Community of Practice on Soil Health in Nature+

Nature-Positive Solutions for Shifting Agrifood Systems to more Resilient and Sustainable Pathways

Overview

Soil health is the inherent ability of soil to function for agroecosystems productivity and environmental sustainability. With the limitations of nutrients, degradation, water conservation, extreme conditions due to climate change and mounting pressure to produce food, soil health is critical for human existence and thus gaining global debates. Developing and implementing the strategies and action plans to ensure soil health and fertility is also the strategic priority by framework for action biodiversity for food and agriculture.

Both globally and at NARS level efforts are leveraged for research and development on soil health but while working with small holder farmer's (SHF) and other stakeholder's we get the message: SHF- maintain and rebuild healthy soils required for continuous productivity and long term sustainability, stakeholder's- apart from good crop/seed and varietal assess, we need innovations to expand soil health into conventional agriculture practices. With the current progress, stakeholder's recognition is of much importance that allows adaptive capacity on soil health practices in building countries design and implement strategies contributing to healthy and nutritious food availability as well as the income generation.

The Community of Practice (CoP) on soil health, developed by a multidisciplinary global team of CGIAR researchers from OneCGIAR Nature positive agriculture initiative supports the research and adaptation of improved soil health practices in the countries. This CoP is a toolbox that provides well understood assessment approach that can be utilized to determine field-specific information on various physio-chemical and biological properties in addition to standard practices. This toolbox also guides researchers and stakeholder's in identifying the constraints and making target specific decision plans and implement systems for maintaining highly productive and healthier soils. However, the framework and soil health indicators for assessment and management described here can be expanded and adapted according to the specific target country plans, policies and strategies. Team of researchers from the OneCGIAR Nature positive agriculture initiative is assisting different countries in designing and implementing the development strategy for better understanding of soil health status through holistic, adaptive, and data-driven approaches.

This COP is divided in four sections:

I Soil health concept

II Soil health assessment

III Soil health management

IV Additional information- specific to target countries

Section I: Soil Health Concept

This section should provide a narrative description and key resources to characterize the soil health approaches and management.

What is soil health?

The terms 'soil health' is becoming increasingly familiar globally. Soil health is "the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems" (FAO and ITPS, 2020). This includes the continued capacity of the soil to function as a vital living system, and promote plant and animal health. Soil health term has been generally preferred by various stakeholder's including farmer's that relates to the important functions of soil including increased crop production, reduced supply of external inputs, water and nutrient retention, reduced stress and carbon sequestration. These soil functions are jeopardized over the long term if the soil is not functioning to its full capacity (Fig. 1).

The below five basic principles of soil make it as living system:

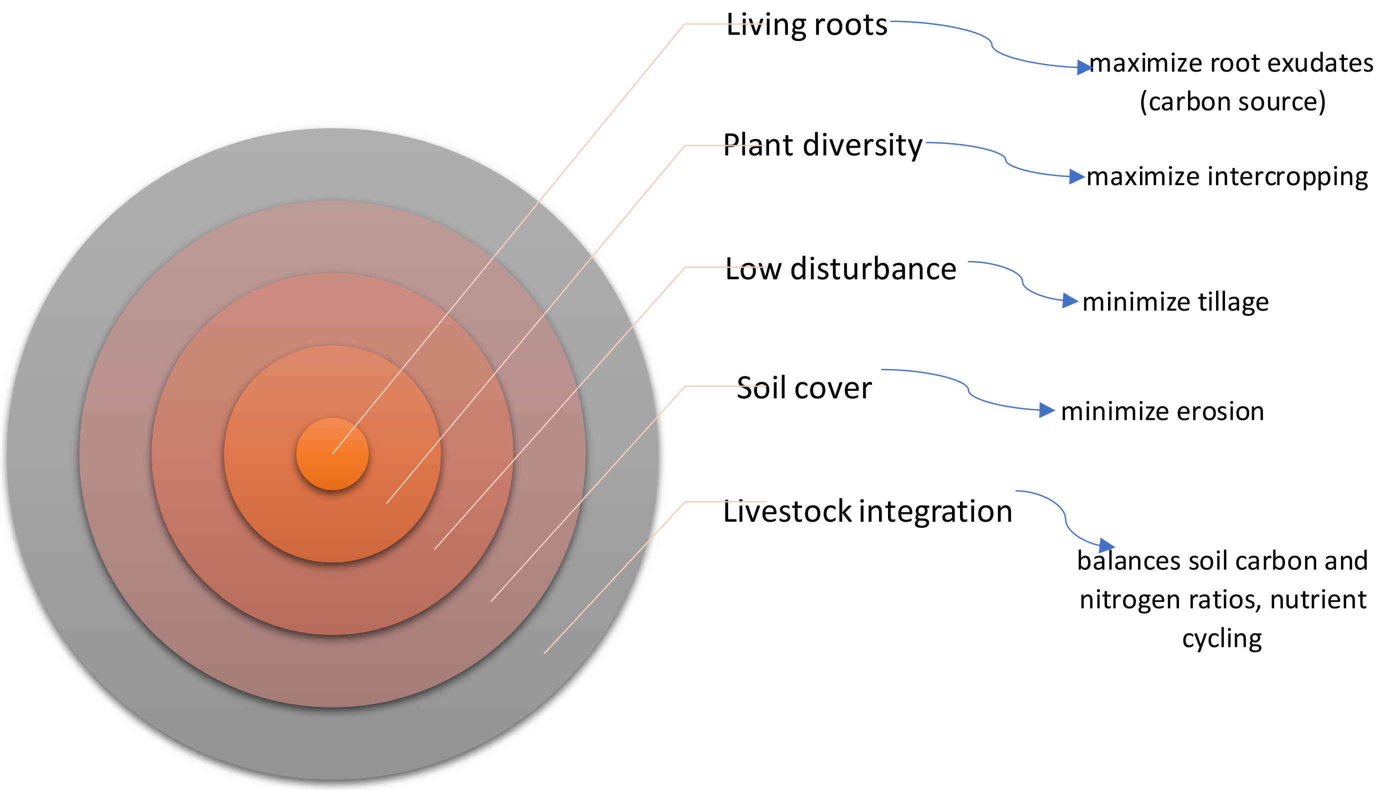

Fig 1: Soul of infinite life (SOIL) as a living system

Life in soil

Improvement of soil health is directly related to the mechanisms of functioning of soil organisms. Both macro and microorganisms plays direct role in the decomposition of soil organic matter on which they feed on. Macro organisms includes arthropods, earthworms that interact early with organic matter and break larger pieces of organic matter into smaller pieces, making expose them to use by next group of small/ microorganisms.

Microorganisms includes bacteria, fungi, and actinomycetes responsible for greater breakdown of organic material in the soil through enzymatic process. One cannot think of maintaining soil health and thus crop productivity without focusing on important processes such as nitrogen fixation, nutrient mobilizations and availability for plants, suppress a/biotic stresses, decomposition of organic matter and maintaining and stabilizing soil structure (Kaushal 2019). Arbuscular mycorrhizal fungi (AMF) are the soil fungi known to accelerate plant growth and survival, increase biomass and resistance to pests and diseases and reduce drought stress (Kaushal 2020). Besides, the fungus also grows extensively in the soil, and absorb more nutrients (specifically phosphorus) for the uptake by plants. In addition AMF are known to increase the plant survival in the nursery by 30%, reduce passage time in the nursery time by 50%, increase recovery of plants after transfer to the field and increase yield by 20%.

