4 Management of soil fertility through application of fertilizers

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Introduction

Plants require nutrients for growth and reproduction. Most crops obtain these nutrients from the soil. Legumes obtain additional nitrogen from the air through biological nitrogen fixation. At harvest, nutrients contained in the crop products (grain, leaves, stalks, etc.) are removed from the fields. The quantity of nutrients removed varies with the crop species, yield, and the portion of the crop that is removed. Also, depending on management, topography, wind speed, soil moisture, and rainfall intensity, nutrients can be lost through soil erosion and leaching to deep soil layers, even below the level of the plant roots.

In East and Southern Africa (ESA), many soils are already limited in their capacity to supply nitrogen and phosphorus to plants, as well as being limited in potassium and secondary micronutrients (Kihara *et al.*, 2017). Some nutrients may be present in limited quantities, while others are in sufficient supply; it is the nutrient(s) in low quantities that limit crop production (Figure 4.1). When plants grow, they take up nutrients from the soil, and the process of removing nutrients in crop products is known as nutrient mining. It is therefore important to replace the nutrients lost from the fields by adding more from external sources (such as fertilizers), while also protecting soils from the processes of erosion and leaching (see Chapters 5 and 6 of this book).

When available nutrients are insufficient to meet crop requirements, yields will be below the maximum potential, and the long-term productivity of the land will decline due to nutrient mining. However, if nutrients are applied in excess of crop requirements, there is a risk of agronomic problems such as crop lodging (falling over) and poor grain yields due to excessive vegetative growth at the expense of grain production (in the case of excess nitrogen). Excess nutrients can also have negative effects on the environment, such as soil poisoning or toxicity, nitrate leaching into groundwater, phosphate runoff into surface water, and release of greenhouse gases to the atmosphere. Using too much fertilizer will also reduce the profitability of crop production.

Nutrients can be added to the soil by growing legumes in rotation or as intercrops (see Chapter 3 of this book), and by the application of industrial fertilizers, farm-made organic fertilizer (manure and compost), and other organic matter such as crop residues and biomass derived from cover crops and agroforestry trees. These technologies have a positive effect on the livelihoods of small-scale farmers by sustainably increasing yields, food security, and incomes.

Africa RISING research in ESA validated the use of industrial and organic fertilizers in a manner that would ensure good yields, and minimize the problems linked with application of too little or too much fertilizer. The trials took place

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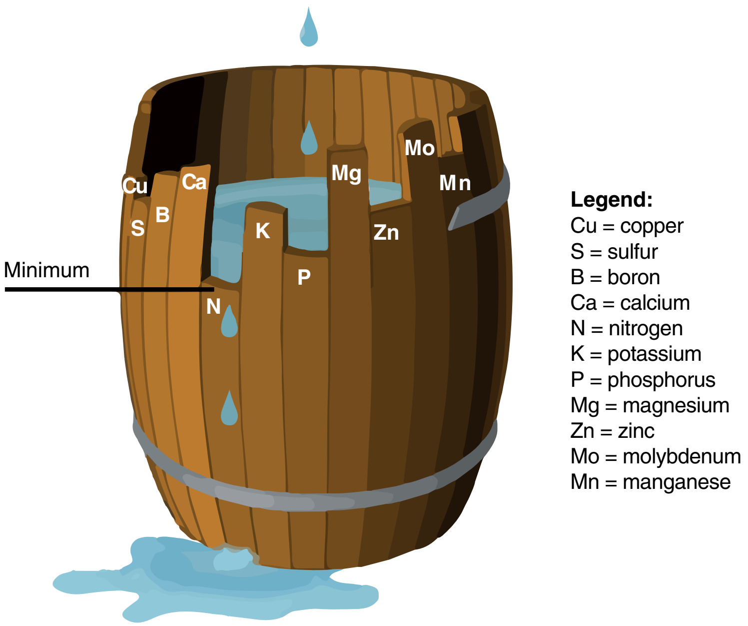

Figure 4.1. Liebig's 'Law of the Minimum' adapted for soils of ESA, illustrating the importance of balanced nutrients for maximum plant growth and productivity. The yield of a plant is limited by a deficiency of any one essential element, even when all others are present in adequate amounts. In this illustration, too little nitrogen is the main problem. If nitrogen is added up to the top, phosphorus becomes the next limiting nutrient. Adapted from Whitson and Walster (1912).

in the highlands, medium altitudes, and lowlands of northern Tanzania (Babati district); the semi-arid zone of central Tanzania (Kongwa and Kiteto districts); and the semi-arid zones of central and southern Malawi (Machinga and Dedza districts).

Before making a decision about which fertilizers to apply, it is important to test the soil and identify which nutrients are lacking. The soils in Babati are of moderate fertility with deficiencies in nitrogen, phosphorus, and, in some locations, low levels of zinc. Soils in Kongwa and Kiteto are heavily eroded and of poor fertility, with widespread deficiencies in nitrogen, phosphorus, sulfur, zinc, and boron. Soils in Machinga and Dedza in Malawi are deficient mostly in nitrogen, sulfur, and zinc.

