FORMAS
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FACTSHEET - TECHNICAL GUIDELINES

FERTILISING RIGHT TO SAVE COSTS AND PROTECT THE ENVIRONMENT

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ABOUT THE PROJECT

The Project ***"Agroforestry: potential for sustainable development in the uplands"*** aims to contribute to sustainable development in sloping upland areas, with focus on evaluating agroforestry practices and systems addressing production and productivity, soil conservation, management practices such as nutrient application and weeding, and competitive effects between trees, crops and forage grass in young and mature agroforestry systems, study fruit value chains and market links, and assess opportunities and bottle-necks for wider agroforestry adoption and increasing of scale.

The Project (formally two projects) is funded by Formas, a Swedish Research Council for Sustainable Development and Vetenskapsrådet / Swedish Research Council, respectively. It is carried out between January 2020 and December 2023 (Formas), and December 2024 (VR), by SLU - Swedish University of Agricultural Sciences and the International Centre for Research in Agroforestry (ICRAF - also known as World Agroforestry) in Viet Nam, the Soil and Fertilizers Research Institute (SFRI) and the Departments of Agriculture and Rural Development from provinces of Dien Bien, Son La and Yen Bai.

PLANTS NEED NUTRIENTS TO DEVELOP

There are 16 elements that are essential for the development of most crops. Carbon (C) in the form of CO2 is taken from the air, and hydrogen (H) and oxygen (O) in the form of H2O come from rainwater or irrigation water. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl) are taken from the soil, animal manure, various organic fertilisers and mineral fertilisers. Plants absorb C from the air during photosynthesis, a natural process where light energy is converted into chemical energy bound in organic compounds. Most other elements are absorbed by plants from the soil solution, and converted into organic matter or used dissolved in the plants´ cell liquid. Leguminous plants, in particular, can obtain nitrogen through the process of biological nitrogen fixation; the nitrogen is fixed from the air with the help of bacteria living in root nodules.

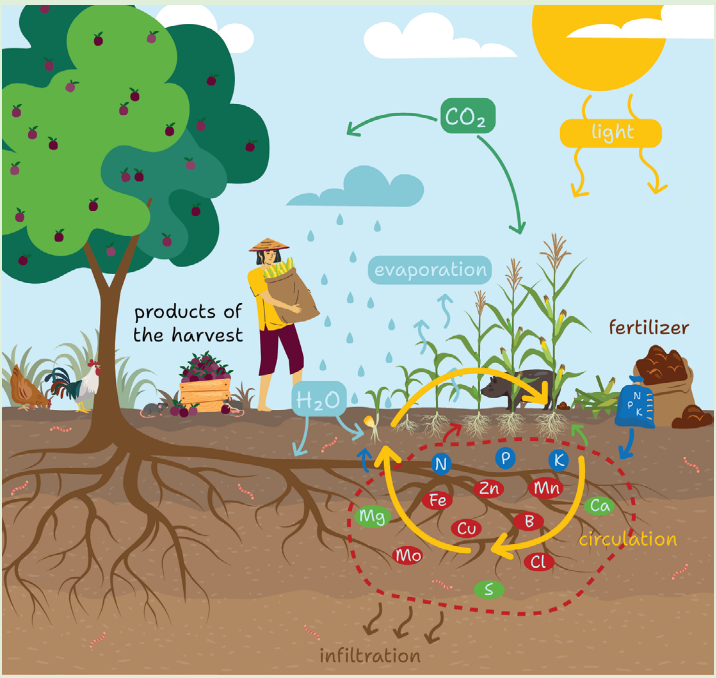


Figure 1. *Nutrient circulation process in agricultural systems*

FUNCTION OF NUTRIENTS

Nutrients from the soil are classified into two types: macronutrients (divided into primary and secondary elements) and micronutrients.

