USING AGRICULTURAL LIME

Technician's Manual

2023 – Version 1

FOLUR
Food · Land Use · Restoration

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Créer des marchés, créer des opportunités

ACKNOWLEDGEMENT

This report is a joint product of the Global Food Systems, Land Use and Restoration (FOLUR) Impact Program and International Finance Corporation (IFC). The realization of this document was made possible through the dedication of both state and non-state actors in Liberia. The manual benefited from review and input from the Conservation International (CI) Liberia for their contributions to this document and their support in organizing a webinar held in April 2023, focusing on the theme "Liming: An Effective Tool to Combat Soil Acidity and Increase Yields."

The team also extends its appreciation to Carrières et Chaux du Mali (CCM), which played a pivotal role in the production of the original document, subsequently adapted to the Ivorian context.

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INTRODUCTION

In Africa, agriculture employs about two-thirds of the continent's workforce and contributes an average of 30 to 60 percent of countries' Gross Domestic Product (GDP)[i].

However, the soils are subjected to severe hardships (massive export of nutrients by crops, exposure of soils during harvesting, inadequate use of chemical fertilizers and pesticides, heavy erosion, monocultures, etc.). They are not as healthy and productive as they should be. Rather, these unsustainable agricultural practices lead to the degradation of agricultural land with 56% being subject to acidity[ii].

In Liberia, more than 70 percent of people rely on agriculture for their livelihoods – the acidity found in 75 percent of soil diminishes the capacity to improve food security and increase efficiency in agricultural value chains, putting farmer livelihoods and the health of the national economy at risk.

It is now essential to rehabilitate these acidic soils in order to improve the health of agricultural land. This rehabilitation is also necessary for developing agricultural systems that are resilient to climate change.

Few farmers, especially small holders, know the state of their soil's fertility, especially if acidity is present. Yet, small-scale tests are simple to carry out: the pH paper strips give the farmer instant feedback. Once these tests have been carried out, applying agricultural lime and adopting good agricultural practices have proven to be very effective solutions to fighting soil acidity, with convincing results.

Liming, developed in Europe since antiquity, is beginning to generate real interest in Africa. Ethiopia, Kenya, Tanzania, and Rwanda have launched strategic plans for acid soil rehabilitation/restoration, which are supported by substantial public investment. These are often accompanied by growing - albeit still modest - private investment from the lime industry.

This manual is intended for agricultural technicians, and anyone interested in soil acidity remediation, as well as in the testing and application of agricultural lime.

A. AGRICULTURE IN LIBERIA

1. Overview

Liberia

The **Republic of Liberia** is located on the West African coast, with country borders of Sierra Leone to its northwest, Guinea to its north, Ivory Coast to its east, and the Atlantic Ocean to its south and southwest. Liberia has a population of 5 million and covers an area of 111,369 km^2. The official language of Liberia is English. However, more than 20 indigenous languages are spoken, reflecting the country's ethnic and cultural diversity.

Liberia remains one of the poorest countries in the world, despite various efforts by the government, and supporting development partners. Poverty is widespread especially in rural areas, where more than two million Liberians are estimated to live below the poverty line. The level of hunger is severe and chronic food insecurity remains a critical challenge for human capital development.

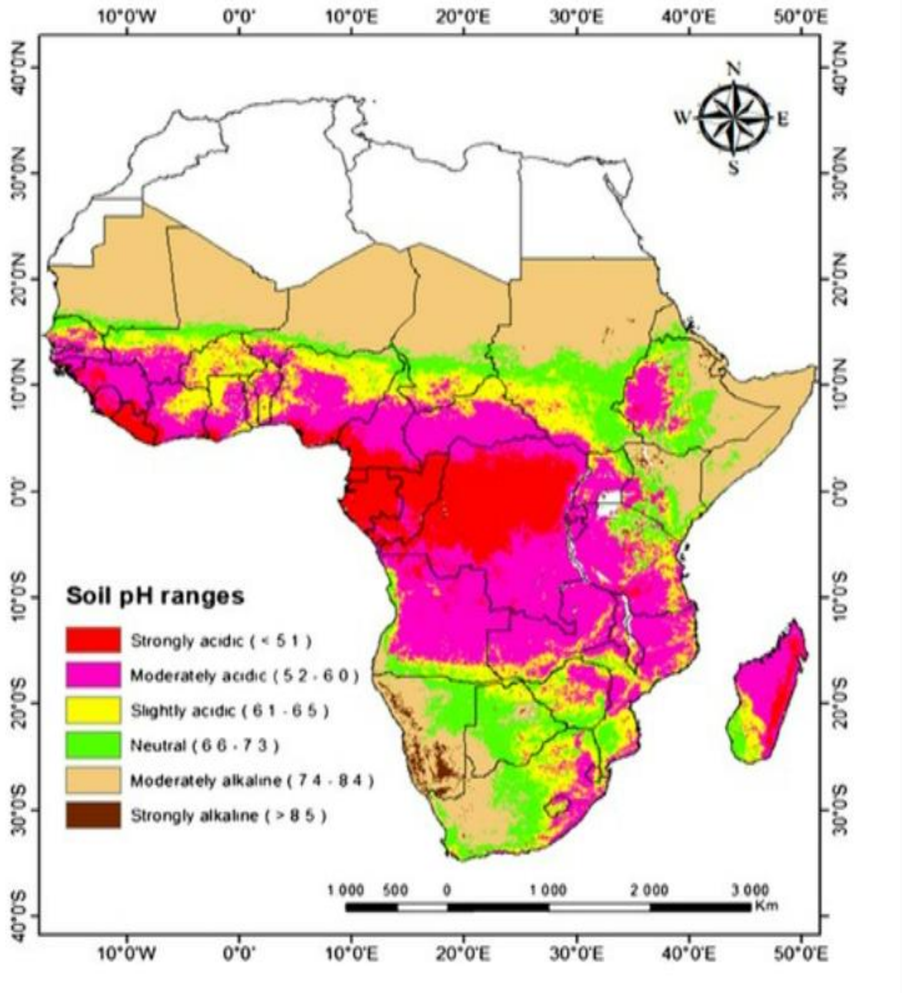
From 2014 to 2021, Liberia experienced two major health emergencies that shifted the Government’s attention from its development plans to focus on implementing emergency response to fight the deadly Ebola Virus Disease (EVD) outbreak (2014-2015) and the COVID-19 pandemic (2020-2021). Responding to the two emergency outbreaks stalled development efforts as well as resources to strengthen national capacity for crisis response.

Agriculture at the heart of the social and economic fabric of the country

Liberia is an agricultural country where more than 60% of its population gains its livelihood in agriculture. Farmers are engaged in cassava, rubber, rice, oil palm, cocoa, or sugarcane production. Cassava and rice are the primary staple food crops, but cassava is more popularly grown than any other food crop. However, overall agricultural productivity is low. As a result, Liberia imports more than 80 percent of its rice, making the country vulnerable to global food price volatility.

The Liberian economy is dominated by services, including agriculture and industry, and remains largely informal, with 87 percent of those aged 15 to 64 employed in the informal sector. Despite the large size of the agricultural economy in the country, productivity is low. Traditionally, Liberia’s poor productivity has been attributed to lack of basic infrastructure such as machines, farming equipment and tools, farm-to-market roads, fertilizers and pesticides, and food storage capacity. However, one crucial factor that could have limited productivity is low soil fertility due to soil acidity. The dominant soils in Liberia are highly leached and acidic Ultisols (see Fig. 1), which are generally infertile.

Figure 1. : Soil pH ranges in Liberia



Cocoa Production in Liberia

Current average cocoa yields in West Africa are around 400 kg/ha although yields of 5,000 kg/ha are achievable. Cocoa yields in Liberia stands at 200 kg per hectare about 30% of that of neighboring countries (Karmo, 2020). In 2016, the country produced about 9,603 metric tons of cocoa beans. Environmental factors like climate, location and crop specific characteristics determine the potential yields. However, the gap between the actual and potential yields can be narrowed if other factors such as water, pest management, and soil fertility are optimized.

