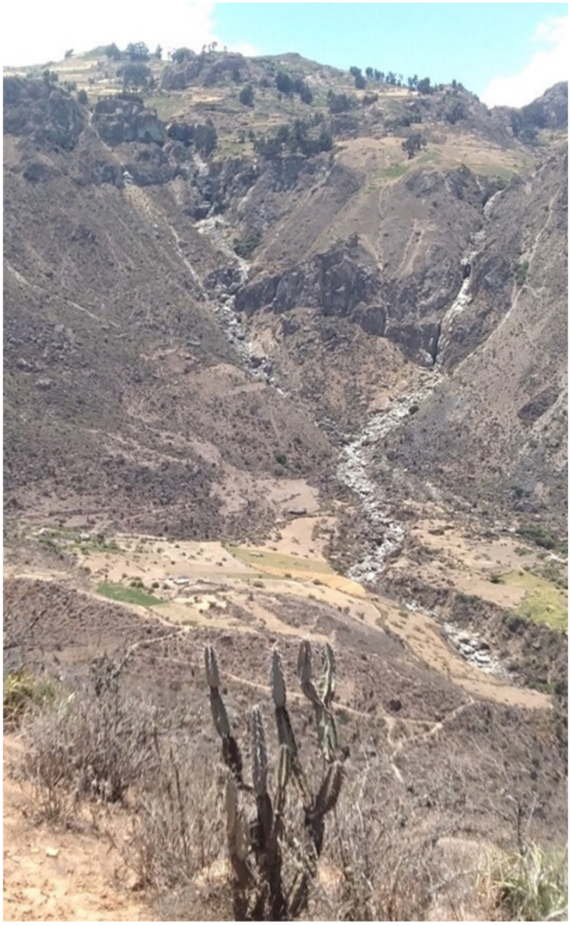
Soil Management and Ecosystem Services: Peru Management Guide



Contents

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Soil Management and Ecosystem Services

This guide provides contextual information on the function that soils play in delivering nature's benefits to humans, also known as 'ecosystem services'. The document, developed by Environment Systems and JNCC, demonstrates how the ecosystem service maps produced by Environment Systems for the EO4cultivar project can be used to help inform decision making through the implementation of ecosystem-based management[1].

Soil and How it Supports 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 Peru is provided in Annex A.

