Soil Management and Ecosystem Services

Contents

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The purpose of this guide is to provide contextual information on the function that soils play in delivering benefits to humans through the concept of ecosystem service. The document demonstrates how the ecosystem service maps developed by the EO4cultivar project can be used to help inform decision making through the implementation of ecosystem-based management[1].

What is soil and how does it support society, the economy and nature?

Soil is comprised of organic matter, minerals, gases, liquids, and organisms that operate together as an ecosystem that supports life. Earth's body of soil, called the pedosphere, has four key functions:

- A medium for plant growth
- Means of water storage, supply and purification
- Maintains Earth's atmosphere through carbon sequestration
- Provides habitat for organisms
- Soils provide multiple ecosystem services that underpin human existence, the way these soil functions operate are summarised in Figure 1.

A more detailed description of soils in Colombia is provided in Annex A.

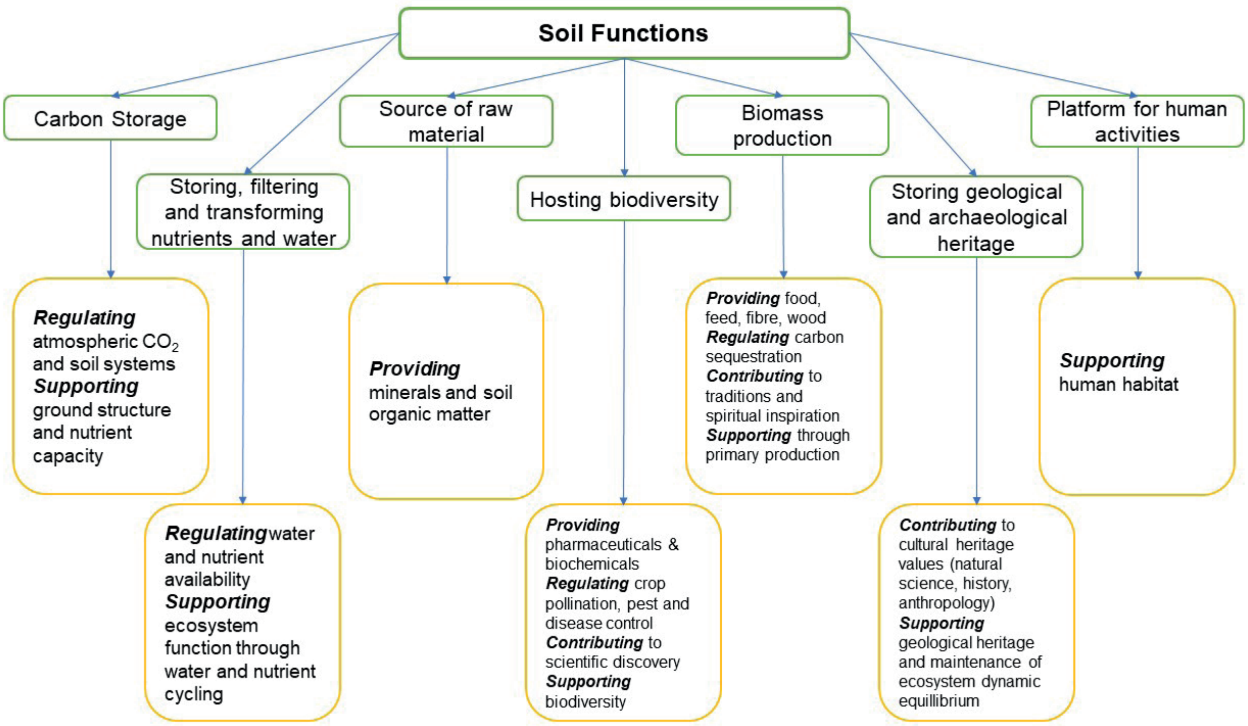

Figure 1: Demonstrating how soil functions (green boxes) underpin ecosystem services (yellow boxes) that provide goods and benefits to society. This has been adapted from *Linking soils to ecosystem services – A global review*[2]**.**

Specific functions of soil which are essential to agricultural crop production include:

- An environment for seed germination, root growth, and the functioning of roots to provide anchorage and absorb water and nutrients.
- Provision of reserves of nutrients within organic matter and mineral components, which are available to plants for uptake through roots[3].
- Transformation of nutrients through biological, chemical and physical processes to make them available for uptake by plants.
- An environment for microorganisms and fauna, which may be beneficial, harmful or neutral towards crop plants. Many organisms are central to the transformations of organic matter, nutrients and pollutants; with major implications for agricultural production and ecosystem processes[3].