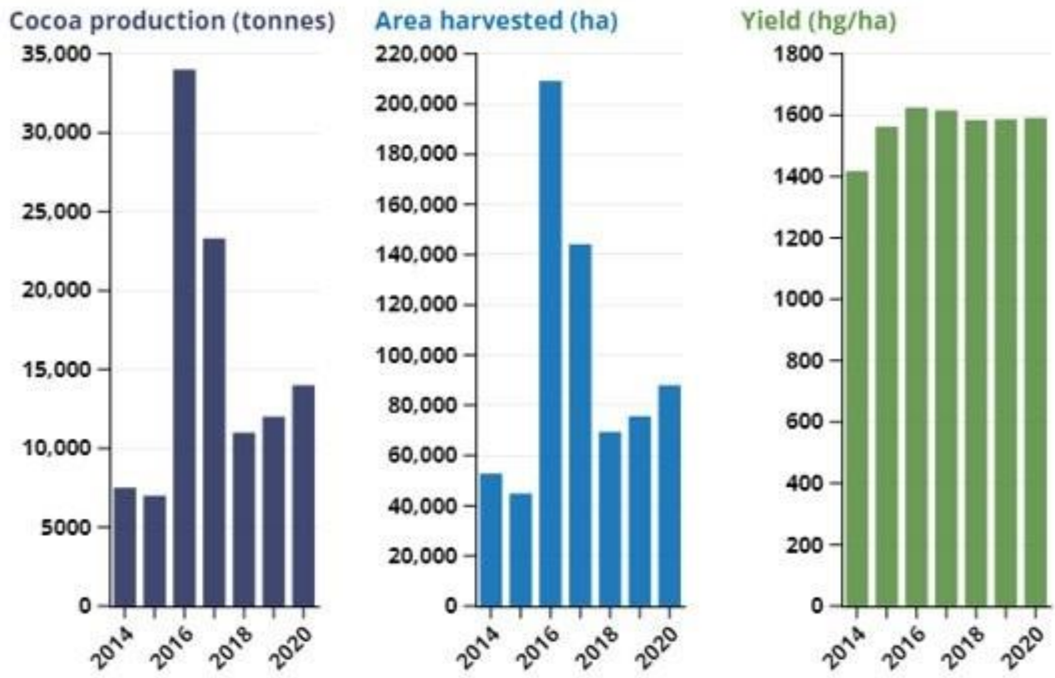
As soil nutrient content in many cocoa growing regions is poor, an obvious way to increase yields is to address soil fertility. As discussed above, Liberian soils are acidic which have adverse effects on nutrient availability to cacao. Unless the soil pH is adjusted using lime, the effects of fertilizer on increasing yield may not be realized.

The optimum range for growing cocoa is at pH 6.0-7.5. However, some cocoa soils are much more acid (less than pH 5), and in fact cocoa is very sensitive to acidity. Therefore, liming should be part of cocoa production especially in areas with soil pH less than 6.

Over 40,000 farmers are growing cocoa in Liberia. Individual farmers cultivate an average three acres of cocoa. The Government of Liberia and IFAD also have a $23 million financing to boost cocoa production, targeting the Nimba County. The government intervention is expected to help increase annual cocoa production to over 10,000 metric tons.

Small scale cocoa production will likely increase as farmers continue to reclaim and rehabilitate their farms. As with the agriculture sector in general, smallholder cocoa farmers and local cooperatives suffer inadequate farm-to-market roads, lack of familiarity with measurement and quality standards, lack of storage facilities, and limited access to updated price and market information.

Figure 2 : Cocoa Production and yield in Liberia and top exporters, 2020

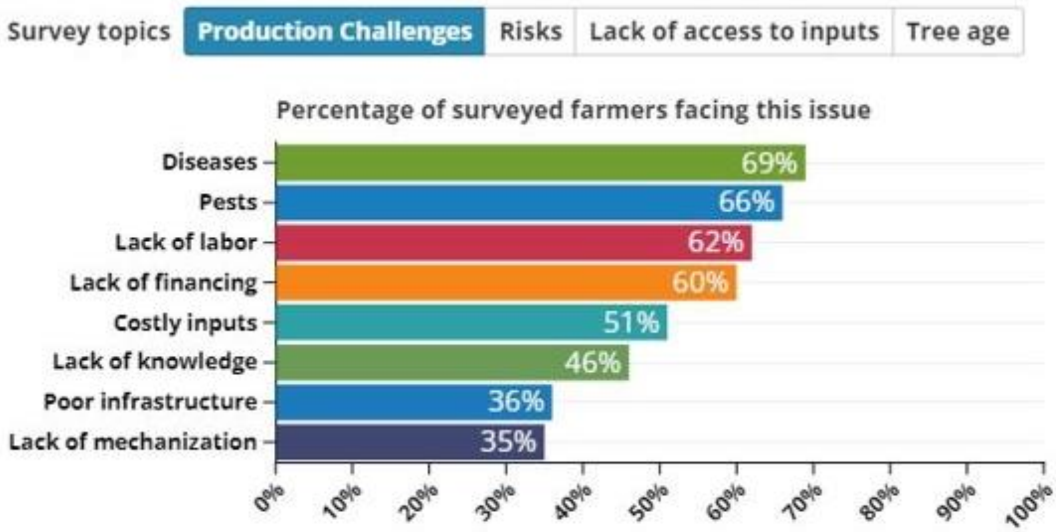


Main challenges facing the agricultural sector

Liberian agriculture is facing multiple challenges:

- ✓ Reducing the high dependence on climatic variations, especially for small growers;
- ✓ Raising the processing level of agricultural products;
- ✓ Increasing the supply of equipment to growers;
- ✓ Mitigating health crisis in different cycles;
- ✓ Strengthening the professional development and integration of growers' organizations in the food industry;
- ✓ Enhancing the inherent fertility of soils through appropriate farming practices (long enough fallows, intercropping, composting, sustainable land management, etc.);
- ✓ And, most importantly, preventing soil acidification and salinization.

Figure 3: Cocoa value chain challenges and risks in Liberia, 2022



2. Low use of fertilizers

The low use of inputs, the salinization of soils and the unpredictable nature of rainfall often push growers to adopt unsustainable farming practices, such as extensive farming, to increase their agricultural yields.

It is, however, increasingly difficult to rely on extensification strategies to sustain agricultural growth and meet the needs of the Liberian population, especially considering climate change, population growth, and declining soil fertility.

The recommended path is the intensification of agricultural production by way of increased productivity. This strategy requires the use of mineral fertilizers, which are the best way to restore soil fertility and increase crop yields.

The average application of nitrogen and phosphate fertilizers per hectare of agricultural land, which has increased over the past several years, is about 25 kg per hectare[iii].

Figure 4: Production costs of cocoa farming in Liberia, 2022

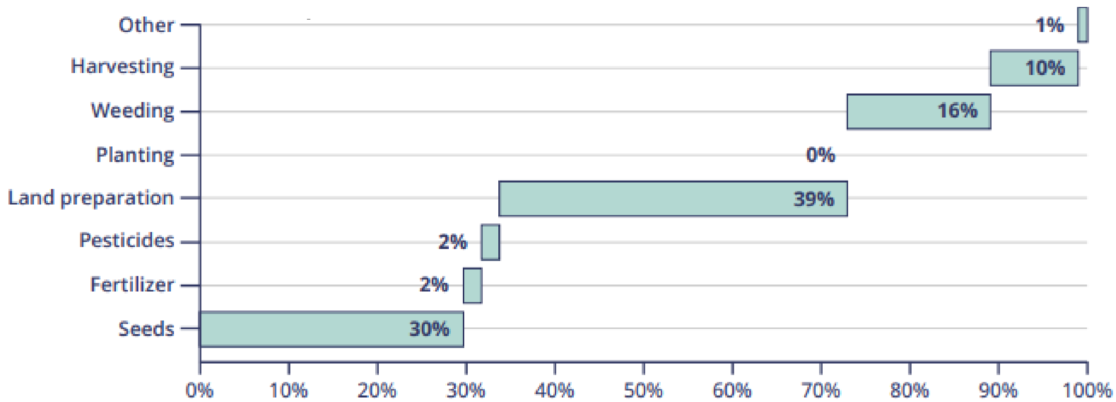
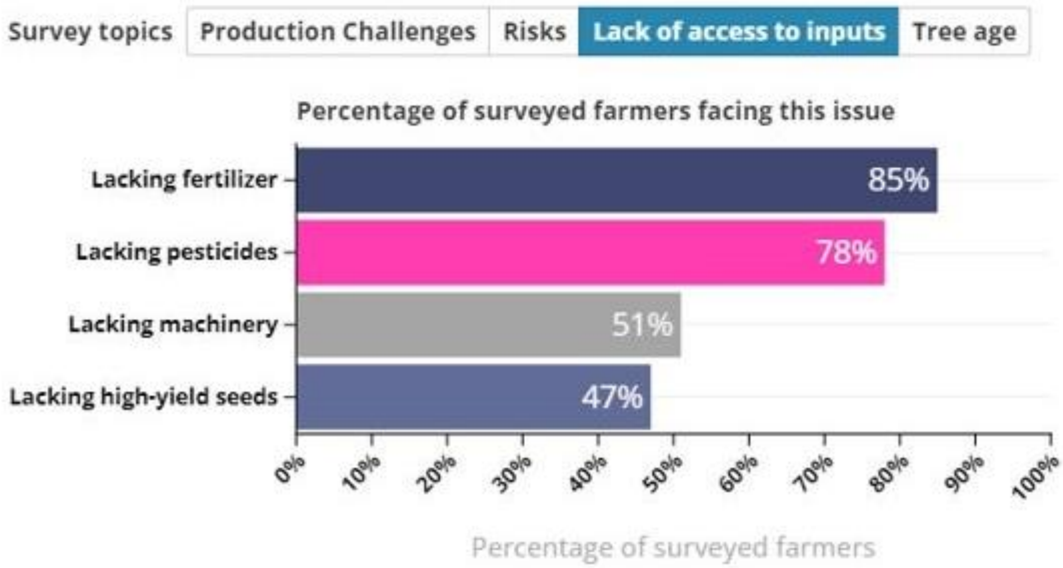