Soil may naturally lack some nutrients or become deficient when crops are harvested or removed over many years of cultivation. Macronutrients are required in large quantities and are the nutrients most commonly applied through fertilisers. Micronutrients are only needed in small amounts for normal plant growth and should be supplemented in very small quantities when the soil cannot provide enough.

The primary nutrients N, P and K are essential macronutrients needed in large quantities for plant growth. N is vital in amino acids, proteins and chlorophyll, P is active in the photosynthesis and metabolism, and K increases plant resistance to a number of stresses imposed by their environment (e.g. drought).

Secondary nutrients are Mg, S, and Ca. Mg is a central component of chlorophyll. S is an essential component of proteins and it is involved in chlorophyll formation. Ca is essential for root development and is a component of cell material. However, the purpose of applying Ca is often to lime the soil, i.e., to reduce soil acidity (increase pH).

Micronutrients include Fe, Mn, Zn, Cu, Mo, Cl, and B. They can be compared to vitamins in human nutrition. Used in small quantities by the plants, their optimal range of supply is very small.

It is important to know that all plant nutrients, whether required in large or small quantities, play specific roles in plant development and cannot be replaced by another. When one of these elements is deficient, it becomes a limiting factor for plant growth. Providing sufficient nutrients is crucial for the proper functioning of the photosynthesis process. In fact, if any nutrient is missing from the soil, the photosynthesis process will slow down. If there is a nutrient deficiency, the plants will show signs of hunger (symptoms of deficiency), like how we exhibit signs of malnutrition when not receiving proper food. However, if provided in excess, it can lead to waste and even toxicity to the crops.

SOIL AND ITS ROLE

Soil is the upper layer of the earth. It consists of mineral particles of various sizes, formed by weathering of parent material (rock) and organic matter (from plants and animals). Depending on the soil´s composition, it can provide different nutrients for crops.

Clay particles in the soil and soil organic matter hold nutrients. Nutrients are attached to clay minerals and organic matter by the mechanism of attracting opposite charges, similar to how a magnet attracts iron. The ability of soil to retain a certain amount of nutrients (storage or absorption capacity) determines the natural fertility of the soil.

Soil surface with positive charge +

Soil surface with negative charge -

Clay particles in soil

Soil organic matter

Soil solution

Nutrient with positive charge +

Nutrient with negative charge -

Water in the soil, known as the soil solution, contains dissolved nutrients that crops can use. Plant roots can only absorb nutrients in a dissolved form. When mineral fertilisers are applied, nutrients dissolve. When organic fertilisers are applied, some of the nutrients first need to be released from the organic material. Nutrients with positive charges (+) and nutrients with negative charges (-) are retained on the soil particle surface by the mechanism of attracting opposite charges and need to be released into the soil solution for plant uptake. Therefore, the processes of nutrient adsorption and release into the soil solution are crucial. Different soils have different adsorption intensities for positively and negatively charged nutrients and control the method and timing of fertiliser application (especially nitrogen fertilisers) to achieve the highest efficiency, avoiding pollution from runoff and preventing fertiliser waste for farmers. Organic matter can retain more nutrients than an equivalent amount of clay soil. Therefore, the accumulation of organic matter in the soil is crucial, especially in tropical areas with degraded soil.

