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Climate Change Mitigation Potential of Ethiopia's Productive Safety Net Program (PSNP)

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Climate Change Mitigation Potential of Ethiopia's Productive Safety-Net Program (PSNP)

This report was prepared on behalf of The World Bank by:

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The PSNP is implemented by the Government of Ethiopia with support from the following development partners: Canadian International Development Agency, Irish Aid, European Commission, Royal Netherlands Embassy, Swedish International Development Cooperation Agency, UK Department for International Development, United States Agency for International Development, World Food Program and World Bank.

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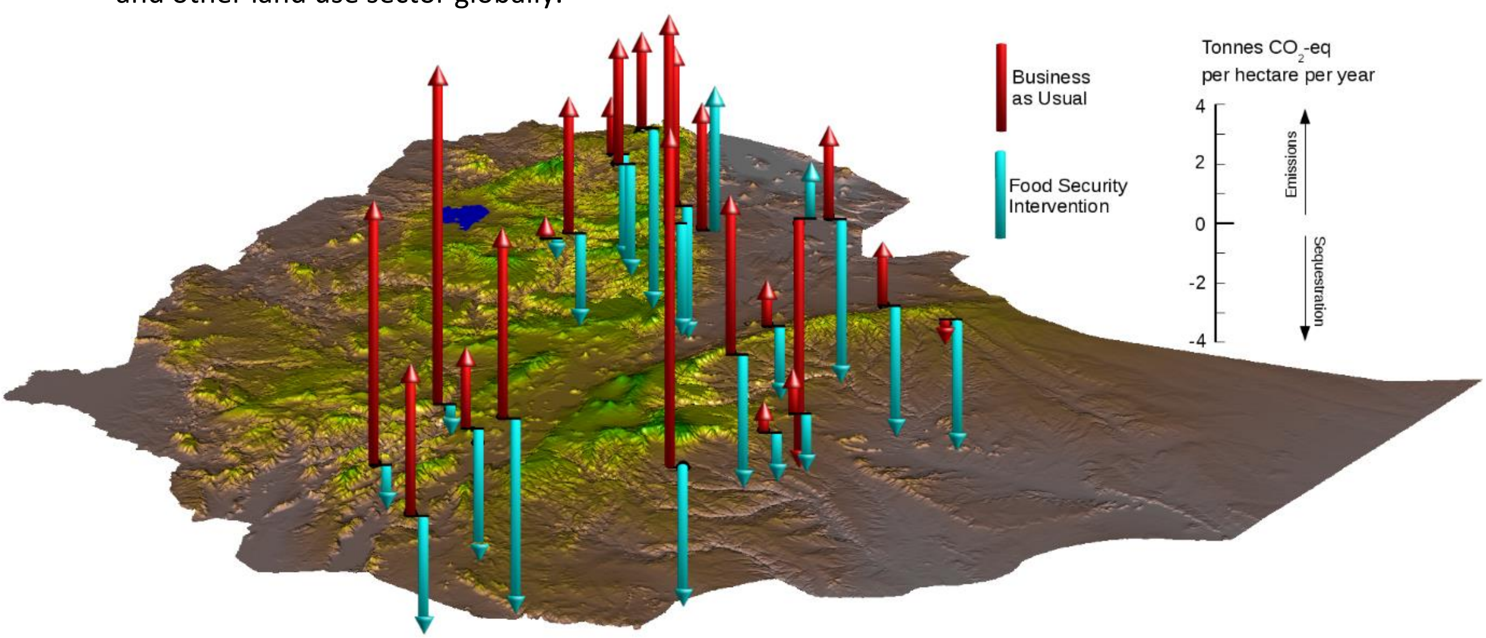
Abstract

Food security programs designed to alleviate poverty, of which Ethiopia's Productive Safety Net Program (PSNP) is a model example, are contributing also to climate-change mitigation in Sub-Saharan Africa. PSNP's climate-smart land management and ecosystem restoration interventions deliver climate-change mitigation principally by sequestering carbon in soils and biomass. This opens a new line of thinking and opportunity where food-security interventions that target underlying drivers of food insecurity—such as ecosystem and land degradation—become a vehicle for climate-change mitigation.

Using a combination of geospatial modeling and biophysical approaches, we here show that the mean carbon benefit of all PSNP sites was 5.7 tonnes CO_2e ha^{-1} yr^{-1}. On average, these carbon benefits were primarily due to increases in biomass (40% of total), in soil organic carbon (38%) and reduced livestock greenhouse gas emissions (22%). Extrapolating these results to the whole of PSNP's 600,000 ha of already-established area enclosures would imply that a total carbon benefit in the order of 3.4 million t CO_2e yr^{-1} has already been achieved by PSNP. This shows that food security safety net programs, despite not being initially intended to provide climate change mitigation, are nonetheless climate smart, achieving mitigation impacts comparable to the largest carbon projects currently implemented in the agriculture forestry and other land use sector globally.



Net greenhouse gas fluxes from project sites with ("food security intervention") or without ("business-as-usual") PSNP.

1 INTRODUCTION

Agriculture, forestry and other land use (AFOLU) activities can result in carbon sequestration in biomass and soils, and greenhouse gas (GHG) emissions (from fertilizers, livestock and other sources). Understanding the overall impact or GHG balance resulting from land management

Why Model

Predictions: *models offer the possibility of making predictions about the future carbon stock changes and greenhouse gas (GHG) emissions.*

Scale: *models can offer a means of estimating information where comprehensive large-scale measurement campaigns are not possible.*

GHG balance: *multiple sources and sinks can be considered at the same time.*

activities can be complex. Models, broadly defined as simplified descriptions of systems based on a set of assumptions which approximate the actual situation, can offer a means of dealing with this complexity. Many models allow multiple sources and sinks of GHG emissions to be considered simultaneously to give an overall GHG balance showing the net impact of activities on the atmosphere.

Models are also useful in other ways. They offer a means of estimating information where comprehensive large-scale measurement campaigns are not possible due to constraints of cost and time. Models combined with strategically-designed measurement campaigns are often more cost-effect than just measurement campaigns alone. They allow future scenarios to be considered and can therefore be useful in terms of planning and long-term predictions. In addition, some models are able to account for land use history. This is needed when considering the impacts of land management on soil organic carbon (SOC) which can take tens to hundreds of years to reach a new stable state after land use change (Post & Kwon, 2000; Guo & Gifford, 2002).

1.1 WHAT TYPES OF MODELS ARE AVAILABLE

Different kinds of models and tools are available to estimate the carbon (C) sequestration potential of land management activities (Denef et al 2012). The choice of model depends on the purpose for which the modeling is being carried out (e.g., to report to a funding agency, to look at the impact of a single commodity, to gain credits from a C certification scheme). It also depends on the types of land use being considered, the sources and sinks of GHGs and the time and resources available to collect the data needed to run the model (Milne et al., 2012; Colomn et al. 2013).

1.1.1 The IPCC Method

Several tools are available which use the computational model developed by the Intergovernmental Panel on Climate Change (IPCC), the result of a huge international effort to pull together studies describing the impact of land management activities on GHG emissions (IPCC 2003; IPCC 2006). These tools use a set of equations which all take the basic form of:

GHG Emissions = Activity Data (AD) x Emission Factor (EF)

Where AD is the type of land use (cropland, forestland, grassland, etc.), the area it covers and the way this land is managed, and the EF is a factor describing the GHG emissions resulting from a given land use activity. The IPCC method includes a large database of EFs plus default information on climate, soil type and land use/management. The method can be used with these default factors (Tier 1) or replaced with country or project specific factors (Tier 2). Countries may also utilize dynamic and empirical models developed within their own country or region, based on the IPCC good practice guidelines (Tier 3). Examples of tools and models which are based on the IPCC method include the Carbon Benefits Project (CBP) Simple and Detailed Assessments, FAO's Ex-Ante Carbon-Balance Tool (EX-ACT), USAID's AFOLU Carbon Calculator, and the Cool Farm Tool.

The IPCC Tier 1 and 2 methods have the disadvantage of assuming two points in time with a linear rate of change between them and does therefore not capture the dynamic way in which most ecosystem processes change over time. These methods approximate dynamic processes using simplified, linear models. It is, however, the only standardized, globally applicable method for GHG accounting for the agricultural sector (for all sources and sinks) and can be used with land use and management information only making it very flexible and easy to apply.

A summary of the most commonly used carbon accounting tools suitable for AFOLU in developing countries (i.e., in tropical and sub-tropical areas) with some of the advantages and constraints is given in Table 1. All tools are different having been designed for different purposes and user groups. The 'best' tool depends on the use to which it is being put, the result needed and the accuracy required for that result. When choosing an appropriate tool or resource, users have to consider a number of factors. Accessibility is often the first consideration. For example, is the tool free to be used by anyone; is it an online resource that requires an active internet connection to use, or can it be downloaded for offline use; and does it rely on any specific software for which a license may be need to be purchased (e.g., Microsoft Excel)? Users also need to consider whether any specialist equipment or expertise is needed (e.g., GIS experience/software) and the kind of analysis the tool was designed for: *ex ante* (a pre-analysis suitable for proposals), *ex post* (analysis after the event), or both. Further, users may have additional requirements which are not covered by all tools, for example inclusion of off-farm GHG emissions or additional economic analysis.

Other major considerations include the GHG emissions and the sources and sinks of these emissions covered by the tool. Some tools such as the USAID AFOLU C Calculator only estimate emissions of CO_2 and others (such as the VCS-approved SALM tool) estimate changes in the three major GHGs (CO_2, CH_4 and N_2O) but only from a single land use category, in this case cropland. In instances where an overall comprehensive greenhouse gas balance is required, a tool which deals with all major GHG emissions (CO_2, CH_4 and N_2O) from all sources and sinks is needed. Further details of the emissions/sources and sinks covered by different tools are given in Milne et al. 2012.

In this project, an online greenhouse gas accounting tool developed by Colorado State University's CBP was used. The CBP system was selected because it includes a comprehensive suite of tools for IPCC Tier 1, 2 and 3 assessments, together with accompanying tools for socioeconomic analysis. It has user-friendly options, has integrated GIS support for describing project boundaries and associating these locations automatically with spatially explicit parameter values to describe local soil types, vegetation and ecosystems, covers all major GHG emissions associated with AFOLU, and can be used for *ex-ante* and *ex-post* analysis and project tracking.

1.1.2 Dynamic Approaches

Ecosystem models such as CENTURY, DayCent or DNDC use complex functions to describe the processes of an ecosystem. They attempt to represent the dynamic processes which occur within an ecosystem which result in changes in stocks and fluxes of carbon and nitrogen. They typically include sub-models of plant productivity, water movement, carbon cycling and the turnover of N, P and K. They can account for land use history which is critical for modeling changes in soil organic carbon (SOC). This is because SOC can take ten to a hundred years to reach a new steady state after land use change, making small differences due to short term management changes difficult to detect. Dynamic models are designed for site scale application but have also been linked to Geographical Information Systems (GIS) for larger scale application (Easter et al, 2007; Milne et al 2007).

In this project the CENTURY dynamic ecosystem model linked to a GIS was used as part of the CBP's Dynamic (Tier 3) Modelling Option

Table 1 Advantages and constraints of some of the most commonly used C accounting tools for AFOLU (Adapted from Milne et al. 2012)

Resource	Accessibility of resource				Needed for use				Analys is type		Additional attributes								
	Free	Online	Download from web	Multiple languages	Cost[1]	Specialist Expertise	Specialist Equipment	Labour[1]	*Ex-ante*	*Ex-post*	Spatial output	Uncertainty given	Permanence	Leakage	Social/Economic analysis	Non-Land Use GHGs (energy, fuel etc.)	Integrated Approach[2]	Incorporated in VCS methodology	Widely tested/used
Calculators																			
USAID AFOLU Carbon Calculator	X	X			L				X					X[a]					
EX-ACT	X		X	X[b]	L				X	X		X		X[c]		X			X
Cool Farm Tool	X		X	X[d]	L				X	X						X			X
ALU	X		X	X[e]	L	X			X	X	X[f]	X[g]							X
Models																			
APEX	X		X		L	X			X	X	X				X[h]	X	X		X
Integrated Tool Sets																			
SALM	X		X			X		M	X	X		X		X		X		X	
CBP Modelling (overall)	X	X	X	X[i]	L	X[j]		L	X	X	X	X			X				
Simple Assessment (calculator)	X	X		X[i]	L			L	X	X	X	X			X[k]				X[l]
Detailed Assessment (calculator)	X	X			L			L	X	X	X	X			X[k]				
Dynamic Modelling (model)	X		X		L	X		L	X	X	X								
CBP Measurement	X	X	X		H	X	X	M H	X	X	X	X		X	X				

1 H=High, M=Medium, L=Low
2 Resource accounts for the movement of C, water or nutrients between sub-units within the landscape rather than simply aggregating

a Partially addressed in project effectiveness
b Guidelines available in multiple languages not tool
c Matrix can be used to assess leakage
d Online questionnaire in Spanish
e Manual only, in English, Chinese and soon Spanish
f ALU can export data which can be mapped into a GIS
g Under development
h Provides simple income cost analysis for farming activities
i Simple Assessment tool available in English, Chinese, Spanish, French and Russian
j Specialist expertise only needed for the Dynamic Modelling Option not other options
k Output feeds into CBP socio-economic tools
l Widely used with summary report, testing still ongoing for detailed report

2 METHODS

2.1 OVERALL APPROACH

The Productive Safety Net Programme (PSNP) and reference sites surveyed and modelled in this study were distributed across all six Carbon Smart Initiative (CSI) Regional States (Tigray, Afar, Amhara, Somali, SNNPR, and Oromia), and encompassed a broad range of sustainable land management (SLM) activities including area enclosures; cut-and-carry forage systems; various agroforestry systems (ranging from alley cropping, through multistory forest gardens and multipurpose forage trees, to silvopasture systems); integrated soil and water conservation;

Modeling Approach

Scenario data and model parameters were generated from

- surveys,
- regionally-specific emission factors,
- linking model to geospatial data for more robust analysis and site-specific emission factors.

Standardized protocols developed for streamlined rapid low-cost assessment of

- activity data collection,
- scenario development,
- leakage assessment.

fertility management with organic fertilizers; rangeland restoration; afforestation, reforestation, and avoided deforestation; improved cropping systems (cover crops, improved varieties, irrigation, legumes on soil bunds, perennial crops); livelihood and diet diversification; and gulley restoration. In many cases the sites were young (less than a few years, and in some cases less than a year old). For the younger sites, interventions may not have been complete at time of survey, and re-vegetation was immature. Therefore the general approach to modeling these sites was to assume that the management plan for these areas would be implemented over time. For consistency, this modeling strategy was applied to all sites, despite observations that indicated that implementation was sometimes not fully in accordance with the planned management. For example, livestock encroachment into area enclosures was sometimes observed (albeit at much reduced stocking densities).

It should be noted therefore, that for the predicted greenhouse gas impacts of the PSNP sites to be fully realized in the future depends on the recommended best management practices at the sites being adhered to, which in some instances would require increased vigilance and monitoring. At the other end of the spectrum, it was possible to also survey and model some sites that were relatively mature (greater than 20 years), where intervention had been originated before PSNP, and the sites later adopted into the PSNP program. Having more mature sites available to study made it possible to directly observe the longer term development of these sites and to improve predictions for younger sites based on data collected at the older ones. Irrespective of the actual start date of implementation at the sites, we applied a uniform 20-year accounting term to all sites in which sites were considered in terms of the land management activities that PSNP had already implemented, or had already begun implementing, with the model being applied to predict the impact of these activities over a 20-year period. Because all sites had already had implementation activities in place, data on how the land was managed before PSNP began as well as during project implementation were often incomplete, and assumptions about historical land use had to be inferred from a combination of field observations of control sites, interviews with farmers and local development agents (DAs), remote sensing, and documentary evidence.

As indicated above, the IPCC categorizes greenhouse gas accounting methodologies into three “Tiers”. Tier 1 is a simple method with default values (referred to in the CBP modeling environment as “Simple Assessment”). This can be used when a) data are limited, b) default values are adequate to describe the project situation, or c) a quick assessment of GHG impacts is required. Tier 2 is similar to Tier 1 but with country- or location-specific emission factors and other data (the CBP “Detailed Assessment”). Tier 2 can be used when more detailed data are available that are specific to the project/country or region, and when a more in-depth analysis is needed. Finally, Tier 3 is used to describe more complex approaches including dynamic models (the CBP “Dynamic Modelling” option). Tier 3 can be used when time and resources are available to collect in-depth data sets and expertise in modeling and GIS are available. Tier 3 is appropriate when the most accurate and precise information possible is needed regarding changes in the greenhouse balance of land use and management practices. In this project, all three tiers were used.

A total of 28 sites were modeled. In order to keep uncertainties low, a Tier 2 approach was used wherever Tier 1 assumptions were not able to accurately describe the site. For example, in many cases IPCC Tier 1 assumptions were not able to describe the systems satisfactorily because crops, tree species, or ecosystems present were not available in the default parameter set, or because the default values were poorly calibrated to the Ethiopian context, in which cases the CBP Detailed Assessment was used (11 sites). Where on-site management activities and vegetation types were adequately described by IPCC Tier 1 parameter values, the CBP Simple Assessment was used (16 sites). A pilot demonstration of the dynamic modelling option was applied to demonstrate the capacity of this system to provide a more comprehensive analysis.

2.2 Modeling Platform

The Carbon Benefits Project provides a set of tools for land management projects to measure monitor and model the GHG impacts of their activities. These tools are available free of charge online at www.unep.org/cbp_pim/. There are three tools developed by Colorado State University (CSU) in conjunction with its partners[1], the Simple Assessment and the Detailed Assessment (both online tools) and the Dynamic Modelling Option (a downloadable tool).

The Simple Assessment Tool provides a basic assessment of the impact of a project on carbon stocks and greenhouse gas emissions. The tool requires information on land use changes and/or livestock production in the project area, is suitable for a quick assessment at any stage including proposals, and uses standard information on greenhouse gas emission rates including default Tier 1 emission factors (IPCC 2003).

The Detailed Assessment Tool provides a more advanced assessment of the impact projects have on carbon stocks and greenhouse gas emissions. This tool requires information on land use changes and/or livestock production in the project area and can utilize local and project specific field measurements and other local datasets to provide Tier 2 emission factors (IPCC 2003). The tool is suitable for detailed reporting in projects with a reasonable focus on climate change mitigation.

For both the Simple and Detailed Assessment Tools, the user first provides spatial information to the online system, describing where project activities are taking place. This can be done by either drawing areas on an online map or uploading a GIS file (Figure 1). Users must then specify the area in each land use category (options include forestland, grassland, annual cropland, perennial cropland, settlements, agroforestry and wetlands) for each spatial area for the Initial Land Use, the Project Scenario and the Baseline Scenario, which is also called the business-as-usual (BAU) scenario (see Section 2.4 on scenario development and data collection) (Figure 2). In addition, users specify the total number of livestock and basic methods of managing livestock manure associated with each spatial unit and for each scenario.

[1] United Nations Environment Program (UNEP), Global Environment Facility (GEF), World Wildlife Fund (WWF), University of East Anglia, University of Leicester, Michigan State University, World Agroforestry Centre (ICRAF), World Soil Information (ISRIC), Center for International Forestry Research (CIFOR), and Centro de Energia Nuclear na Agricultura (CENA).

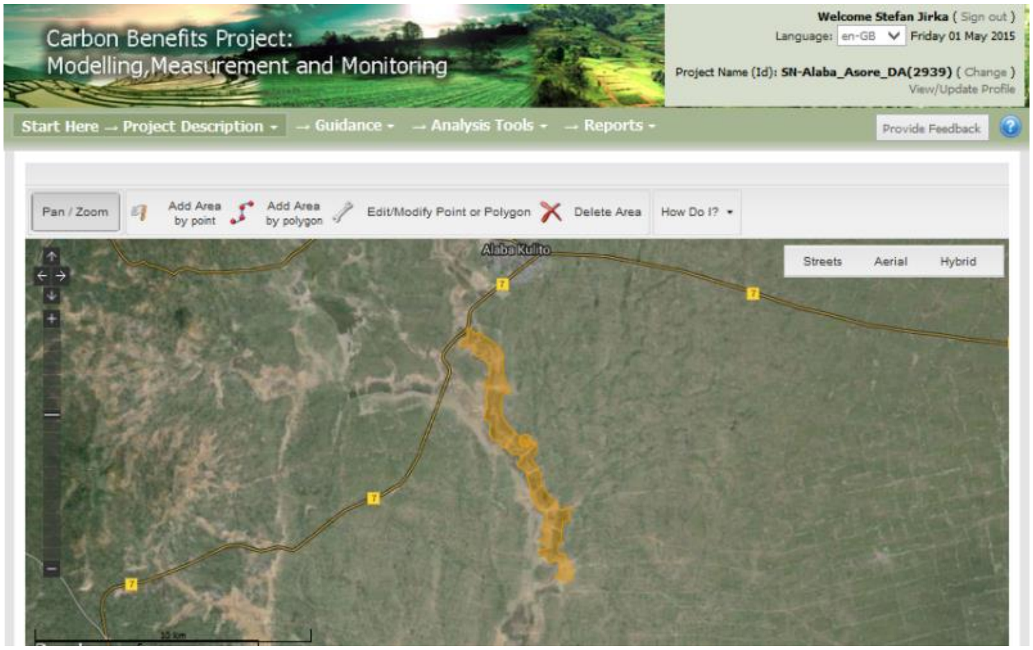
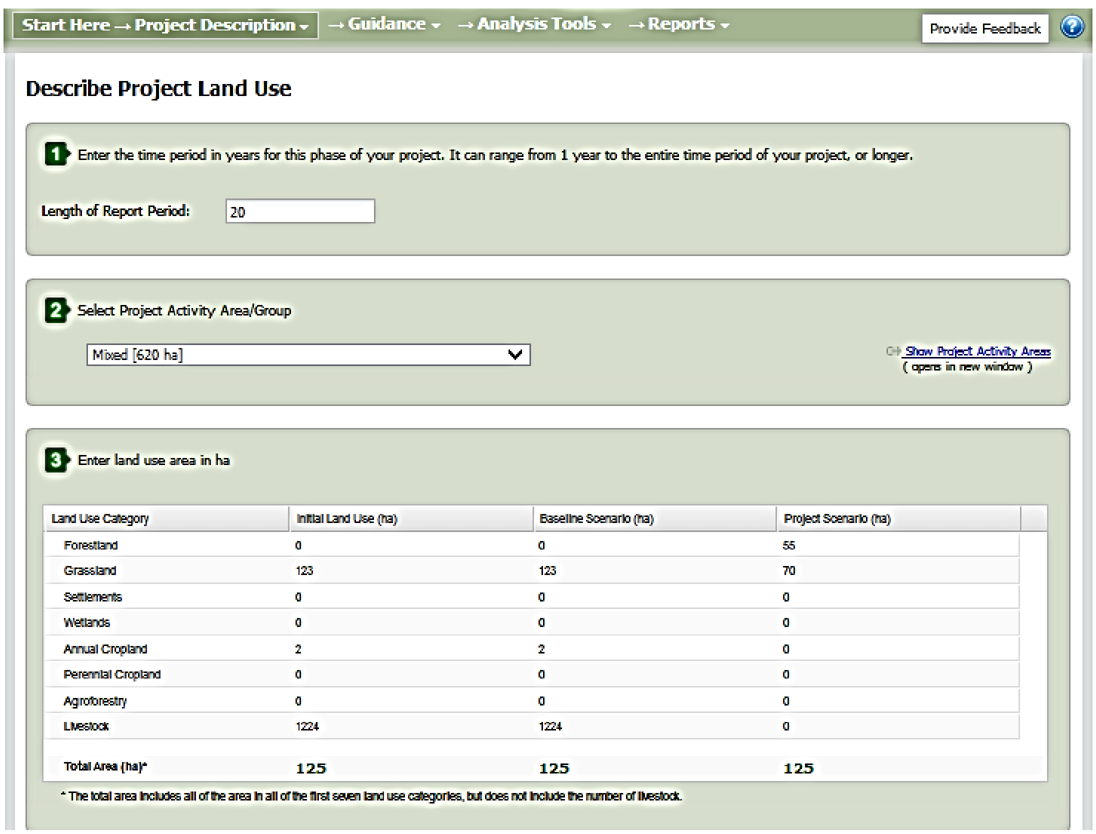


Figure 1: Screenshot of one of the spatial data entry pages of the Carbon Benefits Project



Start Here → Project Description → Guidance → Analysis Tools → Reports

Provide Feedback

Describe Project Land Use

1 Enter the time period in years for this phase of your project. It can range from 1 year to the entire time period of your project, or longer.

Length of Report Period: 20

2 Select Project Activity Area/Group

Mixed [620 ha]

Show Project Activity Areas (opens in new window)

3 Enter land use area in ha

Land Use Category	Initial Land Use (ha)	Baseline Scenario (ha)	Project Scenario (ha)
Forestland	0	0	55
Grassland	123	123	70
Settlements	0	0	0
Wetlands	0	0	0
Annual Cropland	2	2	0
Perennial Cropland	0	0	0
Agroforestry	0	0	0
Livestock	1224	1224	0
Total Area (ha)*	125	125	125

* The total area includes all of the area in all of the first seven land use categories, but does not include the number of livestock.

Figure 2: Screenshot of the CBP page where users describe areas in different land use categories and numbers of livestock

For both the Simple and the Detailed Assessment Tools, users then describe the land management of each land use category for the initial land use and the baseline and project scenarios. Figure 3 shows an example of a page from the Simple Assessment Tool where users enter land management information for annual croplands.

For the Detailed Assessment Tool, more detailed land management information is required. For example, for annual croplands users describe the management of individual crops within a cropping system rather than making generalizations about the entire cropping system. In addition, the user has the option to add their own crops, grass or forest types (Figure 5) and enter Tier 2 emission factors for these (Figure 6).

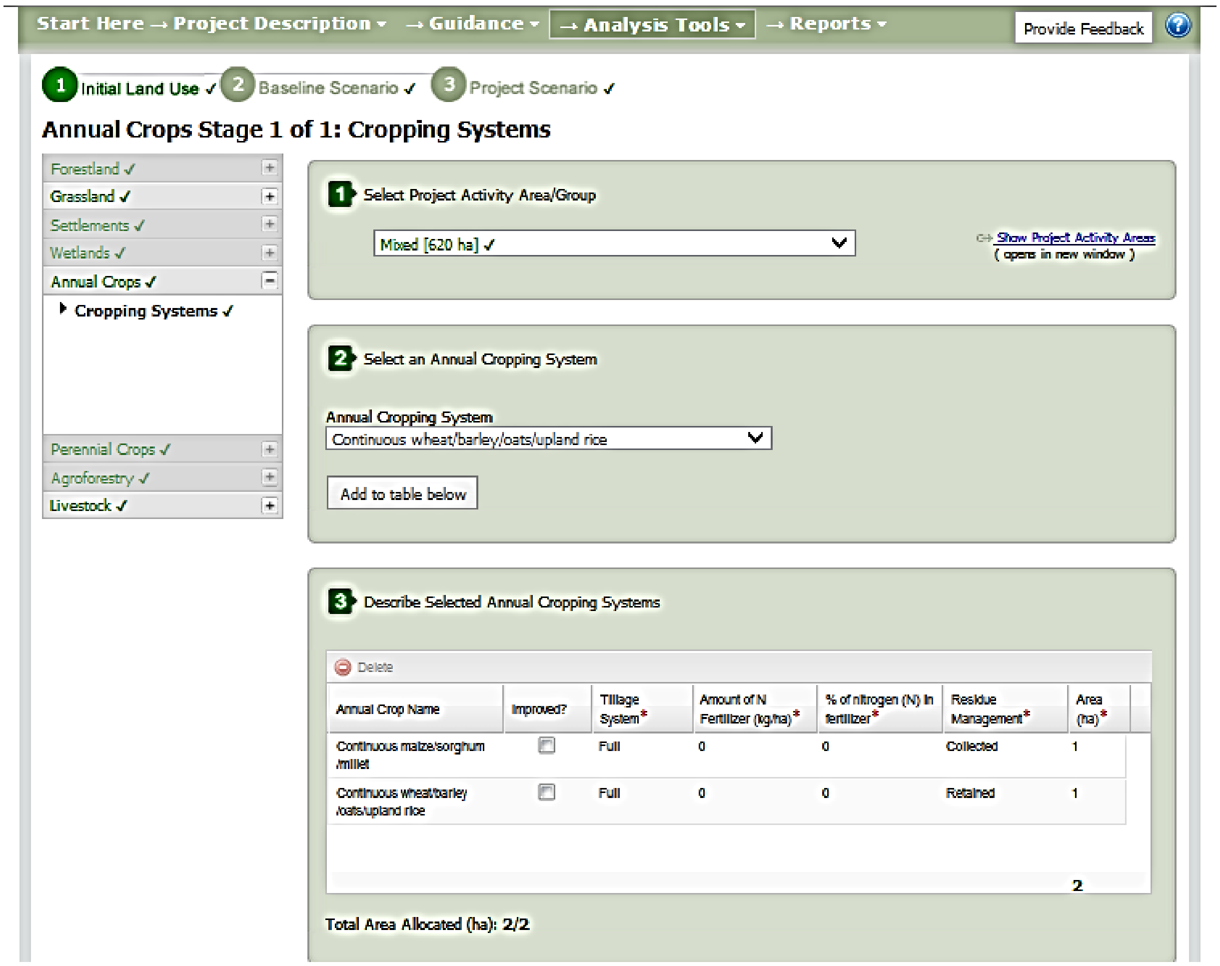


Figure 3: Screenshot of a CBP Simple Assessment page where users enter land management information for annual croplands. N.B., 'Initial Land Use' is highlighted showing that the user is entering management information for annual cropland which was present before the project started. Annual cropland is selected from the left hand menu showing that data is being entered for this land use category.

2.2.1 The Dynamic Modeling Option

This option utilizes the CENTURY Model to assess soil and biomass carbon stock changes. This model is suitable for users with a scientific background who wish to model biomass and organic soil carbon stock changes in projects having a carbon focus. This modeling option is essentially the GEFSOC system as described by Easter et al. 2007. It requires a computer with a LINUX operating system and standard database and geographical information system (GIS). Data layers are assembled and overlain in a GIS to create a 'run file' (Figure 7). Data required are: native vegetation; historic, recent, current and future land use; climate; soils; latitude and longitude.

A site at Asore in Alaba Special Woreda, SNNPR was selected for a pilot demonstration of the capabilities in the Dynamic Modeling Option because intervention on this site began 21 years ago. This site pre-dates PSNP, having been initiated by the Managing Environmental Resources to Enable Transitions (MERET Ethiopia) program, and later adopted into PSNP (https://www.wfp.org/disaster-risk-reduction/meret). Having a site that is significantly older than those initiated by PSNP allowed for verification of the model using data collected on site and from the adjacent control site under BAU management. Soil samples from 0-15 cm, 15-45 cm and 45-100 cm depth were analyzed and fitted to a quadratic regression model to develop the CENTURY model inputs for soil texture, depth, and bulk density. Mean monthly climate data were generated for the site (see Section 2.3.3). Latitude and longitude (WGS 1984 datum) were derived from GPS measurements taken on site, and historic land cover, land use and management information were developed from interviews with local residents and government agency personnel, and validated using historical Landsat imagery (Section 2.3.4).

Modeling SOC stock changes in the present time requires an understanding of native vegetation and the land use and management in the previous 100 years in order to dynamically estimate soil organic carbon and soil nitrogen pools at the start of the modeled period. Running the dynamic modeling system requires developing a management sequence diagram (Figure 4) which describes the chain of land use over the period of interest. The five individual management sequences (TF-DR-CH, TF-DR-DR, TF-DR-ASG, TF-DR-WL, and TF-CL-ASG2, as described in the key to Figure 4) were modeled separately using the climate and soils data for the site. An erosion coefficient of 4.8 kg m^{-2} yr^{-1} from 1987 to 1993 (when severe soil erosion occurred on the four degraded rangeland (DR) sequences) was calculated by minimizing the error function between modeled and measured soil properties.

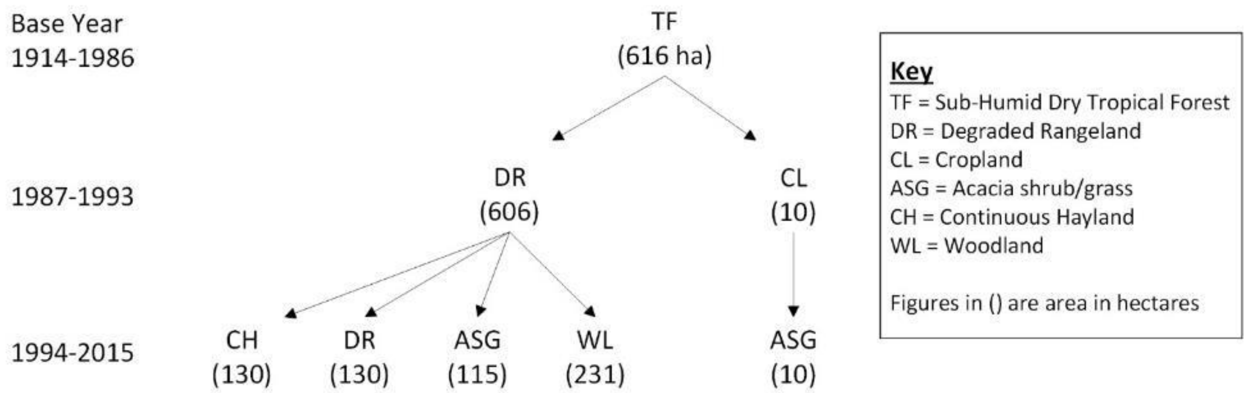


Figure 4: Management Sequence Diagram for the Asore site in Alaba Special Woreda, SNNPR.

Once calculated, the run file was then used to run the CENTURY model. Parameters previously developed for a tropical acacia woodland (a land cover similar to the one at the Asore CSI site) were used for the woody plant growth submodel, and likewise parameters for a tropical grassland were used for the grass/forb plant growth submodel. The complete CENTURY model input files are included in Annex 4.

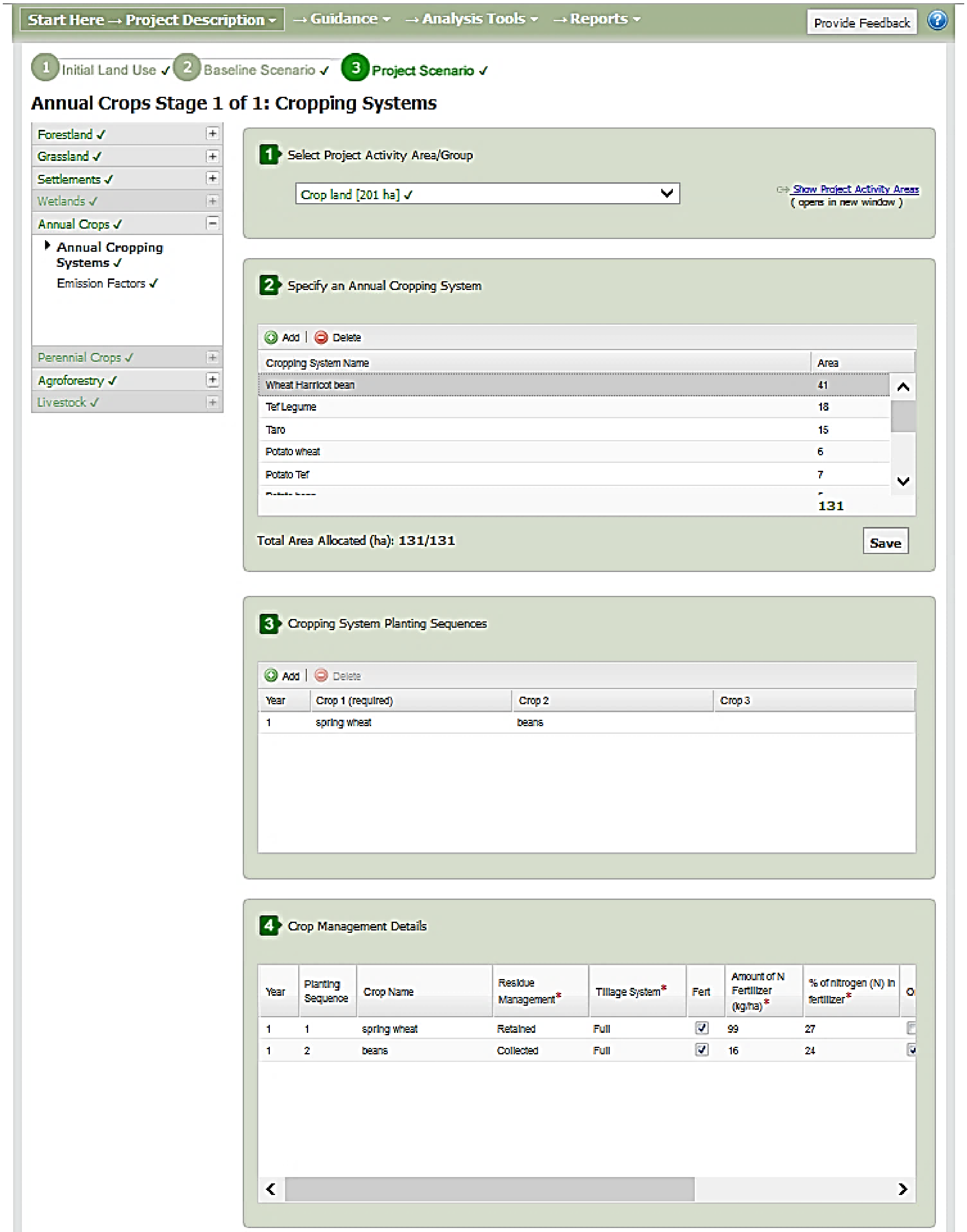


Figure 5: Screenshot of the CBP Detailed Assessment page where users enter land management information for annual croplands.

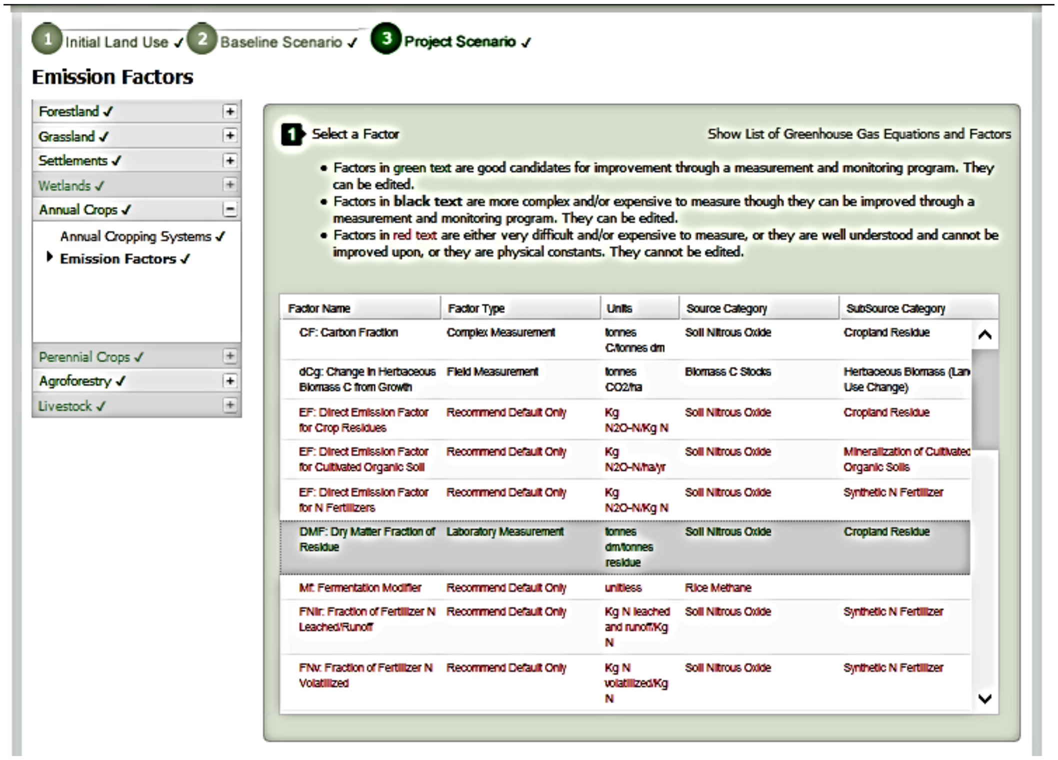


Figure 6: Screenshot of the CBP Detailed Assessment page where users can enter Tier 2 emission factors.

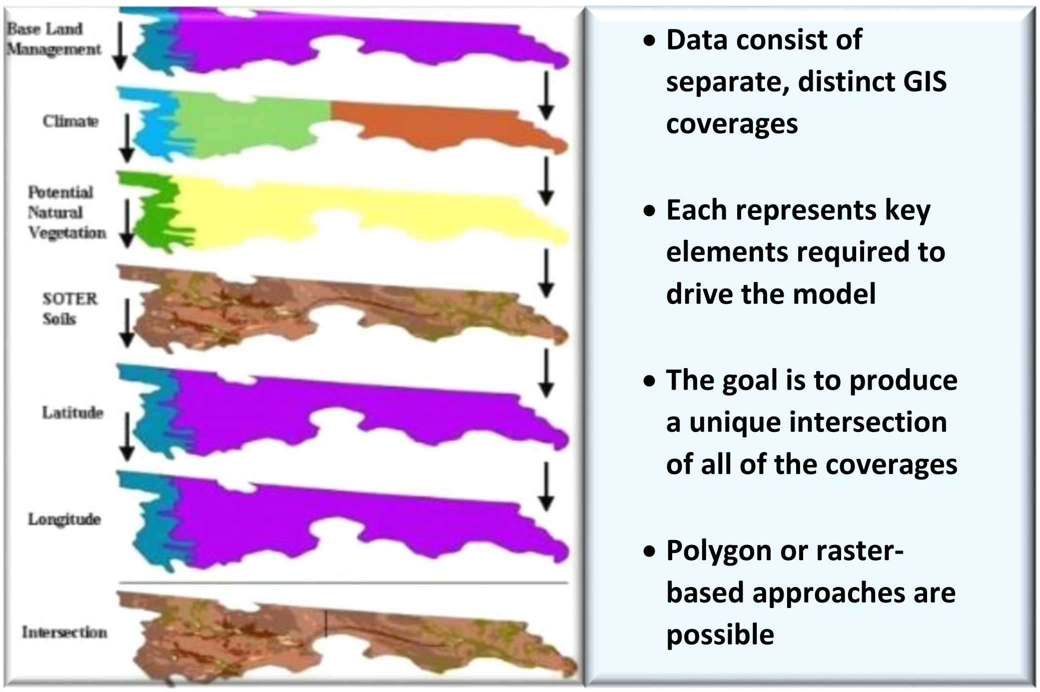


Figure 7: Spatial layers used to construct the run file that drives the Dynamic Modeling Option.

2.3 Geospatial Analysis

Geospatial Analysis

The Issue: Landscape scale data are a prerequisite to scaling up of carbon projects

The problem: Ground-based surveys at the national or landscape scale are time-consuming and expensive

What is required? Improved data and simplified methods are critical to cost-effective scaling up of planning, monitoring and verification

The Approach:

- National, high resolution, geophysical and biophysical geospatial data generated
- Simplified methods for use of remotely sensed data
- Calibrate geospatial methods using field-based surveys
- Link geospatial data to models

2.3.1 Site mapping

The locations of all 28 survey sites, and the CSI woreda boundaries are shown in Figure 8, and summarized in Table 2. The site codes indicated in Table 2 consist of an acronym derived from the first two letters of the region, woreda, and kebele in which the site is located[2]. These site codes are used as shorthand to refer to the individual sites through the remainder of this report, and are the same codes used in the National CSI databank provided to CSI by the Cornell group.

The surveyed region extended through a band of the food-insecure regions from the north to the south of Ethiopia, both within the Rift Valley and into the highlands both east and west of the Rift Valley covering diverse agro-ecosystems, livelihood types and climate risks. A summary of the livelihood zones, main crops and livestock in the areas the CSI sites are located is given in Table 3. Table 4 shows the climate zones and climate variables for the CSI sites, and

[2] In some cases where there is more than one CSI site in the same kebele the first two letters of the watershed name were used instead. Also, where the region, woreda or kebele is made up of more than one word the first letter of each word was used and both letters were capitalized in the acronym. E.g., SNNPR, Damot Gale, Wondara Balose becomes SN_DG_WB.

Table 5 summarizes the main intervention measures (both physical and biological) that are implemented within each of the CSI sites. More detailed site descriptions are given in Annex 3.

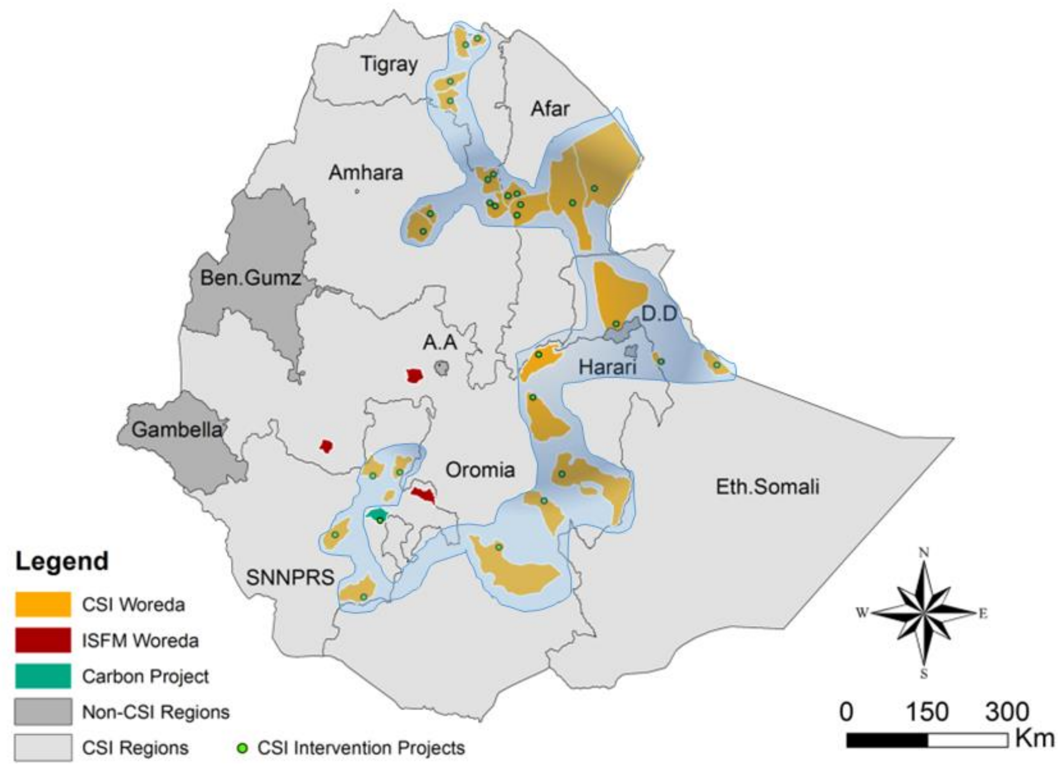


Figure 8: CSI survey woredas and site locations. The corridor created by CSI sites extending from Oromia in the south to Tigray in the north is shaded in light blue.

Table 2: Political locations of CSI survey sites. The site codes below consist of an acronym derived from the first two letters of the region, woreda, and kebele in which the site is located. These site codes are used as shorthand to refer to the individual sites through the remainder of this report, and are the same codes used in the National CSI databank provided to CSI by the Cornell group.

Site Code	Region	Zone	Woreda	Kebele	Watershed
Af_Ch_Ja	Afar	Zone 1	Chifra	Jara	Jara
Af_Du_Ay	Afar	Zone 1	Dubti	Ayrolaf & Gebelaytu	Gebelaytu
Af_El_WL	Afar	Zone 1	Elidar	Woha Limat	Woha Limat
Af_Ew_Bo	Afar	Zone 4	Ewa	Boltiom	Alada Sikuma
Af_Ew_Du	Afar	Zone 4	Ewa	Dubya	Dubya
Am_Ha_SA	Amhara	North Wollo	Habru	Geradu	Sefed Amba
Am_Ha_WA	Amhara	North Wollo	Habru	Geradu	Weira Amba
Am_Ko_05	Amhara	North Wollo	Kobo	05	Rhama Bokum

Am_Ko_Zo	Amhara	North Wollo	Kobo	Zobel	Zobel
Am_Si_Aj	Amhara	South Gonder	Simada	Aje	Ertib Wenz
Am_TG_Ad	Amhara	South Gonder	Tach Gayint	Aduka	Alalo
Or_DL_Od	Oromia	West Harerge	Daro Lebu	Odaleleba	Lege Hora
Or_DM_ND	Oromia	Bale	Delo Mena	Naniga Dhera	Shek Kedir Karo
Or_Go_Ke	Oromia	Bale	Goro	Keku	Wayu Bure
Or_Me_Fa	Oromia	West Harerge	Meiso	Fayo	Fayo
Or_Se_Ch	Oromia	Bale	Seweyna	Chopi	Bila
SN_Al_As	SNNPR	Alaba	Alaba Special Woreda	Asore	Asore
SN_DeG_Bo	SNNPR	Gamo Gofa	Demba Gofa	Borda	Usha
SN_DG_WB	SNNPR	Wolayita	Damot Gale	Wondara Balose	Godaye
SN_Hu_Lo	SNNPR	Wolayita	Humbo	Longena	Gamot Terara
SN_Ko_Le	SNNPR	Segen Peoples'	Konso	Lehaife	Boloshe
SN_So_Sh	SNNPR	Hadiya	Soro	Shera	Sheshecho
So_Gu_Fa	Somali	Fafan	Gursum	Fafan	Caracaska
So_Sh_Ba	Somali	Siti	Shinile	Baraq	Baraq
Ti_Ah_Se	Tigray	Central Tigray	Ahferom	Sero	Chearo
Ti_GM_SL	Tigray	Eastern Tigray	Gulo Mekeda	Shewit Lemlem	Serawat
Ti_KT_DA	Tigray	Central Tigray	Kola Tembain	Dr. Atikilty	Dr. Atikilty
Ti_TA_Ge	Tigray	Central Tigray	Tanqua Aberegele	Gera	Aba Tila

Table 3: Livelihood zones of CSI sites. CSI Livelihood zone numbers are those derived in the CSI phase 1 project by LTS (2013).

Site code	CSI Livelihood zone (LZ)	Livelihood type	LZ Main Crops	LZ Main Livestock	Elevation (m)
Af_Ch_Ja	8. Pastoral	Pastoral	Sorghum	camels & cattle	942
Af_Du_Ay	8. Pastoral	Pastoral	Sorghum	camels & cattle	370
Af_El_WL	8. Pastoral	Pastoral	Sorghum	camels & shoats	375
Af_Ew_Bo	8. Pastoral	Pastoral	Sorghum	camels & cattle	1125
Af_Ew_Du	8. Pastoral	Pastoral	Sorghum	camels & cattle	949
Am_Ha_SA	4. Cereal system Woina Dega: Dry zone	Cropping	Sorghum, teff, fruit/veg & maize	cattle & shoats	1840
Am_Ha_WA	4. Cereal system Woina Dega: Dry zone	Cropping	Sorghum, teff, fruit/veg & maize	cattle & shoats	1984
Am_Ko_05	2. Cereal system vertisols: Woina Dega Wet/moist zone	Cropping	Sorghum, teff, maize	cattle & shoats	1396

Am_Ko_Zo	3. Cereal system : Woina Dega Wet/moist zone	Cropping	Sorghum, teff, fruit/veg & maize	cattle & shoats	2005
Am_Si_Aj	1. Cereal system Dega Zone	Cropping	Wheat & barley	cattle & shoats	2482
Am_TG_Ad	3. Cereal system : Woina Dega Wet/moist zone	Cropping	Sorghum, teff, pulses & maize	cattle & shoats	2288
Or_DL_Od	3. Cereal system : Woina Dega Wet/moist zone	Cropping	Sorghum, maize, coffee & chat	cattle & shoats	1705
Or_DM_ND	7. Agropastoral	Agropastoral	Sorghum, maize & teff	cattle & camels	1125
Or_Go_Ke	7. Agropastoral	Agropastoral	Wheat, maize, teff & sorghum	cattle & bees	1613
Or_Me_Fa	7. Agropastoral	Agropastoral	Sorghum, maize, sesame & groundnuts	cattle & camels	1374
Or_Se_Ch	7. Agropastoral	Agropastoral	Wheat, maize, teff & sorghum	cattle & bees	1543
SN_Al_As	3. Cereal system : Woina Dega Wet/moist zone	Cropping	Maize, wheat, pulses & sorghum	cattle & shoats	1707
SN_DeG_Bo	5. Enset codominant with cereals	Cropping	Enset, sweet potato, maize, teff_& pulses	cattle & shoats	1390
SN_DG_WB	6. Cereals dominant and enset and root crops minor	Cropping	Maize, pulses, sweet potatoes & enset	cattle & shoats	2195
SN_Hu_Lo	6. Cereals dominant and enset and root crops minor	Cropping	Maize, pulses, sweet potatoes & enset	cattle & shoats	1510
SN_Ko_Le	6. Cereals dominant and enset and root crops minor	Cropping	Maize, sorghum, teff & pulses	cattle & shoats	1484
SN_So_Sh	6. Cereals dominant and enset and root crops minor	Cropping	Maize, pulses, sweet potatoes & enset	cattle & shoats	1959
So_Gu_Fa	7. Agropastoral	Agropastoral	Maize & sorghum	cattle & camels	1457
So_Sh_Ba	7. Agropastoral	Agropastoral	Sorghum & maize	cattle & camels	1056
Ti_Ah_Se	1. Cereal system Dega Zone	Cropping	Teff, wheat, barley & millet	shoats & cattle	2038
Ti_GM_SL	1. Cereal system Dega Zone	Cropping	Barley, wheat & cactus fruit	shoats & cattle	2338
Ti_KT_DA	4. Cereal system Woina Dega: Dry zone	Cropping	Sorghum, maize, teff & millet	shoats & cattle	1859
Ti_TA_Ge	4. Cereal system Woina Dega: Dry zone	Cropping	Sorghum, maize, teff & millet	shoats & cattle	1450

Table 4: Climate in CSI sites. NPP = Annual Net Primary Production; MAT = Mean Annual Temperature; MAP = Mean Annual Precipitation; PET = Potential Evapotranspiration; AIX = Aridity Index.

Site code	NPP (Mg C / ha / yr)	MAT (°C)	MAP (mm)	PET (mm)	AIX	Holdridge Zone	Koeppen Climate	Bodykko Climate	Main Growing Season
Af_Ch_Ja	2.0	23.2	1045	1551	0.7	Subtropical subhumid dry forest	Equatorial savannah dry winter	Steppe	25 Jun - 23 Sep
Af_Du_Ay	0.8	24.5	277	1807	0.2	Tropical arid thorn woodland	Arid climate desert hot	Desert	26 Jul - 14 Aug
Af_El_WL	0.4	28.9	349	1818	0.2	Tropical arid thorn woodland	Arid climate desert hot	Desert	26 Jul - 14 Aug
Af_Ew_Bo	2.8	22.1	952	1518	0.6	Subtropical subhumid dry forest	Equatorial savannah dry winter	Steppe	27 Jun - 15 Sep
Af_Ew_Du	1.8	23.1	927	1549	0.6	Tropical subhumid dry forest	Equatorial savannah dry winter	Steppe	29 Jun - 13 Oct
Am_Ha_SA	4.1	17.8	961	1376	0.8	Subtropical subhumid dry forest	Warm temperate dry winter warm summer	Steppe	19 Jun - 4 Oct
Am_Ha_WA	3.1	17.8	1060	1376	0.8	Subtropical subhumid dry forest	Warm temperate dry winter warm summer	Steppe	19 Jun - 4 Oct
Am_Ko_05	3.2	24.6	994	1584	0.6	Tropical subhumid dry forest	Equatorial savannah dry winter	Steppe	30 Jun - 17 Sep
Am_Ko_Zo	4.0	23.0	967	1542	0.6	Subtropical subhumid dry forest	Equatorial savannah dry winter	Steppe	28 Jun - 18 Sep
Am_Si_Aj	3.3	16.6	1512	1286	1.2	Subtropical humid moist forest	Warm temperate dry winter warm summer	Forest	5 May - 17 Oct
Am_TG_Ad	4.5	14.8	1685	1189	1.4	Subtropical humid moist forest	Warm temperate dry winter warm summer	Forest	28 Apr - 21 Oct
Or_DL_Od	5.7	18.7	1288	1230	1.1	Subtropical humid moist forest	Temperate fully humid warm summer	Steppe	6 Feb - 12 Nov
Or_DM_ND	7.9	21.1	845	1264	0.7	Subtropical subhumid dry forest	Equatorial savannah dry summer	Steppe	7 Sep - 4 Dec
Or_Go_Ke	5.0	24.8	489	1537	0.3	Tropical semiarid very dry forest	Arid climate steppe hot	Desert	16 Sep - 1 Nov

Or_Me_Fa	4.5	23.0	892	1514	0.6	Subtropical subhumid dry forest	Equatorial savannah dry winter	Steppe	5 Jun - 10 Oct
Or_Se_Ch	4.7	25.1	581	1553	0.4	Tropical semiarid very dry forest	Warm temperate fully humid warm summer	Steppe	3 Sep - 25 Oct
SN_Al_As	6.2	19.2	1018	1305	0.8	Subtropical subhumid dry forest	Equatorial savannah dry summer	Steppe	26 Jan - 19 Oct
SN_DeG_Bo	8.0	19.2	1712	1275	1.3	Subtropical humid moist forest	Warm temperate dry summer warm summer	Forest	3 Feb - 4 Dec
SN_DG_WB	8.2	18.9	1350	1269	1.1	Subtropical humid moist forest	Arid steppe hot	Semiarid	27 Feb - 9 Nov
SN_Hu_Lo	8.9	19.5	1100	1300	0.9	Subtropical subhumid dry forest	Arid climate steppe hot	Semiarid	3 Mar - 4 Nov
SN_Ko_Le	3.2	20.8	832	1380	0.6	Subtropical subhumid dry forest	Equatorial savannah dry summer	Steppe	12 Jul - 23 Nov
SN_So_Sh	7.5	19.6	1295	1298	1.0	Subtropical humid moist forest	Arid climate steppe hot	Steppe	25 Feb - 29 Oct
So_Gu_Fa	2.4	20.1	671	1359	0.5	Subtropical semiarid thorn woodland	Arid steppe hot	Semiarid	30 Jun - 16 Oct
So_Sh_Ba	1.3	26.8	484	2090	0.2	Tropical semiarid thorn woodland	Arid steppe hot	Semiarid	7 Aug - 22 Aug
Ti_Ah_Se	1.4	19.5	803	1472	0.5	Subtropical subhumid dry forest	Warm temperate dry winter hot summer	Steppe	12 Jun - 25 Sep
Ti_GM_SL	0.7	19.5	804	1559	0.5	Subtropical subhumid dry forest	Warm temperate fully humid hot summer	Steppe	14 Jun - 18 Sep
Ti_KT_DA	1.6	22.4	771	1657	0.5	Subtropical semiarid very dry forest	Equatorial savannah dry winter	Steppe	6 Jun - 16 sep
Ti_TA_Ge	1.3	27.4	820	1734	0.5	Tropical semiarid very dry forest	Arid climate steppe hot	Steppe	4 Jun - 17 Sep

Table 5: Summary of main physical and biological interventions in CSI sites.

Site code	Years	Intervention Type	Physical Measures	Biological Measures
Af_Ch_Ja	3	Improved grassland	Stone and soil bund, deep water infiltration trenches, grassland permanent enclosure	Leguminous tree planting and natural regeneration
Af_Du_Ay	3	Improved cropland	Soil bund, terraces, micro-catchment and irrigation	Leguminous tree hedgerows, wind erosion breaks and shade trees
		Improved woodland	Soil bund, terraces and micro-catchment	*Prosopis* tree hedgerows, wind erosion breaks and shade trees
Af_El_WL	3	Improved woodland	Stone and soil bund terrace, deep water infiltration trenches, woodland permanent enclosure	Leguminous tree planting and natural regeneration
		Improved woodland		Natural regeneration
Af_Ew_Bo	3	Improved woodland	Stone and soil bund, deep water infiltration trenches and woodland permanent enclosure	Leguminous tree planting and natural regeneration
Af_Ew_Du	3	Improved grassland	Stone and soil bund terrace, deep water infiltration trenches, farmer managed grassland area enclosure	Farmer managed natural regeneration
		Improved woodland	Stone and soil bund, deep water infiltration trenches and woodland area enclosure	Natural regeneration
Am_Ha_SA	5	Improved agroforestry	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, cropland with integrated organic and inorganic amendments	Multistory mixed agroforestry system, vegetable, fruit, coffee and leguminous and non-leguminous tree planting
		Improved cropland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, cropland with integrated organic and inorganic amendments	Mixed cereal and legume cropping system, leguminous and non-leguminous tree hedge rows
		Improved woodland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, woodland permanent enclosure	Leguminous and non-leguminous tree planting, natural regeneration
Am_Ha_WA	21	Improved cropland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, cropland with integrated organic and inorganic amendments	Mixed cereal and legume cropping system and leguminous tree planting

		Improved forestland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, forestland permanent enclosure	Leguminous and non-leguminous tree planting and natural regeneration
		Improved grassland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, grassland permanent enclosure	Leguminous tree planting and natural regeneration
Am_Ko_05	5	Improved woodland	Stone and soil bund, hillside terrace, stone check dam, deep water infiltration trenches, woodland area enclosure	Leguminous tree planting and natural regeneration
Am_Ko_Zo	5	Improved cropland	Terrace, soil bund	Mixed cereal cropping system
		Improved woodland	Stone and soil bund, woodland permanent enclosure	Natural regeneration
Am_Si_Aj	5	Improved cropland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches	No biological measure
		Improved woodland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, cropland with integrated organic and inorganic amendments	Mixed cereal and legume cropping system and leguminous and non-leguminous tree planting
Am_TG_Ad	5	Improved cropland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, cropland with integrated organic and inorganic amendments	Mixed cereal and legume cropping system and leguminous tree planting
		Improved woodland	Hillside terrace, stone check dam, eye brow basin, woodland permanent enclosure	Leguminous and non-leguminous tree planting and natural regeneration
Or_DL_Od	17	Improved agroforestry	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches	Multistory mixed agroforestry system, vegetable, fruit and leguminous and non-leguminous tree planting
		Improved woodland	Terrace-Soil bund-Stone bund (Gabion)-Trench (Micro catchment)-Deep Trenches	Leguminous and non-leguminous tree planting-Natural regeneration
Or_DM_ND	20	Improved woodland	Area enclosure of woodland	Natural regeneration
		Improved woodland	Stone and soil bund, terrace, half-moon stone bund and check dam, eye brow basin, deep water infiltration	Leguminous and non-leguminous tree planting and natural regeneration

			trenches, area enclosure of woodland	
Or_Go_Ke	3	Improved cropland	Stone and soil bund, stone check dam, micro basins	No biological measure
		Improved woodland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, forestland permanent enclosure	Leguminous and non-leguminous tree planting and natural regeneration
Or_Me_Fa	2	Improved woodland	Area enclosure of woodland	Natural regeneration
			Stone and soil bund, terrace, half-moon stone bund and check dam, eye brow basin, deep water infiltration trenches, area enclosure of woodland	Leguminous and non-leguminous tree planting and natural regeneration
Or_Se_Ch	3	Improved cropland	Terrace, micro basin	Leguminous tree left on the farm
		Improved woodland	Terrace, micro basin, area enclosure of woodland	Leguminous and non-leguminous tree planting, natural regeneration
SN_Al_As	20	Improved woodland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, woodland permanent enclosure	Leguminous and non-leguminous tree planting, natural regeneration
SN_DeG_Bo	17	Improved cropland	Soil and stone bunds, hillside terrace, micro catchments, organic and inorganic amendments	Mixed cereal and legume cropping system
		Improved woodland	Stone and soil trenches and check dam, area enclosure of woodland	Leguminous tree planting and natural regeneration
		Improved woodland	Terrace-Trench-Microbasin	Leguminous tree planting and natural regeneration
SN_DG_WB	20	Improved agroforestry	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches	Multistory mixed agroforestry system, cereal and leguminous crops, vegetable, fruit, coffee and leguminous and non-leguminous tree planting and leguminous crop and grass strips
		Improved cropland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches	Mixed cereal and legume cropping and leguminous and non-leguminous tree hedgerows and grass and legume strips between terraces
SN_Hu_Lo	8	Improved forestland	Stone and soil bund, stone check dam, deep water infiltration trenches, area enclosure of forestland	Leguminous and non-leguminous tree planting, natural regeneration

SN_Ko_Le	17	Improved forestland	Stone and soil trenches and check-dam, area enclosure of woodland and eucalyptus tree planting	Leguminous and non-leguminous tree planting and natural regeneration
		Improved woodland	Stone and soil trenches and check-dam, area enclosure of woodland	Leguminous and non-leguminous tree natural regeneration
SN_So_Sh	13	Improved cropland	Stone and soil bund, trench, micro basin, half moon, brushwood, check dam	Mixed cereal system, leguminous and non-leguminous tree left on farm
		Improved woodland	Stone and soil bound, trenches, micro basin and check dame, area enclosure acacia dominated forest	Leguminous and non-leguminous tree planting and natural regeneration
		Improved woodland	Stone and soil bound, trenches, micro basin and check-dam, area enclosure acacia dominated forest	Leguminous and non-leguminous tree planting and natural regeneration
		Improved woodland	Stone and soil bound, trenches, micro basin and check-dam, area enclosure grevillea dominated forest	Leguminous and non-leguminous tree planting and natural regeneration
		Improved woodland		Leguminous and non-leguminous tree planting and natural regeneration
		Improved grassland	Stone and soil bund, stone and brushwood check dam, micro basin, area enclosure of grassland	Leguminous tree planting and natural regeneration
So_Gu_Fa	3	Improved cropland	Soil bund, micro catchments possibly maize cropping without fertilizers	Leguminous tree hedgerows and trees left in farm, very sparse and not well-maintained
				No biological measure
So_Sh_Ba	3	Improved woodland	Stone and soil bund, stone check dam, area enclosure of woodland	Leguminous tree natural regeneration very sparse
Ti_Ah_Se	15	Improved cropland	Stone and soil bund, stone check dam, terrace, irrigation, vegetables and teff cropping with organic and inorganic fertilizers	Leguminous and non-leguminous tree hedgerows and trees left in farm
		Improved cropland	Stone and soil bund, terraces, teff cropping with inorganic fertilizers	Leguminous and non-leguminous tree hedgerows and trees left in farm
		Improved cropland	Stone and soil bund, terraces, teff cropping with inorganic fertilizers and bare fallow	Leguminous and non-leguminous tree hedgerows and trees left in farm
Ti_GM_SL	5	Improved woodland	Stone and soil bund, hillside terrace, stone check dam, deep infiltration trenches area enclosure of woodland	Leguminous and non-leguminous tree planting and natural regeneration

Ti_KT_DA	5	Improved cropland	Terrace, stone check dam mixed cereal cropping system and scattered leguminous tree left in the farm	mixed cereal cropping system and scattered leguminous tree left in the farm
		Improved cropland	Terrace, stone check dam mixed cereal cropping system and scattered leguminous tree left in the farm	mixed cereal cropping system and scattered leguminous tree left in the farm
		Improved grassland	Stone and soil bund, stone check dam, area enclosure of grassland	Leguminous and non-leguminous tree natural regeneration
		Improved woodland	Stone and soil bund, stone check dam, area enclosure of woodland	Leguminous and non-leguminous tree natural regeneration
Ti_TA_Ge	2	Improved cropland	Stone and soil bund, hillside terrace, stone check dam, deep water infiltration trenches, percolation pond and pit check dam	Mixed cereal cropping system, scattered leguminous tree left on farms
		Improved woodland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, area enclosure of woodland on mountain side	Leguminous and non-leguminous tree natural regeneration
		Improved woodland	Stone and soil bund, hillside terrace, stone check dam, eye brow basin, deep water infiltration trenches, permanent enclosure of woodland on plain land	Leguminous and non-leguminous tree natural regeneration

For each of the sites, a combination of remote sensing imagery and field survey were used to delineate the boundaries of each land use and land cover type within the project boundaries. An example satellite image of Weira Amba PSNP site in Habru woreda, Amhara, showing land use categories with woodland and grassland on upper slopes transitioning to cropland and gulley restoration on lower slopes is shown in Figure 9. The adjacent kebele used as a control site where no PSNP intervention has been implemented can also be seen in the background of Figure 9. Maps of each of the sites and their locations within the respective regions are shown in Figure 10.