Figure 5: Cocoa value chain challenges and risks in Liberia, 2022



Source: Source: ACET, Regional Collaboration on Overcoming Binding Constraints on

3. Fragile lands

Liberia is richly endowed with abundant rainfall which makes the soil and land suitable for agricultural activities. The country is also endowed with natural resources including forest which constitute by far the largest remaining blocks (about 43%) of the Upper Guinean Forest Ecosystem making them a global hotspot for biodiversity. When managed well, natural resources and associated landscapes have the potential to accelerate economic growth and development, ensuring good governance and poverty reduction. The rural poor inhabitants of Liberia are heavily involved in traditional agricultural practices (shifting cultivation) and depend largely on the forestland, rich soil and rainfalls to achieve agricultural productivity. Such practice is resulting in deforestation and land and soil degradation which have the potential to result in desertification if care is not taken to reverse the situation.

To tackle land degradation, the government of Liberia has initiated and adopted several programs including climate smart agriculture and reforestation/afforestation activities that incorporate the participation of rural communities in forests and natural resources management. The Government is committed to investing in sustainable environment and natural resources management through the promotion of sustainable development in line with various global and regional frameworks. The government has adopted policy measures to ensure the sustainable management of the environment and natural resources for the general good of its people[iv].

Generally, there are three types of soil types in Liberia, i.e. the Lateritic soils or latosols, Sand soils or regosols and Swamp soils. The Lateritic soils cover about 75% of the country. These are reddish-brown in color and quite hard on the surface due to the laterization process.

The latosols have been classified into seven series/types, named after places of occurrence, such as Kakata, Suakoko and Voinjama. They are very acidic and lacking in most nutrients like phosphates and nitrogen. Thus, continuous farming requires the constant use of fertilizers. However, the Latosols are more productive for agriculture purposes than the other 2 types of soils in the country. Normally, latosols are not very well suited for agriculture due to their low humus contents on one hand and low pH on the other hand, but they provide valuable materials for road construction.

Sandy soils or regosols consist of more than 60% coarse and fine sand and contain a small amount of clay. The white to gray color of the sandy soils predominates the coastal plain up to about 16km from the sea and they contain little humus and mineral nutrients. They are porous and do not retain moisture, hence they are not fertile for agriculture production but are only suitable for pastures, oil and coconut palms.

Swamp soils are found along the coast and in the interior; they account for about 4% of all soils. The most frequent are the waterlogged gray hydromorphic soils in the floors of the valley, which are flooded in the rainy season.

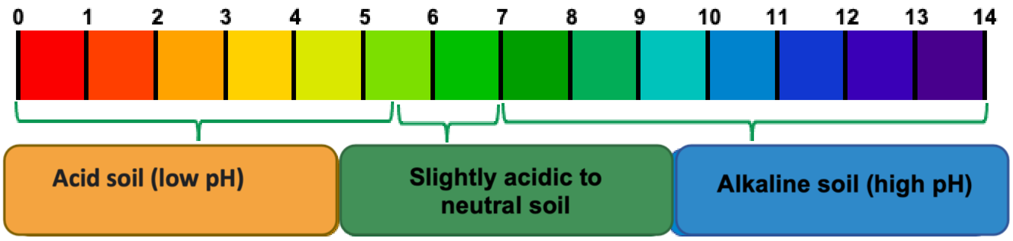
In general, Liberian soils are characterized by a shallow layer of humus, a low humus content and high acidity because of the lack of magnesium and calcium[v].

Evidence of adverse effects of soil acidity on seedlings in a potato field. Seedlings are stunted.

B. SOIL ACIDIFICATION

1. Soil pH

Soil pH (or hydrogen potential) is a measure of the acidity or basicity of soils. It varies between 0 and 14 on a logarithmic scale.



Soil pH is an important measure of the availability of soil nutrients, microbial activity, and plant growth.

More about acidic and basic ions

- ✓ The more acidic a soil is, the more hydrogen ions H+ and to a certain extent aluminum (Al3+), iron (Fe2+) and manganese (Mn2+) ions are present.
- ✓ In basic soil, the basic cations calcium (Ca2+), magnesium (Mg2+), potassium (K+) and sodium (Na+) are abundant.
- ✓ When acidic and basic ions are balanced, the soil is referred to as being neutral and stable, until other factors intervene and destabilize the fragile balance again.

2. Extent of soil acidity in Liberia

There are three dominant soil classes in Liberia, namely laterites (latosols), sandy (Regosols) and alluvial (Fluvisols) soils.

Latosols are widely distributed and cover about 75% of land surface in Liberia where they are very acidic (pH 3-5). These soils are low in fertility and contain abundant Al and Fe oxides.

3. Causes of soil acidity

Soil acidification is the result of a set of complex processes caused by both natural phenomena and human activity. Soil acidity can result from acidic parent materials such as granite. Acidity affects 30% of the world's soils and 75% of the undergrounds of lands not covered by ice.

The acidification of soils depends on their nature, vegetation, climatic conditions, and external factors including agricultural practices: choice of crops, export of residues, and types of fertilizers used

The main natural or anthropogenic causes of soil acidification are the following:

- **Use of nitrogen fertilizers**, especially when applied inappropriately, beyond the crops' needs, particularly in intensive monoculture farming systems. Ammonium nitrogen fertilizer nitrification and nitrate runoff have an acidifying effect. An efficient and balanced nitrogen fertilization reduces acidification.

More on acidic and basic ions

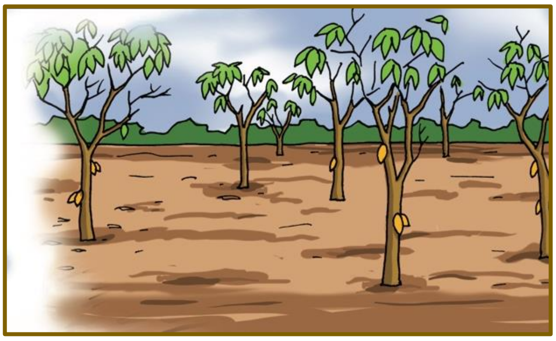
✓ Through nitrification, nitrogen fertilizers contribute to acidification. Ammonium (NH4+) converts into nitrates (NO3-) by producing two H+ protons as shown in the following equation:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$

✓ Depending on the chemical nature of the fertilizer (urea or ammonia fertilizer in particular), the acidification will be accentuated.

$$CO(NH_4)_2 + 2H^+ + 2H_2O = 2NH_4^+ + H_2CO_3$$

Based on the above formula, the NH4+ ion is converted to nitrate, with four hydrogen ions released by the two ammonium ions. This causes soil acidification.



- **Export of post-harvest vegetation and/or crop residues (for fodder or burning for instance).** As the plant grows, it uses certain nutrients (calcium, magnesium, and potassium) that are stored in the leaves, stem, and seeds. After harvest, if these different parts of the plant are not removed, these nutrients are released back into the soil and contribute to its alkalization. In contrast, the export of residues leads to soil depletion and acidification.

- **Leaching, runoff, poorly controlled irrigation, long rainy seasons, and acid rain.** They contribute to the acidification of the soil by carrying the basic elements deep into the soil. In these cases, there is a high presence of aluminum (and sometimes manganese) to the extent of becoming toxic: this is referred to as aluminum toxicity. As a result, it gets harder for crops to absorb other elements such as nitrogen, calcium, phosphorus, magnesium, and potassium. Easily leachable soils such as silts, sands, sandstones, and some granites become more sensitive to these phenomena.