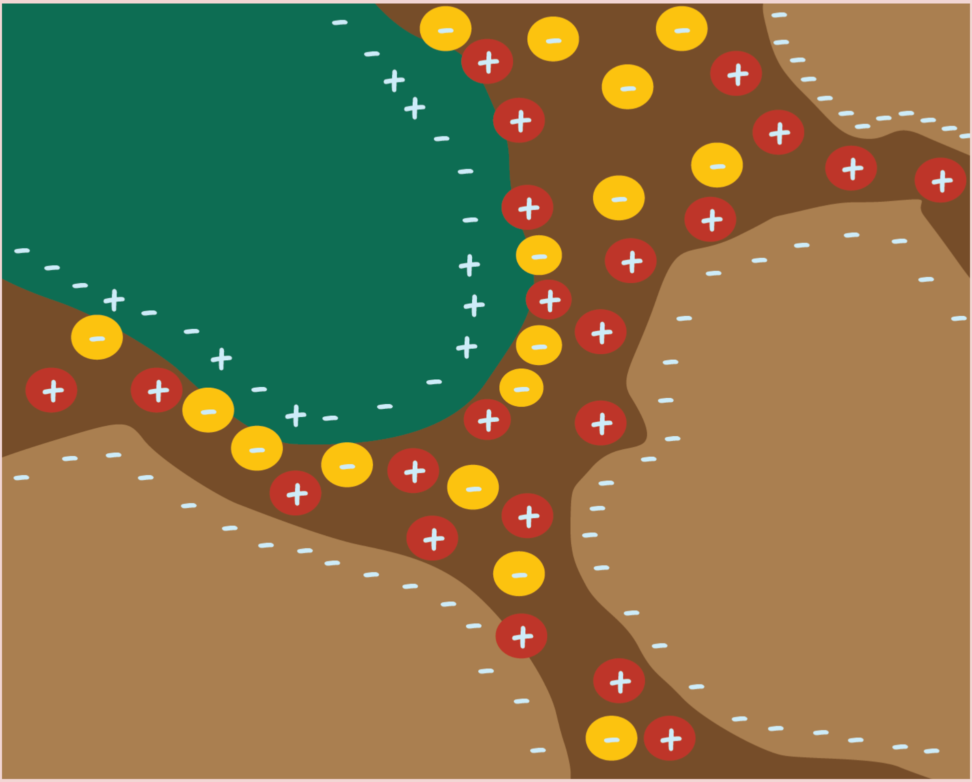


Figure 2. *Soil profile – the mechanism by which nutrients are stored in the soil*

SOIL ORGANISMS AND MICROORGANISMS

The activity of soil organisms is essential for maintaining high soil fertility and promoting good crop productivity. After fertilisers are applied to the soil and organic matter is incorporated by soil organisms, non-soluble forms of nitrogen and phosphorus present in organic material are transformed into plant-available forms through the action of microorganisms. Most of their activities bring benefits to farmers as they decompose fresh organic matter to create humus, aggregate soil particles which improves soil structure, protect roots from diseases and parasites, retain nitrogen and other nutrients, produce hormones that aid in plant growth, and facilitate the binding or decomposition of pollutants. Farmers can support beneficial soil microorganism activities by maintaining good aeration, adequate moisture, and proper drainage, and by keeping the soil pH optimal (between pH 5 and 6) by using lime judiciously and avoiding excessive pH changes. Supplying ample organic matter to the soil and providing soil cover with plants or mulch to reduce erosion and retain moisture are also important, as is avoiding indiscriminate use of crop protection chemicals.

