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AFRICA BUREAU FERTILIZER AND SOIL FERTILITY FACTSHEET

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PURPOSE

The purpose of this factsheet is to:

1. provide a brief summary of basic principles of soil fertility, describe fertilizer types, and fertilizer best management practices.
2. inform Missions and implementing partners about USAID's environmental compliance procedures for fertilizer procurement and use.
3. provide guidance to identify potential environmental impacts of fertilizer application and mitigation measures to consider during implementation of agriculture activities.

The information provided will be particularly useful to USAID staff developing 22 CFR 216 environmental analysis and monitoring documents, such as Initial Environmental Examinations (IEEs) and Environmental Mitigation and Monitoring Plans (EMMPs).

SOIL FERTILITY AND PLANT NUTRITION

Soil fertility is the ability of a soil to sustain plant growth, by providing essential plant nutrients and favorable chemical, physical, and biological characteristics as a habitat for plant growth. It is the foundation for productive farming, nutritious food, and sustainable livelihoods.

Plant nutrients. There are 17 essential nutrients needed for normal plant growth. Carbon, hydrogen and oxygen are obtained from air and water. The remaining 14 are obtained from soil. Nitrogen, phosphorus and potassium are primary macronutrients and are needed in larger amounts than other nutrients. Secondary macronutrients include sulfur, calcium and magnesium. The remaining 8 are micronutrients and are necessary in much smaller amounts. Nutrient availability in soil depends on soil characteristics.

Decline or loss of soil fertility from erosion, acidification, salinization, contamination, and depletion of soil organic matter and plant nutrients can be natural or a result of human activities. When crops are harvested from fields, nutrients are removed from agricultural soils. Other human-induced nutrient losses include removal and burning of vegetation and removal of agricultural residue. Natural ways of nutrient loss include leaching and runoff, wind and water erosion, and soil processes such as denitrification, volatilization, and fixation/immobilization. If the nutrients lost are not replaced, then agricultural soils are not able to sustain crop productivity in the long-term.

Unfortunately, many soils in Africa are degraded or losing their ability to sustain plant growth and provide food and other essential ecosystem services. Loss of nutrients and/or organic matter in agricultural production and wind/water erosion of fertile topsoil are among the main causes for soil degradation and a major concern in many African countries (Tully et al., 2015; Jones et al., 2013).

Restoring soil fertility. Natural processes such as weathering of parent material, atmospheric deposition, and organic matter decomposition can help replenish soil nutrients. Microorganisms and soil fauna contribute to nutrient release by decomposing vegetation, animal manures, and other organic materials. But most of these natural processes work slowly. Farmers can replenish soil nutrients by adding inorganic and organic fertilizers, use of biological N fixing plants (e.g., soy, clover, groundnuts, etc.) as well as changing the soil chemistry to make nutrients more available for crops (e.g., liming).

Water management is important for maximizing crop use of nutrients. About 97% of crop nutrient uptake comes from the soil solution (water-soluble nutrients), which makes water the most important medium for fertilizer delivery. This also means that, for the most part, nutrient mobility is directly linked to water movement. Overall, good water management leads to a more efficient use of fertilizers, increased nutrient uptake, and reduced nutrient losses to the surrounding environment.

FERTILIZERS

A fertilizer is a chemical or natural substance that is used to provide nutrients to plants. Natural fertilizers include materials such as animal and vegetable manures, marl, lime, limestone, basic slag, and wood ashes. Commercial fertilizers are chemically manipulated (i.e., not natural) substances containing one or more recognized plant nutrients designed for use in promoting plant growth. Fertilizers can be classified as organic and inorganic. Inorganic fertilizers are also called mineral fertilizers when the source is a natural deposit, or chemical, when manufactured by industry.