More on aluminum toxicity

When the quantity of Al^{3+} (or $Al(OH)^{2+}$ or $Al(OH)^{2+}$) ions becomes too high, they react with the bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+), and phosphorus forming complex compounds that create a sort of " stopper " preventing the essential elements (phosphorus, magnesium, potassium, calcium) from being available to the plant resulting in poor crop performance. Toxic levels of aluminum in the soil negatively affect root cell division and the ability of the root to elongate. The root tips are deformed and brittle, and root branching is reduces as shown in the image below.

pH 6,8

Consequences of aluminum toxicity on the development of the roots of corn seedlings.

pH 5,2

- **Excessive application of organic fertilizers.** The activity of micro-organisms and roots can then acidify the soil.

More about the mineralization of organic matter

The mineralization of organic matter, i.e., the transformation of complex molecules into simpler ones, does not imply that the latter are readily available to plants. The carbon/nitrogen ratio is a determining factor in the choice of the organic fertilizer to use. The optimal value of this ratio should be between 10 and 25 for the soil to be able to properly feed the plant.

4. Consequences of acidity and solutions

In acidic soil, crops and plots typically show the following symptoms:

- Low plant vigor
- Inhibited plant growth
- Low nodulation of legumes
- Slower root growth
- Persistence of acid tolerant weeds
- Yellow/red discoloration of the leaves
- Increased incidence of disease

These adverse effects are due to the fact that the plant is not able to get the nutrients it needs, mainly potassium, phosphorus, and nitrogen. These are often present but not readily available because of one or more of the previously mentioned reasons. These phenomena are dynamic and complex.

The soil's biological activity is also significantly affected by the acidity of the soil, as it influences the composition of the microflora (bacteria, fungi) and the activity of certain earthworms in the soil.

Lastly, soil acidity is a major cause of lower crop yields, hence lower farm incomes.

In an effort to limit the problem of soil acidity and improve fertility, solutions exist to help with preserving its physical and chemical properties such as:

- Le Resorting to soils acidity-tolerant seeds
- Using organic amendments (organic matter, agricultural lime, etc.)
- Using basic mineral amendments (BMA)

Lime, which is the subject of this paper, is one of the basic mineral amendments.

Liming helps:

- To increase the pH of the soil.
- To improve the structure (physical and chemical properties) of the soil and its productivity.
- To eliminate undesirable elements such as weeds, fungi, and pathogenic micro-organisms, etc.
- To improve the biological activity of the soil.

Liming contributes to the reduction of soil acidity and the improvement in crop yields.

C. Measuring Soil Acidity

This technical chapter addresses the following topics:

- ✓ The various tools available for testing a soil.
- ✓ The steps necessary for a soil test using pH strips.

1. Purpose of soil tests

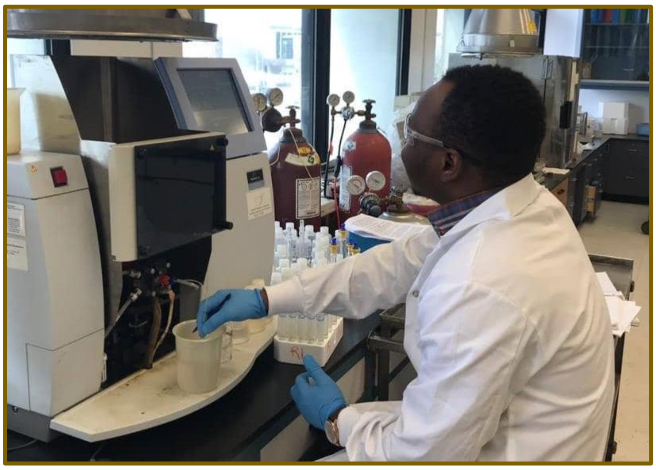
To determine the degree of acidity of soil, it is necessary to measure its pH first. This measurement can provide a diagnosis of acidity to determine whether liming is necessary or not. The pH paper measurement is generally reliable, the margin of error being small.

2. Mesures de pH au laboratoire et in situ

The most common way to measure the pH is to carry out a laboratory analysis:

✓ Advantages: the pH measurement is more accurate and precise, which is useful when liming is being considered for large areas.

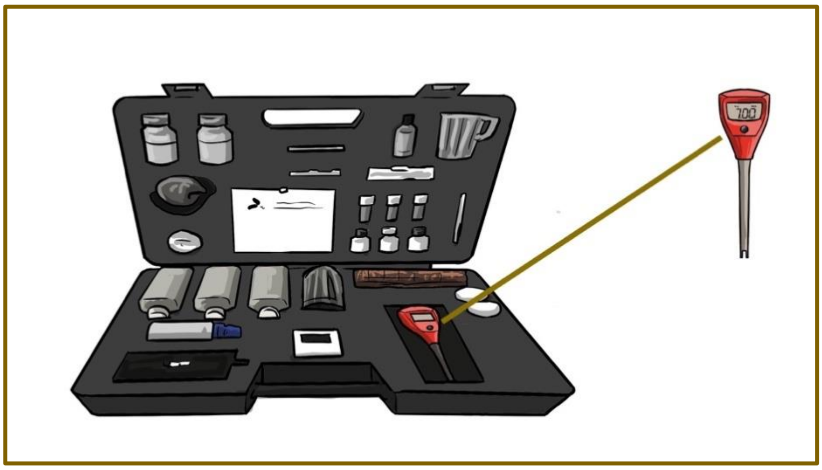
✓ Disadvantages: the process is expensive, the samples needing to be transported to the laboratory, and the analysis may take several days.



The other option is to resort to mobile kits. These "labs in a box" use mini-versions of lab test devices for a series of analyses aimed at measuring soil parameters: pH, nitrate, available sulfur, available phosphorus, available potassium, active soil carbon (organic matter), electrical conductivity (an indicator of levels of overall fertility and salinity), as well as certain physical properties of the soil such as texture, among others. All instruments are battery operated and use potable water (available locally in plastic bottles) to make soil analysis possible in the most remote locations and provide results on the spot.

✓ Advantages: the kit can be transported directly to the site; it can consist of a single probe or of a complete soil diagnosis, etc.

✓ Disadvantages: the kit must be operated by a specialist or a trained person; the process remains costly for the farmer (just like the laboratory).



The mobile analysis kits can be used for a variety of measurements of different parameters. They include a pH meter.

The pH-meter is a pH measuring device. It consists of a double prong electrode, connected to an electronic unit which displays the measured pH value on a screen. This measuring device gives a more accurate measure of the pH of a solution than a pH paper.

Before use, its calibration is essential with the help of two buffer solutions:

- ✓ One with a neutral pH (= 7)
- ✓ The other with an acidic pH (= 4) or a basic pH (= 9)

After calibration, the electrode is rinsed before being dipped in the muddy solution or slurry (soil+water) to be tested. The result is nearly immediate, simple, and reliable.

3. pH paper: how to use it

The most used and least expensive method is the use of pH paper.

pH paper is a paper strip impregnated with a mix of indicators. It helps to measure the overall acidity or basicity of a body or a solution.

When the strip is dipped in a solution, it changes color according to the soil's pH.

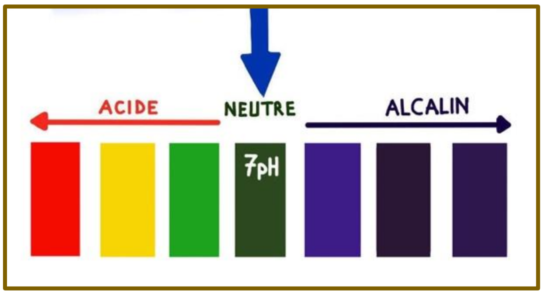
Method of use

Soil sampling

- ✓ Select several locations in the farm, for example, areas with the best, average, and worst yields.
- ✓ Each area should be sampled separately.
- ✓ In each area (best, average, and worst yields) collect 5-8 soil samples from 0-10 cm depth. No need to go deeper.
- ✓ Put the soil samples in a clean, plastic container.
- ✓ Remove the waste such as rocks or stones and plant residues.
- ✓ Mix well the soil in each container.
- ✓ Take a composite sample for about 500 grams from the container and transfer to a clean paper bag. This is now the soil sample that represents an area and ready for testing.
- ✓ Repeat similar steps for the other areas.

Collecting a water sample and testing its pH

- ✓ Collect a representative water sample from a river or well.
- ✓ Put an adequate volume in a clean container.
- ✓ Take a pH paper strip and dip one end into the water sample for 5 to 10 seconds.
- ✓ Take the strip out and shake it.
- ✓ Using the color chart, compare the color change of the wetted paper strip..