Soil functions of wider societal or ecosystem significance include:

- Absorbing water and retaining it for use by vegetation and transfer to rivers and streams. The opposite is surface runoff, where water moves rapidly to rivers, and ultimately to oceans, with little replenishment of soil water storage and increased risk of soil erosion and transfer of sediment to surface waters.
- Influencing water quality, positively or negatively, by regulating the transformations and movement of nutrients, pollutants and sediments to surface and ground-waters.
- Influencing the composition of the atmosphere by acting as source and sink for several greenhouse gases (e.g. carbon dioxide and methane).
- Providing a habitat for soil biota which represent a vast source of biodiversity. Soil biota provide important functions including: nutrient cycling, the carbon cycle, maintaining soil structure.
- Providing a basis for natural and semi-natural vegetation which supports the existence of the multitudes of species, including humans.

The provision of clean drinking water and water for use in agricultural processes is critical for the Magdalena region, as is the management of excess water during heavy precipitation events that can lead to destructive flooding events. The relationships between soil ecosystem functions and delivery of ecosystem services related to water are described in Table 1.

If soils cease delivering such services due to degradation or erosion, the knock-on effects to the rest of the global system will be significant, including significant losses of agricultural production. Areas with degraded soils show significantly lower production, with plants suffering from decreased water nutrition, shallower root depth, compaction and lower chemical fertility.

The effects of agricultural soil loss at a national level can be considerable; annual costs of land degradation due to land use and land cover change have been estimated to be US$231 billion per year, equating to 0.41 % of the global GDP of US$56.49 trillion in 2007[5]. For these reasons, effective soil management that is adapted for a local and regional scale is an important part of sustainable management.

Table 1: Soil functions related to the water cycle and ecosystem services[4].

Soil Function	Mechanism	Consequence	Ecosystem service
Stores water (Storage)	Water held in soil pores supports plant and microbial communities	Biomass production Surface protection	Food Erosion control Nutrient maintenance
Accepts water (Sorptivity)	Water infiltrates into soil with excess expelled as runoff	Surface water runoff reduction	Erosion control Flood protection Water quality regulation
Transmits water (Hydraulic conductivity)	Water entering the soil is redistributed and excess is transmitted deep underground through percolation	Percolation to groundwater	Aquifer recharge Stream flow maintenance Water quality regulation
Cleans water (Filtering)	Water passing through the soil matrix interacts with soil particles and biota	Contaminants removed by biological degradation and retention on sorption sites	Water quality regulation

Adopting a Landscape Approach to Mitigate Pressures Affecting Soil Ecosystem Services

Soil fertility refers to the ability of soil to support and sustain plant growth by making nutrients available for uptake by plants. This process is facilitated by:

- Nutrient storage in organic matter.
- Cycling of nutrients into plant-available forms.
- Mediating nutrient availability to plants.
- Regulating losses to the atmosphere or water via chemical and physical processes[6].

To maintain fertile soils these factors need to be effectively managed in production systems. Sustainable agricultural practises largely depend on promoting long-term fertility and productivity of soils at economically viable levels via:

- Matching the available supply of soil nutrients with the nutrient demands of the crop.
- Maintaining acceptable pest tolerance levels without relying on pesticides.
- Preserve soil properties conducive to plant growth and ecosystem function by reducing detrimental factors such as nutrient leaching[7].