Characteristics of a healthy soil

Soil health and quality maintenance is as much a science as it is an art. In any ecosystem soil health should be a central focus which drives crop, farm, human, environment and ecosystems health in large. Once it is known that what are the characteristics of healthy soil, restoring it's 100% functionality is possible through a well-developed management. Below illustrations shows how the characteristics of a healthy soil has direct impact on producers, consumers and ecosystems health (Fig. 2).

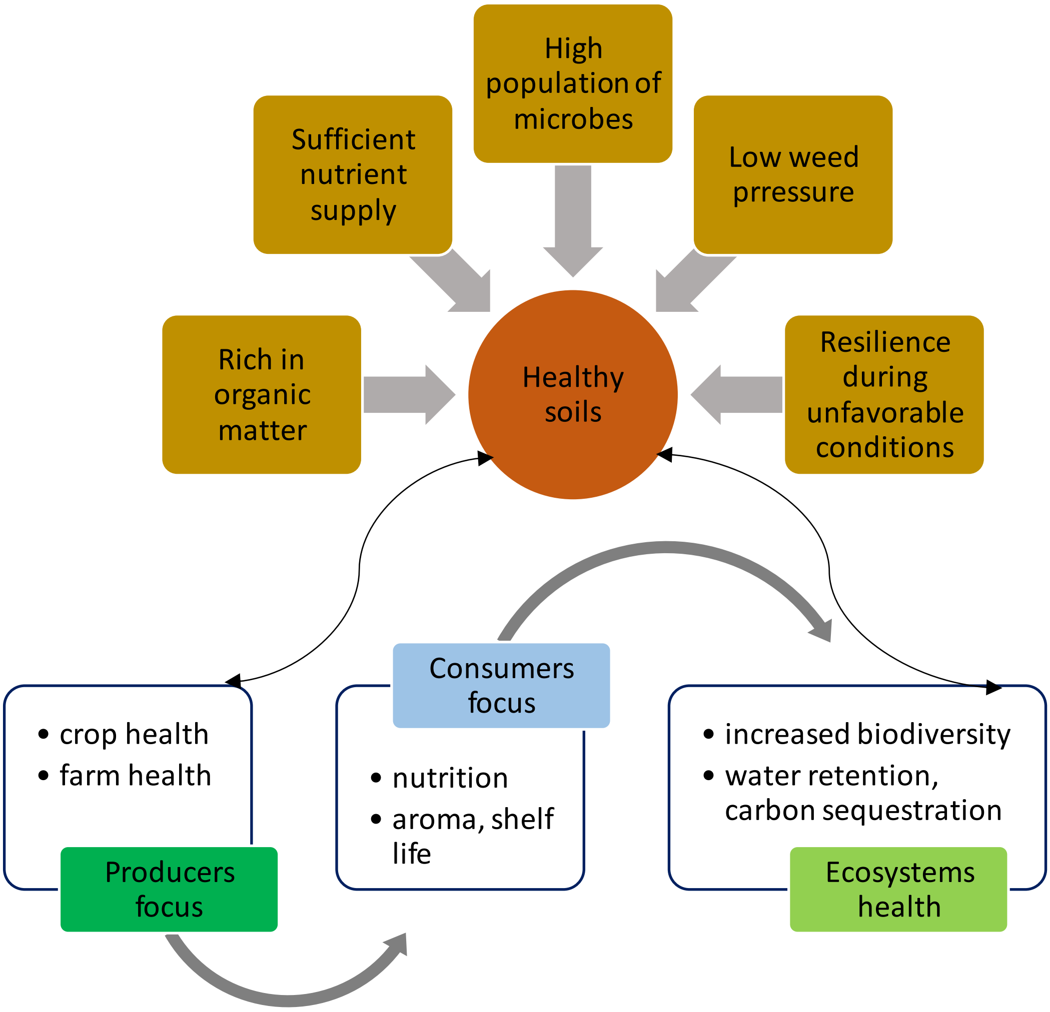

Fig 2: Characteristics of healthy soils and ecosystem health

Section II: Soil Health Assessment

Approach

The soil health team of OneCGIAR Nature positive agriculture is working to address soil issues that reduce soil health, limits crop productivity and small holder farmer's profitability. This CoP is also used for standardizing, rapid and quantitative soil health assessment subject to the relevant soil processes, management approaches, analysis complexity, and resources in different countries. Most importantly this CoP allows for a common protocol understanding containing many potential indicators and metrics to be evaluated for soil health.

On farm assessment

Over the years soil health is a concept that deals with the integration physical and chemical processes of soil, putting biological processes beyond the major focus that are important for sustaining continuous productivity and ecosystems services in large. This CoP brings wide attention of researchers and stakeholder's community including farmers to significantly understand the importance of assessing and managing soil biological functions in diversified crop production systems. For soil health assessment we will evaluate the common minimum indicators on the diversified crop production systems. Few steps involved for on farm assessments includes:

· Participatory approach will be followed to develop qualitative soil health monitoring that allows local capacity building and open up communication among stakeholders, farmers and researchers

· Common minimum indicators will be identified considering physical (feel, infiltration, compaction, retention etc.), chemical and biological (smell, color, organic matter etc.) aspects of on farm soil health assessment. Crop observation based indicators of soil health will provide vital information for soil functioning such as root proliferation and health, nodule formation (for legumes), and decomposition of crop residues.

Soil sampling protocol

Followed by baseline survey, the actual soil sampling in each country will be led by local stakeholder's along with the global team of Nature positive agriculture initiative. As much as possible we will try to focus on the identical management practices and cropping patterns in the different fields for comparison (X vs. Y zones). To address the variability, we will collect the composite samples, by mixing individual samples (subsamples), collected from random sampling zones and multiple locations and mixed together to form a single representative sample that will represent the entire plot/ field (Fig. 3). Following steps will be followed for field sampling design and actual sampling:

1. Determine the location of field/ plot with GPS- helpful re-sampling locations in subsequent events.

2. Remove all the crop residues, debris from the soil surface.

3. Vertically insert the soil probe vertically to the desired depth (10-15 cm) following removal of the probe and transferring the soil core from the probe into a sampling bag. During summers ice packs and coolers should be used for keeping samples.

4. Repeat the steps 2 and 3 from random zones in each field/ plot.

5. A composite sample should be collected in a zig-zag pattern. Samples should be placed in zip lock bags, and store in the refrigerator of soil laboratory of local research institute for analysis. Do not freeze and dry the samples. All the collected samples will be subject to lab analysis for physical, chemical and biological properties (soil health indicators as below), data interpretation, report and recommendations to farmer's.

Fig 3: Soil sampling in various fields/ demo plots, SSA (adopted from SI-MFS, Ghana)

Soil health indicators and scoring

Soil texture: Soil texture defines the inherent soil quality and a mixture of different size of mineral particles- sand (0.05 to 2 mm particle size), silt (0.002 to 0.05 mm), and clay (less than 0.002 mm) result from soil forming processes over the years. Soil texture is usually unchangeable through management practices and thus can be scored from its traits- sandy, sandy loam, loamy, clay, clay loam.

Soil organic matter (SOM): SOM refers to well decomposed material of plants, animals and macro/microorganisms. Soil organic matter measure the soil organic carbon which can be derived using a variety of laboratory analysis methods. Visual color of SOM reflects the soil health information in field.