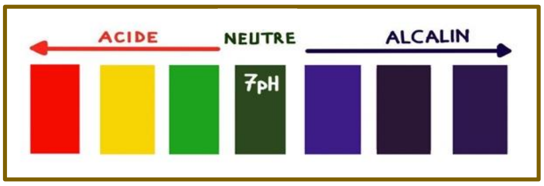


- ✓ The pH paper should display a value close to 7 upon reading. If this is not the case, you should not use this water.

Testing soil samples

- ✓ Ensure that the pH of the water has been assessed beforehand.
- ✓ From each soil sample bag, take about 100 g soil and put in clean plastic or glass containers.
- ✓ Add about 100 milliliters water or 1 part soil/1 part water. Add more water if necessary to obtain a muddy water or slurry.
  Mix the content of each container using a stick until homogenized, without letting it settle.

- ✓ Dip the pH paper strip for 5 to 10 seconds into the muddy mixture.
- ✓ Take the strip out and shake it.



- ✓ The color that appears on the paper shows the level of acidity, neutrality, or alkalinity of the soil (acid, neutral or alkaline).
- ✓ Read and record this number.
- ✓ Do the same with a new strip for each sample.

More on the Basics of the pH concept

A pH of 6 is 10 times more acidic than a pH of 7, but a pH of 5 is 100 times more acidic than a pH of 7. As a matter of fact, the hydrogen potential is proportional to the quantity of hydrogen ions according to the following logarithmic formulas: pH= - log [H+] and H+= log[10-pH]. The more H^+ ions there are in a substance, the lower the pH and vice versa.

REMEMBER

- ✓ It is more practical to test the soil with a pH paper to decide whether to lime or not.
- ✓ For better accuracy in the results, it may be worthwhile to refer to a laboratory.
- ✓ Never forget to test the water that will be used before testing the soil sample.

D. LIMING : OVERVIEW

1. Definition of liming

Liming is an agricultural technique that aims to reduce the acidity of a soil by adding products such as calcium carbonate (limestone, calcium lime) or calcium and magnesium carbonate (dolomite, dolomitic lime). Liming is a desirable practice to overcome the constraints of soil acidity for enhanced crop production. Liming improves soil fertility by increasing the availability of nutrients for plant uptake and thus increases the efficiency of fertilizers.

There are four common types of lime:

- ✓ **Limestone (calcium carbonate, $CaCO_3$):** it is the least expensive and is produced directly by grinding rocks from natural limestone deposits. It does not require further treatment and is not corrosive.

- ✓ **Dolomitic limestone or dolomite:** it contains both calcium and magnesium carbonate. It is also obtained by grinding rocks from natural deposits. It must have specific characteristics to be qualified as dolomite (see below).

- ✓ **Burnt lime or quicklime:** it is a very corrosive white powder, which is obtained by heating limestone or dolomitic limestone in a kiln to remove the CO_2. The use of quicklime in agriculture is not recommended because of the high temperatures it causes when reacting with soil water. Using it requires specialized equipment to prevent burns.

✓ **Hydrated lime or slaked lime (calcium hydroxide):** it is produced by burning limestone or dolomitic limestone with steam. Hydrated lime production is fast, but costly.

Deposit of dolomitic rocks in Karaga, Mali, which are used to produce agricultural lime.

More on the reagents and products involved

- ✓ Liming provides basic amendments or products, for example calcium (CaCO3) and magnesium (MgCO3) carbonates.
- ✓ The objective is to reduce soil acidity by neutralizing the cations that cause aciditiy such as H+ and Al3+.
- ✓ Liming helps make mineral elements such as ammonium (NH4), phosphorus (P), magnesium (Mg), and trace elements such as molybdenum (Mo), manganese (Mn), boron (B), zinc (Zn), and copper (Cu) more available for plant uptake.

The decision to apply both calcium and magnesium should be based on soil test results. If the soil is sufficiently rich in magnesium, the application of products without magnesium is much more economical.

In a soil deficient in magnesium, an annual dose of 30 to 60 kg of magnesium oxide (MgO) per hectare is sufficient to meet the needs of the crops. The lower the soil content, the higher the dose.

By its composition, dolomite helps to fight soil acidity, but also to compensate for magnesium deficiencies.

Blast furnace for pyrolysis and crushing of raw limestone. (Mali)

2. Dolomite

Dolomite-based agricultural lime is obtained through a simple process which consists in extracting, cleaning, and grinding limestone deposits into a finished product.

It is a double carbonate of calcium and magnesium, with the chemical formula $CaMg(CO3)2)$, consisting of:

- ✓ At least 30% calcium oxide (CaO)
- ✓ At least 15% magnesium oxide (MgO)
- ✓ Traces of silicon oxide (<1%), iron oxide (<0.2%), and aluminum oxide (<0.3%)

The lower the proportion of silicon oxide (sand), the better the quality of the dolomite.

Dolomite is used to correct soil acidity in conventional, industrial, and organic agriculture as well as in poultry and livestock farming, and as a stimulant additive for the fertilizer industry.

3. Types of liming

For agricultural lands requiring liming, the first thing to do is to assess the need for lime before choosing and applying the amendment. This requires soil testing for soil pH. There are two types of liming: restoration liming and maintenance liming.

Recovery liming is used to correct a soil that is excessively acidic. The purpose of restoration liming is to raise the pH to a desirable level to quickly create optimal conditions for the crop. It entails raising the pH level by half a point or one point with a single treatment that lasts several years, using 500 kg to 1000 kg of dolomite per hectare.

Maintenance liming is used to offset acidification sources. The natural tendency of a soil is to acidify. Maintenance liming consists in applying regularly (every 3 to 4 years) a basic amendment to maintain the pH and to restore to the soil the calcium and magnesium amounts that have been depleted over time. Crop residue exports, leaching and the acidifying action of mineral fertilizers determine how much to apply. On average, 150 to 500 kg/ha of calcium oxide (CaO) are recommended each year, 300 to 500 kg/ha of CaO on annual crops.

In addition to these treatments, human causes of soil acidification must be addressed.

4. Liming management indicators

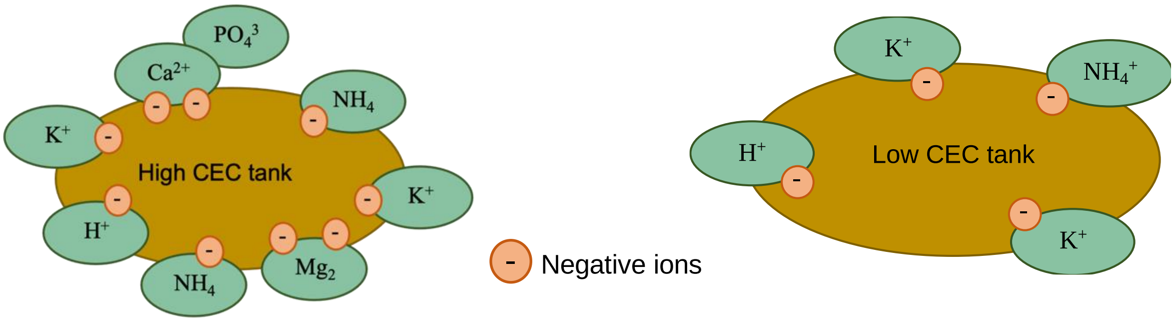
- **First indicator: the pH.**

Measuring the pH is sufficient for diagnosis and decision making. The amount of lime needed to reach a given pH varies from one soil to another.

More on the clay-humus complex

The clay surfaces of mineral soil is naturally negatively charged. Cations therefore are held on these negatively charged surfaces. At very low pH (pH less than 4), aluminum (Al3+) and hydrogen (H+) are abundant in soils which can easily occupy the clay surfaces. This situation is not desirable to plants. From soil fertility aspect, the essential nutrients such as Ca2+, Mg2+, K+, NH4+ are needed for normal plant growth and development. Therefore, soil should be limed to replace H+ and Al3+ on the clay surfaces with essential cations. e the addition of dolomite.