Inorganic fertilizers are nutrient-rich products made industrially by chemical processes, mineral extraction or by mechanical grinding (FAO, 2019). They provide a known amount of nutrients in a form that is quickly available for plant uptake. The most readily available forms of nitrogen (N) and phosphorus (P) needed for plant growth are nitrate (NO_3^-) and phosphate (PO_4^{3-}), respectively. In general, inorganic fertilizers are more soluble and more likely to get lost from the soil quickly. Inorganic fertilizer types come in a variety of forms (FAO, 2019):

- Single or straight - contain only one nutrient. For example, ammonium nitrate (34-0-0), triple superphosphate (0-46-0), and potassium chloride (0-0-60).
- Compound or mixed (NPK fertilizers) - contain 2 or 3 macronutrients, such as diammonium phosphate (18-46-0) and triple 15 (15-15-15).
- Secondary (calcium, magnesium, sulfur) and/or micronutrient (zinc, manganese, boron, etc.).

Fertilizer grade is a term referring to the legal guarantee of the available plant nutrients expressed as a percentage by weight in a fertilizer. When purchasing fertilizers from international and/or national markets, fertilizer grade specifications have to be indicated.

Organic fertilizers are carbon-rich and are derived from organic materials (FAO, 2019). Because of their high organic content, organic fertilizers can help improve soil structure, reduce compaction, hold soil moisture and nutrients, enhance water infiltration, and promote good aeration for plant root growth.

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BENEFITS OF CHEMICAL FERTILIZERS

- Allow growers to maximize crop yield
- Increases agricultural production
- Improves land productivity
- Improves land use efficiency

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BENEFITS OF ORGANIC MATTER

- Improves soil structure, reduces bulk density/compaction, and promotes good aeration for plant root growth.
- Helps soil hold moisture and enhances water infiltration.
- Increases cation exchange capacity or the capacity of soils to store nutrients in a way that allows nutrients to be easily exchanged with plants.
- Binds toxic elements in soils.
- Adds organic carbon which is the food needed by microorganisms to convert nutrients from organic to inorganic form.

Most of the nutrients in organic fertilizers have to be converted into inorganic form (i.e., nitrate, phosphate, etc.) by soil microorganisms before plants can use them. As a result, nutrients from organic fertilizers are usually more slowly released over a longer period. Organic fertilizer types include (FAO, 2018):

- Vegetative: crop residues, green manures, cover crops, fallow periods, and N-fixing legumes.
- Transformed: compost, vermicompost, animal manure, and biochar
- Industrial: biosolids, wastewater, milling wastes (e.g., rice husks, sugarcane mill mud/ash, maize hulls, etc.), residues from agroindustry, and urban wastes.

The nutrient release from organic fertilizers varies depending on the quality of the organic material. Manures usually release plant available nutrients more quickly compared to compost or other vegetative-based organic fertilizers.

Fertilizer selection, application, and use. Nutrient deficiency occurs when plants lack sufficient quantities of nutrients required for its growth. Fertilizers provide nutrients that are not available in the soil, replace lost nutrients, and balance nutrients for better crop quality; thus, improving agricultural productivity and increasing food production. *However, fertilizer application without consideration of the appropriate rate, timing, source or method, can have harmful effects. Too much fertilizer is not only wasteful but can damage plants and harm the environment and climate*. Selection of fertilizer depends on soil quality and condition, and crop to be produced.

Should farmers in Africa apply inorganic or organic fertilizers? Organic and inorganic fertilizers should be considered complementary rather than mutually exclusive. In many cases, the most effective approach is to combine both. Because inorganic fertilizers provide a readily available known amount of nutrients, they can be applied at specific stages of crop growth and optimize fertilizer use efficiency. However, organic fertilizers play an important role in sustaining long-term soil fertility by slowly replenishing soil nutrients and improving soil quality through the addition of organic matter. The use of both fertilizer sources will be critical if Africa is to rebuild its degraded soils, feed itself, reduce poverty, and reduce the clearing of forest and savannas.

As with any technology, it is also strongly recommended that fertilizers be thoughtfully employed according to best practice, promoting integrated soil fertility management, within the context of the prevailing biophysical and socioeconomic conditions, as well as the desired outcomes of development activities.