Industrial fertilizers

Description of the technology

Industrial fertilizers consist of inorganic or synthetically produced organic compounds containing nutrients for plant use. Organic compounds such as phosphate rocks that are further enriched with inorganic compounds are also considered as industrial fertilizers in the context of this chapter. These fertilizers are applied at planting, with nitrogen-containing fertilizers often used for additional top-dressing. The most common nutrients supplied in fertilizers are nitrogen, which promotes the growth of the plant, and phosphorus, which improves root growth and flowering. There are many types of industrial fertilizers; some contain one nutrient (straight fertilizers) while others contain two or more nutrients (compound fertilizers).

Africa RISING tested and validated the following types of fertilizers:

- Diammonium phosphate (DAP): Contains 18% nitrogen, 46% phosphate, and 1.6% sulfur. DAP is the world's most widely used phosphate fertilizer. It is popular because of its relatively high nutrient content and because it is water soluble. It temporarily increases soil acidity, but over time reduces it. Special care needs to be taken to avoid placing DAP near germinating seeds (see below for application modes).

- Minjingu NAFAKA and Minjingu Mazao: Minjingu NAFAKA contains 9% nitrogen, 16% phosphate, 6% potassium, and a small quantity of calcium, magnesium, and sulfur, and the micronutrients zinc and boron. This fertilizer is based on Minjingu phosphate, which is one of the most reactive rocks. Minjingu, mainly an organic fertilizer and often enriched with other chemical elements, is mined from Minjingu mines in the Manyara region of Tanzania, about 80 km from Babati. It is especially suited to soils that are deficient in phosphorus, and can be applied to acidic soils (pH >6) due to the liming effect of the calcium. Before enrichment with micronutrients, it was referred to as Minjingu Mazao.
- Nitrogen, phosphate, sulfur (NPS): Contains 23% nitrogen, 21% phosphate, and 4% sulfur; with a similar product containing zinc and potassium but with reduced phosphate (10%). This is suitable for areas where potassium is not a limiting nutrient. The sulfur included in NPS fertilizer helps the plants to develop chlorophyll for photosynthesis, and improves plant resistance to stresses.
- YaraMila™ CEREAL fertilizer: Contains highly soluble and balanced proportions of macro- and micro-nutrients (23% nitrogen, 10% phosphate, 5% potassium oxide, 3% sulfur, 2% magnesium oxide, and 0.3% zinc). This fertilizer also contains sulfur and other elements that boost plant growth. Because the nitrogen is readily available, it does not increase the acidity of the soil. It releases phosphate over an extended period within a season, thus meeting the plant's needs throughout its growth. Because it has a lower phosphate concentration than DAP, Minjingu, and NPS, bulky amounts of YaraMila™ fertilizer are required to meet recommended phosphate application rates for cereal production in most soils in ESA.
- Urea with 46% nitrogen: This has been used for many years by farmers, especially as a top-dressing for maize and other cereals, since the nitrogen stimulates strong plant growth.
- Calcium ammonium nitrate (CAN) with 26% nitrogen: Is used for top-dressing cereal crops and also supplies calcium and magnesium.

The need for fertilizer is different depending on the location. Some farmers find it better to use fertilizer in areas of poor yields, where the need is greatest (target application). It should be noted that most legumes may not require the application of nitrogen, since the plants fix this nutrient through biological processes. Under severely depleted soil conditions, legumes may need a small amount of 'starter' nitrogen to support good crop development.

Benefits of the technology

Africa RISING research shows that adding the right amount of fertilizer results in more than double the maize yield when compared with farmer practice (continuous cultivation with little or no fertilizer). Under the environmental conditions of the highlands and medium-elevation zones of northern Tanzania, the trials showed that applying fertilizer achieves an increase of 120% or greater (Table 4.1). Even under semi-arid environments, responses of about 57% are obtained. When moisture is inadequate, DAP and YaraMila CEREAL fertilizers are better sources of phosphate than the now replaced Minjingu Mazao fertilizer because it had low phosphate rock solubility (Savini *et al.*, 2015), which could lead to a 10% yield reduction compared with DAP.

Trials across the semi-arid agroecosystems in Malawi showed that the right amount of fertilizer to apply is less than the highest recommended rate for maize of 92 kg nitrogen/ha (as recommended by the Malawi Ministry of Agriculture and Food Security, 2012). Applying 69 kg nitrogen/ha and 18 kg phosphate/ha increased maize yield by between 50% and 300% compared with systems using no fertilizer. Actual maize yield varied quite widely depending on the use of a local maize type or improved variety, and on the use of fertilizer or farmer practice (little or no fertilizer). This is due to the combined effects of variable soil fertility, topography, and/or different agronomic practices

Table 4.1. Benefits of fertilizer use on maize productivity

Nutrient application	Agroecosystem	Average rainfall (mm/year)	Increase in productivity (Grain yield, %)	Gross margin (US$/ha)
P (20 kg/ha) + N (60 kg/ha)	Highlands of northern Tanzania	845	210 (153–444)	685–1,245
	Medium altitudes of northern Tanzania	743	215 (74–470)	820–1,215
	Lowlands of northern Tanzania	769	120 (63–300)	740–1,435
P (15 kg/ha) + N (60 kg/ha)	Semi-arid central Tanzania	408	57 (22–84)	102–357
P (18 kg/ha) + N (69 kg/ha)	Semi-arid central Malawi	855	128 (30–290)	n/a[1]
P (18 kg/ha) + N (69 kg/ha)	Semi-arid southern Malawi	723	187 (50–300)	263% (net income)