In a more visual way, the clay-humus complex represents the cation "reservoir" of the soil:



Example with a clay soil

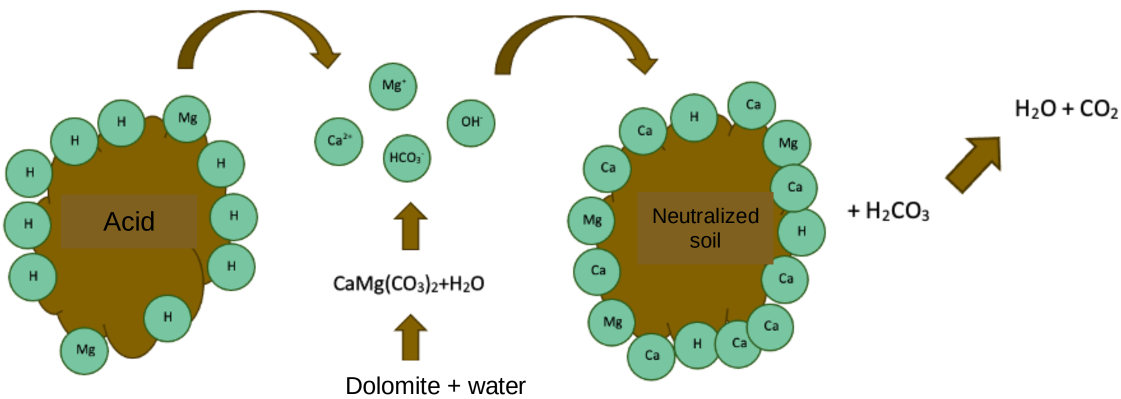
Example with a sandy soil

- **Second indicator: Cation Exchange Capacity (CEC).**

This is about the number of cations (positively charged elements) that a soil can hold at a given pH. These can be strong acids (hydrogen, aluminum) or weak acids (calcium, magnesium). The purpose of liming is to replace strong acids with weak acids since the latter is responsible for soil acidification. The richer the soil is in clay and organic matter, the higher the CEC will be. Unlike sandy soil, a clay-loam soil will have a high CEC. The conditions (pH, nature of acids, etc.) can have an impact on the result; it is therefore important to indicate the method used to determine the CEC (Metson CEC, effective CEC, etc.).

More on the impact of dolomite on the clay-humus complex

Dolomite breaks down to generate calcium (Ca2+), magnesium (Mg+), bicarbonate (HCO3-), and hydroxyl (OH-) ions. The calcium then moves to the surface of the soil particles replacing the H+ ion$^+$.

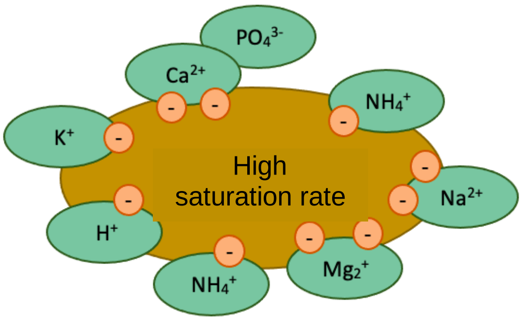


Impact de la dolomie sur le complexe argilohumique

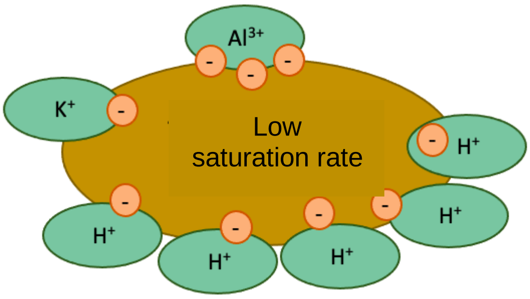
More on other useful indicators

- **Carbonate content ("total limestone")**
  When carbonates are solubilized, under the effect of precipitation, they release calcium (and magnesium) ions which compensate for the losses due to leaching by rain and carbonate ions (anions of a strong base) which neutralize the H ions$^+$. In such situations, it is estimated that a minimum content of 3 g/kg of fine carbonate soil is necessary to prevent a sudden drop in pH.

- **Exchangeable aluminum content (S/T or S/CEC)**
  This is the soil saturation rate in exchangeable nutrient cations (Ca, Mg, K, Na) which refers to the "filling rate" of the CEC by these cations. Depending on the pH, liming may be necessary when the saturation rate is less tha 80%.



S/CEC = 80 %
Liming is not necessary.



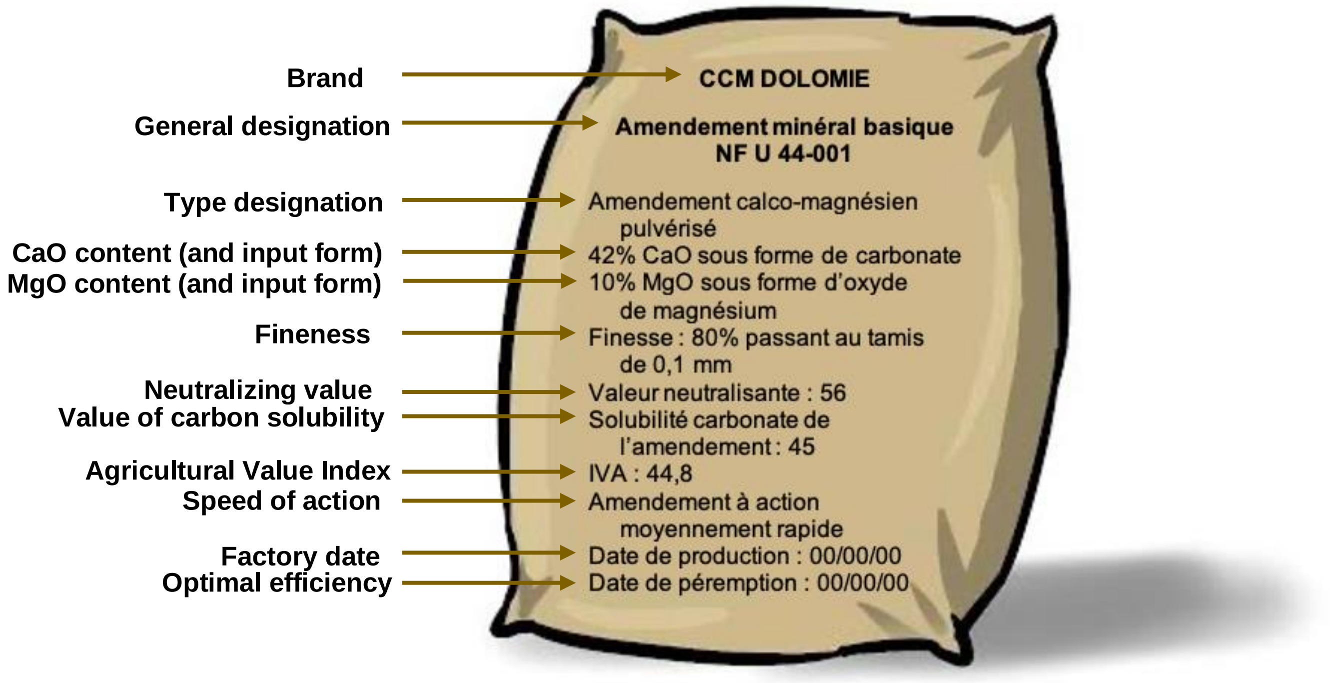
S/CEC < 20 %, acid pH
Liming is necessary.

E. LIMING: APPLICATION

This technical chapter addresses the following:

- ✓ The choice of the type of agricultural lime
- ✓ The method of application of agricultural lime
- ✓ The conditions for the application of agricultural lime

1. Reading an agricultural lime label



The IVA determines the commercial value of agricultural lime according to the formula:
VIF = NRV (Neutralizing Value) x Fineness

2. The Neutralizing Value (NV)

The neutralizing value (NV) is the amount of agricultural lime that can neutralize an acid compared to the amount of pure calcium carbonate ($CaCO_3$) neutralizing the same acidity. It is referred to as Calcium Carbonate Equivalent (CCE). The higher the NV, the more reactive the product. A CCE of 100% indicates that a material will neutralize the same amount of acidity per pound as pure calcium carbonate.

If CCE values are not available, the element contents can be used to calculate them, as in the following table:

Conversion factors for lime-like éléments
Ca (%) x 2,50 = CEC
Mg (%) x 4,17 = CEC
CaO (%) x 1,79 = CEC
MgO (%) x 2,50 = CEC
$MgCO_3$ (%) x 1,19 = CEC
$Ca(OH)_2$ (%) x 1.36 = CEC
Example of liming poducts: Content Ca : 35% : CEC = 35 x 2,50 = 70 % Content Mg : 2% : CEC = 2 x 4,17 = 8,34 % Total CEC : 70 + 8,34 = 78,34 %

3. Speed of action: fineness and solubility

The speed of action of a liming product depends on the fineness and the solubility of this product.

The use of fast-acting products is technically justified only in case of recovery liming. For maintenance liming, rapid action is not necessary: the agricultural lime will gradually dissolve in the soil.

An amendment with a solubility higher than 50% has a fast action; conversely, the action is slow if the solubility is lower than 20%.