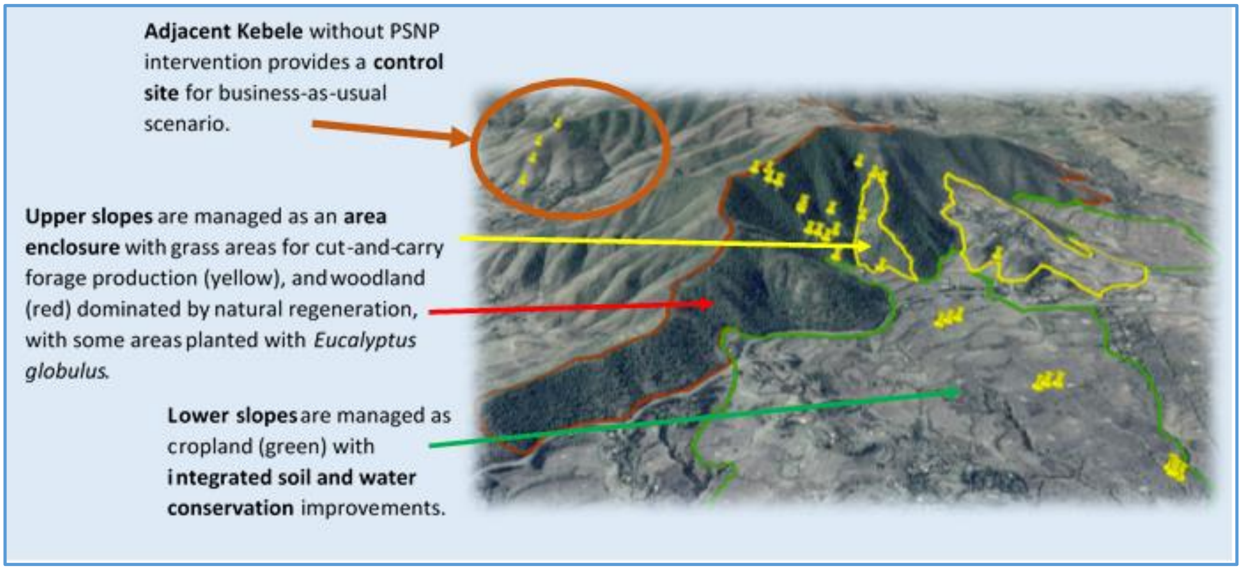


Figure 9: Satellite image of Weira Amba PSNP site in Habru woreda, Amhara, showing land use categories with woodland and grassland on upper slopes transitioning to cropland and gulley restoration works on lower slopes. The adjacent kebele used as a control site where no PSNP intervention has been implemented can be seen in the background. Yellow pins indicate location of 1m soil profiles sampled.

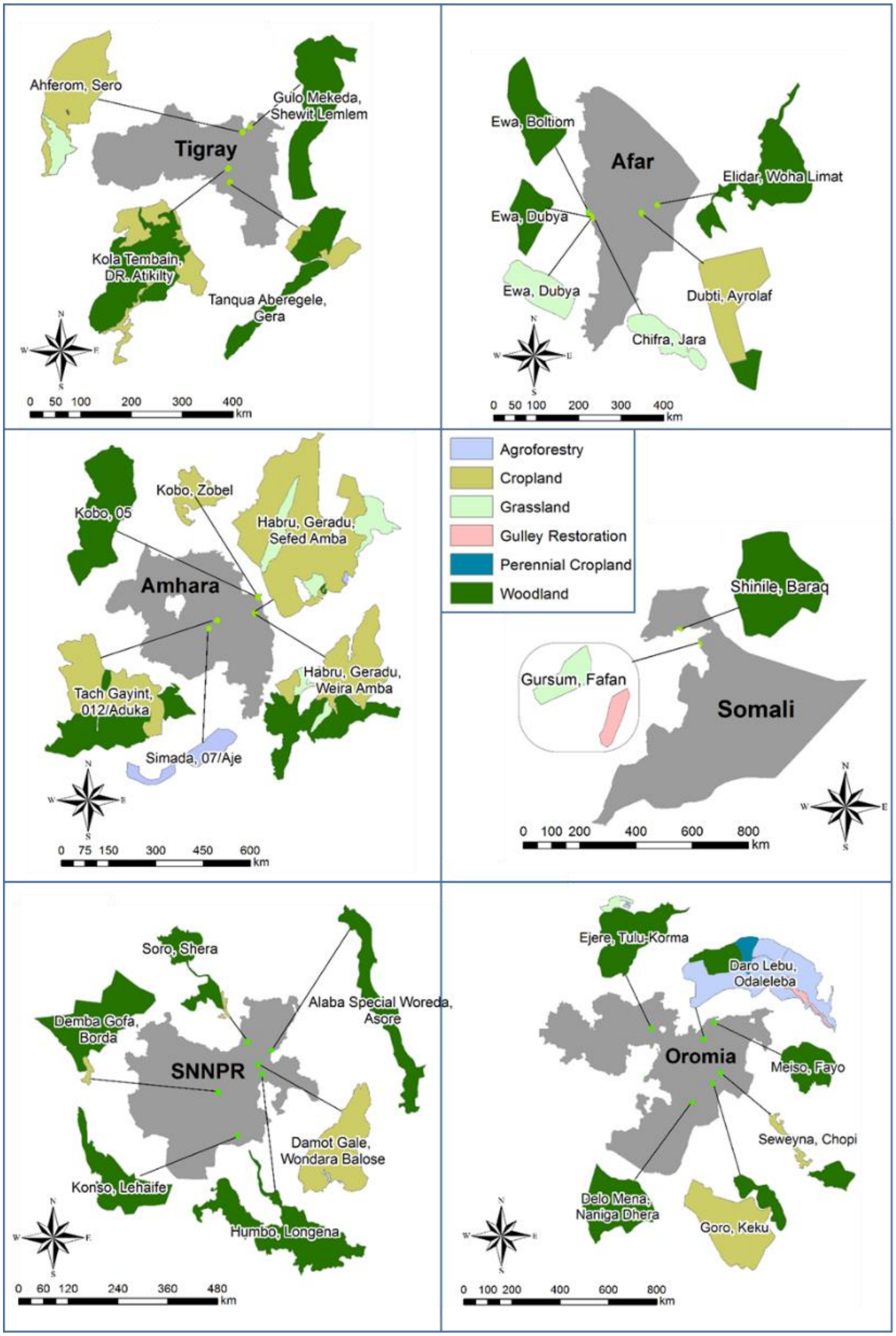


Figure 10: Location, land cover, and land management maps of the CSI survey sites.

2.3.2 Net primary production

Net primary production (NPP) is defined as the rate at which all plants in an ecosystem produce net useful chemical energy through converting carbon dioxide and water to biomass in the process of photosynthesis. NPP is equal to the difference between the rate at which the plants in an ecosystem fix atmospheric carbon dioxide and the rate at which they release some of that carbon dioxide during respiration. Use of NPP maps allowed calculation of site-specific estimates for emission factors related to biomass growth rates for Tier 2 assessments. Data from the NASA MODIS satellite were averaged over 10 years (2004-13) to derive 10-year average NPP (estimated by the NASA MOD17 algorithm; Heinsch et al., 2003) at 1 km resolution for the whole of Ethiopia.

The MOD17 algorithm is based on radiation use efficiency, with productivity under well-watered and fertilized conditions being linearly related to absorbed photosynthetically active radiation (APAR). Translation of APAR to an estimate of productivity is accomplished through a conversion efficiency parameter, ε, which varies by vegetation type and climate conditions. MOD17 applies differences in maximum ε between different types of vegetation and also lowers ε under water-stressed and/or cold temperature conditions. To calculate NPP, MOD17 also estimates daily leaf and fine root maintenance respiration, annual growth respiration, and annual maintenance respiration of live cells in woody tissue.

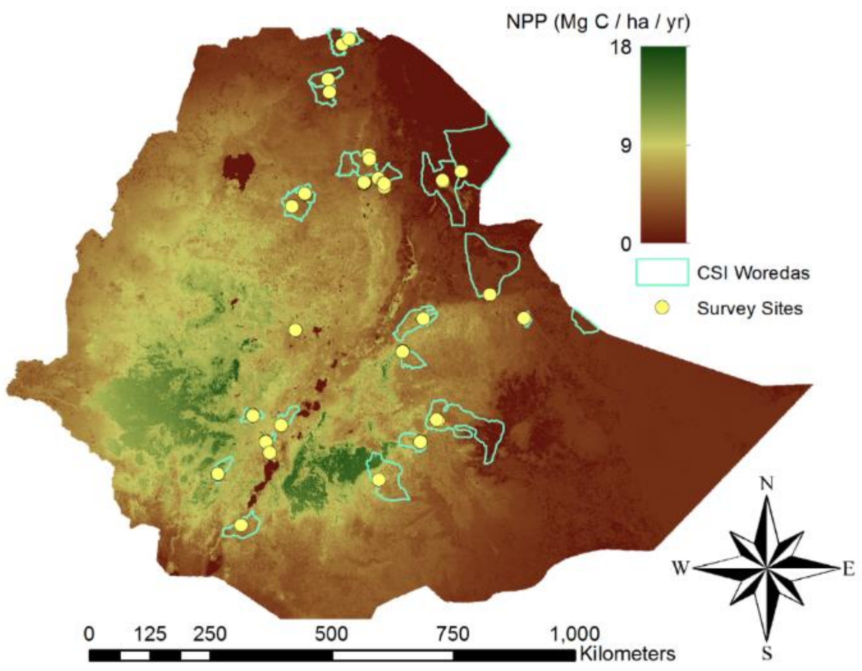


Figure 11: Net Primary Production (NPP) in Ethiopia. 10-year average (2004-2013) derived from MODIS satellite measurements of absorbed photosynthetically active radiation.

2.3.3 Climate maps

High resolution (90m) climate maps for Ethiopia were generated by spatial interpolation of data from the agroclimatic database of the Agromet Group of the Food and Agriculture Organization of the United Nations (FAO), which includes data from over 30,000 climate stations, of which more than 100 stations in or near to Ethiopia were utilized. Many software tools for spatial interpolation of data exist. For this project, we used the FAO New LocClim software, which has the advantages of being free to download, and specifically designed for agroclimatic data analysis. Climate interpolation was conducted by Inverse Distance Weighted Averaging (IDWA) with linear regression for both elevation and horizontal gradients. Regression of vertical (elevation) and horizontal gradients were applied sequentially, rather than as a multiple regression, to avoid colinearity interactions. Elevation dependency was approximated first, followed by estimation of any additional horizontal gradients. Elevation correction was done using the SRTM 90m Digital Elevation Database v4.1, which has a spatial resolution of 3 arc-seconds. IDWA is an averaging algorithm that gives each station a weight proportional to a power of the inverse of its distance from interpolation location. Thus, closer stations contribute more strongly to the average than farther stations (if there is a station very close to the grid point the station is assigned almost all the weight). The power exponent was reduced in those parts of the Afar lowlands close to the western escarpment of the Rift Valley to avoid skewing of the predictions by the large number of nearby stations located in the highlands at the top of the escarpment and the fewer number of stations scattered in the lowlands.

Mean annual temperature, precipitation, potential evapotranspiration, and aridity index are shown in Figure 13 through Figure 16, respectively.

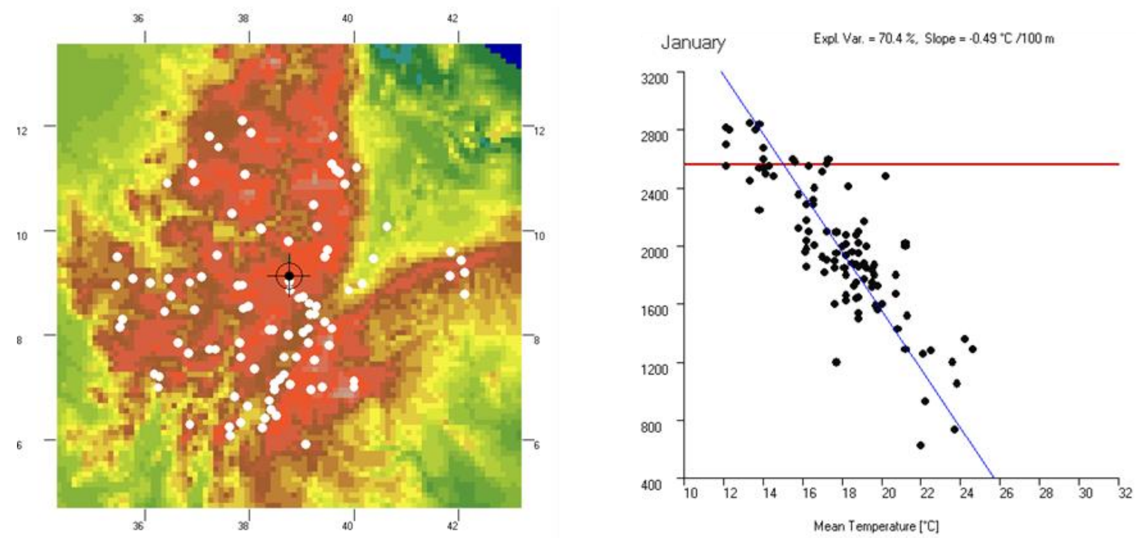


Figure 12: Example of climate interpolation using NewLocClim software, with left panel showing location of the climate stations selected for a central location in Ethiopia, and right panel showing the elevation correction regression.

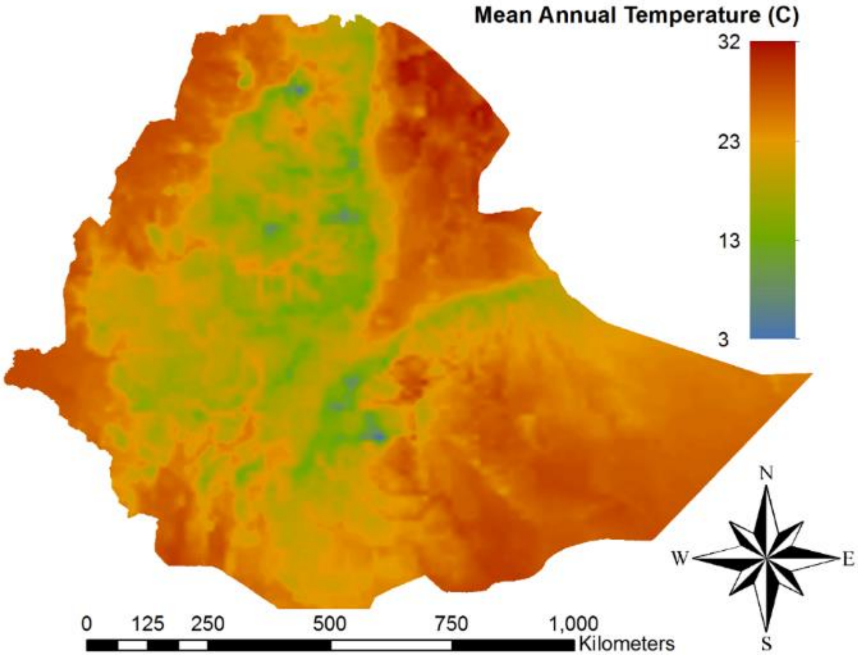


Figure 13: Mean annual temperature (MAT) in Ethiopia.

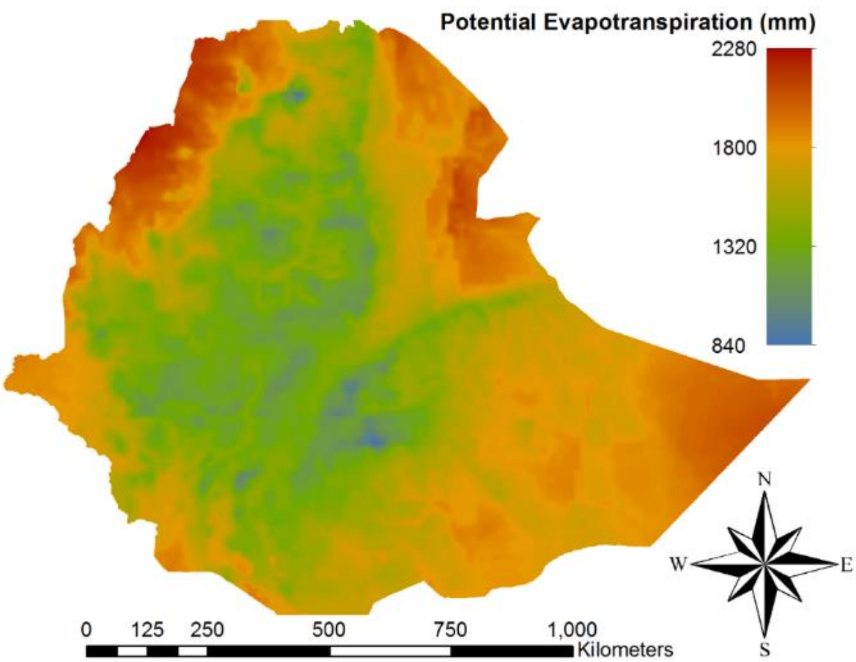


Figure 14: Annual potential evapotranspiration (PET) in Ethiopia.

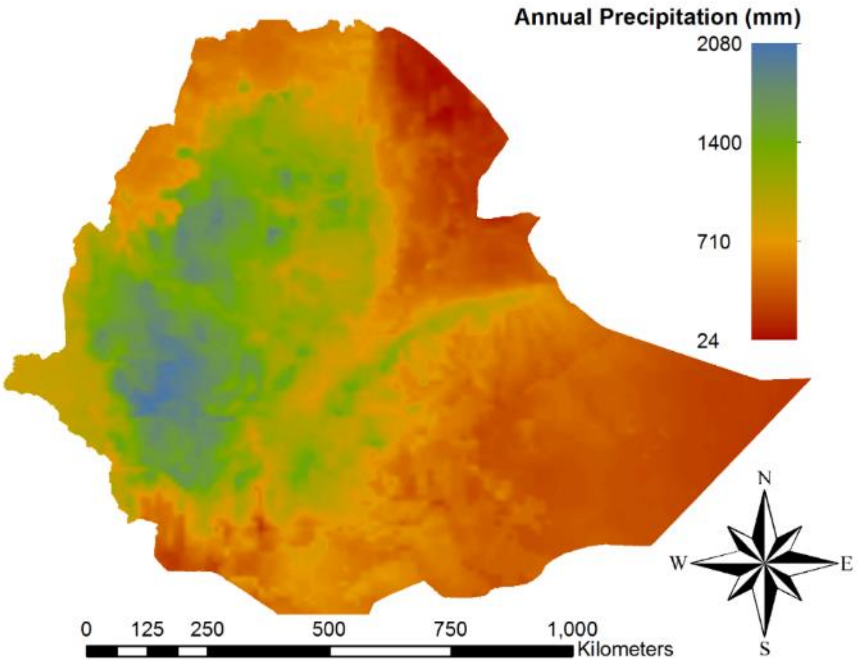


Figure 15: Annual precipitation in Ethiopia

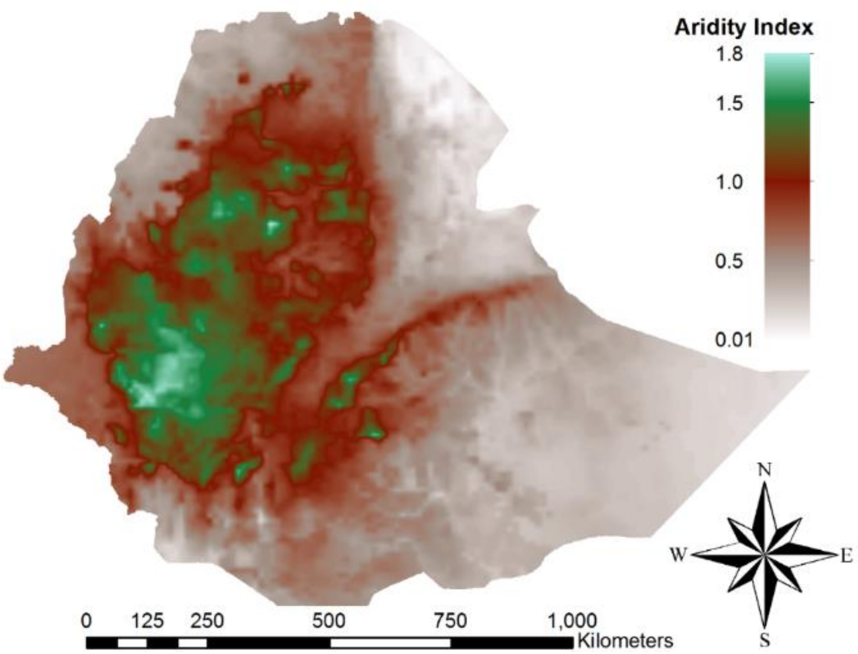


Figure 16: Aridity index (AI) in Ethiopia. AI less than 1 signifies that potential evapotranspiration exceeds precipitation.

2.3.4 Land cover mapping

Landscape-scale geospatial data are required to upscale estimates of carbon sequestration and GHG emissions that are required for climate finance projects. These geospatial data are provided commonly by satellite-based multispectral sensors that generate repeatable, synoptic images of the Earth at landscape-scale. For climate finance projects, such remotely sensed data are used to produce estimates of the area and rates of change of land use and land cover (LULC) under specific sustainable land management practices and food security programs. Estimates produced using remotely sensed data require validation with statistically-sound, field-based sampling surveys to document LULC conditions at periodic intervals.

Improved geophysical and biophysical geospatial data and simplified geospatial analytical methods are critical to cost-effectively upscaling high resolution, field-based estimates of carbon and GHG dynamics. These upscaled estimates are useful for land management and planning, monitoring, and verification purposes at local, regional, and national levels of administration. To facilitate and sustain such upscaling efforts, simplified methods are required to allow suitable calibration and validation of remotely sensed estimates using field-based sample survey sites and linking of validated estimates with spatially-explicit process models of carbon sequestration and GHG emission.

The general approach used in this project to estimate LULC and LULC change is based on the Verified Carbon Standard (VCS) methodology developed by the Institute for Conservation and Sustainable Development of Amazonas and the BioCarbon Fund within the Climate Finance Unit of the World Bank (Pedroni 2012). There are five essential technical components to this methodology:

1. Collection of appropriate data sources over three cycles of approximately 3-5 years per cycle using remotely sensed data which need to be of suitable spatial resolution (or ground sample distance, gsd) from 10m to 100m. Higher resolution data (<5m gsd) are required for field observations for validation, including specification of imagery type, georeferencing accuracy, and sampling design.
2. LULC categories, or types, need to be defined for mapping purposes. Type boundaries can be mapped using remotely sensed data and/or other sources of information using a minimum mapping unit (MMU) of less than or equal to one hectare. The minimum number of categories will be two: Forest Land and Non-Forest Land. Forest Land is defined as having a minimum area of 0.05 – 1 hectare, tree crown cover from 10 – 30%, tree height from 2 – 5 meters at maturity; and will include strata representing different carbon stocks and carbon densities. Non-forest land includes IPCC-specified categories of crop land, grass land, wetlands, settlements, and other land.
3. LULC change categories need to be defined for monitoring and validating sustainable land management projects based on all or a subset of LULC categories as defined above.
4. Analysis of historical and potential LULC and LULC change should be summarized using a LULC change matrix. Image processing specification includes geometric correction

accuracy of less than one pixel quantified using Root Mean Square Error (RMSE) statistic, cloud and shadow removal, radiometric corrections to ensure consistent spectral response using multi-temporal datasets, and pre- and post-classification change detection data.

5. Verifiable accuracy assessment of LULC maps and longitudinal estimates of LULC change needs to be conducted. Accuracy must be estimated on a class-by-class basis using an error matrix to show the proportion of correct classification by class and overall classification accuracy. Off-diagonal cells are to show the relative proportion of misclassification of each class. Minimum overall accuracy of the forest cover benchmark map should be 90% or higher. The minimum classification accuracy of each class should be 80% or higher.

The specific land cover mapping approach for this PSNP-CSI carbon benefits modeling project was used to demonstrate the use of high spatial resolution remotely sensed data for generating validated estimates of forest land cover in selected sites. This phase of the project also demonstrated the use of remotely sensed data of moderate spatial resolution to serve as a monitoring and validation tool for sustainable land management programs and climate finance projects.

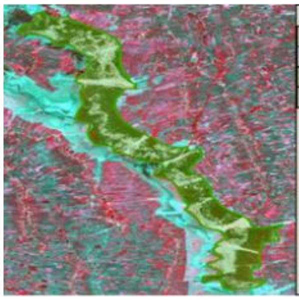
The Astrium Pleiades satellite was tasked to record three images using coordinates supplied by this group to provide high-resolution multispectral and panchromatic imagery for four sites in Amhara and SNNPR based on the maturity of the sites compared to most of the PSNP sites which were still relatively young (See Section 2.1). The dates of image acquisition were 25 October 2014 (Asore site), 05 November 2014 (Godaye site), and 17 October 2014 (Sefed Amba and Weira Amba sites). The digital images were purchased as non-georeferenced “Ortho-Ready” products, one panchromatic image at 0.5m gsd, and four spectral bands in the visible region (blue, green, red) and near-infrared region, all at 2.0m gsd. All Pleiades images were acquired at 12-bit radiometric resolution (4096 levels, or bins).

Spectral data were processed using ENVI 5.2, which included radiometric calibration to convert digital numbers (DNs) to Top of Atmosphere (TOA) radiance, and atmospheric correction using the ENVI 5.2 FLAASH module to convert TOA radiance to surface reflectance. The images were geo-referenced using RPC Orthorectification (ENVI 5.2) and ENVI-provided GMTED2010.jp2 digital elevation model (Danielson and Gesch 2011). The orthorectified images were pan-sharpened to a 0.5m multispectral, four-band image at 0.5m gsd using the Gram-Schmidt Pan Sharpening procedure in ENVI (Mauer 2013; Laben and Brower 2000). Four clip boundaries were created 250m outside the spatial extents of the four sites in order to create subsets of the three pan-sharpened images. Each site was then clipped from image subsets.

Preliminary IsoCluster processing was applied to the SN_Al_As and Am_Ge_WA sites to determine feasibility of mapping and estimating percent forest cover. Given unsatisfactory results on the more mountainous Am_Ge_WA site, primarily caused by hillslope effects, an

NDVI thresholding approach was used to map Forestland from Non-Forestland in the four sites. Existing field-based survey plot locations (as points) were used to assess classification accuracy. After labeling each survey plot location as to land cover type, the point locations were buffered to create 100m^2 zones for each location in each of the four sites. The Tabulate Areas tool in ArcMap was used to summarize land cover classification using the NDVI threshold (Predicted) with the field-based survey plot classification (Observed). Tabulated data were used to generate accuracy assessment error matrices for the four sites (Figure 17). Producer's Accuracy, User's Accuracy, and Overall Percent Correct statistics were calculated and included in the error matrices (Congalton and Green 2002).

Historical and contemporary Landsat images were processed for the Asore site to demonstrate the ability of Earth observation satellite imagery of moderate spatial resolution to monitor land cover change and to serve as a viable validation mechanism for sustainable land management programs and climate finance projects. Landsat imagery for 28 November 1986 and 21 January 1995 (both from Landsat-5 Thematic Mapper, TM) and 24 October 2014 (Landsat-8 Operational Land Imager, OLI) were accessed using the USGS EarthExplorer website. Individual spectral bands were combined using QGIS to create multi-band rasters that were then visualized and exported for display purposes using ArcMap.



a

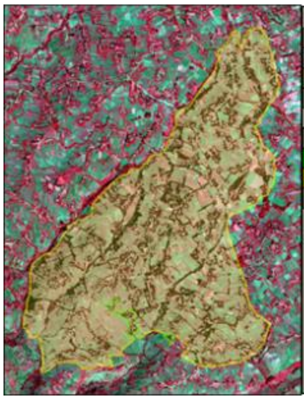
Asore Forest Cover (NDVI5, 25Oct14):

Cover Type	Count*	Area_Ha	Percent
Non-Forest	525,872	254.5	43.7
Forest	677,076	327.7	56.3
Total:	1,202,948	582.2	100.0

Asore Forest Cover Accuracy Assessment*:

	Class	Non-Forest (Observed)	Forest (Observed)	Total	User Acc%	
Predicted	Non-Forest	290	68	358	81.0	
Predicted	Forest	1	428	429	99.8	
	Total:	291	496	787		
	Producer Acc%	99.7	86.3		91.2	= Overall % Correct

* counts of Pleiades MS pixels @ 2.2 meters cell size (4.84 m^2 per pixel, 0.000484 ha/pixel)



b

Godaye Forest Cover (NDVI72, 05Nov14):

Cover Type	Count*	Area_Ha	Percent
Non-Forest	918,931	405.2	72.9
Forest	341,605	150.6	27.1
Total:	1,260,536	555.9	100.0

Cover Type	Non-Forest	Forest	Total, Ha	% Forest
Agroforestry	2.7	2.3	5.0	46.0
Cropland	402.5	148.4	550.9	26.9
Total:	405.2	150.6	555.9	27.1

Godaye Forest Cover Accuracy Assessment*:

	Class	Non-Forest (Observed)	Forest (Observed)	Total	User Acc%	
Predicted	Non-Forest	542	55	597	90.8	
Predicted	Forest	40	247	287	86.1	
	Total:	582	302	884		
	Producer Acc%	93.1	81.8		89.3	= Overall % Correct

* counts of Pleiades MS pixels @ 2.1 meters cell size (4.41 m^2 per pixel, 0.000441 ha/pixel)

c

Sefed Amba Forest Cover (NDVI73, 17Oct14):

Cover Type	Count*	Area_Ha	Percent
Non-Forest	281,206	112.5	80.4
Forest	68,383	27.4	19.6
Total:	349,589	139.8	100.0

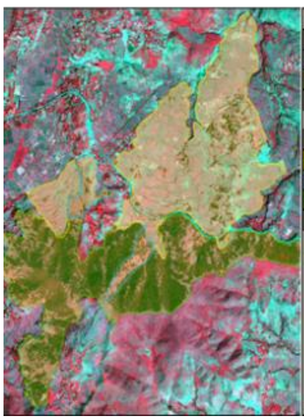
Cover Type	Non-Forest	Forest	Total, Ha	% Forest
Agroforestry	0.4	0.1	0.5	11.0
Cropland	98.6	16.3	114.9	14.2
Grassland	13.2	10.9	24.0	45.2
Woodland	0.3	0.1	0.4	30.2
Total:	112.5	27.4	139.8	19.6

Sefed Amba Forest Cover Accuracy Assessment*:

	Class	Non-Forest (Observed)	Forest** (Observed)	Total	User Acc,%	
Predicted	Non-Forest	593	129	722	82.1	
Predicted	Forest**	23	64	87	73.6	
	Total:	616	193	809		
	Producer Acc%	96.3	33.2		81.2	= Overall % Correct

* count of Pleiades MS pixels @ 2.0 meters cell size (4.0m^2 per pixel, 0.0004 ha/pixel)

** combined AF17 and PW5 plots for "Forest"; combined CL17 and NIO for "Non-Forest"; no Grassland plots



d

Weira Amba Forest Cover (NDVI8, 17Oct14):

Cover Type	Count*	Area_Ha	Percent
Non-Forest	462,314	184.9	64.0
Forest	260,225	104.1	36.0
Total:	722,539	289.0	100.0

Cover Type	Non-Forest	Forest	Total, Ha	% Forest
Cropland	136.0	7.5	143.5	5.2
Grassland	11.1	4.3	15.4	27.9
Woodland	37.8	92.4	130.2	71.0
Total:	184.9	104.2	289.1	36.0

Weira Amba Forest Cover Accuracy Assessment*:

	Class	Non-Forest (Observed)	Forest (Observed)	Total	User Acc,%	
Predicted	Non-Forest	393	11	404	97.3	
Predicted	Forest	55	280	335	83.6	
	Total:	448	291	739		
	Producer Acc%	87.7	96.2		91.1	= Overall % Correct

* count of Pleiades MS pixels @ 2.0 meters cell size (4.0m^2 per pixel, 0.0004 ha/pixel)

Figure 17: Forest land cover proportion and accuracy assessment statistics in four sites: (a) Asore, Alaba Special Woreda, SNNPR, (b) Godaye, Damot Gale, SNNPR, (c) Sefed Amba, Habru, Amhara, and (d) Weira Amba, Habru, Amhara.

The range in forest land cover for the four sites ranged from 19.6% in Sefed Amba to 56.3% in Asore (Figure 17). Intermediate levels of forest land cover occurred in Godaye (27.1%) and Weira Amba (36.0%). Overall classification accuracies for forest land cover ranged from 81.2% (Sefed Amba) to 91.2% (Asore). Intermediate classification accuracies were achieved in Godaye (89.3%) and Weira Amba (91.1%). The multi-temporal sequence of Landsat imagery for the now-forested Asore site indicate essentially highly eroded, bare ground in the mid-1980's during the Ethiopian drought and famine, slowly progressing to a majority of land area under woody vegetation (Figure 18). Comparing moderate spatial resolution imagery (Landsat TM, OLI) with high spatial resolution imagery (Astrium Pleiades) indicates that generalized land cover conditions can be discriminated equally well, especially forest land from non-forest land (Figure 18).

Forest cover in the more mature area enclosures studied here has resulted from management decisions (about how much land to allow for grass forage harvesting) that have been implemented over the last two decades of intervention work on these sites. Left to regenerate without management sites, these enclosures would have tended towards complete forest canopy closure. However, the practices of cut-and-carry forage production and (to a lesser extent) coppicing some trees (especially eucalyptus) for timber production have resulted in the currently observed ratio of forest cover within the enclosures. It is not possible to predict rigorously the precise ratio of forest cover that will be attained in other less mature PSNP enclosures, as that will depend on management choices made over the coming years. Therefore, we estimated the future forest-to-forage ratios in other PSNP sites by extrapolating from the Astrium-Pleiades sites described here to the younger sites, on the basis of most similar agroecological conditions.

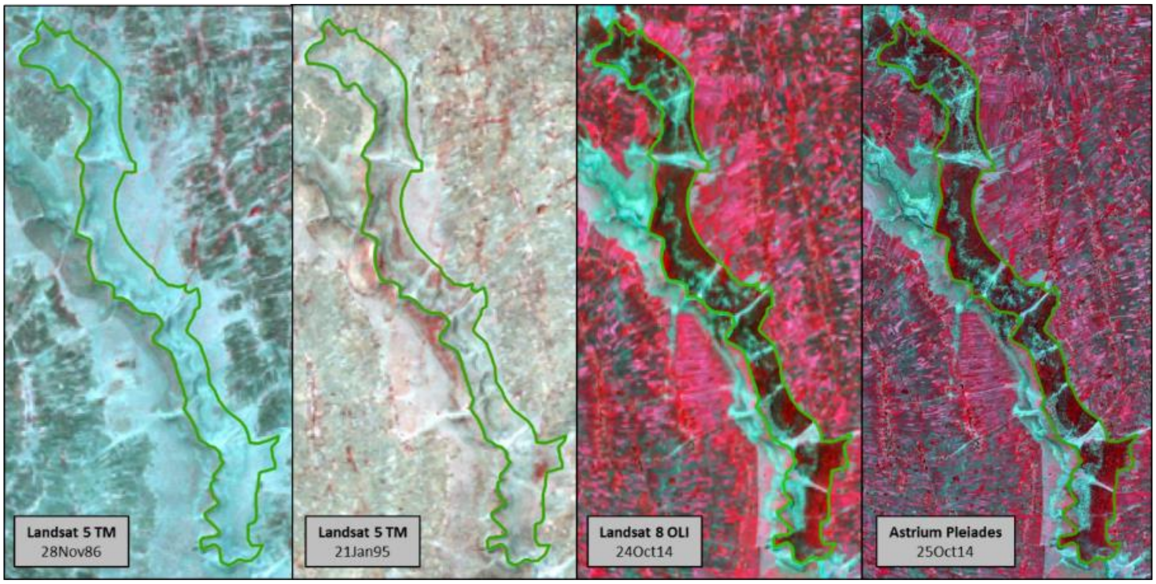


Figure 18: Forest Cover Change in PSNP – CSI Alaba-Asore Intervention Project Site, SNNPR, Ethiopia, 1986 – 2014. False-color composites show live biomass in red hues and bare soil or senescent biomass in gray and brown hues.

In future land cover mapping efforts in support of carbon benefits modeling, multi-temporal land cover classification and mapping can be performed using moderate resolution Landsat imagery. The resulting individual land cover maps from the most historical image (e.g., T_0) can be compared to the most contemporary land cover map (e.g., T_1) using a land cover change matrix (Table 6). In such land cover change matrices, land cover transitions (off-diagonal cells) can be used to estimate and validate dynamic management practices where the central diagonal cells indicate stable, or static, land cover types over time.

Table 6: Example of land-use and land-cover change matrix illustrating gain in forest cover from T0 (column data, 54.6%) to T1 (row data, 68.4%).

				T_0				
T_1	Forest Land	Crop Land	Grass Land	Settlements	Wetlands	Other	%	Area (ha)
Forest Land	48.9	8.3	1.8	5.9	2.3	1.2	68.4	342.0
Crop Land	4.8	3.5	0.3	2.5	1.3	0.5	12.9	64.5
Grass Land	0.1	0.2	0.0	0.4	0.2	0.1	1.0	5.0
Settlements	0.3	1.2	0.2	4.1	1.4	0.4	7.6	38.0
Wetlands	0.2	0.7	0.1	1.3	4.5	0.8	7.6	38.0
Other	0.3	0.4	0.1	0.8	0.7	0.2	2.4	12.0
Total (%):	54.6	14.3	2.5	15.0	10.4	3.2	100.0	
Total (ha):	273.0	71.5	12.5	75.0	52.0	16.0		500.0

Note: No LULC Change 1994 - 2014 = 61.2%

This land cover mapping phase of the Carbon Benefits Modeling project adequately demonstrated how remote sensing and field-based survey methods can be integrated to meet data and information needs of sustainable land management and food security programs. Some form of remotely sensed data is required to characterize, map, and monitor agronomic and environmental resources in support of climate finance programs. Properly defining data resolution requirements dictates which sensor system will provide sustainable land management information of the highest quality in terms of timeliness, accuracy, and efficiency. The high prediction accuracy (81-91%) of tree cover using the NDVI threshold approach developed here for PSNP demonstrates this as a viable method for rapid, low-cost and simple mapping of trees within PSNP areas. This approach could be largely automated, reducing the level of input required from highly trained remote-sensing professionals and associated costs, although professional oversight would nonetheless be required to maintain quality control. It is important to note that the accuracy of this methodology depends critically on correct timing for taking remote sensing imagery; namely, at the end of the rainy season when annual crops and plants are senesced but trees remain in leaf.

2.4 CBP Data collection

Land use and management information is needed to provide activity data for all three assessment options in the CBP. This information was collected and collated during site visits in 2013 - 2014. A simplified, standardized questionnaire was developed for rapid but comprehensive collection of all activity data required for use with the CBP model. Questionnaires were completed for different land use types present at each site (forestland, grassland, cropland, trees in settlements), and for each scenario (initial, business-as-usual, and project). For areas in agroforestry, the management of trees and crops were both recorded. Questionnaires were completed by interviewing local Development Agents (DAs), farmers and agricultural officers and by making observations in the field. An example of a blank questionnaire is provided in Annex 1.

2.4.1 Scenario development

The CBP tools estimate the overall GHG impact of land management activities. This is also referred to as the ‘carbon benefit.’ This means that the CBP system reports the impact of project activities compared to a ‘business-as-usual’ (BAU) scenario with the carbon benefit being the difference between the project scenario and the business-as-usual scenario over a given period of time (Figure 19).

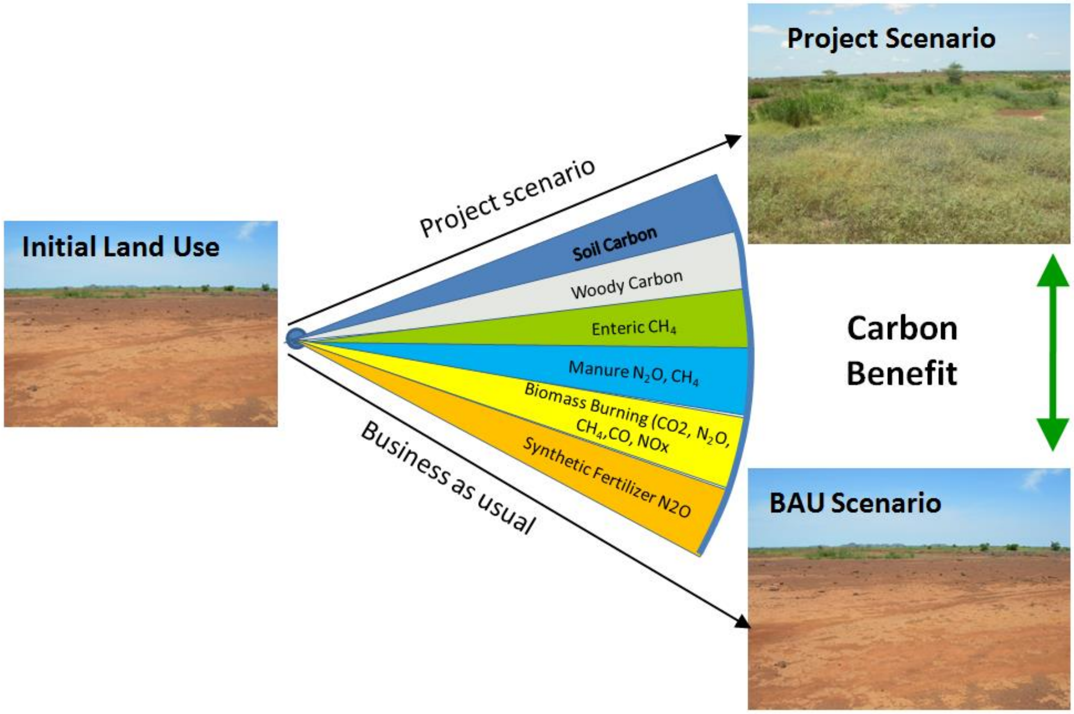


Figure 19: Diagrammatic representation of the carbon benefit of a land management project

In order to use the CBP system, the user has to firstly enter a report period, for example 20 years. The user must then enter information about land use and management for; 'The Initial Land Use' – the starting situation before any project activities took place, 'The Project Scenario' – the land use and management implemented by the project over the report period and 'The Business as Usual (or Baseline) Scenario' – the hypothetical land use and management situation that would have occurred in the same area in the absence of the project over the report period.

For this analysis, PSNP activities were analyzed retrospectively where the impact of project activities circa 1995 – 2015 were considered. Though timescales varied from site to site, a 20-year analysis was conducted for all sites to allow results to be compared. Information on the Initial Land Use and Project Scenario (project activities over the last 20 years) were derived from selected project documents such as CARE's Climate Vulnerability and Capacity Analyses (CVCA) documents, interviews with project personnel, development agents (DAs), and agricultural officers. For the BAU scenarios, a best estimate of how land would have been used and managed in the absence of the project had to be constructed. This was accomplished by considering land use under initial conditions, extracting information from the CVCA documents, gathering the opinion of farmers and DAs, and taking observations of areas surrounding the project sites where possible. In most cases it was assumed that initial conditions would persist throughout the BAU period but that some trends (such as increases in fertilizer use) which were not introduced by the project, would also occur in the BAU scenario. An example summary of scenario development is shown in Figure 20, for a farmer-practice hayland enclosure in a pastoral area of Chifra Woreda, Afar Regional State.

Initial Scenario

Grassland
Grassland system: Rangeland
Condition: Moderately degraded
Improvements: None
Fertiliser: None
Burning: Never

Business as usual

Grassland
Grassland system: Rangeland
Condition: Severely degraded
Improvements: None
Fertiliser: None
Burning: Never
Justification: The surrounding areas were barren, highly degraded and over grazed. In the absence of enclosures these conditions would have prevailed.

Project Scenario

Grassland
Grassland system: Continuous hayland
Condition: nominally degraded
Improvements: None
Fertiliser: None
Burning: Never
Justification: Cut and carry. Grass production high, but no improvements such as irrigation, use of legumes or use of improved pasture species

Figure 20: Example of scenario development for PSNP's CSI sites. Initial, BAU, and projects scenarios are constructed from a combination of field observations, interviews with farmers and local DAs, remote sensing, and use of documentary evidence.

2.4.2 Factors for Tier 2 approach in PSNP sites

The CBP Detailed Assessment allows the user to replace the IPCC EFs with country/project specific EFs. A number of sources can be used to provide factors including field measurements and published studies. In this analysis two sources were used: a) Moderate-resolution Imaging Spectroradiometer (MODIS) satellite maps of NPP for site-specific biomass growth rates (Section 2.3.2), and b) literature values for tier 2 EFs related to crops and ecosystems found in Ethiopia that are not represented in the default IPCC tier 1 database. Two annual crops, teff (*Eragrostis tef*) and taro (*Colocasia esculenta*), and one perennial crop, pigeon pea (*Cajanus cajan*), were commonly grown at some project sites. The CBP did not have default options for these crops, therefore, the CBP Detailed Assessment was used and a literature search conducted to find studies with relevant emission/stock change factors (Table 3). In the case of the annual crops, crop yield and dry matter fraction of residue were found and substituted for default values and in the case of pigeon pea (a perennial crop) woody biomass C growth rate was substituted. In addition, values from the literature were used to create two forest types in the Detailed Assessment, a *Prosopis juliflora* shrubland and an *Acacia* shrubland non-montane native vegetation. The second was necessary as the default option assumed a montane native vegetation type. For forest types, above ground biomass stock and annual growth increment were substituted.

Table 7 Emission/Stock Change factors used in the Detailed Assessment

	Emission/Stock Change Factor/	**Unit**	**Value**	**Source**
Perennial crops				
Pigeon Pea	Woody biomass C growth rate	t/C/ha/yr	3.285	Worku and Demisie 2012
Annual crops				
Teff	Crop yield	Mg/ha	0.91	Ketema, 1997
	Dry matter fraction of residue	t dm/t residue	0.913	Keftasa, 1988
			0.951	Mesfin and Ledin, 2004
			0.932	
Taro	Crop yield	Mg/ha	6.2	Onwueme, 1999
Forestland				
Acacia shrubland (non-montane)	Bw Above ground biomass stock	t dm/ha	25.4	Giday et al. 2013

	Gw annual growth increment	t dm/ha/yr	2.3	Giday et al. 2013
	Root to shoot ratio	ratio	0.48	FRA, 2010
	Biomass expansion factor fuelwood	unitless	6.1	FRA, 2010
	Biomass expansion factor timber	unitless	6.1	FRA, 2010
Prosopis juliflora shrubland	Bw Above ground biomass stock	t dm/ha	22.1	Ansley et al., 2010
	Gw annual growth increment	t dm/ha/yr	8	Abebe, 1994

2.5 LEAKAGE

Leakage refers to the process whereby efforts to reduce emissions in one place fail to eradicate the emissions and instead shift them to another location or sector (Jenkins et al. 2009). This is a common problem in GHG accounting, and methods for dealing with leakage and the scale at which impacts should be addressed are still the subject of much debate.

In the PSNP sites, there are several examples of area enclosures (i.e., livestock exclosures) being constructed to allow grassland to regenerate. Most of these areas remain enclosed and are used for cut-and-carry hay. In these sites there is an obvious leakage impact as livestock are relocated rather than eliminated, and are fed on cut-and-carry hay from the enclosure. Therefore, the emissions from the livestock still have to be accounted for in order to estimate a realistic GHG balance for the PSNP sites. To deal with this issue, in those sites with livestock enclosures, a second project activity area was set up in the CBP system and livestock were assumed to have moved to this with all associated emissions from the livestock themselves and their manure. This 'leakage area' was then included in the GHG balance of the project.

Figure 21 summarizes the methodology employed for estimating livestock leakage in cut-and-carry systems. Because hay from cut-and-carry systems supports livestock outside the project boundaries, it is necessary to estimate the net change in livestock population locally caused by area enclosure. However, the IPCC greenhouse gas accounting methodology does not account for leakage effects when applied to a project-by-project assessment. Therefore no model that uses the IPCC methodology has a built-in means to estimate leakage. To estimate leakage effects of an area enclosure within the CBP modeling environment, we define an additional area (A) where local farmers keep livestock, adjacent (or nearby) to the project area (P). In the business-as-usual (baseline) scenario, project area, P, has P_1 livestock and adjacent area has A_1

livestock. In the project scenario, project area (P) has $P_2=0$ livestock (livestock have been excluded from the project site), and adjacent area (A) has A_2 livestock.

The difference in livestock numbers outside the project site before and after intervention is N, where $N = A_2 - A_1$. We estimate N as the number of livestock that can be supported by the hay removed from the project site. To calculate N, data on mean annual consumption of forage for different livestock types are required, together with estimates of the fraction of the area enclosure that is allocated to forage production and estimates of forage productivity per unit area in a degraded (business-as-usual) site and in an improved (project) site. Note in this calculation that the size and original stock numbers (A_1) of the adjacent area are arbitrary, because we are interested in the difference (N) in livestock before and after enclosure.

Calculating leakage in this manner entails an assumption that the size of A does not change as a result of the area enclosure (i.e., that no new lands are converted to pasture to compensate loss of area in the project). In the context of the Ethiopian PSNP sites surveyed here, this assumption is considered valid because in those regions, there are typically already a high population density in a deforested degraded landscape, leaving little opportunity for local populations to expand their grazing into additional land to compensate for land lost to the enclosure. Although the size of A used in the leakage calculation is arbitrary, it makes sense nonetheless to set it to a rational value, which we define as the area required to support A_1 livestock at average local stocking densities derived from national livestock census data. Also, since it is only the difference ($A_2 - A_1 = N$) in livestock numbers that affects the carbon benefits predicted for the project, we simplify the calculation by setting $A_1=0$ and $A_2=N$. P1 and N are then estimated as the quantity of grass production on the project site before and after intervention, respectively, divided by average forage production per head of livestock, with livestock population allocated to cattle, sheep, goats, horses, mules and asses in proportion to their local relative populations in the most recent (2013) livestock census.

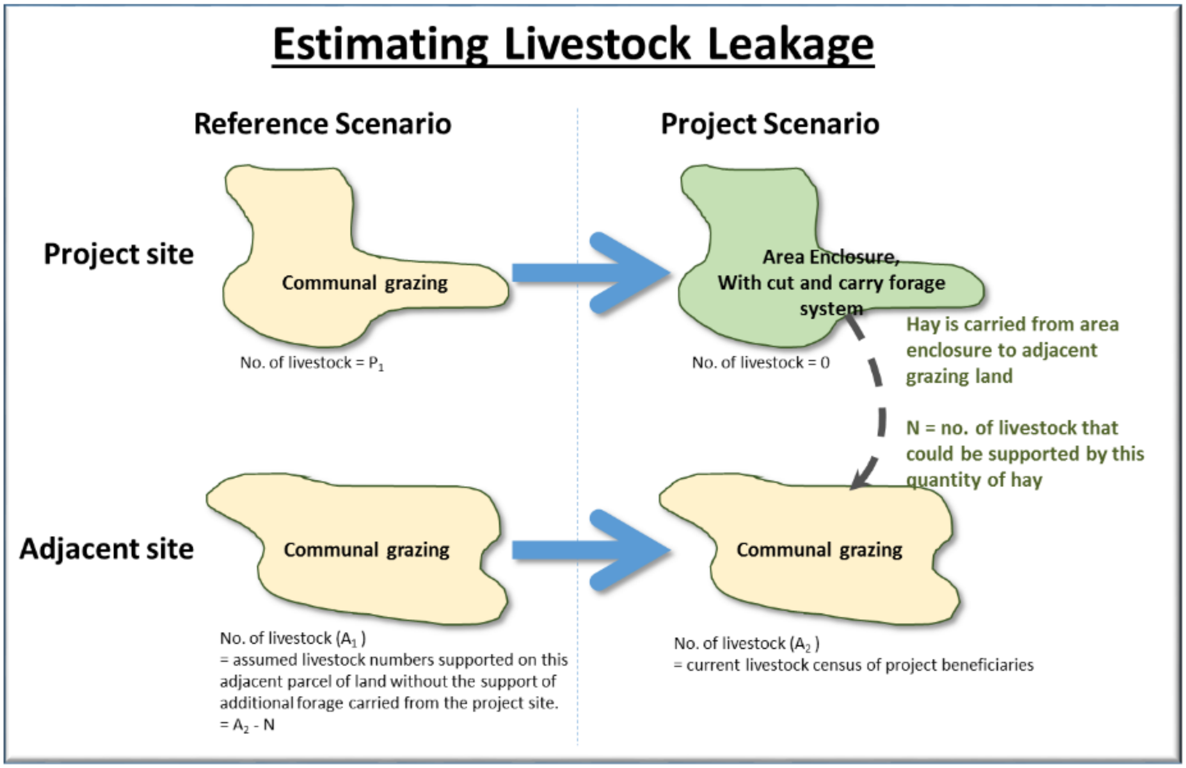


Figure 21: Schematic of simplified protocol for estimating livestock leakage impacts of area enclosures.

3 RESULTS

Fluxes of the greenhouse gases CO_2, CH_4, and N_2O from all of the sources and sinks of the IPCC Agriculture Forestry and other Land Use (AFOLU) GHG accounting methodology (Table 8) were modeled for each of the sites in each of the initial, BAU and project scenarios. Table 9 summarizes the PSNP AFOLU management activities that have an impact on these GHG fluxes (a more detailed breakdown of which activities are utilized in which sites is given in

Table 5).

Table 8: Fluxes which are modeled by the CBP Simple and Detailed Assessments by IPCC AFOLU Source Categories.

Source	**Sub-source**
Enteric Methane	
Manure Methane	
Manure Nitrous Oxide	
Rice Methane*	
Soil Nitrous Oxide	Crop residue N
	Manure in pasture/range/paddock
	Manure N amendments
	Mineralisation of cultivated organic soils*
	Synthetic N Fertiliser
Biomass Carbon Stocks	Forest land
	Grassland/savanna
	Annual cropland
	Perennial cropland
	Agroforestry
	Settlements
	Deforestation
	Shifting cultivation*
Biomass Burning non-CO_2	Cropland residues
	Forest land
	Grassland/savanna
	Annual cropland
	Perennial cropland
	Agroforestry
	Settlements
	Deforestation
	Shifting cultivation*
Soil carbon stocks	Mineral soils
	Organic soils*

* not found in this study

Table 9: Management practices in the PSNP sites surveyed in this study which are likely to have an impact on C stock changes and GHG emissions.

Type of practice	Detail
Soil and water conservation	Stone bunds
	Terracing
	Percolation trenches
	Check dams/gully restoration (stone/brushwood)
	Soil bunds
	Half-moon ditches
	Microbasins
	Planting on soils bunds (cowpea, pigeon pea, *Sesbania sesbans*)
Livestock management	Exclusions
	Enclosures
	Cut-and-carry hay production
Tree planting	Afforestation
	Woodlots (mainly *Eucalyptus globulus* and *Grevillea robusta*)
	Trees on terraces for stabilization
Grass planting	Vetiver hedges
	Elephant grass
Natural regeneration	Enclosures for natural regeneration, trees/shrubs/grasses
Reduced deforestation	Enclosures to create protected areas
Agroforestry	Establish agroforestry gardens
	Introduce fruit trees in croplands
	Use household compost in agroforestry
Irrigation	Pumps
	Drip hoses
Invasive species	*Prosopis* spp. clearing
Agricultural practices	Cover crops
	Improved varieties
	Reduced tillage
	Crop rotations (e.g. increased use of leguminous species)
	Organic fertilisers

The fraction of each site under different types of land cover in each of the scenarios is shown in Figure 22 (these data are also shown in enlarged detail in the land area bar plots in Annex 2). As Figure 22 shows, a broad range of management interventions and changes in land cover were seen in the CSI PSNP sites. It should be noted that it is not only the changes in land cover type that affect GHG fluxes, but also the way in which these land cover types are managed in each scenario. For example, although Af_Ch_Ja can be seen to be 100% grassland in each scenario (Figure 22, top left panel), the management and condition of this grassland does vary between scenarios. Af_Ch_Ja entailed enclosure of common-grazing rangeland into a "nominally degraded" (i.e., nearly native condition) permanent hayland cut-and-carry enclosure in the project scenario, whereas under BAU without intervention, the prevalent processes of increasing land degradation evident in the region are expected to continue, with the initial moderately-degraded rangeland expected to become severely degraded over the next decades. It can be seen in Figure 22 that most project sites involved either improvements to existing land cover types (as noted for Af-Ch_Ja), or land use changes that involved increased biomass stocks in the project site relative to BAU. One exception to this was in Af_Du_Ay, which involved

If food security objectives are to be met at the same time as land conservation objectives, area enclosures should be managed to provide sufficient livelihood benefits to compensate for the opportunity cost of the land becoming unavailable for other uses.

Managing such tradeoffs is not only important to the food security role of PSNP, but is also critical to the long-term protection of land improvements, because communities are less likely to revert to business-as-usual practices if enclosures provide food, forage, fuel, and non-timber forest products.

conversion of woodland (in this case *Prosopis juliflora* shrubland) into annual cropland, with a corresponding loss of both soil and biomass carbon from the initial condition. In all other sites, management activities were aimed at reducing or reversing land degradation, and had a corresponding increase in soil and/or biomass carbon by improving the condition of existing land covers and/or converting some land to woodland, agroforestry, or perennial cropland. In some instances (e.g. Am_Ko_Zo and So_Gu_Fa) woodlands or grassland that would have been converted to annual cropland under business-as-usual became protected as PSNP enclosures. In such cases, it becomes even more important, if food security objectives are to be met at the same time as land conservation objectives, that the area enclosures should be managed in such a way that they provide sufficient livelihood benefits to the local community to compensate for the opportunity cost of the land becoming unavailable for other uses. Managing such tradeoffs is not only important to fulfilling the food security role of PSNP, but is also critical to the long-term protection of any land improvements, because communities are less likely to revert to business-as-usual practices once land is returned to their control if the enclosures are designed to also provide food, forage, fuel, and non-timber forest products from the area enclosures.

While all the enclosures surveyed had a fraction of their area designated for forage grass production, overall only a small proportion of the woodland areas were comprised of tree species that provide food or forage (such as fruit or nut trees, or leguminous species with edible foliage or pods). The only site in which agroforestry or perennial cropland comprised a large fraction of the overall enclosure was Or_DL_Od which was planted with a complex system containing guava, mango, papaya, banana, *Grevillea*, neem, coffee, and sugar cane amongst others. Only one of the area enclosures surveyed (Ti_GM_SL) included an apiary.

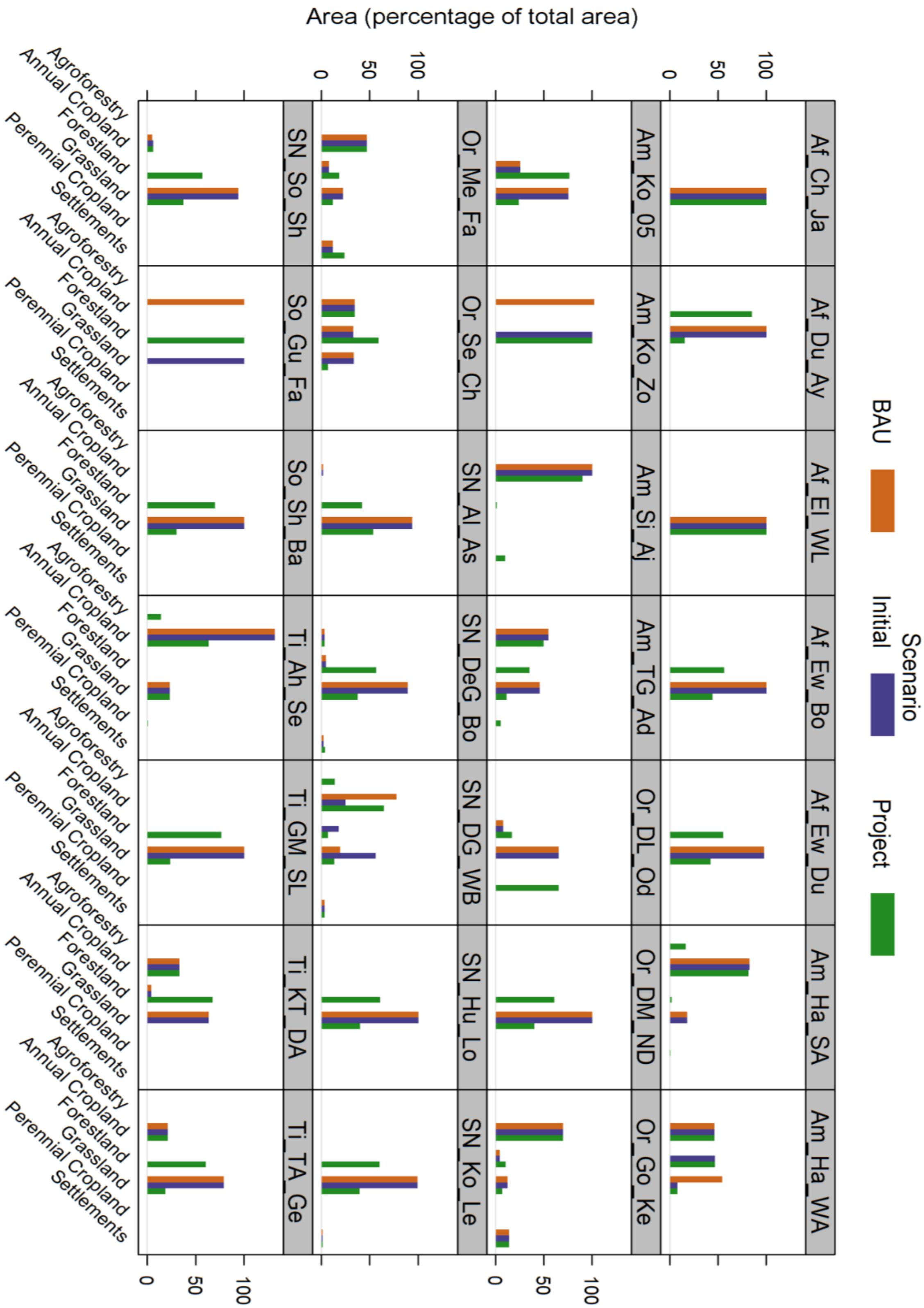


Figure 22: Percentage of land area under each type of management in the Initial, BAU and Project scenarios for all 28 modeled sites.

The ranges of all GHG fluxes resulting from these land use and land management scenarios are shown in Figure 23 (initial scenario), Figure 24 (BAU scenario), and Figure 25 (project scenario) aggregated over all the CSI sites, and broken down by source of emissions. In these boxplots, the solid dots show the median (average) value across all sites, and the boxes show the interquartile range (IQR); i.e., 50% of all values fall within the box. Outliers (atypical values) are shown as open circles outside of the uncertainty ranges designated by the “whiskers” extending from the boxes (which extend to the highest and lowest data within 1.5 IQR of the upper and lower quartiles). Fluxes of all sites have been normalized to a per hectare basis, to facilitate comparison between sites, which vary in size. In addition to these boxplots of the aggregated results, detailed plots of all GHG fluxes for each site can be found in Annex 2.

In all scenarios, the largest source of GHG emissions is enteric methane (CH_4) from ruminant livestock. In aggregate, enteric methane, together with other livestock-related GHG emissions (dominantly N_2O emissions from manure) make livestock the primary source of emissions in all scenarios. It should be noted however that there is significant site-by site variability and not all locations have substantial livestock emissions.

Emissions related to fertilizer application (both organic and inorganic), on the other hand, are very low in all scenarios due to the low application rates of N fertilizer that are prevalent in Ethiopian smallholder farms (Spielman, Kelemwork & Alemu, 2011; Nigussie & Kissi, 2012; Negassa, Gebrekidan & Friesen, 2005). Furthermore, fertilizer application rates do not vary much between scenarios, because PSNP does not in general target fertilizer use as one of its interventions, meaning that PSNP sites have a negligible impact on fertilizer GHG emissions.

In the initial and BAU scenarios, the only significant source of negative emissions (i.e., sequestration) is from forest carbon growth in those sites that have a forest component before intervention. In the Initial and BAU scenarios, forest carbon growth, where it occurs, is less than 1 tonne CO_2e ha^{-1} yr^{-1}. Due to soil and water conservation improvements in the project scenario, biomass sequesters 1.5 – 3 tonnes CO_2e ha^{-1} yr^{-1} (IQR) in agroforestry sites, 2 – 4 tonnes CO_2e ha^{-1} yr^{-1} in forest sites, and 1 – 4 tonnes CO_2e ha^{-1} yr^{-1} (IQR) in silvopasture sites (Figure 25). In the BAU scenario, progressive land degradation makes soil carbon loss a significant source of emissions, in the range of 0 – 2 tonnes CO_2e ha^{-1} yr^{-1} (IQR) (Figure 24). Conversely, in the project scenario, soil restoration is predicted to sequester 1 – 4 tonnes CO_2e ha^{-1} yr^{-1} (IQR) in increased soil organic carbon.