Using Ecosystem Service Modelling to Inform Soil Management

The EO4cultivar project has modelled ecosystem service delivery and produced ecosystem service maps which can help inform ecosystem-based management interventions that support sustainable soil management. Two ecosystem service maps help land managers identify best locations for improving soil management, at both a landscape and individual field scale.

- ***Assessing risk of soil erosion by precipitation*** – This map identifies areas susceptible to erosion by precipitation. It can be used to locate areas to focus management that can help reduce sediment load into rivers by mitigating erosion rates driven by precipitation events. Management activities may include: ecosystem restoration, habitat conservation, installation of buffer strips within crop fields, low tillage management, and guiding crop planting regimes.

- ***Assessing risk of soil erosion by wind*** – This map shows areas with soils that are susceptible to wind erosion. The map helps identify sites where installation of wind breaks, either natural or man-made, could help reduce the loss of top soil from the abrasive effects of wind. It is important to note that the map only shows exposure risk and not the actual severity of wind (i.e. wind speeds) that the site experiences.

Figure 2: Soil erosion on deforested slopes in Sierra Nevada. Picture Matt Smith

Other mapped outputs from the project consider surface water regulation, habitat connectivity and opportunities for enhancing delivery of multiple ecosystem benefits. These products can also be used to address regional management of soil and the ecosystem services it supports.

- ***Places with habitat of key importance for biodiversity*** – The map distinguishes places containing habitat of key importance for biodiversity, including wetlands, woodland and grassland. Intrinsic links between soil biodiversity and nutrients and above ground biodiversity suggests these places are key in supporting healthy soil ecosystems.

- ***Ability of land to moderate surface water runoff map*** – Mapped outputs categorise sites based upon their potential to mediate surface water run-off and regulate flow rates. Management designed to increase water retention (without eroding the soil) can contribute to slowing water run-off and helping water percolate through the soils, which reduces erosion potential.

- ***Opportunities to strengthen ecological networks map*** – These maps identify areas of high, medium and low-effort opportunities to strengthen ecological networks through the landscape. These can also be considered as opportunities to strengthen soil networks and increase below-ground biodiversity. For example, connected woodland habitat will also increase the amount of organic material and carbon present in soils, which can improve the diversity of soil organisms.

- ***Opportunities to deliver multiple ecosystem services*** - ecological connectivity and surface water regulation map – Shows areas delivering multiple ecosystem services. This map can be used to identify areas where soil conservation interventions can deliver multiple benefits.

The mapped outputs from the ecosystem service models identify a range of areas suitable for ecosystem enhancement by identifying the most effective sites for specific interventions. The maps can also guide cooperative action between land managers, or even different industries, in order to preserve the natural environment for the benefit of multiple beneficiaries.

Any management options must consider existing environmental plans and legislation, particularly those relating to nationally and internationally protected areas or other statutory obligations.

Using Ecosystem Service Maps to Inform Management Decisions

Table 2 provides examples of how the mapped outputs can be used to inform ecosystem-based management measures to help conserve soils and maintain ecosystem services critical to sustainable agricultural yield.

Table 2: Possible management measure to enhance soil ecosystem service delivery

Measure type	How to use mapped outputs to inform soil management	Affiliated management option
Planting buffer strips	Use ecological connectivity maps to identify areas of woodland, grassland or wetland which could be better connected through the planting of buffer stirps. Compare areas against soil erosion risk maps & high flow areas to identify areas at risk of erosion and consider planting buffer strips in areas of overlap. Buffer strips also act as wildlife corridors; managers can consult map showing habitats of key importance for biodiversity to enhance potential for delivering multiple benefits.	Maintenance of above ground and below ground biodiversity to improve soil integrity and fertility. Buffer strips act as wind breaks, reducing top soil erosion from wind abrasion, protect watercourses from sedimentation, whilst also creating wildlife corridors to increase connectivity and enhancing biodiversity.