Soil microbial activity: Soil respiration (amount of CO_2 released) is the measurement for the metabolic activity of the soil microbes. Soil respiration is measured in laboratory and has positive correlation with soil microbial activity similar to SOM. Soil enzymes analysis should also be taken into account that plays direct role in the SOM transformation, nutrient cycling, nitrogen fixation, detoxification etc., and thus regulate the agroecosystem.

Water holding capacity (WHC): WHC is an indicator of water that any soil can hold and make it available to crops. WHC is measured in the laboratory as field capacity (against gravity) and permanent wilting point.

Soil nutrients: In any laboratory pH, primary (NPK), secondary (Mg, Fe, Mn and Zn) and micro-nutrients are the traditional analysis for any soil health measurements package. The measured values are interpreted for insufficient, sufficient and excess and sometime related to very crop specific. Primary nutrients plays direct role in crop health and productivity contributing in multiple mechanisms within any plant. Insufficient level of these nutrients in soil indicates poor availability to plants and thus effect productivity. However, the higher amount has many risk of adverse environmental impacts. Secondary and micro-nutrients has similar importance to the crop productivity and sustainability of agroecosystems. Thus availability of soil nutrients on the farm is critical to management practices to maintain general plant health and mitigating stress.

Moreover, depending on the local requirements and importance in country other potential add on test and bioassays (root health bio-assay) will be added for measuring soil health indicators and field assessments. Again using this approach in CoP help farmers for necessary recommendations and guide to take necessary management practices for sustainable crop productivity.

Section III: Soil Health Management

In above steps CoP guides the farmer's and stakeholders about soil health status, identifying constraints and planning process. The purpose of this section of CoP is to identify feasible management options. Managing soils with the applications of amendments such as fertilizers, lime, manures, compost etc. has been a traditional practice from decades. Again for maintaining the soil health, it is important to balance physical, chemical and biological indicators and reducing various stress for ideal soil functioning. In general the goal should counter the five principles (as described in section I) of soil health approach for increasing living roots, crop diversity, soil cover (mulching), reduce disturbance and integrate livestock at a limit. However, depending on country and site specific needs management practices can be selected and **ReDiReCt**.

Following steps should be considered for soil health management processing:

Farming history: This will provide the background information on soil types, cropping systems and patterns followed, management practices and external inputs, if any.

Goals and sampling: The purpose of this step is to decide how and where to take soil samples. This could be targeted with different perspectives such as comparing cropping systems, management practices, low performing crops and so on.

Constraints identifications prioritization: This step allows to identify major physical, chemical and biological constraints that farmers are seeking to be improved for more sustainable crop management practices.

Identifying options: Combining above information should be followed by evaluation and development of management practices so as to generate success stories as community of practices for addressing constraints and improve soil health and crop production as well.

Nature positive agriculture team again highlights to give high priority and focus on five principles of soil health concepts (section I). For effective practices it is also recommended to consider below toolbox **(ReDiReCt)** for improving management practices and soil health status as regenerative agriculture (Fig. 4).

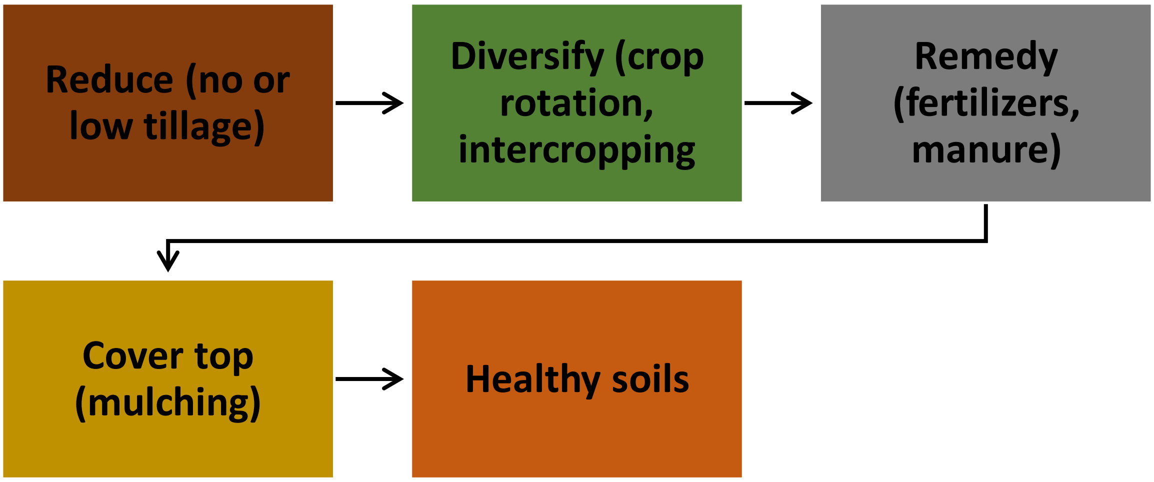

Fig 4: Soil management tool box (**ReDiReCt)**

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Section IV: Additional information

This section includes the information past, ongoing and future work on soil assessment, monitoring, interventions in Nature positive target countries.

VIETNAM

General overview and soil management in target sites: Mai Son (Son La) and Sa Pa (Lao Cai)

Northwest highlands of Vietnam is a largely mountainous region with a challenging terrain, characterized by steep slopes (15º and above), extremely variable altitudes ranging from relatively low land valleys to high elevations of about 1500 masl (ILRI, 2014). Due to limited agricultural land, farmers in this region grow crops on steep slopes, even above 25°, with a high risk of soil erosion (Nguyen and Pham, 2018). In addition, significant levels of seasonal rainfall present greater risk of soil erosion and degradation. Cultivation area is projected to expand into the forests which will in turn threaten soil integrity (ILRI, 2014). This calls for critical considerations to develop sustainable farming systems for improved soil quality and measures to halt or reverse land degradation (Tiemann, 2019).

Son La province is the largest mountainous province in Northwest Vietnam with more than 94% of the land located on slopes, of which 87% is above 25°. Soil degradation on sloping land is particularly pressing in the province. In the last few decades, deforestation and expansion of cropping area on steep slopes has resulted in forest loss, soil degradation and landscape fragmentation (Douxchamps et al. 2021). After many years of intensified agricultural practices on sloping land and predominantly practising monocropping, soil quality has been degraded by nutrient depletion, soil erosion, and improper use of agrochemicals (Hoang et al. 2017). In a recent household survey conducted in Son La province, more than 85% of farmers reported soil fertility challenges, including soil erosion, though some farmers reported applying soil management practices such as recycling biomass, returning crop residues to soils, application of manure to soils, integration of trees and legumes, minimum tillage etc. (Hammond et al., 2021).

In Mai Son district of Son La province, low soil fertility is one of the main constraints for agricultural production. Over the years, cultivation land area per household has decreased due to population increase resulting to conversion of part of the agricultural land for construction or dividing land to offspring. Further decrease in productive land has been caused by land degradation due to soil erosion in sloping areas and poor soils from intensified cultivation (Fig. 5). There is also an increase in fallow land especially in eroded steep slopes adding to the already unproductive rocky areas and infertile soils, challenging agricultural production in the district (Atieno et al. 2021).