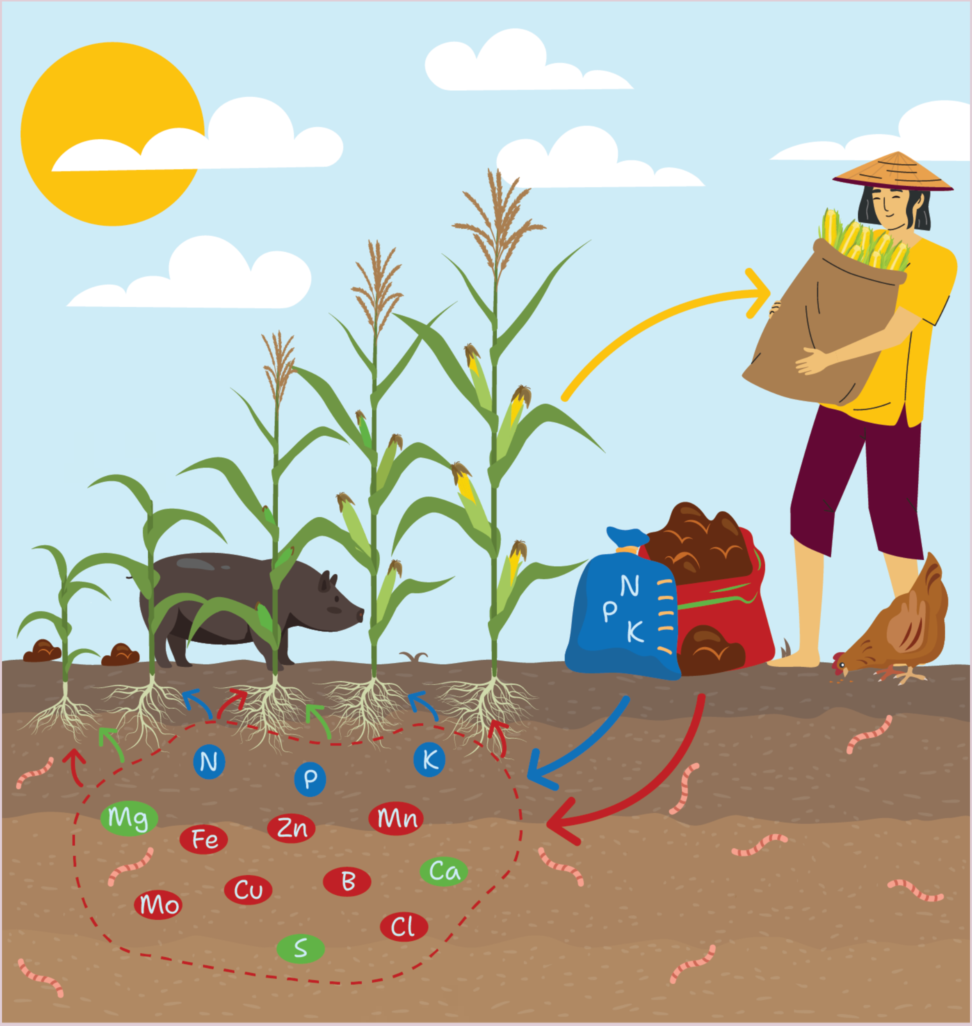


Figure 3:
Soil organisms and microorganisms promote the process of providing nutrients to plants

WHY IS NUTRIENT BALANCE NEEDED?

As mentioned earlier, plants require nutrients for their growth. If any nutrient is deficient, it can limit and affect the absorption of other nutrients, which leads to decreased plant growth and yield. However, an excess of nutrients is also detrimental to plant health and quality.

For instance, nitrogen often shows immediate effects on plant growth and vibrant green colour after fertilisation. However, an excessive amount of nitrogen can lead to reduced crop quality, especially in terms of storage. In rice, for example, over-fertilisation with nitrogen can result in lodging, and susceptibility to pests and diseases, causing significant yield loss. Additionally, excess nitrogen not absorbed by plants can be lost through leaching, deep percolation, and volatilization, leading to wastage for the farmer and negative effects on the environment.

Another example is in soils rich in phosphorus and potassium, along with all necessary secondary and micronutrients. Prioritizing heavy nitrogen fertilisation may initially boost productivity. However, higher yields mean plants will uptake more nutrients (primarily phosphorus and potassium) from the soil until they become limiting factors. Continually applying nitrogen without addressing the balance can be inefficient and result in losses for farmers. Moreover, using pre-mixed NPK fertilisers in inappropriate ratios over an extended period can lead to excesses or deficiencies in certain elements.

Therefore, imbalanced fertilization, not aligned with the needs of the crops, not only contradicts good agricultural practices but also results in labour and capital wastage, environmental harm, and unsustainability. To optimize fertiliser use, a balanced approach is essential. Plants are akin to humans, they require a balanced diet, and an excess of one type of nutrient is not sufficient. An imbalanced diet ultimately leads to diseases. Moreover, plants cannot move around to seek lacking nutrients, so conditions must be created as favourable as possible in their immediate environment.

