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The U.S. Government's Global Hunger & Food Security Initiative

FERTILIZER QUALITY ASSESSMENT IN MARKETS OF KENYA

Joaquin Sanabria[1], Joshua Ariga[2], Job Fugice[1] and Dennis Mose[3]

[1] IFDC, Muscle Shoals, USA; [2] IFDC, Muscle Shoals, USA (former position) and Bill & Melinda Gates Foundation (current position); [3] IFDC, Nairobi, Kenya

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Acronyms and Abbreviations

ACTESA	Alliance for Commodity Trade in Eastern and Southern Africa
AFAP	African Fertilizer and Agribusiness Partnership
B	Boron
BWS	Bag Weight Shortage
Ca	Calcium
CAN	Calcium Ammonium Nitrate
Cd	Cadmium
CFDF	Cumulative Frequency Distribution Functions
COMESA	Common Market for Eastern and Southern Africa
CRH	Critical Relative Humidity
CRI	Coffee Research Institute
DAP	Diammonium Phosphate
EAC	East African Community
ECOWAS	Economic Community of West African States
FDF	Frequency Distribution Function
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
IFDC	International Fertilizer Development Center
K	Potassium
KEBS	Kenya Bureau of Standards
KEPHIS	Kenya Plant Health Inspectorate Service
kg	kilogram
mm	millimeter
MoALF	Ministry of Agriculture, Livestock, and Fisheries
N	Nitrogen
NAIP	National Agricultural Investment Plan
NCPB	National Cereals and Produce Board of Kenya
NPK	Nitrogen, Phosphorus, and Potassium
O	Oxygen
ooc	Out of Compliance
P	Phosphorus
ppm	parts per million
RVoC	Pre-Export Verification of Conformity
REC	Regional Economic Community
RH	Relative Humidity
TL	Tolerance Limit
USAID	U.S. Agency for International Development
Zn	Zinc

FERTILIZER QUALITY ASSESSMENT IN MARKETS OF KENYA

Executive Summary

With funding from the U.S. Agency for International Development (USAID), IFDC is conducting a series of fertilizer quality assessments in Eastern and Southern Africa. Kenya was selected to be the starting country because its large fertilizer market and complex distribution chain provide a good opportunity to test and adjust the methodology for assessment of fertilizer quality in other member states of the Common Market for East and Southern Africa (COMESA) and East African Community (EAC).

The objective of the studies is to conduct fertilizer quality diagnostics in these countries to support the development and implementation of a fertilizer trade and quality regulatory system for these regional economic communities (RECs).

In Kenya, the fertilizer quality assessment team used a random approach to select fertilizer dealers and collect samples for analysis. Data were also collected on fertilizer markets, dealers, products, and storage conditions in the country.

Diammonium phosphate (DAP), calcium ammonium nitrate (CAN), urea, NPK 23-23-0, and NPK 17-17-17 represented nearly 90% of the fertilizer samples collected, reflecting the importance of these five products in the Kenyan markets.

The diagnostic about fertilizer quality of fertilizers traded in a country or a region is based in the frequency and severity of the "out of compliance" (OOC) for individual nutrients in the fertilizers: Total nitrogen (N) OOC frequency in urea is zero while N OOC frequency for the rest of products ranges between 4% (in DAP) and 31% (in 17-17-17); available phosphorus (P_2O_5) OOC frequency ranges between 12% (in DAP) and 36% (in 17-17-17); and soluble potassium (K_2O) OOC frequency is 63% of the 17-17-17 samples. The severity of N OOC ranges between 1.5% N shortage in DAP and 4.7% N shortage in NPK 23-23-0. The severity for P_2O_5 OOC ranges between 3.3% P_2O_5 shortage in NPK 17-17-17 and 4.6% P_2O_5 shortage in NPK 23-23-0. The only K_2O shortage is 1% in NPK 17-17-17.

No fillers or foreign substances that suggest adulteration by dilution of nutrients were found, not even in rebagged fertilizers. There are anecdotal reports of adulteration in fertilizers distributed by the government subsidy program, fertilizers sampled in two NCPB warehouses did not show evidences of adulteration but more extensive sampling in NCPBs is needed to identify possible adulteration in subsidized fertilizers.

No severe degradation of the fertilizers' physical properties were identified; samples did not contain granule fines or dust in high proportions and did not have high moisture content or caking, which could produce uneven distribution of nutrients in the bags. The only plausible explanation remaining for the nutrients being out of compliance in these granulated products is that the nutrient deficiencies originated during the manufacture. The effective inspection of imported products in ports is necessary.

Liquid and crystal fertilizers have serious quality problems. All liquid fertilizers sampled and analyzed were out of nutrient content compliance for the three macronutrients. Total N shortages ranged from 3.6% to 22.5%; P_2O_5 shortages ranged from 3.8% to 18.8%; and K_2O shortages ranged from 2.2% to 19.6%. On average, the N, P, and K shortage severities in liquid fertilizers were four times higher than in the granulated fertilizers. All crystal fertilizers were out of compliance for total N and K_2O, and presented macronutrient shortages with a severity average two times higher than in conventional granulated fertilizers.

It is apparent that the crystal and liquid fertilizers do not go through a quality assurance process before going out to the markets. Despite the serious

low quality problems of crystal and liquid products, there is a market for them, primarily because of limited implementation of the existing fertilizer quality rules.

The cadmium content found in fertilizers containing P_2O_5 traded in Kenya (maximum 2.9 ppm) is well below maximum allowances recommended by Kenya (30 ppm) and international standards.

The frequency of bag weight shortages increases with fertilizer rebagging. Weight shortages were found in 14.5% of the original 50-kilogram (kg) bags, in 23.5% of the 25-kg bags, and in 33.5% of the 10-kg bags.

Lower temperatures and lower relative humidity relative to outside are needed to preserve fertilizer quality during storage, but 50% of the warehouses or storage areas in retailers' shops in Kenya do not reduce temperature relative to the temperature outside the building; similarly, 37% of the storage facilities do not reduce the relative humidity with respect to the relative humidity outside. Hot and wet storage conditions result from absent or insufficient ventilation and poor air circulation through the storage area because of limited or no use of pallets and because no space is left between bag stacks and walls and between stacks and the roof.

The majority of granulated fertilizers are bagged in impermeable bags that preserve the products from contact with water and from absorbing moisture from the environment. However, high moisture content was found in 7% of the DAP samples, 10% of the CAN samples, and 16% of the 23-23-0 samples as a result of non-impermeable bags used, torn bags, or loose bag seams in addition to the hot and moist conditions of many storage facilities.

Degradation of granular integrity of fertilizers is not a major concern in Kenya; the most widely used fertilizers had more than 90% of the material in granule sizes between 1.0 millimeter (mm) and 4.0 mm. The 15% fines (granules between 1.0 and 2.8 mm) found in urea is explained by the combined sampling of granular and prilled urea. The percentage of fines found in fertilizers was low in general, but an analysis of particle size variation against distance from the port of entrance showed increase of fertilizer fine particles as a result of transportation and the accumulation of forces exerted on the fertilizer granules when fertilizers bags are handled manually and individually along the distribution chain.

Market and fertilizer dealer characteristics may have a significant effect on the quality of fertilizers. Data from Kenya indicated that fertilizers sold in rural markets are less likely to comply with the nutrient content specified on the label than fertilizers sold in urban markets. Similarly, compliance with the nutrient content was lower in fertilizers sold in shops with only small-scale farmer customers than in shops with customers of all types of farmers and fertilizer retailers.

These results have implications for fertilizer policy, regulations, and institutional structure. First, it is important that a credible system be established to ensure more stringent pre-export verification of conformity (PVoC) carried out by reputable and internationally accredited companies. This should be followed by confirmatory inspections at the destination port, especially for products that have a history of poor quality or whose origins are suspect. Routine targeted inspections along the domestic value chain, particularly at retail, will help maintain quality; the inspections especially should capture re-bagged products, which are more likely to present nutrient and weight shortages. In addition, training of distributors and agro-dealers on best practices in handling fertilizers and maintaining appropriate storage facilities will provide further support. The capacities of agencies in charge of quality regulations, including laboratory equipment and human or technical expertise, need to be improved. Finally, it is crucial to have a mechanism in place for farmers and other stakeholders to share their complaints on quality to relevant authorities/agencies for action. Therefore, updating the current quality regulatory framework, with clear roles for relevant agencies, in addition to harmonizing regulations across countries, will support the above recommendations and increase access to quality fertilizers.

Section 1. Introduction

Twenty-six percent of the Kenyan gross domestic product and 65% of the country's export income are derived from agriculture. Agriculture provides 70% of informal employment and 18% of formal employment. The National Agricultural Investment Plan (NAIP) recognizes the important role played by fertilizers and complementary inputs in the growth of this sector (Oseko, 2014).

Kenya's fertilizer market is relatively well-developed compared to other countries in sub-Saharan Africa. It is dominated by the private sector with the government providing regulatory oversight and implementation of subsidy programs. During the 2013/14 season, an estimated 665,373 metric tons of fertilizers comprising 37 fertilizer types were consumed, valued at approximately $357 million. The fertilizer distribution chain in Kenya is composed of about 68 importers, 800 distributors, 3,000 wholesalers, and more than 8,000 retailers supplying products to a farmer population with 80% small-scale farmers (Oseko, 2014). Due to its size and complexity, this market poses a challenge to regulators because of the financial and human resource capacity required to cover the expansive territory and markets with numerous distributors and traders at several levels.

Fertilizer regulations in Kenya are under the mandate of the Ministry of Agriculture, Livestock, and Fisheries (MoALF), Kenya Plant Health Inspectorate Service (KEPHIS), and Kenya Bureau of Standards (KEBS). KEBS is charged with standardization and conformity assessment for all products while KEPHIS provides assurance on the quality of agricultural inputs and produce. The Fertilizers and Animal Foodstuffs Act, Chapter 345 (Revised 2014) regulates the importation, manufacture, and sale of agricultural fertilizers and animal foodstuffs.

There is growing recognition in Eastern and Southern Africa that existing national fertilizer policies and regulations need to be updated and harmonized. A number of countries are involved in consultations to integrate and enforce quality standards to reduce fertilizer market distortions and increase demand for fertilizer. The African Fertilizer and Agribusiness Partnership (AFAP) and other organizations continue to have consultations with the East African Community (EAC) and the Common Market for Eastern and Southern Africa (COMESA) countries on harmonizing regulations, standards, and policies. A number of groups composed of these stakeholders continue to deliberate on various issues to fulfill the harmonization objectives.

To support these regulatory reform processes in COMESA, IFDC can utilize available resources, including: (i) methodologies and lessons learned from its contributions to the establishment of a fertilizer quality regulatory framework for the Economic Community of West African States (ECOWAS) and (ii) findings from the ongoing quality assessments being conducted in the region with support from the U.S. Agency for International Development (USAID).

In early 2016, IFDC began preparations for conducting a series of fertilizer quality assessments in East and Southern African countries. Kenya, Tanzania, Zambia, Uganda, Ethiopia, and Malawi are the six countries under the USAID Feed the Future program where fertilizer quality assessments were planned. Kenya was selected for the initial assessment because its large fertilizer market and complex distribution chain provided a good opportunity to test and adjust the methodology that IFDC developed and has been applying in ECOWAS countries.

The main objective of the study conducted in Kenya was to make a fertilizer quality diagnostic that can be used as a baseline by the Kenyan government and by regional economic communities like COMESA to develop regulatory policies at national and international levels. Another objective was to start capacity building among the staff of Kenyan regulatory agencies (MoALF, KEPHIS, and KEBS) to conduct fertilizer quality assessments and to make a fertilizer quality diagnostic in the fertilizer markets of the country. The characterization of fertilizer quality conditions in individual countries is useful in quality regulatory systems that need to be harmonized across borders and domesticated to allow flexibility in implementation tailored to particular country characteristics.