PHOTO: SHIELA CHIKULO/CIMMYT

GENERAL SOIL FERTILITY TRENDS IN AFRICA

Knowledge of soil and its fertility is important not only for our understanding of agricultural systems, but also the protection of the surrounding environment.

Africa has had the lowest rate of fertilizer use of any region in the world and this rate remained the same from 1970s to 2000s (The World Bank, 2013). Inorganic fertilizer application rates have been rising over the last couple of decades but are still low compared to other parts of the world. The global average of application per hectare of cultivated land is 135 kg, while in Sub-Saharan Africa it is 17 kg per hectare (AGRA, 2018). However, fertilizer input can vary considerably across countries based on national policy and economic variables (Sheahana and Barrett, 2017.).

As policy and fertilizer affordability changes across Africa to incentivize the use of fertilizers in agriculture, it is becoming increasingly important to adopt best management practices that reduce nutrient loss from fertilizer application to agricultural fields in order to protect the environment.

FERTILIZERS AND USAID ENVIRONMENTAL PROCEDURES

Fertilizers are frequently lumped together with pesticides under the generic heading of "agrochemicals." From an environmental compliance perspective (22 CFR 216), as well as from a field-level implementation point of view, this is inappropriate, because it implies that fertilizers require the same level of scrutiny reserved for pesticides. Pesticides are subject to clearly defined environmental review procedures [22 CFR 216.3(b)(1)] and an approval process to promote safer use and integrated pest management, whereas such procedures do not apply to fertilizers.

Nevertheless procurement and use of fertilizers must comply with ADS Chapter 312 and ADS 312mad Federal Fertilizer Guidance. Any purchase of ammonium nitrate or calcium ammonium nitrate fertilizer with USAID funding must receive prior approval from the USAID/RFS Chief Scientist and is subject to various specific standards (see Guidance for Fertilizers Containing Ammonium Nitrate) due to the risk of ammonium nitrate and calcium ammonium nitrate use to create improvised explosive devices.

In Africa, Unsustainable Use And Management Of Land Has Led To Problems Of Increased Soil Degradation:

It is estimated that 25% of productive lands in Sub-Sahara Africa are degraded largely due to loss of nutrients and soil organic carbon (Jones et al., 2013). Such soil degradation limits the agricultural productivity of lands, which diminishes food security.

Approximately 26% of Africa is vulnerable to desertification and even areas of low vulnerability could be threatened by desertification under significant climate change, particularly if appropriate land use management is not implemented (Jones et al., 2013).

Soil erosion is a gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing soil deterioration and water quality concerns as soil particles are deposited in streams and other waterways. This is a major environmental issue because it can lead to water pollution.

Basic soil properties that tend to result in **high soil** erosion include:

- high contents of silt and very fine sand.
- expansive types of clay minerals.
- a tendency to form surface crusts.
- the presence of impermeable soil layers.

In contrast, soil properties that tend to make the soil more **resistant to erosion** include:

- high soil organic matter content.
- non-expansive types of clays.
- strong granular structure.

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POTENTIAL ADVERSE ENVIRONMENTAL, HEALTH AND SAFETY IMPACTS OF FERTILIZER

While fertilizers provide a range of benefits, throughout their life cycles of production, use and storage, fertilizers may have a range of adverse impacts on the environment and human health. Surface and groundwater, air, soil, plants, aquatic and soil organisms, humans and other mammals may be adversely impacted mainly due to the excessive, inappropriate, or inefficient use or improper storage of fertilizers.

ENVIRONMENTAL IMPACTS

Surface water and groundwater contamination. Nutrients from applied or stored fertilizers can enter nearby water bodies by dissolving in water and leaching towards groundwater or via runoff/soil erosion which ultimately enters surface waters (e.g., rivers, lakes, etc.). In sandy soils, nutrients move more quickly through the root zone and soil profile than in other soil types (e.g., clays), and excessive water application (or heavy rainfall) or over-application of fertilizers can lead to nutrient loss through leaching. In heavier soils (clays), if nutrients are not adequately incorporated into the soil, the chances for surface runoff in the event of heavy rains or over-irrigation are increased. When high amounts of nutrients are transported to water bodies, excessive algal growth occurs and leads to low-oxygen water levels that can kill fish and reduce essential fish habitats. This process is called eutrophication. Sound water management is especially important in rainfed conditions commonly used throughout Sub-Saharan Africa.