Measure type	How to use mapped outputs to inform soil management	Affiliated management option
Soil quality assessments	There are a number of potential uses for mapped outputs to inform soil quality assessments. Monitoring soil quality in areas of high biodiversity can improve understanding of the biological communities that maintain healthy soils in production areas. Soil property assessments directed to areas identified as susceptible to soil erosion from precipitation and wind. Understanding the composition (i.e. sand or clay), organic matter content, and the bulk and particle density in erosion prone areas can provide a better assessment of erosion potential. Maps can guide soil monitoring to assess whether investment in mitigation measures are having the desired effect.	Soil quality assessments conducted before planting or land conversion can highlight changes in soil condition that might affect yield. This can act as an early warning system to enable appropriate management to take place to mitigate impacts before soils become critically degraded Assessment of soil quality before planting can show where soils are unsuitable for particular activities and reduce the risk of investing in unprofitable crop establishment.
Soil conservation agriculture	Identify areas that provide high contribution to regulating water runoff and where there is risk of erosion by precipitation. Conserving or restoring areas preventing runoff and considering the use of soil conservation agricultural techniques in areas prone to erosion can help increase water infiltration, reduce runoff and lessen risk of flooding and sedimentation of watercourses.	Conservation agriculture involves employing techniques that minimise soil disturbance (e.g. tillage) and providing permanent soil cover (e.g. mulching with organic material). This, combined with crop rotations, can help improve soils. Noting that crop rotation is less feasible for certain crops, such as Banana and Palm. Ecosystem-based management can help improve water infiltration, reduce erosion as well as increase organic matter and carbon content. This can help reduce production costs by reducing requirements for inorganic fertiliser.
Eco-restoration on soils with low organic material and carbon content.	Use maps that identify opportunities to strengthen ecological networks in combination with that multi-benefit map (which identified areas to improve connectivity and surface water regulation), to identify possible opportunities for habitat creation in areas highly connected to existing habitat, and delivering multiple ecosystem services. This enhances the likelihood that restoration will be successful and resilient, which over time encourages higher levels of above-ground biodiversity that leads to improved below-ground biodiversity. The result is likely to increase the soil carbon content.	Contributes to increased soil fertility, particularly in areas where nutrients were limited, can positively affects plant yield. Increased below-ground biodiversity provides a more stable soil ecosystem that is more resilient to pressures such as pest outbreaks. Increasing the amount of organic matter that a soil receives can help prevent soil desiccation through drought.

Measure type	How to use mapped outputs to inform soil management	Affiliated management option
Reducing the contamination of water with chemical leachates from soils.	Use wetland network connectivity in combination with maps that identify sites contributing to water regulation and erosion risk to identify areas of high surface run-off and greater potential to contribute to chemical leaching into wetlands and water courses. Similarly, the mapped output showing where soils are more susceptible to wind erosion can be cross-checked with data on wind direction and strength to assess where wind-blown soils could be contributing to sedimentation and water pollution. Using this type of multi-layered approach identifies areas where investment in minimising soil erosion can have the greatest impact on improving water quality. Use habitat map in combination with water regulation maps to Identify agricultural areas that use high chemical inputs which occur next to watercourses/ within high flow path areas.	Reduced chemical contamination of surrounding water courses due to leaching from soils through water runoff, or windblown particles. Maintains quality of water used in agriculture by limiting contamination. Decreases the environmental impacts of water that runs off into surrounding wetland, estuaries and ocean.

Knowledge requirements to inform soil management

In addition to earth observation products, knowledge regarding soil types, quality status (e.g. is it fertile or degraded) and the environmental context in which the soils are operating, is required to inform effective ecosystem-based soil management.

Information which may prove useful to inform soil management could include:

- Local level research to contextualise and ground truth EO4C map content.
- Local soil assessments to determine the soil type, the status of soil quality and how it could be improved, and establishing baseline data on soil quality before targeting a response.
- Land use and sedimentation extent measurements to identify erosion hotspots.
- Historical land use should be considered to understand long term soil fertility.
- Understanding management in nearby protected areas and integrating this knowledge with management in the production areas to maximise benefits of investment in sustainable management

Whilst products derived from earth observation data can provide a useful starting point to assess potential intervention measures, it is important to consider this information in conjunction with ground data, wider land management objectives, and the corporate sustainability objectives of agricultural businesses.