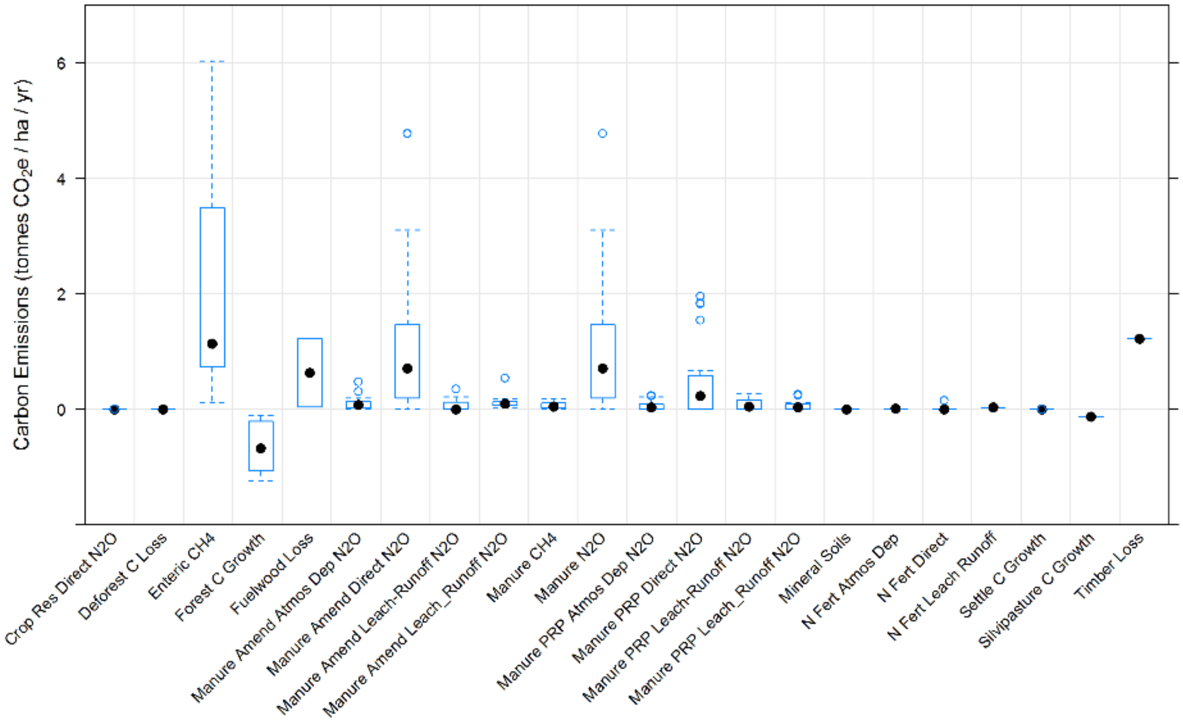


*Figure 23: Greenhouse gas fluxes per unit area of intervention site in the **Initial scenario**, aggregated by source for all CSI sites.*

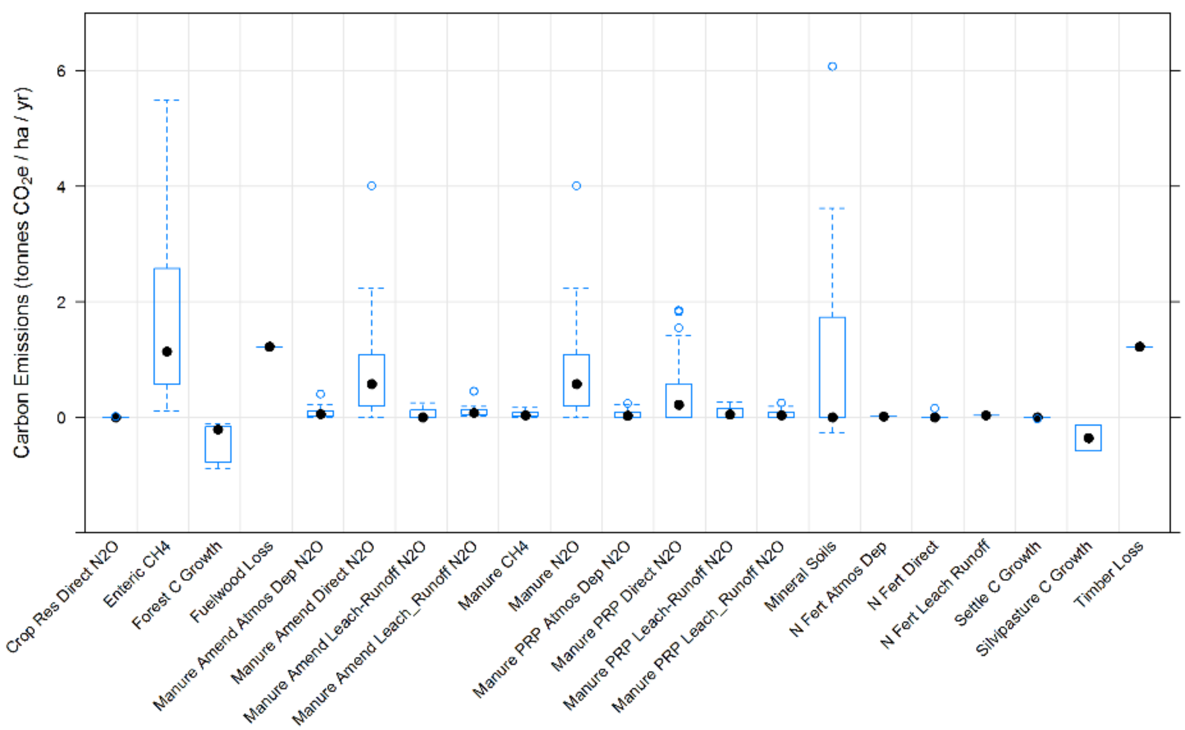


*Figure 24: Greenhouse gas fluxes per unit area of intervention site in the **BAU scenario**, aggregated by source for all CSI sites.*

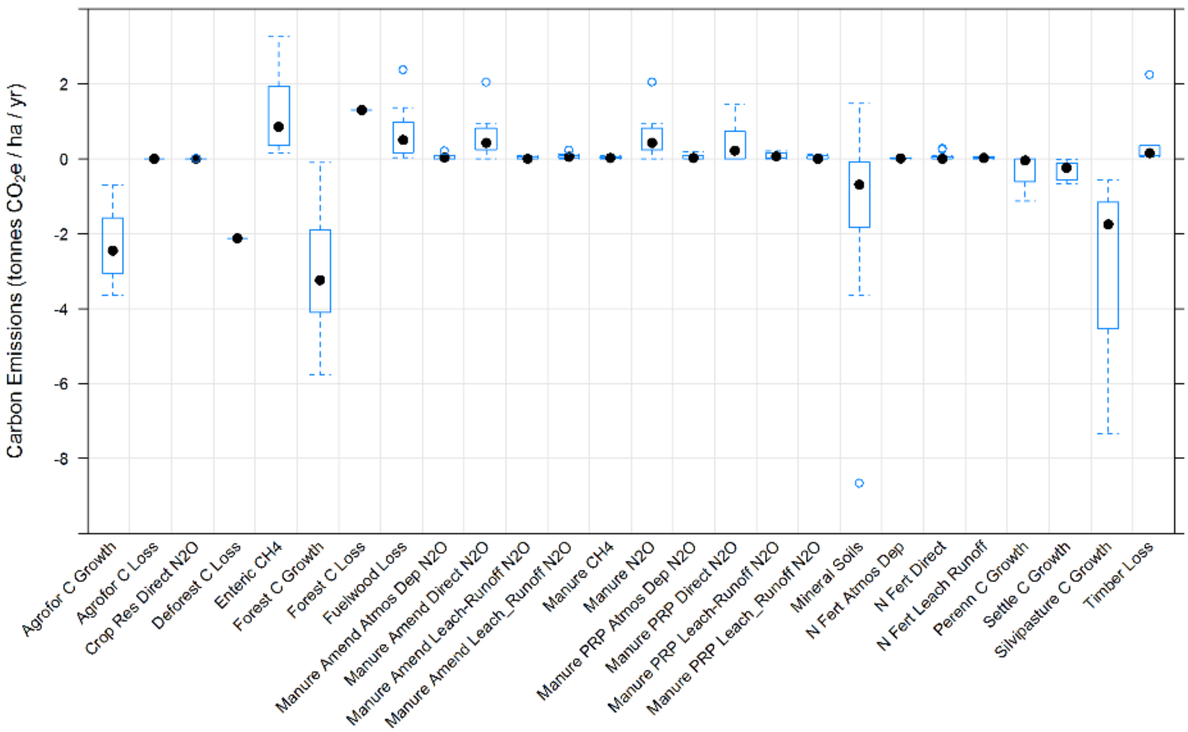


Figure 25: Greenhouse gas fluxes per unit area of intervention site in the ***Project scenario****, aggregated by source for all CSI sites.*

The carbon benefits (defined as the incremental difference between GHG emissions in the Project and BAU scenarios) of each CSI site are shown in Figure 26. Reduced emissions or sequestration are shown as positive benefits, whereas negative benefits indicate increased emissions under the project scenario. Results are shown for total carbon benefits for each site, and also categorized into those attributable to 1) changes in biomass (above- and below-ground), 2) SOC (soil organic carbon stock changes), 3) livestock (emissions from enteric methane and from manure management), and 4) other GHGs (which includes nitrous oxide and methane emissions from fertilizer, soils and fire).

All sites show a positive carbon benefit from increased biomass stocks in the project scenario, with one exception: (Af_Du_Ay) where *Prosopis* shrubland was converted to cropland. *Prosopis juliflora* was introduced to the Afar Region in the late 1970s, since then it has established itself as an aggressive weed forming a monoculture on 3,600 km^2 (particularly along the Awash River Valley), where it forms dense thickets that restrict livestock movement and access to underlying vegetation, and exclude more palatable native vegetation types (Wakie et al. 2014). *Prosopis juliflora* is not without redeeming qualities, however, such as increased vegetation cover and carbon stocks, protein-rich and palatable seedpods, and timber that is used for fuel, charcoal and building (particularly fencing). Nonetheless, it is highly disliked by most pastoral communities in the region due to its adverse impact on traditional pastoralism, and attempts at *Prosopis* eradication form an important part of PSNP in these areas. However, effective eradication of *Prosopis* where it is well-established appears to be unachievable, and management systems that aim to obtain economic benefits from *Prosopis* while managing its extent should be explored more by PSNP, once communities are able to come to terms with the reality that eradication is not a realistic option.

The large negative benefit (i.e., loss relative to BAU) in biomass carbon in deforestation areas such as Af_Du_Ay is attributable to a combination of two factors: 1) there is the foregone annual increment in biomass stocks that would have occurred were the woodland left to grow. However, the total annualized loss of biomass carbon is greater than the foregone annual increment, because it also includes 2) the loss of the carbon stocks that had already accumulated in the biomass. As a general rule, wherever there is deforestation or avoided deforestation (as in Am_Ko_Zo and Am_Ha_WA), the rate of change of carbon stocks can (sometimes greatly) exceed the rate of biomass growth in the forest, leading to relatively large (positive or negative) fluxes and carbon benefits. In Af_Du_Ay, the loss of biomass carbon benefits led to an overall net negative carbon benefit for the PSNP site.

The only other example of a PSNP site where total net emissions are expected to increase under the project scenario was Af_Ch_Ja, where increased livestock densities arising from rangeland improvement were not compensated by the accompanying small increase in soil carbon. Although, in a few sites (Af_Ch_Ja, Af_El_WL, Or_Se_Ch, and Ti_Ah_Se), livestock numbers and associated emissions increased as a result of improved forage productivity in PSNP, more frequently stock numbers went down (Af_Ew_Bo, Af_Ew_Du, Am_Ko_05, Am_TG_Ad, Or_DL_Od, Or_DM_ND, Or_Go_Ke, SN_Al_As, SN_DeG_Bo, SN_Hu_Lo, SN_Ko_Le, SN_So_Sh, So_Sh_BA, Ti_GM_SL, and Ti_TA_Ge), due to conversion of grazing lands to woodland, and to a lesser extent to agroforestry or cropland. Although reduced stocking numbers are clearly beneficial for carbon benefits, they can reduce food security of communities that are dependent on livestock if the loss of forage is not compensated by an increase in other types of foodstuffs. This highlights the need for managing opportunity costs when creating area enclosures and excluding traditional uses of the land by local communities. The greatest synergy between carbon and food-security was on sites with agroforestry, where diet and livelihood diversification were enhanced through introduction of fruit, honey and other non-timber forest products at the same time as carbon stocks were increased through the increase in tree cover.

Almost all sites showed an increase in soil carbon under PSNP management. Only two sites had a significant drop in modeled soil carbon. Af_Du_Ay with its deforestation of *Prosopis juliflora* described above was one (albeit with SOC loss being one order of magnitude lower than the biomass carbon loss). The other site with a small drop in soil carbon stocks predicted is Ti_Ah_Se—a site dominated by cropland that had previously been a largely unmanaged area of highly eroded and gullied sandy soil located on the lower slopes of a mountain valley as it enters the adjacent riparian zone.

As noted above, PSNP has little impact on fertilizer use, with accordingly negligible contribution of associated GHGs to overall carbon benefits in all sites.

The carbon benefits for all 28 sites are aggregated and summarized in Figure 27. The mean carbon benefit of all sites was 5.7 t CO_2e ha^{-1} yr^{-1}. On average, these carbon benefits were approximately equally accounted for by biomass (2.3 ± 4.3 t CO_2e ha^{-1} yr^{-1}) and soil organic carbon (2.2 ± 2. 1 t CO_2e ha^{-1} yr^{-1}), followed by livestock (1.3 ± 2.2 t CO_2e ha^{-1} yr^{-1}). PSNP impacts on other GHGs attributable to fertilizer (mineral and organic) and fire provided only a negligible (-0.03 ± 0.07 t CO_2e ha^{-1} yr^{-1}) contribution to overall carbon benefits. The substantial variability between sites in each of these flux types gave rise to a wide range in the total benefits with the standard deviation, 6.1 tonnes CO_2e ha^{-1} yr^{-1}, being larger than the mean value.

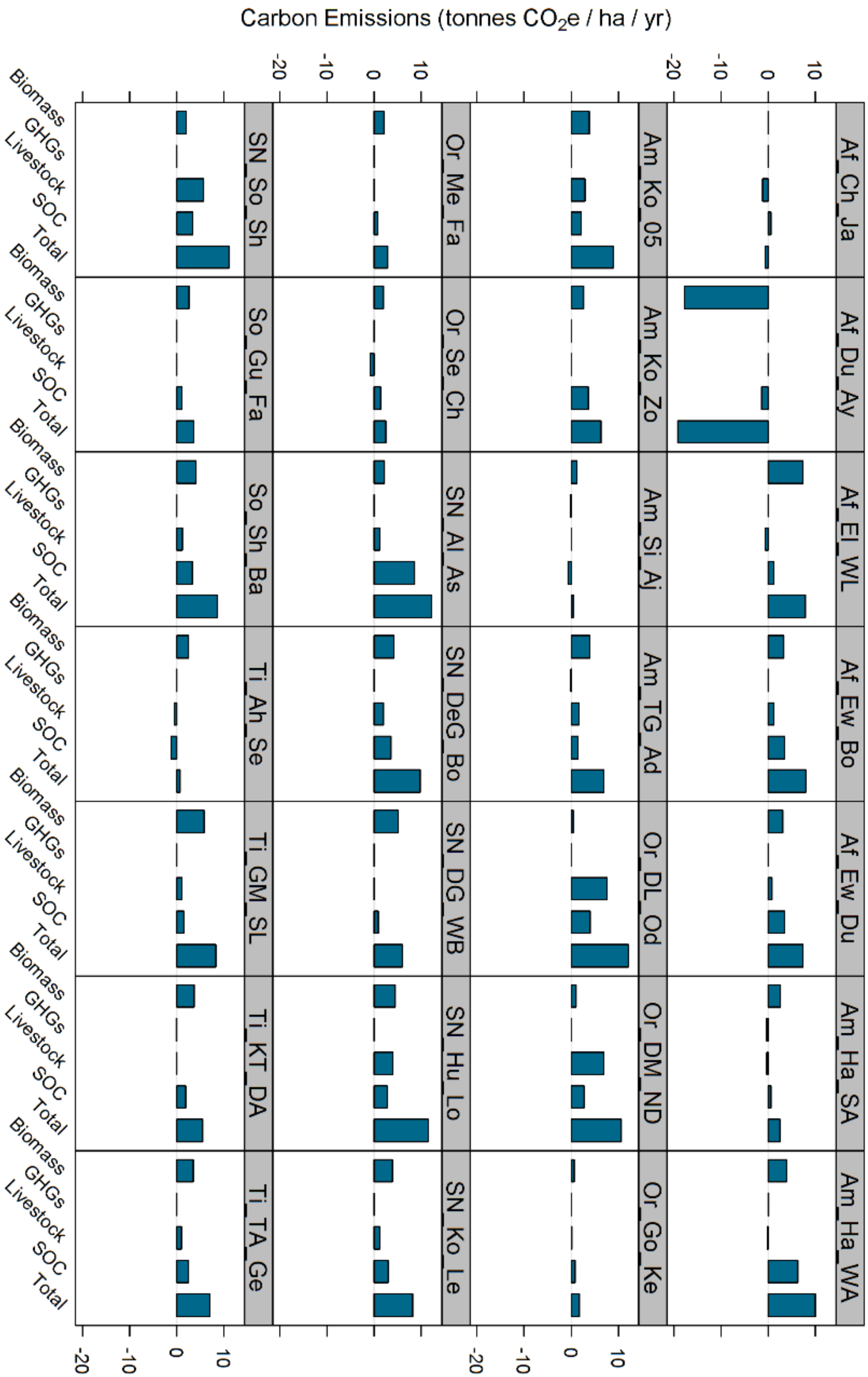


Figure 26: Summary of carbon benefits of all modeled CSI sites

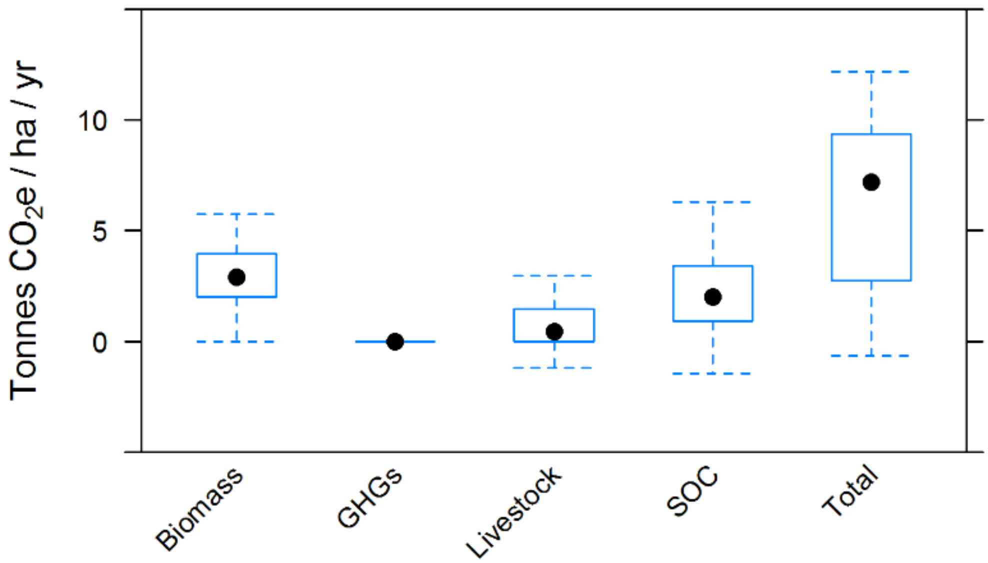


Figure 27: Summary of carbon benefits aggregated over all CSI sites. Positive carbon benefits indicate a net reduction in greenhouse-gas emissions. Black dots indicate median values, and boxes show interquartile range. Outliers not shown.

3.1 Dynamic modeling

CENTURY model results for SOC and biomass carbon (where applicable) at the SN_Al_As site are shown in Figure 28. Five management sequences, described in Figure 4, were modeled. Biomass carbon was predicted in systems where significant woody carbon stocks are expected to accumulate, including the Acacia shrubland (ASG) and woodland (WL) land cover classes. SOC was modeled in all of the systems.

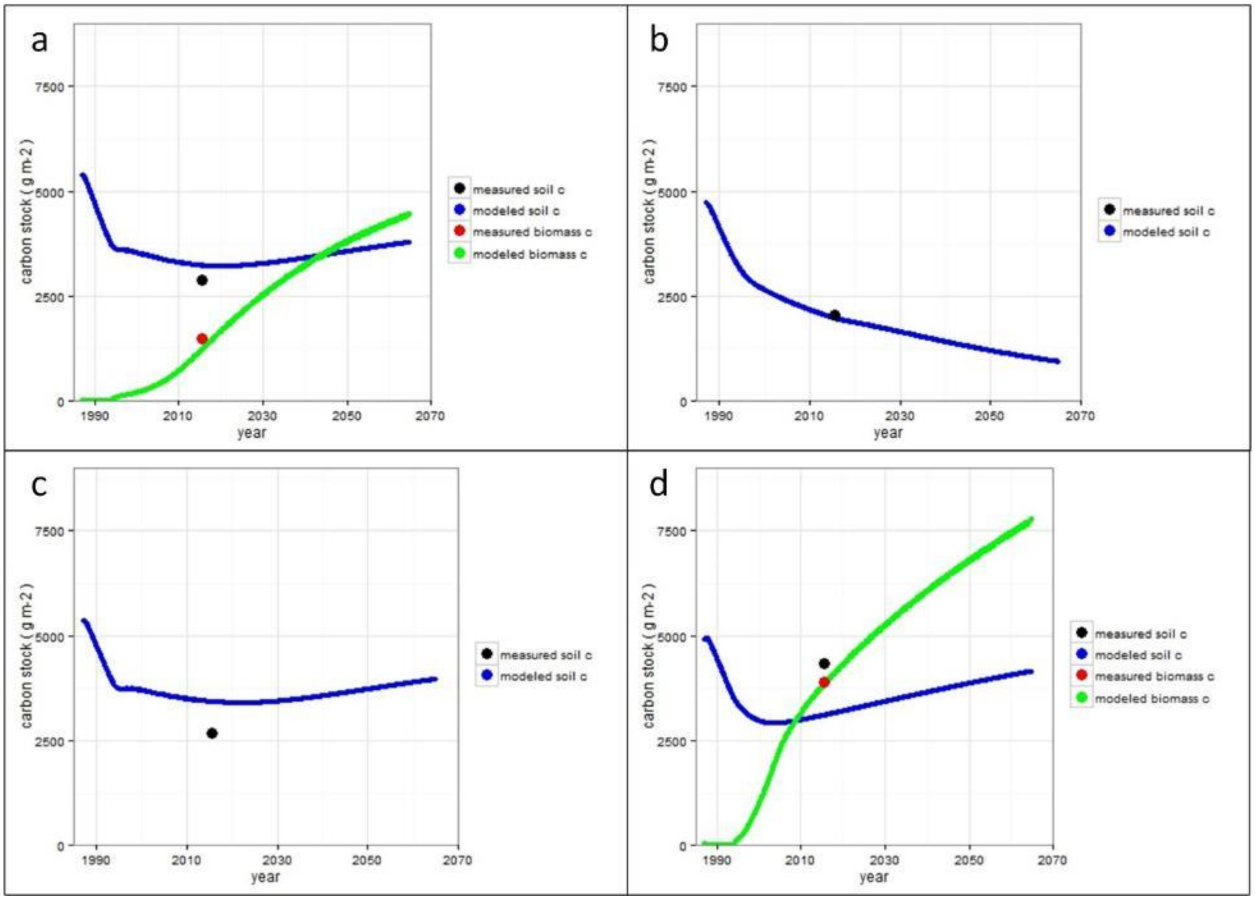


*Figure 28: Organic soil carbon (to 20cm depth) and biomass carbon projections for the TF-DR-ASG (**a**), TF-DR-DR (**b**), TF-DR-CH (**c**), and TF-DR-WL (**d**) management sequences. TF=Tropical forest; DR=degraded rangeland; CH=continuous hayland; ASG=acacia shrub and grassland; and WL=woodland.*

Changes in SOC stocks are shown in Table 10 and Table 11. Changes in woody biomass carbon stocks are shown in Table 12 and Table 13.

Table 10: Modeled changes in soil organic carbon stocks per hectare from 1987 (identified as "equilibrium") to 2035. TF=Tropical forest; DR=degraded rangeland; CH=continuous hayland; ASG=acacia shrub and grassland; and WL=woodland.

		Soil Organic Carbon Stocks (Mg/ha)				Soil Organic Carbon Stock Change (Mg/ha)		
System	**Area (ha)**	**Equilibrium**	**1995**	**2015**	**2035**	**Change to 1995**	**1995-2015**	**2015-2035**
TF-DR-ASG	115	54	36	32	33	-17	-4	1
TF-CL-ASG	10	54	36	32	33	-17	-4	1
TF-DR-CH	130	53	37	34	35	-16	-3	1
TF-DR-DR	130	47	31	20	15	-16	-11	-5
TF-DR-WL	231	49	34	31	35	-15	-3	4

Table 11: Modeled changes in total soil organic carbon stocks from 1987 (identified as "equilibrium") to 2035. TF=Tropical forest; DR=degraded rangeland; CH=continuous hayland; ASG=acacia shrub and grassland; and WL=woodland.

		Soil Organic Carbon Stocks (Mg)				Soil Organic Carbon Stock Change (Mg)		
System	**Area (ha)**	**Equilibrium**	**1995**	**2015**	**2035**	**Change to 1995**	**1995-2015**	**2015-2035**
TF-DR-ASG	115	6,175	4,166	3,714	3,826	-2,009	-451	112
TF-CL-ASG	10	537	362	323	333	-175	-39	10
TF-DR-CH	130	6,933	4,847	4,454	4,526	-2,086	-392	71
TF-DR-DR	130	6,120	4,021	2,575	1,977	-2,099	-1,446	-599
TF-DR-WL	231	11,296	7,769	7,118	8,148	-3,527	-651	1,030

Table 12: Modeled changes in woody biomass carbon stocks per hectare from 1987 (identified as "equilibrium") to 2035. TF=Tropical forest; DR=degraded rangeland; CH=continuous hayland; ASG=acacia shrub and grassland; and WL=woodland.

		Woody Biomass Carbon Stocks (Mg/ha)				Woody Biomass Carbon Stock Change (Mg/ha)		
System	**Area (ha)**	**Equilibrium**	**1995**	**2015**	**2035**	**Change to 1995**	**1995-2015**	**2015-2035**
TF-DR-ASG	115	30	1	12	29	-29	11	17
TF-CL-ASG	10	30	1	12	29	-29	11	17
TF-DR-CH	130	33	1	12	31	-33	0	0
TF-DR-DR	130	31	0	0	0	-31	0	0
TF-DR-WL	231	38	1	38	57	-37	36	19

Table 13: Modeled changes in total woody biomass carbon stocks from 1987 (identified as "equilibrium") to 2035. TF=Tropical forest; DR=degraded rangeland; CH=continuous hayland; ASG=acacia shrub and grassland; and WL=woodland.

		Woody Biomass Carbon Stocks (Mg/ha)				Woody Biomass Carbon Stock Change (Mg/ha)		
System	**Area (ha)**	**Equilibrium**	**1995**	**2015**	**2035**	**Change to 1995**	**1995-2015**	**2015-2035**
TF-DR-ASG	115	3,469	79	1,334	3,318	-3,390	1,255	1,984
TF-CL-ASG	10	302	7	116	288	-295	109	173
TF-DR-CH	130	4,348	91	1,557	4,024	-4,256	0	0
TF-DR-DR	130	4,086	5	5	5	-4,081	0	0
TF-DR-WL	231	8,891	270	8,688	13,055	-8,621	8,418	4,367

Modeled soil organic carbon stocks dropped in the study site by 9,896 Mg (an average of 16 Mg/ha) from 1987 to 1995. Modeled woody biomass carbon stocks during the same period to 1995 dropped by 20,643 Mg (average of 32 Mg/ha). After restoration efforts began in the mid 1990's, modeled woody biomass carbon stocks increased by 11,247 Mg to 2015, and are predicted to increase by 8,990 Mg by 2035. In contrast, modeled soil organic carbon stocks stabilized by 2015 in the ASG, CH and WL land cover classes though they remain low, with little significant increase predicted before 2035. Modeled soil organic carbon stocks continue to decline significantly in the degraded rangeland sites through 2035.

From 1987 to 1993 the Asore, Alaba, SNNPR site went through a period of intensive land use changes, leading to severe soil erosion in much of the watershed. Modeling SOC losses under erosion conditions can be difficult, as a variety of contributing factors lead to uncertainties in plant production, soil stability, and stability of the soil carbon itself. No measurements of soil erosion losses were available for the Asore site, as these must be acquired over multi-annual periods, so we modeled the site to first predict the effects of land use change on soil and woody biomass carbon stocks, and then imposed erosion conditions in an increasing stepwise fashion until, on average across the land cover types, modeled soil organic carbon stocks matched measured SOC stocks. The total erosion losses predicted through this method were 147 kg m^{-2}.

The CENTURY model predicted soil organic stocks within 5% of measured values in the ASG plots, whereas it over-predicted carbon stocks in the CH and DR plots and under-predicted stocks in the WL site. The greatest value in modeling soil organic carbon is in evaluating potential changes over time under specific land management conditions. Soil organic carbon sequestration appears to be possible in the ASG and WL land cover types, as these sites remain relatively undisturbed and no woody biomass or forage is removed. Soil organic carbon stocks would likely remain stable under the CH system, and could increase if moderate hay harvests are made. Degraded rangeland appears likely to continue to lose soil organic carbon if soils are not stabilized and vegetative cover is not restored.

The situation with woody biomass is similar, though the magnitude of change in carbon stocks is greater. Woody biomass carbon stocks appear likely to continue to increase in the next two to three decades if trees are not harvested significantly. Unless soils are stabilized, woody biomass appears unlikely to increase on degraded rangeland.

4 Discussion

4.1 Comparison of Dynamic Modelling to IPCC Tier 1 and Tier 2 Assessment

The findings from the Asore site in Alaba Special Woreda, SNNPR (SN_Al_As) site demonstrate the value of modeling soil organic carbon and woody biomass and provide important insights for future land management activities. The modelling projections indicate that the PSNP's sustainable public work activity at SN_Al_As have likely arrested soil organic carbon stock losses, stabilized stocks in the ASG, CH and WL land use classes, reversed woody biomass carbon loss on the ASG and WL land use classes, and demonstrate the potential for sequestering atmospheric CO_2 as woody biomass and soil organic carbon while stabilizing ecosystems services as an economic resource for improving the livelihoods of residents. Moreover, the projections demonstrate the importance of restoring vegetation cover to degraded lands, and provide a picture as to which interventions have the greatest potential for mitigating greenhouse gas accumulations in the atmosphere.

Restoring woody biomass cover in landscape classes where it is appropriate appears to have the greatest immediate potential on a per-hectare basis to increase total ecosystem carbon stocks. Restoring vegetation cover in degraded rangeland, as demonstrated in the model projections for the CH land use class, appears to have significant potential to sequester atmospheric CO_2 as soil organic carbon.

Restoring woody biomass cover in landscape classes where it is appropriate appears to have the greatest immediate potential on a per-hectare basis to increase total ecosystem carbon stocks.

Restoring vegetation cover in degraded rangeland, appears to have significant potential to sequester atmospheric CO_2 as soil organic carbon

Projected forward from 2015 to 2070, the WL class has the potential to sequester a time-averaged 1.1 Mg C ha^{-1} yr^{-1} in biomass and soil carbon stocks. The ASG class could sequester 0.9 Mg C ha^{-1} yr^{-1} in biomass and soil carbon stocks. Degraded rangeland appears likely to continue to lose soil organic carbon stocks at a time-averaged rate of 0.25 Mg C ha^{-1} yr^{-1}. Whereas the fate of eroded soil organic carbon is uncertain, restoring degraded rangeland to either ASG or WL classes at the SN_Al_As site has the potential for a net benefit of 1.15-1.35 Mg C ha^{-1} yr^{-1} to 2070 in increased soil organic carbon stocks.

Over a project accounting period of 20 years from the start of implementation, the dynamic model predicts a more conservative net carbon benefit of 7.8 tonnes CO_2e ha^{-1} yr^{-1} in biomass and soil carbon combined for the SN_AL_AS site. This is 30% lower than (but within the uncertainty term) the biomass plus SOC benefits predicted by the simple assessment (10.9 tonnes CO_2e ha^{-1} yr^{-1}) reported above in Section 3, thus highlighting the large uncertainties associated with the IPCC Tier 1 emissions factors and the need for more data on PSNP soils and biomass to allow improved Tier 2 assessments. In addition to uncertainties in emission factors, the dissimilarity between the two modeling predictions can also be attributed to the way that the IPCC methodology approaches carbon stock changes. Whereas the dynamic modeling method describes the rate at which stocks change, the IPCC methodology simply calculates the total change in carbon stocks between different land use and land management scenarios without regard to the rate at which those changes accrue. Therefore, using a project accounting period of 20 years may overestimate the rate of change when using the IPCC methodology, with some of those predicted carbon benefits still remaining "in the pipeline" at the end of the accounting period, waiting to be realized as soil and biomass carbon stocks continue to change.

When we analyze the findings from the SN_AL_As site in the larger picture, where rangeland is degraded and forestland, woodland and savanna have been cleared, we can see the benefits of restoring woody biomass cover while stabilizing soils with a combination of grass, forb and woody plants appropriate for the region. Much could be learned by extending the Dynamic Modelling work to a combination of wetter and dryer sites, particularly those with contrasting land use interventions, and where other similar SLM projects such as SLMII have been implemented in Ethiopia. Doing so would allow more thorough quantification of the GHG mitigation potential of different interventions in different ecosystems. It would also allow extending those quantifications to a broader set of ecosystem classes, and provide the basis for more informed decisions about where to prioritize GHG mitigation while implementing land use interventions that have the capacity to improve people's livelihoods.

4.2 Potential Sources of Uncertainty in Modeling Results

The IPCC Tier 1 and Tier 2 Assessments provide uncertainty for the estimated GHG emissions and C stock changes. Uncertainty provides a measure of a lack of knowledge about a parameter. When using the IPCC methodology with default values, a measure of uncertainty is provided. This value has been calculated by the IPCC, taking into consideration sources of uncertainty in all of the studies used to produce the value. Uncertainty can arise for several reasons, including:

1) Modelling errors due to inability of the model to fully describe the process. All models are a simplification of the actual physical reality. Such imperfections in the model cannot be addressed by the end user of a particular model, and it has to be borne in mind that all models have limitations. If a particular model underperforms because it is unable to accurately describe the system in question, one important recourse that users have to address such uncertainties is to apply a more complex model that better describes the system. For example, the CBP system, by including Detailed Assessment and Dynamic Modeling options, gives the user the opportunity to input very detailed information to help the model by providing as much project specific information as possible, or to use increasingly complex models such as CENTURY or RothC to more accurately describe the physical processes. Increasingly complex modeling options typically require more highly trained professionals to conduct the analysis and higher costs to provide the more detailed data required to drive such models. Therefore, it is always important to strike the correct balance between precision, accuracy and cost in relation to project demands.

2) Classification errors. It is important that the most appropriate definitions for land use categories (e.g. agroforestry, silvipasture, perennial cropland, or forestland) are applied, definitions of which can sometimes be blurred. The correct classification to apply needs to be assessed on a case-by-case basis according to the way that the model treats each system. This can differ from the classifications that land managers or agro-ecologists might use. For example, the IPCC methodology for agroforestry systems is calibrated for agroforestry systems that consist of sparse tree cover within a predominantly cropping system. The IPCC agroforestry model therefore performs poorly if applied to some of the densely wooded agroforestry systems found in Ethiopia, which are better described as some combination of woodland, perennial cropland, annual cropland and grassland, according to density and distribution of these various types of vegetation in the agroforestry system. Similarly, the IPCC silvipasture model is also calibrated for low tree densities, and when tree densities are high a better description for the model is a combination of woodland and grassland.

3) Unrepresentative samples. Whether collecting activity data or taking measurements to produce emission or stock change factors, a representative sampling strategy is key. As discussed in Section 4.5 below, the framework of the CSI project, by stipulating the woredas and kebeles in which sites were to be assessed, did not allow for a stratified random sampling methodology. Although there was no known bias towards woredas with higher- or lower-performing sustainable land management interventions in this selection process, future impact assessments would be improved by allowing the flexibility to select survey locations freely, to remove the potential for such biases.

4) Measurement errors: Measurement errors can occur when recording activity data (e.g., errors in area covered by certain land use categories, errors in numbers of tree species present). When collecting data using questionnaires or interviews it is important that the interviewees are made aware that it is not their personal performance that is being assessed, but that the purpose of the survey is to understand the impacts of what is actually implemented. Unless this is made clear, there is an increased risk that interviewees will report their activities inaccurately. For example, if fertilizer application guidelines exist, farmers or DAs may report inaccurately that these guidelines are followed exactly because they are reticent to divulge whether the protocols had been followed as instructed. Similarly, grazing of livestock within area enclosures is typically illegal. Despite this, visual evidence of some grazing within enclosures was often noted. But interviewees were typically unwilling to divulge accurately how much livestock encroachment in fact occurs. A standardized approach which includes adequate replication and well-trained personnel can reduce measurement errors. Cross validation of field-based surveys with remotely sensed data as applied in this study can help to reduce such potential sources of error.

The Detailed Assessment Tool allows the user to specify the uncertainty associated with new emission factors entered into the system. It is therefore important to collate information on any uncertainty associated with new emission factors. If a factor is taken from a published study it may have a measure of variation published with it, for example maize yield may be published as 3 t ha^{-1} +/- 5%. Likewise if using field measurements, error around a mean from several replicates can give a measure of uncertainty. Where there are several different sources of uncertainty the IPCC recommend using the error propagation method[3].

4.3 Methods to further reduce uncertainty

4.3.1 Collating improved activity data

One important type of data required for carbon modeling is documentation of management activities conducted within the project sites. The modeling work presented here used management data from the PSNP and other CSI reference sites that could be ascertained from a combination of remote sensing, farmer interviews, interviews with key informants (DAs and MoA officials), and field-based surveys. Some types of data such as management activities (e.g. multi-year crop rotations, mineral and organic fertilizer application regimes, residue management) could not be observed directly within the time window of the field survey and had to be ascertained from farmer and key informant interviews. In most cases, these data had already been collated by local DAs over the years for purposes other than modeling carbon benefits. Going forward, the process of carbon modelling on PSNP sites could be streamlined if management activity data are collected regularly in a standardized way and centrally collated, using the questionnaire developed for this purpose within the CSI project (Annex 1). Collecting management activity data in the future does not need to be costly as much of the data needed to run the models is already being collected by local DAs, and local government offices. Ideally those already collecting data should be made aware of any additional parameters that need to be collected for carbon modeling purposes and data should be fed back to a central agency.

4.3.2 Improved Tier 2 factors for PSNP regions/activities

In this analysis the Detailed Assessment Tool was used for 11 sites. Tier 2 emission and stock change factors were derived from on-site measurements, remote sensing and also taken from the literature, where applicable. In some cases values were specific to Ethiopia, in others they were for specific crop or forest types but were taken from studies in other areas of the globe (depending on the literature that was available). These emission factors could be improved further by: 1) extending the review of published literature to access useful references not cataloged by the Web of Science database used; 2) contacting local universities or research centers to find any unpublished studies such as Masters and Doctoral Thesis with relevant data;

[3] Methods for recording and analyzing uncertainty can be found in Annex 1 of the *IPCC 2001 report Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* available from http://www.ipcc-nggip.iges.or.jp/public/gp.

3) extending local census data for crop yields to also record residue (e.g. straw and stover) production; and 4) where census data are unavailable, taking field measurements of parameters such as yield and crop residue to yield ratio.

4.4 Cost-benefit analysis and Drivers-Pressures-States-Impact-Response (DPSIR) analysis

The CBP toolset includes a basic cost-benefit analysis (CBA) system which can be applied after the simple or detailed assessment tools have been used. The user can consider those land management practices that are shown to have carbon benefits in terms of the economic costs associated with establishment and ongoing implementation which requires the input of some basic information on costs of labor and materials. Extending the carbon benefits analysis conducted here to include additional economic analysis would be useful for future planning and may also help explain low adoption rates of certain practices.

The CBP toolset also includes the DPSIR (Drivers, Pressures, States, Impact, Response) tool which is a qualitative tool for analyzing the impacts and potential enablers and barriers to uptake of land management practices both socially and economically (Figure 29). This tool can help organize information in a succinct and comparable way. It would be very useful for PSNP to complete a DPSIR analysis using this tool especially for those sites where implementation or uptake of project activities has been low.

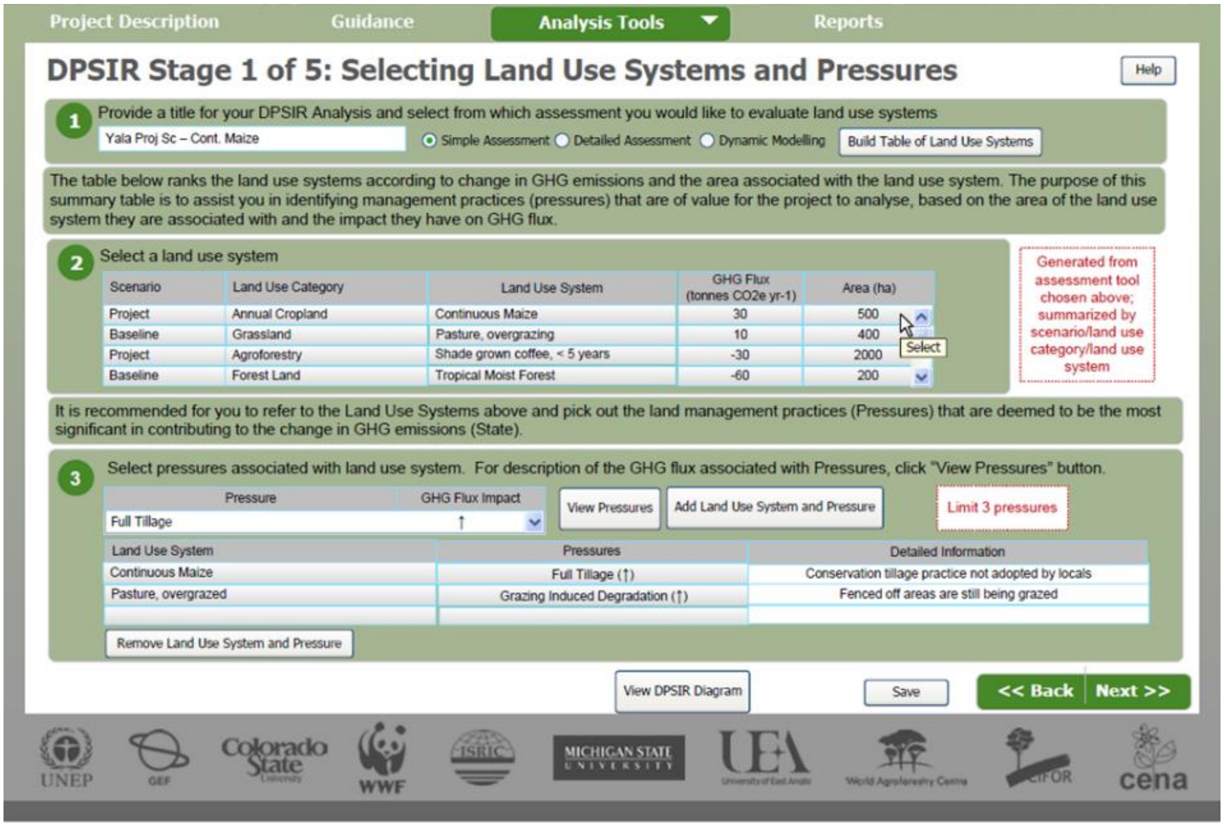


Figure 29: Screen shot from the CBP's online DPSIR tool.

4.5 A 1ST ORDER ESTIMATE OF *POTENTIAL* CARBON BENEFITS IN PSNP

It is a useful and interesting exercise to extrapolate from the CSI sites modeled here to obtain a first order estimate of the carbon benefits that might be attributable to the entire PSNP program. However, we must begin with some caveats about the quality of such an extrapolation. Firstly, the 28 sites modeled here account for a total of 7,000 ha—1 % of the 600,000 ha of area enclosures that have been implemented to-date by PSNP. Based on the mean and standard deviation of carbon benefits from the 28 modeled sites (μ = 5.7, σ = 6.1 t CO_2e ha^{-1} yr^{-1}), to estimate the mean for all of PSNP to within a 90% confidence interval would require a sample size of at least 68 sites. The standard error of the sites modeled here was 1.15 t CO_2e ha^{-1} yr^{-1} (20% of the sample mean). Secondly, site selection for an accurate estimate of the population mean would require that sites were randomly sampled from the whole of PSNP. It was not possible within the framework of the CSI project to apply a completely randomized selection, because the woredas and kebeles in which we operated were selected for us by the CSI consortium without regard to the needs of a quantitative biophysical survey. Nonetheless, there was some randomization in this procedure in the sense that the selection criteria were related to operational aspects of the socioeconomic studies of the CSI project, and as such had no known particular bias towards woredas with higher- or lower-performing sustainable land management interventions. Thirdly, there is no systematic procedure in place for monitoring the location, size, or type of PSNP SLM projects at the national level and, despite requests to the Regional MoA, we were unable to obtain any additional or clarifying data on such monitoring activity. The only national statistic provided was that PSNP has implemented 600,000 ha of area enclosures. In the future it is highly recommended that improved monitoring and evaluation of PSNP activities are conducted, including randomized verification and surveying conducted by a national inspectorate. This will be required both for the purposes of improved impact assessment, but also, critically, because without such an ongoing monitoring and evaluation procedure in place, regional and local incentives to improve quality of performance will be suboptimal, which is likely to lead to reduced performance of the PSNP program.

With these caveats in mind, we can project that the sample mean of 5.7 t CO_2e ha^{-1} yr^{-1} extrapolated to PSNP's 600,000 ha of area enclosures would imply an approximate total potential C benefit on the order of 3.4 million t CO_2e yr^{-1}. With current carbon prices in the range of less than \$1 $tonne^{-1}$ CO_2e under the UNFCCC's Clean Development Mechanism (CDM) market to \$5 $tonne^{-1}$ CO_2e in the voluntary markets (see carbon markets analysis report chapter), this translates to an approximate potential value of carbon benefits of PSNP of \$3.4 million per year over a 20 year accounting period in the CDM or \$17 million per year in voluntary markets. *But*, as outlined in the carbon markets analysis report chapter, compliance markets are in a slump and voluntary markets have only limited transaction volumes, with typically small project sizes.

It is also important to note that, in any case, not all of these benefits could be monetized realistically, because as described in detail in the carbon markets analysis report:

1) only *additional* benefits beyond existing PSNP could be viably eligible for carbon finance;
2) in any AFOLU based carbon finance project, some carbon credits (ranging from 10 up to 50% as determined by a risk rating) are typically withheld to account for risk of underperformance, measurement uncertainty in project greenhouse gas benefits of the interventions, or future losses of carbon stocks from changes in management or natural risks (such as fire, pests or diseases);
3) accepted cost-effective methodologies for some of these benefits (particularly livestock and soil carbon) are in nascent stages and are more challenging to sell in carbon markets;
4) although the benefits modeled here represent a portrayal of the demonstrated potential of PSNP projects if implemented according to their management plans and objectives, it should be noted that actual implementation in some surveyed sites fell short of the management plans and improved monitoring of implementation quality would be required to ensure that sites perform into the future up to the standards of the PSNP management plans;

5) the dynamic modeling described above suggests that the Tier 1 emission factors for Ethiopia in the IPCC methodology may be overestimating carbon accrual rates by as much as 30% in some PSNP sites; and
6) any carbon finance obtained must always be offset against project development, implementation, monitoring and verification costs, which can be substantial—particularly if the carbon project were to include thousands of sub-watershed interventions spread across the entire country as is the case with current PSNP, unless a more cost-effective measurement, verification and reporting mechanism can be designed for this purpose.

4.6 Variability in carbon benefits

Net carbon benefits in the modeled sites ranged from -19 to +12 t CO2e ha^{-1} yr^{-1}. The causes of this variability included i) differences in land use (with activity areas converted to woodland or agroforestry showing highest C benefits); ii) differences in management and implementation (e.g., types of trees planted, quantity of firewood and timber extraction allowed, and how effectively livestock are excluded from enclosures); and iii) climatic and edaphic variation between sites (e.g. more arid zones have lower productivity, and more sandy soils are less able to store carbon). Although some of this variability is due to bioclimatic/edaphic parameters that cannot be controlled, much of it can be accounted for by differences in management and implementation. Thus, the substantial variability between sites indicates potential to increase carbon benefits by improved management and implementation. This is one potential entry point for creating additionality in a carbon finance project (see carbon market analysis report chapter), by using climate funding to finance improvements in implementation beyond what would occur in PSNP without climate finance.

5 Conclusions

Models provide a useful way of estimating the overall GHG impact of land management projects. This is particularly true for landscape scale projects which involve multiple land use/land cover categories and land management interventions. Models offer the possibility of making predictions about the future carbon stock changes and GHG emissions, a means of generating useful land management information where comprehensive large-scale measurement campaigns are not possible, and simultaneous consideration of multiple carbon sources and sinks. Most available tools are based on the IPCC computational method. This method has its drawbacks but is currently the only globally applicable method for GHG accounting for AFOLU. All modeling tools are different having been developed for a range of purposes. Dynamic models attempt to describe the processes that drive ecosystems, however they can be complex to use and data intensive. Therefore, it is always important to strike the correct balance between accuracy and cost according to project demands and data availability and quality.

The analysis conducted here encompassed six regions in Ethiopia incorporating a range of climates and soil properties found throughout the country. The analysis also encompassed a broad spectrum of sustainable land management (SLM) activities and therefore provides a good platform to analyze the potential of AFOLU activities for climate change mitigation in Ethiopia.

Landscape-scale data are a prerequisite to scaling up of carbon projects. But, field-based surveys at the national or landscape scale are time consuming and expensive. Therefore, improved data and simplified methods are critical to cost-effective scaling up of planning, monitoring and verification, with geospatial data being linked to models. National, high resolution, geophysical and biophysical geospatial data were generated. Simplified methods for use of remotely sensed data to measure tree cover were applied using an NDVI threshold methodology. The high prediction accuracy of tree cover using this approach demonstrates this as a viable method for rapid, low cost and simple mapping of trees within PSNP areas.

Area enclosures should be managed in such a way that they provide sufficient livelihood benefits to the local community to compensate for the opportunity cost of the land becoming unavailable for other uses. Managing such tradeoffs is not only important to fulfilling the food security role of PSNP but also critical to the long-term protection of any land improvements, because communities are less likely to revert to business-as-usual practices once land is returned to their control if the enclosures are designed to also provide food, forage, fuel, and non-timber forest products from the area enclosures. While all the enclosures surveyed had a fraction of their area designated for forage grass production, overall only a small proportion of the woodland areas were comprised of tree species that provide food or forage (such as fruit or nut trees, or leguminous species with edible foliage or pods). In only one site did agroforestry or perennial cropland comprise a large fraction of the overall enclosure. Only one of the area enclosures surveyed included an apiary.

The mean carbon benefit of all sites was 5.7 tonnes CO_2e ha^{-1} yr^{-1}. On average, these carbon benefits were approximately equally accounted for by biomass (2.28 ± 4.3 t CO_2e ha^{-1} yr^{-1}), livestock (2.26 ± 0.08 t CO_2e ha^{-1} yr^{-1}), and soil organic carbon (2.22 ± 2. 1 t CO_2e ha^{-1} yr^{-1}).

Based on interquartile range (IQR), biomass sequesters 1.5 – 3 tonnes CO_2e ha^{-1} yr^{-1} in agroforestry sites, 2 – 4 tonnes CO_2e ha^{-1} yr^{-1} in forest sites, and 1 – 4 tonnes CO_2e ha^{-1} yr^{-1} in silvopasture sites. In the BAU scenario, progressive land degradation makes soil carbon loss a significant source of emissions, in the interquartile range of 0 – 2 tonnes CO_2e ha^{-1} yr^{-1} (Figure 24). Conversely, in the project scenario, soil restoration is predicted to sequester 1 – 4 tonnes CO_2e ha^{-1} yr^{-1} (IQR) in increased soil organic carbon. All sites show a positive carbon benefit from increased biomass stocks in the project scenario, with one exception that involved conversion of *Prosopis* shrubland to cropland. Management systems that aim to obtain economic benefits from *Prosopis* while managing its extent should be explored more by PSNP.

Although, in a few sites, modeled livestock numbers and associated emissions increased as a result of improved forage productivity in PSNP, more frequently stock numbers went down due to conversion of grazing lands to woodland, and to a lesser extent to agroforestry or cropland. Although reduced stocking numbers are beneficial for carbon benefits, they can affect the food security of communities that are dependent on livestock if the loss of forage is not compensated by an increase in other types of produce. This highlights the need for managing opportunity costs when creating area enclosures and excluding traditional uses of the land by local communities. The greatest synergy between carbon and food-security was on sites with agroforestry, where diet and livelihood diversification were enhanced through introduction of fruit, honey and other non-timber forest products at the same time as carbon stocks were increased through the increase in tree cover.

Almost all sites showed an increase in soil carbon under PSNP management. Only two sites had a significant drop in modeled soil carbon under the project scenario when either *Prosopis* deforestation was conducted, or grassland was converted to cropland.

PSNP has little impact on fertilizer use, with accordingly negligible contribution of associated GHGs to overall carbon benefits in all sites.

Dynamic modeling demonstrated the great importance of soil erosion as a driver of soil carbon loss in BAU management. Dynamic modeling predicted a net carbon benefit in biomass and soil carbon combined that was 30% lower than predicted by the detailed IPCC assessment, thus highlighting the large uncertainties associated with the default IPCC emission factors for Ethiopia and the need for more data on Ethiopian soils and biomass to allow improved Tier 2 assessments. There are several ways of reducing uncertainty in modeling. The most relevant to this analysis is the collection of data in a standardized way, tailored to provide the specific inputs needed by the models. This should be employed in any future climate change mitigation analysis of the PSNP sites in Ethiopia. Extending the Dynamic Modelling to a range of wetter and dryer sites would allow more thorough quantification of the greenhouse gas mitigation potential of different interventions in different ecosystems. However, it is always important to strike the correct balance between accuracy and cost according to project demands, with more accurate methodologies typically being more labor and data intensive.

Extending the carbon benefits analysis conducted here to include additional economic analysis would be useful for future planning and may also help explain low adoption rates of certain practices.

The mean carbon benefit of 5.7 t CO_2e ha^{-1} yr^{-1} modeled for the CSI sites, extrapolated to PSNP's 600,000 ha of area enclosures would imply an approximate total potential C benefit of PSNP to date in the order of 3.4 million t CO_2e yr^{-1}. It is also important to note that not all of these benefits could be monetized, because 1) only *additional* benefits beyond existing PSNP could be viably eligible for carbon finance; 2) some carbon credits are typically withheld to account for risk of underperformance or future losses of carbon stocks; 3) accepted cost-effective methodologies for livestock and soil carbon are in nascent stages; 4) actual implementation of some PSNP sites may fall short of management objectives unless a comprehensive system of monitoring and evaluation is conducted at the national scale to improve quality control; and 6) carbon finance obtained must be offset against project development, implementation, monitoring and verification costs, which can be substantial.

The substantial variability between carbon benefits observed in different sites indicates the potential to increase carbon benefits by improved management and implementation.

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ANNEX 1. SIMPLIFIED ACTIVITY DATA QUESTIONNAIRE

Date		Interviewer	
Name of project		Interviewee	
Woreda			
Kebele		GPS & elevation	
Watershed		Area	
Scenario		Age of project	

Activity Data Type	units	Value	Comments			
Annual cropland						
Area in Annual Cropland System	ha					
Area in Wetland Rice	ha					
Crop rotation		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Long rain crops							
Short rain crops							
		crop 1	crop 2	crop 3	crop 4	crop 5	crop 6
crop name in rotation							
% of residues burned	%						
% of residues retained	%						
% of residues collected	%						
% of residues grazed	%						
Fertilizer Amount	kg/ha						
% Nitrogen in Fertilizer	%						
Tillage (full/reduced/none)	f/r/n						
Organic fertilizer	y/n						
Cover crops	y/n						
Irrigation	y/n						
Liming	y/n						
		crop 1	crop 2	crop 3	crop 4	crop 5	crop 6
Improved varieties	y/n						
Legume	y/n						
Residue to Yield Ratio (if known)							
Crop Yield (if known)	t/ha						
Perennial cropland							
Area in perennial cropping system	ha						
Fertilizer Amount	kg						
% Nitrogen in Fertilizer	%						
Forestland							
Area in Forest	ha						
Types of trees							
Age of trees (>20 yrs)	y/n						
% loss by fire	%						
% loss by wind	%						
% loss by pest/disease	%						

% loss by other	%					
Area cleared without burning	ha					
Area cleared by burning	ha					
% of forest burned	%					
wood gathered for fuel	m^3					
wood harvested for timber	m^3					
wood harvested for pruning	m^3					
wood removed for other reasons	m^3					

Grassland						
Area in Grassland	ha					
Type		Continuous pasture	Silvopasture	Rangeland	Continuous hayland	
Condition		Nominally degraded or native	Moderately degraded	Severely degraded	Improved	
Improvements		Organic fertilizer	Improved varieties	Irrigation	Liming	Legumes
Burning frequency	yr					
Fertilizer Amount	kg					
Area in Silvipasture	ha					
Types of trees						
Age of trees (>20 yrs)	y/n					
% loss by fire	%					
% loss by wind	%					
% loss by pest/disease	%					
% loss by other	%					
Volume of wood gathered for fuel	m^3					
Volume of wood harvested for timber	m^3					
Volume of wood harvested for pruning	m^4					
Volume of wood removed for other reasons	m^3					
Area of afforestation	ha/yr					
Area of deforestation	ha/yr					

Livestock	
number of months resident per year	
number of livestock and types	
Manure management	

Settlements	
Area in Settlements	ha
% of trees burned	%
number of trees	
% trees lost to other causes	%
% trees lost to pests	%
Tree Crown %	%
% trees lost to wind	%

Agroforestry	
Area in Agroforestry System	ha
Fertilizer Amount	kg

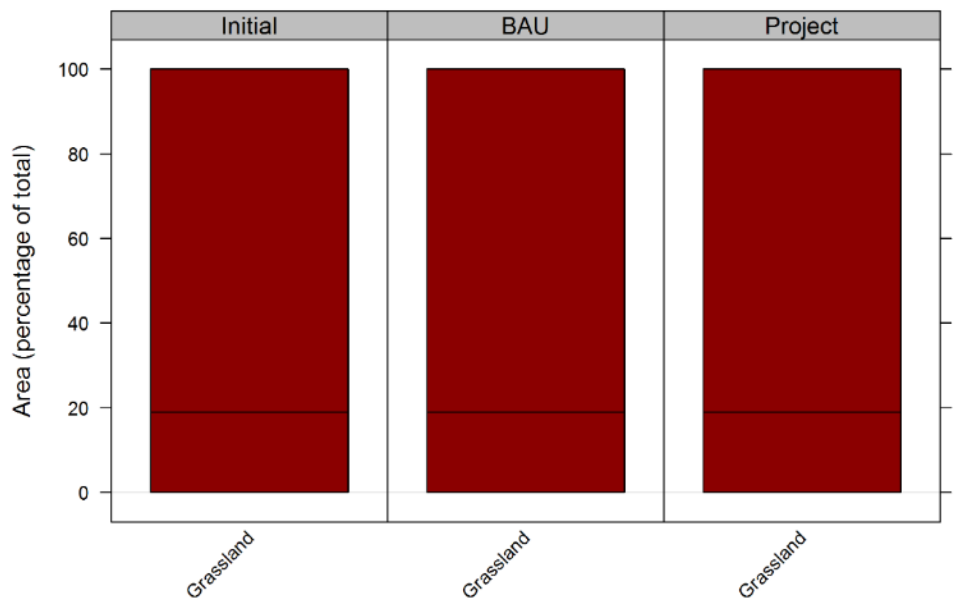
% of trees burned	%
% Nitrogen in Fertilizer	%
number of trees	
% trees lost to other causes	%
% trees lost to pests	%
% trees lost to wind	%

Wetlands

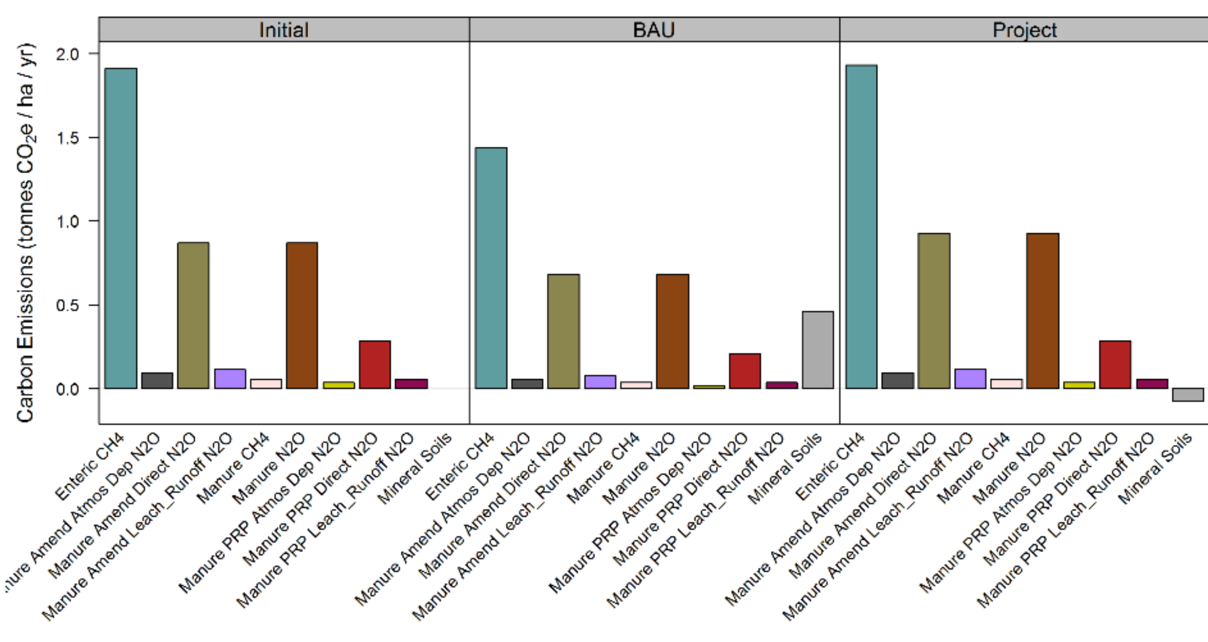
Area in Wetlands	ha

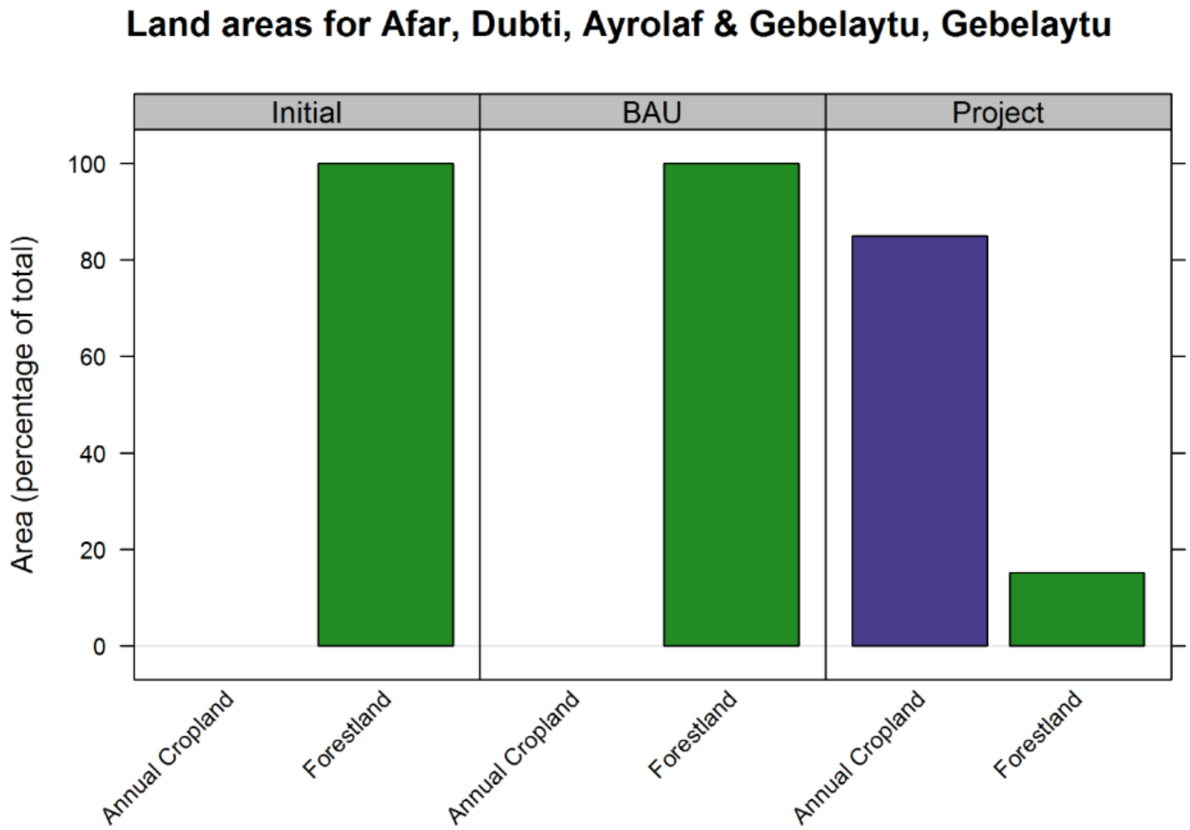
ANNEX 2. DETAILED SITE-BY-SITE CARBON BENEFITS MODEL RESULTS

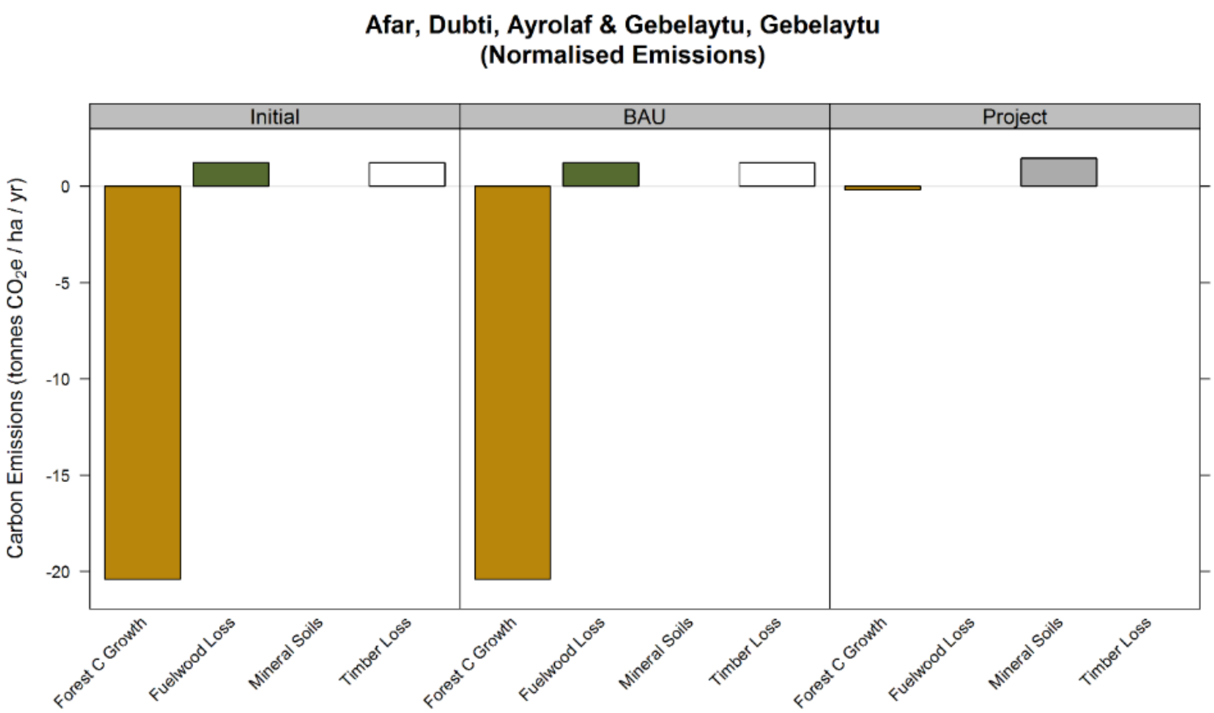
Land areas for Afar, Chifra, Jara

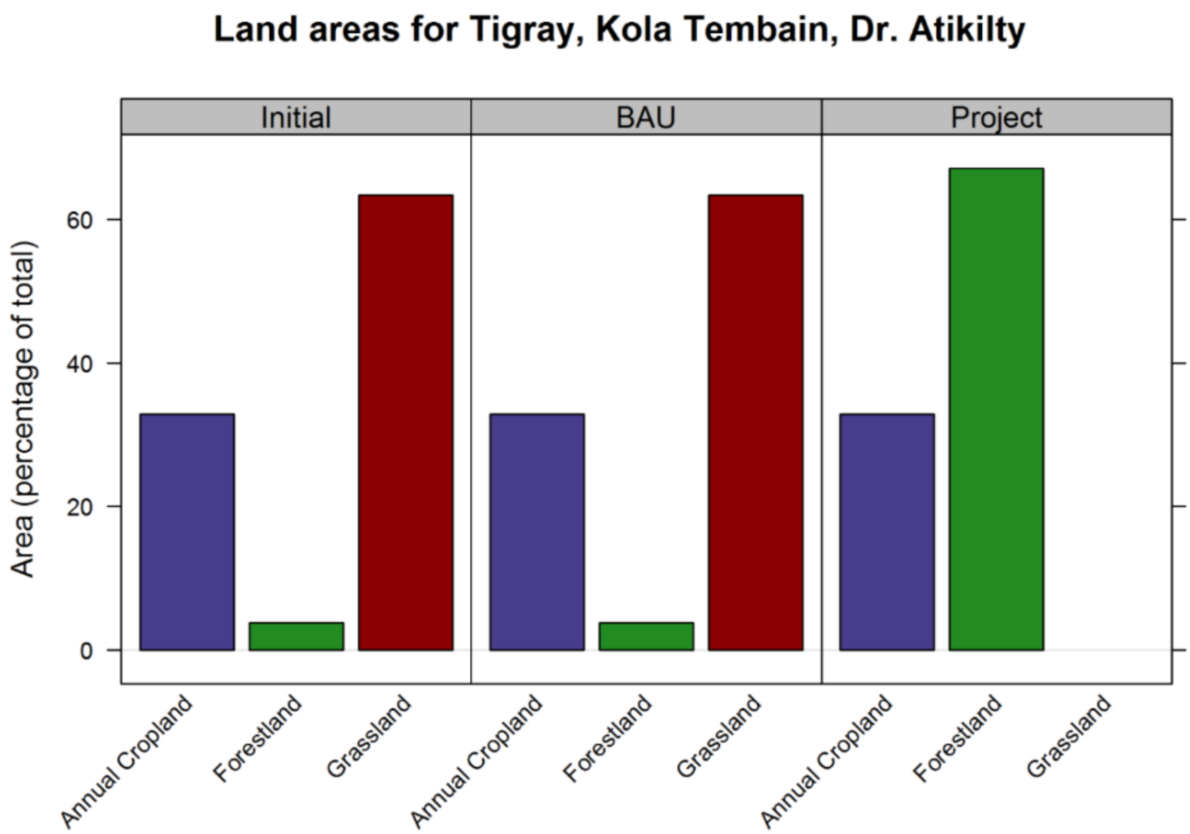


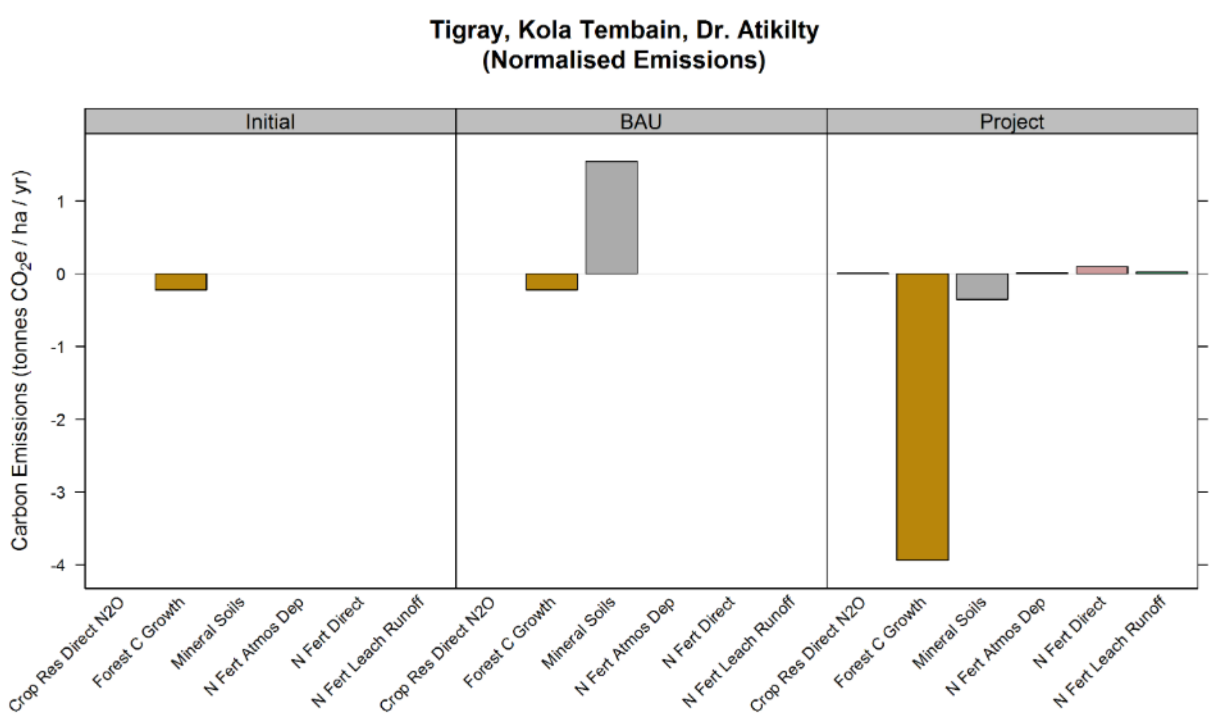
Afar, Chifra, Jara (Normalised Emissions)