1.1. Methodology for Data and Sample Collection

Before conducting the field survey to collect samples across the country, the IFDC team of experts conducted a five-day training session for fertilizer quality inspectors drawn from the relevant agencies in Kenya. This was a key activity within the fertilizer quality diagnostic involving the training of 23 inspectors on a scientific-based methodology for conducting surveys in the fertilizer markets and the analysis of data to produce reports on the quality of fertilizers. The report from this study is also intended to be used as methodological reference material by fertilizer quality inspectors.

The 23 inspectors initially trained are expected to become trainers of additional fertilizer quality inspectors that will work on Kenya fertilizer markets and activities related to the development and implementation of COMESA quality regulatory framework using scientifically based methodologies.

The team also visited a number of laboratories in these agencies and discussed with representatives their suitability for testing some of the samples to be collected from the field. This provided the opportunity to observe and learn about the capacities of these labs and some of the challenges they are facing. There are two areas that stood out from this exercise, specifically the need to improve (i) the capacity of inspectors with updated skills and knowledge on fertilizer quality principles and assessment methodologies, and (ii) the capacity of laboratories, some of which have staff with limited chemistry knowledge, outdated equipment, or instruments with limited capacity to handle a large number of samples necessary to meet deadlines in a timely manner.

The sampling methodology used is diagrammed in Figure 1. It consists of two sampling steps:

1. Random sampling of fertilizer dealers in the country. The random sampling of fertilizer dealers across the country is weighted by the size of the markets; areas with a large number of dealers contribute more to the sample than areas with a small number of dealers.

2. Random sampling of fertilizers from each of the warehouses or shops included in the sample of dealers obtained in the first step.

The weighted random sampling of dealers throughout the agricultural areas of Kenya and the random sampling of fertilizers inside dealers' shops result in the collection of data that is representative of the fertilizer quality in Kenyan markets.

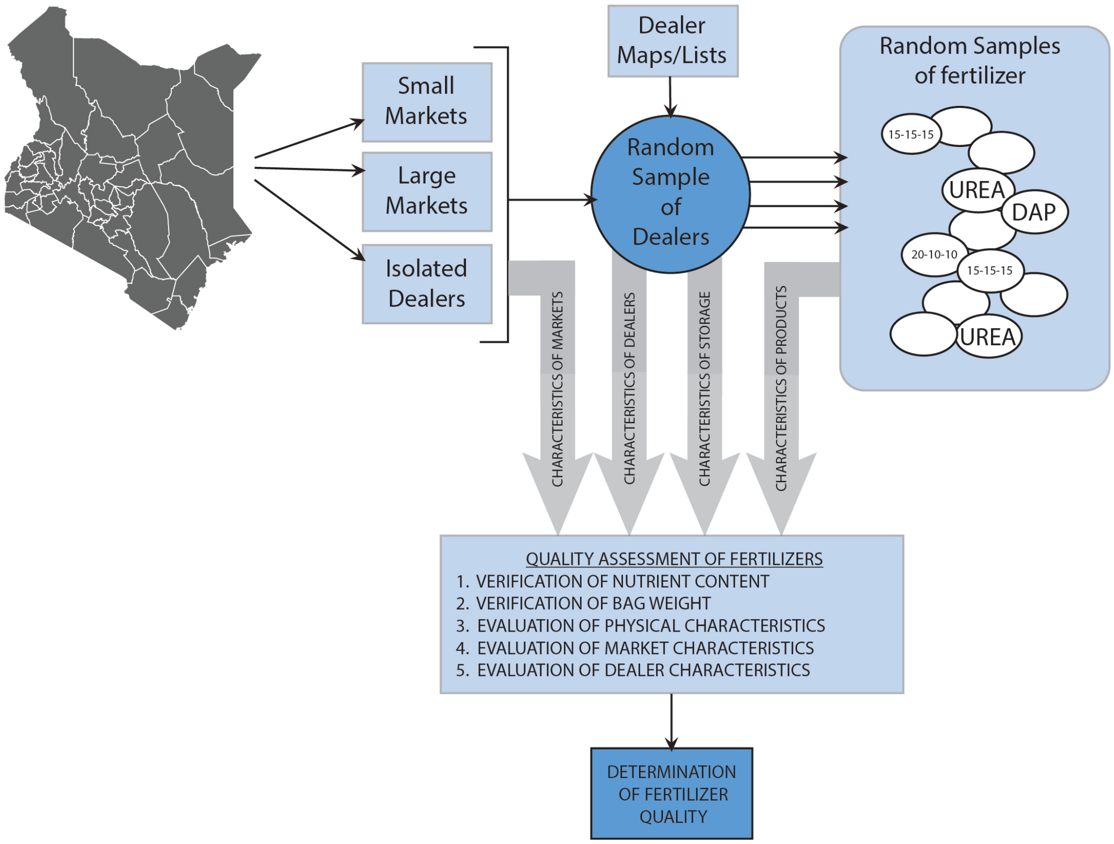


Figure 1. General Methodology for the Quality Assessment of Fertilizers Commercialized in Kenya

Collection of data about characteristics of fertilizer markets, dealers, fertilizer products, and storage conditions is performed in parallel with the fertilizer sampling.

Results from lab analysis and data collected in the field allow researchers to determine the quality status of every fertilizer sample and to identify internal (fertilizer properties) and external (not fertilizer properties) factors that influence the quality of the fertilizers commercialized in Kenya.

1.1.1. Sampling of Fertilizer Dealers

A list of 3,244 agro-dealers provided by the MoALF headquarters was the basis to define a conceptual population of fertilizer dealers in the country. The original list experienced substantial dealer substitutions in provinces where other agro-dealer lists were available from local Ministry officials. The fertilizer dealer sample size was determined based on the sampling capability of eight inspection teams, which depended on the net number of sampling days – discounting travel days – and the number of dealers that teams were able to visit in a day; this depended on the density distribution of the dealers in the markets and the distances between dealers. The random process for selecting the sample portion for each inspection team was weighted per the number of dealers in each province, meaning that the regions with a higher number of dealers will be represented by a higher number in the sample than regions with a smaller number of dealers. The random sample included 196 fertilizer dealers, equivalent to 6% of the population of dealers. Each agro-dealer in the sample was visited by an inspection team who conducted sampling of the fertilizers available in the shop and collected data. Every sampling team received a list containing the sample of dealers assigned to the team and an additional set of dealers, also randomly selected, to substitute dealers from the sample that could not be found or that did not have fertilizers available for sampling at the time of the inspectors' visit.

1.1.2. Random Sampling of Fertilizers and Collection of Data in Each Sample Dealer Shop

The inspection teams collected fertilizer samples following the sampling procedures specified in Appendix A and collected data about the following aspects using procedures outlined in Appendix A.

- Market location and characteristics of the market: country, province, county, town, market name, type of market, concentration of dealers, market location (see Table A1 in Appendix A). The market type is either rural or urban. A market is rural when it is located in an area with a population equal or fewer than 20,000 habitants; otherwise, it is urban. The concentration of dealers can be high, low, or isolated, depending on the number of dealers in the market and the distance between them. The location of the market can be permanent or itinerant.

- Identification and characteristics of the dealer: fertilizer shop owner's or shop attendant's knowledge about fertilizers, training about fertilizer, possession of license, type of customer, and business status (see Table A2 in Appendix A). The answer options in the questionnaire are intuitive, with the exception of the shop owner's or shop attendant's knowledge about fertilizers. This information must be deduced by the inspector from observing the dealer without asking the dealer about his/her knowledge of fertilizers.

- Characteristics of storage: approximate dimensions of the warehouse or shop storage area, qualitative assessment of ventilation, measurement of temperature and relative humidity outside and inside the building or warehouse, fertilizer handling equipment, use of pallets, height of stacks, general housekeeping (see Table A3 in Appendix A).

- Characteristics of fertilizer products: grade, lot, type, blend/compound, bag characteristics, bag weight, bottle characteristics, evidence of quality problems (see Table A4 in Appendix A). Detailed information about the data collection in this table is provided in the data collection and sampling protocol in Appendix A.

- Physical attributes: segregation, granule integrity (fines and dust), presence of filler and impurities, caking, moisture content (see Table A5 in Appendix A). A detailed description of fertilizer physical properties and methods for assessment of physical properties are found in Appendix B.

In each of the distribution points visited, fertilizer products were sampled, labeled, and packed using the sampling protocol described in Appendix A.

1.2. Chemical and Physical Analyses of Fertilizer Samples

1.2.1. Chemical Analysis of Fertilizers

Three laboratories – KEPHIS, KEBS, and the Coffee Research Institute (CRI) laboratory –were visited to observe their equipment, learn about their analytical methodologies and their experience analyzing fertilizers, and observe the capacity of the staff. If these aspects were satisfactory, the lab was given four blind samples to analyze. Based on the reported results from the blind samples, the CRI laboratory was selected to conduct the analysis of fertilizer samples. Duplicate samples were also analyzed by the IFDC laboratory in Muscle Shoals, Alabama, USA.

Nutrients determined were total nitrogen (N), available phosphorus (P_2O_5) and soluble potassium (K_2O). Fertilizer samples in which sulfur (S), calcium (CaO), zinc (Zn), and (B) contents were reported were also analyzed for these nutrients.

Analysis of cadmium (Cd) was performed in a group of fertilizers containing P_2O_5 based on concerns about the natural content of Cd in phosphate deposits and the potential of heavy metal accumulation in soils as fertilizers are applied season after season. Results of Cd concentration in fertilizers were expressed as milligrams cadmium per kilogram of available phosphorus (mg Cd kg^{-1} P_2O_5) in order to be compared with international reports in the literature.

Analysis methodologies used at the IFDC laboratory were: Combustion Analysis for total N and S, Spectrophotometric Analysis for P_2O_5, and Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) for K_2O, CaO, Zn, B, and Cd.

1.2.2. Physical Analysis of Fertilizers

The assessment of the physical properties of fertilizers was conducted as specified in Appendix B. Data were recorded in Table A5.

1.3. Data Analysis and Interpretation

1.3.1. Nutrient Content Compliance

Total N, P_2O_5, and K_2O content in solid compound fertilizers must have a maximum lower limit of 1.1% as established by the Kenya Standard 158 of 2011.

The same standard establishes minimum content limits for secondary and micronutrients as indicated in the following table:

Nutrient	Minimum Tolerance (%)
Sulphur	1.0
Calcium	1.0
Magnesium	0.6
Boron	0.02
Cobalt	0.0005
Copper	0.05
Iron	0.1
Manganese	0.05
Molybdenum	0.0005
Zinc	0.05

Frequency analysis was used to estimate the frequency of out of compliance of total N, P_2O_5, K_2O, and CaO content. The severity of nutrient content shortages was estimated as the average content of the samples out of compliance. For micronutrients and secondary nutrients other than Ca, the frequency of out of compliance could not be determined due to an insufficient number of samples for the fertilizers that reported secondary or micronutrient content.

Cumulative Frequency Distribution Functions (CFDF) were used with quantitative continuous variables such as the nutrient content of fertilizers and the fertilizer Bag Weight Shortage (BWS). The CFDF is used to establish the frequency of occurrences relative to a reference point; the reference point used in the analysis of nutrient content compliance is the Tolerance Limit (TL) established for a nutrient or group of nutrients by the regulators and for the TL of bag weight shortage.

The CFDF is depicted by a continuous ascending line in a coordinate system in which the nutrient contents resulting from chemical analysis or the bag weight differences are in the abscissa and the cumulative frequencies of occurrence (percent) are in the ordinate. The dotted lines on the CFDF indicate the percentage of samples associated with the values for total N, available P_2O_5, or soluble K_2O content or bag weights that are below the TL. Figure 5 through Figure 12 are CFDFs.

The out-of-compliance frequency for a particular fertilizer and nutrient is established determining the frequency associated with nutrient values lower than the TL using the CFDF equation:

$F(X \leq x) = f$

Where **F** is the CFDF.