The finer and more soluble the product, the more expensive and fast acting it is (lime being the most soluble). The price comparison is based on the solubility and per unit of CaO.

Fineness

Based on the reactivity of different lime particle sizes, as noted above, lime should be ground or pulverized to particle sizes under 5 mm.

Three classes of grinding fineness are defined:
- ✓ Pulverized amendment: more than 80% of the product passes the 0.315 mm sieve.
- ✓ Ground amendment: more than 80% of the product passes through a 4 mm sieve.
- ✓ Crushed amendment: less than 80% of the product passes the 4 mm sieve.

More on adsorption capacity

The finer the product, the stronger its adsorption capacity, i.e. the capacity of basic cations to bind to the clay-humus complex by displacing acid cations.

Different types of fineness

Solubility

Solubility can be estimated by measuring the carbon solubility (S) of the components of the amendment and can range from 0 to 100%.

An amendment with a solubility higher than 50% has a rapid action. Conversely, the action is slower with a solubility below 20%.

4. Categories of amendments

Depending on the amendment chosen, the speed of action will be more or less important:

- ✓ Fast acting (a few weeks): lime, crushed chalk;
- ✓ Moderately fast acting (a few months): crushed limestone;
- ✓ Slow action (several years): crushed limestone.

The characteristics of the different amendments are summarized in the table below:

Type and Name	CaO (%)	Mg0 (%)	Neutralizing value	Speed of Action	Indicative costs
Raw products					
Pulverized limestone	46 to 54	0 to 5	45 to 54	Rapid action	Average cost
Ground limestone	46 to 54	0 to 5	45 to 54	Medium-Fast action	Low cost
Pulverized dolomite	30 to 35	18 to 20	58 to 60	Medium-Fast action	Average cost
Crushed dolomite	30 to 35	18 to 20	58 to 60	Slow action – soft rock	Low cost
Crushed limestone	> 35		> 35	Slow action – soft rock	Low cost

5. Recommended doses

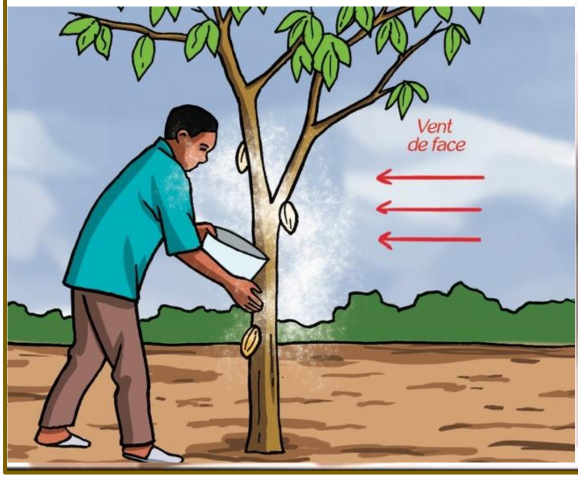
To know the amount of amendment to apply, the following formula must be used:

$$Amount\ of\ amendement\left(\frac{kg}{ha}\right) = \frac{amount\ of\ CaO\ \text{to}\ apply\ (\frac{kg}{ha})}{Amendment\ neutralizing\ value/100}$$

For example, if one wishes to apply 250 kg of CaO per hectare, using crushed limestone with a neutralizing value of 50, the amount of amendment required would be 500 kg/ha. (250/0,5= 500).

It is necessary to carry out a pre-incorporation step to homogenize the soil-fertilizer mixture before deep tillage.

NOT TO DO



TO DO

If it is windy, lime can be blown onto non-targeted plots. Avoid inhaling or coming into contact with lime or carrying out liming without proper protection

Lastly, solutions for the rational application of agricultural lime by micro doses are undergoing experimentation, but no such recommendation is currently available for farms.

Caution must be taken not to apply agricultural lime in excess: the soil may become too basic and the plant will no longer be able to absorb important elements such as potassium, phosphorus or iron.

6. Taking the soil pH into account

The progress in terms of the soil's pH and its calcium and magnesium levels must be measured every 5 years.

If the pH is below 6, and based on this parameter only, measuring the amendments could be more frequent, and carried out, for instance, every three years.

The pH varies according to the season. It is therefore necessary to carry out subsequent regular analyses during the same period of the year.

The following table summarizes what to do, depending on the crop and the pH level:

Soil Acidity Level	Very acidic soil	Acidic soil	Low acid soil		Neutral ground	Basic soil
Ca/CEC	< 40%	40 à 60%	60 à 75%	75 à 90%	90 à 140%	> 140%
Water pH	< 5,4	5,4 – 5,8	5,8 – 6,2	6,2 – 6,5	6,5 – 7,2	> 7,2
Pasture	Tunaround	Maintenance	Dead end	Dead end	Dead end	Dead end
Cereals and derivatives	Turnaround	Turnaround	Maintenance	Dead end	Dead end	Dead end
Barley	Turnaround	Turnaround	Maintenance	Maintenance	Dead end	Dead end

"Impasse" means that the causes of a farm’s poor health are to be found elsewhere than in the acidity of its soil.

As a general rule, sudden increases in pH should be avoided: it is recommended no more than 0.5 to 1 pH point increase per amendment action.

7. Taking the texture of the soil into account

CEC is a fundamental soil property that depends on the clay and organic matter content on the one hand, and on the type of clay present in the soil on the other. The types of clay vary in part according to the climate, except for areas where the parent rock is relatively young (volcanic areas, calcareous rocks in coastal areas, etc.). The higher the CEC of the soil, the higher the dose to be applied.

Based on the soil texture, the following table provides the approximate amount of finely ground limestone to apply in order to raise the pH by one unit at a depth of 18 cm.

Soil texture	Quantity of lime needed (kg/hectare)	
	pH 4,5 to pH 5,5	pH 5,5 to pH 6,5
Sandy loam with sand	600	900
Sand loam	1100	1550
Clayey	1700	2200
Loam	2700	3100
Loamy clay	3350	4200

8. Taking OM inputs into account

The biological activity of a soil changes with the pH. The diversity, abundance, and activity of the microflora (bacteria, fungi, mycorrhizae...) are indeed influenced by the pH. Under the action of micro-organisms brought by organic matter (OM), the dead organic matter will be transformed either into stable humus or into microbial biomass which corresponds to the most active component. Organic matter also contributes to the maintenance of the soil's acid-base balance.

For example, fresh manure contains 3.8 kg of calcium oxide (CaO) per ton. A spreading of 15 tons of manure per hectare (recommended amount) will therefore represent a supply of about 57 kg of calcium oxide. It is important to take this into account in order to adjust the amount to apply and thus limit the cost of liming.

After liming, a mature manure should be applied. le chaulage doit être mûr.

If lime and organic matter (or manure) must be applied, the two should not be directly mixed.

If lime and organic matter (or manure) must be applied, the two should not be directly mixed. Liming should be carried out first so that the lime can be incorporated through plowing before spreading and quickly burying the organic matter to limit nitrogen losses by volatilization.

More on "Nitrogen starvation"

If fresh organic matter, such as manure and lime are applied at the same time, the phenomenon known as "nitrogen starvation" can occur: the microbes use the available nitrogen to perform their activities including organic matter decomposition to the detriment of the plants which will then suffer from nitrogen deficiency. This is N immobilization.

9. Taking the purity of the product into account

The recommendations from analysis labs are based on agricultural lime with pure calcium carbonate which completely neutralizes acid. Due to natural impurities, however, agricultural lime available on the market is never 100% pure. The recommendation must therefore be adjusted based on the purity factor.

For instance, a product with a calcium carbonate purity of over 95% will neutralize soil acidity more effectively than a product with a 60% purity. The latter will need to be applied in larger amounts than the former to have the same effect.