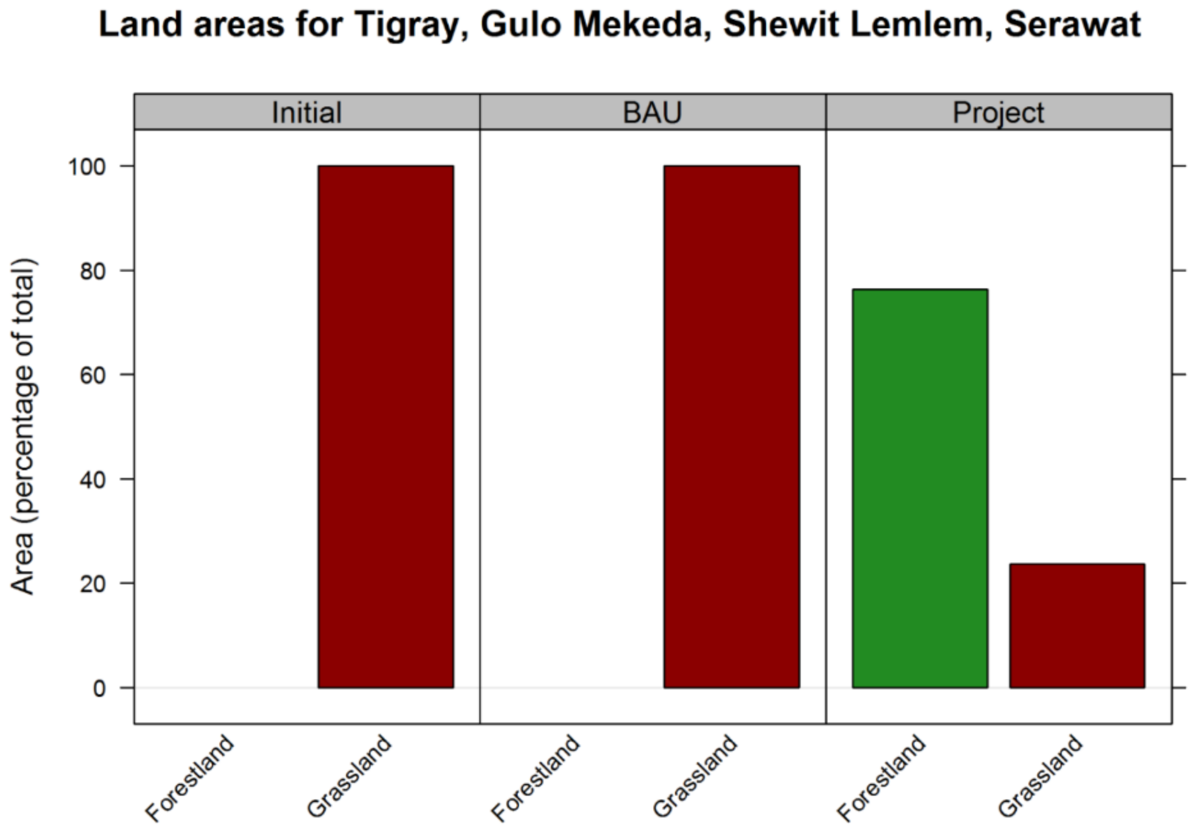


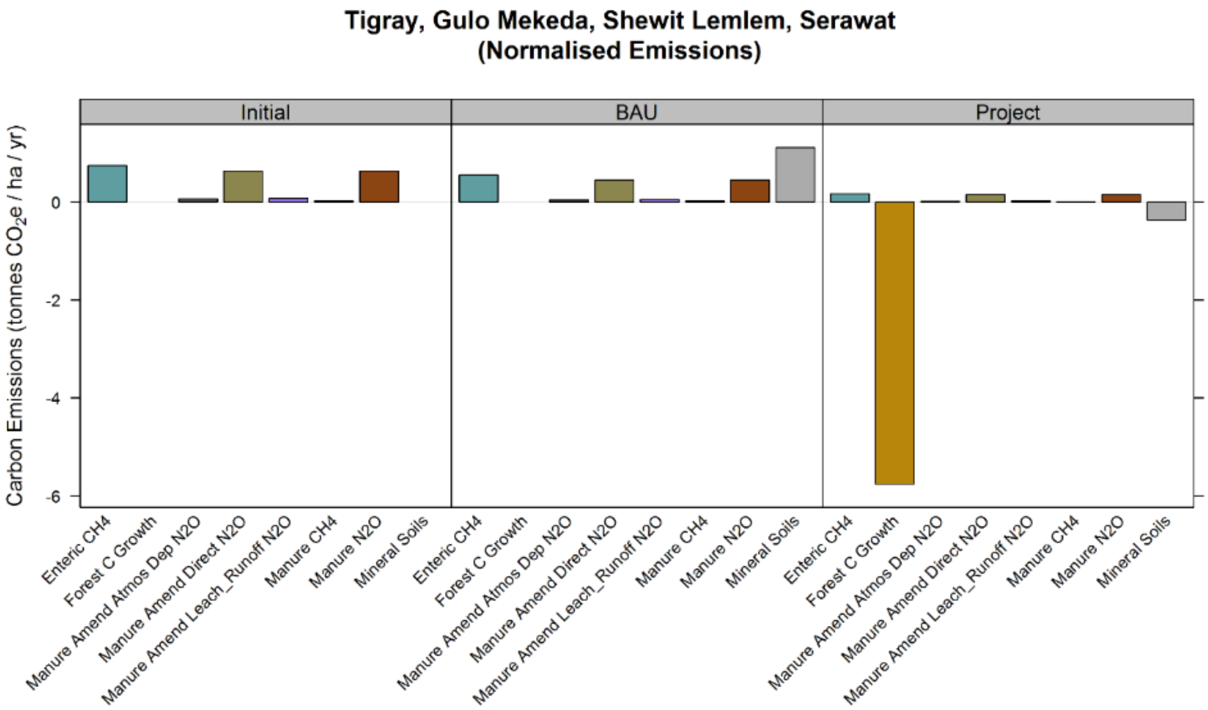

Land areas for Afar, Dubti, Ayrolaf & Gebelaytu, Gebelaytu
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
100
Annual Cropland
Forestland


Afar, Dubti, Ayrolaf & Gebelaytu, Gebelaytu
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
0
-5
-10
-15
-20
Forest C Growth
Fuelwood Loss
Mineral Soils
Timber Loss

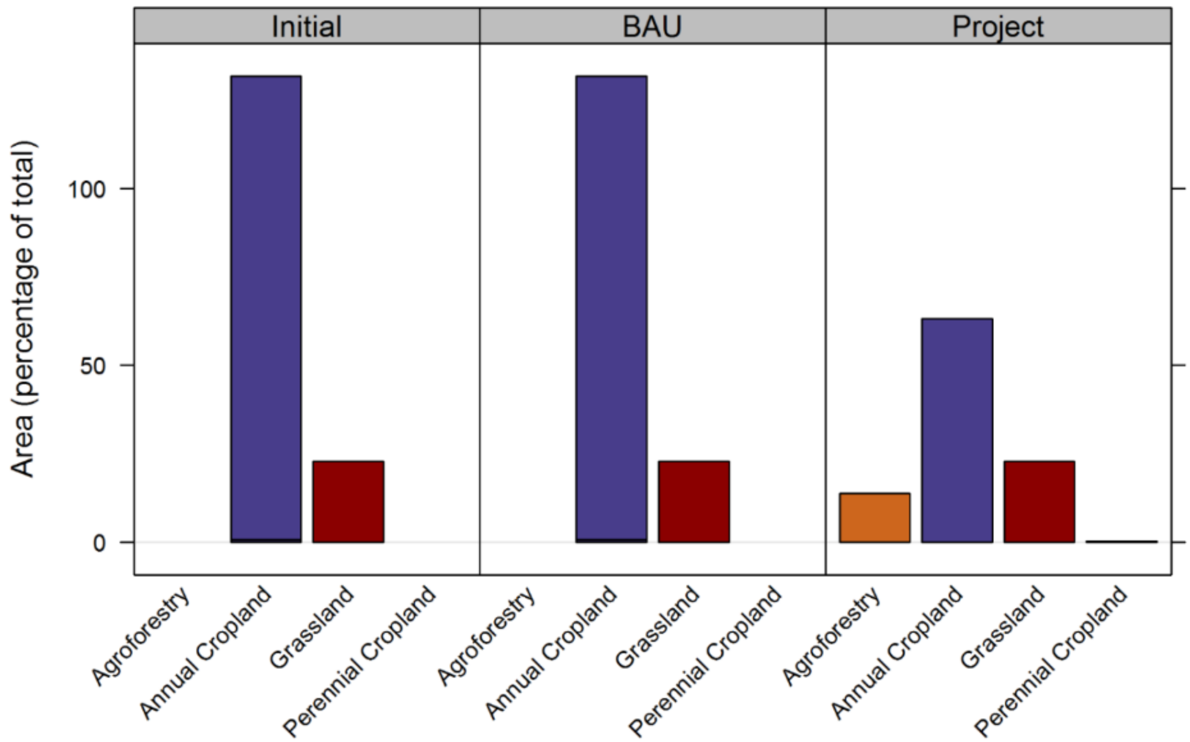

Land areas for Tigray, Kola Tembain, Dr. Atikilty
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
Annual Cropland
Forestland
Grassland


Tigray, Kola Tembain, Dr. Atikilty
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
1
0
-1
-2
-3
-4
Crop Res Direct N2O
Forest C Growth
Mineral Soils
N Fert Atmos Dep
N Fert Direct
N Fert Leach Runoff

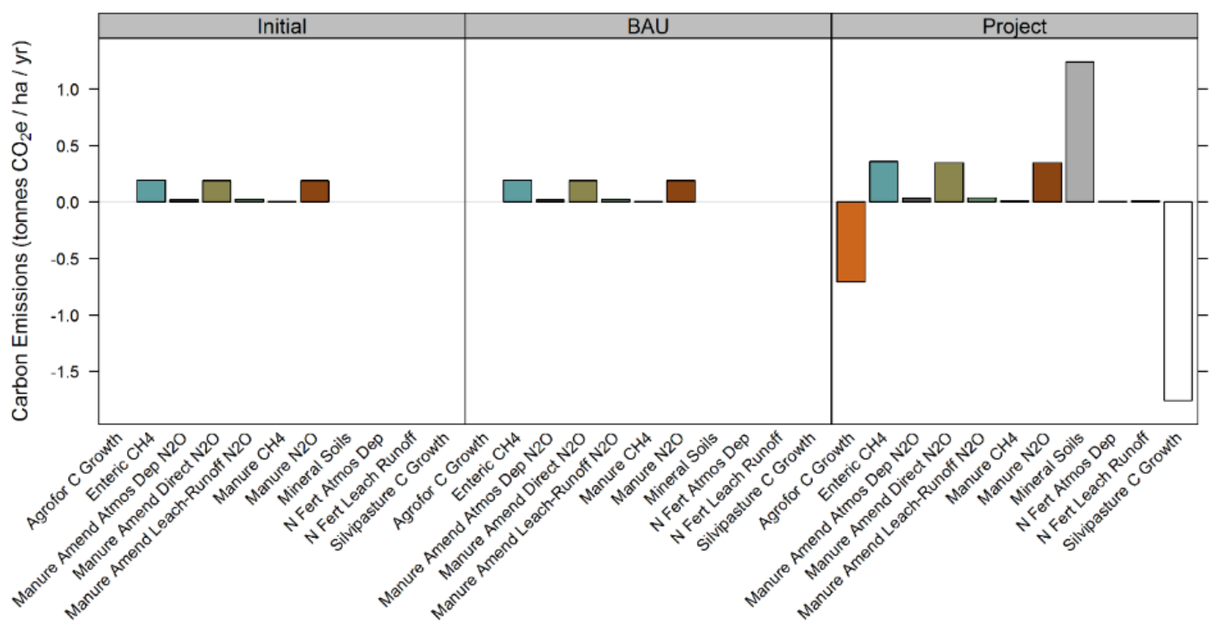

Land areas for Tigray, Gulo Mekeda, Shewit Lemlem, Serawat
Initial
BAU
Project
Area (percentage of total)
100
80
60
40
20
0
Forestland
Grassland
Forestland
Grassland
Forestland
Grassland


Tigray, Gulo Mekeda, Shewit Lemlem, Serawat
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
0
-2
-4
-6
Enteric CH4
Forest C Growth
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach_Runoff N2O
Manure CH4
Manure N2O
Mineral Soils

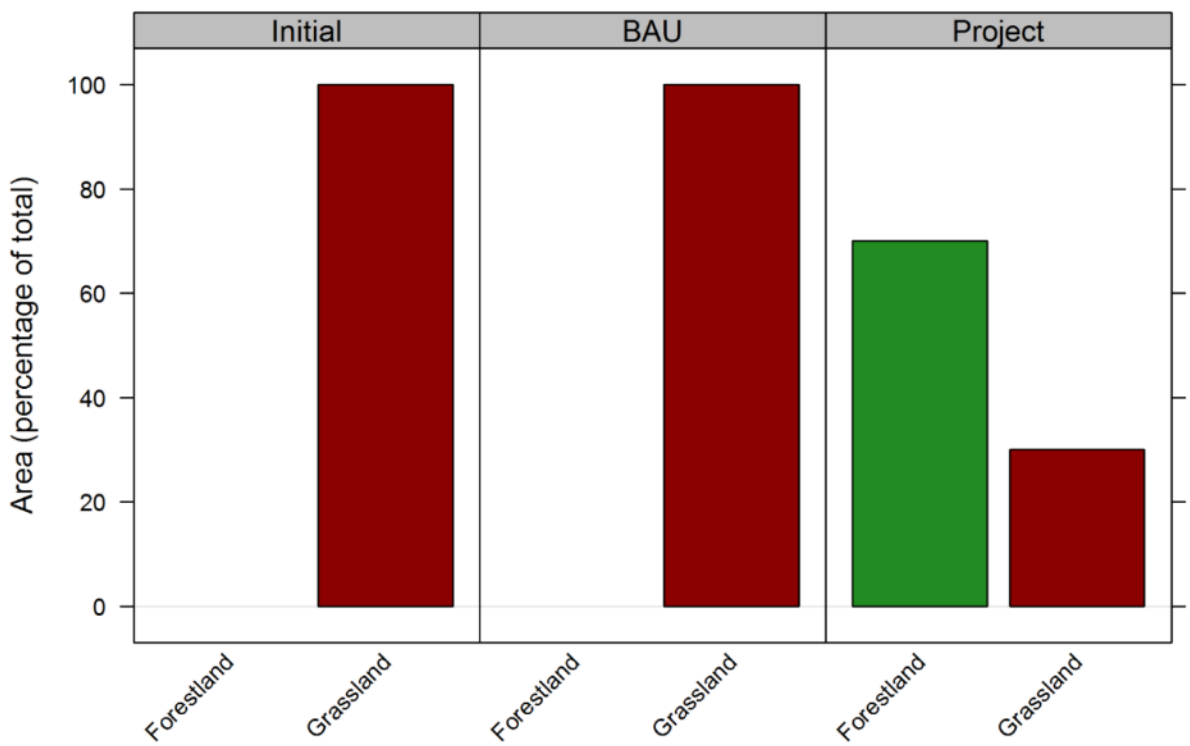
Land areas for Tigray, Ahferom, Sero, Chearo



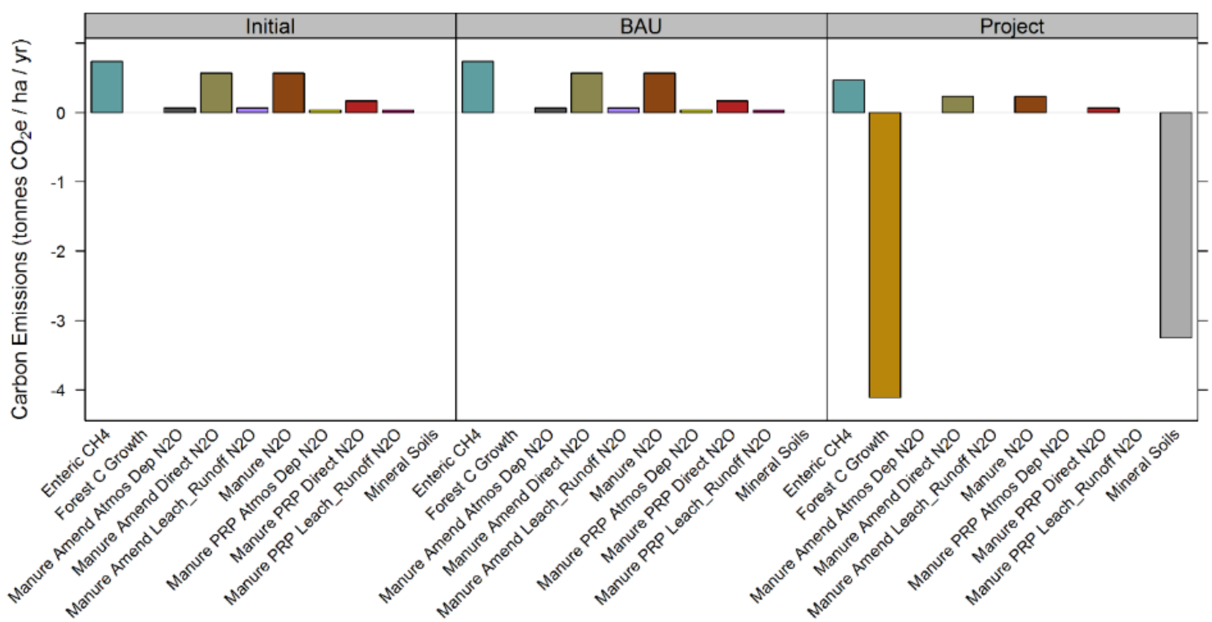
Tigray, Ahferom, Sero, Chearo (Normalised Emissions)

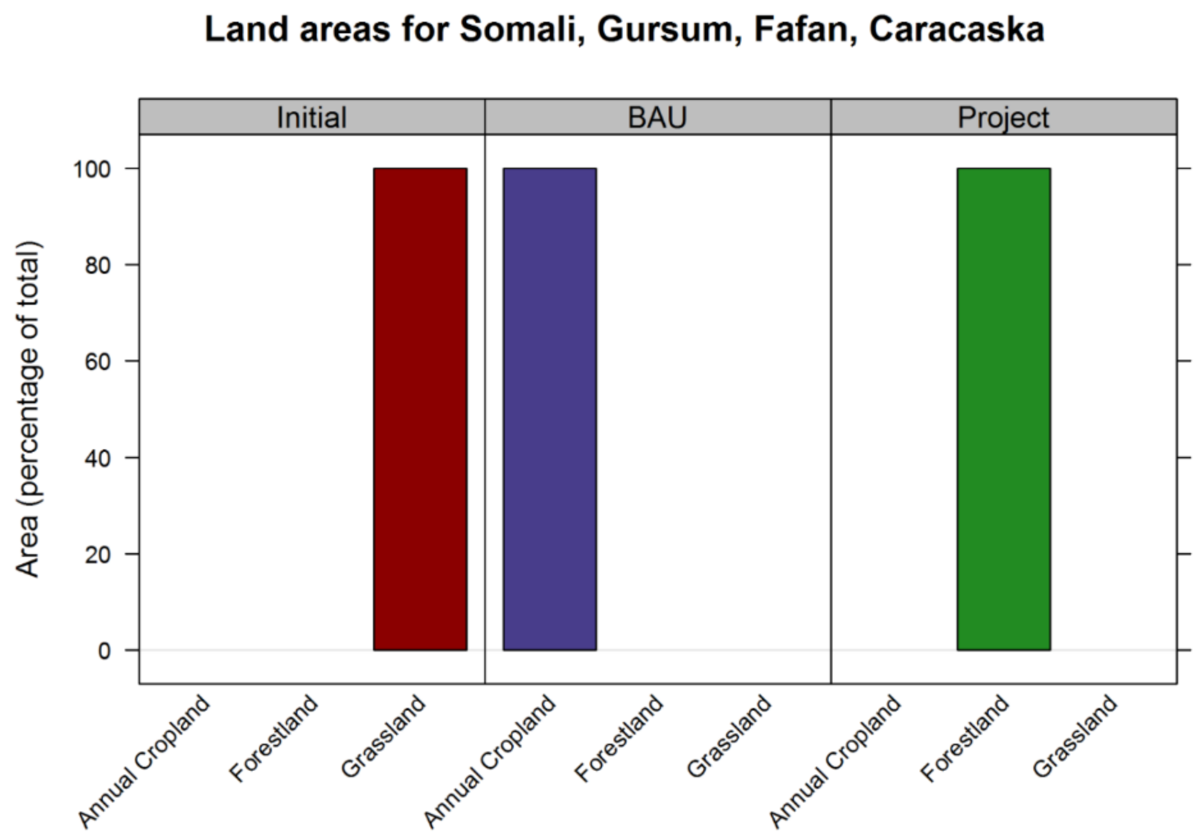


Land areas for Somali, Shinile, Baraq

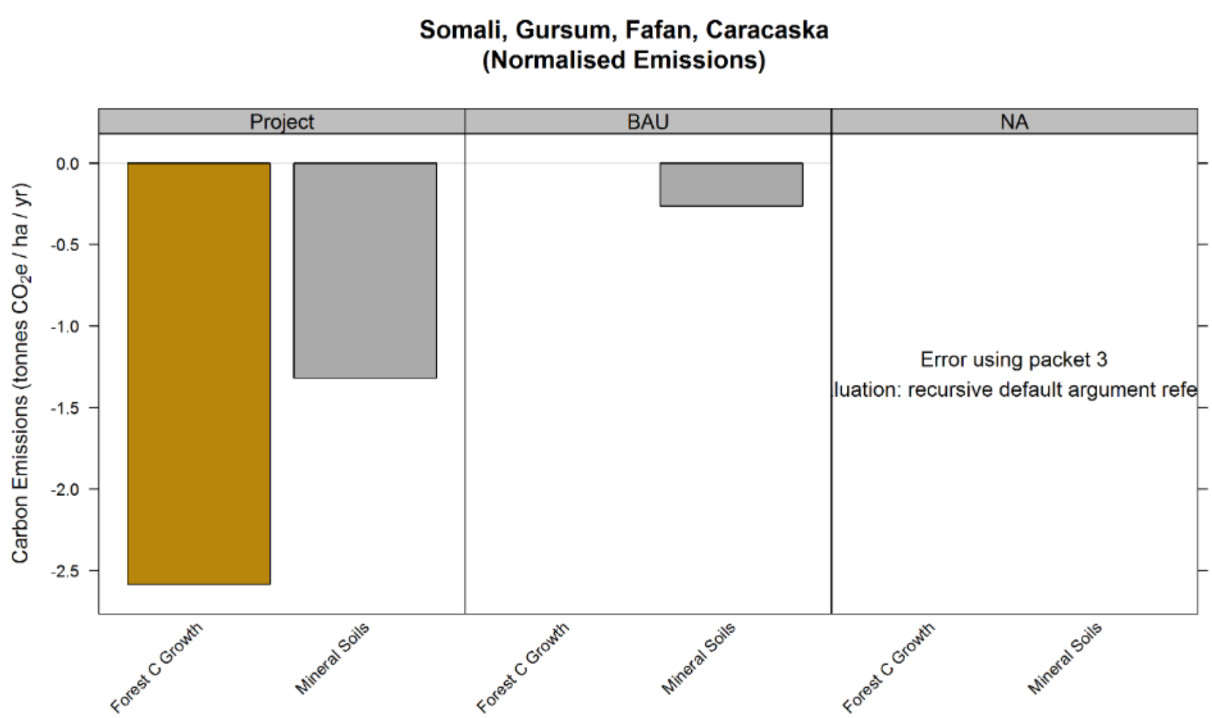


Somali, Shinile, Baraq
(Normalised Emissions)



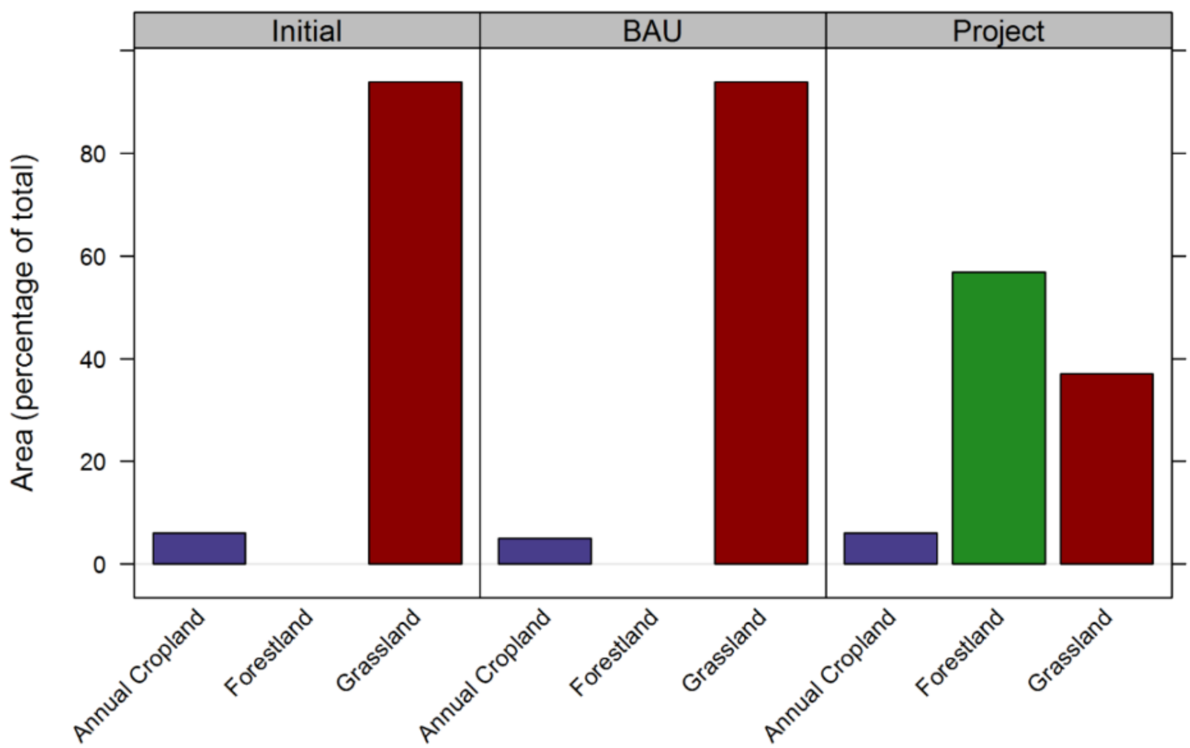


Land areas for Somali, Gursum, Fafan, Caracaska
Initial
BAU
Project
Area (percentage of total)
100
80
60
40
20
0
Annual Cropland
Forestland
Grassland

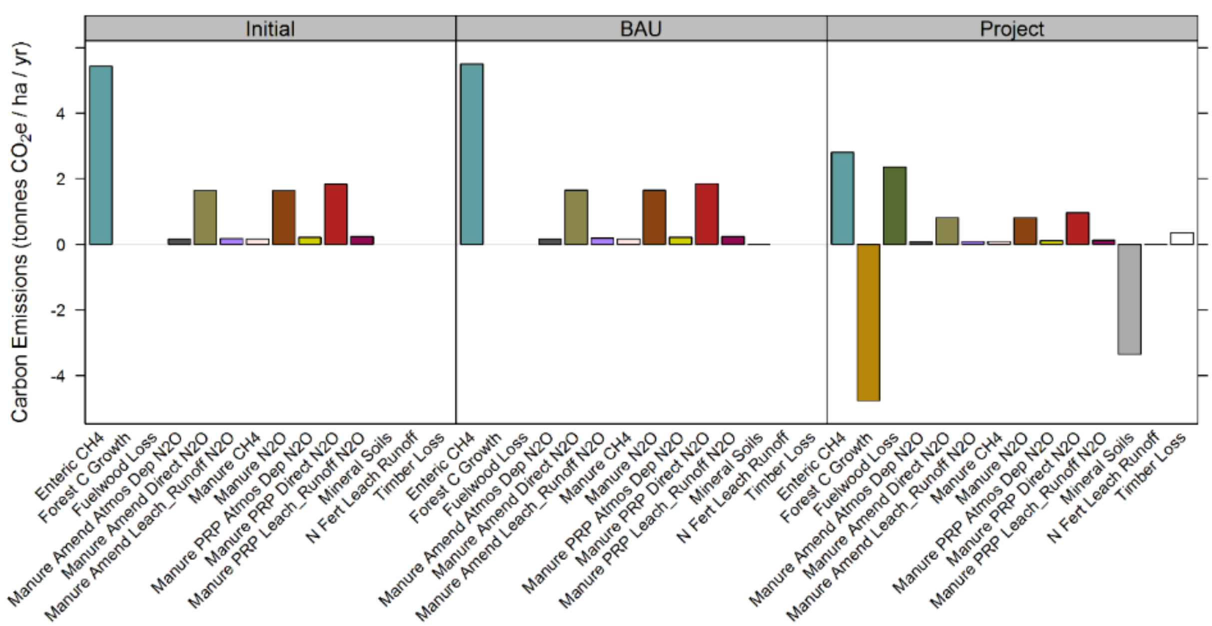


Somali, Gursum, Fafan, Caracaska
(Normalised Emissions)
Project
BAU
NA
Carbon Emissions (tonnes CO2e / ha / yr)
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Error using packet 3
luation: recursive default argument refe
Forest C Growth
Mineral Soils

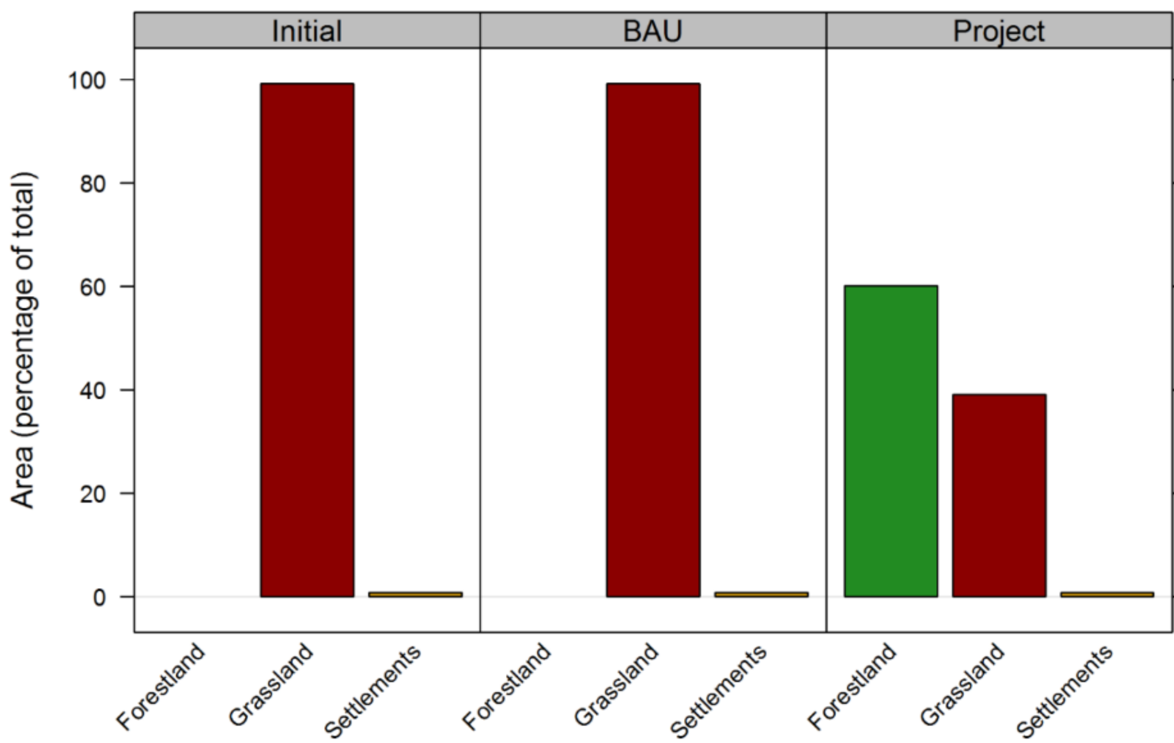
Land areas for SNNPR, Soro, Shera, Sheshecho



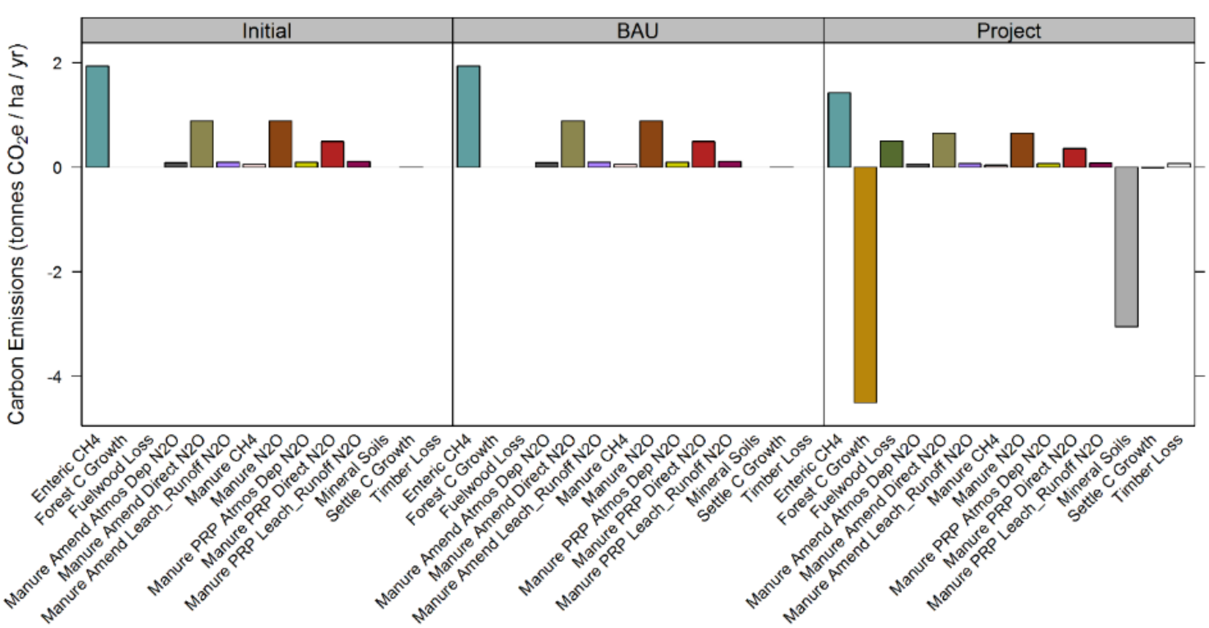
SNNPR, Soro, Shera, Sheshecho
(Normalised Emissions)

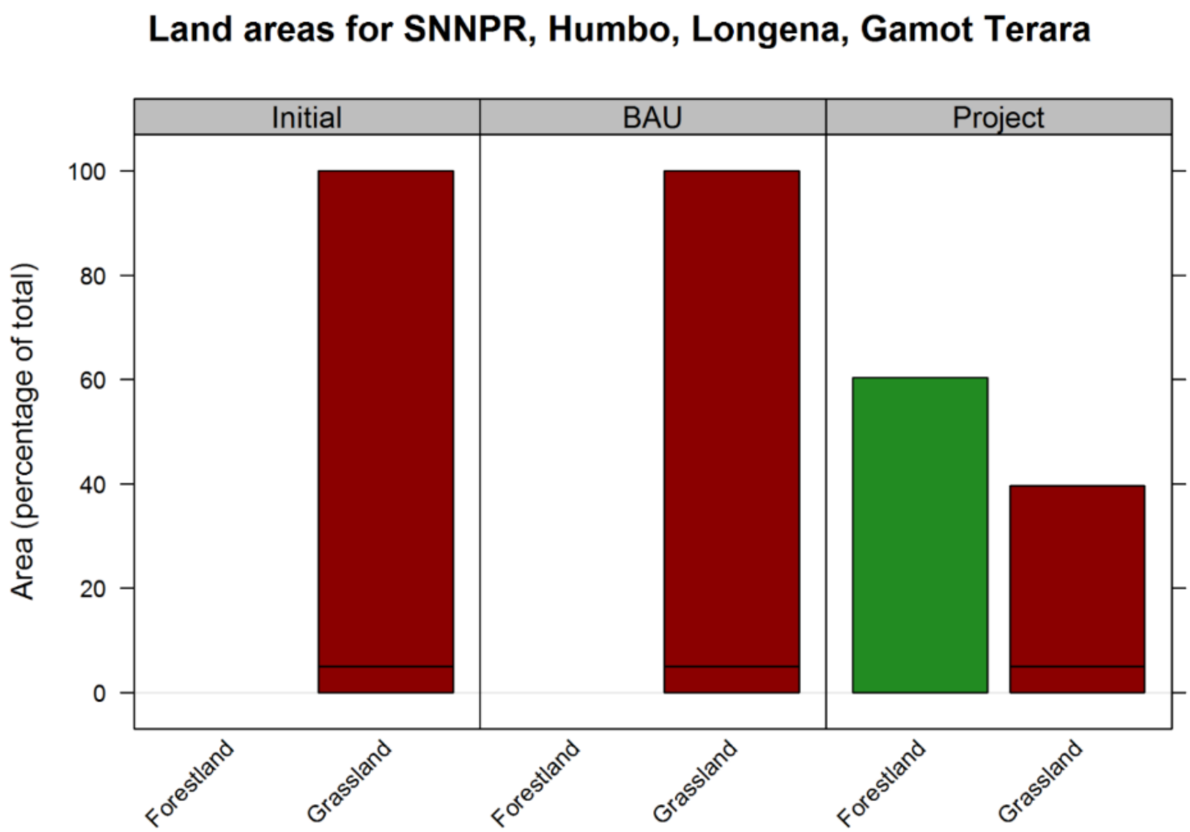


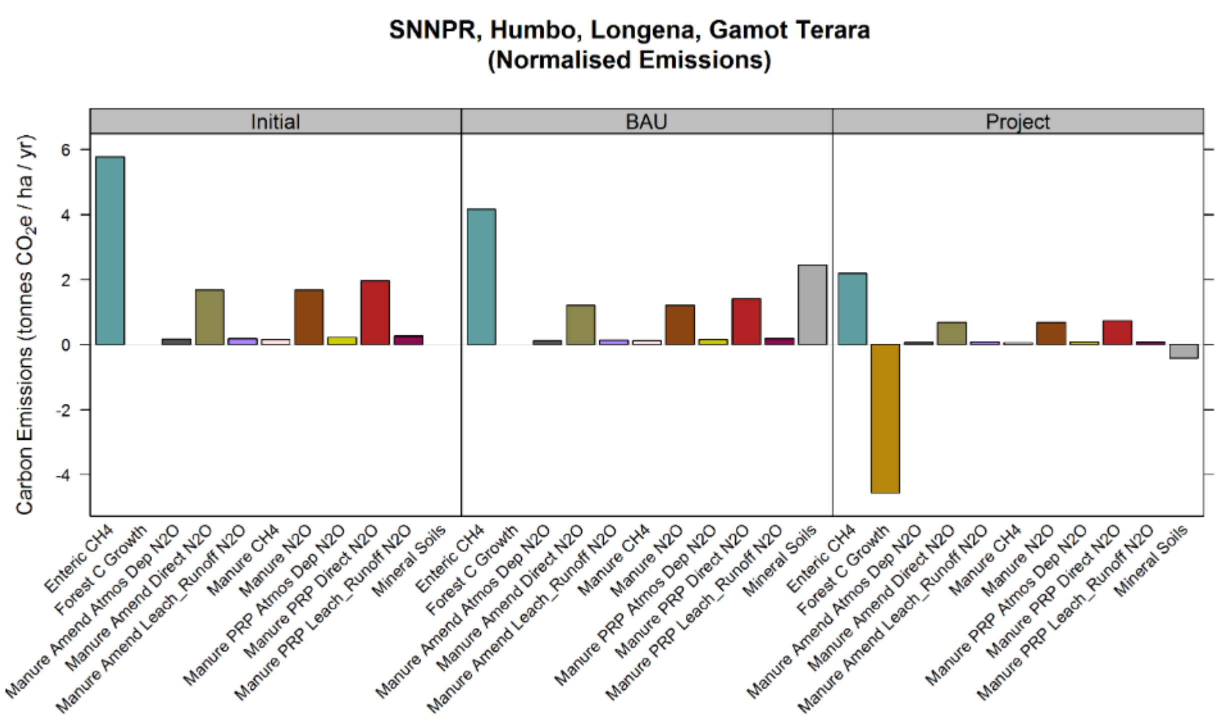
Land areas for SNNPR, Konso, Lehaife, Boloshe



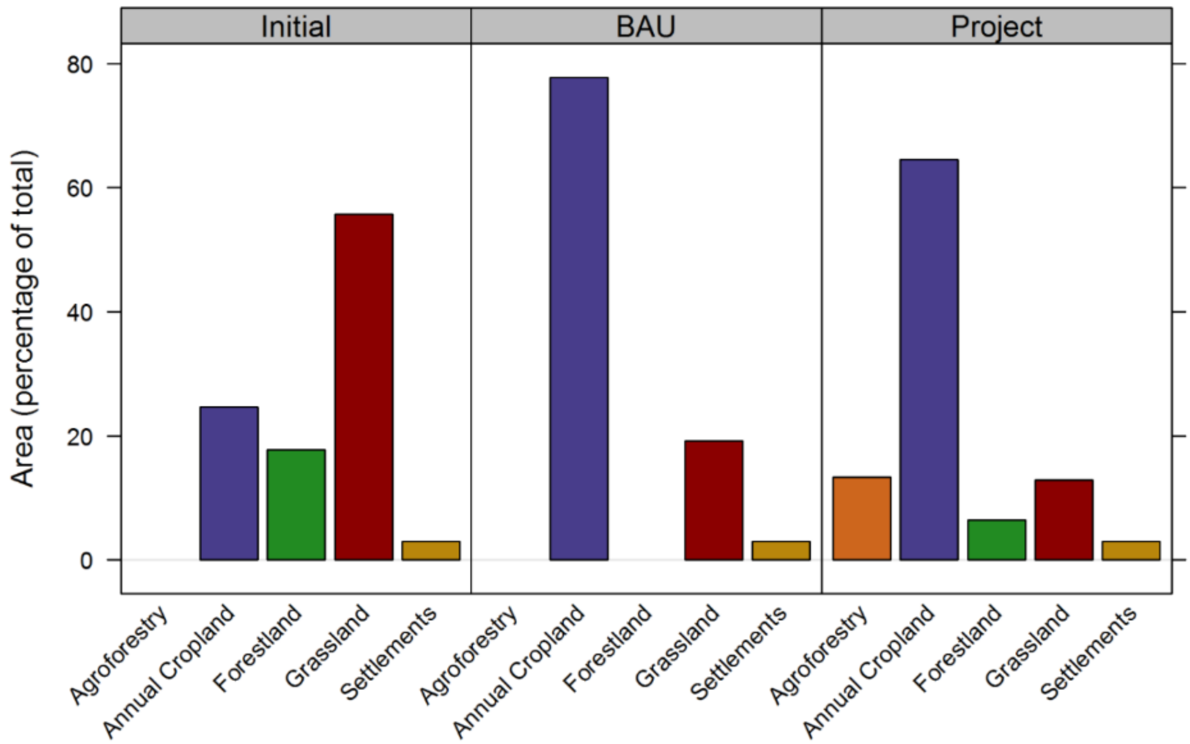
SNNPR, Konso, Lehaife, Boloshe (Normalised Emissions)



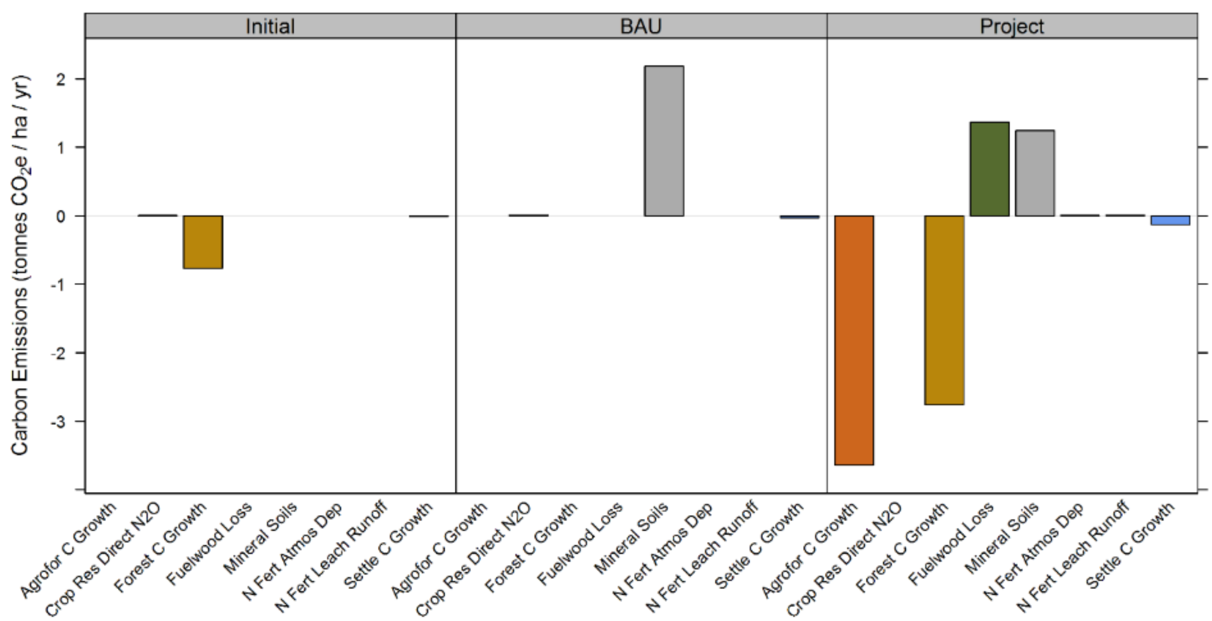

Land areas for SNNPR, Humbo, Longena, Gamot Terara
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
100
Forestland
Grassland
Forestland
Grassland
Forestland
Grassland

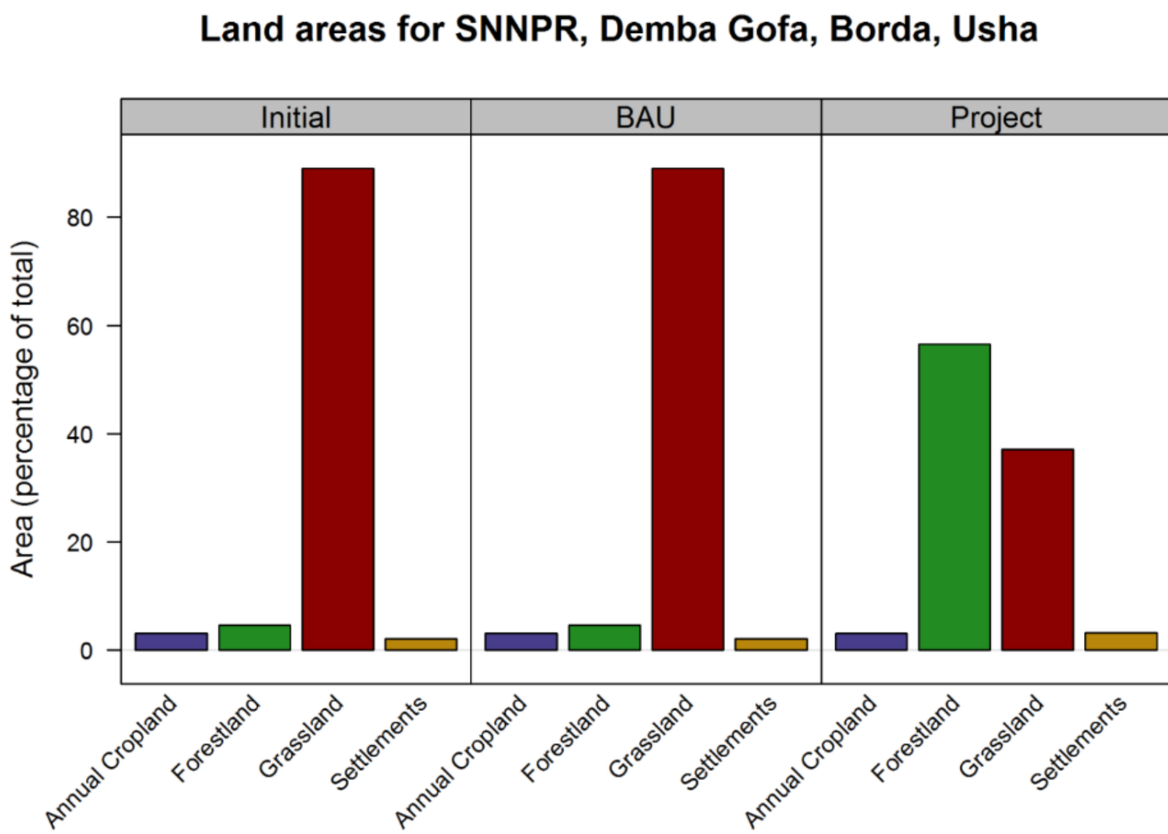

SNNPR, Humbo, Longena, Gamot Terara
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
6
4
2
0
-2
-4
Enteric CH4
Forest C Growth
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach_Runoff N2O
Manure CH4
Manure N2O
Manure PRP Atmos Dep N2O
Manure PRP Direct N2O
Manure PRP Leach_Runoff N2O
Mineral Soils

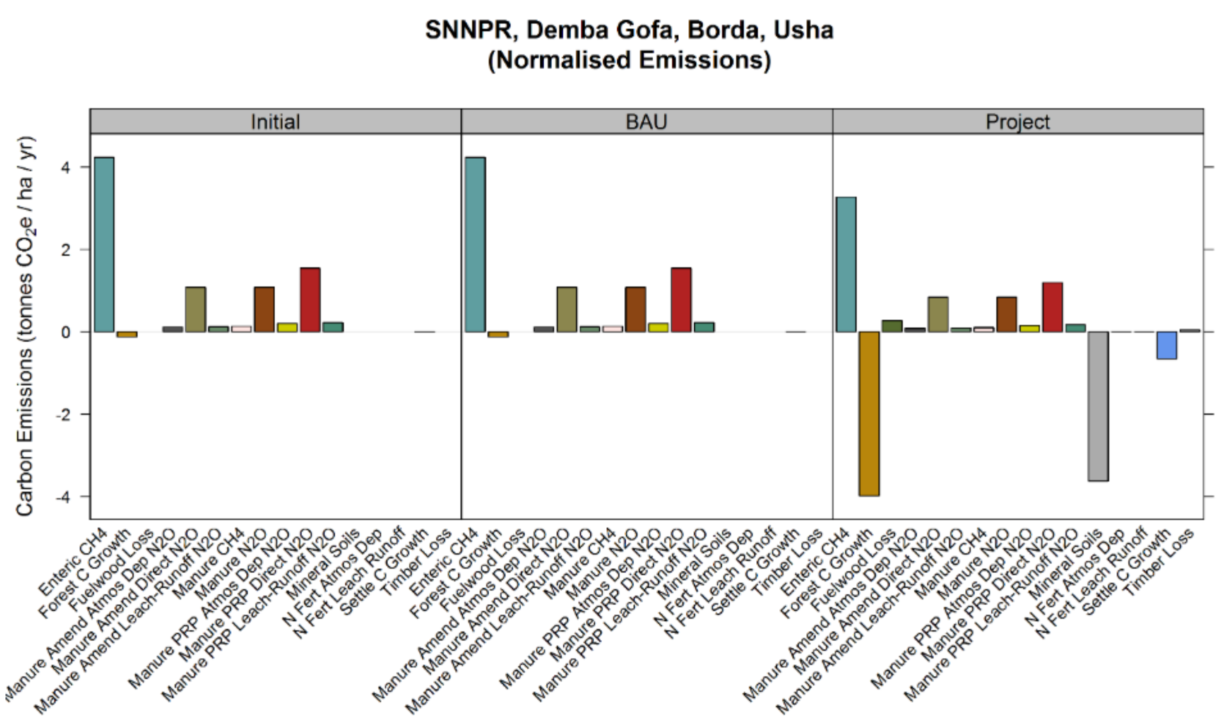
Land areas for SNNPR, Damot Gale, Wondara Balose, Godaye

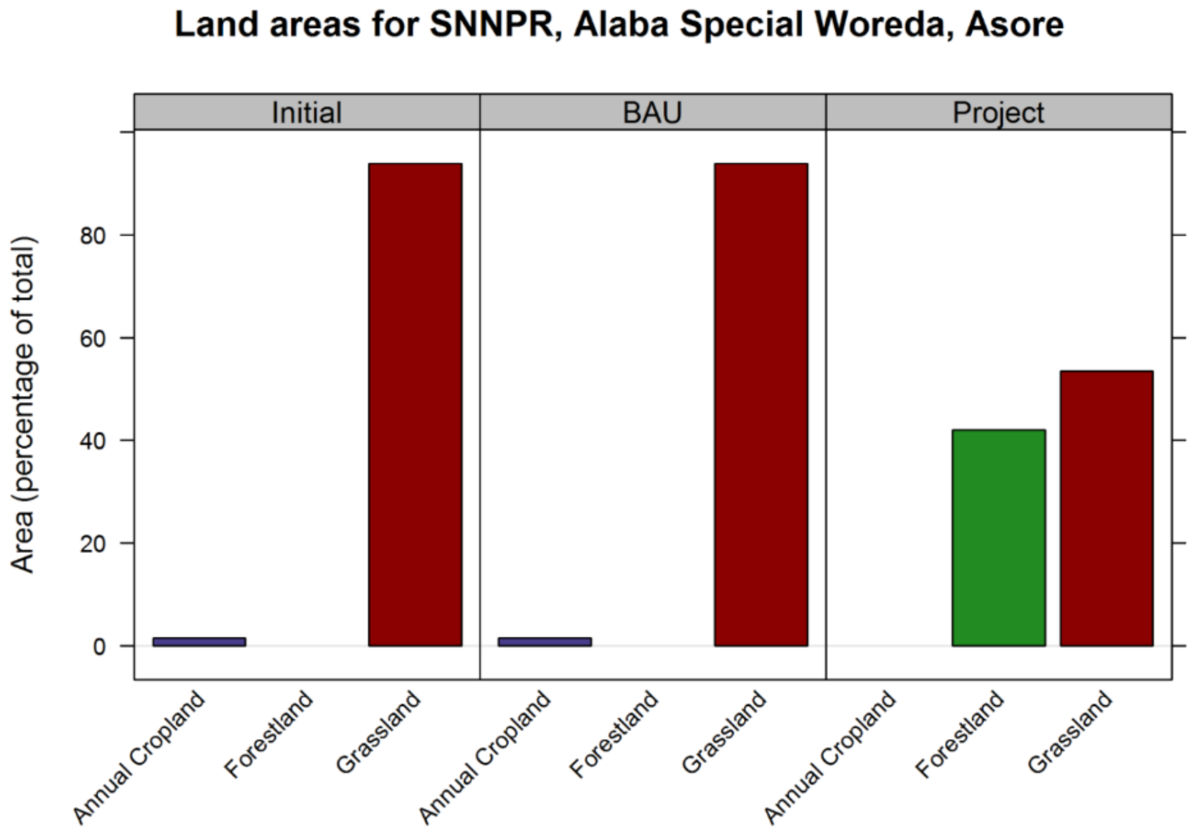


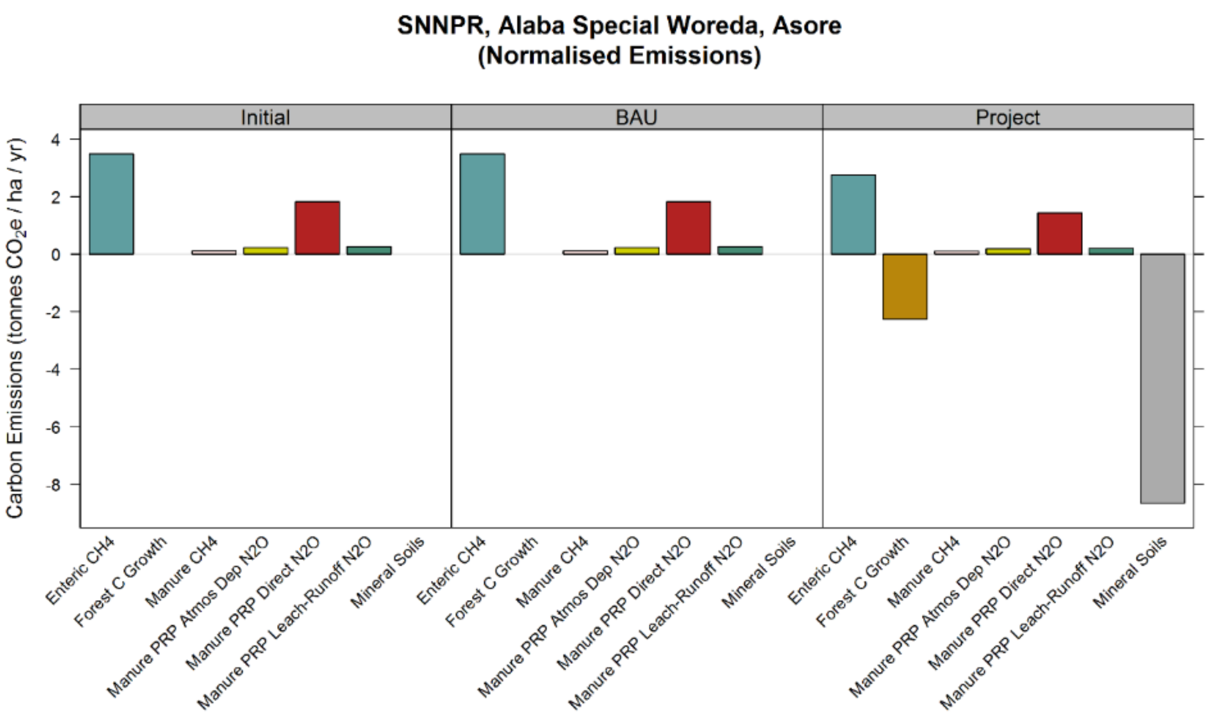
SNNPR, Damot Gale, Wondara Balose, Godaye
(Normalised Emissions)

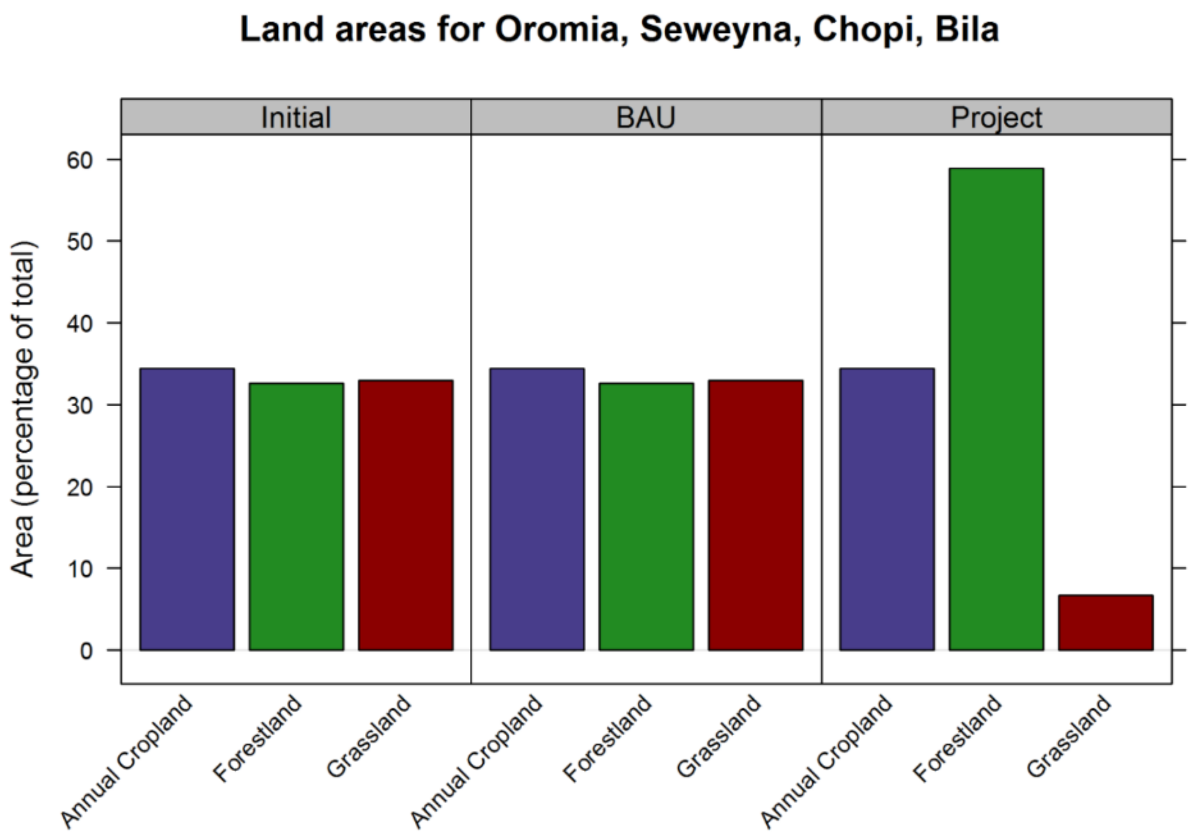


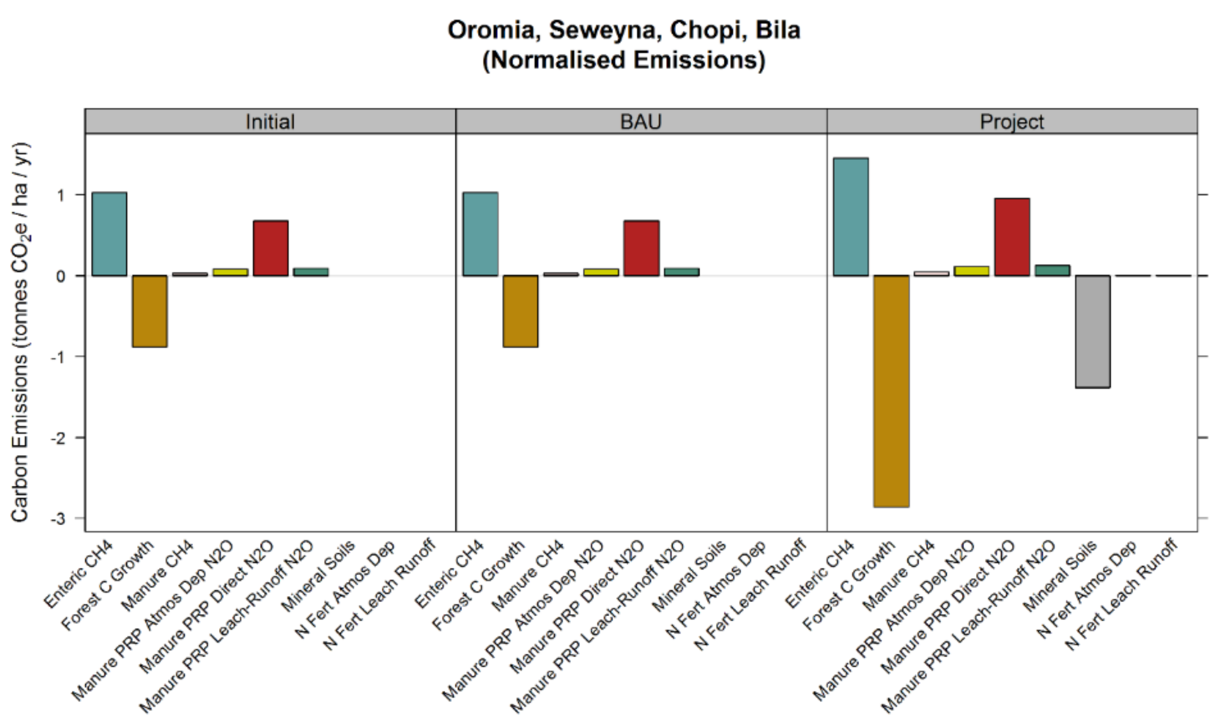

Land areas for SNNPR, Demba Gofa, Borda, Usha
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
Annual Cropland
Forestland
Grassland
Settlements