X is the variable associated with a nutrient or weight difference

x = nutrient content in label – TL – 0.1

(A nutrient content is out of compliance when it has a deficit of at least TL + 0.1)

f is the frequency of the nutrient content out of compliance.

Example: The frequency of total N out of compliance in DAP (Figure 5A) is:

$F(N_{DAP} \leq 18 - 1.1 - 0.1) =$
$F(N_{DAP} \leq 16.8) = 4\%$

1.3.2. Bag Weight Verification

Prior to sampling each fertilizer product in a shop or warehouse, a bag was randomly selected to be weighed for the verification of the weight declared on the fertilizer label. The weight reported on the label and the weight obtained from the scale are recorded in two separate columns in the survey questionnaire (Table A4), and the data were used for development of the weight CFDF. The CFDF graphs have the Bag Weight Shortage (BWS) in the abscissa and the cumulative frequency (percent) in the ordinate. The frequency of BWS was determined using the following general expression:

$$F(BWS \leq -1\%) = f$$

In Figure 11, for example, it can be established that the frequency of bags with shortages higher than 1.0% of the bag weight is 19%.

1.3.3. Evaluation of Fertilizer Physical Properties, Characterization of Markets and Dealers, and Qualitative Storage and Packing Conditions

Given the discrete or categorical nature of some of the fertilizer physical property variables, such as caking or moisture content, as well as the characteristics of markets, dealers, and some of the storage and packing characteristics, the frequencies associated with the different categories of these discrete variables were obtained directly from the Frequency Distribution Function (FDF). Figures 3 and 4 and Figures 13 through 18 are FDFs. In Figure 3A, for example, the frequency of rural markets is 60%.

1.3.4. Factors Influencing Fertilizer Quality

The factors that have the potential to affect the chemical and physical properties of fertilizers can be classified as internal and external factors. Some of the internal factors are themselves fertilizer characteristics, such as physical properties that are expected to influence the fertilizers' nutrient content compliance, or factors related to the environment (storage) where fertilizers are located. External factors like characteristics of markets and dealers have an indirect effect on fertilizer quality; the potential effect of these types of factors on fertilizer quality is associated with behaviors of dealers and consumers based on their knowledge about fertilizers and the location of the markets and shops. Internal factors have a high likelihood of influencing the physical and chemical properties of fertilizers while external factors have a potential effect on fertilizer quality; a potential effect means that such impact may or may not occur.

Relationships tested were:

- Effect of physical properties on nutrient content compliance.
- Effect of storage conditions on nutrient content compliance.
- Effect of market characteristics and dealer characteristics on nutrient content compliance.
- Effect of storage conditions on fertilizer physical properties: moisture content, caking, and granule integrity.

The relationships enumerated above were tested with logistic regression models (Stokes et al., 2009). The response variable in the models associated with the three initial relationships was nutrient content compliance, and the explanatory variables were the set of physical properties, the set of storage characteristics, and the set of market and dealer characteristics, respectively, for the three initial relationships.

The nutrient content compliance was transformed into a binomial variable with values "Yes" and "No"; the variable was "Yes" when the nutrient content values (either N, P_2O_5, or K_2O) were equal to or higher than the Tolerance Limit, and the variable became "No" when the nutrient content values were lower than the Tolerance Limit. A global nutrient content compliance was also created; it took the value "Yes" when the compliance for the three macronutrients was "Yes" and took the value "No" when at least one of the macronutrients had "No" compliance.

Then, models of the nutrient content compliance as a function of physical properties, storage conditions, and market and dealer characteristics were fit and the parameters were estimated with the maximum likelihood estimation method. Significant tests for parameters associated with the explanatory variables were conducted to determine whether a variable was influential in the nutrient content compliance. Odds ratios were calculated to estimate the influence magnitude of the significant variable on the nutrient content compliance. In Table 5, for example, the odds ratio associated with fertilizer buyers indicates that the odds of global nutrient content compliance are 3.27 times higher when the fertilizer buyers are "all types of farmers + retailers" than when the fertilizer buyers are "only small-scale farmers."

To test the last relationship enumerated above, a response variable for each of the physical properties was made up; the values of the response variable were the categories of each physical property. Then, models were fit and tested as described in the previous paragraph.

Section 2. Results

2.1. Distribution of Fertilizer Samples

The distribution of fertilizer types sampled is shown in Figure 2A. The distribution of the 585 fertilizer samples collected is shown in Figure 2B; this distribution is expected to reflect the dominant fertilizer types and fertilizer products in the markets of Kenya. The market importance pattern of the five most important fertilizers in Figure 2 follows the same pattern of fertilizer consumption in 2013 reported by Oseko (2014). The conventional granulated fertilizers account for 96% of the fertilizers in the market, and the crystal and liquid fertilizers account for 2.4% and 1.6%, respectively, of the fertilizers traded in the country. The fertilizers in crystalized and liquid forms are used primarily in the production of vegetables through foliar application or fertigation.

Among the granulated fertilizers, the most common product is DAP, which represents 46% of the products in the market. Urea follows with 23%, CAN with 13%, 23-23-0 with 7%, and 17-17-17 with 5%. The rest of the fertilizers in Figure 2B include a few granulated products and the majority of the crystal and liquid fertilizers found in the markets; only one or two samples of each of these remaining products were collected.

2.2. Characterization of Fertilizer Markets and Fertilizer Dealers

The characteristics of fertilizer markets and fertilizer dealers can have an indirect effect on the quality of the fertilizers traded. Fertilizers' chemical and physical properties and storage conditions have a direct effect on fertilizer quality. The type of market, either rural or urban (Figure 3A); the market location, either itinerant or permanent (Figure 3B); and the concentration of dealers in the markets – high, low, or isolated – (Figure 3C) can influence the quality of the fertilizers found in the markets. The rural markets, itinerant markets, and markets with isolated dealers are expected to have fertilizer quality problems with higher frequency and higher severity than urban markets, permanent markets, and markets with a high concentration of dealers. Rural markets, itinerant markets, and isolated dealers have three characteristics associated with fertilizers of low quality: less observation from regulatory authorities, less competition, or no competition, between dealers, and less or no freedom of choice for farmers to select dealers and/or fertilizers.

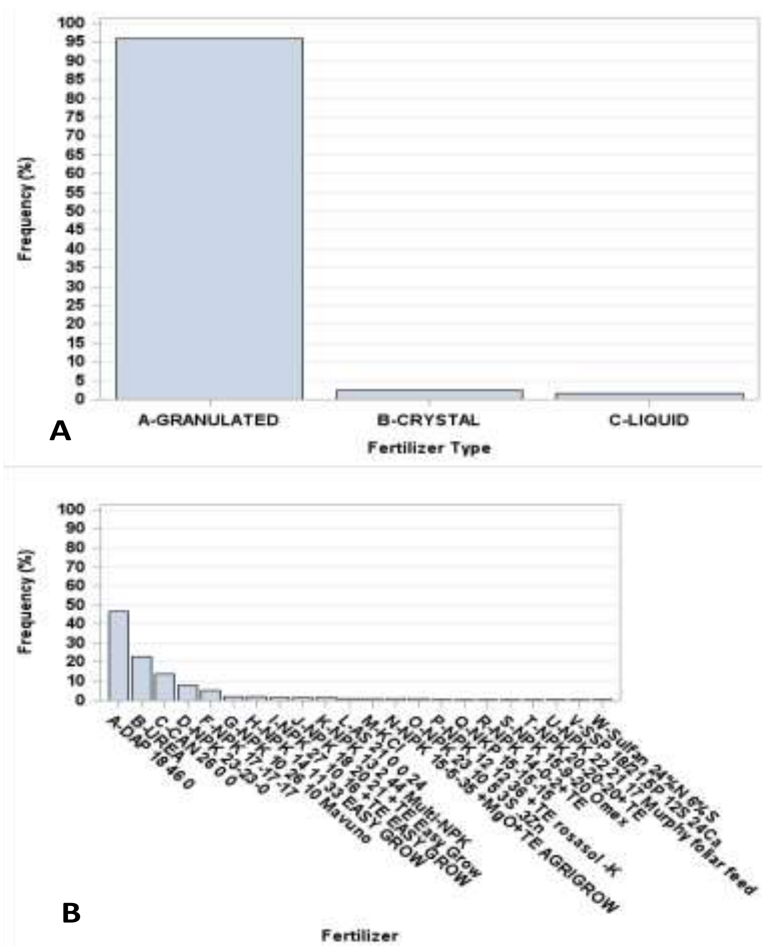


Figure 2. Distribution of Fertilizers Types (A) and Distribution of Fertilizer Products Sampled (B)

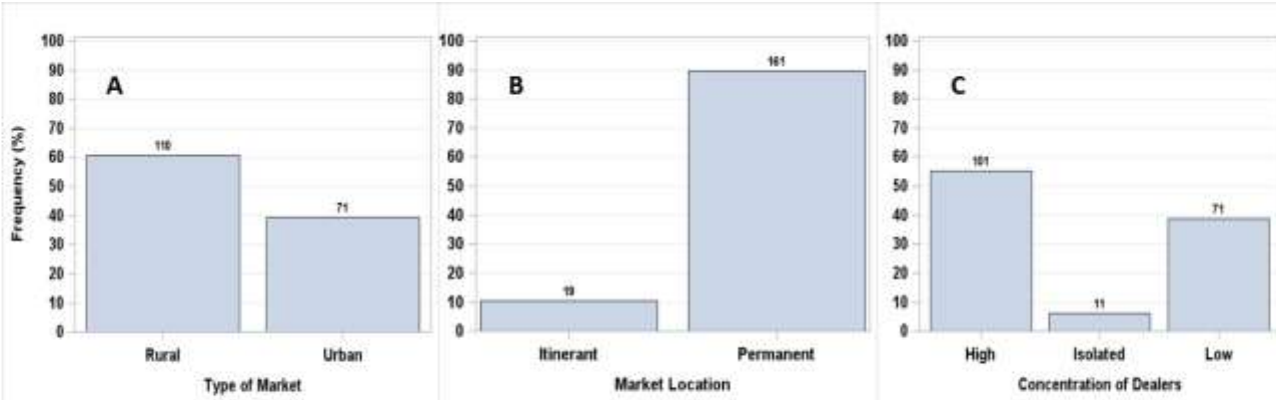


Figure 3. Frequency Distribution of Fertilizer Market Characteristics

In Kenya, 60% of the markets are rural, because they are located either in the countryside or in small towns. The remaining 40% are urban, located in large towns or cities (Figure 3A). Ninety percent of the markets are permanent and 10% are itinerant (Figure 3B). Fifty-five percent of the markets have a high concentration of dealers, 39% have low concentration, and 6% are isolated or located outside markets, such as beside roads, trails, or rivers where farmers can buy fertilizers while traveling.

Some fertilizer dealer characteristics also have the potential to affect the quality of fertilizer in an indirect way. One is the degree of the dealer's knowledge about fertilizers, including understanding the association between the chemical and physical properties of fertilizers and their nutritional characteristics and also understanding the appropriate environmental and management conditions necessary for the conservation of the chemical and physical properties of the fertilizers (Figure 4A). In Kenya, 35% of the fertilizer dealers have limited or no knowledge about fertilizers (Figure 4A); 34% have not received training about fertilizers; 83% are small retailers; and 70% sell mainly to small-scale farmers.

Dealers' access to training also could affect the quality of the fertilizers that the dealer sells (Figure 4B). A dealer with limited or no knowledge about fertilizers would not be able to distinguish high quality products from low quality products when purchasing them from manufacturers, importers, wholesalers, or other retailers. This type of dealer also has greater potential to mismanage the fertilizers in his/her store or warehouse in ways that degrade the physical and/or chemical properties of the fertilizers. Similarly, dealers that have not had an opportunity to receive training about fertilizer quality are more likely to purchase poor quality fertilizers or mismanage fertilizer products.