Notes: for northern Tanzania, work was undertaken in Babati district using DAP and Minjingu Mazao fertilizers. For semi-arid central Tanzania, work was done in districts of Kongwa and Kiteto using DAP, Minjingu, and YaraMila CEREAL fertilizers. Both YaraMila™ and Minjingu supply additional nutrients needed by plants in small doses (micro-nutrients) and reduce soil acidity due to the presence of basic cations in their formulation. In Malawi, the work was conducted in Machinga and Dedza districts using NPS fertilizer and urea.
[1]n/a = not applicable.

adopted by farmers, such as planting density, time of planting, and weed management (Kihara *et al.*, 2015).

The research shows that it is important to use fertilizer and to grow an improved maize variety with good agronomic practices, such as timely planting and proper plant spacing, to reduce variability in productivity (Figure 4.2). The increase in yield due to fertilizer application is sufficient, in most cases, to offset the cost of inputs and other operations, as noted by the marginal rate of return of at least 1.6 in Babati, Kongwa, and Kiteto districts, Tanzania (Table 4.2).

The results of the experiments show that farmers should apply fertilizers to decrease the chance of net financial loss. Without fertilizers, the chance of loss or of doubling invested capital are about the same, but when farmers apply fertilizers, the chance of loss is completely reduced and/or eliminated (Figure 4.3).

For optimum benefit from these technologies, farmers should use improved agronomic practices, such as row planting at the appropriate spacing, weeding at the right time, and disease and pest control. Even without fertilizer, improved practices enhance crop productivity by 20–45%, and yield benefits increase further when improved practices are combined with fertilizer application (Figure 4.4).

Farmers' responses

A clear demonstration of the benefits of fertilizer use with good agronomic practices, derived from farmer participatory evaluation (150 male farmers and 106 female farmers) was captured for the 2015/16 cropping season (Table 4.3). Both female and male farmers perceived that the new technologies increase grain yield and net returns (income). In addition, male farmers perceived that the technologies reduce production risk. The farmers understood that using fertilizers will provide higher financial returns and reduce risk, as compared with their existing practice. However, the technology will also increase the requirement for cash, and those without access to finance may be unable to adopt it. Affordability is more important for women farmers than men; this could be due to women's limited access to financial resources. Providing loans for inputs is likely to enhance the adoption of this technology, particularly among women farmers.

Making the most of industrial fertilizer application

Industrial fertilizers undergo various changes in the soil, and these influence the solubility and

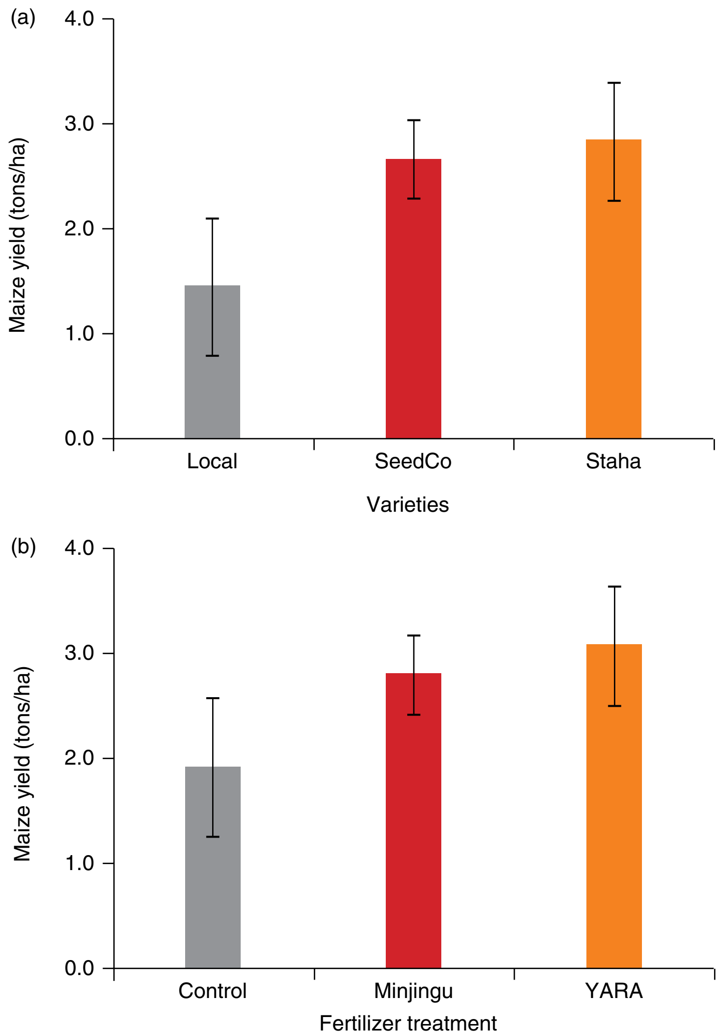

Figure 4.2. Maize yield response to improved seed variety (a) and fertilizers (b) in farmer-managed plots (n=275) at Moleti and Njoro villages in Kongwa district, Tanzania. Application rates were 15 kg phosphorus/ha and 60 kg nitrogen/ha. Error bars are standard deviations.

availability of nutrients to plants. When plants receive nutrients through their roots, fertilizers should be added to the soil in a form that maximizes take-up of nutrients by the roots to support strong plant growth and development. Management practices for fertilizer application are guided by the four 'R's or 'rights': the right nutrient source (type of fertilizer) for the targeted crop(s); the right rate or quantity being applied; the right time of application; and the right place of application (Figure 4.5).