Fig 4: Cultivation on sloping lands in Vietnam

Integrated solutions need to be explored to address these soil health challenges in Northwest highlands of Vietnam. There have been few comprehensive research programs and studies on soil quality improvement in this region including, increasing land cover, minimum tillage, agroforestry, integration of leguminous forages and fodder grasses, terracing, contour farming. These measures not only reduce soil erosion and improve soil fertility, but also provide additional food source, livestock feed and diversified income stream (forage grasses and legumes) (ILRI, 2014; Nguyen and Pham, 2018).

Constraints in adoption of these measures should be carefully considered. For instance, legume crops are not traditionally grown or consumed in the region. However, some dual-purpose legumes and forage legume varieties (e.g., cowpea, rice bean, Sunn hemp, lablab etc) are available and could be integrated into the systems. Further studies should evaluate the long-term benefits and return on investments of different soil health management practices (Douxchamps et al., 2021).

Information about soil health status and management practices in Sa Pa (Lao Cai) are scanty as this is a new area for the NATURE+ implementation team. This gap will be filled by assessments planned for 2023.

Soil baseline assessment

The agricultural system must be transformed to simultaneously provide global food security and environmental integrity. To address these challenges, sustainability in agriculture must be enhanced. This is particularly true for rapidly developing countries such as Vietnam. The United Nations Sustainable Development Goals calls for the implementation of the development of a more sustainable agriculture and a greener eco-environment and food industry. To be successful, it requires the alleviation of the deleterious effects of intensive agriculture, excessive use of external resource inputs, e.g., mineral fertilizers and agrochemicals which must be prohibited as much as possible and in parallel, internal regulatory ecosystem processes must be promoted.

Ecological intensification is the strategy of choice to achieve these goals, as it focuses on managing and promoting ecosystem service-providing organisms and processes that make a quantifiable direct or indirect contribution to agricultural production. The benefits of ecologically intensifying agriculture are achieved through greater reliance on biodiversity and ecosystem services, including the management of soils and their biota. Soils provide habitat to a wealth and diversity of organisms, including microbes, invertebrates and vertebrates, adding up to several thousands of species per cubic meter of soil making it one of the most biodiverse habitats on earth. Plant roots, the associated microbiome, and soil microbiota interact in a multitude of ways and collectively perform multiple functions, such as the enhancement of nutrient availability, prevention of pests and diseases, carbon storage, and improvement of soil structure and water holding capacity.

Soil health, as already described in section I, is the capacity of a living soil to function. While it has become clear that many agricultural management practices, such as intensive tillage, fertilization, and pesticide use, lead to reductions in soil biodiversity, the resulting, potential negative effects on ecosystem function and service provisioning are more difficult to assess and quantify.

Evidence is increasing that the functional redundancy of soil microorganisms (meaning that different microbes perform similar functions and the loss of certain taxa can be compensated by other groups) is limited and that changes in soil microbial community composition and the loss of specific species can potentially result in a loss of certain functions. By using dilution and addition approaches, experimental results have demonstrated the importance of soil biodiversity per se and/or community composition for crucial ecosystem functions, such as mediating plant nutrition and growth, decomposition, nutrient mineralization and nutrient retention. Large-scale, genetically-uniform, intensive monoculture production systems favour strong outbreaks and epidemics of pests and pathogens in agroecosystems with adverse effects on food security. Higher biodiversity at several levels, including soils, has been shown to reduce the emergence and damage of such pests and diseases. Manipulation of plant microbiomes (e.g., through breeding for specific plant traits or by introducing potentially beneficial rhizosphere microbial species or species communities) could be a viable approach for reducing diseases by improving microbe-mediated pathogen suppression and the plant immune system. Soil communities are extremely complex and diverse, performing a myriad of functions. Soil biodiversity showed stronger links with ecosystem functioning at relatively lower soil biodiversity levels and community composition showed stronger effects compared with species richness. It is, therefore, suggested that a basic toolbox of organisms with certain functional traits may be sufficient to provide a basic level of internal (agro-)ecosystem regulatory processes.

However, due to constantly changing environmental conditions and increased emergence of extreme weather or other disturbance events, additional levels of biodiversity and functional redundancy will be required to provide species pools that can assure a biodiversity insurance effect to increase biodiversity-supported ecosystem resilience. The level of complexity and connectedness of soil communities are important features to maintain ecosystem functioning. The connectedness of the entire soil community was shown to correspond with increased efficiency of carbon uptake by the soil food web.

In a recent study, soil community network complexity was positively related to several ecosystem functions simultaneously (Fig. 5). Diversity enhances soil health and agricultural sustainability their structure, diversity and functional potential within the complex interactions between plants, soil and soil microbiota at spatial and temporal scales under natural field conditions increases. A meaningful functional characterization of soil biological communities in realistic agricultural scenarios, however, remains challenging. While molecular approaches can provide information about the taxonomic and functional potential of soil biological communities, these measures often show little direct links with actual process measurements. This is most likely related to the vast variety of biological, chemical and physical factors simultaneously acting at multiple levels. Enhancing ecosystem services in high-input farming systems can be challenging and it will require novel design of the systems, both in concept and in practice (Fig. 6).

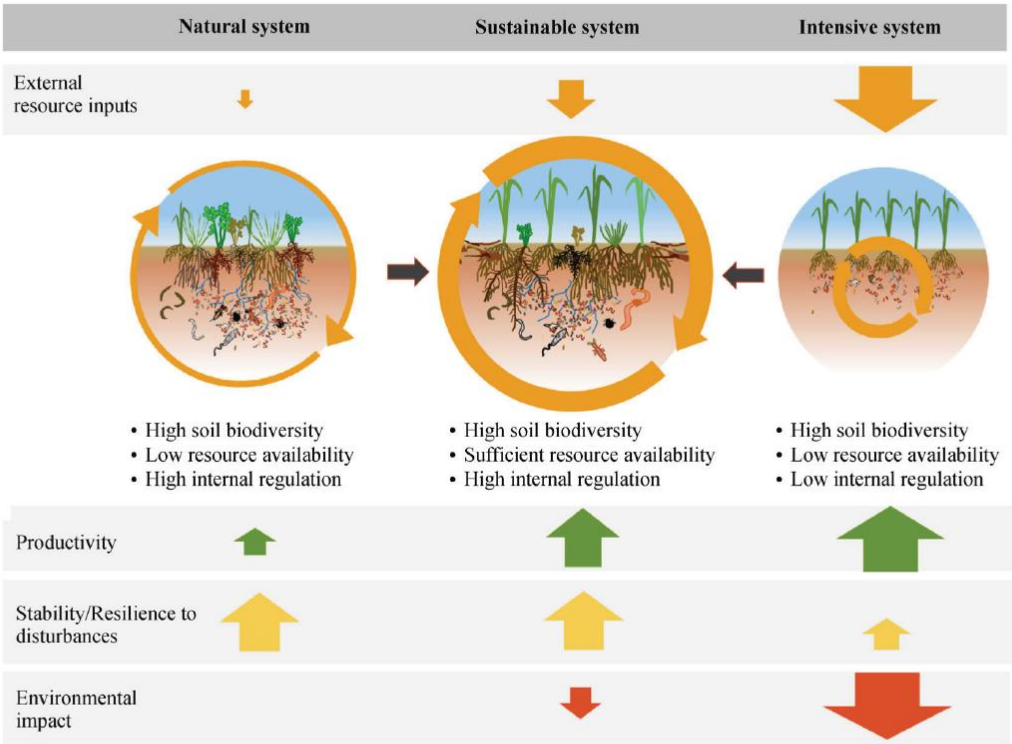

Fig 5: Conceptualization of a sustainable cropping system combining features of natural ecosystems with features of intensive cropping systems.