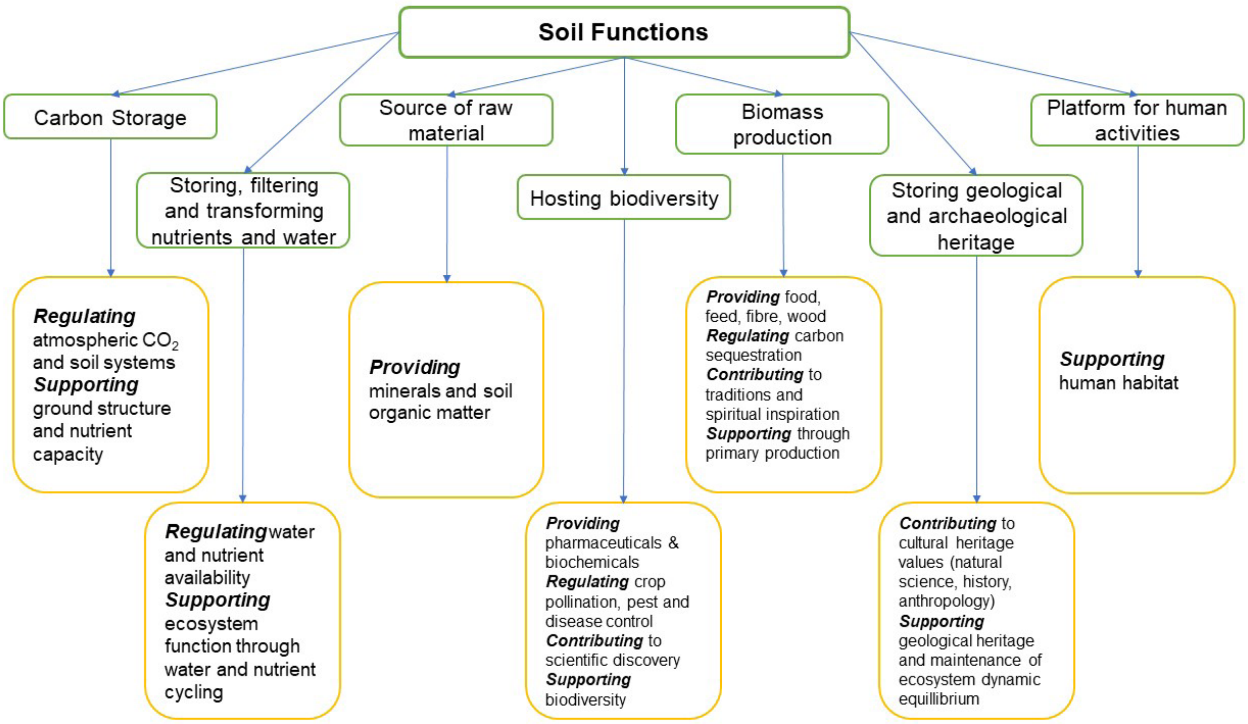

Figure 1. Demonstrating how soil functions (green boxes) underpin ecosystem services (yellow boxes) that provide goods and benefits to society. This has been adapted from *Linking soils to ecosystem services — A global review.*[2]

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, providing less opportunity to replenish soil and groundwater reserves, increasing soil erosion risk 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, and are essential for nutrient cycling.
- 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 La Libertad, 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 become degraded (e.g. by erosion or compaction), they have less capacity to deliver these important ecosystem services, which results in increasing risk in areas such as flood susceptibility, water quality, biodiversity loss, and agricultural production. Areas with degraded soils show significantly lower production; plants may suffer from restricted rooting depth, and decreased water or nutrient availability.

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[4]. 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[5].

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 loss of organic matter, and 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: native habitat restoration, habitat conservation, installation of buffer strips within crop fields and alongside watercourses, low tillage management, and guiding crop planting regimes.
- ***Assessing opportunities to enhance surface water regulation*** - This map identifies agricultural and scrubland areas where the vegetation cover could be enhanced to slow the flow of runoff into watercourses, which also reduces soil erosion and can improve the organic matter content, and water-holding capacity of soils. Management activities may include: native habitat restoration and tree planting, installation of buffer strips within crop fields and alongside watercourses, and amending crop rotations and planting regimes.

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, supporting ecosystem services.

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

- ***Opportunities to strengthen ecological networks*** – These maps identify areas presenting high, medium and low-effort opportunities to strengthen ecological networks through the landscape. These can also be considered as opportunities to reduce soil erosion 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 and increase the water-storage capacity of soils.

- ***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 interventions can deliver multiple benefits, including soil conservation and improvement of soil condition.

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 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.
Soil quality assessments	There are a number of potential uses for mapped outputs to inform soils quality assessments. Monitoring soil quality in areas of high biodiversity can improve understanding of the biological communities, and nutrient and chemical application regimes that promote healthy soils in production areas. Soil quality assessments could be directed to areas identified as susceptible to soil erosion from precipitation. Understanding the composition (e.g. proportions of sand, silt, clay and organic matter), and the bulk density in erosion prone areas can provide a better assessment of erosion risk. Maps can guide soil monitoring to assess whether 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.

Measure type	How to use mapped outputs to inform soil management	Affiliated management option
Soil conservation	Identify areas that provide high contribution to regulating water runoff and where there is risk of erosion by precipitation. Conserving or restoring habitats in erosion prone areas helps prevent runoff and considering the use of soil conservation agricultural techniques in these areas can help increase water infiltration 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. Ecosystem-based management can help improve water infiltration, reduce erosion as well as increase organic matter and carbon content of soils. This can help lower production costs by reducing requirements for inorganic fertiliser[8].
Combating soil salinisation	Identify areas that provide low contribution to regulating water runoff in agricultural areas close to the coast, and target these areas for soil conservation agriculture to reduce demand on the groundwater resource9; improve irrigation efficiency.	Grow crops with lower water demands; apply mulching to conserve water; plant native, deep-rooted species to restore soil condition, and help replenish the groundwater resource.
Eco-restoration on soils with low organic material and carbon content.	Use maps that identify opportunities to strengthen ecological networks in combination with the multi-benefit map that identifies 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 and below-ground biodiversity. The result is likely to increase soil carbon content.	Contributes to increased soil fertility and water-retention, which positively affects plant yield. Increased below-ground biodiversity can increase resilience to pressures such as pest outbreaks. Increasing the amount of organic matter stored within a soil increases its water-holding capacity and reduces risk of drought conditions occurring.
Reducing the contamination of water caused by 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, and the marine environment. Using this type of multi-layered approach identifies areas where investment in minimising soil erosion can have the greatest impact on improving water quality.	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 environments.