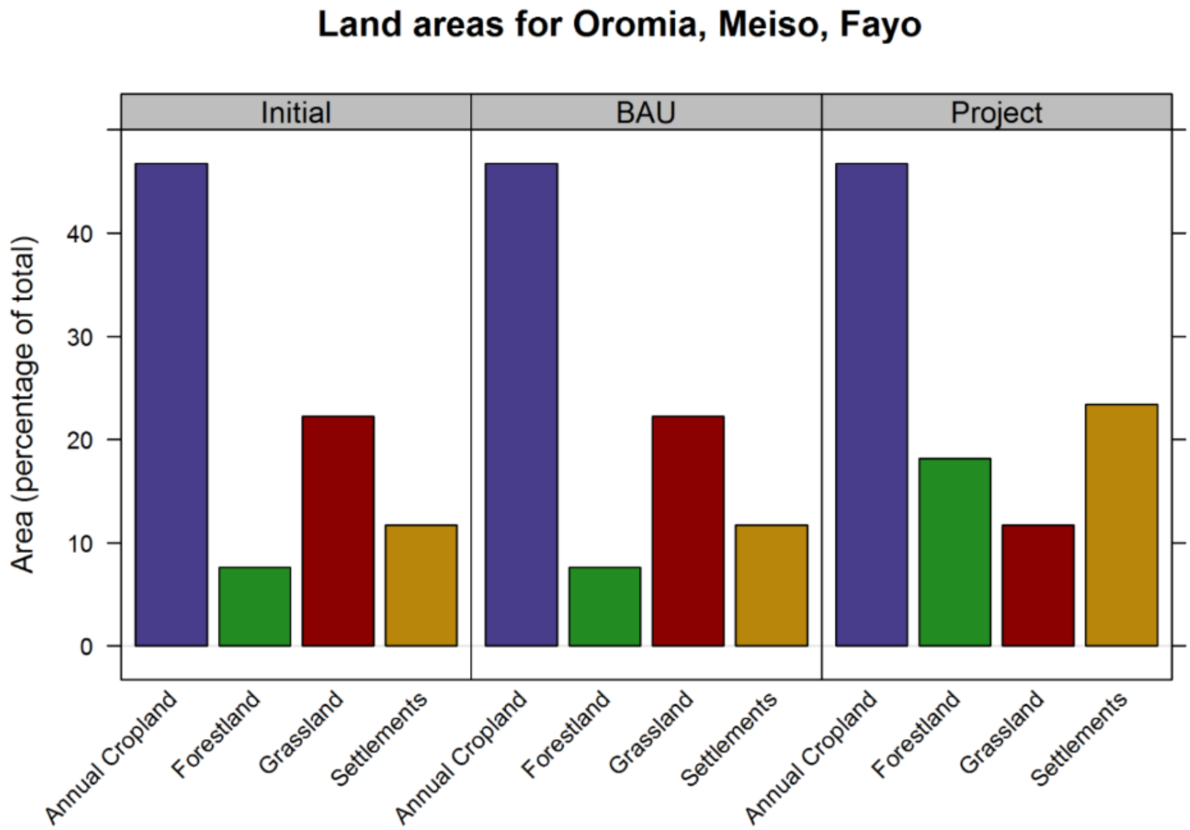

SNNPR, Demba Gofa, Borda, Usha
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
4
2
0
-2
-4
Enteric CH4
Forest C Growth
Fuelwood Loss
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach-Runoff N2O
Manure CH4
Manure N2O
Manure PRP Atmos Dep N2O
Manure PRP Direct N2O
Manure PRP Leach-Runoff N2O
Mineral Soils
N Fert Atmos Dep
N Fert Leach Runoff
Settle C Growth
Timber Loss

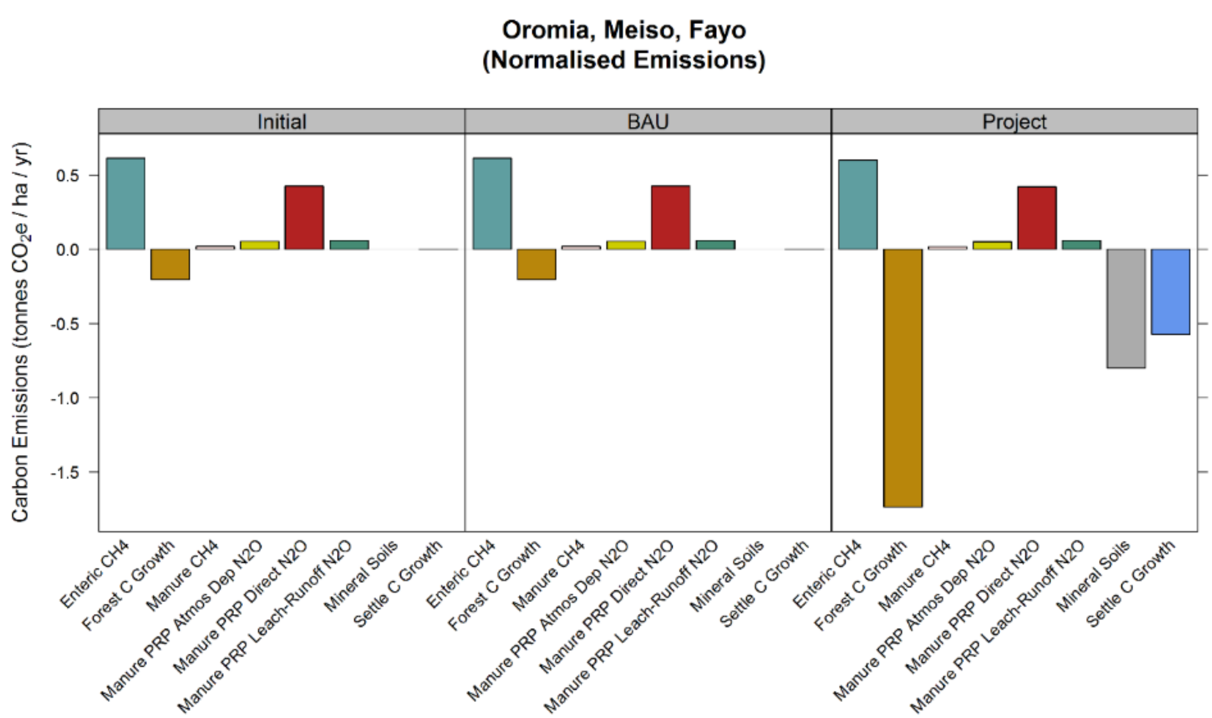

Land areas for SNNPR, Alaba Special Woreda, Asore
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
Annual Cropland
Forestland
Grassland

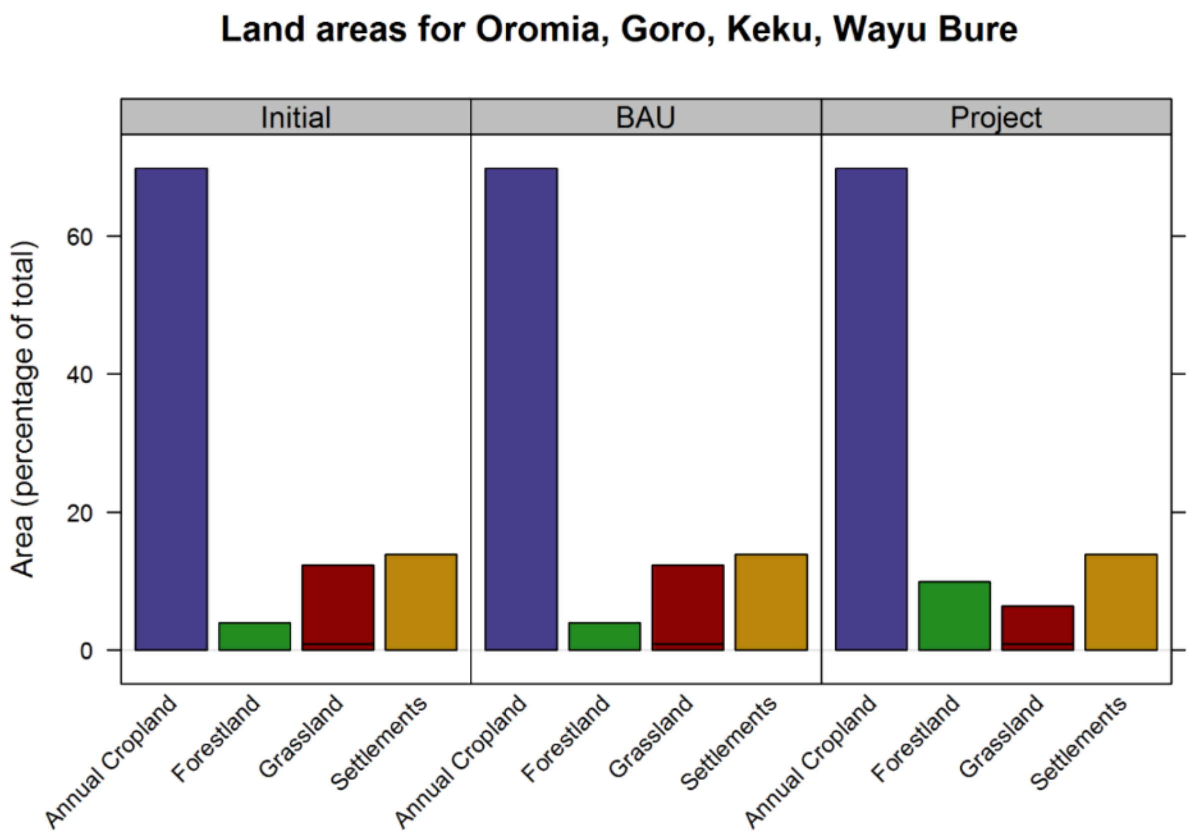

SNNPR, Alaba Special Woreda, Asore
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
4
2
0
-2
-4
-6
-8
Enteric CH4
Forest C Growth
Manure CH4
Manure PRP Atmos Dep N2O
Manure PRP Direct N2O
Manure PRP Leach-Runoff N2O
Mineral Soils

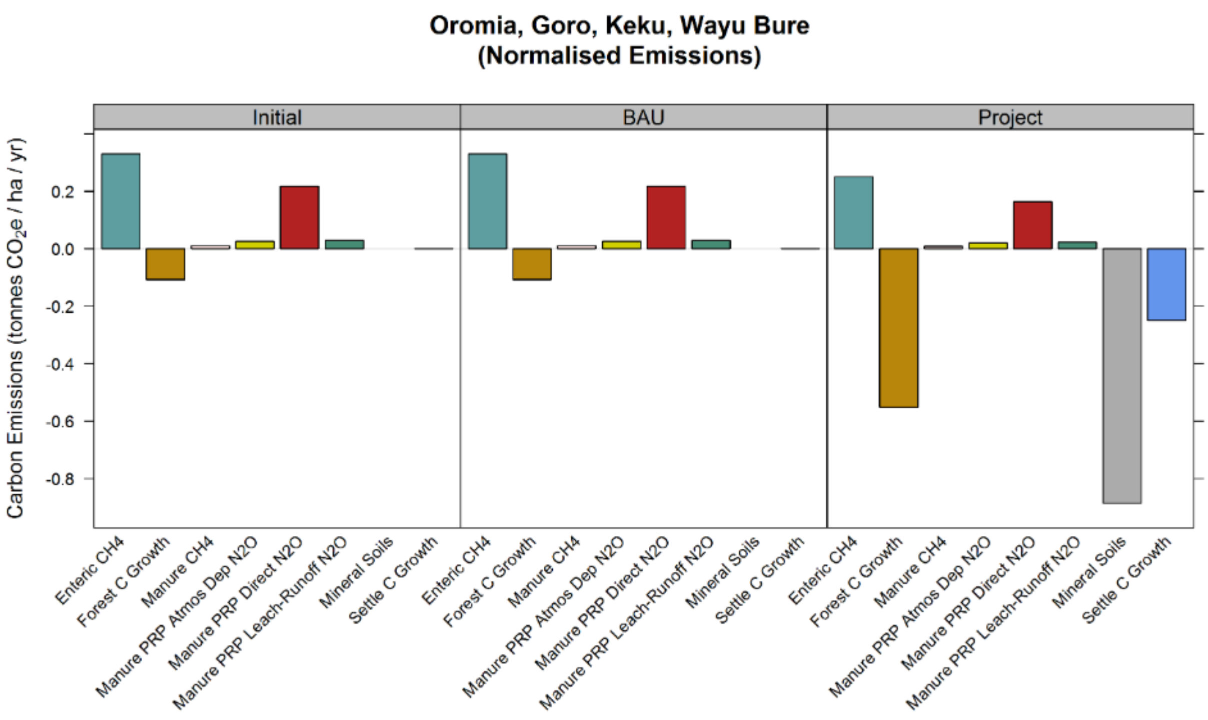

Land areas for Oromia, Seweyna, Chopi, Bila
Initial
BAU
Project
Area (percentage of total)
0
10
20
30
40
50
60
Annual Cropland
Forestland
Grassland

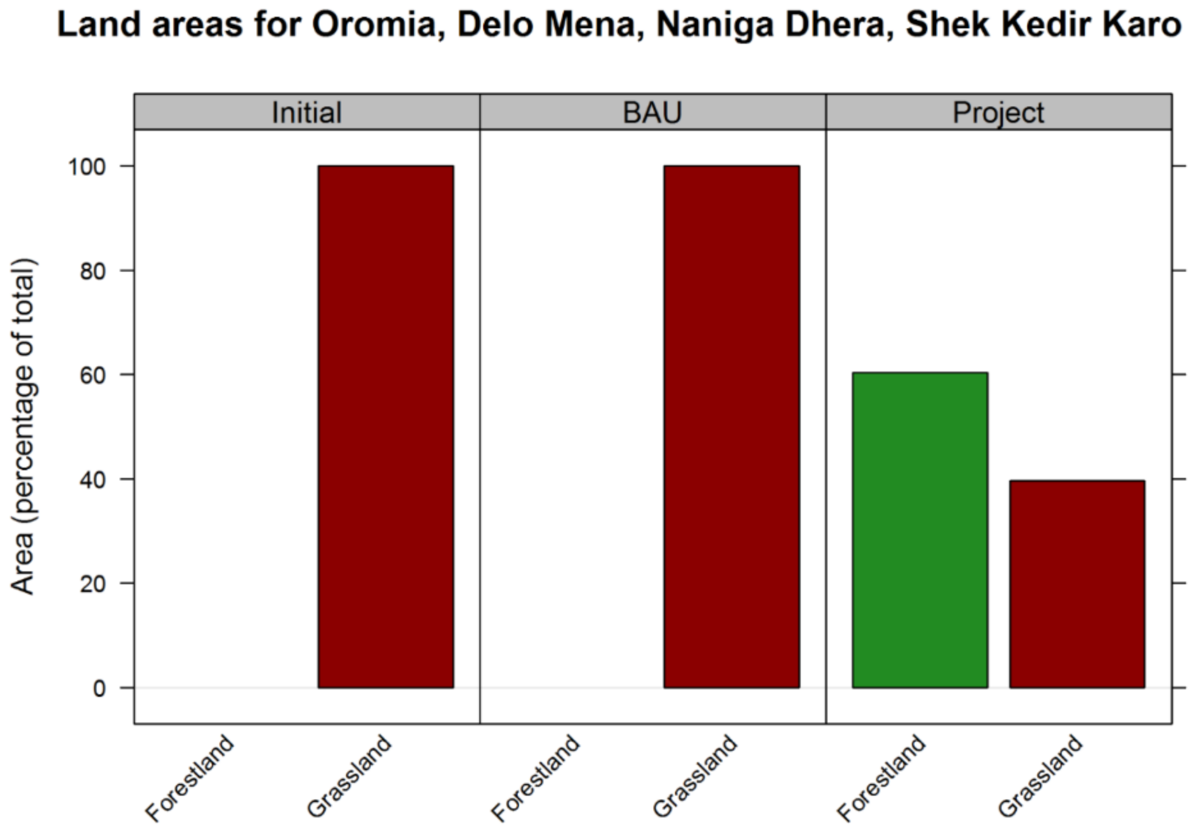

Oromia, Seweyna, Chopi, Bila
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
1
0
-1
-2
-3
Enteric CH4
Forest C Growth
Manure CH4
Manure PRP Atmos Dep N2O
Manure PRP Direct N2O
Manure PRP Leach-Runoff N2O
Mineral Soils
N Fert Atmos Dep
N Fert Leach Runoff

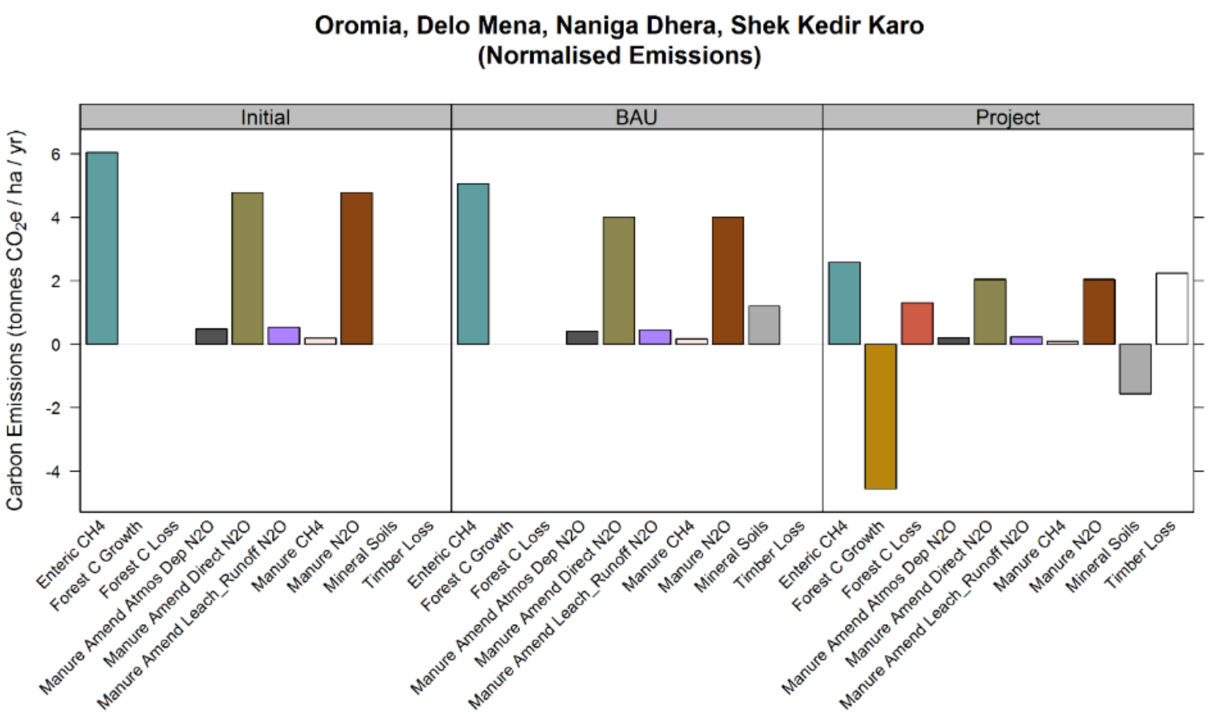

Land areas for Oromia, Meiso, Fayo
Initial
BAU
Project
Area (percentage of total)
0
10
20
30
40
Annual Cropland
Forestland
Grassland
Settlements

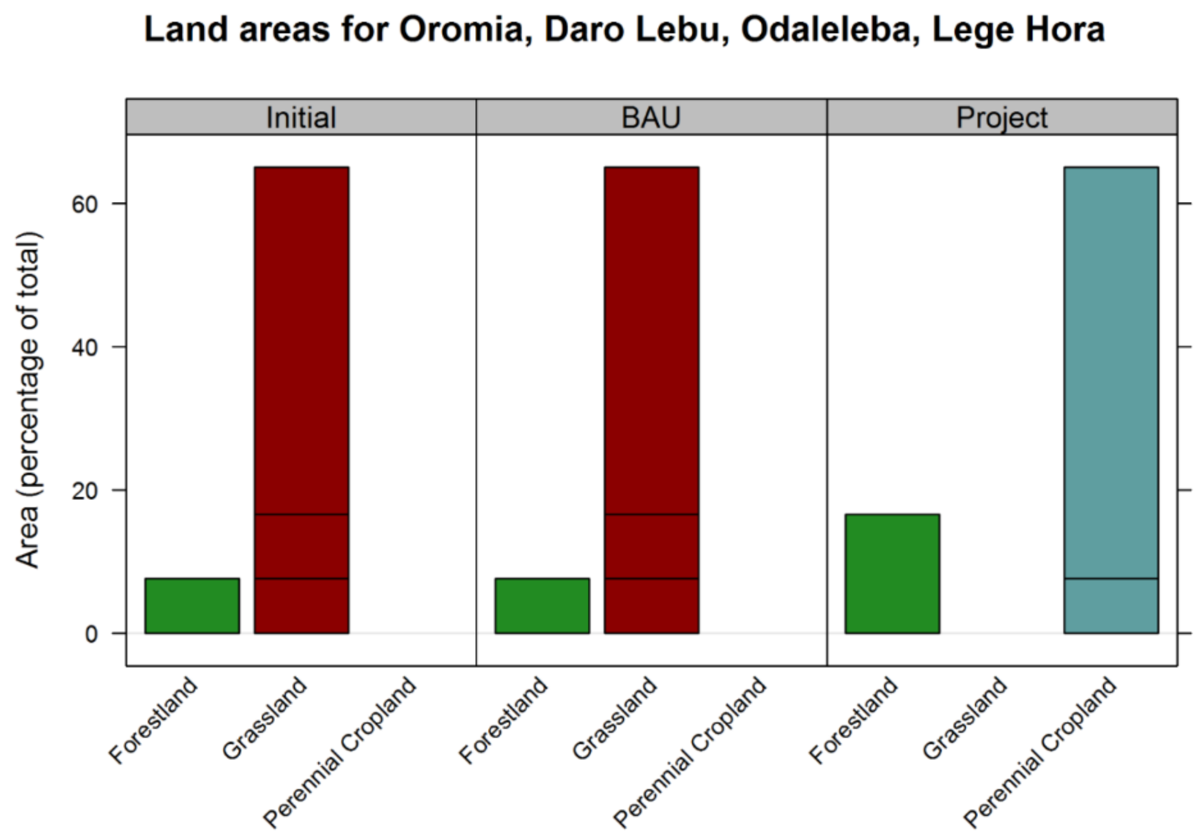

Oromia, Meiso, Fayo
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
0.5
0.0
-0.5
-1.0
-1.5
Enteric CH4
Forest C Growth
Manure CH4
Manure PRP Atmos Dep N2O
Manure PRP Direct N2O
Manure PRP Leach-Runoff N2O
Mineral Soils
Settle C Growth

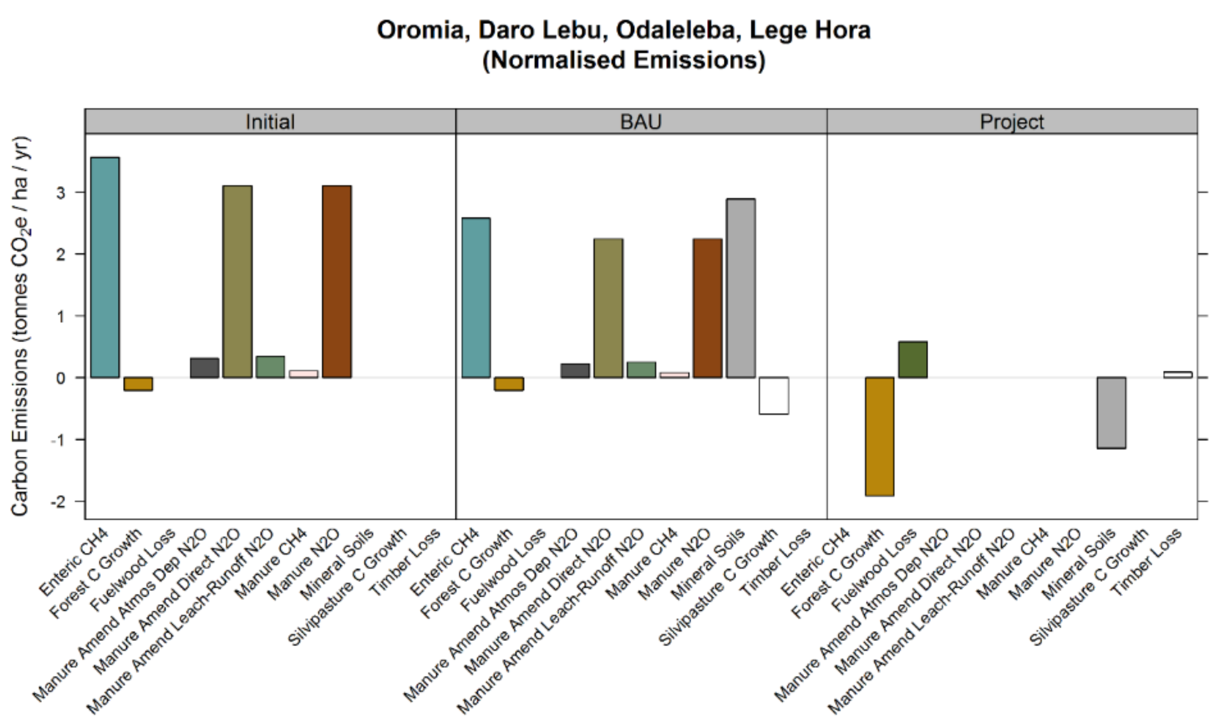

Land areas for Oromia, Goro, Keku, Wayu Bure
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
Annual Cropland
Forestland
Grassland
Settlements


Oromia, Goro, Keku, Wayu Bure
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Enteric CH4
Forest C Growth
Manure CH4
Manure PRP Atmos Dep N2O
Manure PRP Direct N2O
Manure PRP Leach-Runoff N2O
Mineral Soils
Settle C Growth

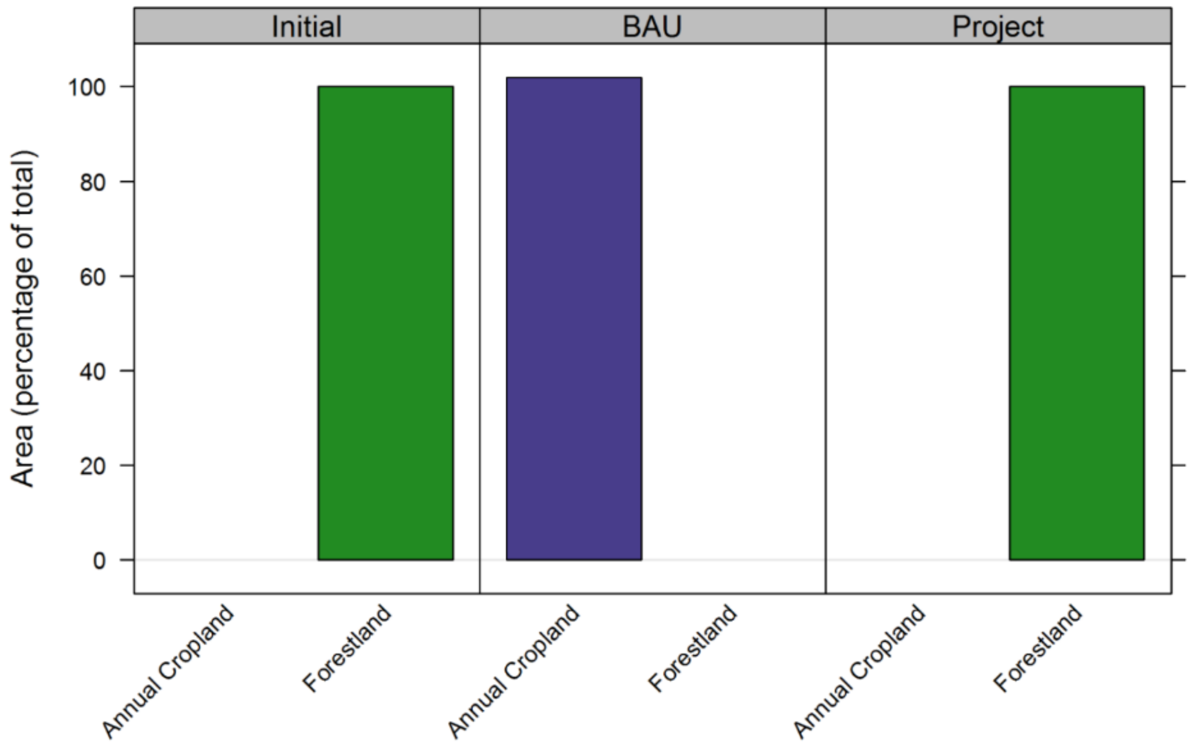

Land areas for Oromia, Delo Mena, Naniga Dhera, Shek Kedir Karo
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
100
Forestland
Grassland


Oromia, Delo Mena, Naniga Dhera, Shek Kedir Karo
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
-4
-2
0
2
4
6
Enteric CH4
Forest C Growth
Forest C Loss
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach_Runoff N2O
Manure CH4
Manure N2O
Mineral Soils
Timber Loss

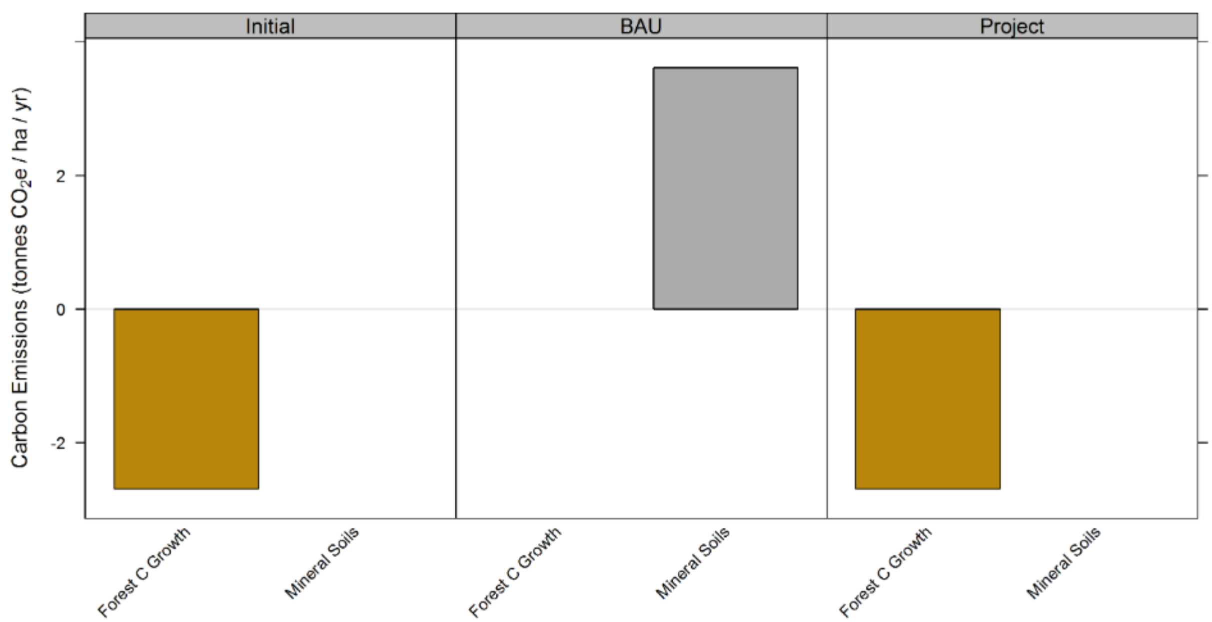

Land areas for Oromia, Daro Lebu, Odaleleba, Lege Hora
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
Forestland
Grassland
Perennial Cropland

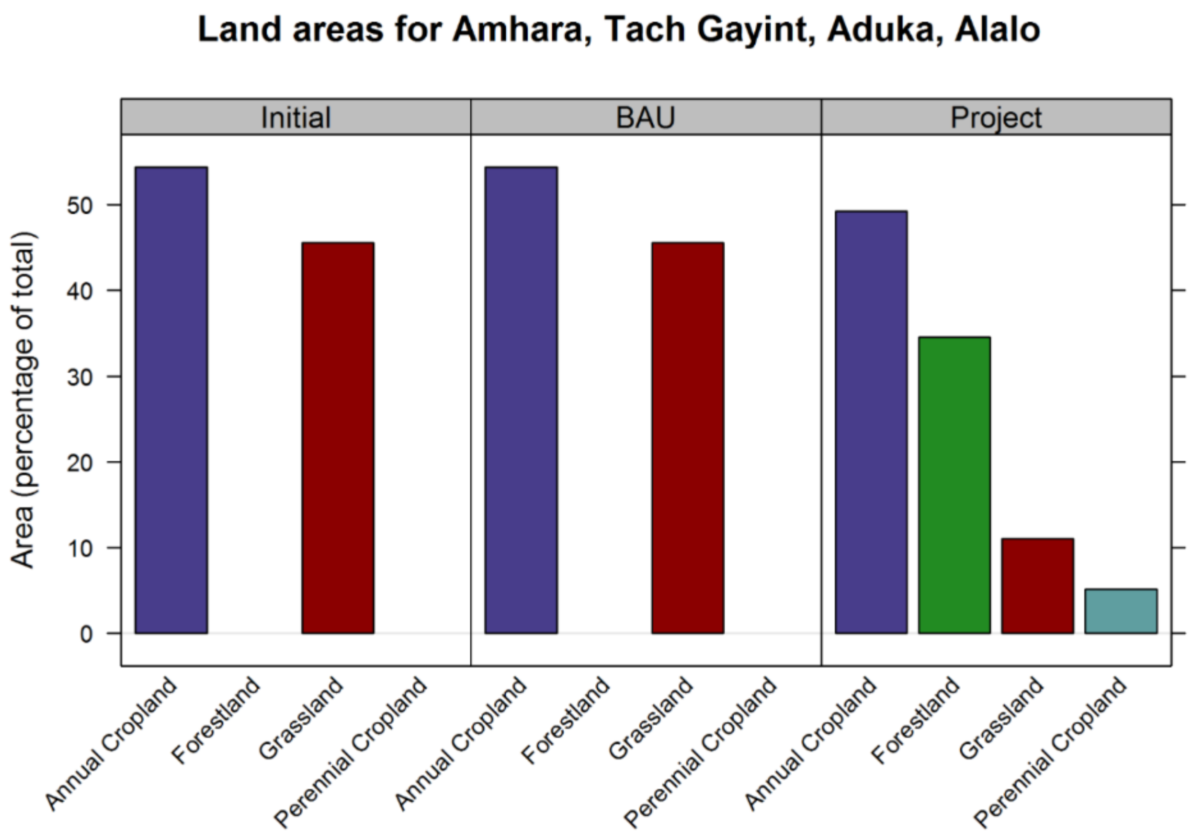

Oromia, Daro Lebu, Odaleleba, Lege Hora
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
-2
-1
0
1
2
3
Enteric CH4
Forest C Growth
Fuelwood Loss
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach-Runoff N2O
Manure CH4
Manure N2O
Mineral Soils
Silvipasture C Growth
Timber Loss

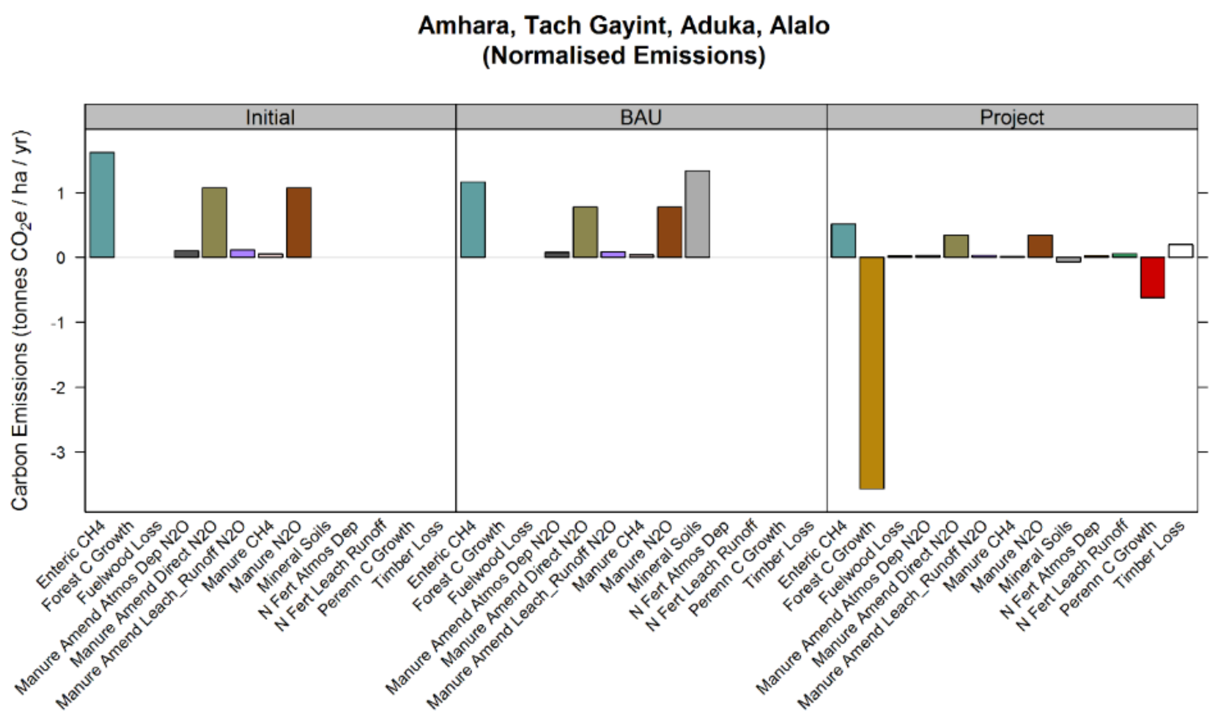
Land areas for Unknown Site

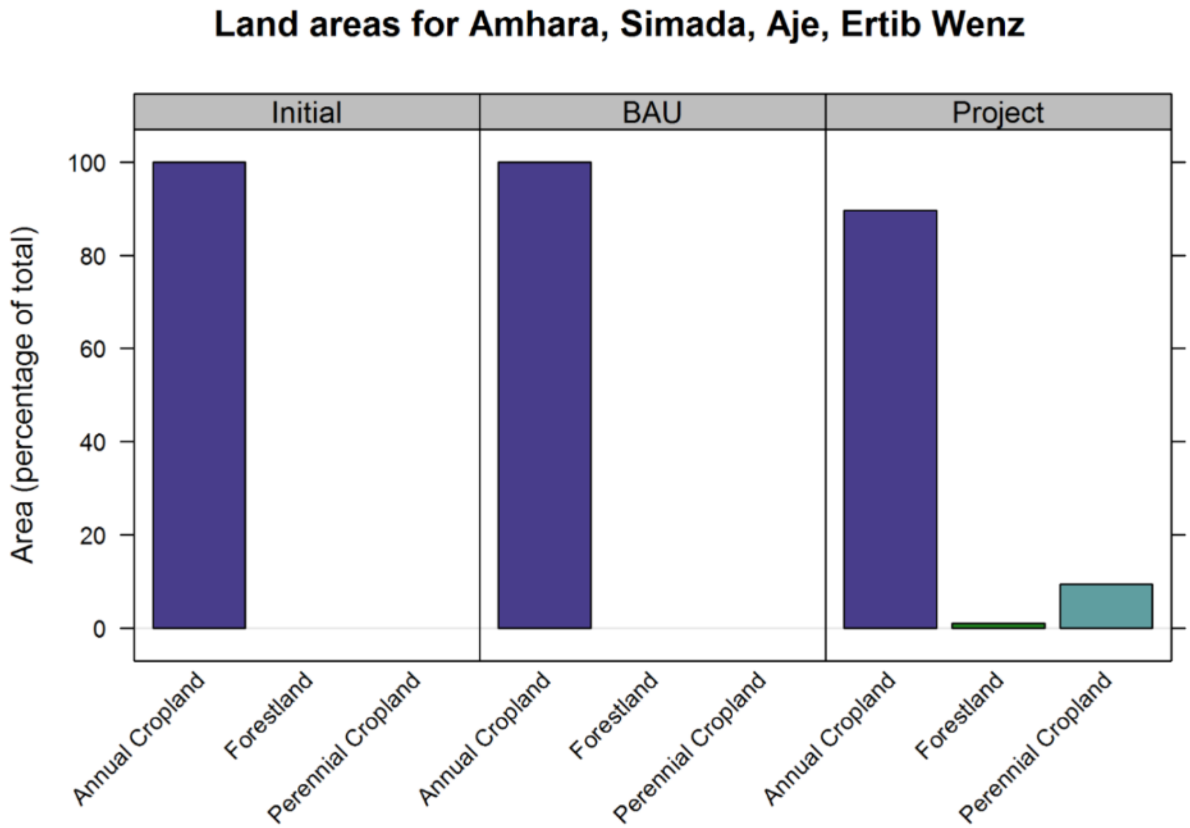


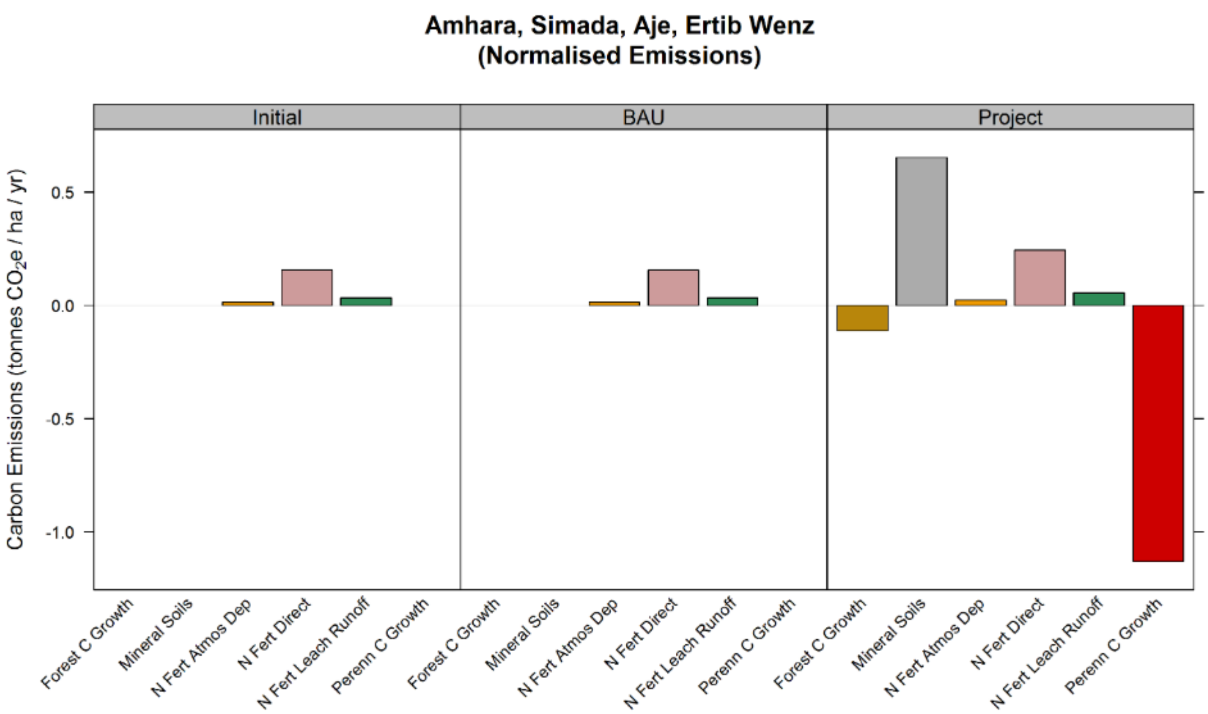
**Unknown Site
(Normalised Emissions)**

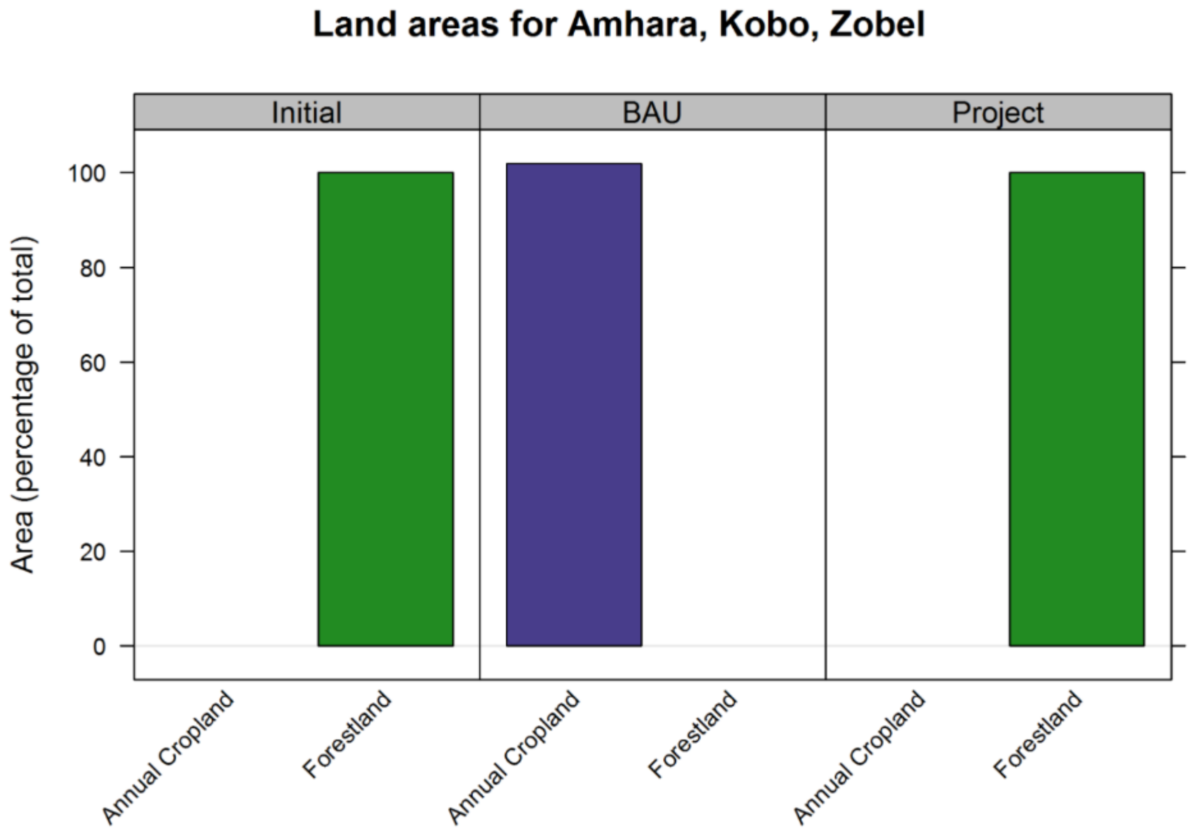


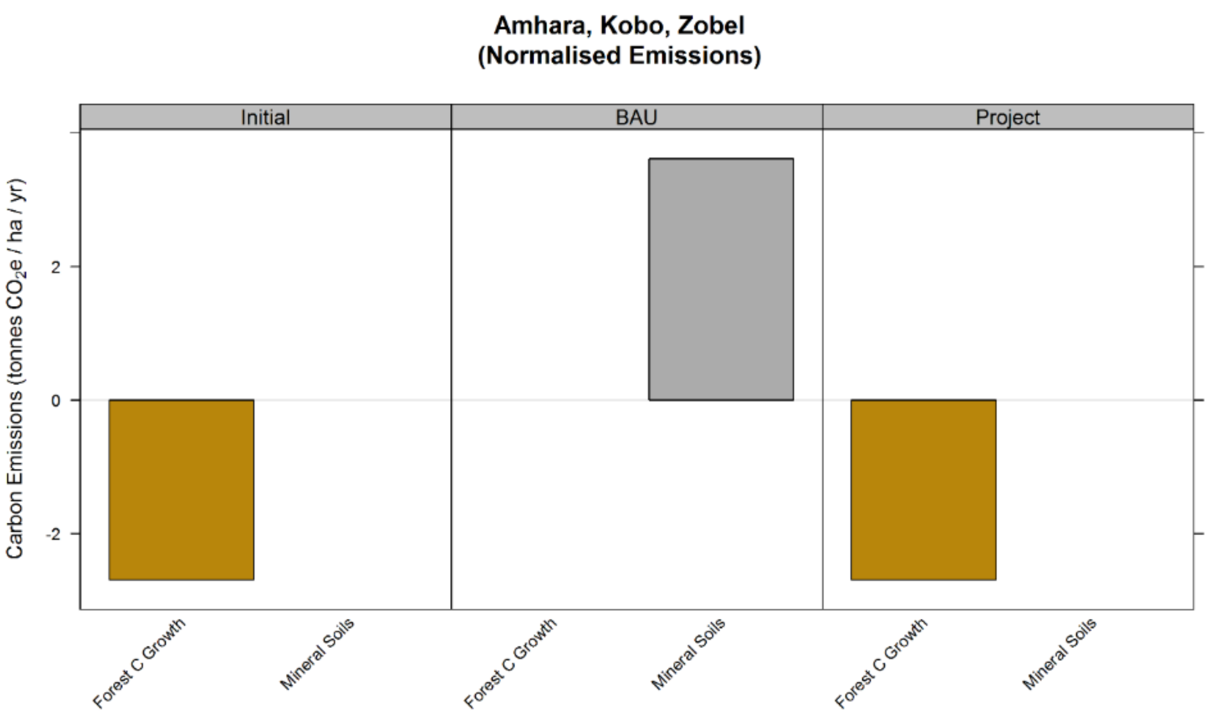

Land areas for Amhara, Tach Gayint, Aduka, Alalo
Initial
BAU
Project
Area (percentage of total)
0
10
20
30
40
50
Annual Cropland
Forestland
Grassland
Perennial Cropland

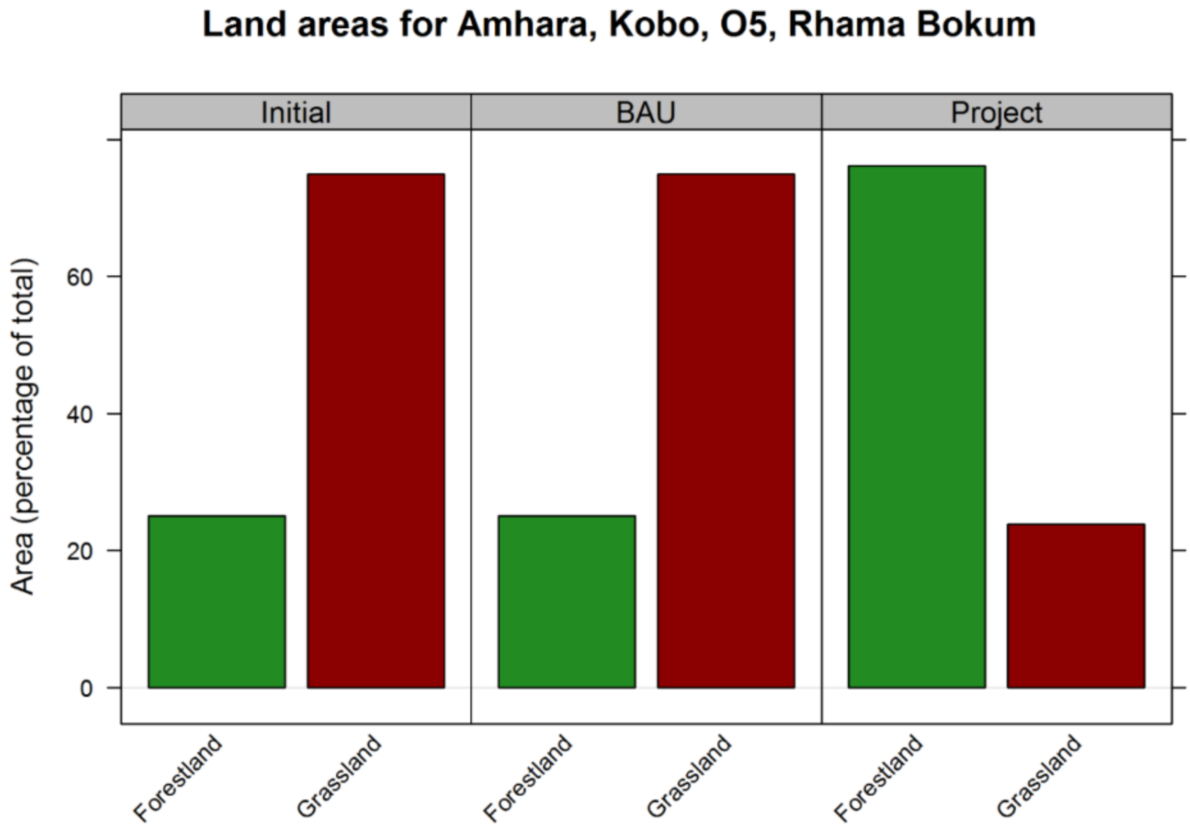

Amhara, Tach Gayint, Aduka, Alalo
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
1
0
-1
-2
-3
Enteric CH4
Forest C Growth
Fuelwood Loss
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach_Runoff N2O
Manure CH4
Manure N2O
Mineral Soils
N Fert Atmos Dep
N Fert Leach Runoff
Perenn C Growth
Timber Loss

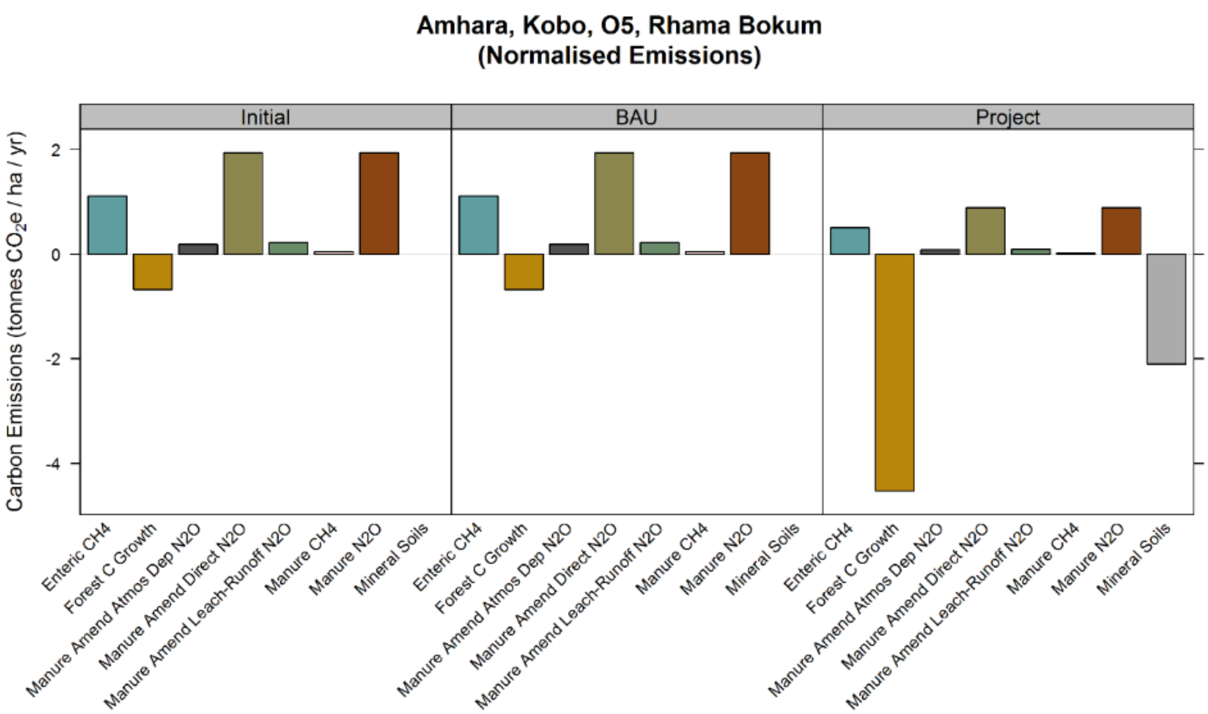

Land areas for Amhara, Simada, Aje, Ertib Wenz
Initial
BAU
Project
Area (percentage of total)
100
80
60
40
20
0
Annual Cropland
Forestland
Perennial Cropland


Amhara, Simada, Aje, Ertib Wenz
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
0.5
0.0
-0.5
-1.0
Forest C Growth
Mineral Soils
N Fert Atmos Dep
N Fert Direct
N Fert Leach Runoff
Perenn C Growth

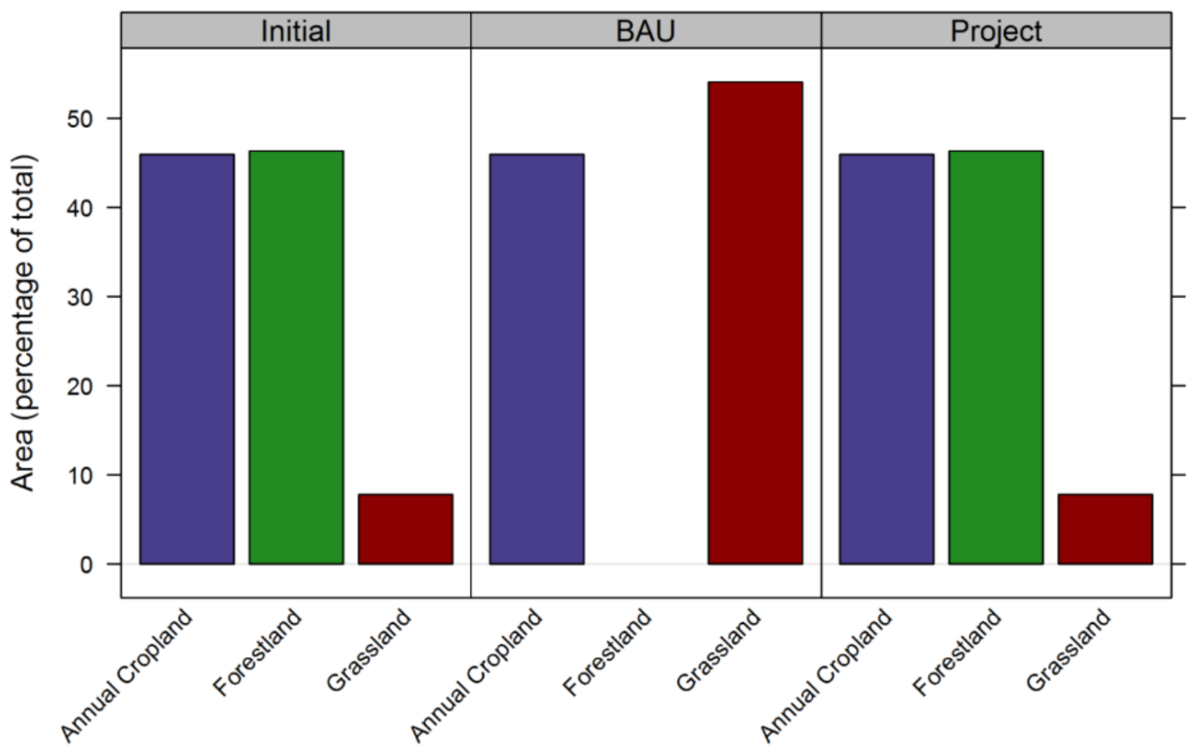

Land areas for Amhara, Kobo, Zobel
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
100
Annual Cropland
Forestland


Amhara, Kobo, Zobel
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
-2
0
2
Forest C Growth
Mineral Soils

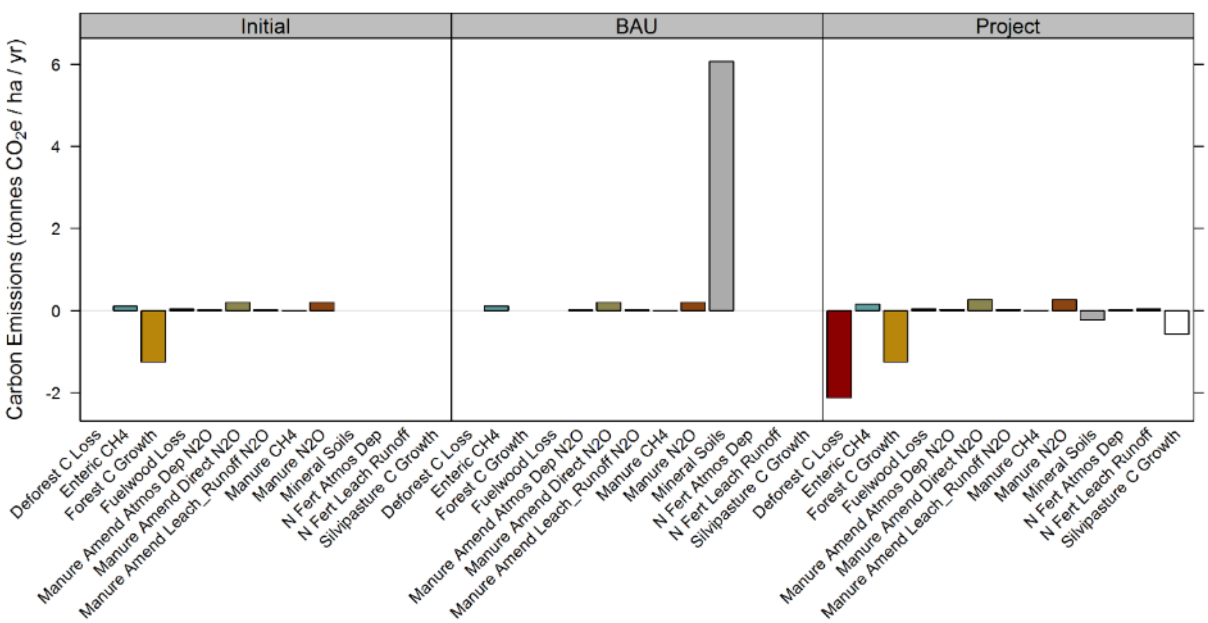

Land areas for Amhara, Kobo, O5, Rhama Bokum
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
Forestland
Grassland
Forestland
Grassland
Forestland
Grassland

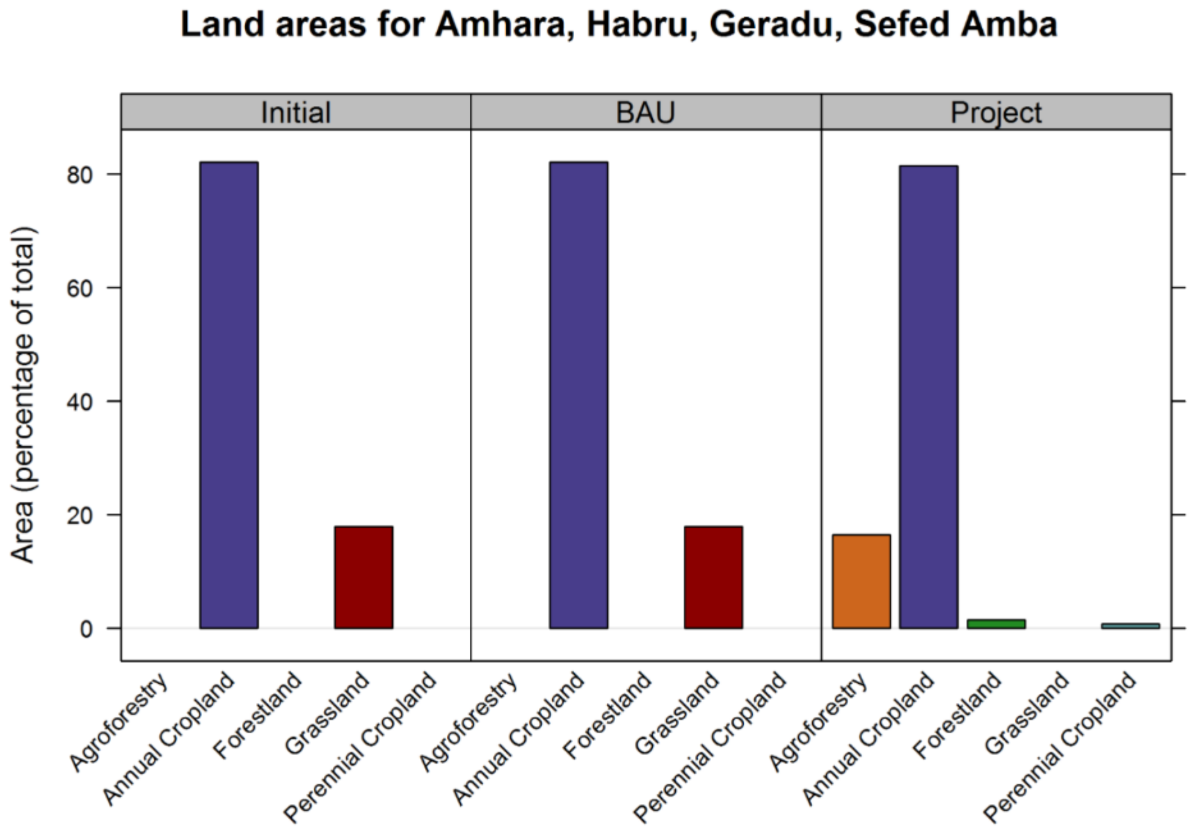

Amhara, Kobo, O5, Rhama Bokum
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
2
0
-2
-4
Enteric CH4
Forest C Growth
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach-Runoff N2O
Manure CH4
Manure N2O
Mineral Soils

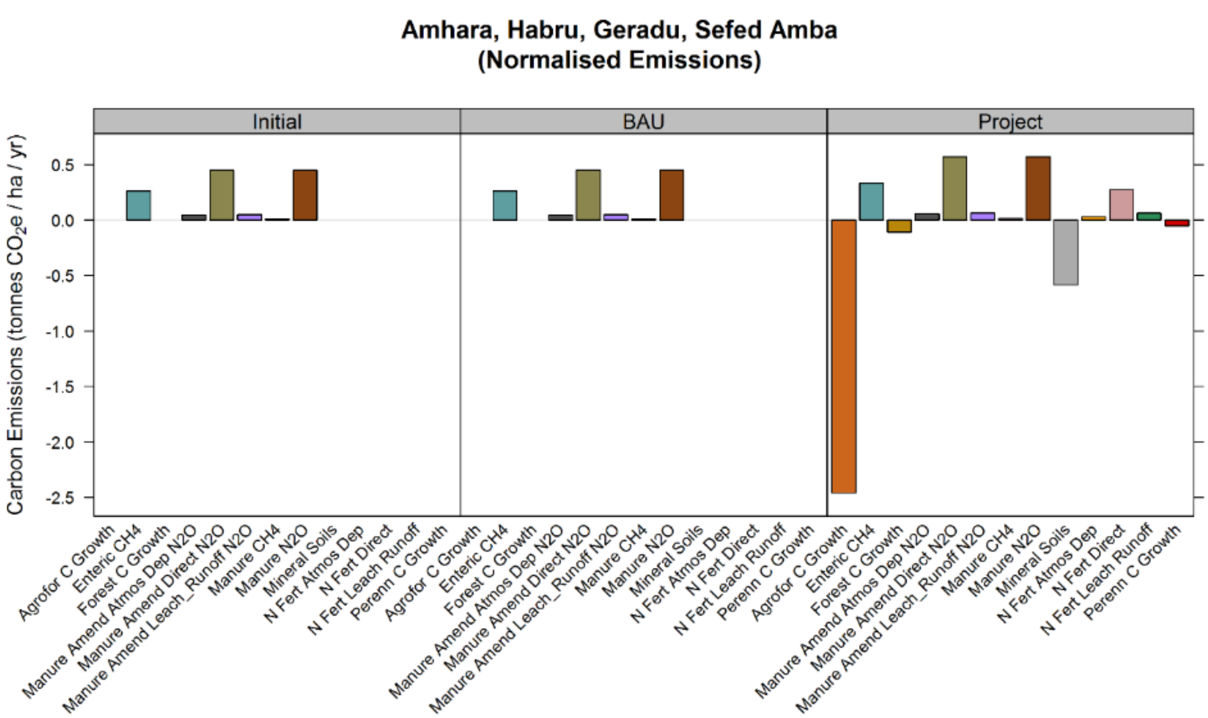
Land areas for Amhara, Habru, Geradu, Weira Amba