Greenhouse gas (GHG) emissions. Fertilizer application can contribute to fine-particulate air pollution and result in GHG emissions. After fertilizer application to the field, nitrous oxide can be produced by a process called denitrification in which soil microbes convert nitrate to various gaseous forms of nitrogen, including nitrous oxide. This likely occurs in soils that are periodically flooded or experience occasional heavy rains. Methane emissions in agriculture largely occur during rice paddy cultivation and residue burning. According to UNEP, the use of inorganic fertilizers, and manure storage and use, contributed almost 40 % of agricultural GHG emissions (UNEP, 2021).

Soil acidification leading to nutrient imbalances, crop deficiencies, plant toxicity and soil biodiversity decline. Nitrogen fertilizers, particularly ammonium-based fertilizers, can acidify the soil. Deficiencies of major crop nutrients (N, P, K, S, Ca, and Mg) and trace elements such as molybdenum occur in acidic soils because these nutrients become less available to plants. Molybdenum deficiency can also affect the growth of N-fixing legumes. In contrast, the availability of iron, manganese, copper, zinc, and aluminum increases in acidic soils and may result in toxicity to plants. Additionally, decline in soil biodiversity is linked to long-term increased application of inorganic fertilizers and the loss of organic matter, because soil biota depends on organic matter to live.

Shifts in microbial composition of soil. Excessive chemical fertilizer application aggravates the decline of soil organic matter and typically reduces beneficial soil bacterial and fungal communities (e.g., rhizobia, mycorrhizal fungi, actinomycetes, etc.), which enables the increase of pathogenic microbiota (i.e., pathogens and parasites).

Damage to crops. Fertilizer over-application and inappropriate timing and placement can result in crop damage referred to as "fertilizer burn" due to excess salts.


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HEALTH AND SAFETY IMPACTS

Toxic gas emissions. Chemical compounds such as nitrogen oxides and ammonia released by fertilizers can be toxic to humans and cause or worsen respiratory illness, particularly as a result of frequent and prolonged exposure. Storing bagged fertilizers in spaces where people work and live causes toxic gas emissions and can have adverse impacts on human health.

Particulate air pollution. Solid inorganic fertilizers can generate harmful particulate matter during broadcast application as wind blows and produces dust. Fine particulate matter with a diameter of less than 2.5 micrometers (PM 2.5) is harmful to human health because these particles can penetrate lungs and cause respiratory diseases, as well as eye, throat, and nose irritation. Atmospheric ammonia produced via volatilization can also result in the formation of particulate matter that can not only cause health problems but can result in uncontrolled N deposition at pristine ecosystems.

Water pollution. Incidental ingestion of nitrate that has leached into drinking water may elevate nitrate levels in blood and change how oxygen is carried, potentially leading to fatal baby-blue syndrome or methemoglobinemia in children. Long-term exposure can also cause health problems for healthy adults.

Accumulation of heavy metals and other toxic substances in soils and plants. Inorganic fertilizers, as well as some manures, sewage sludge, and biosolids can contain heavy metals such as mercury, lead, chromium, cadmium, and arsenic. Heavy metals can leach into water, accumulate in soils and might be taken up by plants/harvest, creating risk for human exposure. Leafy and root vegetables have the greatest ability to accumulate heavy metals that have harmful effects on human health.

Release of pathogens, veterinary pharmaceuticals and endocrine disruptors from organic fertilizers. Waste-derived and non-composted manure fertilizers can carry various pathogens such as Shiga toxin-producing Escherichia coli (STEC), Salmonella spp., and Listeria spp., frequently involved in fresh produce outbreaks, and/or expose people to harmful chemicals such as antibiotics or other drugs used for treatment of animals.