The status of the dealer either as a wholesaler, as a retailer, or as both wholesaler and retailer can affect the quality of the products found in his/her shop or warehouse (Figure 4C). Retailers are more likely to distribute products of substandard quality than wholesalers. Smaller retailer enterprises are more likely to sell low quality fertilizer. This phenomenon may be explained by three factors. First, the retailer is located at a low point in the distribution chain and receives products that have passed through several hands, which raises the possibility of the products experiencing changes (some of them can be intentional to cause adulteration) that degrade their physical and/or chemical characteristics. Second, retailers have customers that are less likely to demand higher quality standards compared to wholesalers' customers. Third, unlike wholesalers, retailers are less likely to interact directly with importers who may share some knowledge on how to maintain the quality of fertilizers.

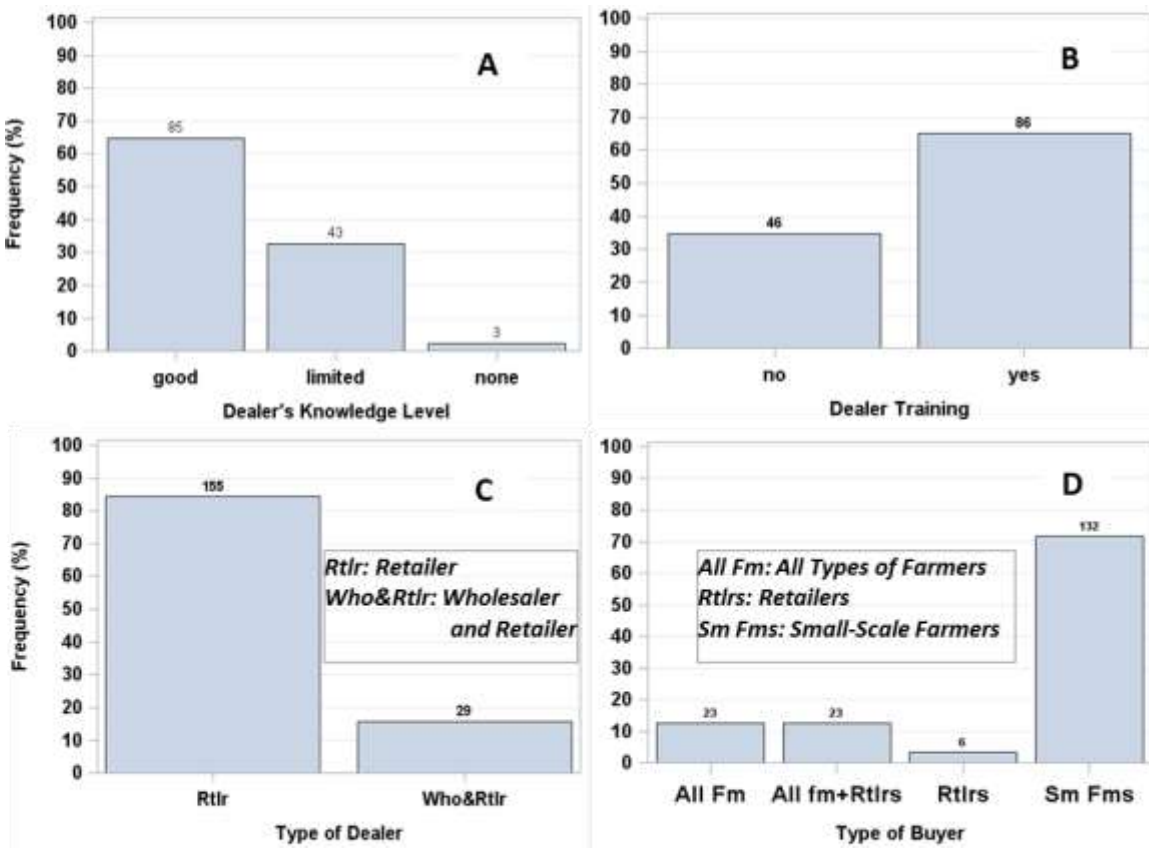


Figure 4.   Frequency Distribution of Fertilizer Dealer Characteristics

The type of customers can be very influential on the quality of fertilizers traded by the dealer (Figure 4D). Dealers that sell fertilizers mainly to small-scale farmers are more likely to trade fertilizers with quality problems than dealers that sell to commercial farmers, to all types of farmers, or to retailers. Small-scale farmers are less quality demanding than commercial farmers or fertilizer retailers.

Statistical associations of the market and dealer characteristics with nutrient content shortages in the fertilizers and with degradation of the physical properties of the fertilizers are tested in section 2.10 of this report.

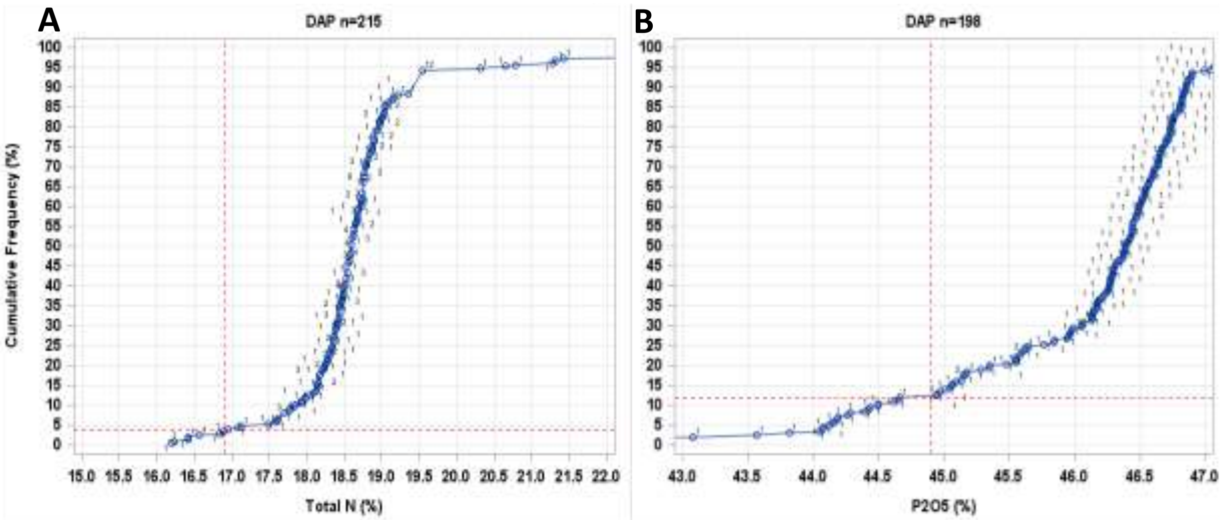


Figure 5. Cumulative Frequency Distributions for Total Nitrogen and P_2O_5 Content in DAP. Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary

2.3. Nutrient Content Compliance of Granulated Fertilizers

2.3.1. Diammonium Phosphate (DAP)

The tolerance limit for total N and P_2O_5 content in DAP is 1.1%. Eight samples, or 4% of the DAP samples, were out of compliance with respect to total N content; the average total N deficiency was 1.5% (Figure 5A). Twenty-two samples, or 12% of the samples, were out of compliance with respect to P_2O_5 content; the average P_2O_5 shortage was 4.3% (Figure 5B). The main sources of variability associated with the nutrient content in DAP are the random variability associated with the addition of nutrients to the DAP granule during manufacture, the physical and chemical transformation of the fertilizer along the distribution chain, and the random variability associated with chemical analysis in the laboratories. Among the 207 DAP samples collected in the markets, the fertilizer quality inspectors did not find any evidence of adulteration, such as presence of foreign materials that may suggest nutrient dilution; physical properties were not altered as a result of product handling along the distribution chain to the point of causing uneven nutrient distribution inside the bags; and the random variability connected to the chemical analysis in IFDC labs is known to be near negligible. Considering these factors, the most likely explanation for the nutrient shortages identified in the DAP samples is the variability associated with nutrient addition to the fertilizer granule during manufacture.

2.3.2. Calcium Ammonium Nitrate (CAN)

Tolerance limits for total N and CaO contents in CAN are 1.1% and 1%, respectively. There were nine samples, or 14% of the CAN samples, out of compliance for total N content. The average total N shortage was 4.4% (Figure 6A). Only one sample, or 2% of the CAN samples, was out of compliance with respect to the CaO content (Figure 6B). There was no evidence of severe physical property degradation or adulteration that may affect nutrient content in the CAN bags, leaving the manufacturing processes as the most likely explanation for the 14% out of compliance for total N.

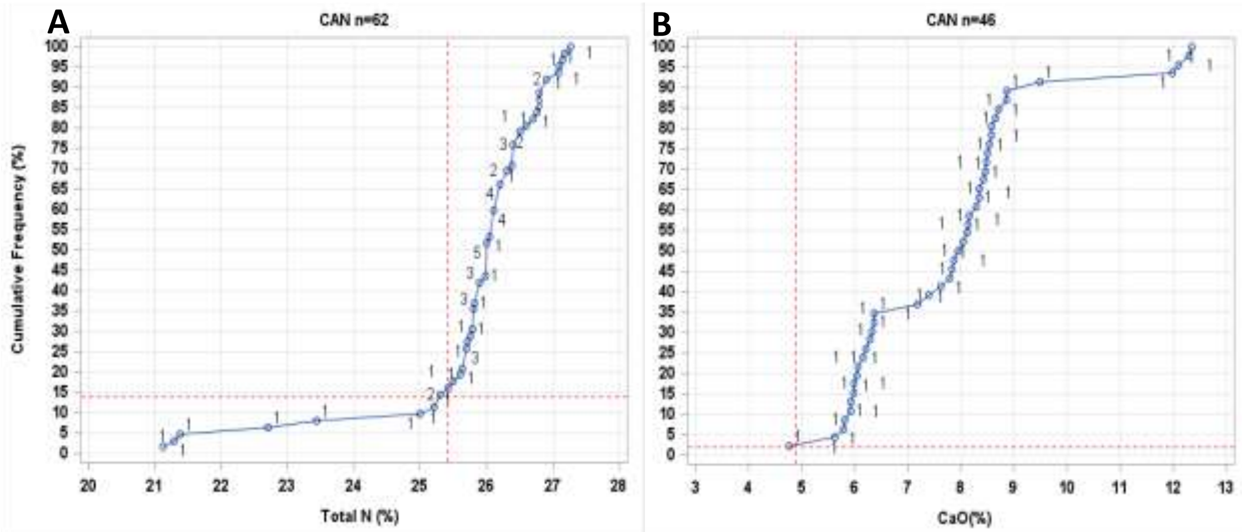


Figure 6. *Cumulative Frequency for Total Nitrogen and CaO Content in CAN Fertilizer. Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary*

2.3.3. NPK 23-23-0

The tolerance limit for total N and P_2O_5 contents in the NPK 23-23-0 fertilizer is 1.1%. Four samples, or 12% of the 23-23-0 samples, were out of compliance for the total N content. The average total N shortage was 4.7% (Figure 7A). Eight samples, or 23% of the 23-23-0 samples, were out of compliance for P_2O_5 content, and the average P_2O_5 shortage was 4.6% (Figure 7B). The lack of evidence for nutrient content reduction in the analyzed samples due to adulteration or degradation of physical properties suggests that the nutrient content shortages of NPK 23-23-0 are the result of insufficient control in the manufacturing processes.

2.3.4. Urea

The frequency distribution of the total N content of urea is expected to be asymmetric, as in Figure 8. It has more total N values higher than 46% than values lower than 46%. One explanation for values higher than 46% is the presence of Biuret (a double urea molecule) formed during the manufacture as an impurity that can increase total N content by around 1%. On the other hand, the most reasonable explanation for the total N values lower than 46% is an error from the chemical analysis. Figure 8 shows that the analytical error is near 0.5% of total N content.

Based on the above analysis, all 35 samples of urea are in compliance with total N content. Some international norms on total N content in urea use a tolerance limit of 0.5% due to the expected random error associated with the chemical analysis.