Adopting an ecosystems approach helps identify pathways through which different anthropogenic pressures are acting on the environment, and distinguish those who may be affected. The use of ecosystem service concepts enables actors to consider how to meet the needs of multiple beneficiaries through strategic investments in soil conservation practices. This provides benefit to both the business and those who also depend on the wider soil ecosystem outside of the production site.

Pressures Affecting Soil Ecosystem Services

In order for managers to identify suitable soil management practices they must consider pressures that are driving soil degradation. Soil condition can be degraded due to certain practises that alter soil structure (compaction) or soil biodiversity (application of chemicals). Exposure to wind and water erosion and loss of soil biodiversity caused by nutrient imbalances, all reduce provision of soil ecosystem services.

Use of Agrochemicals

Intensification and expansion of agriculture has resulted in natural habitat conversion, altering the availability of a natural balance of soil nutrients, requiring fertilisers and other agrichemicals to be input into the ecosystem to facilitate crop growth. Excessive chemical inputs decrease air, soil and water quality, ultimately leading to land degradation and the loss of soil functionality[10].

Decreasing soil quality is a global challenge ; in the last two decades soil organic carbon, an indicator of soil health, has seen an estimated 8% loss globally through land conversion and unsustainable land management practises[11].

In 2011 average fertiliser application in Colombia was 360kg of nutrients per hectare, which is more than double the average use across South America . Agrochemical usage varies due to differences in the soil quality and composition, susceptibility of crops to pests and diseases, and levels of knowledge regarding appropriate use. There is very little diversification of the fertilisers used, and low rates of organic manures and bio-fertilisers use. Intensive fertiliser and pesticide use is a key driver of soil degradation in Colombia and the Atlantic/Caribbean region is significantly impacted by this anthropogenic pressure[12].

Global initiatives in ecological agriculture and avoiding toxic agricultural substances remain at early stages of development, but initiatives have begun emerging in recent years to encourage uptake of more sustainable agricultural production (see Table 3).

Table 3: A range of initiatives in Colombia are demonstrating the environmental, social and economic benefits of adopting agro-ecology in different types of agricultural production system

Asoprosierra – Coffee producers adopt environmentally friendly production systems that conserve soils, encourage ecological diversity and while increase sustainability of the local ecosystem. Their environmentally friendly production and associative work has allowed them to enter into different sustainable production schemes that involve certification processes such as Organic and Fair Trade[13].
PUR Project – Coffee for Peace – The project supports organic coffee installation and agroforestry coffee systems as a solution to empower communities and ensure ecosystem restoration. The project is reconciling farmers with their traditional agricultural practices and supporting the peace transition[14].
Fundación La Tregua - Fundación La Tregua is an NGO based in Cali, Colombia that is dedicated to supporting Colombian small-holder conventional farmers in transitioning to agroecology[15].
Lab Campesino – Laboratorio Campesino is working towards the transition to Agroecology of Tierra Libre, in the municipality of Fusagasugá. The initiative uses local innovation opportunities as a framework to identify actors, interrelations, and varying elements of innovation networks to generate agro-ecology implementation strategies[16].

Soils and Climate Change

In Colombia, the El Niño-Southern Oscillation (ENSO) cycle has a strong effect on precipitation, river discharge and soil moisture. El Nino is associated with decreased soil moisture, evapotranspiration and rainfall, which diminishes the average river flow in western, central and northern regions of Colombia[17].

The opposite patterns are observed during the cold phase (La Niña), which causes intense and abundant rainfall, increased river flow and flooding and increased soil moisture.

The 2010/11 La Nina event affected more than 3 million people in Colombia, the agricultural sector suffered severe contraction in growth, more than the two preceding decades (-4.5%). Flooding significantly decreased production of crops and livestock and eroded soils. Sugar cane, cocoa, coffee, plantain and banana crops represented 72% of the affected area of permanent crops[17].