Right nutrient source: This is required to improve the agronomic performance of crops. Apply only the nutrients that are needed, based on a soil test. Applying a fertilizer with nutrients that are not needed decreases the efficiency and profitability of fertilizer use. Straight fertilizers, compound fertilizers, and specialty blends of micronutrients are available. Soil pH and drainage conditions are also important factors to consider when selecting the right fertilizer.

Table 4.2. Marginal rates of return on fertilizer application in Tanzania

	Babati		Kongwa and Kiteto	
Fertilizer source	Low rainfall	High rainfall	Low rainfall	High rainfall
DAP	2.3	2.4	n/a[1]	n/a
Minjingu Mazao	2.1	1.6	1.9	2.3

[1]n/a = not applicable.
Source: Adapted from Kihara *et al*. (2017; CC BY-SA 4.0). No data for DAP in Kongwa and Kiteto.

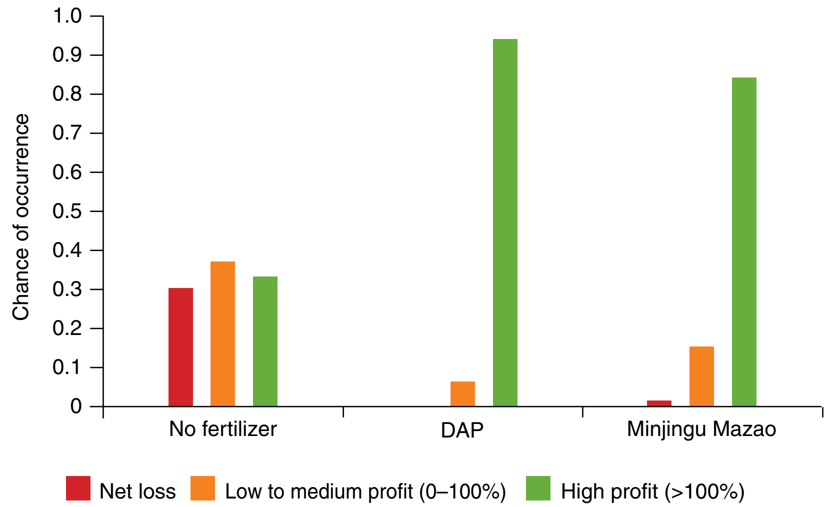

Figure 4.3. Profit levels and chance of occurrence with and without fertilizers in Babati, Tanzania. On the y axis, 1 represents 100% chance of occurrence.

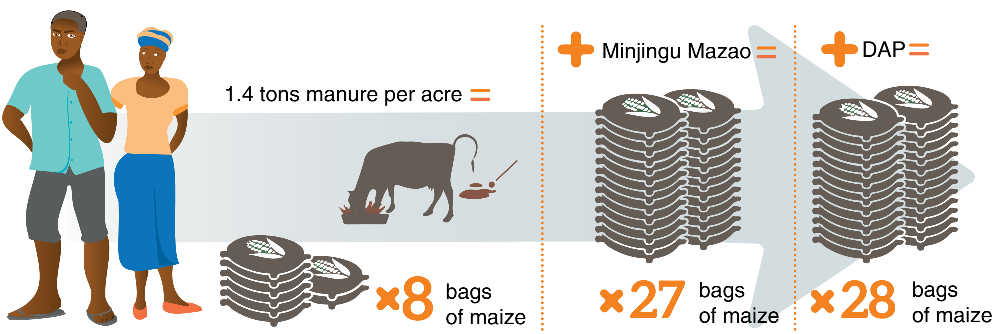

Figure 4.4. Yield (on acre basis) obtained under farmer practice and with different fertilizers in Babati, northern Tanzania in the 2015/16 cropping season. Data are derived from participatory evaluation. One bag is equivalent to 100 kg. Adapted from CIAT (2016; CC BY NC SA).

Industrial fertilizers are supplied as granules or liquids. Liquid fertilizers are for foliar application and are used mostly for specialty horticultural crops, while those supplied in solid form are used for soil application. Slow-release nitrogen fertilizers have become available more recently. Specialty and slow-release fertilizers are more expensive, but result in higher yields by ensuring the gradual release of small amounts of nutrients to the plant; they also reduce the need for top-dressing.

When soils are degraded and low in organic matter, it is advisable to add organic nutrients such as farmyard manure and compost, to improve the physical structure and increase the ability of the soil to hold water and nutrients (see the next section of this chapter). In addition, legumes grown in one season are a source of nitrogen for the next non-legume crop in a rotation or intercrop system, helping farmers save money on chemical nitrogen fertilizers (see Chapter 3 of this book).