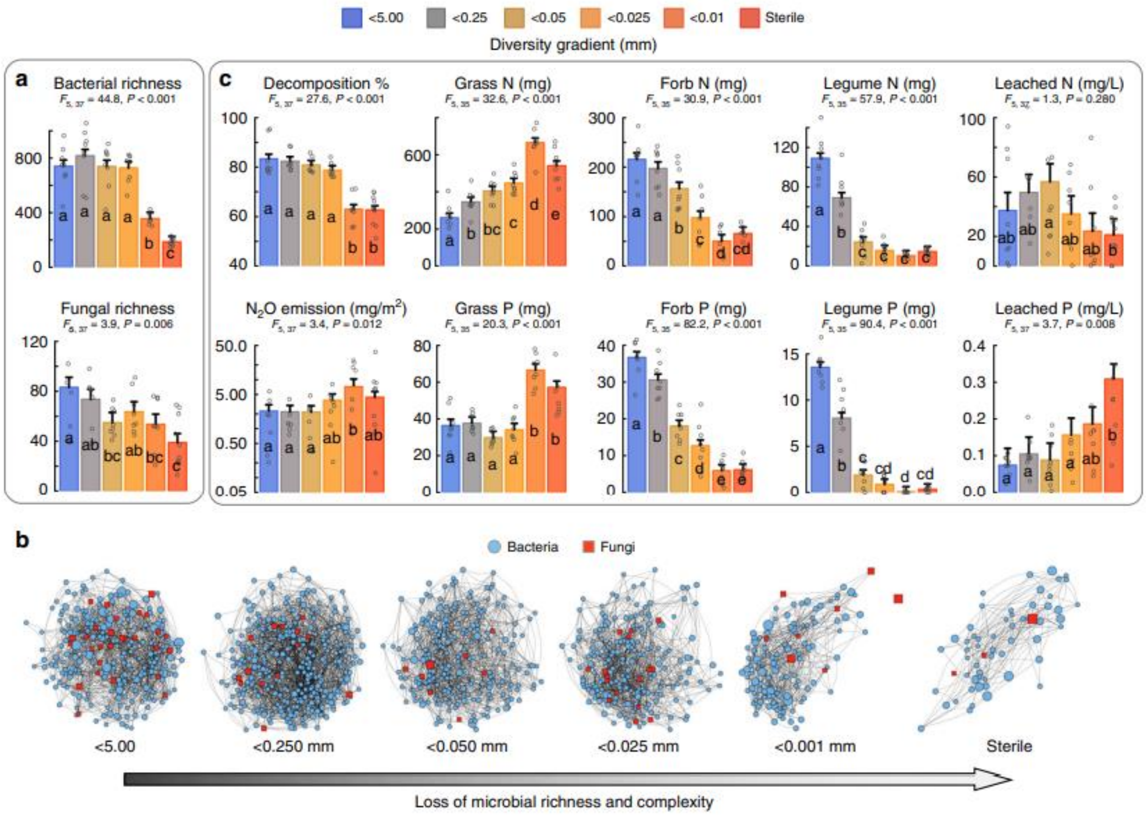

Fig 6: Soil microbial community composition and ecosystem functioning with progressive simplification of the soil biome.

In the framework of the study we plan in Lao Cai province, the idea is to assess the physical and chemical characteristics and microbial diversity in soils in the main cropping systems (WP1) and agroforestry or tree-based systems (WP3). Sampling across different farming practices found in the study landscapes (e.g. monocrop vs. intercrop vs. crop rotation; residue management) will allow to see how farming practices can influence soil characteristics and microbial diversity (WP3) and thereby contribute to yields and quality of annual and tree crops.

The study will be carried out at baseline and repeated after 2-4 years of interventions. An initial identification of target cropping and agroforestry systems will be identified during the field visit in Lao Cai Region. Potential sites/farms and plantations shall be geographically located and listed along with the support of the national partner (NOMAFSI). Based on such information, a field visit shall be organized for the final choice of the sites with the objective to have a significant number of replicates (farms or plantations but also samples coming from each site) for running a complete and strong scientifically analysis. Based on these results, we will be able to gain a better understanding of how the cropping systems and/or the forest cover influence soil microbial diversity in Lao Cai and based on this set of data, define the work plan for the upcoming years. Furthermore, a similar study will be conducted is Son La province, in collaboration with the One CGIAR SAPLING Initiative, with the aim to understand the impact of different forage species on soil health (WP2).

Soil interventions

WP3 has a specific focus to tackle soil degradation and, if needed, promote restoration. For 2023, an initial set of WP3 activities are planned in Lao Cai. These include:

- Scoping study of lessons learned from past restoration efforts, including impacts on soil health

- Inventory of useful tree species and their traits to support species and germplasm selection for restorative, farmer-selected land use practices and diverse site characteristics (e.g. soils prone to erosion, overgrazing)
- Initiating restoration 'living labs' for participatory testing and evaluation of restoration practices

Additional soil-related activities in both Lao Cai and Son La will be identified based on the result of the baseline assessments.

Soil indicators

For the soil assessment, the factors to measure are as follows: soil physical and chemical characteristics, total bacterial diversity, total fungal diversity, total Arbuscular Mycorrhizal Fungi (AMF) diversity (if fresh roots can be collected) and total diversity of protists.

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INDIA

General overview and soil management in target sites: Akole tehsil Maharashtra state

The study area of Akole tehsil is hilly agroecosystem and the average rainfall of the area is around 2000 to 2200 mm with 45 to 90 rainy days in the season. Nearly 80% of rainfall received during the period of south west monsoon. The maximum and minimum temperature is 39 ^{o}C degree and 17.5 ^{o}C, respectively during summer season. The revenue villages selected for the present studies are Bari, J. wadi, Pendshet, Chicondi, Murshet and Panjre and agriculture is a major occupation for these villagers as 1215 families engaged in own farm activity are marginal farmers with average land holding between 1.1 to 1.4ha. Nearly, 42% families of these villages work as casual labour in village and nearby towns/cities. It is observed that 28% households migrate to nearby cities to obtain daily work. Out of total cultivable land (1859.75 Ha) only 8 % is under irrigation in rabbi season. The 92 % area is rainfed. The irrigation facilities are available in Panjre and Murshet villages by the Bhandrdara dam.

At summit of the landscape, soil is very young and may come under entisol and inceptisol soil orders with varying cultivation period (Fig. 7). The low intensive annual cropping systems been adapted over there and land fallowing after some period cultivation is also very commonly prevails it. Rice was widely grown in kharif season for taking up the situation of high rainfall during the monsoon period. Further, millets are being grown in the rabi season. Some farmers may cultivate wheat and gram crops. Vegetables in the rabi season are cultivated with assured water sources as either intercrops with fruit species such as mango, dominantly grown to have some harvest in the summer season or sole annual crop. The average productivity is very low compare to the average values for Ahmednagar district and Maharashtra state.