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 map content.
- Local soil quality assessments to determine the soil type and status of soil quality and how it could be improved, and to establish baseline data on soil quality before targeting a response.
- Land use and sedimentation rate measurements to identify erosion hotspots.
- Historical land use should be considered to understand long term trends in soil fertility and condition.
- Understanding the flows and dependencies between agricultural areas and surrounding habitat, particularly in upstream areas.
- Management of agricultural areas should be integrated with management in nearby protected areas and of habitats in the upper catchment, to maximise benefits of investment in sustainable management and delivery of business-critical ecosystem services.

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 identify 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

Soil condition can be degraded due to certain practises that alter soil structure (e.g. compaction), soil biodiversity (e.g. application of chemicals), or chemical composition of the physical and aqueous environment (e.g. fertility, salinisation). Exposure to wind and water erosion, loss of soil carbon, fertiliser and pesticide application, and over-extraction of groundwater all reduce provision of soil-based ecosystem services, on which long-term agricultural viability and habitat condition depend. Maintenance of these processes is an important factor to consider in management.

Salinisation

Soils and the water within them contain natural salts, but when the salt concentration rises too high it becomes toxic to plants; this a particular risk in arid and coastal soils. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) listed salinisation as one of the major factors reducing plant grown and productivity globally, affecting around 60 million hectares of irrigated farmland. South America is estimated to contain around 70 million ha of saline soils (including irrigated and non-irrigated areas)[10].

Salinisation in agricultural systems is caused by inefficient irrigation practices; either over- or under-irrigation. Over-irrigation causes waterlogging, which draws up salts from the groundwater system to the plant root zone; this is a particular problem in coastal systems where the groundwater is penetrated by sea water. Plants take up water but most of the salts remain in the soil, with the concentration building up over time. Conversely, under-irrigation also leads to a build-up of salts in the root zone due to evaporation. Salt build-up is exacerbated if the irrigation water itself contains salts[9].

It is sometimes, but not always, possible to reverse soil salinisation over time, but this is a very expensive process that may involve capturing and treating saline water, but must also include increasing irrigation efficiency and reducing crop water demand (e.g. by mulching, increasing soil organic matter content, planting more drought-tolerant crops or varieties)[11] and promoting groundwater recharge using a catchment-based approach.

Loss of Organic Matter

Organic matter is a key source of nutrients; the highest levels of organic matter are found under dry tropical forest cover. Clearing forests for agriculture initially provides crops with a nutrient-rich soil medium, but cropping cannot replenish soil organic matter content to the same extent. At the same time, soils under the more open cropped canopy, and under more intensive tillage practices, are subject to higher mineralisation rates, therefore the soil organic matter content decreases over time[12].

This has implications for crop nutrition, increases erosion risk, and decreases the water-holding capacity of soils. As such, loss of organic matter in the upper catchment zone can have significant impacts both locally and downstream. It has been estimated that La Libertad experienced a loss of 265 hectares of dense forest per year, between 2011 and 2018, representing a loss of 1% of its forest cover over a 10-year period[13].

Use of Agrochemicals

Expansion and intensification of agriculture has resulted in an increase in the use of fertilisers and other agrichemicals to be input into the ecosystem to increase crop growth, and to introduce crop growth to dryland soils. Excessive chemical inputs decrease air, soil and water quality, ultimately leading to terrestrial, freshwater and marine ecosystem degradation.

Decreasing soil quality is a global challenge; in the last two decades soil organic carbon, an indicator of soil health, has decreased due to continuous cropping and unsustainable land management practices, leading to a decline in soil fertility; a trend which is also seen across Latin America[14].

Mining

La Libertad is an important centre for mineral extraction in Peru, particularly gold; Lagunas Norte, one of the largest gold mines in the world, is sited in this region. Mining for silver, lead, copper, zinc and a range of other metals also occurs within La Libertad, and coal mining was historically practiced at Alto Chicama. While large-scale, modern mining activities are regulated and have procedures for dealing with soil contaminants such as arsenic and mercury, small, unregulated mines present a greater risk of contaminants entering the soil and watercourses. Mining practices (Figure 2) increase the risk of soil erosion.