Skin burn. Commercially produced fertilizers contain chemicals that can burn and damage skin, particularly if handled with bare hands.

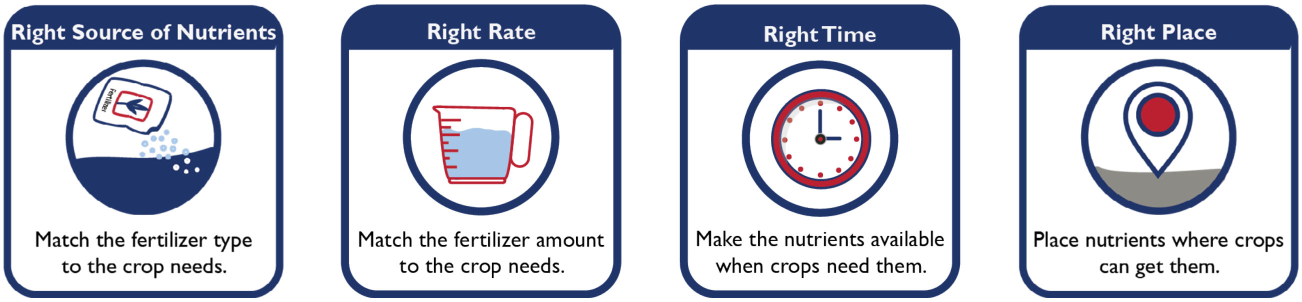
Odors. Stored or applied fertilizer and manure odors can be a nuisance for nearby neighbors and communities. Constant nuisance to odors can degrade the quality of life.

Reactivity. Ammonium nitrate, frequently added to improve a fertilizer's nitrogen content, is relatively stable under most conditions. However, if fertilizer comes into contact with a source of ignition, or even when large amounts are exposed to extreme heat, it can lead to a violent explosion.

MITIGATIONS OF POTENTIAL ADVERSE IMPACTS

FOLLOW FERTILIZER APPLICATION GUIDELINES & AGRICULTURAL BEST PRACTICES

Practice nutrient management or The 4 Rs (4 "rights" of fertilizer management). This will not only help increase fertilizer use efficiency and crop yield, but most importantly minimize nutrient loss to the environment.



Always avoid indiscriminate use of chemical fertilizers to prevent nutrient leaching to groundwater or surface runoff, as well as other issues such as soil acidification. Do not apply fertilizers when the risks of leaching and gaseous losses are high (i.e., during periods of heavy rain or water logging). Consider soil properties when determining the correct source, rate, timing and placing of fertilizers.

Practice Integrated Soil Fertility Management (ISFM). Use of organic inputs, inorganic fertilizers, and improved seeds combined with knowledge to adapt practices to local conditions (e.g., soil type, topography, climate, etc.). See Africa Soil Health Consortium Handbook for more information.

Practice conservation agriculture. This type of sustainable farming is based on three principles: 1) minimal mechanical soil disturbance (no till/reduced till), 2) soil organic cover (crop residues, compost, mulch), and 3) species diversification (crop rotation, fallow periods, use of N-fixing legumes, cover crops).

Reduce soil erosion. Maintain or improve the physical, chemical, and biological condition of the soil to minimize erosion. Keep the soil covered as much as possible! This will help keep soil and nutrients in the field and prevent them from getting lost into the water. Conservation agriculture and ISFM are great practices to reduce soil erosion.

Increase microbial activity in soils. Make the soil environment optimal for the beneficial microorganisms by avoiding excessive chemical fertilizer applications and providing the needed organic matter for improved soil aeration, moisture content and soil buffering capacity, which minimizes changes in pH.

Maintain buffer zones to reduce the amount of nutrients that reach nearby water bodies and minimize soil erosion.