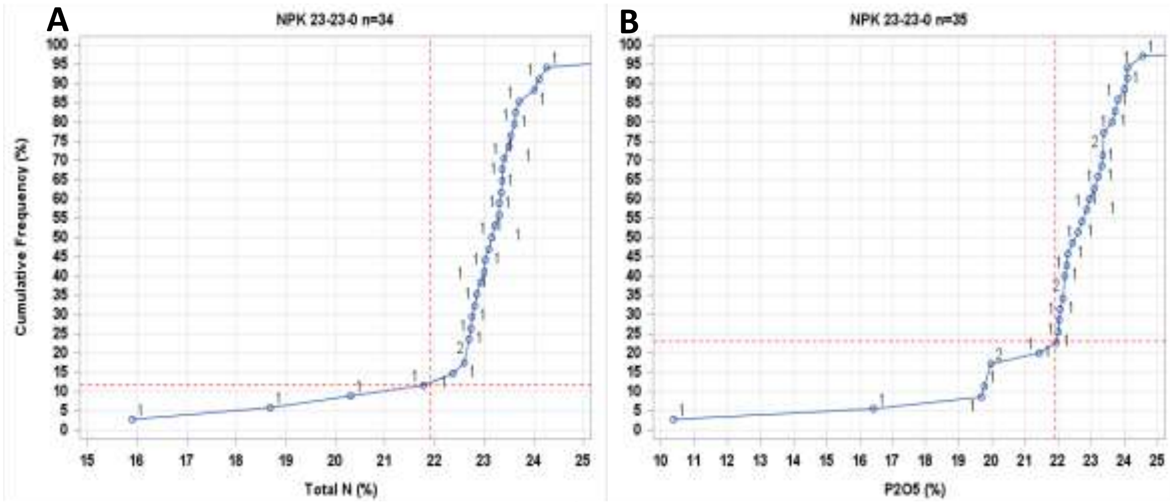


Figure 7. Cumulative Distribution Frequency of Total N and P_2O_5 Content in the NPK 23-23-0 Fertilizer. Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary

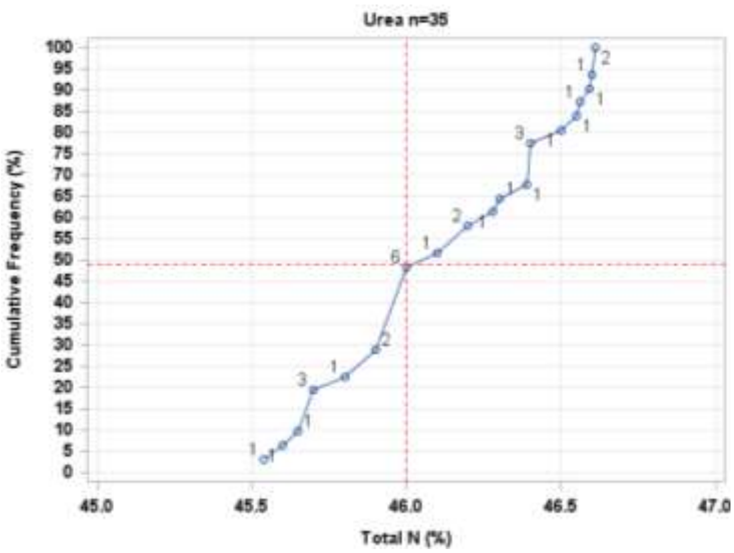


Figure 8. Cumulative Frequency Distribution for Total N Content in Urea.

2.3.5. NPK 17-17-17

The tolerance limit for total N, P_2O_5, and K_2O content in NPK 17-17-17 is 1.1%. Seven samples, or 31% of the 22 samples collected, were out of compliance for total N; the average total N shortage was 3.3% (Figure 9A). Eight samples, or 36% of the 22 samples collected, were out of compliance for P_2O_5 content; the average P_2O_5 shortage was 3.3% (Figure 9B). Fourteen samples, or 63% of the 22 samples, were out compliance for K_2O content in the NPK 17-17-17 fertilizer; the average K_2O shortage was 2.4% (Figure 9C). No evidence of adulteration, such as the presence of fillers, impurities, or rebagging, were found among the 22 samples. The minor degradation of physical properties (moisture content and granule degradation) does not align with the high frequency of nutrient deficiencies in the fertilizer. The small sample size (22 bags) of this fertilizer may have led to an overestimation of the percentage of bags out of compliance for the three nutrients. However, the frequent nutrient shortages identified in NPK 17-17-17 still indicate problems likely associated with the manufacture of the fertilizer, which is imported mainly from Eastern European countries.

2.3.6. NPK 10-26-10

The bulk blend NPK 10-26-10 was the only bulk blend fertilizer found in this survey. The tolerance limit for total N, P_2O_5, and K_2O content is 1.1%. From the nine samples collected, none presented total N content shortages (Figure 10A); only one sample was out of compliance for P_2O_5 content (Figure 10B), and two samples were out of compliance for K_2O content (Figure 10C). Three samples were processed with the sieve box method to estimate granule segregation, low quantities (<5%) of fines from KCl were detected.

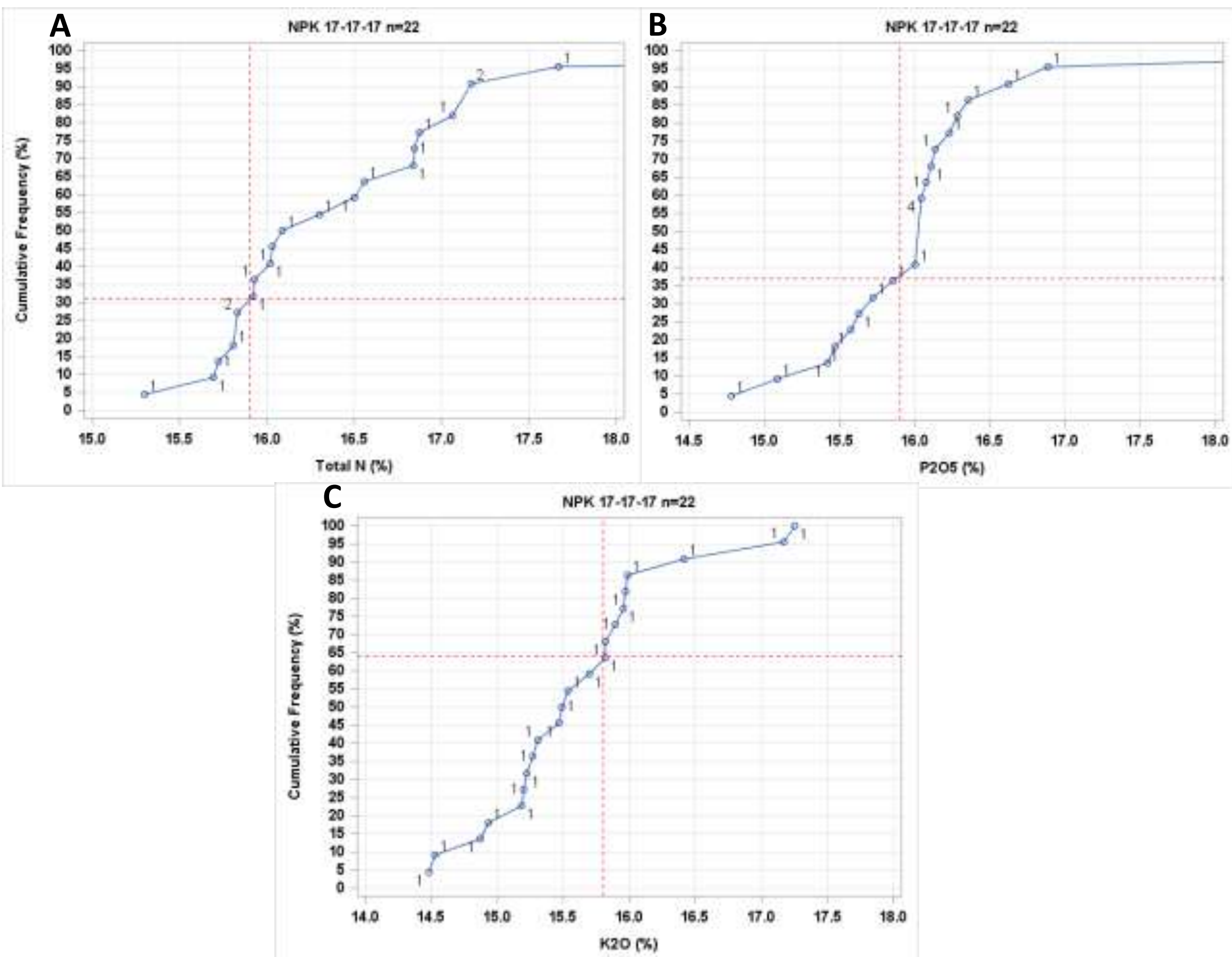


Figure 9. Cumulative Frequency Distribution for Total N, P_2O_5, and K_2O Content of NPK 17-17-17 Fertilizer. Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary

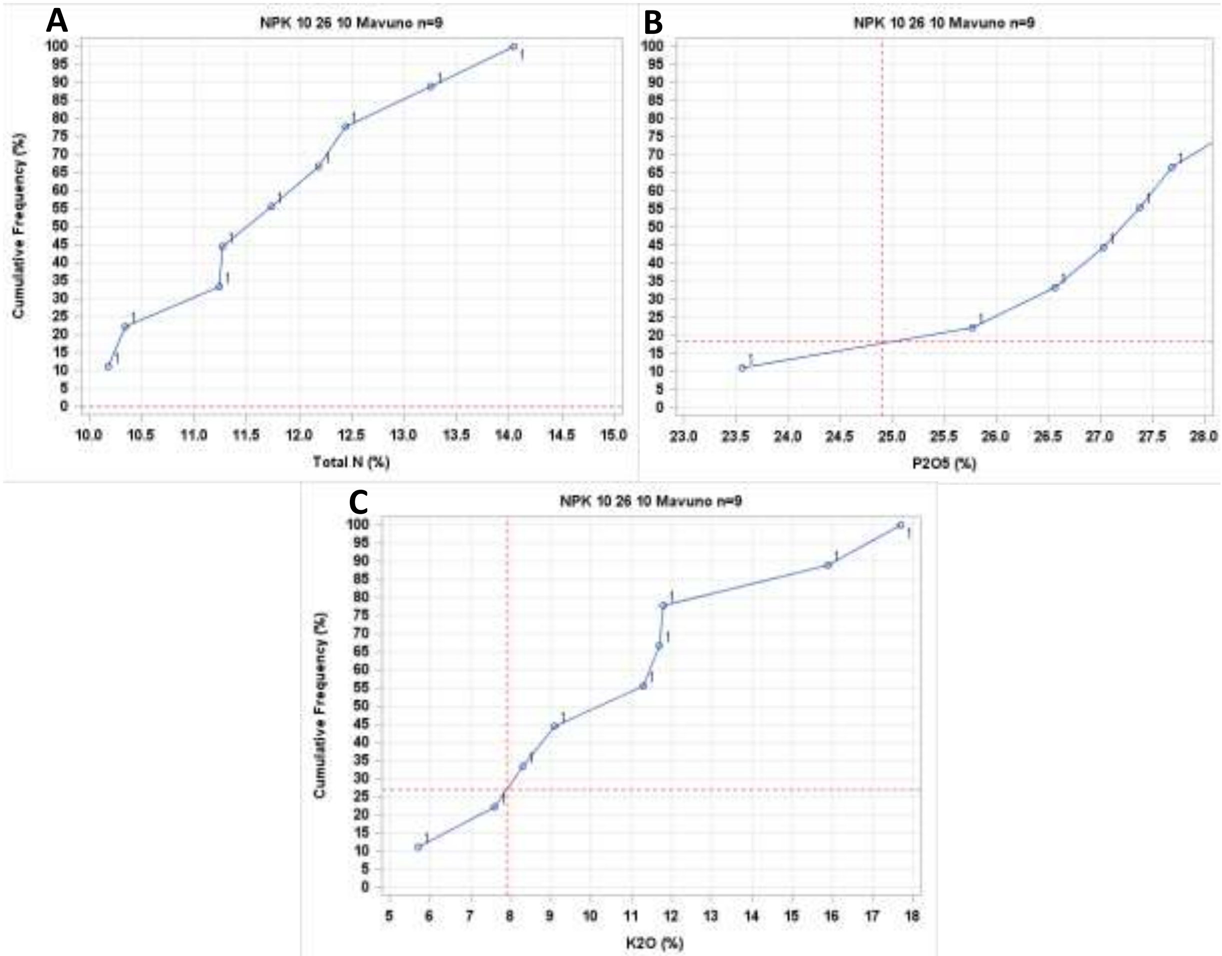


Figure 10. ***Cumulative Frequency Distribution for Total N, P_2O_5, and K_2O Content in the NPK 10-26-10 fertilizer. Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary***