Right rate: The amount of fertilizer applied depends on the soil condition (i.e., level of limitation), rainfall, and affordability. Over-application reduces agronomic efficiency, lowers incomes, and contributes to environmental degradation (e.g., water pollution). Under-application results in inefficiency and a poor harvest. Hybrid crop varieties use fertilizers more efficiently than local varieties and, although they require larger amounts of fertilizer, application is likely to be profitable. Application of 1 kg of nitrogen/ha resulted in 26 kg of hybrid maize grain yield, compared with only 17 kg of grain yield for local varieties (Vanlauwe *et al.*, 2011) using the same agronomic practices.

Table 4.3. Farmer qualitative assessment of industrial fertilizers in Babati, Tanzania

	DAP		Minjingu Mazao	
Evaluation criteria	Male	Female	Male	Female
Accessibility	3.6	3.6	5.8	5.6
Affordability	4.8	2.6	2.4	3.2
Labor requirement	3.4	2.2	2.6	2.8
Cash requirement	3.4	2.6	2.4	2.6
Grain yield	7.0	7.4	7.0	7.2
Net return	7.2	7.0	6.8	7.2
Risk reduction	6.6	3.8	6.6	4.2

Note: Rating score: 1 = the lowest and 10 = the highest. Figures greater than 5 are perceived to show an improved performance of the technology compared with the traditional practice; figures lower than 5 show a reduced performance.

Right time: Most nutrients and micronutrients are applied when the crop is first planted, to support the growth of the plants. Nutrients that move quickly through the soil (e.g., the nitrogen supplied by industrial fertilizers) need to be applied two or three times, usually one third at planting followed by top-dressing, with one third at four weeks, and one third at eight weeks after planting, or one third at planting and the remainder at about four weeks after planting. The top-dressing must be applied when the soil is moist to ensure the nitrogen passes quickly into the soil (Figure 4.6). Under dry conditions, the nitrogen should be applied and then immediately covered with soil to avoid nitrogen being lost via volatilization. Slow-release fertilizer may be applied once at planting because the nitrogen is released gradually while the plant grows.

Right place: Fertilizer placement is determined by the mobility of the nutrients and the spacing of the crop. See section below on fertilizer application at planting.

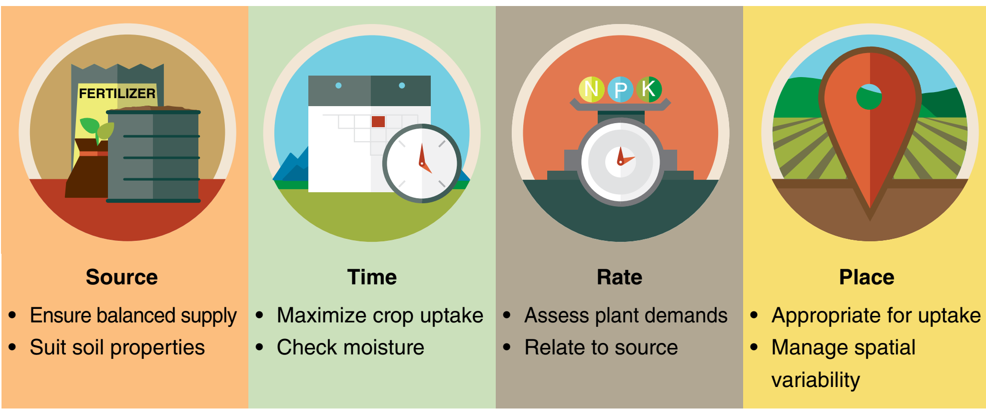

Figure 4.5. The 4 'R's of nutrient stewardship. Adapted from Zingore *et al*. (2014) and The Fertilizer Institute (2017) with permission from Fertilizer Canada.

Figure 4.6. A farmer applying industrial fertilizer (urea top-dressing) (Photo courtesy of Millennium Promise, 2010.)

How to get started

Basic requirements of good agricultural practice

- Soil analysis is important to guide specific nutrient applications, especially for sites where this has not already been done. Analysis can be done by government or commercial laboratories, or by using portable laboratories, which are often cheaper.
- Use good-quality seed of improved crop varieties that are suitable for the area.
- Protect farms from surface runoff, since this carries away the topsoil and applied fertilizers.
- Create planting rows across the line of slope to avoid creating surface water runoff channels.
- Prepare the land early and plant on time. Late planting can reduce available seasonal water for optimum plant growth, and periods of water stress may coincide with critical crop growth stages.
- Plant seeds at an even depth of 2–5 cm (for maize and pigeonpea) in firm, moist soil to ensure good seed-to-soil contact. This maximizes moisture uptake and subsequent germination.
- Use the correct planting density and row spacing for each crop to maximize yields. Recommendations should be available from the seed provider or local extension agent.
- Keep the crop free from weeds, diseases, and pests.