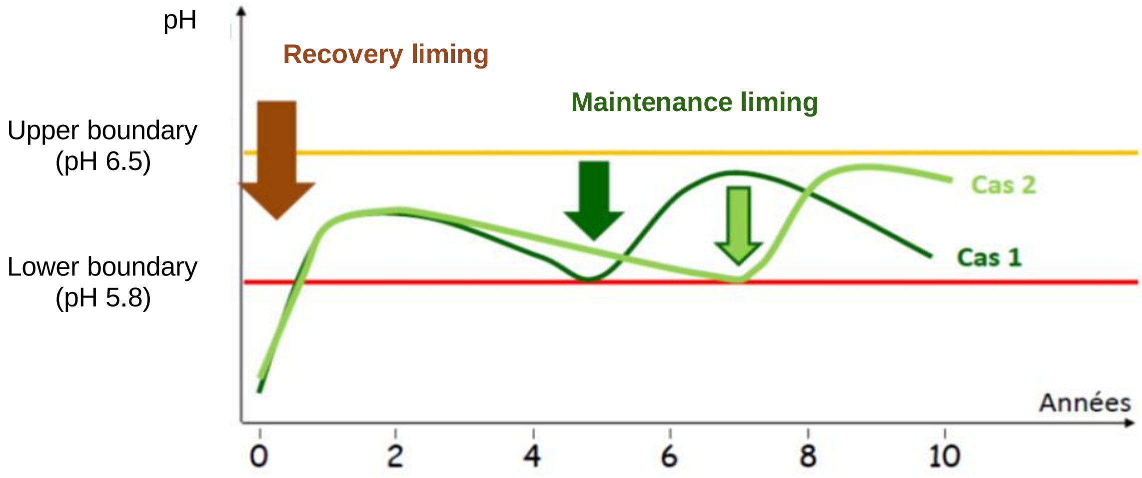
The purer the lime, the more effective it is.

10. When should liming be carried out?

Unlike fertilizers which are applied every year, dolomite is usually applied once every three years.

It is important to carry out the application under conditions that do not degrade the soil structure and that facilitate the incorporation of the amendment into the soil. The intercropping period seems to be the most suitable to lime.

The graph below suggests a schedule:



Liming schedule for recovery/maintenance

Delaying the application of amendments for one or two years can have an impact on yield, as shown in the following table.

	If the application of the amendment is delayed by one or two years :			
pH		5,5 < soil pH < 6	6 < soil pH < 6,5	Soil pH > 6,5
Return Risk	High	Average	Weak	Weak
Advice	Urgent recovery with fast-acting [products (example: pulverized carbonates, etc	Recovery based on fast or medium-fast acting products (example: pulverized or ground carbonates) pulverized	Maintenance based on slow-acting products	Dead end or maintenance in certain situations (drained unstable soils)

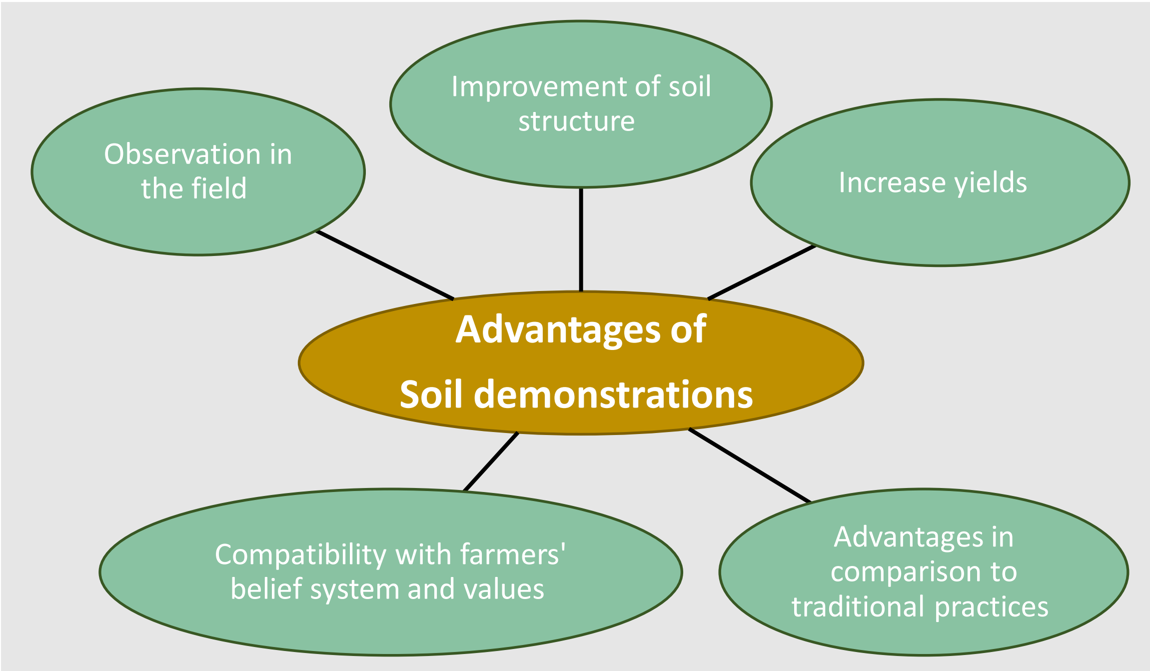
REMEMBER

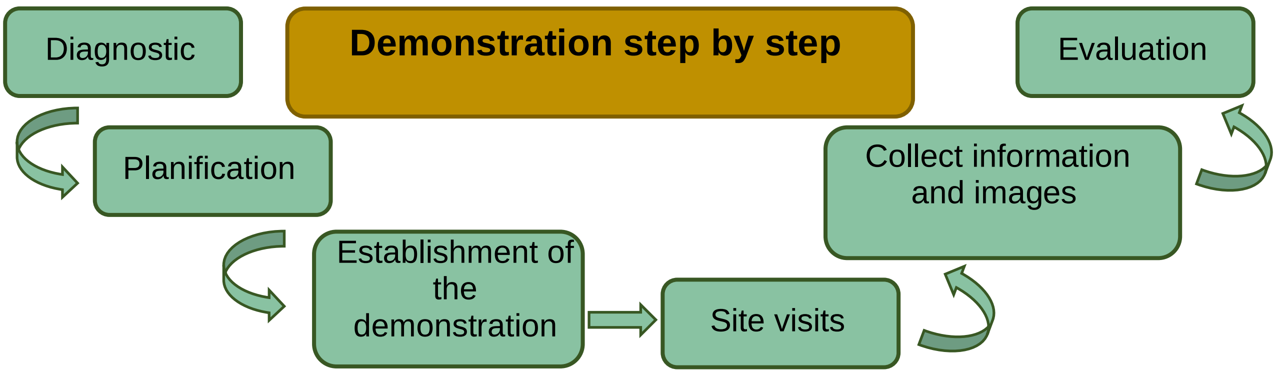
- ✓ In terms of effectiveness of liming, the speed of action of the product is a determining factor.
- ✓ It is dependent on the purity and fineness of the lime.
- ✓ To avoid damage, disease or loss of product, it is recommended to follow the instructions and take into account the application rules.
- ✓ The best time to lime is during the intercropping period.

F. THE FIELD SCHOOLS

1. Rationale for the demos and the steps

The demos have many advantages which highlight the benefits of liming. They can be carried out in six steps.





2. Liming trial results

Overall objective: Contribute to the improvement of soil fertility by correcting its pH.
Specific objective: Develop an adapted participatory approach to fight soil acidity through the application of dolomite.

- **Protocol used**

✓ Selection of demo sites
✓ Delimitation of elementary plots

✓ Collection of soil samples for analysis

✓ Spreading of organic fertilizer and agricultural lime

✓ Plowing and seeding

✓ Crop maintenance

✓ Phytosanitary treatments

✓ Cross-farm visits: collecting testimonies, videos, developing skits, documentary film

✓ Harvesting and evaluating yields

✓ Reporting of results

✓ Collecting growers' opinions

- ✓ Soil sampling in elementary plots

♦ Second year: monitoring the post-lime effects

- ✓ The following activities have been added:
  - Training on soil identification and indicator species
  - Measuring pH correction by dolomite
  - Assessing prices and situation of lime dealers in the different areas
  - Checking the status of the inventory
  - Evaluating storage time

3. The overall benefits of liming

The results of liming trials, field demonstrations, and baseline studies all attest to the positive impact of liming on soil health and on plants:

- ✓ Increased absorption of nitrogen, phosphorus and potassium and availability of other trace elements
- ✓ Stimulation of the soils' biological activity
- ✓ Growth of more vigorous root systems
- ✓ Improved nitrogen uptake by legumes
- ✓ Reduction of manganese and aluminum toxicity in soil solution
- ✓ Enhanced quality of the soil structure, therefore, better tolerance to drought
- ✓ Provision of a low-cost source of calcium and magnesium
- ✓ Improved preservation of crops, hence, reduced post-harvest losses
- ✓ Increased yields and income for the grower
- ✓ Reduced need for fertilizers and herbicides, therefore, reduced expenses on agricultural inputs
- ✓ Compliance of the dolomite with organic agriculture's specifications and standards and improvement of the overall nutritional health

References

Much of the information in this technical manual is derived from the "Training and Exchange Workshop on Agricultural Lime Produced by CCM S.A.", jointly organized by CCM and IFC on November 18 and 19, 2021, at the Onomo Hotel, Bamako, Mali.

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