Table 1. Compliance Analysis for Total N, P_2O_5, and K_2O Content in Crystal and Liquid Fertilizers

		Total N			P_2O_5			K_2O		
TYPE	FERTILIZER	n Samples	% ooc[1]	Shortage Mean (%)[2]	n Samples	% ooc[1]	Shortage Mean (%)[2]	n Samples	% ooc[1]	Shortage Mean (%)[2]
CRYSTAL	NPK 14-11-33 EASY GROW	8	50	-1.5	38	3	-1.9	8	88	-2.6
	NPK 27-10-16 +TE EASY GROW	7	71	-2.3	29	2	-3.4	7	86	-2.2
	NPK 18-20-21 +TE EASY GROW	6	67	-2.3	17	1	-9.5	6	67	-1.7
	NPK 13-2-44 Multi-NPK	5	20	-2.8	0	0	0.0	5	40	-1.4
	NPK 15-5-35 +MgO+TE AGRIGROW	4	25	-7.6	0	0	0.0	4	50	-4.1
	NPK 15-9-20 Omex	2	50	-1.5	0	0	0.0	2	0	0.0
LIQUID	NPK 12-10-8 + TE AGROFEED	5	100	-3.6	80	4	-4.3	5	100	-3.2
	NPK 20-20-20 Diamond Plant	5	100	-9.1	100	5	-11.3	5	100	-14.3
	NPK 10-10-10 Crop Sta	3	33	-5.4	0	0	0.0	3	67	-3.1
	NPK 14-12-8 Booster Extra Foliar Feed	3	67	-8.7	67	2	-9.8	3	100	-4.2
	NPK 22-21-17 Murphy Foliar Feed	2	100	-4.3	100	2	-3.8	2	100	-2.2
	NPK 25-5-5 +Na+Se Booster	2	100	-22.5	100	2	-4.8	2	100	-4.3
	NPK 12-10-8 Osho Agrofeed	2	100	-6.3	50	1	-9.8	2	100	-4.8
	NPK 19-19-19 +Te Super Nguvu	2	100	-18.6	50	1	-18.8	2	100	-18.8
	NPK 19-19-19 Tomex	2	100	-10.7	100	2	-11.5	2	100	-15.4
	NPK 19-19-19 Laibuta	2	100	-16.4	100	2	-18.2	2	100	-16.7
	NPK 22-20-20 Beta Booster	2	100	-21.1	100	2	-19.5	2	100	-19.6

[1] Out of Compliance. [2] Tolerance Limit is 1.1%.

2.4. Nutrient Content Compliance of Crystal and Liquid Fertilizers

All crystal fertilizers analyzed presented total N shortage means larger than the tolerance limit of 1.1% (Table 1). The departures from the tolerance limit range from 0.4% for NPK 14-11-33 Easy Grow and NPK 15-9-20 Omex to 6.5% for NPK 15-5-35+MgO+TE Agrigrow. The percentage of crystal fertilizer samples out of compliance for total N range from 20% to 71%. The three crystal fertilizers with P_2O_5 content lower than 10% showed no P_2O_5 shortages while the other three fertilizers presented P_2O_5 shortages with departures from the tolerance limit (1.1%) ranging from 0.8% to 8.4% P_2O_5. The percentage of samples out of P_2O_5 compliance ranged from 1% to 3%. Only NPK 15-9-20 Omex showed no shortages of K_2O content; all other crystal fertilizers had K_2O shortages that departed from the 1.1% tolerance limit ranging from 0.3% to 3.0% K_2O. The percentage of samples out of K_2O content compliance ranged from 40% to 88%.

Macronutrient content shortages in liquid fertilizers were far more prevalent than in the crystal fertilizers, both in terms of severity and frequency. Total N content shortages ranged from 2.5% to 21.4% total N, and the percentage of samples with total N shortages was 100% in nine of 11 fertilizer products analyzed. P_2O_5 content shortages ranged from 0% to 18.4% P_2O_5, and the percentage of samples with P_2O_5 content shortages was 100% in six of the 11 fertilizers. K_2O content shortages had a severity that ranged from 1.1% to 18.5% K_2O content shortage. Ten of 11 fertilizer products showed K_2O content out of compliance in 100% of the samples.

Table 2. Severity of Macronutrient Shortages per Type of Fertilizer

		Shortage Mean (%)		
Fertilizer Type	**n Samples**	**Total N**	**P_2O_5**	**K_2O**
GRANULATED	384	-2.5	-4.9	-3.0
CRYSTAL	32	-5.8	-10.8	-3.2
LIQUID	30	-11.2	-13.4	-12.4

The severity of nutrient shortages in liquid fertilizers is about three times higher than in granulated products for total N and P_2O_5 and four times higher for K_2O. Crystal fertilizer shortages are two times higher than the granulated products for total N and P_2O_5. The imported granulated products go through some type of quality control during the manufacturing process and then at least one additional control at the entrance to Kenya in an attempt to comply with country regulations. In contrast, it is unknown whether there is quality control during the local manufacture of crystal or liquid products, and there are no regulations for the quality control of these two types of fertilizers either during manufacturing or during distribution through the markets.

Manufacturers and distributors of liquid and crystal fertilizers in Kenya still have a market for their products, despite the bad quality, because of two factors: the lack of quality assurance regulation/implementation and lack of farmer knowledge. Farmers, in most cases, do not know if crystal or liquid fertilizers are actually working for their crops because these products are mainly applied to complement basic fertilization with conventional granulated products. The farmers can mistake the response due to the basal granulated fertilizers with the expected response from liquid or crystal fertilizers, which in many cases have limited or no nutritional value.

Secondary and micronutrients were not analyzed in either crystal or liquid fertilizers because these nutrients are not reported on fertilizer labels for these two types of fertilizers. Occasionally, some labels of crystal or liquid fertilizer display the symbol "TE" to indicate that the product contains trace elements, but the type of micronutrient and the quantity present are not specified.

The frequency and severity of out-of-compliance nutrient content for all fertilizers sampled in Kenya, classified by fertilizer type, are shown in Table C1. The geographical distribution across Kenya of total N shortages is shown in Table C2. Geographical distribution across Kenya of the bag shortages is presented in Table C3, and differences in secondary or micronutrient content with respect to label specifications in granulated fertilizers are presented in Table C4 of Appendix C. Negative values are associated with a shortage of the nutrient relative to the quantity specified in the fertilizer label.

2.5. Cadmium Content in Fertilizers

Cadmium is considered a toxic heavy metal and occurs naturally in soils and in the phosphate rock deposits used to manufacture fertilizers. Its accumulation in soil and uptake by crops have raised concerns and prompted considerable research and legislation to understand the problem and magnitude of the risks and to protect the public against the potential health problems associated with exposure to this heavy metal.

Cadmium content in phosphate rock used for the manufacture of fertilizers varies with location and type of phosphate deposits. Roberts (2014) presents a table that shows a wide range of Cd concentrations. For example, the sedimentary deposits in China contain Cd with a concentration average lower than 2 parts per million (ppm), while sedimentary deposits from different locations in Morocco have concentrations ranging from 15 to 38 ppm, and sedimentary deposits in the United States have Cd concentrations ranging from 6 to 92 ppm. Igneous deposits in Russia contain Cd concentrations averaging 1 ppm, and igneous deposits from various locations in Brazil average less than 2 ppm Cd.

In Table 3, DAP presents the highest mean for Cd content. From the 101 DAP samples analyzed for Cd, there were three samples with values of 12. 5, 11.8, and 6.2 mg of Cd/kg P_2O_5, which were far higher than the rest of the values (maximum 1.33 mg Cd/kg P_2O_5). The three DAP samples with high values were taken from DAP bags imported from Tanzania (two bags) and Morocco, respectively. However, even the highest Cd concentration from the three DAP samples, with a value 12.5 mg Cd/kg P_2O_5, is lower than the maximum limit demanded by states in the U.S. and European countries. The limits of 889, 338, and 180 mg Cd/kg P_2O_5 are demanded by the U.S. states of Washington, Oregon, and California, respectively, and the proposed limits by the European Union in 2001 range between 20 and 60 mg Cd/kg P_2O_5.

A low average Cd concentration (Table 3) was found in 17 samples of NPK 23-23-0 (most were from fertilizers imported from China) and three samples of NPK 17-17-17 (two samples were from fertilizers imported from Russia and one was imported from Ukraine). This is consistent with the low Cd content reported by Roberts (2014) for phosphate rocks from China and Russia.

Table 3. Cadmium Content in Phosphate Fertilizers Sampled in Kenya

		Cd Concentration Mean	
FERTILIZER	n samples	ppm	mg/kg P_2O_5
DAP 18 46 0	101	2.90	1.33
NPK 23-23-0	17	0.46	0.10
NPK 17-17-17	3	0.23	0.04
NPK 10 26 10 Mavuno	2	0.12	0.03
NPK 27 10 16 +TE Easy Grow	2	0.55	0.03
NPK 15-5-35 +MgO+TE Agrigrow	3	0.11	0.01
NPK 23 10 5 3S .3Zn	1	0.05	0.01
NPK 20-20-0	1	0.25	0.05
NPK 22 21 17 Murphy foliar feed	1	0.24	0.04
SSP 18/21.5P 12S 24Ca	2	1.70	0.31

2.6. Bag Weight Verification

The most frequent weights of fertilizer bags found in Kenyan markets are 50, 25, and 10 kg. The tolerance limit of weight shortage with respect to the weight specified on the label is 1%, meaning 0.5, 0.25, and 0.1 kg for the three bag sizes, respectively. The CFDF in Figure 11 shows how the frequency of underweight bags increases as the bag size decreases. The chance of obtaining a 10-kg bag that is underweight is 38%, 28% for an underweight 25-kg bag, and 19% for an underweight 50-kg bag.

Underweight bags result from lack of control in filling and weighing the bags during manufacture or rebagging. In some cases, it is possible that the underweighted bags are the result of a deliberate act. The random error committed during the filling of the bags can be estimated from the weighted mean of frequencies associated with overweight 50-kg bags. The random error calculated this way is 4.5%. After subtracting the random error, it is estimated that 33.5% (one-third) of the 10-kg bags are intentionally underweight; similarly, the intentional underweighting of 25-kg bags and 50-kg bags is 23.5% and 14.5%, respectively.

2.7. Storage and Packing Conditions

Physical properties of fertilizers in terms of moisture content, caking susceptibility, and integrity of the granules are highly affected by the temperature and relative humidity (RH) of the storage areas. In general, high temperature and high RH during the storage period are detrimental to the fertilizers' physical properties. The Critical Relative Humidity (CRH) involves the interaction of temperature and relative humidity. The CRH of any particular fertilizer depends on the hygroscopic characteristics of the constituent materials of the fertilizer. Figure 12D, which has been constructed with RHs measured at temperatures between 28-32°C, shows that the CRH for NPK 17-17-17 is 45% and 55% for CAN. This means that the 17-17-17 fertilizers at a storage temperature of 30°C start absorbing moisture from the air when the room RH is 45%. The CAN fertilizers at a storage temperature of 30°C start absorbing moisture from the air at 55% RH. The two conditions of 30°C and 45% RH or higher, which trigger moisture absorption by 17-17-17 fertilizers, occur in about 80% of storage facilities found in Kenya. Similarly, the conditions that prompt the CAN fertilizer to start absorbing moisture from the air occur in approximately 50% of the storage facilities found in Kenya.