For good agricultural practices, it is crucial to maintain optimal soil pH through lime application (for acidic soils) and to use balanced fertilisers, providing appropriate amounts of nitrogen, phosphorus, and potassium based on soil reserves, crop requirements, and expected yields, while supplementing magnesium, sulphur, and micronutrients when necessary.

Sustaining micronutrient levels in the soil can be achieved through continuous use of organic and animal-based fertilisers from agricultural by-products. Furthermore, combining fertiliser use with good agricultural practices ensures that plants receive the necessary nutrients in a balanced ratio and at the right time. Farmers should be aware of this, as the economic benefit they derive from farming is partly influenced by how they fertilise their crops. Thus, promoting balanced crop nutrition contributes to economic benefits for farmers.

HOW TO CALCULATE WHETHER FERTILISER USE IS IN BALANCE ?

The method widely used to determine the fertiliser application rate is based on recommendations and local experience for each type of crop. Recommendations are derived from fertiliser trials, involving different fertiliser levels that result in statistically significant productivity responses. Research institutions often carry out fertiliser trials providing useful recommendations on fertiliser quantities correlated with crop productivity and economic efficiency, as well as the timing of application based on different growth stages. However, its limitations become evident when applied in areas with soil characteristics significantly different from the trial locations. Therefore, farmers often combine recommendations with local experience, adjusting them to suit their specific soil conditions. Relying on experience also reveals limitations, such as uncertainties about effectiveness and economic viability. Moreover, not all nutrients applied to the soil can be fully utilized by plants due to factors like leaching, deep percolation, volatilization, or fixation in the soil, which cannot be precisely quantified. Hence, farmers need skills to identify the nutritional needs of each crop, adjust fertiliser quantities according to each crop's requirements per season or year, and integrate good practices to minimize nutrient losses.

To assess whether the current fertiliser use is reasonable, farmers can calculate the nutrient amount extracted by the harvested products using the nutrient content in each ton of agricultural produce (Equation 1). Table 1 provides the nitrogen, phosphorus, and potassium content per ton of some common grain, vegetable, tuber, and fruit crops.

EQUATION (1)

$$X = y \times B$$

Where:

X is the nutrient content in the harvested product [kg],
y is the mass of the harvested agricultural product [tons],
B is the nutrient content per ton of the product [kg].

Table 1: Amount of N, P, K (kg) contained in 1 ton of some main agricultural products (Paul 2023)

	Name of the product	N [kg]	P [kg]	K [kg]
1	Maize (seed)	13	1.9	4.3
2	Coffee (fresh fruit)	5.2	0.3	5.6
3	Cabbage (fresh)	2.9	0.6	3.4
4	Broccoli (fresh)	6.2	0.7	6.3
5	Gourd (fresh fruit)	1.6	0.3	2
6	Strawberry (fresh fruit)	14	6.9	14.7
7	Longan (fresh fruit)	2	0.4	2.4
8	Mango (fresh fruit)	1	0.1	1.7
9	Plum (fresh fruit)	1.1	0.2	1.9
10	Macadamia (seed)	12.8	1.9	3.4

Then, the farmer can compare it with the amount of fertiliser used to produce that quantity of agricultural products as follows:

EQUATION (2)

$$Z = C - X$$

Where:

C is the amount of fertiliser used [kg],
X is the nutrient content in the harvested product [kg],
Z is the difference between the amount applied and the amount carried away [kg].

If the amount of fertiliser used (Z) has a positive value (+), it means that the amount of fertilizer applied exceeds the amount taken away. The higher this value, the greater the accumulation in the soil but also the risks for nutrient loss, indicating a need to investigate the reasons behind it and implement good farming practices to address the issue.

