilizer use.
Agricultural outcomes

DNDC model outputs 20-year stream of crop yields for cowpea and millets and biomass yield for each scenario selected by the users. Users can view these in Map View or Chart View. These outcomes are available per hectare or for the region. The total value for the region is based on total area under the region with the improved technology.

- **Total crop yield** based on output from DNDC model given the parameter assumptions chosen by the users, soil conditions and the climate forecast.

- **Total biomass yield** based on output from DNDC model given the parameter assumptions chosen by the users, soil conditions and the climate forecast. Biomass yield can be either left as crop residue for incorporation in the field or harvested as fodder for livestock or other uses. It is valued at fodder cost if more residue is extracted than needed for livestock.

- **Incremental crop yield** is the difference in crop yield per hectare between user selected technology and BAU, given the parameter assumptions chosen by the users, soil conditions and the climate forecast.

- **Incremental biomass yield** is the difference in biomass yield per hectare between user selected technology and BAU, given the parameter assumptions chosen by the users, soil conditions and the climate forecast.
Users can view all outputs in Map View or Chart View. Map View allows the users to see differences in outcomes by geography. Chart View allows users to see outcomes over time in line graphs, or across technologies in bar graphs.
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Users can also view the outcomes based on low, medium or high adoption rates.
DST accounts for several factors that determine financial and economic returns from agricultural technologies that need to be specified. Users should refer to USAID guidelines conducting cost-benefit for more details. Some key definitions and parameters needed are as follows:

- Financial analysis is done from the perspective of stakeholders such as farmers using real prices (adjusted for inflation) that prevail in the market in local currency (which is converted using exchange rates)
  - Flow of input usage and their costs
  - Output (yield) flow and output prices
  - Taxes, levies or subsidies

- Economic analysis is done from the perspective of society and adjusts for any distortions in the financial analysis including externalities such as GHG emissions
  - Non-marketed costs and benefits of the technology
  - Social cost of carbon
  - Value of environmental benefits/costs

**Role of this parameter in analysis:**
- Input usage and costs determines the total cost of the technology both under BAU and improve technology for the time period of analysis.
- Output or total production and output prices determines the returns or the benefits from the technology for the time period of analysis.
- Social and environmental costs and benefits determine the costs and benefits to the society as a whole.
Social cost of carbon. The social cost of carbon is an estimate of the economic costs, or damages, of emitting one additional ton of carbon dioxide into the atmosphere. U.S. Federal government social cost of carbon as of July 19, 2021 was $51. Users can choose other prices to assess the sensitivity of outcomes to social cost of carbon.
In the financial analysis, for both BAU and improved technologies, cash flows have to be estimated using details on quantity and unit prices and itemization that will allow adjustments for the economic analysis. Real prices should be used, adjusted for inflation in local currency. The stream of net returns is estimated as the difference in benefits and costs.

Once the stream of financial returns are determined, exchange rates can be used to convert them in USD if needed.

**Incremental financial returns.** The difference in returns from BAU and improved technology is the incremental returns from shifting to the new technology.

**Net present value.** Using discount rates, either 10 or 12 percent, net present value of stream of financial returns is estimated.

Users can view results on a per hectare basis or for each region.

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**CBA output helps policy makers decide the ideal options**

- Comparison of incremental NPV of financial returns can determine if the improved technology leads to higher returns to the stakeholder from whose perspective the analysis is done. If information is available, a distributional analysis can also be conducted to understand the extent to which women or vulnerable groups benefit.

- Comparison of incremental financial and economic returns can determine if there is a wedge between what stakeholders receive and benefits to the society. If financial returns are greater than economic returns it means that the technology results in negative externalities. If the economic returns are greater than financial returns it means that the technology has positive externalities.
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Outcome Variable
- Financial returns (US$/ha)
- Region
- Crop

Option Rate
- Technology
- Millet Fertilization
- Crop Fertilization

Revenue (US$/ha)
- Improved dual-purpose crops
- Improved dual-purpose crops + P30/DR
- Millet Fertilization
- Crop Fertilization
Economic analysis accounts for GHG emissions or sequestration along with social cost of carbon to value it. Other environmental benefits can be quantified and monetized using values that are accepted in the literature. Any transfers such as taxes or subsidies are removed in the analysis.

Once stream of economic returns are determined, exchange rates can be used to convert them in USD if needed.

**Incremental economic returns.** Difference in returns from BAU and improved technology is the incremental returns from shifting to the new technology.

**Net present value.** Using discount rates, either 10 or 12 percent, net present value of stream of financial and economic returns can be estimated.

Users can view results on a per hectare basis or for each region.

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CBA output
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CBA analysis and output