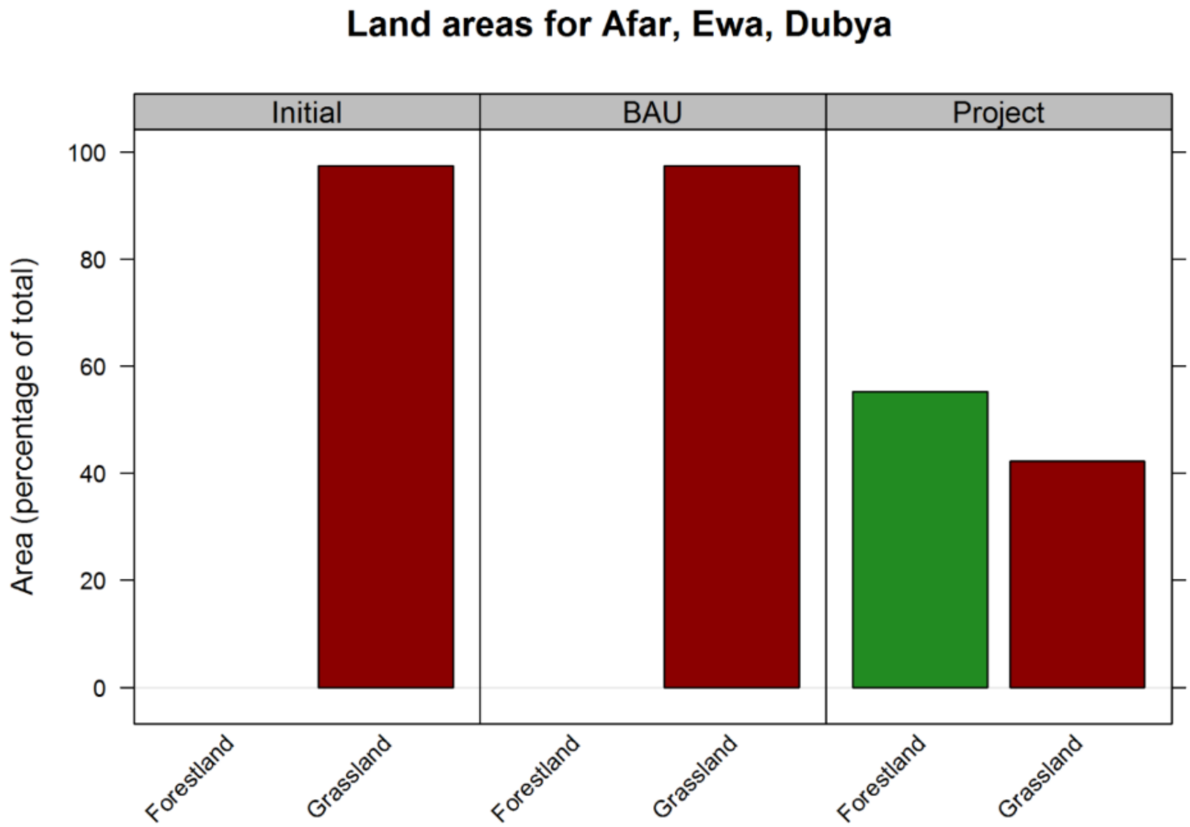


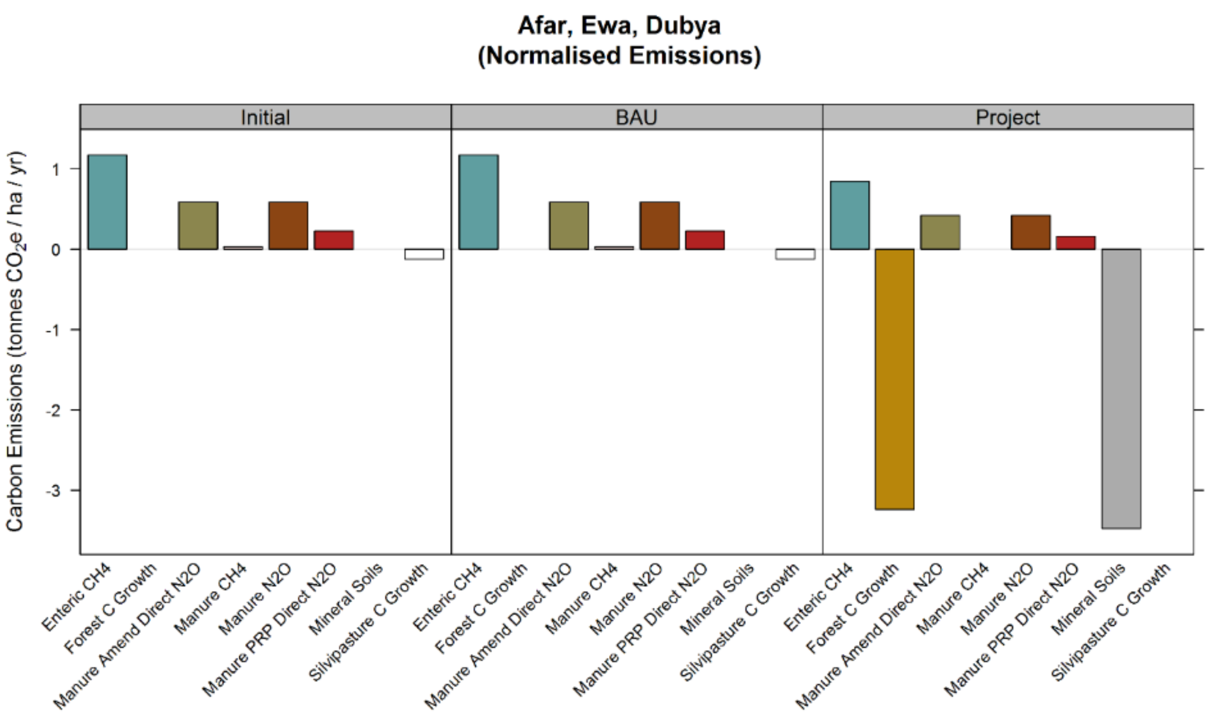
Amhara, Habru, Geradu, Weira Amba (Normalised Emissions)



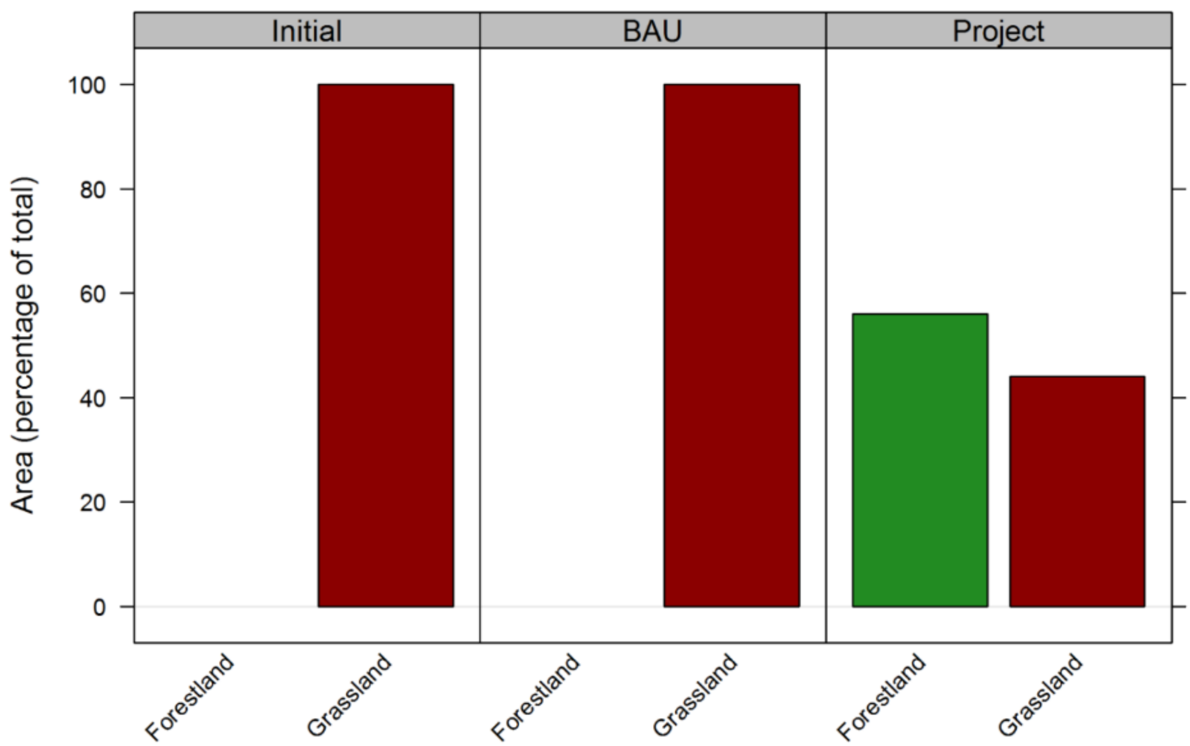

Land areas for Amhara, Habru, Geradu, Sefed Amba
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
Agroforestry
Annual Cropland
Forestland
Grassland
Perennial Cropland


Amhara, Habru, Geradu, Sefed Amba
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Agrofor C Growth
Enteric CH4
Forest C Growth
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach_Runoff N2O
Manure CH4
Manure N2O
Mineral Soils
N Fert Atmos Dep
N Fert Direct
N Fert Leach Runoff
Perenn C Growth

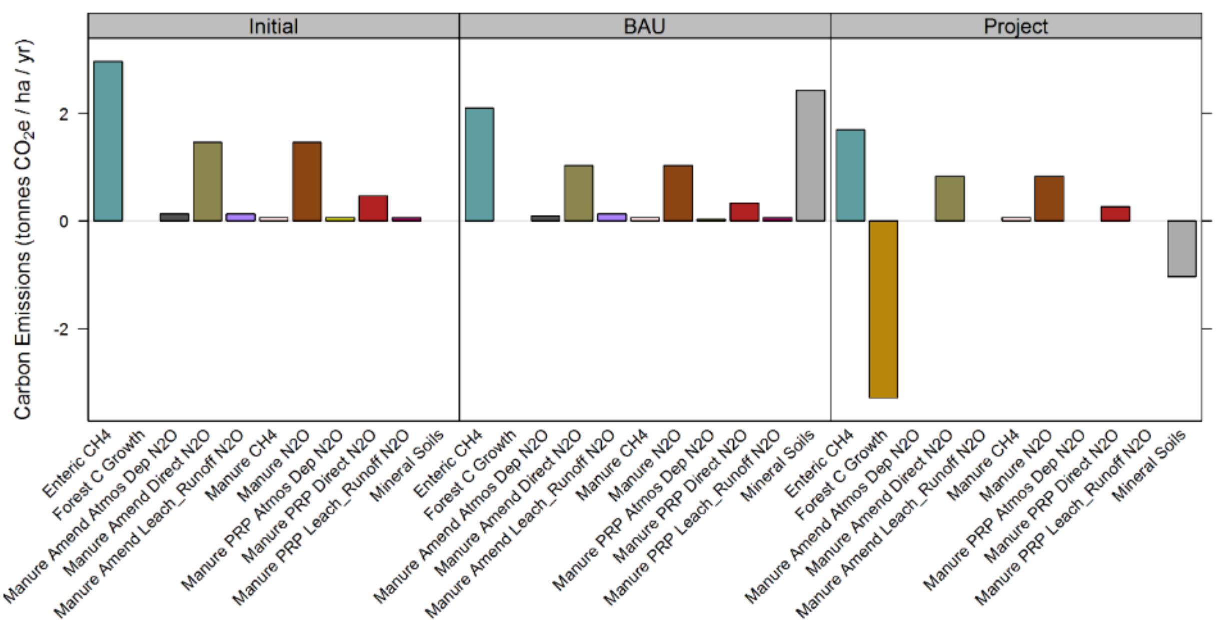

Land areas for Afar, Ewa, Dubya
Initial
BAU
Project
Area (percentage of total)
100
80
60
40
20
0
Forestland
Grassland


Afar, Ewa, Dubya
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
1
0
-1
-2
-3
Enteric CH4
Forest C Growth
Manure Amend Direct N2O
Manure CH4
Manure N2O
Manure PRP Direct N2O
Mineral Soils
Silvipasture C Growth

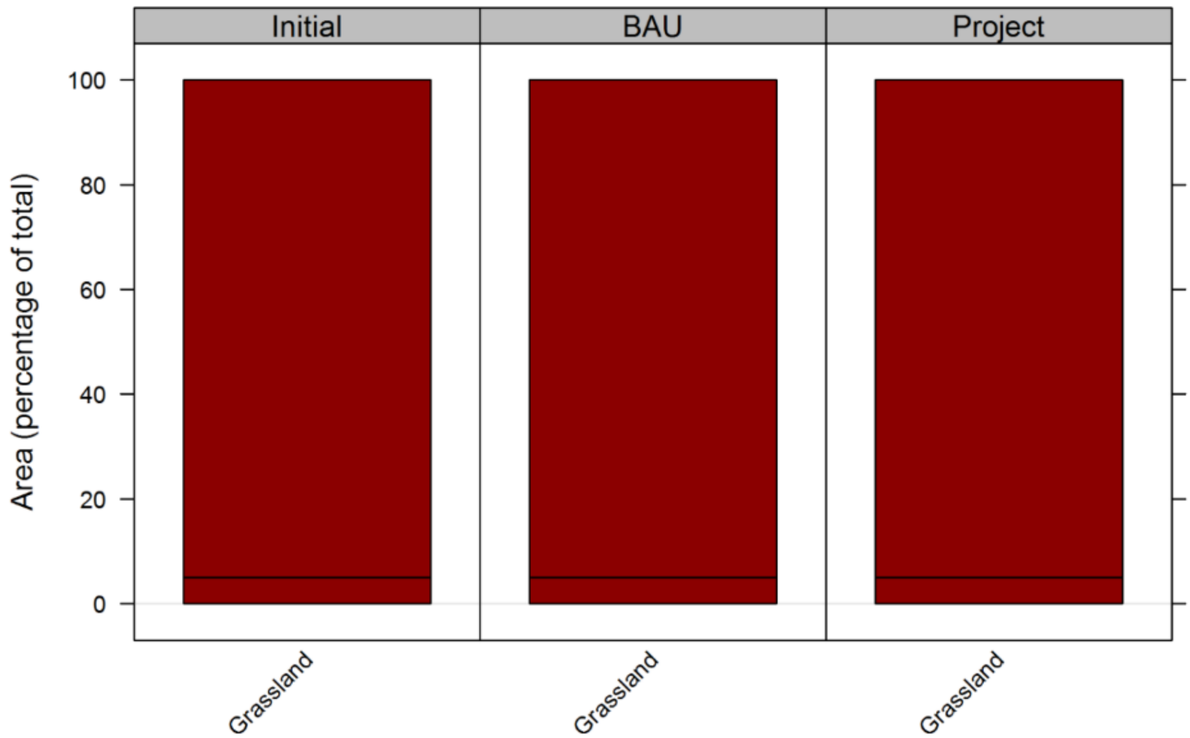
Land areas for Afar, Ewa, Boltiom, Alada Sikuma



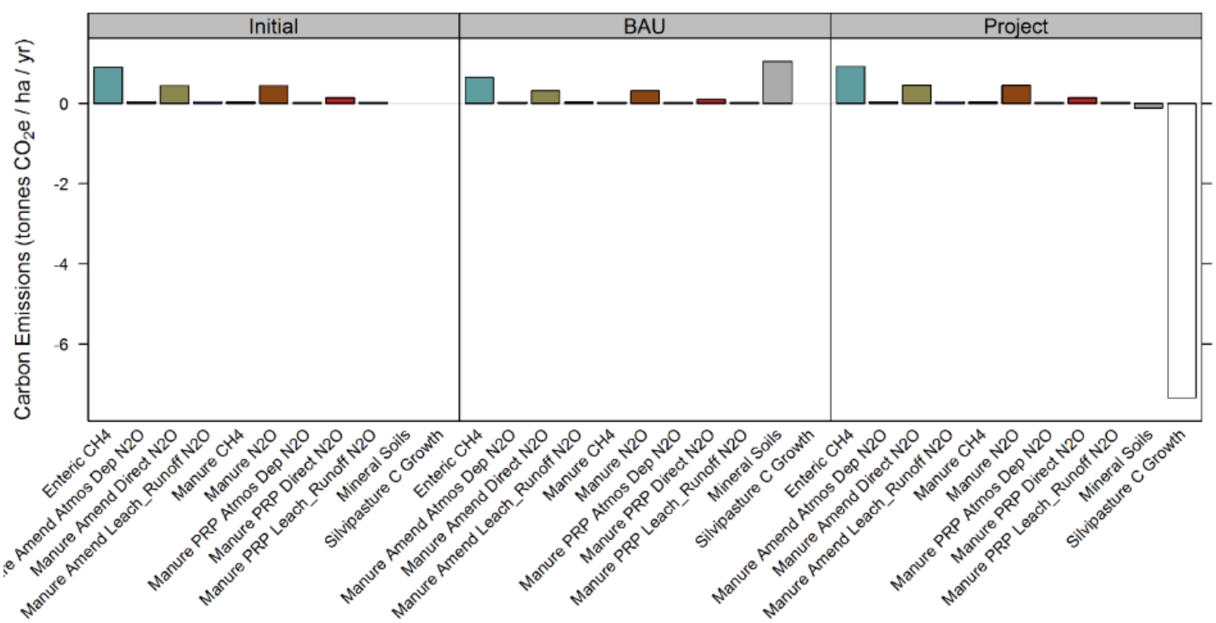
Afar, Ewa, Boltiom, Alada Sikuma (Normalised Emissions)

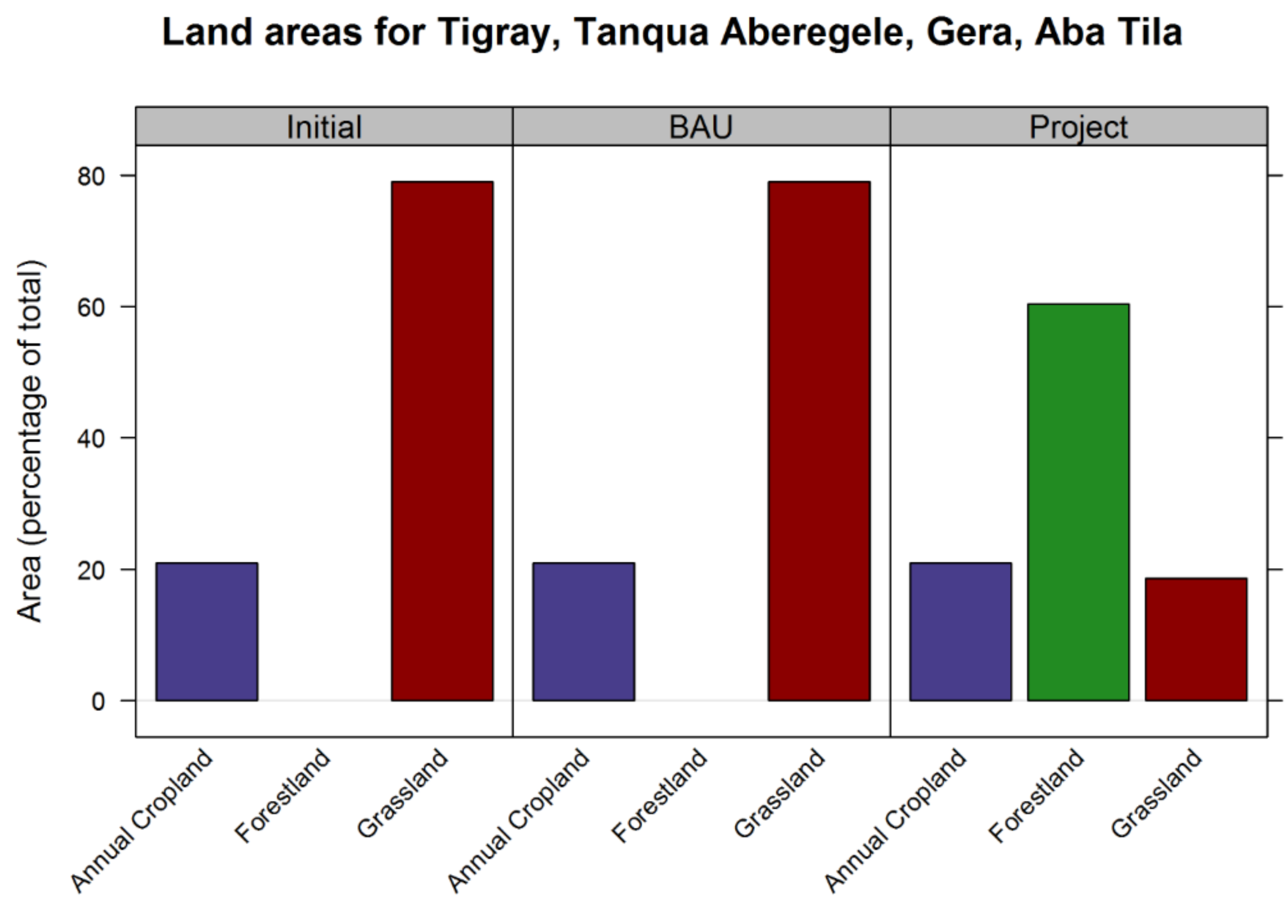


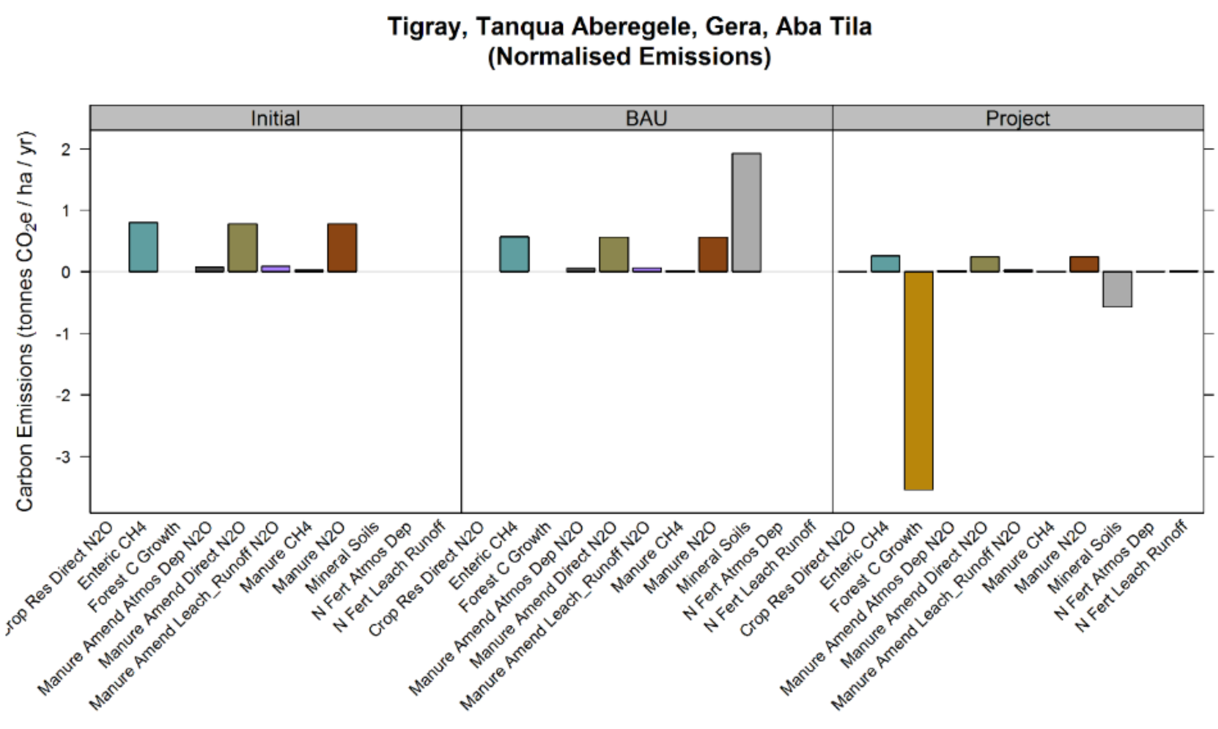
Land areas for Afar, Elidar, Woha limat, Woha Limat



**Afar, Elidar, Woha limat, Woha Limat
(Normalised Emissions)**



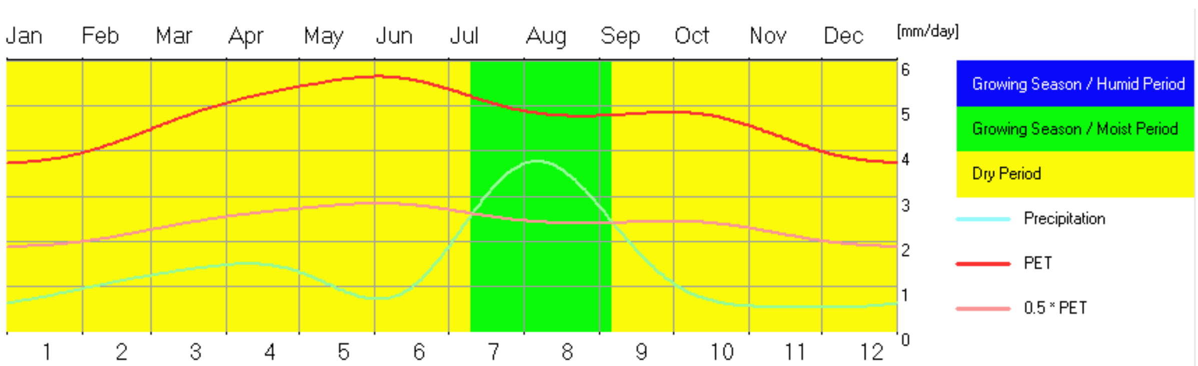

Land areas for Tigray, Tanqua Aberegele, Gera, Aba Tila
Initial
BAU
Project
Area (percentage of total)
0
20
40
60
80
Annual Cropland
Forestland
Grassland


Tigray, Tanqua Aberegele, Gera, Aba Tila
(Normalised Emissions)
Initial
BAU
Project
Carbon Emissions (tonnes CO2e / ha / yr)
2
1
0
-1
-2
-3
Crop Res Direct N2O
Enteric CH4
Forest C Growth
Manure Amend Atmos Dep N2O
Manure Amend Direct N2O
Manure Amend Leach_Runoff N2O
Manure CH4
Manure N2O
Mineral Soils
N Fert Atmos Dep
N Fert Leach Runoff

Annex 3. Site descriptions

Region	Afar
Woreda	Chifra
Kebele	Jara
Site Code	Af-Ch-Ja
GPS	11.672 N, 40.004 E
Elevation	949 m
Size	5.3 ha

Surrounding area is semi-arid and sparsely vegetated, with occasional small native shrubs (predominantly *Acacia* spp.). Ground vegetation is almost absent due to heavy grazing. Within this denuded landscape, a few (10 within watershed) farmer-practice enclosures (each approximately 2 ha) are present in which native grasses are grown in a cut-and-carry system. Enclosure boundaries are fenced with layered thorny brash, with constant vigilance and upkeep required to prevent intrusion of livestock. Only those farmers who are most vigilant are successful at maintaining hay enclosures. Branches for fencing are cut from surrounding native shrubs and may be a contributory factor in shrub loss in adjacent land.



Koeppen Class: BSh
Budyko Climate: Semiarid

Radiation index of Dryness: 3.377
Budyko Evaporation 495 mm/year
Budyko Runoff 17 mm/year
Budyko Evaporation 96.7 %
Budyko Runoff 3.3 %

Aridity: semiarid

Aridity Index: 0.3
Moisture Index: -70 %.
DeMartonne Index: 15
Precipitation Deficit: 1219 mm/year

Climatic net primary production: 864 g(DM)/m2/year,

NPP(Temperature): 2517 g(DM)/m2/year

NPP(Precipitation): 864 g(DM)/m2/year

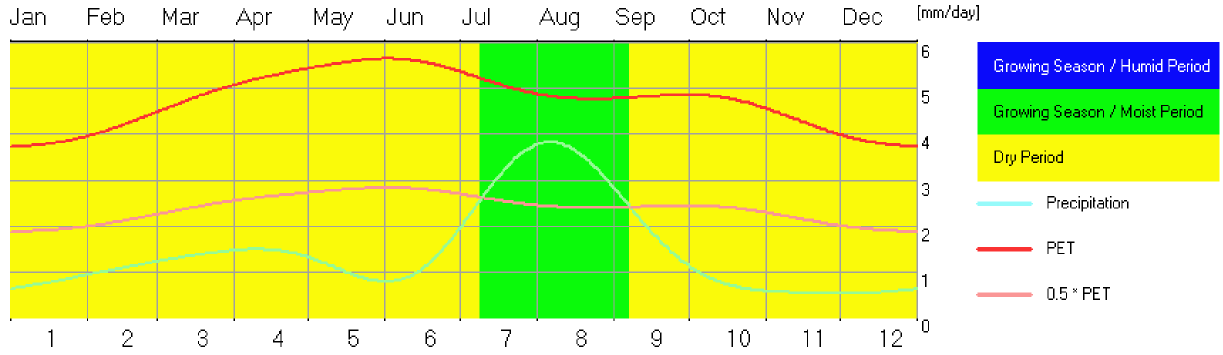
NPP is precipitation limited.

Gorczynski Continentality Index: 38.5

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	22	27	39	44	32	18	85	94	42	19	20	17	458
Effective Rain Ratio [%]	96	95	93	92	95	97	84	82	93	97	97	97	90
Rainy Days	3	4	5	5	4	2	9	11	5	2	3	2	55
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Afar
Woreda	Ewa
Kebele	Boltiom
Site Code	Af-Ew-Bo
GPS	11.7481 N, 39.9844 E
Elevation	955 m
Size	2.3 ha

Area is semi-arid and sparsely vegetated, with occasional small native shrubs (predominantly *Acacia* spp.) and sparse to absent ground vegetation. Three hectares of stone bunds and trenches were constructed on shallow hillside one and a half years before survey, but the site was not enclosed and is still heavily overgrazed. Even within the site, ground vegetation is absent and no signs of vegetative regeneration were observed. No biological measures (planting or seeding) were undertaken. Shrub density is significantly lower within the site than on the adjacent control site just outside the PSNP boundary (300 shrubs ha^{-1} of 1-3 m height in control site, compared to approximately 5 ha^{-1} in PSNP site). Local pastoralists interviewed claimed that there is an interest in and support for the implementation of enclosures with cut-and-carry systems, which they believe would aid in drought-resilience. However, to-date such projects have had little success locally because fencing is inadequate or absent and animals easily enter the site. The site was modeled under the assumption that these inadequacies in implementation would be addressed going forwards. Without functioning stock exclusion and shrub regeneration, measurable carbon or other benefits will be unlikely to accrue.



Koeppen Class: BSh

B = Arid Climate

S = Steppe

h = hot

Budyko Climate: Semiarid
Radiation index of Dryness: 3.298
Budyko Evaporation 505 mm/year
Budyko Runoff 18 mm/year
Budyko Evaporation 96.5 %
Budyko Runoff 3.5 %

Aridity: semiarid
Aridity Index: 0.3
Moisture Index: -70 %.
DeMartonne Index: 15
Precipitation Deficit: 1208 mm/year

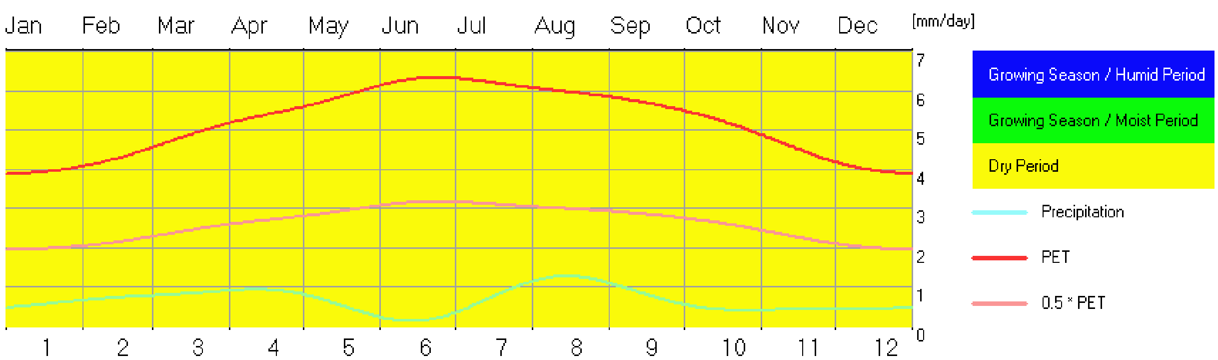
Climatic net primary production: 880 g(DM)/m2/year,
NPP(Temperature): 2515 g(DM)/m2/year
NPP(Precipitation): 880 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 36.7

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	22	27	39	44	32	21	86	95	45	20	20	17	467
Effective Rain Ratio [%]	96	95	93	92	95	97	83	81	92	97	97	97	89
Rainy Days	3	3	5	5	4	2	10	11	5	2	3	2	55
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Afar
Woreda	Dubti
Kebele	Ayrolaf
Watershed	Gebelaytu
Site Code	Af-Du-Ay
GPS	11.795 N, 41.084 E
Elevation	372 m
Size	726 ha

Area is extremely arid and sparsely vegetated. PSNP activities include *Prosopis juliflora* (an invasive shrub) clearance and also road maintenance. Project site is cleared *Prosopis* land that is planted primarily in maize. A smaller cleared area is devoted to natural regeneration.



Koeppen Class: BWh

Budyko Climate: Desert
Radiation index of Dryness: 7.667
Budyko Evaporation 234 mm/year
Budyko Runoff 1 mm/year
Budyko Evaporation 99.4 %
Budyko Runoff 0.6 %

Aridity: arid
Aridity Index: 0.12
Moisture Index: -88 %.
DeMartonne Index: 6
Precipitation Deficit: 1661 mm/year

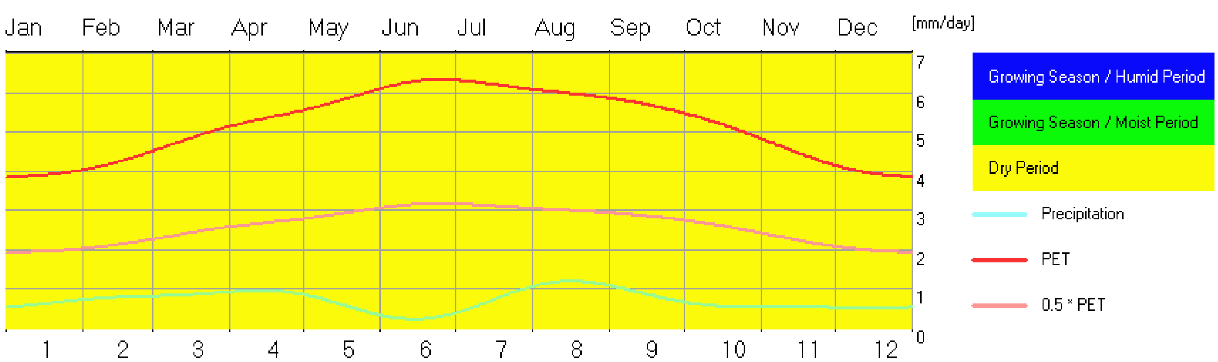
Climatic net primary production: 434 g(DM)/m2/year,
NPP(Temperature): 2651 g(DM)/m2/year
NPP(Precipitation): 434 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 50.9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	16	19	23	28	17	-1	25	39	21	11	15	14	226
Effective Rain Ratio [%]	97	97	96	95	97	-999	96	93	97	98	98	98	96
Rainy Days	2	2	3	3	2	0	2	4	2	1	2	2	25
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Afar
Woreda	Elidar
Kebele	Woha Limat
Site Code	Af-El-WL
GPS	11.946944 N, 41.426945E
Elevation	385 m
Size	400 ha

Area is extremely arid and sparsely vegetated. PSNP site has natural regeneration of native shrubs, primarily *Acacia* spp., in areas where livestock are prohibited from grazing.



Koeppen Class: BWh
B = Arid Climate
D = Desert
h = hot

Budyko Climate: Desert
Radiation index of Dryness: 7.174
Budyko Evaporation 250 mm/year
Budyko Runoff 2 mm/year
Budyko Evaporation 99.3 %
Budyko Runoff 0.7 %

Aridity: arid
Aridity Index: 0.13
Moisture Index: -87 %.
DeMartonne Index: 7
Precipitation Deficit: 1636 mm/year

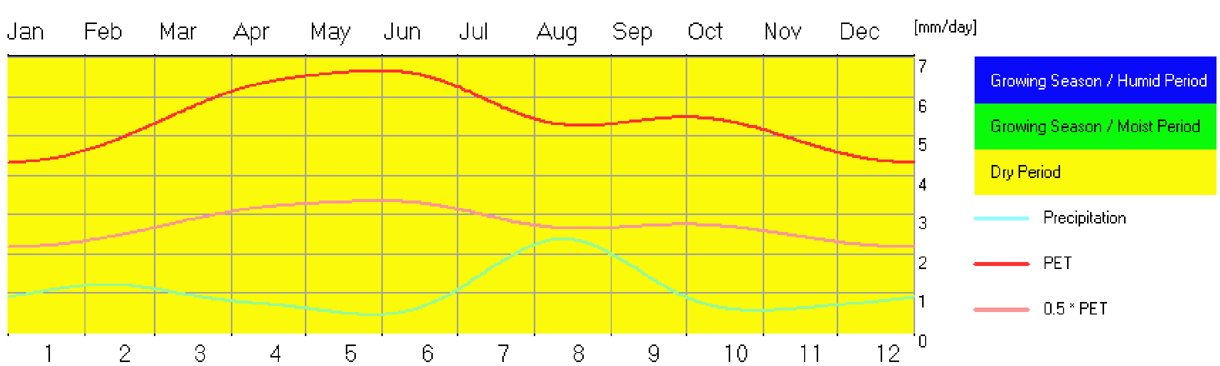
Climatic net primary production: 462 g(DM)/m2/year,
NPP(Temperature): 2641 g(DM)/m2/year
NPP(Precipitation): 462 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 49.3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	18	21	23	29	19	3	23	37	22	15	17	15	242
Effective Rain Ratio [%]	97	96	96	95	97	99	96	94	96	98	97	97	96
Rainy Days	2	3	3	3	2	0	2	3	2	2	2	2	26
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Afar
Woreda	Ewa
Kebele	Dubya
Site Code	Af-Ew-Du
GPS	11.748 N, 39.0833 E
Elevation	987 m
Size	4 ha

Area is extremely arid and sparsely vegetated. PSNP activities include natural regeneration of native shrubs, primarily *Acacia* spp., in enclosures where livestock are prohibited from grazing. Stone bunds are constructed to reduce erosion and build soils.



Koeppen Class: BSh
B = Arid Climate
S = Steppe
h = hot

Budyko Climate: Desert
Radiation index of Dryness: 4.854
Budyko Evaporation 372 mm/year
Budyko Runoff 6 mm/year
Budyko Evaporation 98.5 %
Budyko Runoff 1.5 %

Aridity: arid
Aridity Index: 0.19
Moisture Index: -81 %.
DeMartonne Index: 9
Precipitation Deficit: 1626 mm/year

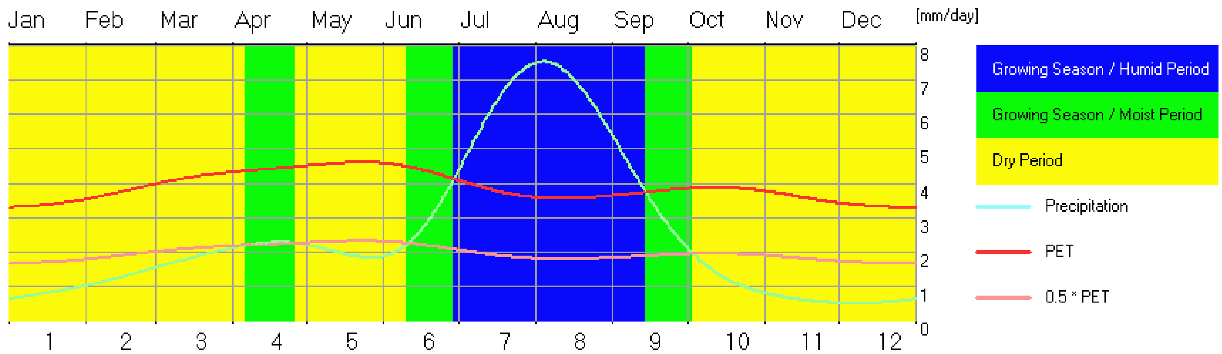
Climatic net primary production: 666 g(DM)/m2/year,
NPP(Temperature): 2736 g(DM)/m2/year
NPP(Precipitation): 666 g(DM)/m2/year
NPP is precipitation limited.

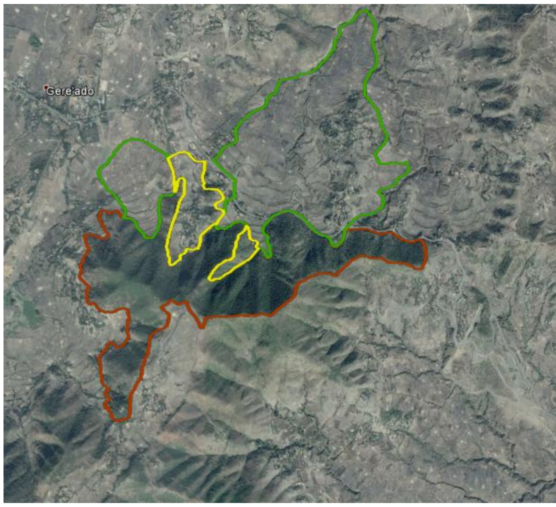
Gorczynski Continentality Index: 48

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	29	33	24	23	16	16	49	68	35	17	20	24	353
Effective Rain Ratio [%]	95	94	96	96	97	97	91	88	94	97	97	96	93
Rainy Days	3	3	2	2	1	1	4	6	3	2	2	3	32
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Amhara
Woreda	Habru
Kebele	Geradu
Watershed/site name	Weira Amba
Site Code	Am-Ha-WA
GPS	11.737389 N, 39.6306 E
Elevation	1930 – 2230 m
Size	285 ha

The entire mountain constitutes the PSNP watershed on which a 10-12 year old area enclosure has been created. Physical structures include microbasins and some terraces. The mountain was previously highly degraded and subject to extensive erosion. One part of the watershed, closest to the village, is still used as free grazing, and remains highly degraded with sparse shrub vegetation amidst bare soil and extensive evidence of overland flow and erosion. Vegetation on most of the rest of the watershed is forest (mixed *Acacia*, *Olea*, and other native trees from natural regeneration, with patches of eucalyptus interspersed). Some isolated areas of grassland from which cut-and-carry hay is harvested are also present interspersed with the woodland. Lower reaches of the hill are terraced cropland with basins for water catchment. Main crops are teff rotated with millet and maize.





Koeppen Class: Cwb

- C = Warm Temperate Climate
- w = with dry winter
- b = warm summer

Budyko Climate: Steppe

- Radiation index of Dryness: 1.734
- Budyko Evaporation 796 mm/year
- Budyko Runoff 126 mm/year
- Budyko Evaporation 86.3 %
- Budyko Runoff 13.7 %

Aridity: subhumid

- Aridity Index: 0.65
- Moisture Index: -35 %.
- DeMartonne Index: 32
- Precipitation Deficit: 491 mm/year

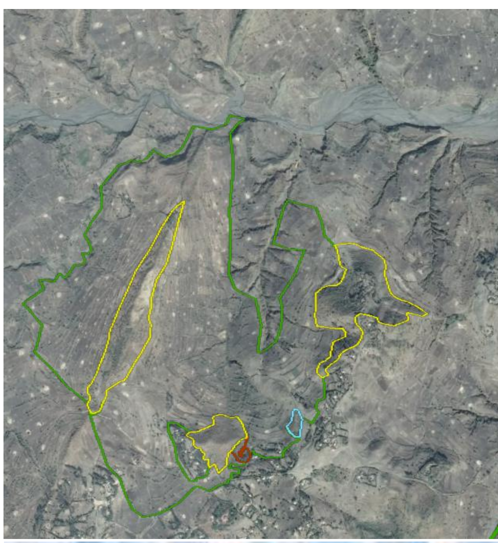
Climatic net primary production: 1374 g(DM)/m2/year,
NPP(Temperature): 2138 g(DM)/m2/year
NPP(Precipitation): 1374 g(DM)/m2/year
NPP is precipitation limited.

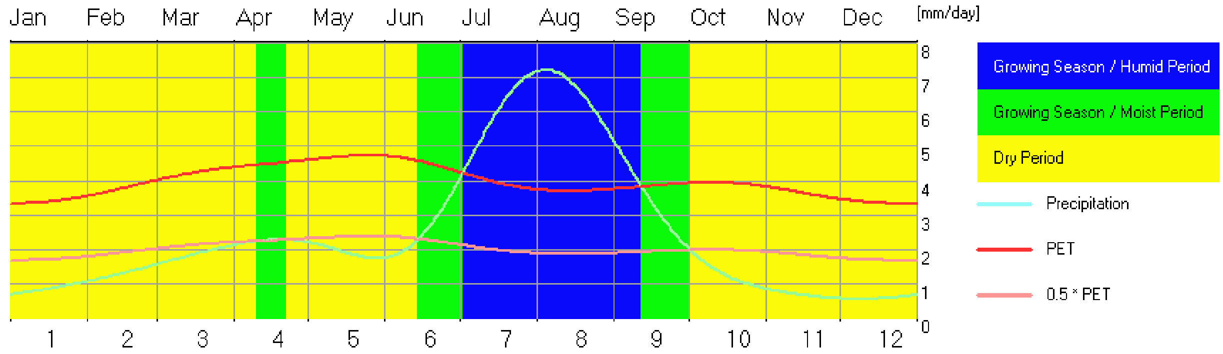
Gorczynski Continentality Index: 12

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	1	0
Effective Rain [mm]	23	29	53	64	60	54	141	143	79	34	25	16	722
Effective Rain Ratio [%]	96	95	91	88	89	90	66	64	85	94	96	97	78
Rainy Days	4	4	8	9	8	7	20	21	11	5	4	2	103
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Amhara
Woreda	Habru
Kebele	04 Geradu
Watershed	Sefed Amba
Site Code	Am-Ha-SA
GPS	11.758056 N, 39.627058 E
Elevation	1860 m
Size	328 ha

Soil and water conservation site with mixed cereal, livestock, fruit and vegetable production supporting 174 households. Physical measures include 42 large water-harvesting reservoirs to provide supplementary irrigation, deep trenches and micro and macro basins for water catchment. Terraces use soil bunds on the shallower slopes and stone bunds (some over 2 m high) on steep slopes. Pigeon pea planted on soil bunds and in more degraded areas for cut-and-carry system. Central area dominated by extensive cereal cropping is surrounded by homesteads with tree fruit and vegetable production. Communal grazing with cut-and-carry grass area on northwestern slopes is silvopasture on terraces.





Koeppen Class: Cwb
C = Warm Temperate Climate
w = with dry winter
b = warm summer

Budyko Climate: Steppe
Radiation index of Dryness: 1.793
Budyko Evaporation 781 mm/year
Budyko Runoff 116 mm/year
Budyko Evaporation 87.1 %
Budyko Runoff 12.9 %

Aridity: dry subhumid
Aridity Index: 0.62
Moisture Index: -38 %.
DeMartonne Index: 31
Precipitation Deficit: 548 mm/year

Climatic net primary production: 1346 g(DM)/m2/year,
NPP(Temperature): 2186 g(DM)/m2/year
NPP(Precipitation): 1346 g(DM)/m2/year
NPP is precipitation limited.

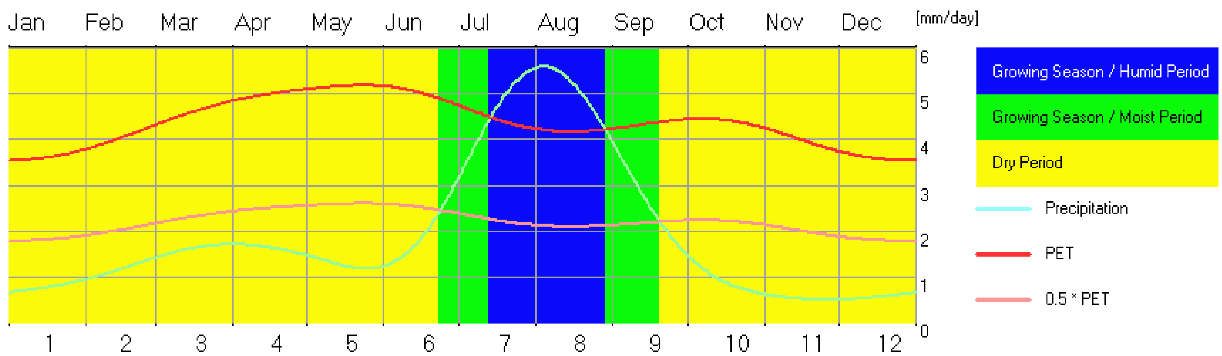
Gorczynski Continentality Index: 14.1

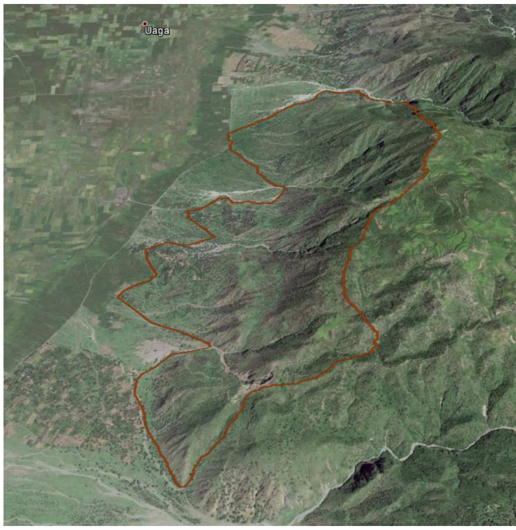
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	25	30	53	64	60	48	137	141	75	34	26	17	712

Effective Rain Ratio [%]	96	95	91	88	89	92	67	66	86	94	96	97	79
Rainy Days	4	4	8	9	8	6	19	20	10	5	4	3	100
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Amhara
Woreda	Kobo
Kebele	05
Watershed	Rhama Bokum / Weynweha
Site Code	Am-Ko-05
GPS	12.287478 N, 39.712181 E
Elevation	1400-1900 m
Size	325 ha

The project is an area enclosure established on a western escarpment rising from a flat plateau at 1400 m elevation to a ridge at 1900 m elevation. The plateau below the site is dominated by cereal cropland. Although the project design documents describe the watershed as being 2700 ha in extent, the area enclosure appears to be on 325 ha, with much of the rest of the watershed comprising settlements and cropland on the lower slopes and valley floor. Natural regeneration is characterized by the most abundant species being *Dichrostachys cinerea*, *Erythrina abyssinica*, *Acacia seyal*, *Grewia bicolor*, and *Allophylus abyssinicus*. Large water catchment basins have been dug at low density, and there is terracing with stone bunds and trenches, but much of the terracing has fallen into disrepair. Nonetheless, regeneration of the native woodland should serve to stabilize the soils. The area has large potential for biodiversity and carbon storage, but was only established for one to three years before the survey in November 2013, and was accordingly still only in the early stages of recovery from the more degraded condition, having dense ground vegetation but only sparse shrub cover and occasional trees. The site was deforested in the 1980's since when flash flooding in the valley below has increased. Grass is harvested by cut-and-carry from the areas located closer to settlements (by 1350 households), and will be a limiting factor on the rate at which woodland regenerates. Limited timber extraction to provide tool handles is expected to resume once woodland recovers.





Koeppen Class: BSh

B = Arid Climate

S = Steppe

h = hot

Budyko Climate: Semiarid

Radiation index of Dryness: 2.417

Budyko Evaporation 646 mm/year

Budyko Runoff 50 mm/year

Budyko Evaporation 92.8 %

Budyko Runoff 7.2 %

Aridity: semiarid

Aridity Index: 0.44

Moisture Index: -56 %.

DeMartonne Index: 22

Precipitation Deficit: 901 mm/year

Climatic net primary production: 1110 g(DM)/m2/year,

NPP(Temperature): 2351 g(DM)/m2/year

NPP(Precipitation): 1110 g(DM)/m2/year

NPP is precipitation limited.

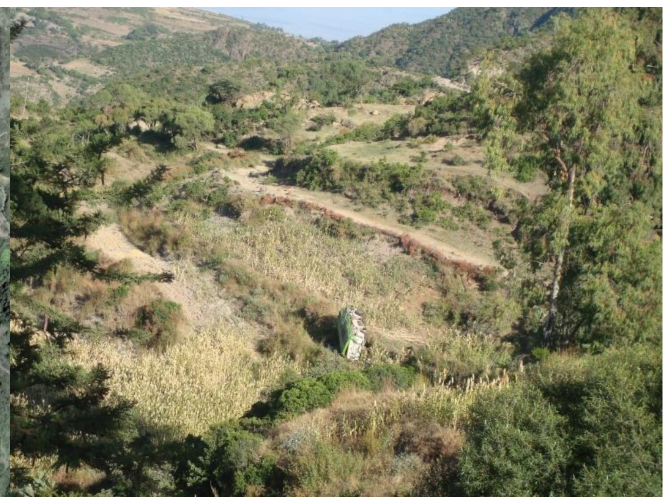
Gorczynski Continentality Index: 23.3

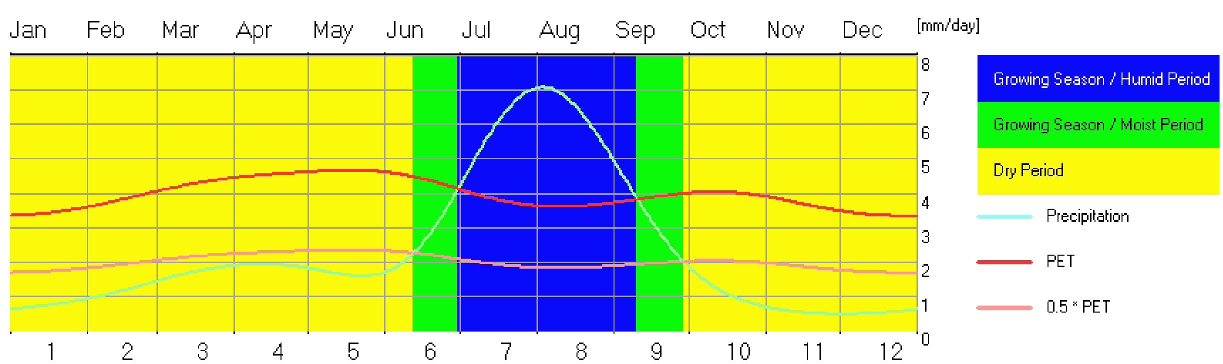
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost	0	0	0	0	0	0	0	0	0	0	0	0	0

Frequency [%]													
Effective Rain [mm]	22	27	49	48	40	39	118	122	58	25	20	18	586
Effective Rain Ratio [%]	96	95	91	92	93	93	75	73	90	96	97	97	84
Rainy Days	3	4	7	6	5	5	15	16	7	3	3	3	77
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Amhara
Woreda	Kobo
Kebele	Zobel
Site Code	Am-Ko-Zo
GPS	12.1922 N, 39.726 E
Elevation	1992 m
Size	9 ha

The project area is located at the top of a mountain ridge between the Kobo plateau to the west, and the western escarpment of the rift valley falling to the Afar lowlands to the east. Most of the mountains at this elevation have intact forest, due to the low population density. However, cropland expansion is slowly encroaching into the native woodland, and establishment of an area enclosure is expected tio reduce the deforestation rate.





Koeppen Class: Cwb

C = Warm Temperate Climate
w = with dry winter
b = warm summer

Budyko Climate: Steppe

Radiation index of Dryness: 1.913
Budyko Evaporation 750 mm/year
Budyko Runoff 97 mm/year
Budyko Evaporation 88.6 %
Budyko Runoff 11.4 %

Aridity: dry subhumid

Aridity Index: 0.59
Moisture Index: -41 %.
DeMartonne Index: 29
Precipitation Deficit: 596 mm/year

Climatic net primary production: 1291 g(DM)/m2/year,

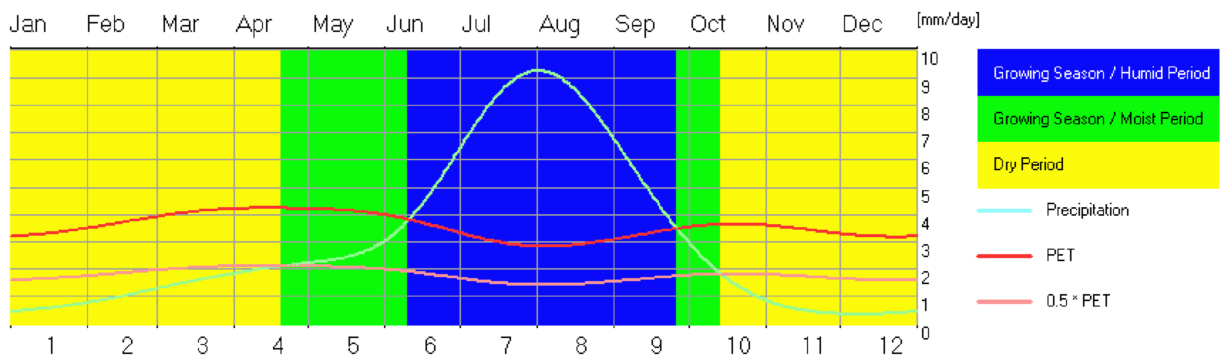
NPP(Temperature): 2162 g(DM)/m2/year
NPP(Precipitation): 1291 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 14.9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	21	27	51	55	51	54	137	139	72	30	22	16	675
Effective Rain Ratio [%]	97	96	91	90	91	91	67	67	87	95	96	97	80
Rainy Days	3	4	7	8	7	7	20	20	10	4	3	3	96
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Amhara
Woreda	Tach Gayint
Kebele	Aduka
Site name	Alalo
Site code	Am-TG-Ad
GPS	11.543 N, 38.531 E
Elevation	2265 m
Watershed Area	136 ha

Soil and water conservation project in watershed on a lateral mountainside. Steep slopes characterize most of the watershed. Headwaters at the top of escarpment have been turned into exclusion zones for livestock and are reforested in part and otherwise contain natural regeneration. Less steep areas below the headwaters are dedicated to terraced croplands. Settlements are sparsely scattered throughout the project area. Project initiated in 2010 and consists of multiple physical and biological SWC practices. In headwater exclusion zones: half-moon bunds, stone-faced bunds, afforestation with *Acacia saligna* and *Eucalyptus globulus*, and cut-and-carry for fodder. In lower elevation and less steep croplands: 1) physical SWC include stone-faced bunds, soil bunds, percolation trenches, silt storage dam (occasionally in the larger gulleys to trap silt), check dams in the gulleys planted with forage crops; and 2) biological SWC practices include ridges on soil bunds (terraces) planted with *Sesbania sesbans*, cowpea, and pigeon peas.



Koeppen Class: Cwb

C = Warm Temperate Climate

w = with dry winter

b = warm summer

Budyko Climate: Steppe

Radiation index of Dryness: 1.396

Budyko Evaporation 900 mm/year

Budyko Runoff 217 mm/year

Budyko Evaporation 80.5 %

Budyko Runoff 19.5 %

Aridity: subhumid

Aridity Index: 0.86

Moisture Index: -14 %.

DeMartonne Index: 42

Precipitation Deficit: 179 mm/year

Climatic net primary production: 1572 g(DM)/m2/year,

NPP(Temperature): 1960 g(DM)/m2/year

NPP(Precipitation): 1572 g(DM)/m2/year

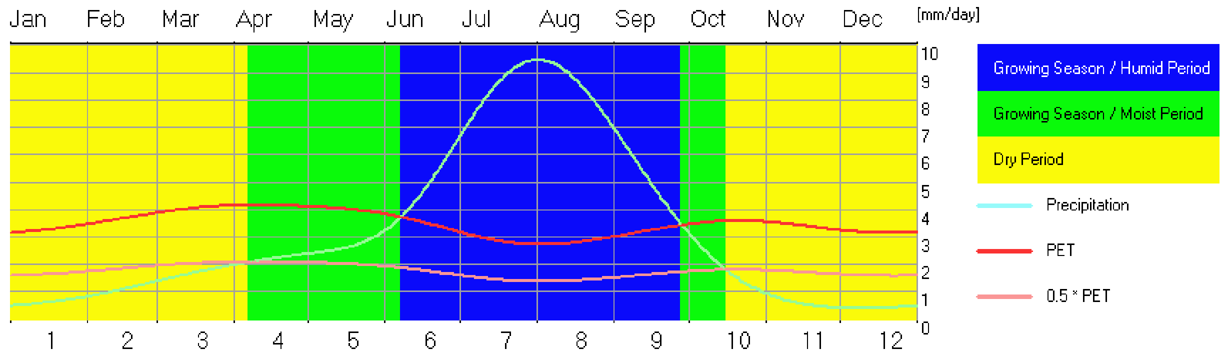
NPP is precipitation limited.

Gorczynski Continentality Index: 5.1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	3	1	0	0	0	0	0	0	0	1	3	4	1
Effective Rain [mm]	16	24	49	59	72	94	153	152	104	45	22	12	802
Effective Rain Ratio [%]	97	96	91	89	87	81	55	57	79	92	96	98	72
Rainy Days	3	4	7	9	11	14	25	24	16	7	4	2	126
Solid Precipitation Ratio [%]	1	0	0	0	0	0	1	1	0	1	1	1	0

Region	Amhara
Woreda	Simada
Kebele	Aje
Site name	Ertib Wenz
Site code	Am-Si-Aj
GPS	11.3137 N, 38.2919 E
Elevation	2475m
Watershed Area	247 ha

Soil and water conservation project in watershed on a relatively flat plateau with small, gently sloped (~50m elevation drop) hill at headwaters. Hillside is mostly covered with biological and physical SWC practices to reduce historic erosion and flooding scenarios in lower lying flat croplands that suffer drainage problems. Very little tree, shrub or natural vegetation cover. Vast majority is croplands. Three main settlements are located at the bottom of the watershed. Project initiated in 2010 and consists of multiple SWC practices, primarily revegetation activities on the hillside, but also some limited activities in the croplands immediately adjacent and at the base of the hill. In the headwater exclusion zones: extensive stone-faced bunds forming hillside terraces, percolation trenches at the foot of hill, microbasins (aka half-moon bunds), a cut-off drain (diversion canal) at the top of the drainage, "eye-brow basin" (half-moon basins with a pit), and check dams along gulleys with and without gabions (wire mesh to maintain integrity of the stone dams). In the croplands, soil bunds, and biological SWC practices *including Sesbania sesbans* and cowpeas planted along ridges formed by soil bunds. Also, *Acacia* and eucalyptus planted extensively on hillside terraces.



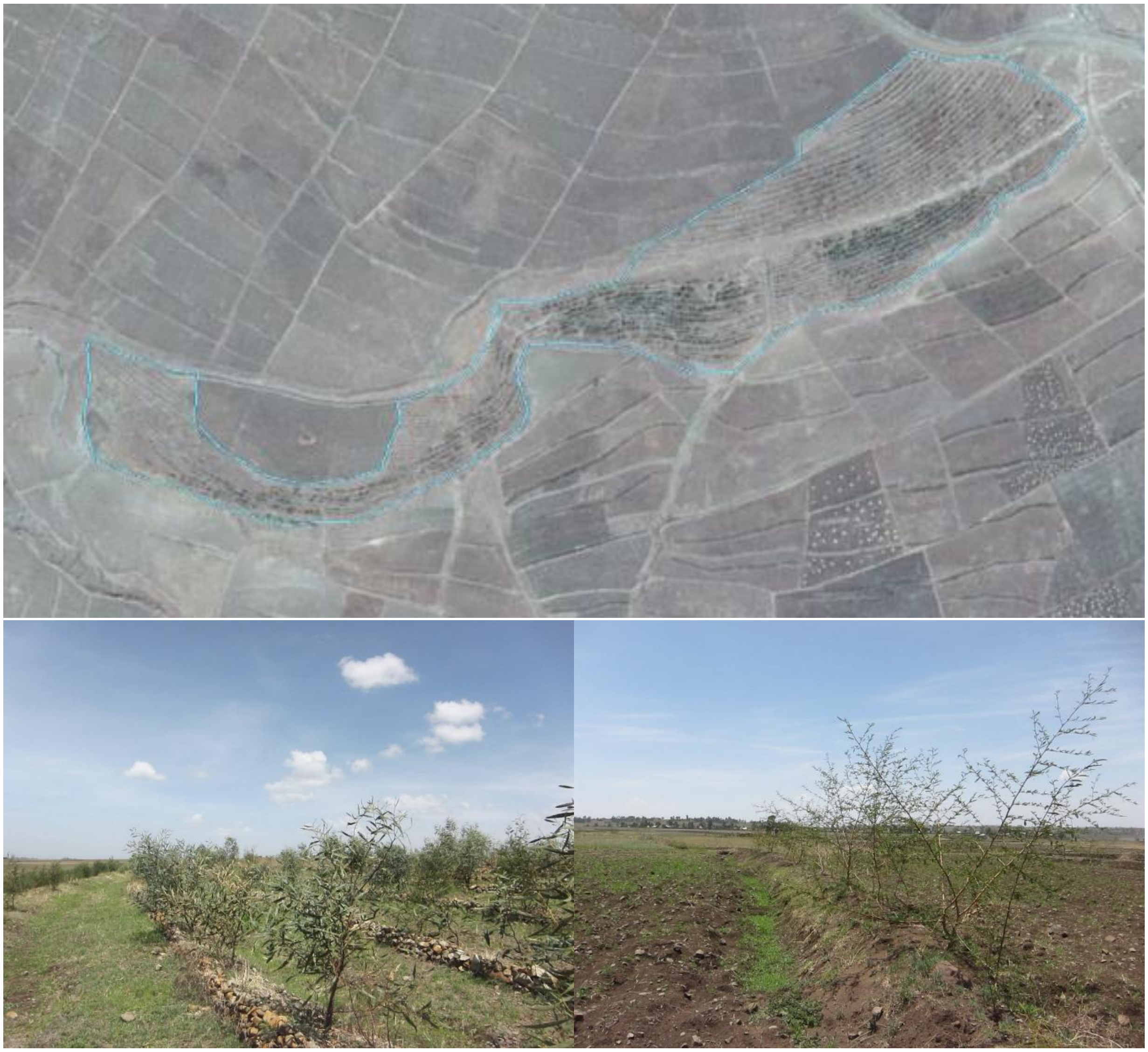


Figure 30 Amhara, Simada, Aje

Koeppen Class: Cwb
C = Warm Temperate Climate
w = with dry winter
b = warm summer

Budyko Climate: Steppe
Radiation index of Dryness: 1.334
Budyko Evaporation 923 mm/year
Budyko Runoff 242 mm/year
Budyko Evaporation 79.2 %

Budyko Runoff 20.8 %

Aridity: subhumid
Aridity Index: 0.92
Moisture Index: -8 %.
DeMartonne Index: 45
Precipitation Deficit: 100 mm/year

Climatic net primary production: 1617 g(DM)/m2/year,
NPP(Temperature): 1923 g(DM)/m2/year
NPP(Precipitation): 1617 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 4.6

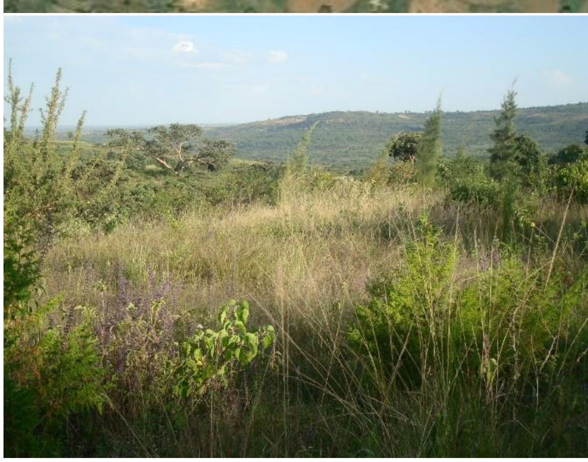
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	4	2	0	0	0	0	0	0	0	2	4	5	1
Effective Rain [mm]	17	26	52	63	75	99	153	152	108	48	23	13	829
Effective Rain Ratio [%]	97	96	91	89	86	80	54	56	78	92	96	98	71
Rainy Days	3	4	8	9	11	15	25	25	16	8	4	2	130
Solid Precipitation Ratio [%]	1	0	0	0	0	0	1	1	1	1	1	1	1

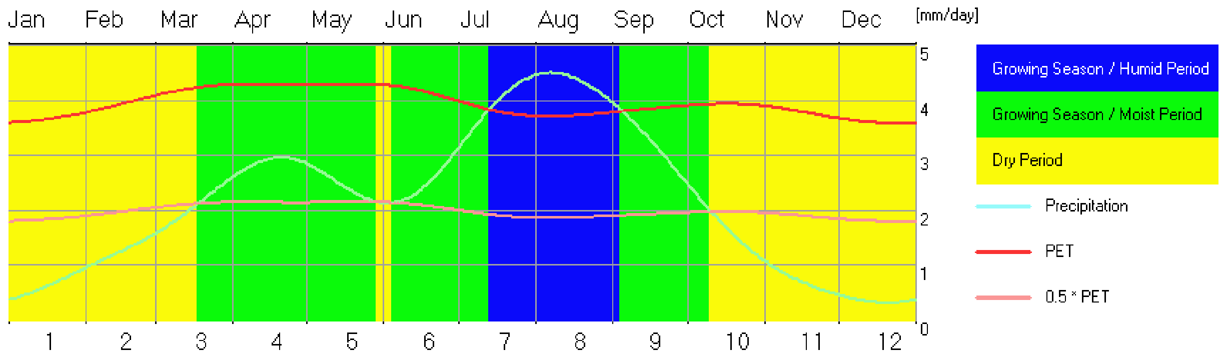
Region	Oromia
Woreda	Daro Lebu
Kebele	Odaleleba
Site name	Lege Hora
Site code	Or-DL-Od
GPS	8.6194 N, 40.3411 E
Elevation	1715-1748 m
Area	17 ha

The project is situated on a hill, maximum elevation 1748 m, with an area enclosure extending down to 1715 m elevation on NW - SE slopes. Prior to enclosure, the project site was sparsely vegetated and highly degraded, with extensive erosion and numerous erosion gullies. The area enclosure has no boundary fence, but is protected by a local by-law. No evidence of grazing encroachment was seen, despite locals using a path through the enclosure to move their livestock between pasture and homes on a daily basis. Local respect for the enclosure by-laws was further evidenced by the fact that during surveying several farmers separately volunteered the question as to whether the enclosure project could be extended to include more of the surrounding degraded land.