If the amount of fertilizer used (Z) has a negative value (-), it means that the amount of fertiliser applied is less than the nutrient content taken away. In this case, the crops are currently utilizing nutrients already present in the soil, which could be either naturally occurring or residual from the previous crop season, meaning that in the end the soil will be mined for nutrients leading to deficiency.

► It is important to monitor and supplement at a minimum level equivalent to the amount taken away in the next crop season because it could be a limiting factor for crop productivity in the upcoming season.

Note that this calculation method does not aim to determine the exact quantity of fertiliser lost through processes such as leaching, deep percolation, volatilization, or fixation in the soil. Its purpose is to help farmers assess the status of their fertiliser use and take measures for improvement.

Table 2 provides an example of research conducted in Ban Mon commune, Mai Son district, Son La province.

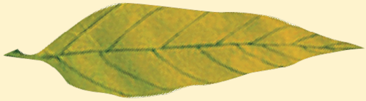
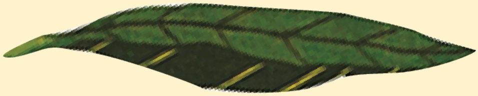
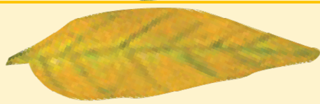
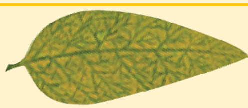
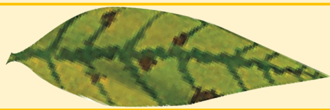
Table 2: Average amount of fertilizer per cultivated hectare, amount of nutrients in harvested agricultural products and estimated nutritional imbalance for some main agricultural products in Ban Mon commune, Mai Son district, Son La province (Paul 2023, La et al. 2023)

	Name		N [kg/ha]	P [kg/ha]	K [kg/ha]
1	Maize	Amount of fertilizer applied	215	55	30
		Amount in harvested products	160	20	85
		Amount in excess/deficiency	**55**	**35**	**-55**
2	Coffee	Amount of fertilizer applied	102.6	61.7	90.8
		Amount in harvested products	54.9	7	25.3
		Amount in excess/deficiency	**47.7**	**54.7**	**65.5**
3	Cabbage	Amount of fertilizer applied	150	60	110
		Amount in harvested products	60	10	60
		Amount in excess/deficiency	**90**	**50**	**50**
4	Broccoli	Amount of fertilizer applied	140	75	220
		Amount in harvested products	85	10	85
		Amount in excess/deficiency	**55**	**65**	**135**
5	Gourd	Amount of fertilizer applied	280	75	150
		Amount in harvested products	140	50	165
		Amount in excess/deficiency	**140**	**25**	**-15**
6	Strawberry	Amount of fertilizer applied	430	160	305
		Amount in harvested products	55	20	55
		Amount in excess/deficiency	**375**	**140**	**250**

	Name		N [kg/ha]	P [kg/ha]	K [kg/ha]
7	**Longan**	Amount of fertilizer applied	160	65	95
		Amount in harvested products	3	1	4
		Amount in excess/deficiency	**157**	**64**	**91**
8	**Mango**	Amount of fertilizer applied	45	15	25
		Amount in harvested products	5	0.6	1.3
		Amount in excess/deficiency	**40**	**14.4**	**23.7**
9	**Plum**	Amount of fertilizer applied	345	160	305
		Amount in harvested products	55	35	55
		Amount in excess/deficiency	**290**	**125**	**250**
10	**Macadamia**	Amount of fertilizer applied	80	35	60
		Amount in harvested products	0.5	0.05	0.1
		Amount in excess/deficiency	**79.5**	**34.95**	**59.9**