Fig 7: Soil at summit position of the landscape

The slopy land on igneous rock/basalt with shallow soil depth inherits soil and nutrient loss may be major soil problems. The soil is slightly red in colour and coarse texture with low to moderate water holding capacity. It appears to have low soil carbon and soil aggregates that these soil attributes may cause poor soil quality with respect to food production services and soil biodiversity. At mid-slope and foot slope of the landscape, the soils were might be mostly inceptisol and vertisol soil orders with moderately higher soil depth (Fig. 8). With sparsely distributed water storage structure, the cropping intensity is relatively higher compared to the summit of landscapes at the Akole tehsil. Deep rooted crops such sugarcane and maize crops cultivation has been observed over there. The soil colour was slightly dark to highly dark in colour.

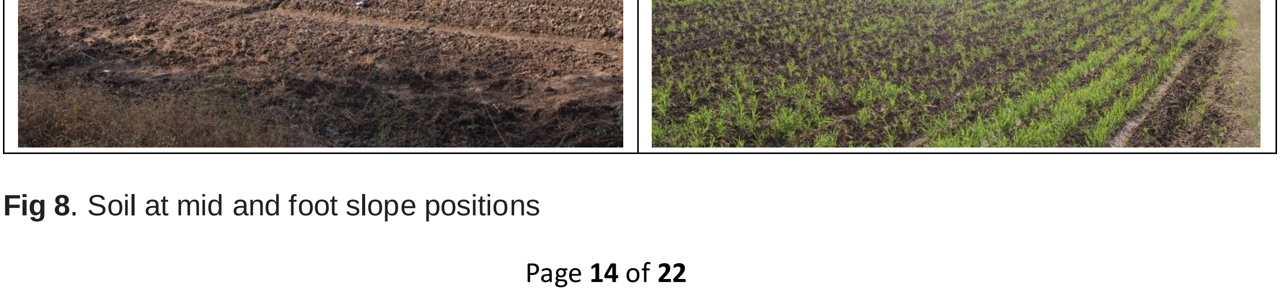

Fig 8. Soil at mid and foot slope positions

The soil pH of the study place was slightly acidic to calcareous (pH=5.2 – 8.3) nature. 50.8% samples have recorded low soil organic carbon, 27.1% medium and 22.1 % high soil carbon status recorded in the forest area in the study region. Soils were non-calcareous to highly calcareous soils. With respect to soil fertility, the soil available nitrogen is varied highly since the study covers different land uses. Similarly, 36.8 % area under higher phosphorus fertility while it was nearly 88.5% area under higher potassium fertility category. The exchangeable calcium and sulphur (85%) deficient in soil are well recognised from the study area. Soil micro nutrients deficiency is also prevails in the study region.

Soil interventions

We are partnering with BAIF organization for implementation and data collection in field sites. Below are some of the proposed soil interventions to be followed in different WP of the initiatives during field activities in 2023 and beyond.

Integrated nutrient management systems: Integrated nutrient management is a practice that combines organic manures that are available locally at very low price and modern input of fertilizer as nutrient management for achieving higher and sustainable crop yield ensuring more resource use efficiency and environmental quality.

Soil quality and agricultural productivity: The environment that the soil offers for root growth determines the soil's capacity for generating crops, because roots require air, water, nutrients, and enough room to thrive. How well roots develop is determined by soil characteristics such as water storage capacity, soil reaction, depth, texture, and density. Changes in these soils have a direct impact on the plant's health.

Effect of INM on soil physical properties: Soil physical properties are closely related with SOC and OM, thus, any soil management practice that enhances soil organic matter has direct bearing on soil physical properties and microbial biomass, for this, combined use of organic and inorganic nutrient sources might be the right proposition for these soils, primarily for the improvement of soil physical health.

Effect of INM on soil fertility: The application of organic manure increased the soil's SOC, and this combination had a substantial impact on crop growth, development, and productivity. Most of the research results clearly demonstrated that INM enhances the yield potential of crops over and above achievable yield with recommended fertilizers.

Effect of INM on biological properties: Microorganisms play a definitive and very crucial role in soil fertility. They also play an important role in the decomposition of organic matter and also in decomposition of toxic waste and other pollutants. Since, soil microbial and enzyme systems are associated with organic manure management, incorporation of organic manures into soil not only plays an important role in soil chemical and biological activity, but also affects the rate at which nutrients become available to crop plants as well as other forms of life. The organic manures, in addition to nutrient supply they have microbial load and growth promoting substances which helps in improving the plant growth, metabolic activity and resistance to pest and diseases.

Soil assessment and indicators

Soil health indicators for assessing soil physical chemical and biological processes can be studied during Nature+ field experiments.

Soil water holding capacity: Soil water holding capacity is the amount of water a given soil can hold for crop use. Crop production point of view, soils with more WHC can support higher plant growth and development and reduce leaching losses of nutrients and pesticides.

Bulk density: Bulk density is a soil attributes routinely measured to characterize the state of soil compactness in response to land use and management. It has been considered a useful indicator for the assessment of soil health with respect to soil functions such as aeration, infiltration (Reynolds et al. 2009), rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activities influencing the key soil processes and productivity.

Aggregate stability: Aggregate stability is an indicator of organic matter content, biological activity, and nutrient cycling in soil and is determined by soil structure as influenced by a range of chemical and biological properties and management practices (Moebius et al. 2007). It is considered as a useful soil health indicator since it is involved in maintaining important ecosystem functions in soil including organic carbon (C) accumulation, infiltration capacity, movement and storage of water, and root and microbial community activity.

Soil available nutrients: The soil nutrients (NPK and micro nutrients) provides the indication of a soil's capacity to support plant growth; conversely, it may identify critical or threshold values for environmental hazard assessment. Nutrient cycling, especially N, is intimately linked with soil organic C cycling and possibly the cycling of other plant-available nutrients.

Soil organisms: Soil organisms are an integral part of the ecosystem involved in different functions. They are soil organic matter decomposition, nutrient cycling, bioturbation, and pest and disease control in agroecosystems. Soil biological indicators are more sensitive and helps to detect well in advance for soil managements intervention compared to chemical and physical indicators. Soil enzymes, microbial biomass, and microbial activity are important soil biological attributes in relevance to nutrient cycling which can be considered for intervention of nutrient management system in our studies.

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KENYA

General overview and soil management in target sites: Kisumu and Vihiga

The study sites Kisumu and Vihiga located in western Kenya with lower and upper midland agroecological zones and an average rainfall of 1350 to 2000 mm. The annual maximum and minimum temperature varies between 28 ^{o}C degree and 17 ^{o}C. The farmers are mostly marginal with average land holding between 0.4 ha to <1 ha having coffee, tea, sugarcane, rice and cotton as major cash crops and bananas, beans, cassava, maize, millet, sorghum, sweet potatoes, as the subsistence crops in the region. Soil types varied from dark red-brown to sandy and clay soils.

Soil assessment

The livelihood of the people of western Kenya is mainly based on mixed crop farming that is dominated by maize, a major staple crop for the country. The region faces a challenge of land use/cover changes resulting from high population pressure causing, among others, intensification of crop production, cultivation of steep lands, and deforestation. The average soil loss through sheet, rill and inter-rill soil erosion processes was 0.3 t/ha/y and 0.5 t/ha/y, in the years 1995 and 2017, respectively. Of the total soil loss, farms contributed more than 50%, both in 1995 and 2017 followed by grass/shrub (7.9% in 1995 and 11.9% in 2017), forest (16% in 1995 and 11.4% in 2017), and the least in built-up areas. The highest soil erosion rates were observed in farms cleared from forests (0.84 tons/ha) followed by those converted from grass/shrub areas (0.52 tons/ha). The rate of soil erosion was observed to increase with slope due to high velocity and erosivity of the runoff. Areas with high erodibility in the region are found primarily in slopes of more than 30 degrees (Kogo et al. 2020).