Physical measures implemented include gulley restoration with galvanized steel gabion-reinforced stone check dams, soil bund terracing, micro basins and stone-faced trenches for water catchment. Rehabilitated Gulley had extensive vegetation, including bananas, and deep soil in the top half, graduating to localised accumulations of sedimentary soil amongst bare rock at the lower reaches of the gulley. The control gulley sampled outside the area enclosure, by contrast, had only thin accumulations of soil and bare rock at all locations along it, and was comparatively sparsely vegetated.

Biological measures include: 1) the hilltop has coppiced *Eucalyptus globulus* spaced at 3-4m apart, with abundant ground vegetation. Due to concern that eucalyptus could be detrimental because of excessive transpiration and shading of ground vegetation, work has begun to interplant the eucalypts with *Grevillea robusta* in planting basins, with the intention to remove the eucalyptus as the Grevillea mature. However, the presence of dense ground vegetation around and between the eucalyptus, together with the observed pooling of water in microbasins, and trenches at elevation below the eucalyptus suggested that no detrimental impacts of eucalyptus were occurring. Given the beneficial impacts of the eucalyptus in terms of soil stabilization, increased carbon storage, timber provision for firewood and building, forage production, improved water infiltration and reduced soil evaporation from the ground cover vegetation, caution was advised in removal of the eucalyptus which appeared to be already an effective management system. 2) Below the eucalyptus, several distinct type of agroforestry management practices are implemented, with the area established increasing each year as resources allow. The agroforestry tree species include fruit trees (principally guava), Grevillea robusta, neem, and coffee. The main agroforestry combination observed were guava/neem; Grevillea; and mixed agroforestry including fruit, timber and coffee species interspersed. Undergrowth and grass is physically removed from below agroforestry stands (under the belief that this would increase water availability for trees). Advice was given to leave ground vegetation intact, or place surface mulch around tree stems. 3) One relatively-small area was planted with sugar cane and enset. Although this is not currently account for a large fraction of the land use, soil samples were taken from this land use to inform on whether this is a land use that should be expanded or not with respect to its impacts on soil carbon and soil fertility.





Koeppen Class: Aw
A = Equatorial Climate
w = savannah with dry winter

Budyko Climate: Steppe
Radiation index of Dryness: 2.053
Budyko Evaporation 717 mm/year
Budyko Runoff 80 mm/year
Budyko Evaporation 90 %
Budyko Runoff 10 %

Aridity: dry subhumid
Aridity Index: 0.55
Moisture Index: -45 %.
DeMartonne Index: 27
Precipitation Deficit: 641 mm/year

Climatic net primary production: 1233 g(DM)/m2/year,
NPP(Temperature): 2235 g(DM)/m2/year
NPP(Precipitation): 1233 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 20.8

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	20	34	54	81	66	57	104	106	82	44	24	10	682

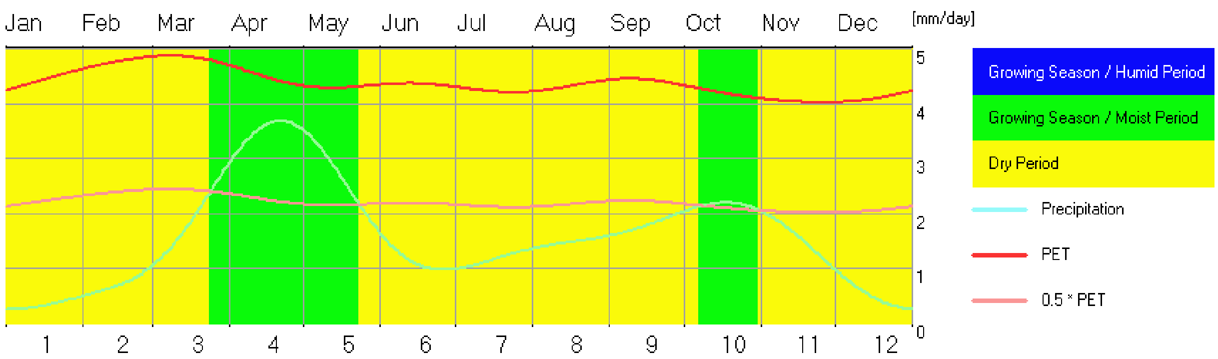
Effective Rain Ratio [%]	97	94	90	85	88	90	79	78	85	92	96	98	86
Rainy Days	3	5	7	11	9	8	14	15	11	6	3	2	94
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Oromia
Woreda	Delo Mena
Kebele	Nanega Dhera
Site name	Hajii
Site code	Or-DM-ND
GPS	6.4425 N, 40.1511E
Elevation	1161 m
Area	943 ha

Permanent enclosure with reduced, but not eliminated grazing pressure. Grazing by goats and camels is still evident, but Kebele NRM department and Farm Africa representatives claim that grazing is greatly reduced by introduction of a by-law that limits grazing. The only physical intervention applied to the entire site is a boundary of brash. In the most degraded areas, physical and biological intervention include soil bunds, half-moon terraces, microbasin planting holes in which trees are planted, and trenches. Surface erosion and overland flow is evident along margins of the site, no physical measure to limit erosion have been applied here. A water catchment pond has been constructed adjacent to one of these erosion flows, but trenches and bunds constructed appear insufficient to divert water into the pond which was empty at time of survey.

Until burning was legislated against in the 1980s site was burned regularly to control succession and increase grass yield. Since cessation of burning there have been no fire events, and less degraded areas have recovered abundant tree and shrub cover. Whether adoption of the site into PSNP two years ago has had further impact on site regeneration could not be determined from available data. What was clear was that locations outside enclosure close to houses were more severely degraded than the PSNP site, with only sparse vegetation cover, and no physical or biological measures implemented by households to limit further degradation. Modeling approach assumed that enforcement will be improved going forwards.

Figure 31 Oromia, Delo Mena, Nanega Dhera



Koeppen Class: BSh

B = Arid Climate

S = Steppe

h = hot

Budyko Climate: Semiarid

Radiation index of Dryness: 2.991

Budyko Evaporation 550 mm/year

Budyko Runoff 25 mm/year

Budyko Evaporation 95.6 %

Budyko Runoff 4.4 %

Aridity: semiarid

Aridity Index: 0.36

Moisture Index: -64 %.

DeMartonne Index: 17

Precipitation Deficit: 1024 mm/year

Climatic net primary production: 952 g(DM)/m2/year,
NPP(Temperature): 2432 g(DM)/m2/year
NPP(Precipitation): 952 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 13.6

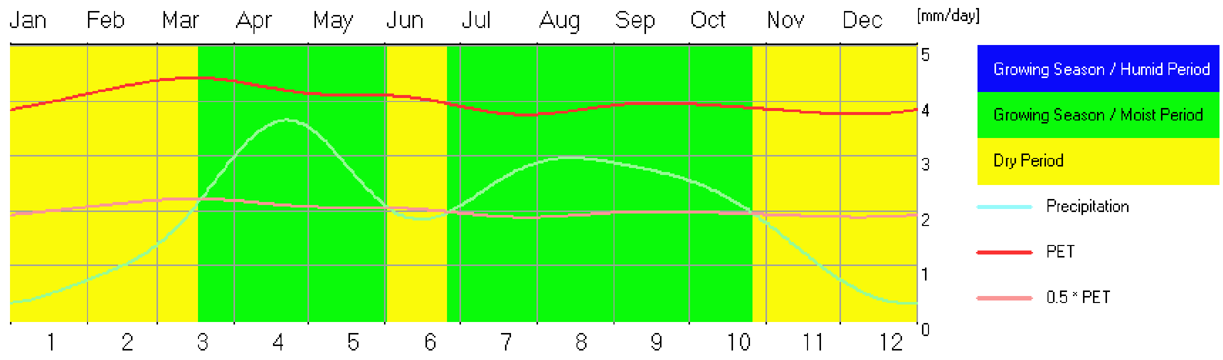
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	13	22	44	97	67	26	39	45	44	61	43	13	515
Effective Rain Ratio [%]	98	96	92	81	88	96	93	92	92	89	93	98	90
Rainy Days	2	3	5	12	8	3	5	6	6	8	6	2	66
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Oromia
Woreda	Goro
Kebele	Keku
Site name	Wayu Bure
Site code	O-G-K-WB
Lat,Long	6.9473, 40.6807
Elevation	1682 m
Watershed Area	500 ha

This watershed constitutes a wide depression surrounded by chains of low hills in all its directions except in its outlet in the northwest. Large part of the depression is occupied by croplands and many of the households are found settled the far end of the depression in the southwest next to the farm lands. The project area covers a very small land up in the hills in the northeastern direction. It is a permanent enclosure, which is dominantly covered by acacia woodlands and other small shrubs and bushy species. Tree density and height increases towards the center from the periphery.

This project was initiated in 2011 with main objectives of enhancing tree regeneration, implementing various SWC measures and apiculture. Biological measures undertaken include Gravilla robusta, Jatropha, Cordia Africana, Acacia spp., Chen'a, Biresa, Bilal, Chile, and Bika. Likewise, different physical measures which include micro-basins, terraces, and stone-faced soil bunds (inside croplands) are established.

Despite the presence of community bylaws that govern protection of the area closure, it seems that the laws are not well respected by certain members of the community who were observed grazing/browsing their animals inside the area closure. Modeling approach assumed that enforcement will be improved going forwards.



Koeppen Class: Aw

A = Equatorial Climate

w = savannah with dry winter

Budyko Climate: Steppe

Radiation index of Dryness: 2.276

Budyko Evaporation 672 mm/year

Budyko Runoff 59 mm/year

Budyko Evaporation 91.9 %
Budyko Runoff 8.1 %

Aridity: dry subhumid
Aridity Index: 0.5
Moisture Index: -50 %.
DeMartonne Index: 24
Precipitation Deficit: 730 mm/year

Climatic net primary production: 1154 g(DM)/m2/year,
NPP(Temperature): 2254 g(DM)/m2/year
NPP(Precipitation): 1154 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 12

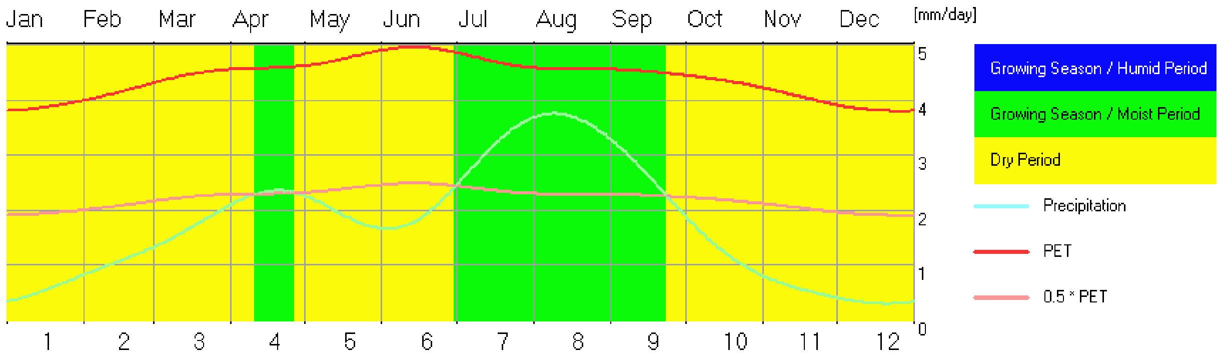
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	17	29	51	95	73	45	74	79	68	61	35	12	641
Effective Rain Ratio [%]	97	95	91	81	86	92	86	85	88	89	94	98	88
Rainy Days	2	4	7	13	10	6	10	11	9	9	5	2	88
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Oromia
Woreda	Mieso
Kebele	Fayo
Site name	Fayo
Site code	Or-Mi-Fa
Lat,Long	9.2305, 40.7328
Elevation	1410
Watershed Area:	112 ha

With a total area of 112 ha, this watershed constitutes a lower hill in its rear end in the western direction. Of the 112 ha land area, 92 ha has been designated for project intervention activities in 2011 with the main objectives of working on various SWC activities and plant restoration that has been severely degraded in the past. As part of the conservation strategy, an area closure has been established on the hillside, which is the main focus of the project. Based on types of SWC activities put in place, the area closure can be divided into two where half of the hillside constitute both physical and biological measures such as stone bunds and terraces, trenches, naturally regenerating vegetations (e.g. Accacia spp., Kitkita (Amha), and Dedeho (Amha), and recently planted seedlings of various species (e.g. Olea Africana, Shinus molle, Cordia Africana, Moringa). These measure are not present in the other side of the hills, it is only enclosed for natural regeneration of bushy species which are doing relatively well.

Like in other CSI sites, protection of the area closure is governed by bylaws set by the community. Besides, civil servants of various sectoral offices in the Woreda also take part and contribute occasionally towards the proper protection and conservation of the site in different ways such as planting and building of various conservation structures. As part of reinforcing biological conservation activities in the watershed, a new nursery site is on the process of being established at the foothill of the area closure.

Figure 32 Oromia, Mieso



Koeppen Class: BSh

B = Arid Climate

S = Steppe

h = hot

Budyko Climate: Semiarid

Radiation index of Dryness: 2.622

Budyko Evaporation 604 mm/year

Budyko Runoff 38 mm/year
Budyko Evaporation 94 %
Budyko Runoff 6 %

Aridity: semiarid
Aridity Index: 0.4
Moisture Index: -60 %.
DeMartonne Index: 20
Precipitation Deficit: 965 mm/year

Climatic net primary production: 1042 g(DM)/m2/year,
NPP(Temperature): 2385 g(DM)/m2/year
NPP(Precipitation): 1042 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 33.9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	17	29	45	66	54	45	88	94	67	32	20	10	567
Effective Rain Ratio [%]	97	95	92	88	90	92	83	82	88	95	97	98	88
Rainy Days	2	4	6	8	7	5	11	12	8	4	3	1	71
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

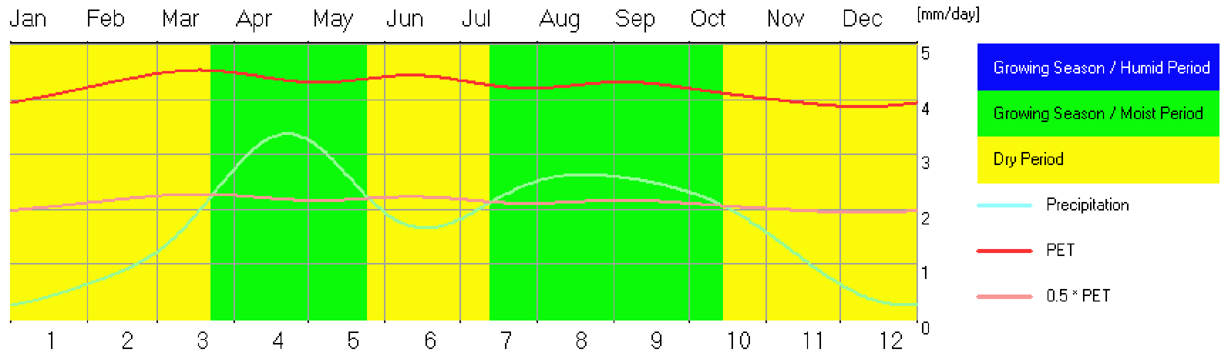
Region	Oromia
Woreda	Seweyna
Kebele	Chopi
Site name	Bila
Site code	Or-Se-Ch
Lat,Long	7.3329, 40.9882
Elevation	1583
Watershed Area	1435 ha

This is a very vast watershed with a total area of 1435 ha. The landscape is dominated by gently sloping ground descending down towards the outlet of the watershed in the northwest. At the background of these flat lands there are chains of limestone hills rising well above 2000 m.a.s.l altitude. These hills separate this watershed from adjacent watershed behind. The gentle sloping grounds are covered with scattered acacia woodlands and isolated shrubs, which are left for free grazing/browsing by domestic animals. Settlements and croplands are located in these low-lying areas. Half way up from these woodlands till the hilltops is the area designated as an area enclosure. The naturally regenerated vegetation is more dense and tall relative to those in the flat lands. High in the middle part of the hills are sparsely grown and tall junipers (*Junipers procera*) trees. These species of trees are indicators which tell that the area was once densely covered with this species in the past. These, however, were seriously deforested and degraded (even using fire) in the past for farmland expansion, fuel wood collection, and for farm tools making.

In an effort to conserve the area, a restoration project was underway since 2011 with prime objectives of implementing SWC activities, tree regeneration, beekeeping, and securing animal fodder via cut and carry system. Accordingly, biological measures for regenerating native species of trees (e.g. Accacia spp., Ficus vasta, Haroresa, Bilala, Qulqulecha, Birecha, Hamecha, Chene'a, Girarsa, Birbirsa, Gatira, Hidhecha, Olea Africana, Cactus, Sisal) and physical measures notably micro-basins and terraces were established.

The residents in the watershed practice mixed farming where they cultivate crops (e.g. sorghum) and keep cattle, goats and camel dominantly. Though the watershed is vast, it is only smaller part of it which is enclosed for conservation. The settlers practice free grazing in areas which are not protected while they practice cut and carry to feed their animals from inside the area closure.

Figure 33 Oromia, Seweyna



Koeppen Class: Aw

A = Equatorial Climate

w = savannah with dry winter

Budyko Climate: Semiarid

Radiation index of Dryness: 2.574

Budyko Evaporation 615 mm/year

Budyko Runoff 41 mm/year

Budyko Evaporation 93.8 %

Budyko Runoff 6.2 %

Aridity: semiarid

Aridity Index: 0.42

Moisture Index: -58 %.
DeMartonne Index: 21
Precipitation Deficit: 889 mm/year

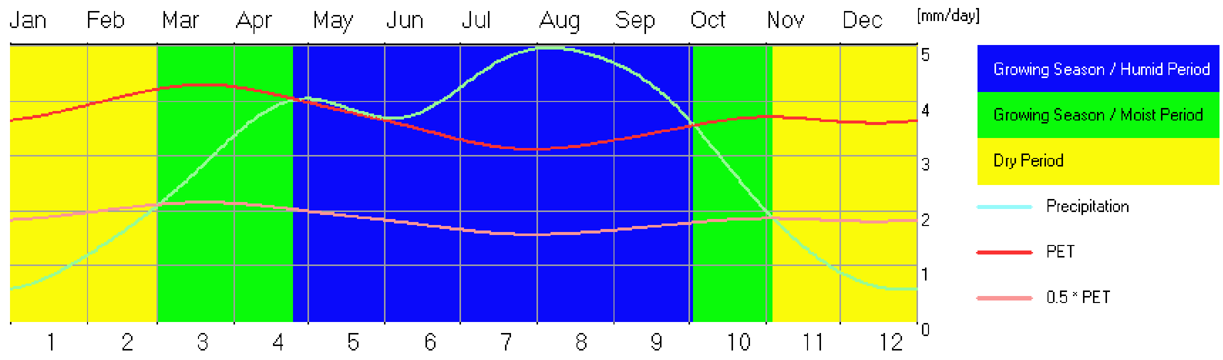
Climatic net primary production: 1060 g(DM)/m2/year,
NPP(Temperature): 2332 g(DM)/m2/year
NPP(Precipitation): 1060 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 12.9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	15	26	46	89	69	41	65	72	63	56	30	10	583
Effective Rain Ratio [%]	98	96	92	83	87	93	88	87	89	90	95	98	89
Rainy Days	2	3	6	11	9	5	9	10	8	7	4	1	75
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	SNNPR
Woreda	Alaba Special Woreda
Site name	Asore
Watershed/site name	Asore
Site code	SN-Al-As
Survey date	13/10/13
Lat,Long	7°14'41"N, 38°5'37"E
Elevation	1703 m

Area enclosure with physical soil and water conservation measures including soil and stone bunds, micro-basins and trenches. Planted with *Grevillea robusta, acacia spp., Eucalyptus spp. and Pinus Patula*, together with natural regeneration, now 20 years old. The enclosure also contains a mosaic of grassland (40% of the area) used for cut-and-carry grass production. Local farmers report greatly increased productivity of land (and forage obtained from it) since enclosure and SWC intervention. This is supported by condition of control site on opposite bank of the river that borders the enclosure; the control site being highly degraded, with extensive sheet and gulley erosion, sparse to absent vegetation, and exposed parent material in many areas.



Koeppen Class: BSh
B = Arid Climate
S = Steppe
h = hot

Budyko Climate: Steppe
Radiation index of Dryness: 1.501
Budyko Evaporation 892 mm/year
Budyko Runoff 189 mm/year
Budyko Evaporation 82.5 %
Budyko Runoff 17.5 %

Aridity: subhumid
Aridity Index: 0.81
Moisture Index: -19 %.
DeMartonne Index: 37
Precipitation Deficit: 262 mm/year

Climatic net primary production: 1537 g(DM)/m2/year,
NPP(Temperature): 2175 g(DM)/m2/year
NPP(Precipitation): 1537 g(DM)/m2/year
NPP is precipitation limited.

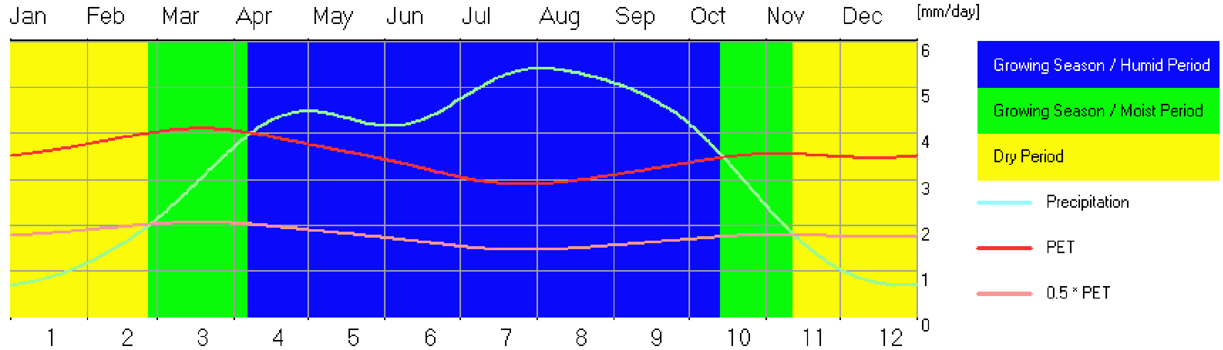
Gorczynski Continentality Index: 9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	26	44	70	97	98	90	116	113	103	73	39	18	886
Effective Rain Ratio [%]	96	92	87	81	81	83	75	76	79	87	93	97	82
Rainy Days	4	6	10	13	14	13	17	16	15	10	6	3	127
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	SNNPR
Woreda	Damot Gale
Kebele	Wondara Balose
Watershed/site name	Godaye
Site code	SN-DaG-WB
Lat,Long	6.9389°N, 37.809°E
Elevation	2210 m
Area	160 ha

Integrated soil and water conservation, with mixed cereal, vegetable, taro, and agroforestry food production systems. Located on lower north eastern slopes of a mountain that rises 900 m from the surrounding upland plain. Field crop production dominates the central, lower and flatter parts of the site, with households, home gardens, and agroforestry located on the surrounding ridges. Field boundaries are formed by soil bunds with adjacent water-conservation trenches, and are planted with perennial legumes (pigeon pea). Isolated areas of the site have not yet received SWC intervention, and show significant signs of erosion and gullying, and sparse-to-absent vegetation.



Koeppen Class: BSk
B = Arid Climate
S = Steppe
k = cold

Budyko Climate: Steppe
Radiation index of Dryness: 1.332
Budyko Evaporation 950 mm/year
Budyko Runoff 251 mm/year
Budyko Evaporation 79.1 %
Budyko Runoff 20.9 %

Aridity: subhumid
Aridity Index: 0.94
Moisture Index: -6 %.
DeMartonne Index: 43
Precipitation Deficit: 73 mm/year

Climatic net primary production: 1649 g(DM)/m2/year,
NPP(Temperature): 2063 g(DM)/m2/year
NPP(Precipitation): 1649 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 12.8

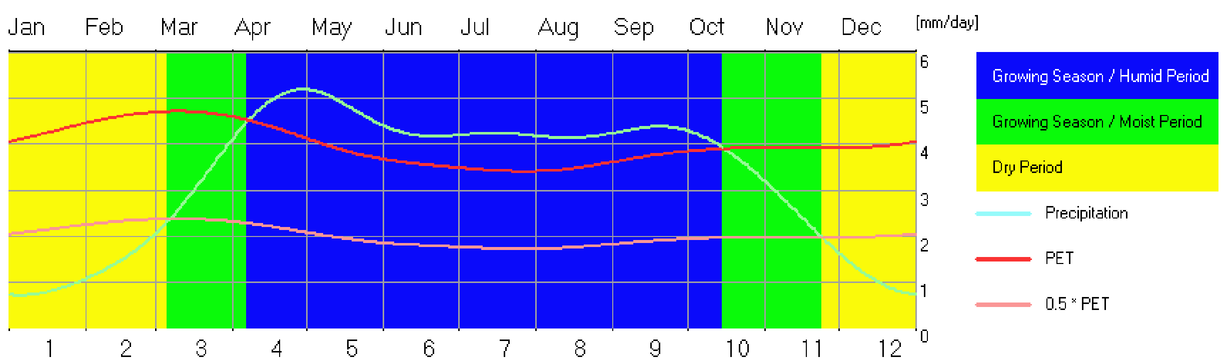
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	28	43	75	105	106	99	124	120	110	86	43	22	961

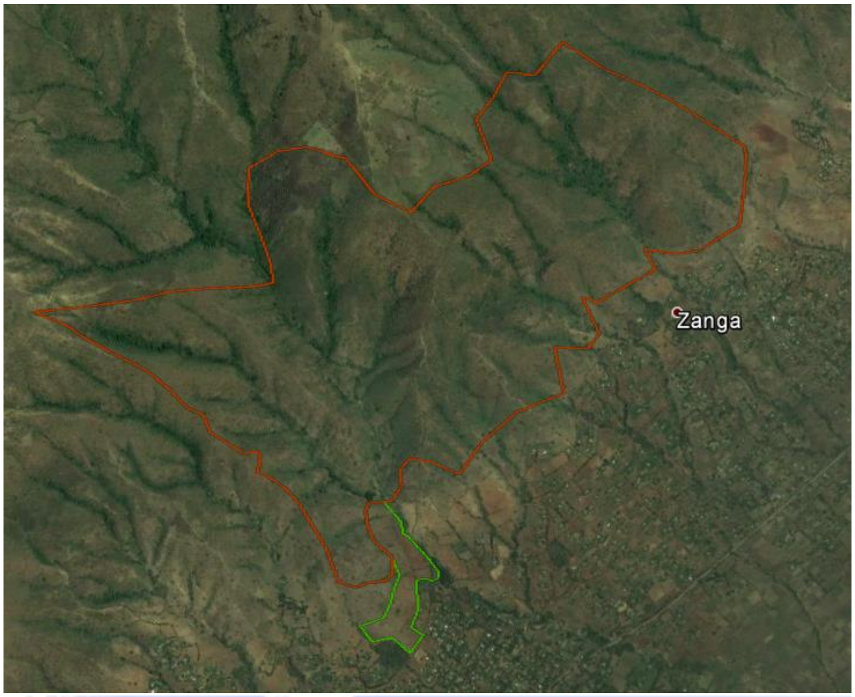
Effective Rain Ratio [%]	95	93	86	79	78	80	73	74	77	83	92	96	80
Rainy Days	4	6	11	15	15	14	19	18	16	13	7	3	141
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

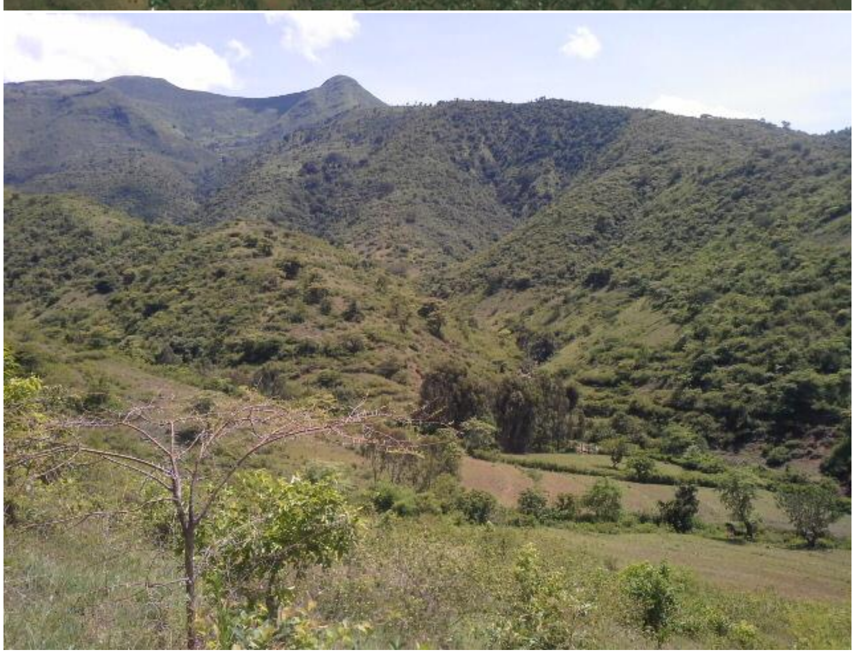
Region	SNNPR
Woreda	Demba Gofa
Kebele	Borda
Site name	Usha
Site code	S-DG-B-U
Lat,Long	6.3436,36.9205
Elevation	1430
Watershed Area	136 ha

The project site is located some 6 km to the northeast of Sawla town, capital of Gofa Zone. It is located along the western escarpment of an extensive depression running in a northeast direction. The topography is characterized by rugged landscape with steep and dissected hills covered with woody vegetation. Whereas, settlements are located along the southern foothills of the mountain.

Intervention activities were started with the objectives of enhancing natural regeneration through various SWC activities. Besides, it aims at securing animal fodder through encouraging the local community to practice cut and carry system rather than free grazing. Beekeeping, as a means of income diversifications remains the other aspect which the project intervention targeted. The intervention activities within the watershed were started in different years. As a result, we have two permanent closures, one with 9 years old and the other only 4 years. Biological and physical measures are established in both of these sites. Accacia spp., Eucalyptus globulus, Lantana camara, Subo (local name), Woiba (local name), vetiver hedgerows (inside cropland) represent the major biological conservations measures undertaken. On the other hand, terraces, stone bund, micro-basins, and trenches are important physical structures established.




Zanga



Koeppen Class: As
A = Equatorial Climate
s = savannah with dry summer

Budyko Climate: Steppe
Radiation index of Dryness: 1.367
Budyko Evaporation 956 mm/year
Budyko Runoff 243 mm/year
Budyko Evaporation 79.7 %
Budyko Runoff 20.3 %

Aridity: subhumid
Aridity Index: 0.83
Moisture Index: -17 %.
DeMartonne Index: 38
Precipitation Deficit: 253 mm/year

Climatic net primary production: 1647 g(DM)/m2/year,
NPP(Temperature): 2344 g(DM)/m2/year
NPP(Precipitation): 1647 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 25.1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	28	41	76	116	113	97	108	100	104	95	64	27	970
Effective Rain Ratio [%]	95	93	86	75	76	81	78	80	79	81	88	95	81
Rainy Days	4	5	10	15	15	13	15	14	14	13	8	4	130
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	SNNPR
Woreda	Konso Special Woreda
Kebele	Lehaife
Site name	Boloshe
Site code	SN-Ko-Le
Lat,Long	5.4019, 37.3469
Elevation	1473 m
Watershed Area	95 ha

This is a relatively dry watershed with its topography characterized by gentle to flat grounds where large part of it is occupied by gullies and highly degraded landscape. However, some of these features are currently covered with vegetation as a result of project intervention activities in some parts of it. Otherwise, significant part of the designated watershed still constitutes severely eroded and shattered grounds.

Settlements are located in two areas: at the rear ends of the watershed in the northwest and the other one in the southwest direction along the main highway. Croplands are located in the northern border and to a certain extent the southwestern part of the watershed.

In response to the very severe land degradation caused by deforestation and overgrazing, rehabilitation activities started some 9 years ago in limited portion of the watershed. The intervention activities continued and scaled up year after year to reach and cover a total of 94.5 ha today with objectives of initiating plant regeneration, SWC, and availing animal fodder through cut and carry system. To meet these objectives, both biological (e.g., Accacia mellifera, Kitkita (Amh), Gravillae robusta, Eucalyptus globulus, Elephant grass) and physical measures (e.g. deep trenches, micro basin, soil bunds and stone check dams) are established in the project site. As part of a physical measure, a pond is established to reduce run-off and serve as a source of drinking water for both humans and livestock.

As a result of the intervention activities, the landscape is now changed into a mosaic of land use constituting a mix of grass, bush (Acacia mellifera) lands and Ecucalyptus compartments.

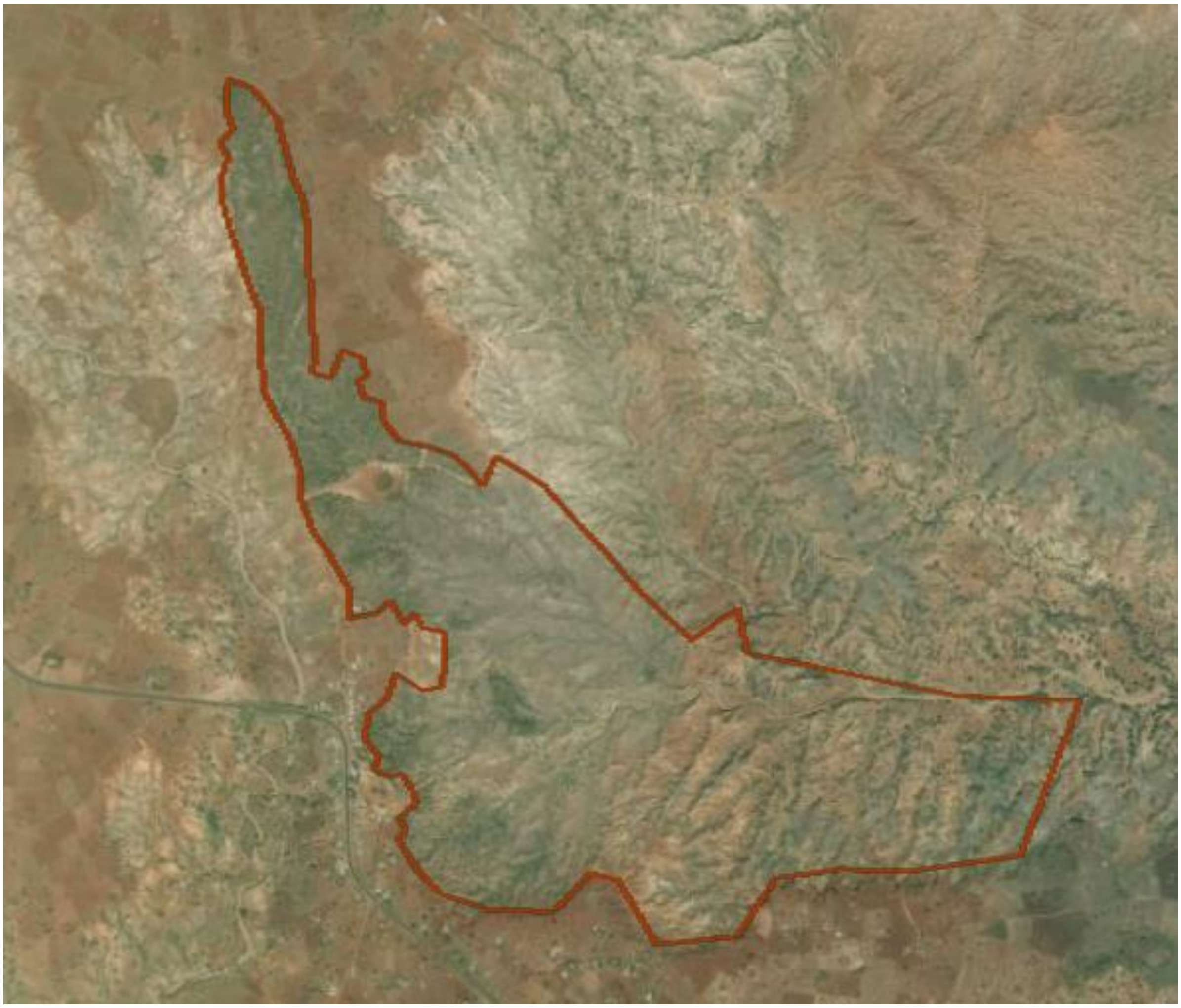
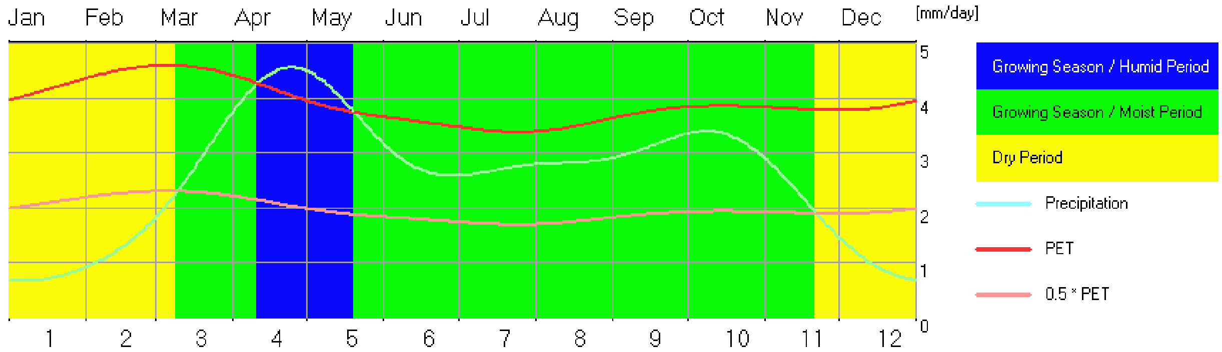


Figure 34 SNNPR, Konso



Koeppen Class: As
A = Equatorial Climate
s = savannah with dry summer

Budyko Climate: Steppe
Radiation index of Dryness: 1.754
Budyko Evaporation 814 mm/year
Budyko Runoff 127 mm/year
Budyko Evaporation 86.5 %
Budyko Runoff 13.5 %

Aridity: subhumid
Aridity Index: 0.66
Moisture Index: -34 %.
DeMartonne Index: 31
Precipitation Deficit: 484 mm/year

Climatic net primary production: 1394 g(DM)/m2/year,
NPP(Temperature): 2257 g(DM)/m2/year
NPP(Precipitation): 1394 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 28.8

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	25	37	68	109	96	67	77	76	76	88	57	27	801
Effective Rain Ratio [%]	96	94	87	78	81	88	86	86	86	83	90	96	85
Rainy Days	3	5	9	15	13	9	11	11	11	12	8	4	111
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

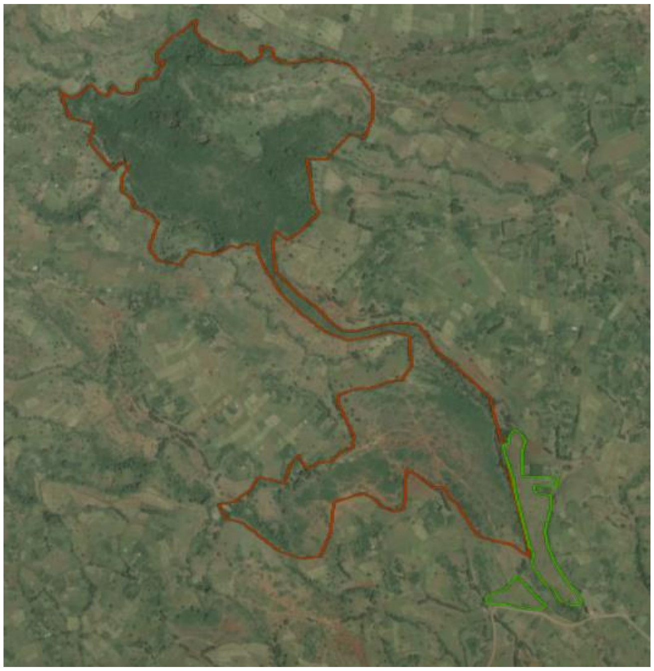
Region	SNNPR
Woreda	Soro
Kebele	Shera
Site name	Sheshecho
Site code	SN-So-Sh
Lat,Long	7.4297,37.5697
Elevation	1970 m
Watershed Area	35 ha

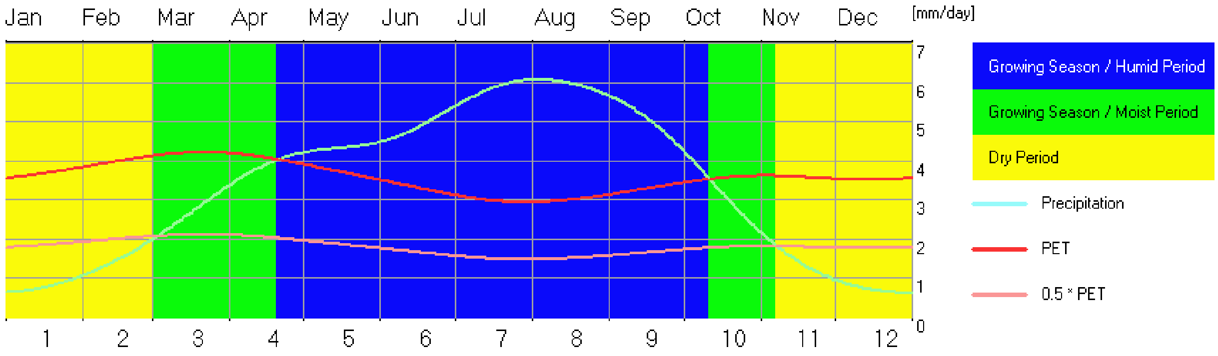
The watershed is located in a relatively steep slope landscape dissected by headstream river starting from foothills of big mountain ranges in Southeast direction. The valley separates croplands and settlements from project site western direction. Settlements are located along the ridges in the eastern and south-eastern sides of the watershed

The intervention was started in 2010 as a response to severe land degradation problem caused by overexploitation of the vegetation cover and the resulted severe soil erosion. Thus the objective of the project was aimed rehabilitation of the degraded landscape through regeneration of indigenous tree species, implementing cut and carry system for animal fodder, practicing beekeeping activities as an alternative income source, and engagement on SWC activities. Various physical and biological SWC measures are put in place inside the permanent area closure. The types of physical structures worked out include among others soil bunds, half-moon ditches, trenches, micro-basins, bushwood-check dams. As of the biological measures, various species of trees notably *Gravillae. r*, *Eucalyptus. g*, *Accacia d*, *Vetievera zizanoides*, sisal, *Kitkita (Amh)*, *Olea Africana*, *Croton, Podocarpus.g* are seen well established alongside naturally regenerated grasses and other bushy species vegetations.

Croplands are located on a steep slope opposite to the project site closure separated with a deep river valley. Only little SWC interventions (in the form of soil bunds and grass strips only) were made on the croplands to reduce the runoff.

The area enclosure is protected by law whereby any member bypassing the laws shall be punished in cash. However, the local community are allowed to collect traditional medicinal plants as well as cut grass for animal feed with discount payment.




Jan
Feb
Mar
Apr
May
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Aug
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[mm/day]
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
9
10
11
12
Growing Season / Humid Period
Growing Season / Moist Period
Dry Period
Precipitation
PET
0.5 * PET

Koeppen Class: BSh
B = Arid Climate
S = Steppe
h = hot

Budyko Climate: Steppe
Radiation index of Dryness: 1.294
Budyko Evaporation 963 mm/year
Budyko Runoff 269 mm/year
Budyko Evaporation 78.2 %
Budyko Runoff 21.8 %

Aridity: subhumid
Aridity Index: 0.95
Moisture Index: -5 %.
DeMartonne Index: 43
Precipitation Deficit: 71 mm/year

Climatic net primary production: 1676 g(DM)/m2/year,
NPP(Temperature): 2121 g(DM)/m2/year
NPP(Precipitation): 1676 g(DM)/m2/year
NPP is precipitation limited.

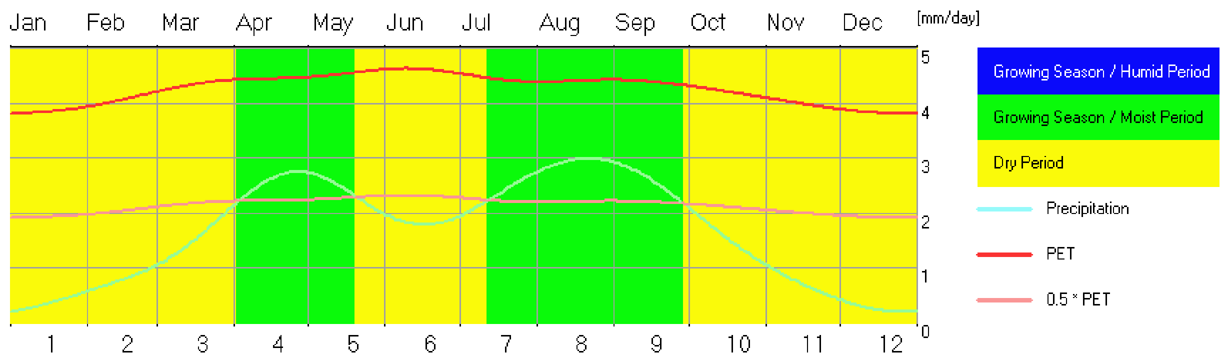
Gorczynski Continentality Index: 11.8

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	25	40	72	97	106	110	131	129	116	80	41	21	968
Effective Rain Ratio [%]	96	93	87	81	78	77	70	71	75	85	93	96	79
Rainy Days	4	6	10	14	15	16	19	19	17	12	6	3	141
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Somali
Woreda	Gursum
Kebele	Fafan
Watershed / Site	Caracaska
Site Code	So-Gu-Fa
GPS	9° 14’ 09’’ N; 42° 35’ 20’’ E
Elevation	1442 m
Size	40x15 m (<0.1 ha)

Site is only 0.1 ha in size, situated on an area of flat, bare land adjacent to a PSNP grain warehouse. A grid of micro-basins were dug 3 weeks prior to the survey date, and spaced in a 2x3 m grid orthogonal grid. Linear micro-bunds are constructed from the removed soil adjacent to the microbasins. Site is bounded by a road to the south, an erosion gulley to the East, and by cereal fields to the North and West. Located beside the Jijiga-Harar road, approx 300 m West of Fafan. Adjacent fields are used to grow maize (early variety: 120 days), and sorghum. Check dams were applied only on small secondary gulleys, and half have been lost already in floods. Main gulley has small area of bank ridges planted with cacti and succulents to stabilise banks, but not in systematic way and on a stretch of only 3 to 4 meters. The rest of watershed up to hills has no intervention. According to Mercy Corps CSI informant, the plan is to plant trees into the micro-basins. Above-ground biomass is currently almost absent. Small amount of vegetation that was previously present was removed during physical structure construction.

There is no fencing of the area, and no plans for a systematic rangeland management system to be implemented.



Koeppen Class: BSh

B = Arid Climate

S = Steppe

h = hot

Budyko Climate: Semiarid

Radiation index of Dryness:	2.749
Budyko Evaporation	575 mm/year
Budyko Runoff	32 mm/year
Budyko Evaporation	94.7 %
Budyko Runoff	5.3 %

Aridity: semiarid

Aridity Index: 0.39
Moisture Index: -61 %.
DeMartonne Index: 19
Precipitation Deficit: 951 mm/year

Climatic net primary production: 995 g(DM)/m2/year,

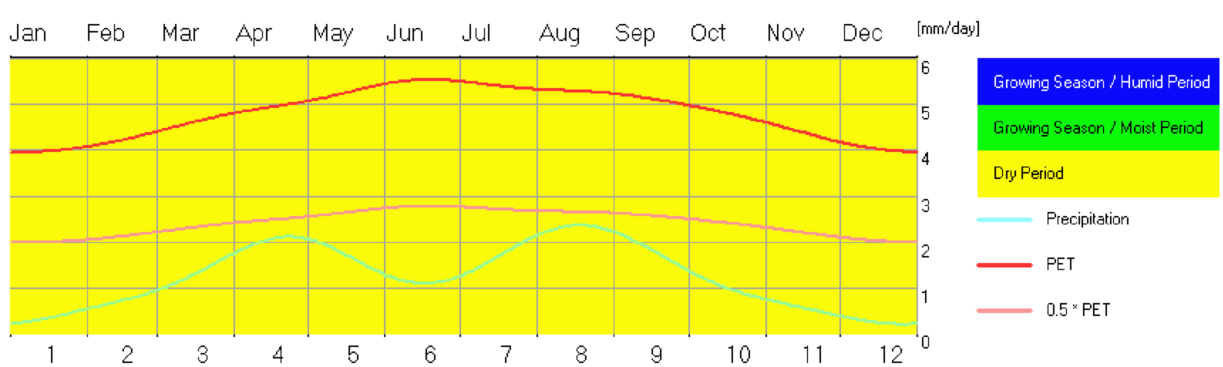
NPP(Temperature): 2313 g(DM)/m2/year
NPP(Precipitation): 995 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 21.1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	13	23	39	73	66	45	66	80	68	40	21	7	542
Effective Rain Ratio [%]	98	96	93	87	88	92	88	85	88	93	96	99	89
Rainy Days	2	3	5	9	9	6	9	10	9	5	3	1	71
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Somali
Woreda	Shinile
Kebele	Baraq
Watershed/site name	Baraq
Site code	So-Sh-Ba
GPS	9°40'39" N, 41°57'40" E
Elevation	1070 m
Area	1 ha

Surrounding area arid and sparsely vegetated, with occasional small native shrubs (predominantly acacia spp.) and little ground vegetation. A series of ten stone bunds, each 100 m long, and up to 30cm high, have been constructed on approximately 1 ha of bare stony hillside. Bunds were constructed only a few months previous to survey. Lower bunds are located on shallow slope at base of hill and continue up slope for 100 m. Bunds are low and poorly constructed, with large stones absent in many areas, and small stones or infill absent in others. No water catchment structures or biological measures have been implemented, and area is not enclosed. No increase in sparse vegetation relative to surrounding areas is evident. Neither is there any evidence of soil accumulation on the bunds. On the soil bund area, a total of 41 ha^{-1} small (1 to 2 m) acacia shrubs are present. Ground vegetation is almost absent. Adjacent control site had 43 ha^{-1} small acacia shrubs (not statistically different). Ground vegetation was, as on the project site, almost absent. Site was modeled under the assumption that the enclosure would be enforced allowing for natural regeneration of the native acacia shrubland combined with cut-and-carry grass production.



Koeppen Class: BSh
B = Arid Climate
S = Steppe
h = hot

Budyko Climate: Desert
Radiation index of Dryness: 3.793
Budyko Evaporation 441 mm/year
Budyko Runoff 11 mm/year
Budyko Evaporation 97.6 %
Budyko Runoff 2.4 %

Aridity: semiarid
Aridity Index: 0.26
Moisture Index: -74 %.
DeMartonne Index: 13
Precipitation Deficit: 1305 mm/year

Climatic net primary production: 777 g(DM)/m2/year,
NPP(Temperature): 2503 g(DM)/m2/year
NPP(Precipitation): 777 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 39.3

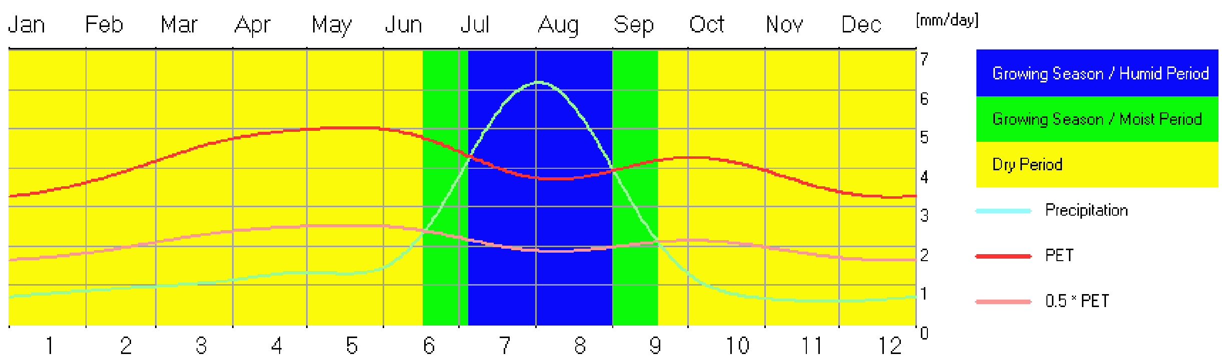
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	11	20	34	59	49	27	49	67	48	26	18	7	416
Effective Rain Ratio [%]	98	97	94	89	91	96	91	88	92	96	97	99	92
Rainy Days	2	3	4	7	6	3	6	8	5	3	2	1	50
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Tigray
Woreda	Ahferom
Kebele	Siero
Site name	Chearo
Site code	Ti-Ah-Si
Lat,Long	14.3201 N, 39.2236
Elevation	2047 m
Area	400 ha

The site encompasses a broad valley, between eroded hills with sparse ground and shrub vegetation. Site was previously heavily gullied until restoration work began in 2008. Soil accumulation from check dams and terracing was followed by implementation of a mixed SLM project dominated by cereal production, with vegetables, agroforestry, and tree fruit. Agroforestry trees (mainly *Luecaena leucophalus* and *Acacia*) provide fertility (N fixation), forage, firewood, and shade. Trees are present both as hedgerows, and also (esp. acacia) as intermittent mature standards within fields. Mineral and organic fertilizers (both compost and manure) are both used in production systems. Compost is produced from both household waste and from vegetable production waste. Approximately 840 households farm the 400 ha site (average plot approx. 0.5 ha). Application rates of inorganic fertilizer and mineral fertilizer varies by plot. Soil is very sandy.

Irrigation is provided from both catchment ponds/wells and from river, using mechanical pumps and drip hoses. Irrigated area is subset of each plot (0.04 ha), with non-irrigated areas used mainly for wet season cereal production, with some irrigation supplementation when required due to water stress.

Figure 35 Tigray, Ahferom



Climatic Information for
Longitude: 39.224°
Latitude: 14.32°
Altitude: 2000m

Koeppen Class: Cfb
C = Warm Temperate Climate
f = fully humid
b = warm summer

Budyko Climate: Semiarid

Radiation index of Dryness: 2.345
Budyko Evaporation 650 mm/year
Budyko Runoff 53 mm/year
Budyko Evaporation 92.5 %
Budyko Runoff 7.5 %

Aridity: semiarid

Aridity Index: 0.47
Moisture Index: -53 %.
DeMartonne Index: 24
Precipitation Deficit: 799 mm/year

Climatic net primary production: 1119 g(DM)/m2/year,

NPP(Temperature): 2154 g(DM)/m2/year
NPP(Precipitation): 1119 g(DM)/m2/year
NPP is precipitation limited.

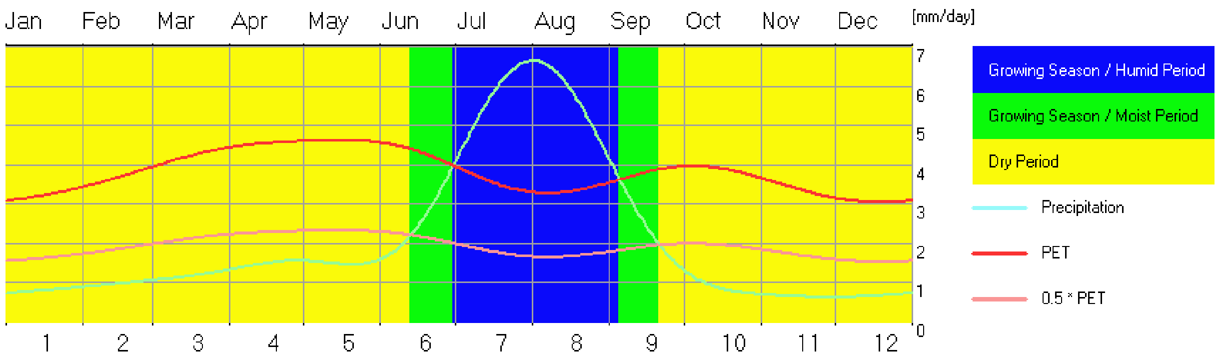
Gorczynski Continentality Index: 10.2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	1	0	0	0	0	0	0	0	0	0	0	1	0
Effective Rain [mm]	20	23	30	40	42	49	128	127	52	27	22	19	579
Effective Rain Ratio [%]	97	96	95	93	93	91	71	72	91	96	96	97	82
Rainy Days	3	3	4	6	6	7	18	18	7	4	3	3	82
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Tigray
Woreda	Gulo Mekeda
Kebele	Shewit Lemlem
Site name	Serawat
Site code	Ti-GM-SL
Lat,Long	14°25'9.00"N, 39°21'23.00"E
Elevation	2346 m
Area	30 ha

Soil and water conservation project on steep-sloped highly eroded escarpment at head of an ephemeral fluvial valley descending from higher plateau to lower plains. Plateau has extensive cereal (teff, barley, wheat) production present. Enclosure is a community-shared common-land resource. Where SWC measures are not present, high erosion rates on valley slopes evident from ground surface of thin (18-20cm) entisols and exposed parent material.

Project consists of stone-bund terraces with stone-faced trenches and micro basin water catchment. Terraces are planted with trees following establishment. 15 hive apiary on site shared by 16 beneficiaries. Grazing excluded, with cut and carry system for local beneficiaries to collect grass.


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
[mm/day]
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
11
12
Growing Season / Humid Period
Growing Season / Moist Period
Dry Period
Precipitation
PET
0.5 * PET

Koeppen Class: Cfb

C = Warm Temperate Climate

f = fully humid

b = warm summer

Budyko Climate: Steppe

Radiation index of Dryness: 2.115

Budyko Evaporation 688 mm/year

Budyko Runoff 70 mm/year

Budyko Evaporation 90.7 %

Budyko Runoff 9.3 %

Aridity: dry subhumid

Aridity Index: 0.55

Moisture Index: -45 %.

DeMartonne Index: 28

Precipitation Deficit: 630 mm/year

Climatic net primary production: 1186 g(DM)/m2/year,

NPP(Temperature): 2000 g(DM)/m2/year

NPP(Precipitation): 1186 g(DM)/m2/year

NPP is precipitation limited.

Gorczynski Continentality Index: 7.7

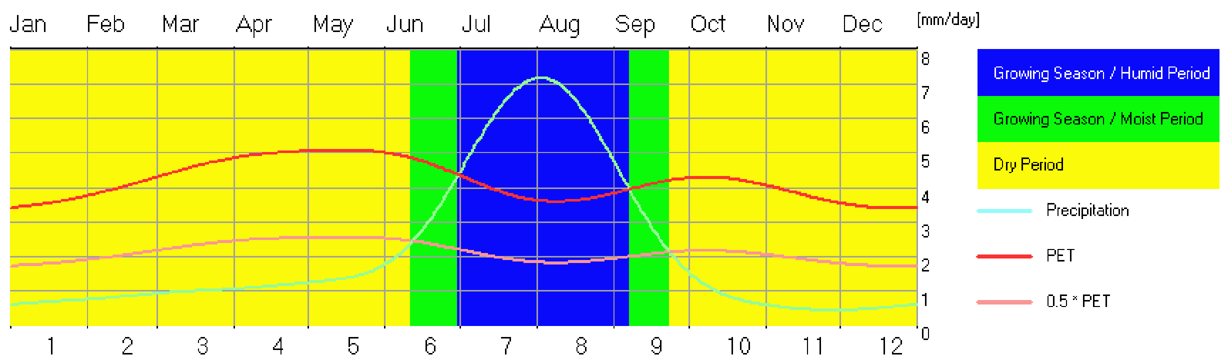
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	4	2	0	0	0	0	0	0	0	1	3	6	1
Effective Rain [mm]	21	24	34	47	47	51	134	132	51	28	24	20	614
Effective Rain Ratio [%]	97	96	94	92	92	91	69	70	91	95	96	97	81
Rainy Days	3	4	5	7	7	7	20	20	8	4	4	3	92
Solid Precipitation Ratio [%]	1	0	0	0	0	0	0	0	0	0	1	1	0

Region	Tigray
Woreda	Kola Tembein
Kebele	Doctor Atikilti
Site name	Doctor Atikilti
Site code	Ti-KT-DA
Lat,Long	13.6789 N, 38.9579 E
Elevation	1920 m
Area	256 ha

Soil and water conservation project on steep-sloped highly eroded escarpment. Settlement is located on flatland at head of watershed and is planted primarily with cereals (teff, barley, maize). Community-shared common land resource. Where SWC measures are not present, high erosion rates on valley slopes leads to surface of only entisols or exposed rock.

Project consists of stone-bund terraces entirely covering the steep hillsides. Trenches are occasionally present for rain water harvesting. Terraces are formed naturally by deposition behind stone bunds, with no soil movement by people. Terraces are planted with acacia trees following establishment. Bedrock exposed by erosion in many places. Livestock are excluded from the project area.

Cropland is estimated to be 45 ha within the watershed and is located on flat land at both the head of the catchment and on the valley floor in fluvial (or alluvial?) soils. SWC measures include stone-bund terraces and occasional percolation trenches.



Koeppen Class: Cwb

C = Warm Temperate Climate
w = with dry winter
b = warm summer

Budyko Climate: Steppe

Radiation index of Dryness: 2.143
Budyko Evaporation 703 mm/year
Budyko Runoff 71 mm/year
Budyko Evaporation 90.8 %
Budyko Runoff 9.2 %

Aridity: dry subhumid

Aridity Index: 0.51
Moisture Index: -49 %.
DeMartonne Index: 26
Precipitation Deficit: 748 mm/year

Climatic net primary production: 1205 g(DM)/m2/year,

NPP(Temperature): 2210 g(DM)/m2/year
NPP(Precipitation): 1205 g(DM)/m2/year

NPP is precipitation limited.

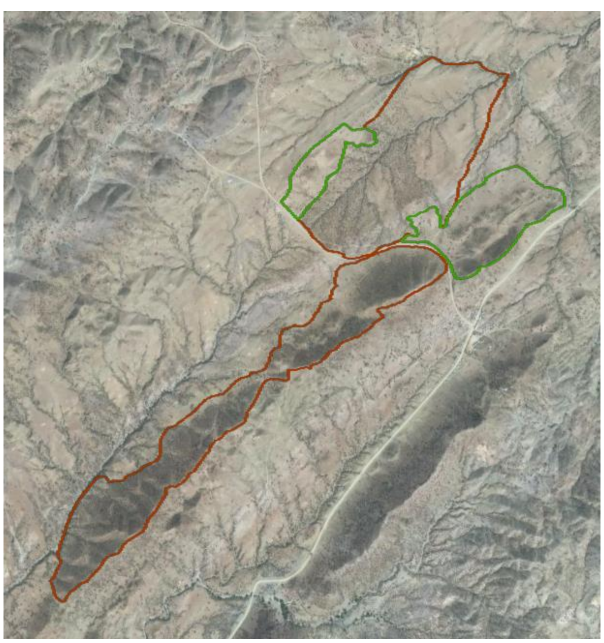
Gorczynski Continentality Index: 9.7

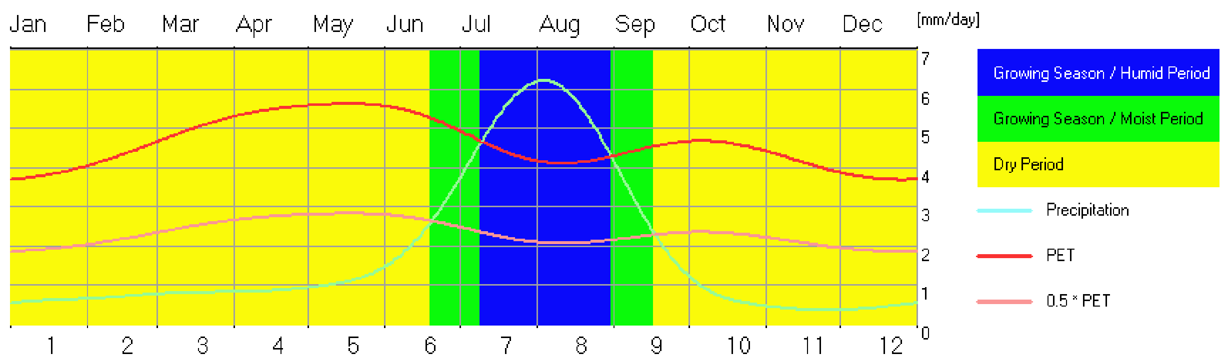
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	17	20	30	36	44	61	138	140	62	28	18	16	609
Effective Rain Ratio [%]	97	97	95	94	92	89	67	66	89	95	97	97	79
Rainy Days	3	3	4	5	6	8	20	20	9	4	3	2	87
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

Region	Tigray
Woreda	Tanqua Abergele
Kebele	Gera
Site name	Aba Tila
Site code	Ti-TA-Ge
Lat,Long	13.4339 N, 38.9904 E
Elevation	1450 m
Area	210 ha

Soil and water conservation project in bowl-shaped watershed. Headwater areas on lateral sides of watershed are steeply sloped, whereas middle part of the headwaters is relatively flat. Core of the watershed is relatively flat containing many primary ephemeral streams that converge on a secondary ephemeral stream in the center. Settlement is sparsely scattered throughout the project area.

Headwater hillsides are extensively covered with stone-faced bunds and occasional percolation trenches. Flat central part of the watershed is covered extensively with percolation trenches, check dams in gulleys, and occasional stone-faced bunds. Soils are highly eroded in many places leading to exposed rock. Soils have started to regenerate in areas where SWC measures are present. Livestock are excluded from the project area. Cut and carry practices are employed in the project area.





Koeppen Class: BSh
B = Arid Climate
S = Steppe
h = hot

Budyko Climate: Semiarid
Radiation index of Dryness: 2.616
Budyko Evaporation 617 mm/year
Budyko Runoff 39 mm/year
Budyko Evaporation 94 %
Budyko Runoff 6 %

Aridity: semiarid
Aridity Index: 0.39
Moisture Index: -61 %.
DeMartonne Index: 20
Precipitation Deficit: 1023 mm/year

Climatic net primary production: 1060 g(DM)/m2/year,
NPP(Temperature): 2382 g(DM)/m2/year
NPP(Precipitation): 1060 g(DM)/m2/year
NPP is precipitation limited.