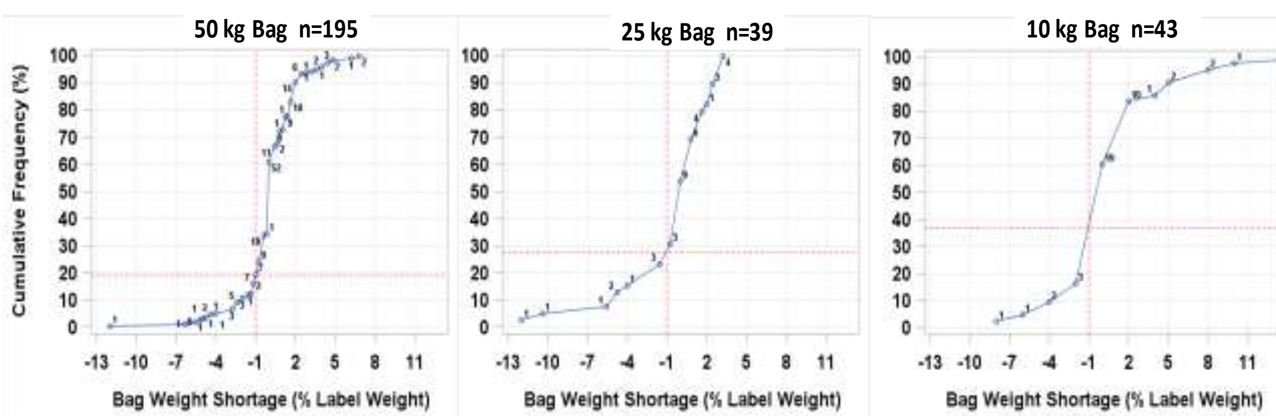


Figure 11. Cumulative Frequency Distribution Functions for the Weight Verification of the Most Common Bag Sizes. Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary

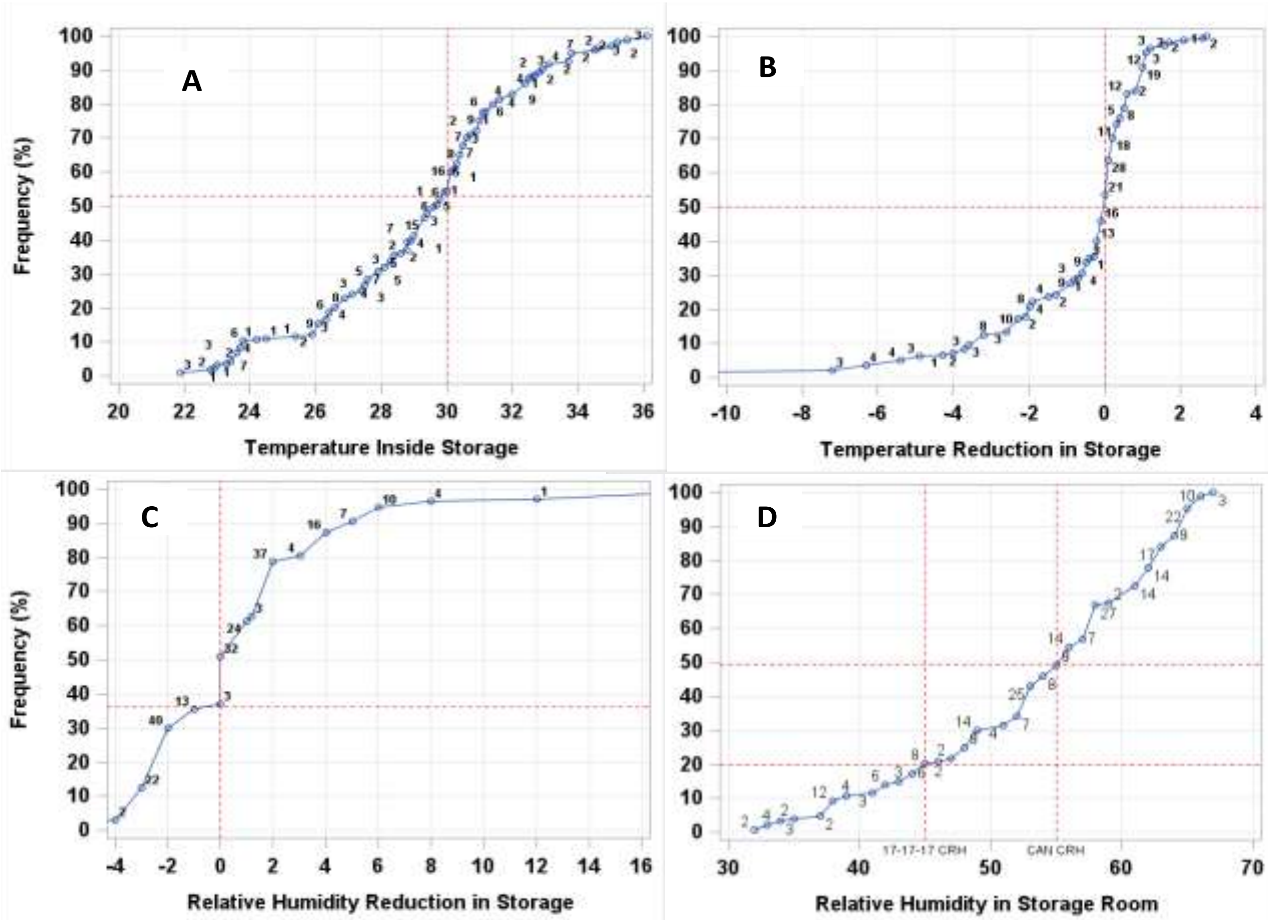


Figure 12. Cumulative Frequency Distribution of Temperature (A), Temperature Reduction Inside the Warehouse Relative to Temperature Outside (B), Relative Humidity Reduction Inside the Warehouse Relative to Outside (C), and Critical Relative Humidity in the Storage Warehouses for 17-17-17 and CAN (D). Vertical dotted line represents the out-of-compliance boundary, and horizontal dotted line represents the frequency for the boundary

Figures 12A, 12B, 12C, and 12D were constructed only with storage temperatures and RHs measured during the afternoon. Forty-eight percent of the storage facilities inspected in Kenya presented temperatures higher than 30°C (Figure 12A). Only 50% of the storage facilities inspected presented temperature reduction with respect to the temperature outside (Figure 12B). Reductions of 2°C or higher occurred in 20% of the facilities, and reductions of 4°C or higher took place in 8% of the storage facilities inspected in Kenya (Figure 12B). Only 37% of the storage facilities inspected in Kenya showed RH reductions relative to the RH outside, and 30% of them presented RH reduction of 2% or higher (Figure 12C).

Using air conditioning to control temperature and RH in fertilizer storage facilities in Africa is possible in very few storage warehouses owned by importers or large wholesalers. In the fertilizer markets inspected in Kenya, not even one storage facility with air conditioning was found. The best resource that fertilizer distributors and dealers have along the distribution chains in Kenya to reduce temperature and RH relative to outside is appropriate ventilation and air circulation through the storage area. Vents of adequate size, location, and number are needed for ventilation, and the use of a sufficient number of pallets in the fertilizer stacks is needed to obtain air circulation throughout the storage area. Another storage condition that favors air circulation within the storage areas is leaving empty spaces between fertilizer stacks and the walls and between fertilizer stacks and the roof.

Forty-five percent of the storage room facilities (Figure 13A) have deficient or no ventilation, and 45% of the storage rooms do not use pallets or use just a few of them (Figure 13C). These serious limitations in ventilation and air circulation are directly associated with the failure of many storage warehouses to reduce temperature and RH with respect to the conditions outside.

2.8. Physical Properties of Fertilizers

Adequate moisture content was found primarily in the six main fertilizers; 75% percent or more of the samples presented "adequate" moisture content in DAP, urea, 17-17-17, and 10-26-10 fertilizers. Still, 7%, 12%, and 16% of DAP, CAN, and 23-23-0 fertilizers, respectively, presented high moisture content (Figure 14). The dominant adequate moisture content in the most common fertilizers result from the appropriate bag types used to pack the fertilizers in Kenya. Despite the limited capability of the storage facilities to reduce RH and temperature, more than 90% of the fertilizer bags inspected were packed in impermeable bags, either with the combination of an inner impermeable layer and a woven exterior or plastic laminated bags, that prevent the fertilizer products from coming in contact with water or absorbing moisture from the air (Figure 15). Conditions that would allow fertilizers to come in contact with water or absorb moisture from the environment, such as torn bags or bags with loose seams, occurred with very low frequency (Figure 16).

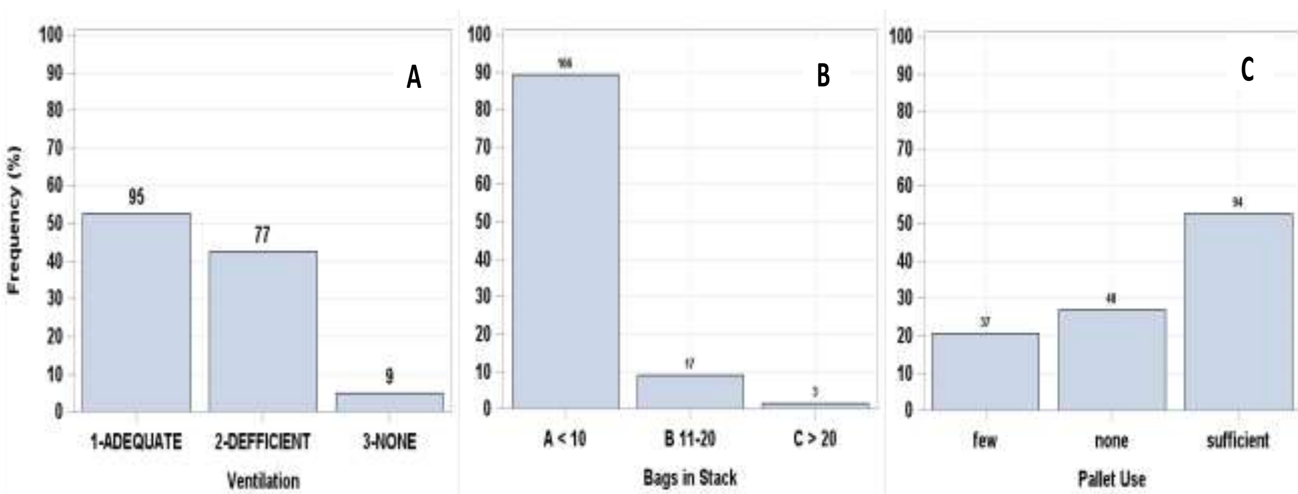


Figure 13. Frequency Distribution of Ventilation, Height of Bag Stacks, and Use of Pallets in Storage Rooms