In both the sites, the effect of population growth on ecologically sensitive areas as well as the increasing density of population has forced farmers in poor areas to cut back on fallow periods, essential to restore soil fertility necessitating the applying extra fertilizer to compensate for it. As a result, soil fertility gradually deteriorates and yields fall, forcing the farmers to cut fallow periods back even further. Some of the common local strategies of managing soil fertility in Western Kenya include mulching, agroforestry, crop rotation, fallowing and the use of animal as well as compost manures. There have been recorded cases of resistance to adapt to the modern soil health management systems unless those that they themselves have tested and proven.

Farmers harness a raft of on-farm measures in Vihiga county to cope with climate risks and shocks, such as the following: growing short-maturity and drought-tolerant crop varieties, water harvesting, conservation agriculture, tree planting, fodder conservation, livestock breed improvement and value addition (Vihiga County risk profile, CGIAR, 2021). In Kisumu County approximately 34% of the land in the county is dedicated to subsistence crops, 34% to natural pastures, and 18% to commercial crop production; homesteads extend over 7% of the land. Small-scale production represents 90% of total agricultural production in the county; it accounts for 75% of the total agricultural output and 70% of the marketed agricultural produce (Kisumu County risk profile, CGIAR, 2018).Moreover, a team of Alliance of Bioversity International and CIAT visited both counties and assessed the soil health challenges as described above.

With the observed decrease in food production quality and quantity, hence food security, reactive and proactive measures need to be put in place. Some of the challenges experienced with the adoption of the Nature+ initiatives are that: most of the farmers are doing subsistence farming hence do not see the need to incur more in changing their farming practices and soil health management; many residents are still holding onto the indigenous knowledge of maintaining soil health and are therefore reluctant to adjust to modern and improved initiatives unless they have tested and approved of them by themselves; many farmers are living below the poverty level and therefore may not afford the capital investment that would be incurred with the respective changes. The literacy level in the county is also low and therein the amount of awareness and knowledge of Nature+ initiatives is supposedly low.

According to Household Food Insecurity Access Prevalence in 2018, 71.3% of households in Kisumu County were either moderately food insecure (26.3%) or severely food insecure (45%), implying a high prevalence of food insecurity in Kisumu. Measured in terms of the Months of Adequate Household Food Provisioning indicator, 27% of the households consider their monthly food access to be constrained. The study presented to the Food Liaison Advisory Group (FLAG) which was instituted following a partnership between Kisumu County and Food and Agriculture Organization of the United Nations (FAO), also indicates that Kisumu County experiences low levels of dietary diversity coupled with the high levels of food insecurity. Levels of food insecurity, or food poverty, in Kisumu are generally high, with particularly high rates being measured in the poorer settlement areas.

Not only this but small-scale farmers are also vulnerable to climate change due to their livelihoods dependent on natural resources such as soil, weather, water and the ecosystem at large. Farmers' capability to withstand hard climate is jeopardized when the smallholder farmers' land is subjected to prolonged drought or floods. The aftermath affects households' income, leading to loss of assets such as crops, livestock and land.

Recommendations are made that workshops be made with evidenced reports and results of the benefits of nature+ initiatives to make convincing arguments to the farmers; subsidies made for the farmers to aid in smooth transition to nature+ initiatives as the incurred cost will be more affordable; and conducting campaigns and marketing strategies to promote nature + initiatives.

Interventions

Rebuilding up soil organic carbon and by extension nitrogen and phosphorus fertility is a way to mitigate climate change. Push-pull technology could mitigate climate change through sequestering carbon in soils, biologically fixing nitrogen and availing phosphorus (Ndayisaba, 2022). This information would be used to optimize cropping systems towards sustainable intensification of agriculture in both sites. In environments where crop pests and parasites are a challenge, and pesticides and/or herbicides are used as control measures, adoption of biological control involving crop self defense mechanisms, trap crops, natural enemies and other biochemically mediated mechanisms (Mutyambai et al., 2019), reduces the need for pesticides and/ or herbicides and related emissions. These chemicals get to the soil either deliberately or not hence affecting the soil health quality.

Liming consistently increased maize yields on soils with an initial soil pH between 4.0 and 5.7 in Western Kenya, with or without fertilizer use. For a soil pH of 5, applying 2 t/ha lime resulted in a significant increase in maize yields of 57% (from 2.3 to 3.6 t/ha) in the first year after application. Despite these positive effects on yield, associated profits – when including costs of labor - were only positive when liming was combined with fertilizer (N, P) application. While liming causes substantial GHG emissions per tonne lime applied, these were offset when expressing GHG emissions per tonne of grain maize, due to the observed yield increases.

The MBILI intercropping system optimizes yield of both component crops in the intercrop and has since been adopted in western Kenya where farmers consider it more productive than conventional intercropping. A recent study comparing the MBILI system and conventional intercropping showed that the spatial rearrangement in MBILI resulted in higher legume and cereal yields when compared to conventional intercropping systems (Fig. 8).

Use of vermiculture is gradually evolving and growing in western Kenya (Fig. 8). This is the use of red ant (earthworms) to decompose organic wastes and kitchen refuse leading to leaching of the nutrients back into the sol making it fertile. These earthworms help also in the aeration of the soil and nutrient cycling (Henze J., et al. 2020).

Fig 8. Intercropping in Vihiga county and adoption of vermiculture in Kisumu county

Alliance team will build on these interventions through farm aggregation in both counties where small holder farms will be aggregated through the co-design and participatory approach. Following this multiple interventions will be introduced in the farm focusing on restoring soil fertility, land degradation and crop management practices.

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COLOMBIA

General overview and soil management in target sites

The study area for nature positive initiative is Narino and Putamayo. Narino is situated at 77°18'58'' west longitude and 1°10'11.4'' north latitude, at an altitude of 2820 meters with total area of 1,138,910 km^2. Averagely, the annual temperature is 120 C, the average precipitation ranges from 800 to 1000mm, the annual relative humidity ranges from 70 to 80%. The main type of soil in the area is andisol soil. The area is mainly characterized by four main agricultural systems: Pastures, silvopastoral system, potato monoculture and silvoagricultural system. Based on the recent studies done in the area, the soil degradation identified in the area include 15% land overutilization, 13% land overutilization, soil erosion, soil sealing, pollution and contamination, salinization, compaction, desertification and loss of organic matter, soil acidification, decreased soil organic carbon, low total nitrogen and organic bases. Agroforestry systems, forest plantations, monocultures and native forests as well as residential and settlement areas are the main land uses. The average annual loss of soil due to erosion is approximately 11.7mg/ha while the loss of soil organic matter due to oxidation is approximately 600kg/ha.