Climate change poses a threat to soil quality and it is predicted that soil degradation rates will rise with climate change, with increased flooding and pest and disease outbreaks. Around 60% of crop production areas in Colombia are predicted to be affected by these pressures; 36% of cropped areas are expected experience a decrease in precipitation by more than 3%. Sea level rise may also contribute to salinisation, further contributing to soil degradation[12].

Soil Erosion and Sedimentation

Soil erosion is the displacement of soil; a process driven by erosive agents including plant, animal, and human activities. Weather conditions resulting in excessive precipitation, ice formation or high winds and snow also contribute to erosion. Erosive farming activities such as tillage are also a key driver[18].

Erosion adversely affects crop productivity by reducing the availability of water, nutrients, and organic matter, and root depth. Both water and wind erosion remove organic matter and finer soil particles, reducing the capacity of soil to retain water. Soils degraded by erosion can experience reduced water infiltration by up to 93%[19].

Where eroded soil is washed into watercourses, sediment loads are increased and result in decreased water quality. Sedimentation negatively impacts habitats and wildlife downstream due to the nutrient and chemical loads held within the soil particles. Sedimentation can also reduce the amount of water available for extraction, disrupt hydrological processes critical for aquifer recharge, as well as resulting in damage to irrigation equipment.

Figure 4: Sediment load deposition in two of the main rivers within the area of interest; Rio Frio (top) and Rio Sevilla (bottom). Pictures Matt Smith

Annex A

Soils in Colombia and Magdalena Region

Colombia consists of ten soil types, as mapped by the US Department of Agriculture, four of which are found in the EO4cultivar area of interest (see Figures 4 and 5). The variety of soils present in the country reflects the variance in climatic, topographic, and geologic conditions.