Gorczynski Continentality Index: 14.2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Ground Frost Frequency [%]	0	0	0	0	0	0	0	0	0	0	0	0	0
Effective Rain [mm]	15	17	26	28	36	54	124	131	52	23	15	14	535

Effective Rain Ratio [%]	98	97	96	95	94	91	73	70	91	96	98	98	82
Rainy Days	2	2	3	3	4	6	16	18	7	3	2	2	68
Solid Precipitation Ratio [%]	0	0	0	0	0	0	0	0	0	0	0	0	0

ANNEX 4. DYNAMIC MODEL PARAMETER VALUES

```
CENTURY site file for SNNPR, Alaba Special Woreda, Asore ASG model runs:
X     Asore ASG input parameters
*** Climate parameters    climate data for precip/temp  std & skew 30 year data
3.1               PRECIP(1)
8.8               PRECIP(2)
9.8               PRECIP(3)
12.4              PRECIP(4)
10.8              PRECIP(5)
6.5               PRECIP(6)
13.1              PRECIP(7)
12.9              PRECIP(8)
11.3              PRECIP(9)
4.9               PRECIP(10)
3.2               PRECIP(11)
5.4               PRECIP(12)
    1.7434        PRCSTD(1)
    1.5903        PRCSTD(2)
    3.9085        PRCSTD(3)
    4.0425        PRCSTD(4)
    5.0834        PRCSTD(5)
    7.8130        PRCSTD(6)
    7.4170        PRCSTD(7)
    4.9992        PRCSTD(8)
    6.9514        PRCSTD(9)
    4.7154        PRCSTD(10)
    3.8298        PRCSTD(11)
    2.3158        PRCSTD(12)
    1.4145        PRCSKW(1)
    0.5059        PRCSKW(2)
    0.8501        PRCSKW(3)
    0.3968        PRCSKW(4)
    0.7749        PRCSKW(5)
    0.9489        PRCSKW(6)
    1.2683        PRCSKW(7)
    0.4616        PRCSKW(8)
    0.7289        PRCSKW(9)
    0.5417        PRCSKW(10)
    0.2601        PRCSKW(11)
    0.5048        PRCSKW(12)
10.7              TMN2M(1)
12.0              TMN2M(2)
12.3              TMN2M(3)
12.8              TMN2M(4)
12.0              TMN2M(5)
12.3              TMN2M(6)
12.8              TMN2M(7)
12.6              TMN2M(8)
12.5              TMN2M(9)
10.5              TMN2M(10)
9.1               TMN2M(11)
7.9               TMN2M(12)
27.6              TMX2M(1)
28.1              TMX2M(2)
27.7              TMX2M(3)
27.0              TMX2M(4)
26.8              TMX2M(5)
25.1              TMX2M(6)
23.5              TMX2M(7)
23.7              TMX2M(8)
25.1              TMX2M(9)
26.6              TMX2M(10)
27.1              TMX2M(11)
27.7              TMX2M(12)
*** Site and control parameters
0                 IVAUTO flag for source of initial soil C values
1.0               NELEM
7.25              SITLAT
```

```
38.09               SITLNG
0.47                SAND
0.23                SILT
0.31                CLAY
1.47                BULKD
6.0                 NLAYER
6.0                NLAYPG
1.0                 DRAIN
0.3                 BASEF
0.6                 STORMF
1.0                 SWFLAG flag for source of values for awilt, afield
0.2                 AWILT(1)
0.2                 AWILT(2)
0.2                 AWILT(3)
0.2                 AWILT(4)
0.2                 AWILT(5)
0.2                 AWILT(6)
0.2                 AWILT(7)
0.2                 AWILT(8)
0.2                 AWILT(9)
0.2                 AWILT(10)
0.3                 AFIEL(1)
0.3                 AFIEL(2)
0.3                 AFIEL(3)
0.3                 AFIEL(4)
0.3                 AFIEL(5)
0.3                 AFIEL(6)
0.3                 AFIEL(7)
0.3                 AFIEL(8)
0.3                 AFIEL(9)
0.3                 AFIEL(10)
5.7                 PH
1.0                 PSLSRB
100.0               SORPMX
*** External nutrient input parameters
0.21                EPNFA(1)
0.0028              EPNFA(2)
-0.92               EPNFS(1)
0.028               EPNFS(2)
0.0                 SATMOS(1)
0.0                 SATMOS(2)
0.0                 SIRRI
*** Organic matter initial values
 21.738             SOM1CI(1,1)
0.0                 SOM1CI(1,2)
 251.98             SOM1CI(2,1)
 0.0                SOM1CI(2,2)
 3091.0             SOM2CI(1)
0.0                 SOM2CI(2)
 2205.9             SOM3CI(1)
0.0                 SOM3CI(2)
 16.54              RCES1(1,1)
 29.455             RCES1(1,2)
 29.455             RCES1(1,3)
 5.3706             RCES1(2,1)
 129.62             RCES1(2,2)
 129.62             RCES1(2,3)
 16.554             RCES2(1)
 148.4              RCES2(2)
 148.4              RCES2(3)
 6.5063             RCES3(1)
 96.584             RCES3(2)
 96.584             RCES3(3)
 136.23             CLITTR(1,1)
0.0                 CLITTR(1,2)
 237.16             CLITTR(2,1)
0.0                 CLITTR(2,2)
 94.544             RCELIT(1,1)
300.0               RCELIT(1,2)
300.0               RCELIT(1,3)
 91.726             RCELIT(2,1)
```

```
300.0             RCELIT(2,2)
300.0             RCELIT(2,3)
 21.848           AGLCIS(1)
0.0               AGLCIS(2)
 0.31585          AGLIVE(1)
0.0               AGLIVE(2)
0.0               AGLIVE(3)
 622.69           BGLCIS(1)
0.0               BGLCIS(2)
 11.307           BGLIVE(1)
0.45              BGLIVE(2)
0.45              BGLIVE(3)
 118.63           STDCIS(1)
0.0               STDCIS(2)
 1.675            STDEDE(1)
0.2               STDEDE(2)
0.2               STDEDE(3)
*** Forest organic matter initial parameters
0.0               RLVCIS(1)
0.0               RLVCIS(2)
0.0               RLEAVE(1)
0.0               RLEAVE(2)
0.0               RLEAVE(3)
0.0               FBRCIS(1)
0.0               FBRCIS(2)
0.0               FBRCHE(1)
0.0               FBRCHE(2)
0.0               FBRCHE(3)
0.0               RLWCIS(1)
0.0               RLWCIS(2)
0.0               RLWODE(1)
0.0               RLWODE(2)
0.0               RLWODE(3)
0.0               FRTCIS(1)
0.0               FRTCIS(2)
0.0               FROOTE(1)
0.0               FROOTE(2)
0.0               FROOTE(3)
0.0               CRTCIS(1)
0.0               CRTCIS(2)
0.0               CROOTE(1)
0.0               CROOTE(2)
0.0               CROOTE(3)
0.0               WD1CIS(1)
0.0               WD1CIS(2)
0.0               WD2CIS(1)
0.0               WD2CIS(2)
0.0               WD3CIS(1)
0.0               WD3CIS(2)
0.3               W1LIG
0.3               W2LIG
0.3               W3LIG
*** Mineral initial parameters
 0.79343          MINERL(1,1)
0.0               MINERL(2,1)
0.0               MINERL(3,1)
0.0               MINERL(4,1)
0.0               MINERL(5,1)
0.0               MINERL(6,1)
0.0               MINERL(7,1)
0.0               MINERL(8,1)
0.0               MINERL(9,1)
0.0               MINERL(10,1)
0.5               MINERL(1,2)
0.0               MINERL(2,2)
0.0               MINERL(3,2)
0.0               MINERL(4,2)
0.0               MINERL(5,2)
0.0               MINERL(6,2)
0.0               MINERL(7,2)
0.0               MINERL(8,2)
```

```
0.0                 MINERL(9,2)
0.0                 MINERL(10,2)
0.5                 MINERL(1,3)
0.0                 MINERL(2,3)
0.0                 MINERL(3,3)
0.0                 MINERL(4,3)
0.0                 MINERL(5,3)
0.0                 MINERL(6,3)
0.0                 MINERL(7,3)
0.0                 MINERL(8,3)
0.0                 MINERL(9,3)
0.0                 MINERL(10,3)
0.0                 PARENT(1)
50.0                PARENT(2)
50.0                PARENT(3)
0.0                 SECNDY(1)
15.0                SECNDY(2)
2.0                 SECNDY(3)
0.0                 OCCLUD
*** Water initial parameters
 0.60673            RWCF(1)
0.0                 RWCF(2)
0.0                 RWCF(3)
0.0                 RWCF(4)
0.0                 RWCF(5)
0.0                 RWCF(6)
0.0                 RWCF(7)
0.0                 RWCF(8)
0.0                 RWCF(9)
0.0                 RWCF(10)
0.0                 SNLQ
0.0                 SNOW
```

<u>CENTURY site file for Asore CH model runs:</u>

```
X     Asore CH input parameters
*** Climate parameters
3.1                 PRECIP(1)
8.8                 PRECIP(2)
9.8                 PRECIP(3)
12.4                PRECIP(4)
10.8                PRECIP(5)
6.5                 PRECIP(6)
13.1                PRECIP(7)
12.9                PRECIP(8)
11.3                PRECIP(9)
4.9                 PRECIP(10)
3.2                 PRECIP(11)
5.4                 PRECIP(12)
    1.7434          PRCSTD(1)
    1.5903          PRCSTD(2)
    3.9085          PRCSTD(3)
    4.0425          PRCSTD(4)
    5.0834          PRCSTD(5)
    7.8130          PRCSTD(6)
    7.4170          PRCSTD(7)
    4.9992          PRCSTD(8)
    6.9514          PRCSTD(9)
    4.7154          PRCSTD(10)
    3.8298          PRCSTD(11)
    2.3158          PRCSTD(12)
    1.4145          PRCSKW(1)
    0.5059          PRCSKW(2)
    0.8501          PRCSKW(3)
    0.3968          PRCSKW(4)
    0.7749          PRCSKW(5)
    0.9489          PRCSKW(6)
    1.2683          PRCSKW(7)
    0.4616          PRCSKW(8)
    0.7289          PRCSKW(9)
    0.5417          PRCSKW(10)
```

```
    0.2601        PRCSKW(11)
    0.5048        PRCSKW(12)
10.7              TMN2M(1)
12.0              TMN2M(2)
12.3              TMN2M(3)
12.8              TMN2M(4)
12.0              TMN2M(5)
12.3              TMN2M(6)
12.8              TMN2M(7)
12.6              TMN2M(8)
12.5              TMN2M(9)
10.5              TMN2M(10)
9.1               TMN2M(11)
7.9               TMN2M(12)
27.6              TMX2M(1)
28.1              TMX2M(2)
27.7              TMX2M(3)
27.0              TMX2M(4)
26.8              TMX2M(5)
25.1              TMX2M(6)
23.5              TMX2M(7)
23.7              TMX2M(8)
25.1              TMX2M(9)
26.6              TMX2M(10)
27.1              TMX2M(11)
27.7              TMX2M(12)
*** Site and control parameters
0                 IVAUTO flag for source of initial soil C values
1.0               NELEM
7.25              SITLAT
38.09             SITLNG
0.42              SAND
0.16              SILT
0.42              CLAY
1.16              BULKD
6.0               NLAYER
6.0              NLAYPG
1.0               DRAIN
0.3               BASEF
0.6               STORMF
1.0               SWFLAG flag for source of values for awilt, afield
0.2               AWILT(1)
0.2               AWILT(2)
0.2               AWILT(3)
0.2               AWILT(4)
0.2               AWILT(5)
0.2               AWILT(6)
0.2               AWILT(7)
0.2               AWILT(8)
0.2               AWILT(9)
0.2               AWILT(10)
0.3               AFIEL(1)
0.3               AFIEL(2)
0.3               AFIEL(3)
0.3               AFIEL(4)
0.3               AFIEL(5)
0.3               AFIEL(6)
0.3               AFIEL(7)
0.3               AFIEL(8)
0.3               AFIEL(9)
0.3               AFIEL(10)
5.7               PH
1.0               PSLSRB
100.0             SORPMX
*** External nutrient input parameters
0.21              EPNFA(1)
0.0028            EPNFA(2)
-0.92             EPNFS(1)
0.028             EPNFS(2)
0.0               SATMOS(1)
0.0               SATMOS(2)
```

```
0.0                 SIRRI
*** Organic matter initial values   Carbon values reflect 1986 averages
 21.738             SOM1CI(1,1)
0.0                 SOM1CI(1,2)
 251.98             SOM1CI(2,1)
 0.0                SOM1CI(2,2)
 3091.0             SOM2CI(1)
0.0                 SOM2CI(2)
 2205.9             SOM3CI(1)
0.0                 SOM3CI(2)
 16.54              RCES1(1,1)
 29.455             RCES1(1,2)
 29.455             RCES1(1,3)
 5.3706             RCES1(2,1)
 129.62             RCES1(2,2)
 129.62             RCES1(2,3)
 16.554             RCES2(1)
 148.4              RCES2(2)
 148.4              RCES2(3)
 6.5063             RCES3(1)
 96.584             RCES3(2)
 96.584             RCES3(3)
 136.23             CLITTR(1,1)
0.0                 CLITTR(1,2)
 237.16             CLITTR(2,1)
0.0                 CLITTR(2,2)
 94.544             RCELIT(1,1)
300.0               RCELIT(1,2)
300.0               RCELIT(1,3)
 91.726             RCELIT(2,1)
300.0               RCELIT(2,2)
300.0               RCELIT(2,3)
 21.848             AGLCIS(1)
0.0                 AGLCIS(2)
 0.31585            AGLIVE(1)
0.0                 AGLIVE(2)
0.0                 AGLIVE(3)
 622.69             BGLCIS(1)
0.0                 BGLCIS(2)
 11.307             BGLIVE(1)
0.45                BGLIVE(2)
0.45                BGLIVE(3)
 118.63             STDCIS(1)
0.0                 STDCIS(2)
 1.675              STDEDE(1)
0.2                 STDEDE(2)
0.2                 STDEDE(3)
*** Forest organic matter initial parameters
0.0                 RLVCIS(1)
0.0                 RLVCIS(2)
0.0                 RLEAVE(1)
0.0                 RLEAVE(2)
0.0                 RLEAVE(3)
0.0                 FBRCIS(1)
0.0                 FBRCIS(2)
0.0                 FBRCHE(1)
0.0                 FBRCHE(2)
0.0                 FBRCHE(3)
0.0                 RLWCIS(1)
0.0                 RLWCIS(2)
0.0                 RLWODE(1)
0.0                 RLWODE(2)
0.0                 RLWODE(3)
0.0                 FRTCIS(1)
0.0                 FRTCIS(2)
0.0                 FROOTE(1)
0.0                 FROOTE(2)
0.0                 FROOTE(3)
0.0                 CRTCIS(1)
0.0                 CRTCIS(2)
0.0                 CROOTE(1)
```

```
0.0                CROOTE(2)
0.0                CROOTE(3)
0.0                WD1CIS(1)
0.0                WD1CIS(2)
0.0                WD2CIS(1)
0.0                WD2CIS(2)
0.0                WD3CIS(1)
0.0                WD3CIS(2)
0.3                W1LIG
0.3                W2LIG
0.3                W3LIG
*** Mineral initial parameters
 0.79343           MINERL(1,1)
0.0                MINERL(2,1)
0.0                MINERL(3,1)
0.0                MINERL(4,1)
0.0                MINERL(5,1)
0.0                MINERL(6,1)
0.0                MINERL(7,1)
0.0                MINERL(8,1)
0.0                MINERL(9,1)
0.0                MINERL(10,1)
0.5                MINERL(1,2)
0.0                MINERL(2,2)
0.0                MINERL(3,2)
0.0                MINERL(4,2)
0.0                MINERL(5,2)
0.0                MINERL(6,2)
0.0                MINERL(7,2)
0.0                MINERL(8,2)
0.0                MINERL(9,2)
0.0                MINERL(10,2)
0.5                MINERL(1,3)
0.0                MINERL(2,3)
0.0                MINERL(3,3)
0.0                MINERL(4,3)
0.0                MINERL(5,3)
0.0                MINERL(6,3)
0.0                MINERL(7,3)
0.0                MINERL(8,3)
0.0                MINERL(9,3)
0.0                MINERL(10,3)
0.0                PARENT(1)
50.0               PARENT(2)
50.0               PARENT(3)
0.0                SECNDY(1)
15.0               SECNDY(2)
2.0                SECNDY(3)
0.0                OCCLUD
*** Water initial parameters
 0.60673           RWCF(1)
0.0                RWCF(2)
0.0                RWCF(3)
0.0                RWCF(4)
0.0                RWCF(5)
0.0                RWCF(6)
0.0                RWCF(7)
0.0                RWCF(8)
0.0                RWCF(9)
0.0                RWCF(10)
0.0                SNLQ
0.0                SNOW
```

<u>CENTURY site file for Asore DR model runs:</u>

```
X     Asore DR input parameters
*** Climate parameters
3.1                PRECIP(1)
8.8                PRECIP(2)
9.8                PRECIP(3)
12.4               PRECIP(4)
```

```
10.8               PRECIP(5)
6.5                PRECIP(6)
13.1               PRECIP(7)
12.9               PRECIP(8)
11.3               PRECIP(9)
4.9                PRECIP(10)
3.2                PRECIP(11)
5.4                PRECIP(12)
    1.7434         PRCSTD(1)
    1.5903         PRCSTD(2)
    3.9085         PRCSTD(3)
    4.0425         PRCSTD(4)
    5.0834         PRCSTD(5)
    7.8130         PRCSTD(6)
    7.4170         PRCSTD(7)
    4.9992         PRCSTD(8)
    6.9514         PRCSTD(9)
    4.7154         PRCSTD(10)
    3.8298         PRCSTD(11)
    2.3158         PRCSTD(12)
    1.4145         PRCSKW(1)
    0.5059         PRCSKW(2)
    0.8501         PRCSKW(3)
    0.3968         PRCSKW(4)
    0.7749         PRCSKW(5)
    0.9489         PRCSKW(6)
    1.2683         PRCSKW(7)
    0.4616         PRCSKW(8)
    0.7289         PRCSKW(9)
    0.5417         PRCSKW(10)
    0.2601         PRCSKW(11)
    0.5048         PRCSKW(12)
10.7               TMN2M(1)
12.0               TMN2M(2)
12.3               TMN2M(3)
12.8               TMN2M(4)
12.0               TMN2M(5)
12.3               TMN2M(6)
12.8               TMN2M(7)
12.6               TMN2M(8)
12.5               TMN2M(9)
10.5               TMN2M(10)
9.1                TMN2M(11)
7.9                TMN2M(12)
27.6               TMX2M(1)
28.1               TMX2M(2)
27.7               TMX2M(3)
27.0               TMX2M(4)
26.8               TMX2M(5)
25.1               TMX2M(6)
23.5               TMX2M(7)
23.7               TMX2M(8)
25.1               TMX2M(9)
26.6               TMX2M(10)
27.1               TMX2M(11)
27.7               TMX2M(12)
*** Site and control parameters
0                  IVAUTO flag for source of initial soil C values
1.0                NELEM
7.25               SITLAT
38.09              SITLNG
0.56               SAND
0.13               SILT
0.31               CLAY
1.32               BULKD
6.0                NLAYER
6.0                NLAYPG
1.0                DRAIN
0.3                BASEF
0.6                STORMF
1.0                SWFLAG flag for source of values for awilt, afield
```

```
0.2                 AWILT(1)
0.2                 AWILT(2)
0.2                 AWILT(3)
0.2                 AWILT(4)
0.2                 AWILT(5)
0.2                 AWILT(6)
0.2                 AWILT(7)
0.2                 AWILT(8)
0.2                 AWILT(9)
0.2                 AWILT(10)
0.3                 AFIEL(1)
0.3                 AFIEL(2)
0.3                 AFIEL(3)
0.3                 AFIEL(4)
0.3                 AFIEL(5)
0.3                 AFIEL(6)
0.3                 AFIEL(7)
0.3                 AFIEL(8)
0.3                 AFIEL(9)
0.3                 AFIEL(10)
5.7                 PH
1.0                 PSLSRB
100.0               SORPMX
*** External nutrient input parameters
0.21                EPNFA(1)
0.0028              EPNFA(2)
-0.92               EPNFS(1)
0.028               EPNFS(2)
0.0                 SATMOS(1)
0.0                 SATMOS(2)
0.0                 SIRRI
*** Organic matter initial values   Carbon values reflect 1986 averages
 21.738             SOM1CI(1,1)
0.0                 SOM1CI(1,2)
 251.98             SOM1CI(2,1)
 0.0                SOM1CI(2,2)
 3091.0             SOM2CI(1)
0.0                 SOM2CI(2)
 2205.9             SOM3CI(1)
0.0                 SOM3CI(2)
 16.54              RCES1(1,1)
 29.455             RCES1(1,2)
 29.455             RCES1(1,3)
 5.3706             RCES1(2,1)
 129.62             RCES1(2,2)
 129.62             RCES1(2,3)
 16.554             RCES2(1)
 148.4              RCES2(2)
 148.4              RCES2(3)
 6.5063             RCES3(1)
 96.584             RCES3(2)
 96.584             RCES3(3)
 136.23             CLITTR(1,1)
0.0                 CLITTR(1,2)
 237.16             CLITTR(2,1)
0.0                 CLITTR(2,2)
 94.544             RCELIT(1,1)
300.0               RCELIT(1,2)
300.0               RCELIT(1,3)
 91.726             RCELIT(2,1)
300.0               RCELIT(2,2)
300.0               RCELIT(2,3)
 21.848             AGLCIS(1)
0.0                 AGLCIS(2)
 0.31585            AGLIVE(1)
0.0                 AGLIVE(2)
0.0                 AGLIVE(3)
 622.69             BGLCIS(1)
0.0                 BGLCIS(2)
 11.307             BGLIVE(1)
0.45                BGLIVE(2)
```

```
0.45              BGLIVE(3)
 118.63           STDCIS(1)
0.0               STDCIS(2)
 1.675            STDEDE(1)
0.2               STDEDE(2)
0.2               STDEDE(3)
*** Forest organic matter initial parameters
0.0               RLVCIS(1)
0.0               RLVCIS(2)
0.0               RLEAVE(1)
0.0               RLEAVE(2)
0.0               RLEAVE(3)
0.0               FBRCIS(1)
0.0               FBRCIS(2)
0.0               FBRCHE(1)
0.0               FBRCHE(2)
0.0               FBRCHE(3)
0.0               RLWCIS(1)
0.0               RLWCIS(2)
0.0               RLWODE(1)
0.0               RLWODE(2)
0.0               RLWODE(3)
0.0               FRTCIS(1)
0.0               FRTCIS(2)
0.0               FROOTE(1)
0.0               FROOTE(2)
0.0               FROOTE(3)
0.0               CRTCIS(1)
0.0               CRTCIS(2)
0.0               CROOTE(1)
0.0               CROOTE(2)
0.0               CROOTE(3)
0.0               WD1CIS(1)
0.0               WD1CIS(2)
0.0               WD2CIS(1)
0.0               WD2CIS(2)
0.0               WD3CIS(1)
0.0               WD3CIS(2)
0.3               W1LIG
0.3               W2LIG
0.3               W3LIG
*** Mineral initial parameters
 0.79343          MINERL(1,1)
0.0               MINERL(2,1)
0.0               MINERL(3,1)
0.0               MINERL(4,1)
0.0               MINERL(5,1)
0.0               MINERL(6,1)
0.0               MINERL(7,1)
0.0               MINERL(8,1)
0.0               MINERL(9,1)
0.0               MINERL(10,1)
0.5               MINERL(1,2)
0.0               MINERL(2,2)
0.0               MINERL(3,2)
0.0               MINERL(4,2)
0.0               MINERL(5,2)
0.0               MINERL(6,2)
0.0               MINERL(7,2)
0.0               MINERL(8,2)
0.0               MINERL(9,2)
0.0               MINERL(10,2)
0.5               MINERL(1,3)
0.0               MINERL(2,3)
0.0               MINERL(3,3)
0.0               MINERL(4,3)
0.0               MINERL(5,3)
0.0               MINERL(6,3)
0.0               MINERL(7,3)
0.0               MINERL(8,3)
0.0               MINERL(9,3)
```

```
0.0                 MINERL(10,3)
0.0                 PARENT(1)
50.0                PARENT(2)
50.0                PARENT(3)
0.0                 SECNDY(1)
15.0                SECNDY(2)
2.0                 SECNDY(3)
0.0                 OCCLUD
*** Water initial parameters
 0.60673            RWCF(1)
0.0                 RWCF(2)
0.0                 RWCF(3)
0.0                 RWCF(4)
0.0                 RWCF(5)
0.0                 RWCF(6)
0.0                 RWCF(7)
0.0                 RWCF(8)
0.0                 RWCF(9)
0.0                 RWCF(10)
0.0                 SNLQ
0.0                 SNOW
```

<u>CENTURY site file for Asore WL model runs:</u>

```
X     Asore WL input paramters
*** Climate parameters
3.1                 PRECIP(1)
8.8                 PRECIP(2)
9.8                 PRECIP(3)
12.4                PRECIP(4)
10.8                PRECIP(5)
6.5                 PRECIP(6)
13.1                PRECIP(7)
12.9                PRECIP(8)
11.3                PRECIP(9)
4.9                 PRECIP(10)
3.2                 PRECIP(11)
5.4                 PRECIP(12)
    1.7434          PRCSTD(1)
    1.5903          PRCSTD(2)
    3.9085          PRCSTD(3)
    4.0425          PRCSTD(4)
    5.0834          PRCSTD(5)
    7.8130          PRCSTD(6)
    7.4170          PRCSTD(7)
    4.9992          PRCSTD(8)
    6.9514          PRCSTD(9)
    4.7154          PRCSTD(10)
    3.8298          PRCSTD(11)
    2.3158          PRCSTD(12)
    1.4145          PRCSKW(1)
    0.5059          PRCSKW(2)
    0.8501          PRCSKW(3)
    0.3968          PRCSKW(4)
    0.7749          PRCSKW(5)
    0.9489          PRCSKW(6)
    1.2683          PRCSKW(7)
    0.4616          PRCSKW(8)
    0.7289          PRCSKW(9)
    0.5417          PRCSKW(10)
    0.2601          PRCSKW(11)
    0.5048          PRCSKW(12)
10.7                TMN2M(1)
12.0                TMN2M(2)
12.3                TMN2M(3)
12.8                TMN2M(4)
12.0                TMN2M(5)
12.3                TMN2M(6)
12.8                TMN2M(7)
12.6                TMN2M(8)
12.5                TMN2M(9)
10.5                TMN2M(10)
```

```
9.1                 TMN2M(11)
7.9                 TMN2M(12)
27.6                TMX2M(1)
28.1                TMX2M(2)
27.7                TMX2M(3)
27.0                TMX2M(4)
26.8                TMX2M(5)
25.1                TMX2M(6)
23.5                TMX2M(7)
23.7                TMX2M(8)
25.1                TMX2M(9)
26.6                TMX2M(10)
27.1                TMX2M(11)
27.7                TMX2M(12)
*** Site and control parameters
0                   IVAUTO flag for source of initial soil C values
1.0                 NELEM
7.25                SITLAT
38.09               SITLNG
0.43                SAND
0.20                SILT
0.37                CLAY
1.03                BULKD
6.0                 NLAYER
6.0                NLAYPG
1.0                 DRAIN
0.3                 BASEF
0.6                 STORMF
1.0                 SWFLAG flag for source of values for awilt, afield
0.2                 AWILT(1)
0.2                 AWILT(2)
0.2                 AWILT(3)
0.2                 AWILT(4)
0.2                 AWILT(5)
0.2                 AWILT(6)
0.2                 AWILT(7)
0.2                 AWILT(8)
0.2                 AWILT(9)
0.2                 AWILT(10)
0.3                 AFIEL(1)
0.3                 AFIEL(2)
0.3                 AFIEL(3)
0.3                 AFIEL(4)
0.3                 AFIEL(5)
0.3                 AFIEL(6)
0.3                 AFIEL(7)
0.3                 AFIEL(8)
0.3                 AFIEL(9)
0.3                 AFIEL(10)
5.7                 PH
1.0                 PSLSRB
100.0               SORPMX
*** External nutrient input parameters
0.21                EPNFA(1)
0.0028              EPNFA(2)
-0.92               EPNFS(1)
0.028               EPNFS(2)
0.0                 SATMOS(1)
0.0                 SATMOS(2)
0.0                 SIRRI
*** Organic matter initial values   Carbon values reflect 1986 averages
 21.738             SOM1CI(1,1)
0.0                 SOM1CI(1,2)
 251.98             SOM1CI(2,1)
 0.0                SOM1CI(2,2)
 3091.0             SOM2CI(1)
0.0                 SOM2CI(2)
 2205.9             SOM3CI(1)
0.0                 SOM3CI(2)
 16.54              RCES1(1,1)
 29.455             RCES1(1,2)
```

```
 29.455           RCES1(1,3)
 5.3706           RCES1(2,1)
 129.62           RCES1(2,2)
 129.62           RCES1(2,3)
 16.554           RCES2(1)
 148.4            RCES2(2)
 148.4            RCES2(3)
 6.5063           RCES3(1)
 96.584           RCES3(2)
 96.584           RCES3(3)
 136.23           CLITTR(1,1)
0.0               CLITTR(1,2)
 237.16           CLITTR(2,1)
0.0               CLITTR(2,2)
 94.544           RCELIT(1,1)
300.0             RCELIT(1,2)
300.0             RCELIT(1,3)
 91.726           RCELIT(2,1)
300.0             RCELIT(2,2)
300.0             RCELIT(2,3)
 21.848           AGLCIS(1)
0.0               AGLCIS(2)
 0.31585          AGLIVE(1)
0.0               AGLIVE(2)
0.0               AGLIVE(3)
 622.69           BGLCIS(1)
0.0               BGLCIS(2)
 11.307           BGLIVE(1)
0.45              BGLIVE(2)
0.45              BGLIVE(3)
 118.63           STDCIS(1)
0.0               STDCIS(2)
 1.675            STDEDE(1)
0.2               STDEDE(2)
0.2               STDEDE(3)
*** Forest organic matter initial parameters
0.0               RLVCIS(1)
0.0               RLVCIS(2)
0.0               RLEAVE(1)
0.0               RLEAVE(2)
0.0               RLEAVE(3)
0.0               FBRCIS(1)
0.0               FBRCIS(2)
0.0               FBRCHE(1)
0.0               FBRCHE(2)
0.0               FBRCHE(3)
0.0               RLWCIS(1)
0.0               RLWCIS(2)
0.0               RLWODE(1)
0.0               RLWODE(2)
0.0               RLWODE(3)
0.0               FRTCIS(1)
0.0               FRTCIS(2)
0.0               FROOTE(1)
0.0               FROOTE(2)
0.0               FROOTE(3)
0.0               CRTCIS(1)
0.0               CRTCIS(2)
0.0               CROOTE(1)
0.0               CROOTE(2)
0.0               CROOTE(3)
0.0               WD1CIS(1)
0.0               WD1CIS(2)
0.0               WD2CIS(1)
0.0               WD2CIS(2)
0.0               WD3CIS(1)
0.0               WD3CIS(2)
0.3               W1LIG
0.3               W2LIG
0.3               W3LIG
*** Mineral initial parameters
```

```
 0.79343          MINERL(1,1)
0.0               MINERL(2,1)
0.0               MINERL(3,1)
0.0               MINERL(4,1)
0.0               MINERL(5,1)
0.0               MINERL(6,1)
0.0               MINERL(7,1)
0.0               MINERL(8,1)
0.0               MINERL(9,1)
0.0               MINERL(10,1)
0.5               MINERL(1,2)
0.0               MINERL(2,2)
0.0               MINERL(3,2)
0.0               MINERL(4,2)
0.0               MINERL(5,2)
0.0               MINERL(6,2)
0.0               MINERL(7,2)
0.0               MINERL(8,2)
0.0               MINERL(9,2)
0.0               MINERL(10,2)
0.5               MINERL(1,3)
0.0               MINERL(2,3)
0.0               MINERL(3,3)
0.0               MINERL(4,3)
0.0               MINERL(5,3)
0.0               MINERL(6,3)
0.0               MINERL(7,3)
0.0               MINERL(8,3)
0.0               MINERL(9,3)
0.0               MINERL(10,3)
0.0               PARENT(1)
50.0              PARENT(2)
50.0              PARENT(3)
0.0               SECNDY(1)
15.0              SECNDY(2)
2.0               SECNDY(3)
0.0               OCCLUD
*** Water initial parameters
 0.60673          RWCF(1)
0.0               RWCF(2)
0.0               RWCF(3)
0.0               RWCF(4)
0.0               RWCF(5)
0.0               RWCF(6)
0.0               RWCF(7)
0.0               RWCF(8)
0.0               RWCF(9)
0.0               RWCF(10)
0.0               SNLQ
0.0               SNOW
```

<u>CENTURY Equilibrium Schedule File used for the Asore model runs</u>

```
1             Starting year
10090         LAST, year
asore.100     Site file name
0             Labeling type
-1            Labeling year
-1.00         Microcosm
-1            CO2 Systems
2             Initial system
G3            Initial crop
TRSH          Initial tree

Year Month Option
1             Block #   equilibrium grass & tree
10000         LAST, year
15            Repeats # years
1             Output starting year
12            Output month
50            Output interval
M             Weather choice
```

```
1 1 CROP G3,  1 1 TREE TRSH
1 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
2 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
3 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
4 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
5 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
6 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
7 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
8 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
9 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
10 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
11 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
12 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
13 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
14 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
15 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 6 FIRE M, 6 TREM SAV, 7 GRAZ GM,
15 9 GRAZ GM, 12 LAST, 12 TLST,
-999 -999 X
1             Block #   equilibrium grass & tree
10090         LAST, year
15            Repeats # years
10001         Output starting year
1             Output month
0.0833        Output interval
M             Weather choice
1 1 CROP G3,  1 1 TREE TRSH
1 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
2 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
3 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
4 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
5 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
6 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
7 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
8 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
9 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
10 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
11 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
12 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
13 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
14 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 7 GRAZ GM, 9 GRAZ GM, 12 LAST, 12 TLST,
15 1 FRST, 1 TFST, 3 GRAZ GM, 5 GRAZ GM, 6 FIRE M, 6 TREM SAV, 7 GRAZ GM,
15 9 GRAZ GM, 12 LAST, 12 TLST,
-999 -999 X
```

<u>CENTURY Degraded Rangeland schedule file used for the Asore Model runs for 1987-1993</u>

```
1987          Starting year
1993          LAST, year
asore_DR.100     Site file name
0             Labeling type
-1            Labeling year
-1.00         Microcosm
-1            CO2 Systems
3             Initial system
G3            Initial crop
TRSH          Initial tree
1987 1 EROD 0.4,
1987 2 EROD 0.4,
1987 3 EROD 0.4,
1987 4 EROD 0.4,
1987 5 EROD 0.4,
1987 6 EROD 0.4,
1987 7 EROD 0.4,
1987 8 EROD 0.4,
1987 9 EROD 0.4,
1987 10 EROD 0.4,
1987 11 EROD 0.4,
1987 12 EROD 0.4,
1988 1 EROD 0.4,
1988 2 EROD 0.4,
1988 3 EROD 0.4,
1988 4 EROD 0.4,
```

```
1988 5 EROD 0.4,
1988 6 EROD 0.4,
1988 7 EROD 0.4,
1988 8 EROD 0.4,
1988 9 EROD 0.4,
1988 10 EROD 0.4,
1988 11 EROD 0.4,
1988 12 EROD 0.4,
1989 1 EROD 0.4,
1989 2 EROD 0.4,
1989 3 EROD 0.4,
1989 4 EROD 0.4,
1989 5 EROD 0.4,
1989 6 EROD 0.4,
1989 7 EROD 0.4,
1989 8 EROD 0.4,
1989 9 EROD 0.4,
1989 10 EROD 0.4,
1989 11 EROD 0.4,
1989 12 EROD 0.4,
1990 1 EROD 0.4,
1990 2 EROD 0.4,
1990 3 EROD 0.4,
1990 4 EROD 0.4,
1990 5 EROD 0.4,
1990 6 EROD 0.4,
1990 7 EROD 0.4,
1990 8 EROD 0.4,
1990 9 EROD 0.4,
1990 10 EROD 0.4,
1990 11 EROD 0.4,
1990 12 EROD 0.4,
1991 1 EROD 0.4,
1991 2 EROD 0.4,
1991 3 EROD 0.4,
1991 4 EROD 0.4,
1991 5 EROD 0.4,
1991 6 EROD 0.4,
1991 7 EROD 0.4,
1991 8 EROD 0.4,
1991 9 EROD 0.4,
1991 10 EROD 0.4,
1991 11 EROD 0.4,
1991 12 EROD 0.4,
1992 1 EROD 0.4,
1992 2 EROD 0.4,
1992 3 EROD 0.4,
1992 4 EROD 0.4,
1992 5 EROD 0.4,
1992 6 EROD 0.4,
1992 7 EROD 0.4,
1992 8 EROD 0.4,
1992 9 EROD 0.4,
1992 10 EROD 0.4,
1992 11 EROD 0.4,
1992 12 EROD 0.4,
1993 1 EROD 0.4,
1993 2 EROD 0.4,
1993 3 EROD 0.4,
1993 4 EROD 0.4,
1993 5 EROD 0.4,
1993 6 EROD 0.4,
1993 7 EROD 0.4,
1993 8 EROD 0.4,
1993 9 EROD 0.4,
1993 10 EROD 0.4,
1993 11 EROD 0.4,
1993 12 EROD 0.4,

Year Month Option
1             Block #   equilibrium grass & tree
```

```
1993          LAST, year
7             Repeats # years
1987          Output starting year
1             Output month
0.0833        Output interval
M             Weather choice
1 1 CROP G3,  1 TREE TRSH, 1 TFST,
1 1 FRST, 1 TREM KILL, 2 TREM CLEARCUT, 2 TLST,
1 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
1 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
1 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
2 1 FRST, 1 GRAZ GOVER, 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
2 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
2 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
3 1 FRST, 1 GRAZ GOVER, 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
3 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
3 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
4 1 FRST, 1 GRAZ GOVER, 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
4 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
4 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
5 1 FRST, 1 GRAZ GOVER, 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
5 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
5 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
6 1 FRST, 1 GRAZ GOVER, 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
6 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
6 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
7 1 FRST, 1 GRAZ GOVER, 2 GRAZ GOVER, 3 GRAZ GOVER, 4 GRAZ GOVER, 5 GRAZ GOVER,
7 6 GRAZ GOVER, 7 GRAZ GOVER, 8 GRAZ GOVER, 9 GRAZ GOVER, 10 GRAZ GOVER,
7 11 GRAZ GOVER, 12 GRAZ GOVER, 12 LAST,
-999 -999 X
```

CENTURY Cropland schedule file used for the Asore Model runs for 1987-1993

```
1987          Starting year
1993          LAST, year
asore_ASG.100     Site file name
0             Labeling type
-1            Labeling year
-1.00         Microcosm
-1            CO2 Systems
3             Initial system
G3            Initial crop
TRSH          Initial tree
1987 1 EROD 0.4,
1987 2 EROD 0.4,
1987 3 EROD 0.4,
1987 4 EROD 0.4,
1987 5 EROD 0.4,
1987 6 EROD 0.4,
1987 7 EROD 0.4,
1987 8 EROD 0.4,
1987 9 EROD 0.4,
1987 10 EROD 0.4,
1987 11 EROD 0.4,
1987 12 EROD 0.4,
1988 1 EROD 0.4,
1988 2 EROD 0.4,
1988 3 EROD 0.4,
1988 4 EROD 0.4,
1988 5 EROD 0.4,
1988 6 EROD 0.4,
1988 7 EROD 0.4,
1988 8 EROD 0.4,
1988 9 EROD 0.4,
1988 10 EROD 0.4,
1988 11 EROD 0.4,
1988 12 EROD 0.4,
1989 1 EROD 0.4,
1989 2 EROD 0.4,
1989 3 EROD 0.4,
1989 4 EROD 0.4,
```

```
1989 5 EROD 0.4,
1989 6 EROD 0.4,
1989 7 EROD 0.4,
1989 8 EROD 0.4,
1989 9 EROD 0.4,
1989 10 EROD 0.4,
1989 11 EROD 0.4,
1989 12 EROD 0.4,
1990 1 EROD 0.4,
1990 2 EROD 0.4,
1990 3 EROD 0.4,
1990 4 EROD 0.4,
1990 5 EROD 0.4,
1990 6 EROD 0.4,
1990 7 EROD 0.4,
1990 8 EROD 0.4,
1990 9 EROD 0.4,
1990 10 EROD 0.4,
1990 11 EROD 0.4,
1990 12 EROD 0.4,
1991 1 EROD 0.4,
1991 2 EROD 0.4,
1991 3 EROD 0.4,
1991 4 EROD 0.4,
1991 5 EROD 0.4,
1991 6 EROD 0.4,
1991 7 EROD 0.4,
1991 8 EROD 0.4,
1991 9 EROD 0.4,
1991 10 EROD 0.4,
1991 11 EROD 0.4,
1991 12 EROD 0.4,
1992 1 EROD 0.4,
1992 2 EROD 0.4,
1992 3 EROD 0.4,
1992 4 EROD 0.4,
1992 5 EROD 0.4,
1992 6 EROD 0.4,
1992 7 EROD 0.4,
1992 8 EROD 0.4,
1992 9 EROD 0.4,
1992 10 EROD 0.4,
1992 11 EROD 0.4,
1992 12 EROD 0.4,
1993 1 EROD 0.4,
1993 2 EROD 0.4,
1993 3 EROD 0.4,
1993 4 EROD 0.4,
1993 5 EROD 0.4,
1993 6 EROD 0.4,
1993 7 EROD 0.4,
1993 8 EROD 0.4,
1993 9 EROD 0.4,
1993 10 EROD 0.4,
1993 11 EROD 0.4,
1993 12 EROD 0.4,

Year Month Option
1              Block #   equilibrium grass & tree
1993           LAST, year
2              Repeats # years
1987           Output starting year
1              Output month
0.0833         Output interval
M              Weather choice
1 1 TREE TRSH, 1 TFST, 1 TREM KILL, 2 TREM CLEARCUT, 2 TLST,
1 5 CULT K, 6 CROP SW2, 6 PLTM, 7 CULT C, 11 LAST, 11 HARV G,
2 5 CULT K, 6 CROP C4, 6 PLTM, 7 CULT C, 11 LAST, 11 HARV G90S,
-999 -999 X
```

CENTURY Degraded Rangeland schedule file for Asore Model runs, 1994-2015 and 2016-2065

1994-2015:

```
1994           Starting year
2015           LAST, year
asore_DR.100      Site file name
0              Labeling type
-1             Labeling year
-1.00          Microcosm
-1             CO2 Systems
3              Initial system
G3             Initial crop
TRSH           Initial tree

Year Month Option
1              Block #   equilibrium grass & tree
2015           LAST, year
1              Repeats # years
1994           Output starting year
1              Output month
0.0833         Output interval
M              Weather choice
1 1 CROP G3, 1 FRST,
1 1 EROD 0.4, 1 GRAZ GOVER,
1 2 EROD 0.4,
1 3 EROD 0.4, 3 GRAZ GOVER,
1 4 EROD 0.4,
1 5 EROD 0.4, 5 GRAZ GOVER,
1 6 EROD 0.4,
1 7 EROD 0.4, 7 GRAZ GOVER,
1 8 EROD 0.4,
1 9 EROD 0.4, 9 GRAZ GOVER,
1 10 EROD 0.4,
1 11 EROD 0.4, 11 GRAZ GOVER,
1 12 EROD 0.4, 12 LAST,
-999 -999 X
```

2016-2065:

```
2016           Starting year
2065           LAST, year
asore_DR.100      Site file name
0              Labeling type
-1             Labeling year
-1.00          Microcosm
-1             CO2 Systems
3              Initial system
G3             Initial crop
TRSH           Initial tree

Year Month Option
1              Block #   equilibrium grass & tree
2065           LAST, year
1              Repeats # years
2016           Output starting year
1              Output month
0.0833         Output interval
M              Weather choice
1 1 CROP G3, 1 FRST,
1 1 EROD 0.4, 1 GRAZ GOVER,
1 2 EROD 0.4,
1 3 EROD 0.4, 3 GRAZ GOVER,
1 4 EROD 0.4,
1 5 EROD 0.4, 5 GRAZ GOVER,
1 6 EROD 0.4,
1 7 EROD 0.4, 7 GRAZ GOVER,
1 8 EROD 0.4,
1 9 EROD 0.4, 9 GRAZ GOVER,
1 10 EROD 0.4,
1 11 EROD 0.4, 11 GRAZ GOVER,
1 12 EROD 0.4, 12 LAST,
-999 -999 X
```

CENTURY cut-and-carry hay schedule file for Asore Model runs, 1994-2015 and 2016-2065

```
1994-2015:
1994          Starting year
2015          LAST, year
asore_CH.100     Site file name
0             Labeling type
-1            Labeling year
-1.00         Microcosm
-1            CO2 Systems
3             Initial system
G3            Initial crop
TRSH          Initial tree

Year Month Option
1             Block #   equilibrium grass & tree
2015          LAST, year
1             Repeats # years
1994          Output starting year
1             Output month
0.0833        Output interval
M             Weather choice
1 1 CROP G3,
1 1 FRST, 1 TFST, 5 HARV H, 7 HARV H, 9 HARV H, 12 LAST, 12 TLST,
-999 -999 X
2016-2065:
2016          Starting year
2065          LAST, year
asore_CH.100     Site file name
0             Labeling type
-1            Labeling year
-1.00         Microcosm
-1            CO2 Systems
3             Initial system
G3            Initial crop
TRSH          Initial tree

Year Month Option
1             Block #   equilibrium grass & tree
2065          LAST, year
1             Repeats # years
2016          Output starting year
1             Output month
0.0833        Output interval
M             Weather choice
1 1 CROP G3,
1 1 FRST, 1 TFST, 5 HARV H, 7 HARV H, 9 HARV H, 12 LAST, 12 TLST,
-999 -999 X
```

CENTURY Acacia shrub/grassland schedule file for Asore Model runs, 1994-2015 and 2016-2065

1994-2015:

```
1994           Starting year
2015           LAST, year
asore_ASG.100     Site file name
0              Labeling type
-1             Labeling year
-1.00          Microcosm
-1             CO2 Systems
3              Initial system
G3             Initial crop
TRSH           Initial tree

Year Month Option
1              Block #   equilibrium grass & tree
2015           LAST, year
1              Repeats # years
1994           Output starting year
1              Output month
0.0833         Output interval
M              Weather choice
1 1 CROP G3,  1 1 TREE TRSH
1 1 FRST, 1 TFST, 5 HARV H, 7 HARV H, 9 HARV H, 12 LAST, 12 TLST,
-999 -999 X
```

2016-2065:

```
2016           Starting year
2065           LAST, year
asore_ASG.100     Site file name
0              Labeling type
-1             Labeling year
-1.00          Microcosm
-1             CO2 Systems
3              Initial system
G3             Initial crop
TRSH           Initial tree

Year Month Option
1              Block #   equilibrium grass & tree
2065           LAST, year
1              Repeats # years
2016           Output starting year
1              Output month
0.0833         Output interval
M              Weather choice
1 1 CROP G3,  1 1 TREE TRSH
1 1 FRST, 1 TFST, 5 HARV H, 7 HARV H, 9 HARV H, 12 LAST, 12 TLST,
-999 -999 X
```

CENTURY woodland schedule file for Asore Model runs, 1994-2015 and 2016-2065

1994-2015:

```
1994           Starting year
2015           LAST, year
asore_WL.100     Site file name
0              Labeling type
-1             Labeling year
-1.00          Microcosm
-1             CO2 Systems
3              Initial system
G3             Initial crop
TRSH           Initial tree

Year Month Option
1              Block #   equilibrium grass & tree
2015           LAST, year
1              Repeats # years
```

```
1994          Output starting year
1             Output month
0.0833        Output interval
M             Weather choice
1 1 TREE ASOREWL
1 1 TFST, 12 TLST,
-999 -999 X
```

2016-2065:

```
2016          Starting year
2065          LAST, year
asore_WL.100     Site file name
0             Labeling type
-1            Labeling year
-1.00         Microcosm
-1            CO2 Systems
3             Initial system
G3            Initial crop
TRSH          Initial tree

Year Month Option
1             Block #   equilibrium grass & tree
2065          LAST, year
1             Repeats # years
2016          Output starting year
1             Output month
0.0833        Output interval
M             Weather choice
1 1 TREE ASOREWL
1 1 TFST, 12 TLST,
-999 -999 X
```

CENTURY tree.100 input parameters used for the Asore site

```
TRSH               Tropical Shrub #[Optimized for Asore, Ethiopia, MJE April 2015]
2.0               'DECID'
0.125             'PRDX(2)'
30.0              'PPDF(1)'
45.0              'PPDF(2)'
1.0               'PPDF(3)'
2.50              'PPDF(4)'
20.0              'CERFOR(1,1,1)'
300.0             'CERFOR(1,1,2)'
300.0             'CERFOR(1,1,3)'
30.0              'CERFOR(1,2,1)'
250.0             'CERFOR(1,2,2)'
250.0             'CERFOR(1,2,3)'
90.0              'CERFOR(1,3,1)'
1100.0            'CERFOR(1,3,2)'
1100.0            'CERFOR(1,3,3)'
150.0             'CERFOR(1,4,1)'
4000.0            'CERFOR(1,4,2)'
4000.0            'CERFOR(1,4,3)'
140.0             'CERFOR(1,5,1)'
4000.0            'CERFOR(1,5,2)'
4000.0            'CERFOR(1,5,3)'
140.0             'CERFOR(1,6,1)'
4000.0            'CERFOR(1,6,2)'
4000.0            'CERFOR(1,6,3)'
40.0              'CERFOR(2,1,1)'
300.0             'CERFOR(2,1,2)'
300.0             'CERFOR(2,1,3)'
55.0              'CERFOR(2,2,1)'
250.0             'CERFOR(2,2,2)'
250.0             'CERFOR(2,2,3)'
90.0              'CERFOR(2,3,1)'
1100.0            'CERFOR(2,3,2)'
1100.0            'CERFOR(2,3,3)'
150.0             'CERFOR(2,4,1)'
4000.0            'CERFOR(2,4,2)'
4000.0            'CERFOR(2,4,3)'
140.0             'CERFOR(2,5,1)'
```

```
4000.0          'CERFOR(2,5,2)'
4000.0          'CERFOR(2,5,3)'
140.0           'CERFOR(2,6,1)'
4000.0          'CERFOR(2,6,2)'
4000.0          'CERFOR(2,6,3)'
60.0            'CERFOR(3,1,1)'
300.0           'CERFOR(3,1,2)'
300.0           'CERFOR(3,1,3)'
55.0            'CERFOR(3,2,1)'
250.0           'CERFOR(3,2,2)'
250.0           'CERFOR(3,2,3)'
90.0            'CERFOR(3,3,1)'
1100.0          'CERFOR(3,3,2)'
1100.0          'CERFOR(3,3,3)'
150.0           'CERFOR(3,4,1)'
4000.0          'CERFOR(3,4,2)'
4000.0          'CERFOR(3,4,3)'
740.0           'CERFOR(3,5,1)'
4000.0          'CERFOR(3,5,2)'
4000.0          'CERFOR(3,5,3)'
740.0           'CERFOR(3,6,1)'
4000.0          'CERFOR(3,6,2)'
4000.0          'CERFOR(3,6,3)'
1.50            'DECW1'
.50             'DECW2'
.60             'DECW3'
.230            'FCFRAC(1,1)'
.270            'FCFRAC(2,1)'
.280            'FCFRAC(3,1)'
.20             'FCFRAC(4,1)'
.020            'FCFRAC(5,1)'
.0              'FCFRAC(6,1)'
.180            'FCFRAC(1,2)'
.280            'FCFRAC(2,2)'
.290            'FCFRAC(3,2)'
.20             'FCFRAC(4,2)'
.050            'FCFRAC(5,2)'
.0              'FCFRAC(6,2)'
0.20            'TFRTCN(1)
0.04            'TFRTCN(2)
0.25            'TFRTCW(1)
0.06            'TFRTCW(2)
6               'FNFTIM'     Fruit fall time in months (EM)
3000.           'FNGDDL(1) length fruit growing in DD (EM)
12.8            'FNGDDL(2) Base temp for growing DD (EM)
40.             'FNGDDL(2) Max temp for growing DD
.080            'LEAFDR(1)'
.030            'LEAFDR(2)'
.030            'LEAFDR(3)'
.030            'LEAFDR(4)'
.030            'LEAFDR(5)'
.030            'LEAFDR(6)'
.030            'LEAFDR(7)'
.030            'LEAFDR(8)'
.030            'LEAFDR(9)'
.030            'LEAFDR(10)'
.030            'LEAFDR(11)'
.030            'LEAFDR(12)'
.00600          'BTOLAI'
1000.0          'KLAI'
-.47000         'LAITOP'
6.0              'MAXLAI'
1.0              'MAXLDR'
.250            'FORRTF(1)'
.0              'FORRTF(2)'
.0              'FORRTF(3)'
500.00          'SAPK'
.0              'SWOLD'
.20             'WDLIG(1)'
.20             'WDLIG(2)'
.250            'WDLIG(3)'
```

```
.350            'WDLIG(4)'
.350            'WDLIG(5)'
.350            'WDLIG(6)'
0.50            'WOODDR(1)'
.10             'WOODDR(2)'
.010            'WOODDR(3)'
.002            'WOODDR(4)'
.004            'WOODDR(5)'
.004            'WOODDR(6)'
.001            'SNFXMX(2)'
.0              'DEL13C'
1.25            'CO2IPR(2)'
0.75            'CO2ITR(2)'
1.25            'CO2ICE(2,1,1)'
1.0             'CO2ICE(2,1,2)'
1.0             'CO2ICE(2,1,3)'
1.25            'CO2ICE(2,2,1)'
1.0             'CO2ICE(2,2,2)'
1.0             'CO2ICE(2,2,3)'
1.0             'CO2IRS(2)'
1.0             'BASFC2'
400.0           'BASFCT'
2400.0          'SITPOT'
7.0             'TMPLFF
10.0            'TMPLFS
ASOREWL         Tropical Woodland #[Optimized for Asore, Ethiopia, MJE April 2015]
2.0             'DECID'
0.185           'PRDX(2)'
30.0            'PPDF(1)'
45.0            'PPDF(2)'
1.0             'PPDF(3)'
2.50            'PPDF(4)'
20.0            'CERFOR(1,1,1)'
300.0           'CERFOR(1,1,2)'
300.0           'CERFOR(1,1,3)'
30.0            'CERFOR(1,2,1)'
250.0           'CERFOR(1,2,2)'
250.0           'CERFOR(1,2,3)'
90.0            'CERFOR(1,3,1)'
1100.0          'CERFOR(1,3,2)'
1100.0          'CERFOR(1,3,3)'
150.0           'CERFOR(1,4,1)'
4000.0          'CERFOR(1,4,2)'
4000.0          'CERFOR(1,4,3)'
140.0           'CERFOR(1,5,1)'
4000.0          'CERFOR(1,5,2)'
4000.0          'CERFOR(1,5,3)'
140.0           'CERFOR(1,6,1)'
4000.0          'CERFOR(1,6,2)'
4000.0          'CERFOR(1,6,3)'
40.0            'CERFOR(2,1,1)'
300.0           'CERFOR(2,1,2)'
300.0           'CERFOR(2,1,3)'
55.0            'CERFOR(2,2,1)'
250.0           'CERFOR(2,2,2)'
250.0           'CERFOR(2,2,3)'
90.0            'CERFOR(2,3,1)'
1100.0          'CERFOR(2,3,2)'
1100.0          'CERFOR(2,3,3)'
150.0           'CERFOR(2,4,1)'
4000.0          'CERFOR(2,4,2)'
4000.0          'CERFOR(2,4,3)'
140.0           'CERFOR(2,5,1)'
4000.0          'CERFOR(2,5,2)'
4000.0          'CERFOR(2,5,3)'
140.0           'CERFOR(2,6,1)'
4000.0          'CERFOR(2,6,2)'
4000.0          'CERFOR(2,6,3)'
60.0            'CERFOR(3,1,1)'
300.0           'CERFOR(3,1,2)'
300.0           'CERFOR(3,1,3)'
```

```
55.0                 'CERFOR(3,2,1)'
250.0                'CERFOR(3,2,2)'
250.0                'CERFOR(3,2,3)'
90.0                 'CERFOR(3,3,1)'
1100.0               'CERFOR(3,3,2)'
1100.0               'CERFOR(3,3,3)'
150.0                'CERFOR(3,4,1)'
4000.0               'CERFOR(3,4,2)'
4000.0               'CERFOR(3,4,3)'
740.0                'CERFOR(3,5,1)'
4000.0               'CERFOR(3,5,2)'
4000.0               'CERFOR(3,5,3)'
740.0                'CERFOR(3,6,1)'
4000.0               'CERFOR(3,6,2)'
4000.0               'CERFOR(3,6,3)'
1.50                 'DECW1'
.50                  'DECW2'
.60                  'DECW3'
.230                 'FCFRAC(1,1)'
.270                 'FCFRAC(2,1)'
.280                 'FCFRAC(3,1)'
.20                  'FCFRAC(4,1)'
.020                 'FCFRAC(5,1)'
.0                   'FCFRAC(6,1)'
.180                 'FCFRAC(1,2)'
.280                 'FCFRAC(2,2)'
.290                 'FCFRAC(3,2)'
.20                  'FCFRAC(4,2)'
.050                 'FCFRAC(5,2)'
.0                   'FCFRAC(6,2)'
0.20                 'TFRTCN(1)
0.04                 'TFRTCN(2)
0.25                 'TFRTCW(1)
0.06                 'TFRTCW(2)
6                    'FNFTIM'     Fruit fall time in months (EM)
3000.                'FNGDDL(1) length fruit growing in DD (EM)
12.8                 'FNGDDL(2) Base temp for growing DD (EM)
40.                  'FNGDDL(2) Max temp for growing DD
.080                 'LEAFDR(1)'
.030                 'LEAFDR(2)'
.030                 'LEAFDR(3)'
.030                 'LEAFDR(4)'
.030                 'LEAFDR(5)'
.030                 'LEAFDR(6)'
.030                 'LEAFDR(7)'
.030                 'LEAFDR(8)'
.030                 'LEAFDR(9)'
.030                 'LEAFDR(10)'
.030                 'LEAFDR(11)'
.030                 'LEAFDR(12)'
.00600               'BTOLAI'
1000.0               'KLAI'
-.47000              'LAITOP'
6.0                   'MAXLAI'
1.0                   'MAXLDR'
.250                 'FORRTF(1)'
.0                   'FORRTF(2)'
.0                   'FORRTF(3)'
500.00               'SAPK'
.0                   'SWOLD'
.20                  'WDLIG(1)'
.20                  'WDLIG(2)'
.250                 'WDLIG(3)'
.350                 'WDLIG(4)'
.350                 'WDLIG(5)'
.350                 'WDLIG(6)'
0.50                 'WOODDR(1)'
.10                  'WOODDR(2)'
.010                 'WOODDR(3)'
.002                 'WOODDR(4)'
.004                 'WOODDR(5)'
```

```
.004               'WOODDR(6)'
.001               'SNFXMX(2)'
.0                 'DEL13C'
1.25               'CO2IPR(2)'
0.75               'CO2ITR(2)'
1.25               'CO2ICE(2,1,1)'
1.0                'CO2ICE(2,1,2)'
1.0                'CO2ICE(2,1,3)'
1.25               'CO2ICE(2,2,1)'
1.0                'CO2ICE(2,2,2)'
1.0                'CO2ICE(2,2,3)'
1.0                'CO2IRS(2)'
1.0                'BASFC2'
400.0              'BASFCT'
2400.0             'SITPOT'
7.0                'TMPLFF
10.0               'TMPLFS
```

<u>CENTURY crop.100 input parameters used for the Asore site</u>

```
G3        grass__mixed_50%_warm_50%_cool
100.0              'PRDX(1)'
22.0               'PPDF(1)'
38.0               'PPDF(2)'
0.3                'PPDF(3)'
5.0                'PPDF(4)'
1.0                'BIOFLG'
60.0               'BIOK5'
1.0                'PLTMRF'
100.0              'FULCAN'
0.0                'FRTC(1)'
0.0                'FRTC(2)'
0.0                'FRTC(3)'
400.0              'BIOMAX'
20.0               'PRAMN(1,1)'
100.0              'PRAMN(2,1)'
100.0              'PRAMN(3,1)'
60.0               'PRAMN(1,2)'
160.0              'PRAMN(2,2)'
200.0              'PRAMN(3,2)'
40.0               'PRAMX(1,1)'
200.0              'PRAMX(2,1)'
230.0              'PRAMX(3,1)'
120.0              'PRAMX(1,2)'
260.0              'PRAMX(2,2)'
270.0              'PRAMX(3,2)'
50.0               'PRBMN(1,1)'
390.0              'PRBMN(2,1)'
340.0              'PRBMN(3,1)'
0.0                'PRBMN(1,2)'
0.0                'PRBMN(2,2)'
0.0                'PRBMN(3,2)'
55.0               'PRBMX(1,1)'
420.0              'PRBMX(2,1)'
420.0              'PRBMX(3,1)'
0.0                'PRBMX(1,2)'
0.0                'PRBMX(2,2)'
0.0                'PRBMX(3,2)'
0.02               'FLIGNI(1,1)'
0.0012             'FLIGNI(2,1)'
0.26               'FLIGNI(1,2)'
-0.0015            'FLIGNI(2,2)'
0.02               'HIMAX'
0.0                'HIWSF'
2.0                'HIMON(1)'
1.0                'HIMON(2)'
0.0                'EFRGRN(1)'
0.0                'EFRGRN(2)'
0.0                'EFRGRN(3)'
0.02               'VLOSSP'
0.2                'FSDETH(1)'
0.95               'FSDETH(2)'
```

```
0.1               'FSDETH(3)'
150.0             'FSDETH(4)'
0.15              'FALLRT'
0.05              'RDR'
0.15              'RTSEN'
2.0               'RTDTMP'
0.0               'CRPRTF(1)'
0.0               'CRPRTF(2)'
0.0               'CRPRTF(3)'
0.0               'SNFXMX(1)'
-21.0             'DEL13C'
1.15              'CO2IPR(1)'
0.77              'CO2ITR(1)'
1.0               'CO2ICE(1,1,1)'
1.0               'CO2ICE(1,1,2)'
1.0               'CO2ICE(1,1,3)'
1.15              'CO2ICE(1,2,1)'
1.0               'CO2ICE(1,2,2)'
1.0               'CO2ICE(1,2,3)'
1.0               'CO2IRS(1)'
SW2     Spring_wheat
265.0             'PRDX(1)'
18.0              'PPDF(1)'
35.0              'PPDF(2)'
0.7               'PPDF(3)'
5.0               'PPDF(4)'
0.0               'BIOFLG'
1800.0            'BIOK5'
0.4               'PLTMRF'
150.0             'FULCAN'
0.45              'FRTC(1)'
0.1               'FRTC(2)'
3.0               'FRTC(3)'
400.0             'BIOMAX'
20.0              'PRAMN(1,1)'
100.0             'PRAMN(2,1)'
100.0             'PRAMN(3,1)'
60.0              'PRAMN(1,2)'
160.0             'PRAMN(2,2)'
200.0             'PRAMN(3,2)'
40.0              'PRAMX(1,1)'
200.0             'PRAMX(2,1)'
230.0             'PRAMX(3,1)'
120.0             'PRAMX(1,2)'
260.0             'PRAMX(2,2)'
270.0             'PRAMX(3,2)'
45.0              'PRBMN(1,1)'
390.0             'PRBMN(2,1)'
340.0             'PRBMN(3,1)'
0.0               'PRBMN(1,2)'
0.0               'PRBMN(2,2)'
0.0               'PRBMN(3,2)'
60.0              'PRBMX(1,1)'
420.0             'PRBMX(2,1)'
420.0             'PRBMX(3,1)'
0.0               'PRBMX(1,2)'
0.0               'PRBMX(2,2)'
0.0               'PRBMX(3,2)'
0.18              'FLIGNI(1,1)'
0.0               'FLIGNI(2,1)'
0.06              'FLIGNI(1,2)'
0.0               'FLIGNI(2,2)'
2500.             'GDDLIM'
0.35              'HIMAX'
0.40              'HIWSF'
1.0               'HIMON(1)'
0.0               'HIMON(2)'
0.65              'EFRGRN(1)'
0.6               'EFRGRN(2)'
0.6               'EFRGRN(3)'
0.04              'VLOSSP'
```

```
0.0                'FSDETH(1)'
0.0                'FSDETH(2)'
0.0                'FSDETH(3)'
200.0              'FSDETH(4)'
0.12               'FALLRT'
0.05               'RDR'
1.00               'RTSEN'
2.0                'RTDTMP'
0.0                'CRPRTF(1)'
0.0                'CRPRTF(2)'
0.0                'CRPRTF(3)'
0.0                'SNFXMX(1)'
-27.0              'DEL13C'
3.0                'AGLCLAI(1)'
34.65736           'AGLCLAI(2)'
1.3                'CO2IPR(1)'
0.77               'CO2ITR(1)'
1.0                'CO2ICE(1,1,1)'
1.0                'CO2ICE(1,1,2)'
1.0                'CO2ICE(1,1,3)'
1.3                'CO2ICE(1,2,1)'
1.0                'CO2ICE(1,2,2)'
1.0                'CO2ICE(1,2,3)'
1.0                'CO2IRS(1)'
C4    maize-C4, medium production
500.0              'PRDX(1)'
30.0               'PPDF(1)'
45.0               'PPDF(2)'
1.0                'PPDF(3)'
2.5                'PPDF(4)'
0.0                'BIOFLG'
1800.0             'BIOK5'
0.5                'PLTMRF'
150.0              'FULCAN'
0.45               'FRTC(1)'
0.1                'FRTC(2)'
3.0                'FRTC(3)'
700.0              'BIOMAX'
20.0               'PRAMN(1,1)'
100.0              'PRAMN(2,1)'
100.0              'PRAMN(3,1)'
60.0               'PRAMN(1,2)'
160.0              'PRAMN(2,2)'
200.0              'PRAMN(3,2)'
40.0               'PRAMX(1,1)'
200.0              'PRAMX(2,1)'
230.0              'PRAMX(3,1)'
120.0              'PRAMX(1,2)'
260.0              'PRAMX(2,2)'
270.0              'PRAMX(3,2)'
45.0               'PRBMN(1,1)'
390.0              'PRBMN(2,1)'
340.0              'PRBMN(3,1)'
0.0                'PRBMN(1,2)'
0.0                'PRBMN(2,2)'
0.0                'PRBMN(3,2)'
60.0               'PRBMX(1,1)'
420.0              'PRBMX(2,1)'
420.0              'PRBMX(3,1)'
0.0                'PRBMX(1,2)'
0.0                'PRBMX(2,2)'
0.0                'PRBMX(3,2)'
0.10               'FLIGNI(1,1)'
0.0                'FLIGNI(2,1)'
0.06               'FLIGNI(1,2)'
0.0                'FLIGNI(2,2)'
0.53               'HIMAX'
0.30               'HIWSF'
1.0                'HIMON(1)'
0.0                'HIMON(2)'
0.75               'EFRGRN(1)'
```

```
0.6                 'EFRGRN(2)'
0.6                 'EFRGRN(3)'
0.04                'VLOSSP'
0.0                 'FSDETH(1)'
0.0                 'FSDETH(2)'
0.0                 'FSDETH(3)'
500.0               'FSDETH(4)'
0.1                 'FALLRT'
0.05                'RDR'
1.00                'RTSEN'
2.0                 'RTDTMP'
0.0                 'CRPRTF(1)'
0.0                 'CRPRTF(2)'
0.0                 'CRPRTF(3)'
0.0                 'SNFXMX(1)'
-15.0               'DEL13C'
4.0                 'AGLCLAI(1)'
173.2868            'AGLCLAI(2)'
1.0                 'CO2IPR(1)'
0.77                'CO2ITR(1)'
1.0                 'CO2ICE(1,1,1)'
1.0                 'CO2ICE(1,1,2)'
1.0                 'CO2ICE(1,1,3)'
1.0                 'CO2ICE(1,2,1)'
1.0                 'CO2ICE(1,2,2)'
1.0                 'CO2ICE(1,2,3)'
1.0                 'CO2IRS(1)'
```

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