Figure 2. Mining practices increase soil erosion risk in the Viru catchment area, La Libertad. Photo by N. Parker.

Soils and Climate Change

In Peru, the El Niño-Southern Oscillation (ENSO) cycle, whereby the surface temperature of the south Pacific Ocean fluctuates, with a resulting impact on weather patterns; particularly precipitation. This then impacts on river discharge, slope stability and soil moisture. El Niño is associated with increased rainfall, flooding and mudslides, particularly in northern Peru. Destructive flash flooding was experienced during the 1997/98 El Nino, with the coastal Sechura Desert being transformed into a lake. Similar destruction occurred during the 2017 El Niño.

The opposite patterns are observed during the ocean cooling phase (La Niña), which causes cooler air temperatures, less evaporation, and less rainfall. Mild La Nina events can be beneficial for fruit and vegetable producers, but extreme events, leading to droughts, harm production.

The ENSO cycle is driven by changes in ocean surface temperature; therefore, climate change has the potential to change the frequency and intensity of these events. However, the complexity of the ENSO phenomenon means that it is not clear whether climate change will serve to enhance or weaken it, or whether it will increase or decrease the frequency of El Niño and La Niña events[15].

Climate change poses a threat to soil quality and increased risk of desertification. It is predicted that soil degradation rates will rise with climate change, which is driving glacial melt, more extreme precipitation and drought events, and sea level rise. More intense precipitation events present a higher soil erosion risk due to water abrasion, particularly on steep slopes or thinly vegetated soils. Additionally, glacial melt results in higher river flows during the rainy season; this also increases erosion risk. Sea level is predicted to rise 50 cm by 2100, presenting an increased salinisation risk in coastal areas[16].

Soil Erosion and Sedimentation

Soil erosion is the displacement of soil; a process driven by erosive agents including plant, animal, and human activities, but particularly by deforestation and intensive agriculture. When dense vegetation canopies and root systems are disturbed, soil particles become vulnerable to erosion by precipitation, winds, ice formation, snow, or animal trampling. While erosive farming activities such as tillage and overgrazing are key drivers, mining and road and infrastructure construction are other causes, as well as the disrepair of historic landscape features such as terraces[17].

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%[18], which can contribute to flash flooding in downstream areas. Soil erosion can also increase the risk of landslides[19].

Figure 3. Steep slope erosion gullies in the Viru catchment, La Libertad. Photo by N. Parker.

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. Thinly vegetated soils on steep slopes are particularly vulnerable to erosion (Figure 3).

Annex A

Soils in Peru and La Libertad Region

Eight broad soil types are found in Peru, as mapped by the US Department of Agriculture; three of which are found in the EO4cultivar area of interest (Viru catchment, La Libertad); Figure 4. The variety of soils present in the country reflects the variance in climatic, topographic, and geologic conditions.