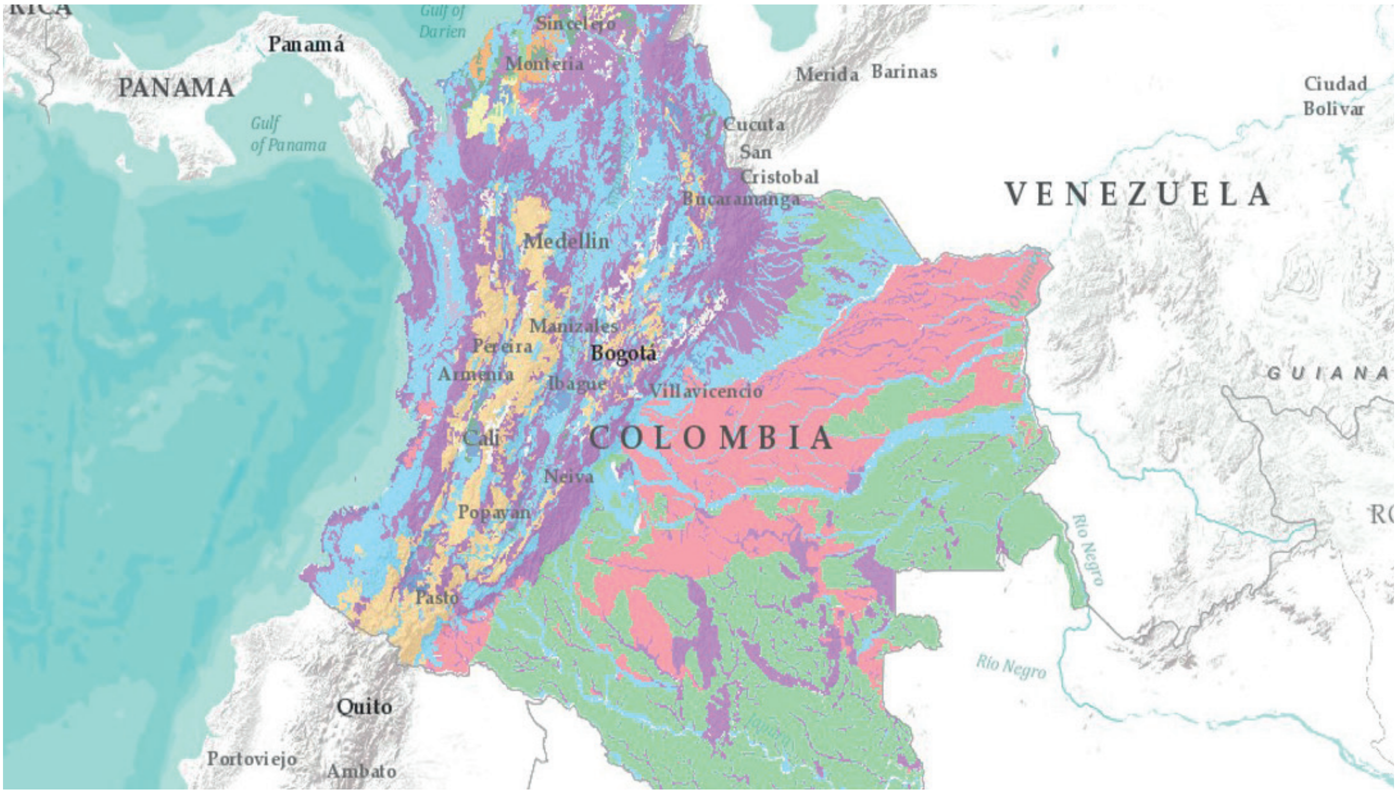

Figure 5: Soil map of Colombia, yellow point in the north of the country shows location of the EO4cultivar area of interest. Adapted from the United States Department of Agriculture soil map[20].