Fertilizer application at planting

- The choice of application method depends on the nature of the fertilizer, with the objective being to maximize nutrient uptake by the crops. The right amount of fertilizer should be added, based on analysis of limiting nutrients.
- Application in a planting hole: place fertilizer approximately 5 cm below or to the side of the seed (Figure 4.7). Do not place seeds in contact with the fertilizer as this can affect germination. For large grain crops such as maize, place fertilizer and seed at least half a finger deep and one finger apart.
- Application in bands: when plants are close together (e.g., beans, soybean), place

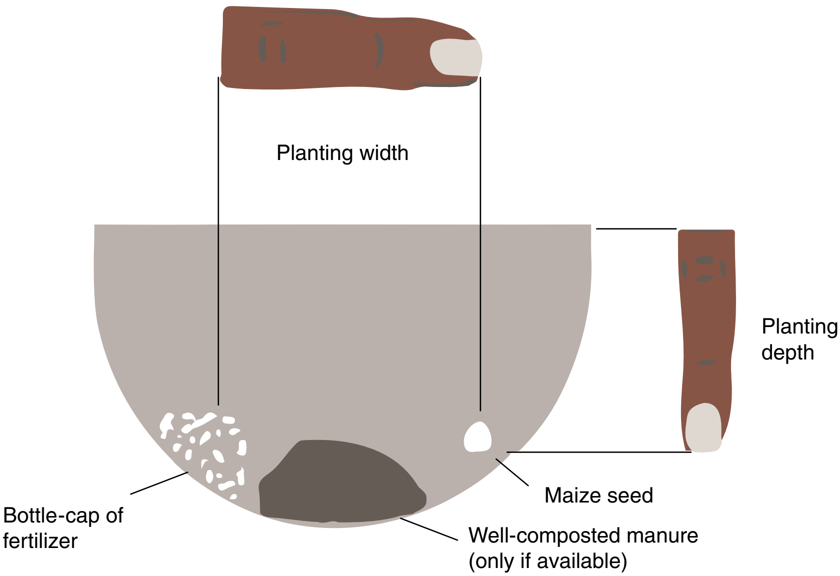

Figure 4.7. Fertilizer application in a planting hole.

the fertilizer in a line along the planting furrow. Mix the fertilizer with the soil before planting the seeds. The fertilizer depth depends on the crops and system, as well as the type of fertilizer. Place immobile nutrient fertilizers (phosphates) at 10–15 cm below the soil surface.

- Broadcasting: Spread the fertilizer over the soil surface and incorporate it in the soil through primary or light tillage. Do not use this method for large-seeded cereals and legumes.

At top-dressing

- Use urea or CAN for top-dressing cereal crops.
- For maize, apply at about four to six weeks after planting (or when the maize is knee high) in a weed-free field.
- Do not top-dress legume crops in sole crops or intercrops.
- Top-dress when soils are sufficiently moist; place the fertilizer next to the planting hill.
- Cover the fertilizer with soil to minimize loss.
- Weed at least twice and avoid weeding when the soil is dry, since excessive evaporation of soil moisture can cause plants to wilt.

Sustainability

- Train farmers on the principles and procedures of using fertilizers properly, including the 4 ‘R’s, the need for soil analysis, and where to get assistance.
- Educate farmers on the options available to correct different soil nutrient deficiencies.
- Train farmers on accompanying technologies needed to maximize the benefits of using fertilizers.

Application of farmyard manure and compost alone or in combination with industrial fertilizers

Description of the technology

Organic sources of nutrients are particularly important in degraded soils, where fertilizer uptake by plants may be limited by the soil’s physical and biological properties. Farmyard manure is rich in nutrients, but poor methods of collection, storage, and application can lead to large losses of nutrients. Depending on the condition of the land, the quality of livestock feed, and application rate, farmyard manure can contain similar amounts of nitrogen, phosphorus, and potassium as industrial fertilizers, with nutrients released gradually through the season as the organic matter decomposes.

Manures and composts are accepted as 'right source' nutrients. The highest concentration of nutrients is provided by manure derived from poultry droppings, followed by goats and sheep, and then cattle manure. For each manure type, the nutrient concentration varies widely from place to place, and from farmer to farmer, depending on the method of collection, storage, materials fed to the livestock, and the composting process (Table 4.4). Low-quality manure has a nitrogen content of less than 0.6%, while high-quality manure contains at least 1.6% nitrogen (Table 4.5). Most chicken and goat or sheep manures are classified as high quality. Cattle fed on rations containing leguminous plants also produce high-quality manure, while cattle feeding mostly on cereals, especially free-ranging cattle, produce low-quality manure.

Compost is made from the stalks and leaves of crops, grasses, and other vegetative matter that is not fed to livestock. The components (mixed materials such as crop residues, kitchen waste, animal droppings, and ash) are given time to break down to make a fine soil-like organic matter. The materials are arranged in successive layers, either in a pit or on the soil surface, and kept moist under shade. The pile should be turned every three weeks or so and kept for at least three months until the composting process is complete (see Karanja *et al*., 2005 for more information on making compost). When compost is made mostly from legume residues, animal dung, and ash, it will be of high quality, while compost made mostly from cereal residues (e.g., maize, rice, and wheat), will be of low quality.

Compost and manures also contain a large amount and diversity of helpful microorganisms, which convert nutrients into forms that are easily accessible to plants. However, compost and manures are not usually available in sufficient quantities for application at the recommended rates of 10–15 t/ha (Mafongoya *et al*., 2006), and the nutrients contained may be imbalanced, requiring combination or integration with industrial fertilizers. As with industrial fertilizers, use of organic resources and combining them with industrial fertilizers should follow the 4 'R's approach.