Putamayo is in the Amazon region, between 01º26'18'' and 00º27'37'' north latitude, and 73º50'39'' and 77º4'58'' west longitude at an altitude of 900 meters above the sea level. The total area of the department of Putumayo is 24,885 km2. Annually the average temperature ranges from 24 to 270 C, the average precipitation ranges from 2300 to 3900mm, and the average relative humidity is more than 80%. The type of soil in the department ranges from anthropogenic and natural, alluvial soils and sandy clay. Silvopastoral, agrisilvicultural and strategic agroforestry are the main agricultural systems in the area. Based on the recent studies in the area, the following soil degradation aspects have been identified: Low soil organic carbon, soil acidification, high aluminum saturation, low cation exchange capacity, low base saturation, high soil penetration resistance, decreased microporosity, increased microporosity, decreasing infiltration rates, soil erosion, decreased soil organic matter, reduced microbial activities, nitrate leaching. Deforestation of natural forests has been done to allow for land use and cover changes and adoption of 71.18% protected forest, moors and wetlands, fruit trees such as tree tomato, lulo, blackberry, granadilla, the main crop being beans and in livestock activity the Creole Holstein breed that produces milk and the artisanal production of rainbow trout predominate, palm oil, sugarcane, biofuel, bananas, wheat, barley, potatoes, tobacco, sesame, African oil palms, cocoa, peanuts (groundnuts), grapes, soybeans, and citrus fruits.

In both the sites, few soil management practices employed including establishment of cover cropping, agroforestry, application of organic manure, use of organic mulch, rotational grazing, fallow farming, and crop rotation (Ordoñez et al., 2020: Olaya-Montes et al., 2021). Home gardens comprised biannual, annual, and perennial crops and small animal species, requiring multiple daily, weekly, monthly, semi-annual, and yearly activities that could generate employment for several household members, drawing on the human capital of each (Palacios et al., 2021). Approximately more than 52,500 families have been identified with the growing of cacao without any agricultural restriction and therefore cacao must compete with other crops for prime areas (León-Moreno et al., 2019). Few other studies done by Medina-Sierra et al., 2022 revealed the physical and chemical nature of soils but actual soil health assessment, interventions and monitoring needs to be done in these sites. The Alliance team Nature+ initiative in collaboration with its partners including NARS such as Agrosavia will focus on the soil health work including biological which will assess the below ground soil biodiversity in diverse agroecologies, cropping systems and management practices of small holder farmer's fields.

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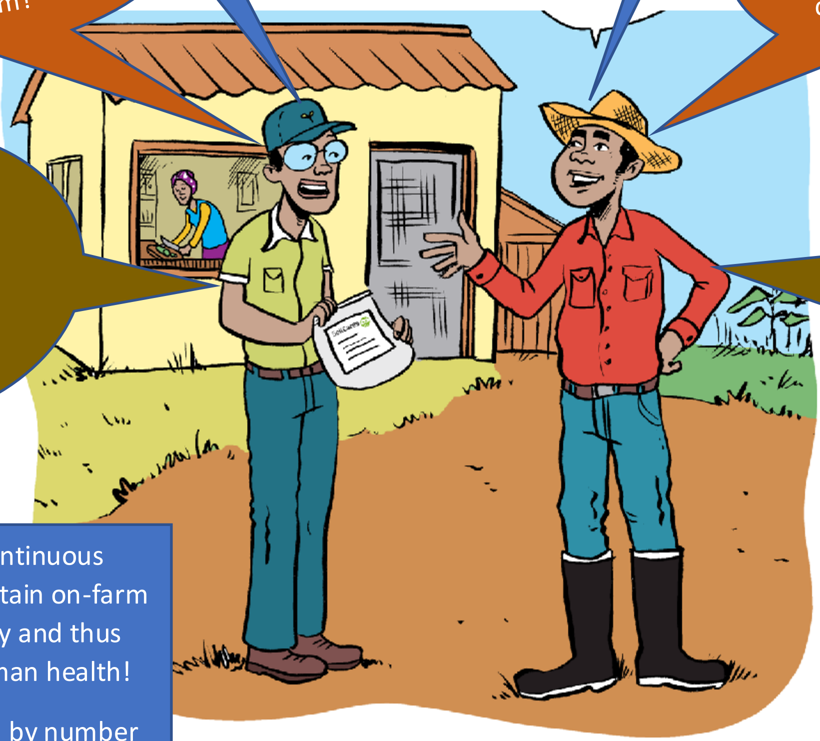
MUST NOT MISS

Planning and making a baseline survey?

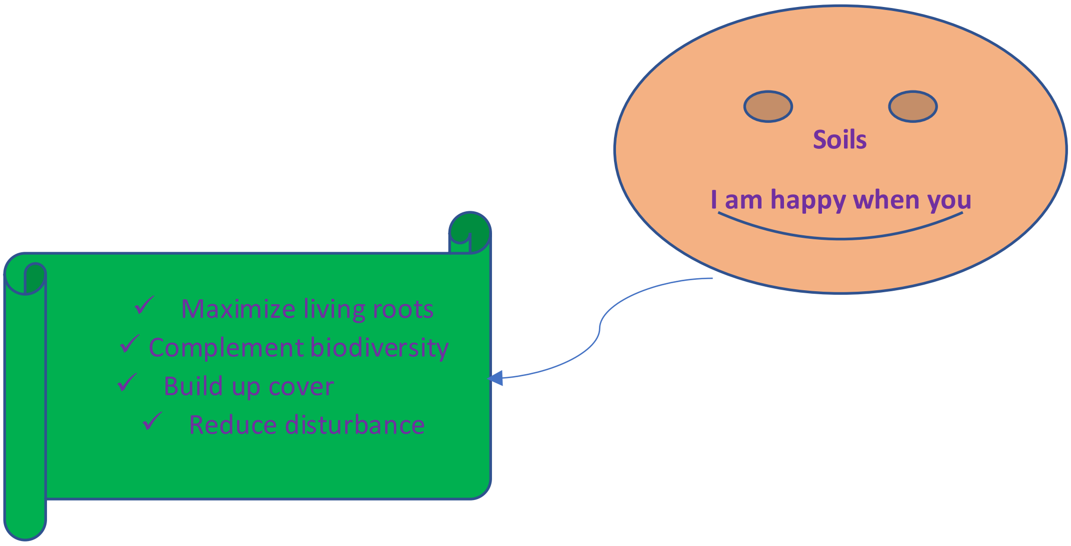
I am the soul of infinite life (SOIL)



Soil health is the continuous capacity of soil to maintain on-farm productivity, diversity and thus plant, animal and human health!

Soil health is impacted by number of factors and measurements follows soil testing in lab and field.


Have you ever observed any of the key impacts on the soil on:
Quality degradation, contamination, erosion, compaction and loss of agricultural production potential over the time?
Yes, I do observe the contamination of pesticides and my productivity is getting low every year even when I apply very high amount of fertilizers.
What are the major crops you cultivate?
I grow Maize, Groundnuts, Soybean, Cowpea
Which major cultivation practices you follow? Monocropping, Intercropping, Crop rotation
I just grow them randomly
Do you use external inputs in soil?
Fertilizer- NPK, Manure/FYM/ or use crop mulching
I don't know the importance of that and right usage.
Please advise me and help to get my soil and productivity better.
For sure, we the team of Nature+ is here to help you and other farmer's on that.
Soon we will come back for sampling and other advise, till then please remember the below words from your soil.


Soils
I am happy when you
✓ Maximize living roots
✓ Complement biodiversity
✓ Build up cover
✓ Reduce disturbance