Consider site location, site-specific features and weather when applying fertilizers including distance from sources of drinking water, soil type and its properties, crop nutrient requirements and fertilizer source to improve fertilizer use efficiency and to prevent nutrient loss. Follow weather forecasts and avoid conditions that create a high risk for nutrients to leave the field. Where heavy metal contamination potential exists, test and monitor soil and water.

Reduce crop damage/chemical burn. Implement 4Rs of fertilizer management, and where possible, use slow-release fertilizers. Do not fertilize during droughts or when plants are wet, and water thoroughly after applying granular fertilizer to rinse the fertilizer off the plants and allow the salts to distribute themselves in the soil.

If possible and accessible, identify nutrient deficiencies by soil analysis, plant analysis and/or obtaining historical information regarding the amount of fertilizer applied in the past and previous nutrient deficiency symptoms observed on crops. This will help farmers make better decisions to improve fertilizer use efficiency and not only improve agricultural productivity, but also prevent nutrient loss.

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HANDLE, STORE AND APPLY FERTILIZERS WITH CONSIDERATION FOR ENVIRONMENTAL, OCCUPATIONAL, AND PUBLIC HEALTH SAFELY.

When handling – When using commercial fertilizer, always read product labels and the supplier Safety Data Sheet. Always follow label directions, which is vital not only for fertilizer application and handling but also for appropriate disposal of fertilizer bags and containers. Use appropriate personal protective equipment (PPE) when handling fertilizers. Provision and use of PPE must occur during activities in which fertilizers are directly provided.

When storing - Assign an area dedicated to fertilizer storage that is protected from flooding; away from nearby surface and groundwater sources and neighboring dwellings; protected from extreme heat, sources of ignition and flooding; and separate from other agricultural inputs, fuels and lubricants to prevent cross-contamination of seeds, feed, or harvested crops and/or potential mixing in case of a fire or evacuation emergency. Fertilizers should be stored in their original containers unless damaged, preventing contact with the floor and upright. Labels should be visible and readable. Food or beverage containers should never be used for storage of fertilizers.

When applying – Always require appropriate use of PPE when applying fertilizers. Use fertilizers according to appropriate nutrient management techniques (i.e. 4Rs and ISFM), and implement best management practices such as conservation agriculture and buffer zones, particularly near rivers.

Do not apply fertilizers when the risks of gaseous losses are high (i.e., during periods of heavy rain or water logging). Where possible, use controlled release formulations, and where appropriate, apply fertilizer by direct injection to minimize evaporation and odors.

Do not apply raw, un-composted livestock manure to food crops unless it is: 1) incorporated into the soil a minimum of 120 days prior to harvest when the edible portion of the crop has soil contact; or 2) incorporated into the soil a minimum of 90 days prior to harvest of all other food crops.

Apply only properly treated sewage sludges or other biosolids that meet quality requirements for concentration of trace elements, pathogens and vectors of disease. When possible, use composting, as this process can effectively reduce pathogens and the bioavailability of heavy metals by converting some metals into stable organic forms, and can potentially degrade organic contaminants and other emerging substances of concern.

BUILD AWARENESS AND PROVIDE TRAINING

Build awareness among farmers and input suppliers regarding the environmental and human health and safety risks of fertilizers.

Provide training to farmers on fertilizer best management practices (e.g., methods of application, proper timing of application, ISFM, etc.) and safe use (e.g., health and environmental risks, appropriate storage and handling, use of PPE, etc.).

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  - https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/pnw508_0.pdf
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SUGGESTED READING

- Africa Soil Health Consortium Handbook
- Global Soil Doctors Programme
  - Fertilizer and Training Aid Modules
  - Soil Testing Methods Manual
- The International Code of Conduct for the Sustainable Use and Management of Fertilizers
- Soil Atlas of Africa
- USAID Sector Environmental Guideline: Crop Production
- USAID Sector Environmental Guidelines: Dryland Agriculture
- 4R Plant Nutrient Management in African Agriculture
- Fertilizer use optimization in Sub-Saharan Africa
- Fertilizer manual
- User's Manual: Fertilizers
- Sub-Saharan Africa Soil Fertility Prioritization Report


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