Benefits of the technology

Research conducted in Babati district, Tanzania in the 2014 and 2016 seasons showed that applying farmyard manure (6 t/ha) increased yields of maize and pigeonpea compared with the controls (Table 4.6). Combining small amounts of industrial fertilizers with farmyard manure tripled the yields of both maize and pigeonpea. Applying farmyard manure also increased farmers' net incomes per hectare from US$ 434 to 865 relative to the control. Combining half the amount of farmyard manure with small amounts of Minjingu Mazao increased incomes still further, from US$ 865 to 1,647.

Table 4.5. Common convention on manure quality

Category	Nitrogen content	Carbon: nitrogen ratio
High quality	>1.6%	<10
Low quality	<0.6%	>17

Source: Bationo *et al*. (2004).

Table 4.4. Indicative means and ranges of manure quality parameters for East and Southern Africa

Manure	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Carbon (g/kg soil)	Carbon/ nitrogen ratio
Cattle manure[1]	1.4 (0.5–2)	0.6 (0.2–1.6)	1.3 (0.5–2.7)	35 (17–52)	26 (17–56)
Manure/compost[2]	1.1 (0.3–1.9)	0.3 (0.1–0.8)	2.4 (0.4–7)	24	23
Farmyard manure[3]	1.6	0.5	1.43	69.1[4]	7.5[4]
Goats/sheep[1]	1.5 (0.9–2.3)	0.4 (0.2–0.8)	1.4 (0.7–2.6)	32 (20–46)	22 (15–26)
Poultry[1]	1.7 (0.9–2.6)	1.3 (0.3–1.8)	0.7 (0.5–0.9)	35 (28–48)	20 (16–33)

Sources: [1]Lekasi *et al*. (2001), [2]Lekasi *et al*. (2003), [3]Kimani and Lekasi (2004) and [4]Saidia and Mrema (2017). Data in parentheses are analytical ranges.

Table 4.6. Changes in maize and pigeonpea grain yields and net incomes in Babati district, Tanzania, using farmyard manure

Manure technology	Agroecology	Increase in productivity (Grain yield, %)	Gross margin (US$/ha)
Farmyard manure (6 t/ha)	Highlands of northern Tanzania	65 (41–93)	185–388
Farmyard manure (6 t/ha)	Medium altitudes of northern Tanzania	46 (0–139)	–12 to 162
Farmyard manure (6 t/ha)	Lowlands of northern Tanzania	No change	232–495
Farmyard manure + fertilizer[1]	Highlands of northern Tanzania	173 (123–283)	639–947
Farmyard manure + fertilizer[1]	Medium altitudes of northern Tanzania	141 (33–181)	542–799
Farmyard manure + fertilizer[1]	Lowlands of northern Tanzania	96 (24–199)	592–860
Farmyard manure (5 t/ha)	Semi-arid central Tanzania	145 (–19 to 304)	–235 to 955
Farmyard manure + fertilizer[2]	Semi-arid central Tanzania	189 (–21 to 425)	–294 to 1347

[1]Application of farmyard manure (3 t/ha) and Minjingu Mazao (10 kg phosphate/ha).
[2]Application of farmyard manure (5 t/ha) and Minjingu Nafaka (15 kg phosphate/ha).
Values in parentheses are grain yield ranges.

Africa RISING demonstration sites in the semi-arid zones of central Tanzania showed a mean maize grain yield of 2.9 t/ha when manure was applied alone at 5 t/ha, compared with a yield of 1.2 t/ha for farmers' traditional practice (with no or only small quantities of manure and no fertilizers). This represents an increase of 145%. The mean maize grain yield was 3.4 t/ha when manure was supplemented with industrial fertilizer, an increase of 189% over farmers' traditional practice (Table 4.6). Incomes increased accordingly. The maize grain yields and gross margins differed widely between farmer-managed plots, suggesting that farmers may obtain variable results for a given technology, depending on how they implement or adapt the technology to local conditions.

Additional benefits of the combined application of farmyard manure and fertilizer have been identified elsewhere. Residual benefits (i.e., yield increases beyond the season of application) are often realized and, with a long duration of application, benefits can persist for up to eight years (Kihanda *et al*., 2006). Fields applied with about 3.5 t/ha of manure for at least two of the previous five seasons produced an additional 800 kg/ha of maize compared with fields that had manure applied less frequently (Kihara *et al*., 2015). Other known benefits of manure and compost include improved soil structure, aeration, and moisture-holding capacity, and these translate into the improved yields and profitability.

Although application of farmyard manure can increase yields, it is associated with some risk of net income loss due to the high labor costs of acquiring it and applying it to the fields. In some cases, this means the increase in yield may not be sufficiently great to offset the costs. Combining manure with industrial fertilizers eliminates the risk of loss and increases the chance of doubling the capital invested. Figure 4.8 shows the risk of a loss is high if farmers use no fertilizer, but less if they use organic manure alone, and less still if they mix the manure with industrial fertilizer.