Table 3: Signs of lack of nutrients on the surface of plant leaves

	Symptoms
1	Dwarf tree has an unusual green color. Leaves are erect, light green to yellow, burned in severe cases.
2	Dwarf tree has an unusual dark green color. Leaves are erect and often narrow. Leaves are greenish brown to black in severe cases. The underside of the leaf is dark bronze.
3	The leaves have lost their green color, there are small dead spots at the leaves tips and edges. The leaves are rusty brown, with edges and tips curved and wavy.
4	The tree is dark green, the young buds lose their green color, curl and gradually die at the leaf tips and edges, and finally the top buds die.
5	The leaves lose their green color starting from the tips and edges, with no dead spots. The leaf veins are still green. Leaf tips and leaf edges or leaf bottoms curl down. May cause necrosis (acute). Leaves fall easily.
6	Light green leaves, pale veins, no dead spots.
7	The leaves have lost their green color, have no spots, and the main veins of the leaves are still green.
8	The leaves lose their green color, the main veins and secondary veins turn dark green, forming squares.
9	Leaves are narrow and small, leaf blades lose their green color, leaf veins remain green, dead spots develop all over the leaf, including leaf veins, leaf tips and leaf edges.
10	Loss of green color between leaf veins. Leaves often wilt and fall easily.
11	Young leaves at the top buds lose color and weaken starting from the bottom. Top buds die.
12	Leaves are light green, golden yellow to orange, have dead spots all over the leaf surface (except veins), the underside of the leaf secretes resin.

Cause	Illustration
Lack of N	
Lack of P	
Lack of K	
Lack of Ca	
Lack of Mg	
Lack of S	
Lack of Fe	
Lack of Mn	
Lack of Zn	
Lack of Cu	
Lack of B	
Lack of Mo	

FERTILISATION ACCORDING TO GOOD AGRICULTURAL PRACTICES

Start with small changes that have significant impacts. In principle, what is taken away must be replenished in some way. As mentioned earlier, plants need 16 essential elements to grow, and these cannot be replaced. Organic matter and soil particles retain nutrients on the surface and gradually supply them to crops. Therefore, organic matter is crucial for soil improvement. Additionally, organic matter such as animal manure and unharvested plant parts can provide sufficient micronutrients and some macronutrients. Chemical fertilisers primarily supply macronutrients. By recovering dispersed nutrient sources and optimizing the reuse of wastes generated in the production process, such as unharvested plant parts or livestock waste (manure, urine, animal hair), all these wastes can be converted into organic fertilizers.

Compare the balance between the amount of fertiliser used and the amount carried away with the harvested product. For deficient factors, at least the amount taken away needs to be replenished with fertiliser. If there is an excess, it can be reduced, but this is only effective when the organic matter content in the soil is increased to retain the applied nutrients (limiting loss), as analysed above.

Observe and analyse the real relationship between components such as topography, soil quality, and rainfall patterns to determine intervention measures. Planting contour lines on sloping land and using crop strips as erosion barriers help reduce runoff, forming terraces on sloping land, thereby decreasing the amounts of nutrients lost through erosion. Intercropping trees with crops is advantageous because deep-rooted trees can utilize nutrients permeating past the crop root zone, reducing the fertiliser requirement for the trees.

Create a soil environment with a pH of 5-6 by applying lime. This creates favourable conditions for soil organisms and microorganisms to thrive while releasing nutrients that are fixed on soil particles for the crops.

In general, implementing methods to increase soil pH, selecting diverse intercropping, crop rotation, planting leguminous crops, applying rational fertilization, and maximizing ground cover will generate diverse income, meeting human food needs and exchanges. This model not only provides environmentally friendly agricultural products but also has the potential for eco-tourism, conserving the local natural values.

Figure 5: Figure 5: Guinea grass planted along contour lines helps reduce erosion, form terraces on sloping land and serve as animal feed. Fruit trees with deep roots can use part of the fertilizer for deep-rooted corn, and forage grass can use part of the fertilizer for corn and fruit trees along the slopes.

Figure 6. Preparing land for short-term crops to intercrop with fruit trees. Weeds are used as an organic source. The stems are cut, no herbicides are used. Plum trees can use part of the deeply infiltrated nutrients from short-term crops.

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NOTES

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