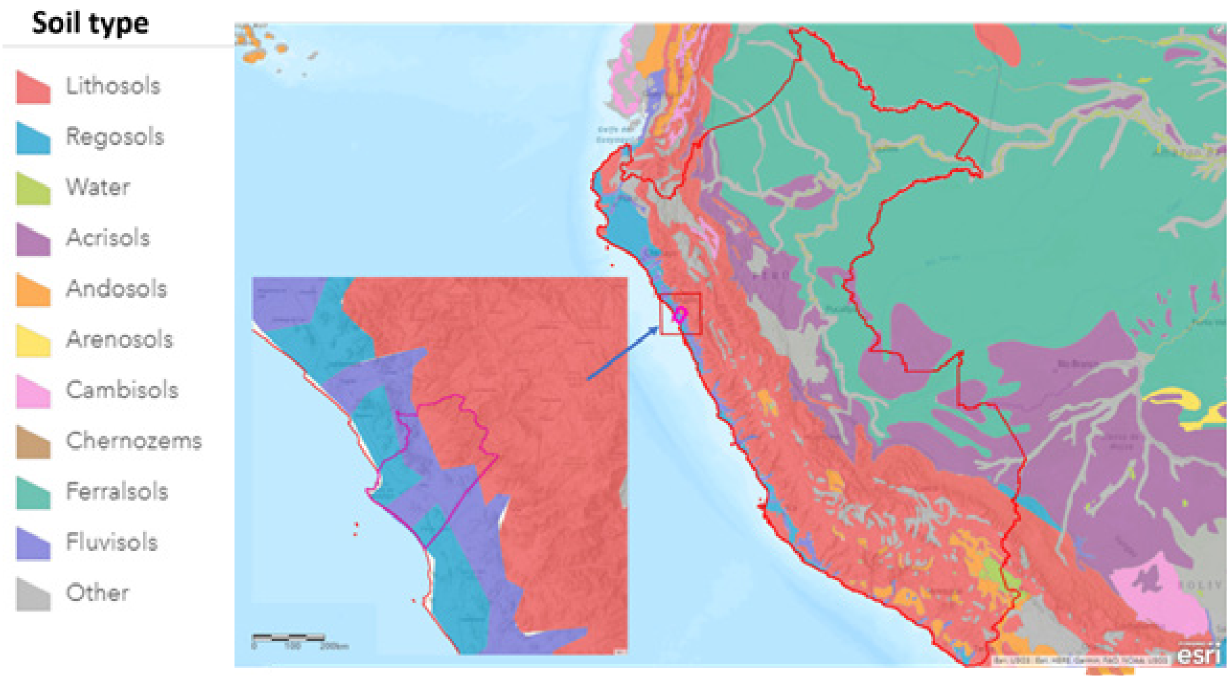

Figure 4. Soil map of Peru highlighting soil types within EO4cultivar focal area (Viru catchment, La Libertad), based on United States Department of Agriculture soil classification.

Existing and Historic Soil Management Initiatives in Peru and La Libertad

In recognition of the links between soil condition and water management, the National Water Resources Plan (Plan Nacional de Recursos Hídricos, PNRH 2015-35) calls for increasing the crop area under mechanized irrigation from the current 2% to 24% by the year 2035, to maintain soil moisture at optimal levels for crop growth without wasting water, which could also slow down the rate of salinisation in affected soils. The Plan also calls for reforesting upstream areas of watersheds to reduce soil erosion and reservoir sedimentation.

In 2016 the national government passed the National Strategy to Combat Desertification and Drought 2016-2030 into law. The Strategy aims to increase understanding of existing soil quality baselines, and the causes and consequences of desertification, land degradation and drought. It also aims to strengthen regulatory frameworks, raise awareness of the soil degradation issues, develop multisectoral regional plans and programs to combat desertification, and promote sustainable land management[20].

Initiative 20x20 is a country-led initiative to restore 20 million hectares of degraded and deforested land across South America, by 2020. Peru joined the Initiative in 2014 with a pledge to restore 3.2 million hectares of degraded land; 2 million hectares through sustainable commercial afforestation, and 1.2 million hectares through rehabilitation of degraded land, divided as follows[21]:

- 390,000 ha – water erosion
- 300,000 ha – salinization
- 200,000 ha – overgrazing
- 155,000 ha – soil compaction
- 155,000 ha – agrochemical contamination

Soil rehabilitation and management activities may currently be facilitated through AGRO RURAL, an Executing Unit attached to the Ministry of Agrarian Development and Irrigation. AGRO RURAL was created in 2008; its creation absorbed the preceding National Program for the Management of Watersheds and Soil Conservation (PRONAMACHCS), which was set up in 1981 to tackle the problems of deforestation and soil erosion[22].

PRONAMACHCS identified a lack of knowledge as the main barrier to farmers managing land in a sustainable way and the Program placed a strong emphasis on technology transfer. Soil conservation projects targeted 38,920 hectares of land; the majority of these areas consisted of terraces. In La Libertad, soil conservation works near the towns of Huamachuco and Otuzco focussed on restoration of terraces and retaining walls, gully control, cross-contour infiltration ditches, slope stabilisation, and agroforestry[23].

Between 2013 and 2017, A Rocha Peru and the National University of Trujillo undertook a dry forest restoration project in Ascope province La Libertad, working in collaboration with local communities to restore ‘Algarrobo’ trees (Prosopis pallida) and also seedlings of other native species such as ‘Zapote’, ‘Tara’ and native cotton, as a way to diversify incomes for local communities. Algarrobo trees in particular are beneficial for soil remediation due to their deep root network, nitrogen-fixing ability, and for its ability to increase soil carbon stores following the decomposition of leaf litter[24].

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