Farmers' responses

Manure is a locally available fertilizer resource. Many farmers use their own manure and attach no monetary value to the cost of labor involved in applying it to their fields. They often collect manure out of the cropping season when they are less busy and may apply it before tilling the lands. Experience shows that it may be better to

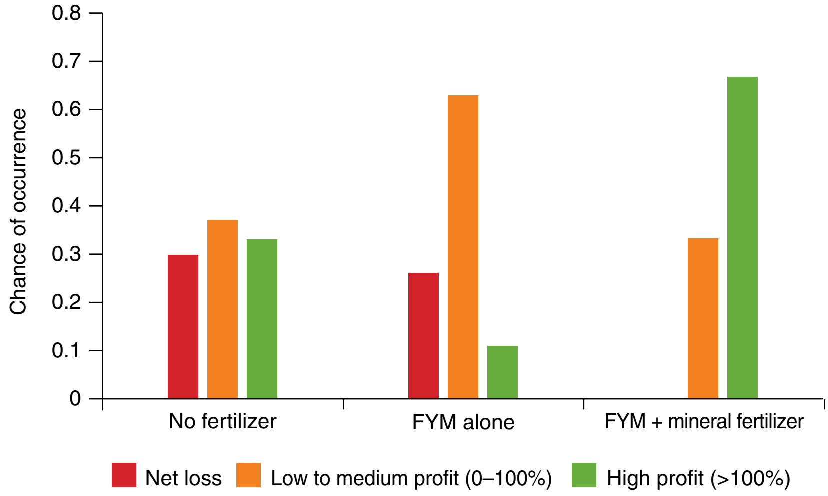

Figure 4.8. Profit levels and their chance of occurrence with and without farmyard manure (FYM) in Babati, Tanzania. In the y axis, 1 represents 100% chance of occurrence.

apply the manure at the time of planting. It is important to ensure farmers know how to make good farmyard manure/compost to maximize on yield benefits and to save cash by compensating industrial fertilizers with manures.

Making the most of organic fertilizer application

Right nutrient source: Compost and manures (particularly cattle manure) generally release nutrients into the soil more slowly than industrial fertilizers. They are therefore suitable for long-duration crops such as maize. Chicken manure releases nutrients more quickly and is therefore more suited to high-value, fast-growing crops such as vegetables.

Right rate: The quantity of compost and manure applied is normally based on the soil nutrient status, plant nutrient requirements, and the type and variety of crop, as well as the quality and availability of the manure and compost. The rate of application also depends on how often the manure is applied. Fields with a history of frequent application (every season) require less than fields that have had nothing applied for several seasons.

Right time: Because they release nutrients slowly, compost and manures are applied at the beginning of the crop cycle, at planting, or during or just before the land preparation stage. This choice depends on labor availability, volume, and quality of manure, and desired application method. Low-quality manure should be applied before planting to avoid competition for labor, especially when the planting window is short. High-quality manure should be applied immediately before sowing to prevent the nutrients being lost through leaching.

Right place: Manure of low quality can be applied by spreading followed by ploughing it under before the sowing time, banding (i.e., placing it in a line along a planting furrow), or putting it in the planting hole at planting time. With manure of high quality, e.g., poultry and goat or sheep manure, placement in the planting holes is the most appropriate solution, and especially for such crops as maize and pigeonpea, which are planted at a wide spacing (>25 cm apart). For other crops where spacing is small, banding is the most appropriate method.

Effective weed control: Timely planting allows the crop to establish early, use residual soil moisture, and outcompete weeds. Weeds compete with crops for nutrients, water, and light. The number of weeding cycles will depend on the density of weeds likely to cause crop losses. Generally, farmers should remove weeds at least twice to ensure good crop performance. Some weeds such as striga are parasitic and fertilizers can help to reduce the effects of these weeds.

Good soil fertility management also promotes plant vigor, helping crops to outcompete and sometimes even smother weeds. Weeding should be avoided if the soils are dry, since the weeds can help to protect the soil surface and prevent excessive water evaporation.

Access to knowledge: Local extension officers, agro-dealers, and seed companies can advise farmers on which varieties of maize (or other crops) are best suited to a particular location. They can also advise on the most effective way to make good-quality compost, and which industrial fertilizers are best to complement application of farmyard manure. Look out for field days, agricultural shows, and other events hosted by research institutions, seed and fertilizer companies, and other non-governmental organizations.

How to get started

- Ensure there is plenty of well-decomposed farmyard manure or compost available in advance of planting the crop.
- Never apply partially rotten farmyard manure as it may scorch young seedlings. Apply manure and compost in the right place (see above for industrial fertilizers). For large-seeded crops, apply manure in the planting hole and broadcast before planting (following the 4 'R's).
- Compost and manure must be incorporated in the soil and not left exposed to the sun or rain, since nutrients such as nitrogen will be lost to the atmosphere or leached into the soil. When applying to planting hills, bury the manure under 5 cm of soil.
- The quality of the manure or compost will determine the quantity to apply. This depends on the materials used to make the compost. Farmers can get advice from a local extension agent or, if possible, conduct chemical analysis. The quantity applied also depends on the amount of added industrial fertilizers (if any) and the nutrient demands of the target crop.
- When applying in hills, an appropriate container should be used to scoop only the right amount of manure per hill or hole. The container could be made from an old water bottle, for example.
- Some portions of the field will be more fertile than others. Target the manure or compost to the portions of the field that require it most (i.e., where yields are lower).
- It is better to apply moderate amounts of manure (about 3.5 t/ha) every season rather than larger quantities several years apart.
- Adopt good agricultural practices to derive the maximum benefits from the manure application.

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