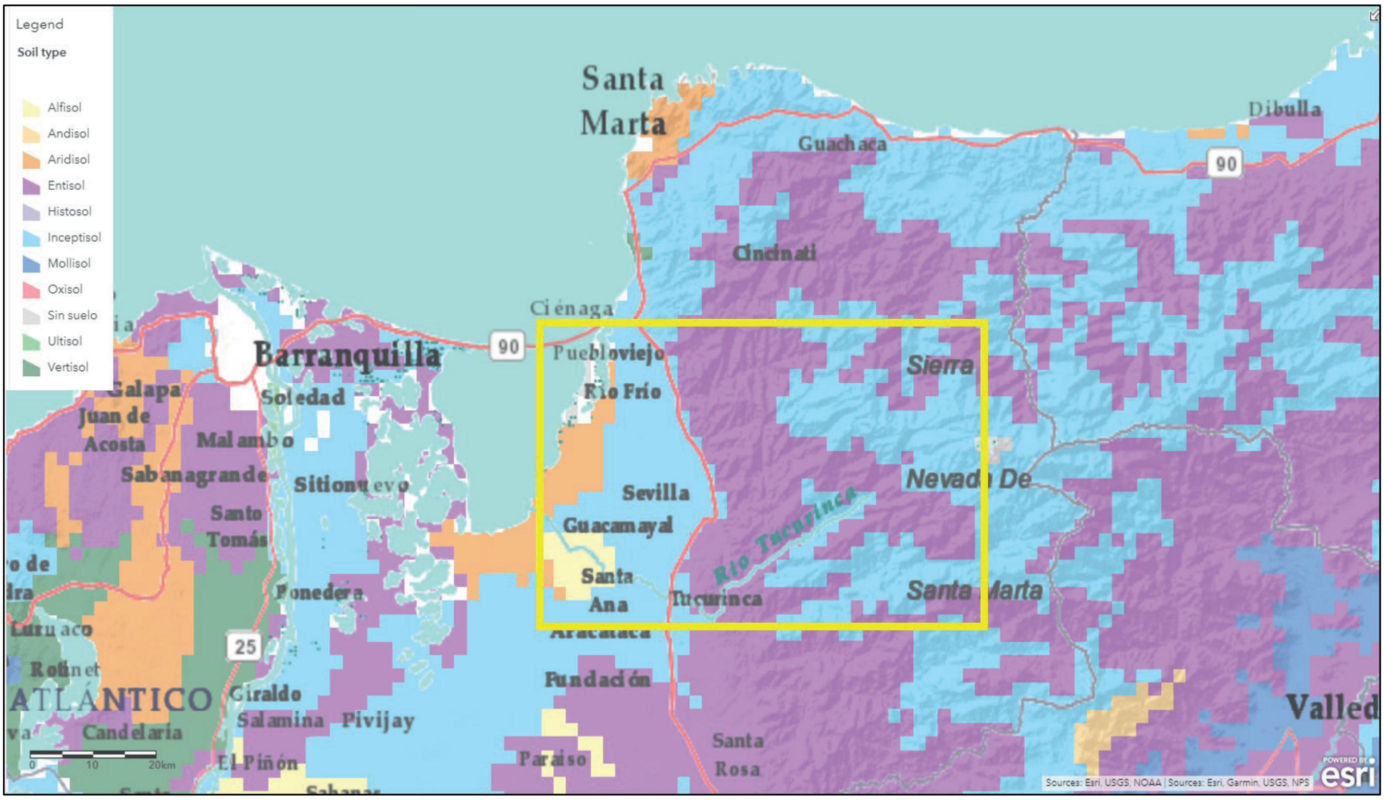

Figure 6: Soil map of EO4cultivar area of interest, project focal area is delineated by the yellow line. Adapted from United States Department of Agriculture soil classifications[20].

Soil use in Colombia and the Magdalena region

The CORPAMAG environment plan 2013-2027 describes the extent of land use in the Magdalena region of Colombia between 2004 and 2009 (Table 2) and suggests that 40% of soil is properly managed and 25% is overexploited (i.e. the dominant land use is above the level of sustainable capacity ascribe to the soil type)[21]. Therefore, a range of management measures are required to ensure soils are manage in accordance with soil type and its suitability to support particular production activities.

Table 1: Land use by year for the Magdalena region 2004-2009 entries marked with (-) represent no data available.

Use	2004	2008	2009
Agriculture	1,049,100	1,559,500	1,326,000
Transient/temporary	362,700	501,300	339,200
Annual	178,100	265,900	148,000
Permanent	508,300	801,400	838,800
Livestock	9,068,300	15,485,800	15,523,800
Pastures	9,068,300	15,485,800	15,523,800
Forests	930,500	-	-
Natural	771,800	-	-
Plantation	158,800	-	-
Bodies of water	2,973,900	2,929,400	-
Other uses	313,600	680,600	-

Existing soil management initiatives in Colombia

Colombia has initiatives in place for addressing soil erosion and improving degraded land (recuperación de suelos en areas degradadas) alongside the National Plan for Ecological Restoration, Rehabilitation and Recovery of Degraded Areas; both are implemented by the Ministry for Environment and Sustainable Development. There is a national programme for monitoring land and land degradation in Colombia that has defined methods and protocols for managing salinization, desertification and soil erosion[22]. A sales tax is automatically applied to all transactions; since 2012 animal feed, tools and machinery for soil preparation have been subject to a preferential 5% rate rather than the 10% standard rate.

A guide to good agricultural practises on Banana farms in the Magdalena region produced by Asociacion de Bananeros de Colombia (Augura) considers a set of criteria for successful banana growth which includes soil management and decreasing chemical run off from farms[23]. The guidance recommends:

- Soils suitable to grow bananas are: sandy loam, clay loam, sandy clay loam and silt loam (soils with >40% clay content are not recommended for bananas).
- Soils must have good internal drainage (but also water retention) and high fertility and depth ranging from 1.2-1.5 m.
- Soil acidity should be 6.5 (pH between 5.5 and 7.5).

Key considerations related to soil management include:

- Performing soil studies during site selection.
- Soil preparation should use equipment that does not alter soil structure (e.g. chisel ploughs).
- Drainage systems should be built late in the rainy season and early in the dry season to avoid loss of soil through rain water run-off[22].
- The Regional Environmental Management Plan (2013-2027) published by CORPAMAG outlines strategic plans and targets to achieve environmental sustainability in the Magdalena region. The plan recognises the requirement for better management of overexploited soils (25% in the Magdalena Region), mitigating the impacts inappropriate waste disposal has on soils, and reducing compaction of soils from livestock farming[21].

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