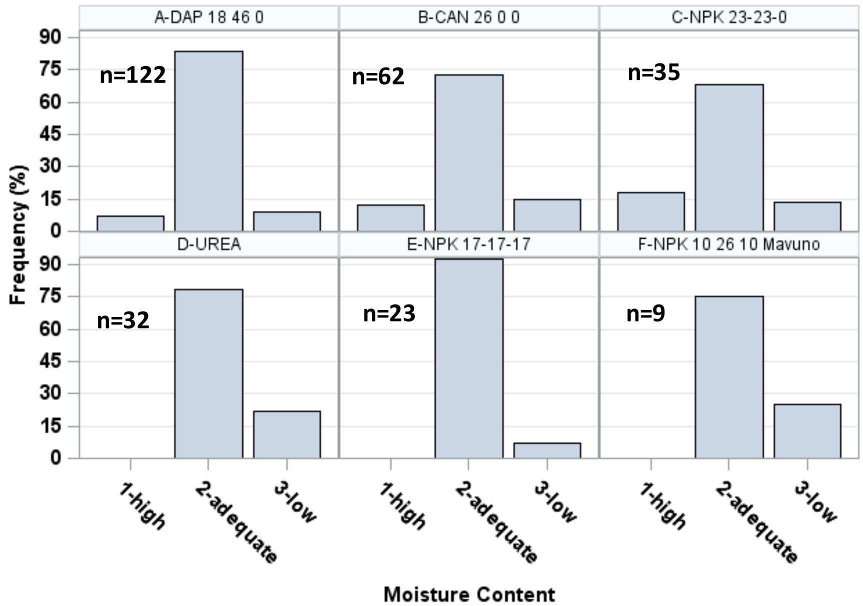


Figure 14. Frequency Distribution of Moisture Content from the Most Common Fertilizers in Kenya

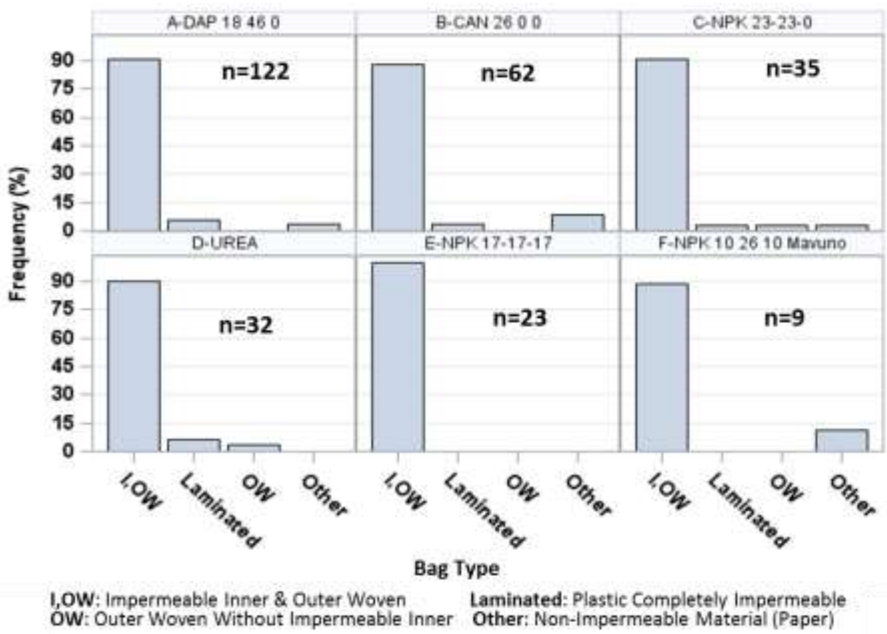


Figure 15. Frequency Distribution of Bag Types Used in the Most Common Fertilizers in Kenya

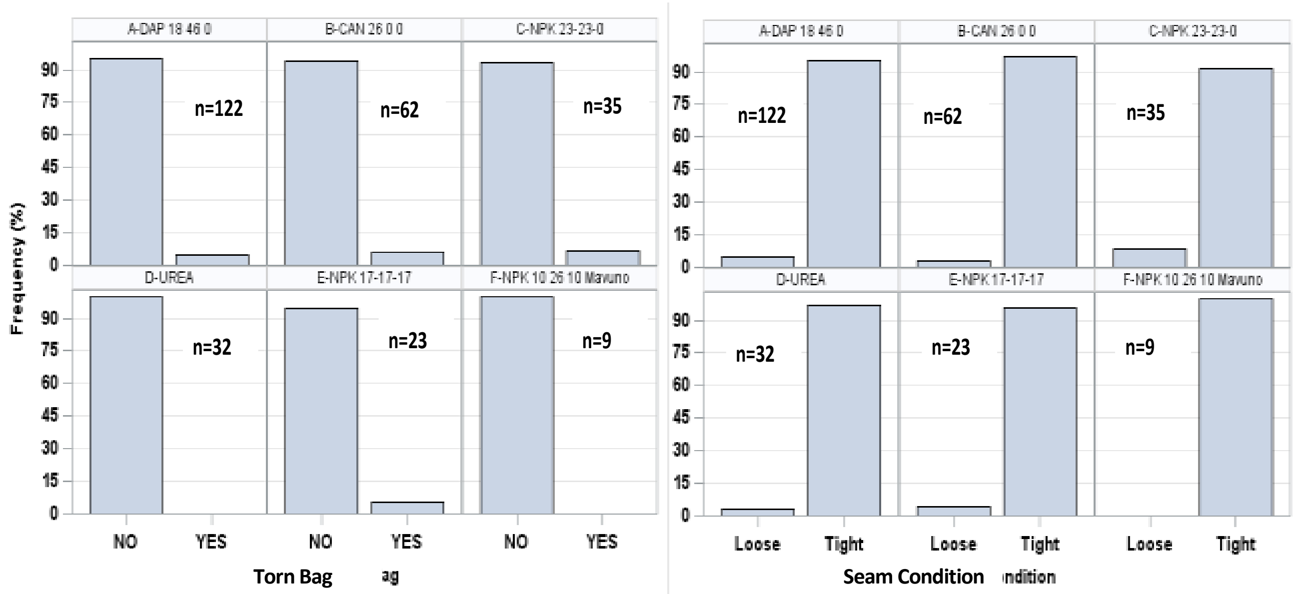


Figure 16. Frequency Distribution for Integrity and Seam Condition of Bags Used to Pack the Most Common Fertilizers in Kenya

The highest frequency of caking occurred in urea; 28% of the bags examined presented some degree of caking. DAP and CAN presented 25% of bags with some degree of caking, NPK 23-23-0 had 24% of bags with some degree of caking, and NPK 17-17-17 had 12% (Figure 17). A factor that may have contributed to these frequencies of caking is the pressure exerted to bags at the bottom of the piles stacked high; 11% of the storage rooms inspected had stacks with more than 10 bag layers (Figure 13B). Other factors include the moisture content in the categories of low or high that were identified in 10% to 22% of the fertilizer dealers inspected (Figure 14) and the absence or insufficient use of pallets in 48% of the storage facilities inspected (Figure 13C).

Granular integrity of the six most common fertilizers (Figure 18) is not a major concern. All six fertilizers analyzed have at least 90% of the material with granule sizes between 1.0 and 4.0 mm. The highest percentage of fines, which are granules with diameters between 1.0 and 2.8 mm, occurred in 15% of bags of urea, DAP, and NPK 23-23-0. The highest frequency of dust occurrence, particles with a diameter lower than 1.0 mm, was 7% of the CAN bags evaluated. The percentage of fines and dust may originate in the granulation process itself or from fracture or abrasion of the regular size granules and fines as a result of the manual and individual handling of fertilizer bags. When fertilizer bags are handled with mechanical devices that move groups of bags on pallets, each individual bag is subject to significantly reduced crushing, impact, and abrasive forces that degrade the granule. With mechanical handling, the forces that cause granule degradation are reduced considerably both in frequency and magnitude.

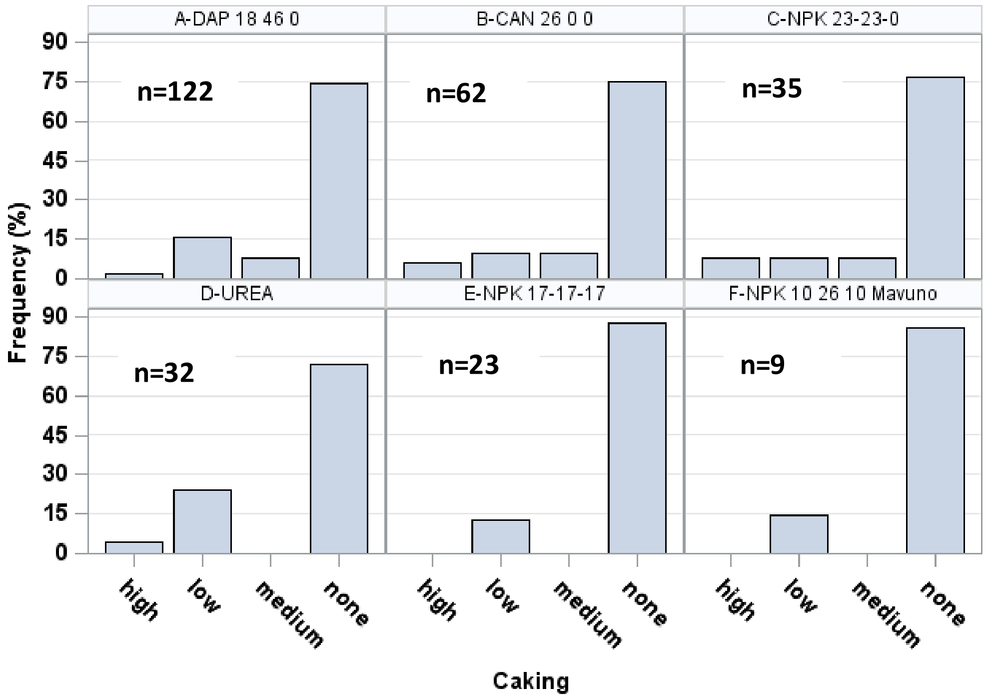
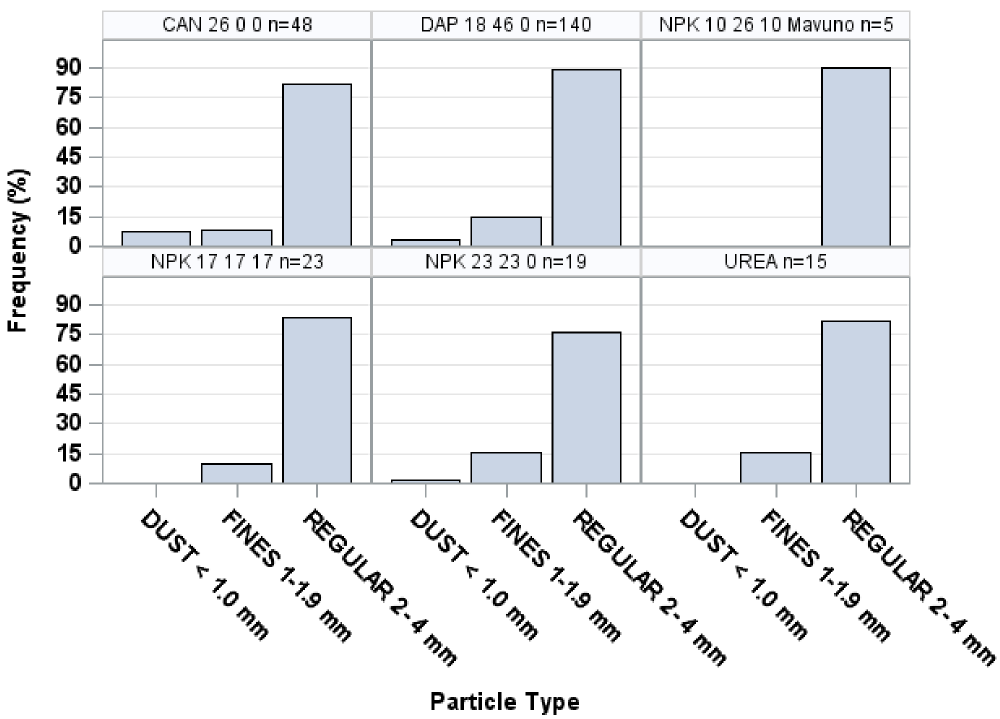


Figure 17. Frequency Distribution of Caking from the Most Common Fertilizers in Kenya



Note: The percentage for each particle type category comes from averaging the same category across the n sieve boxes.

Figure 18. Frequency Distribution of Granule Size Distribution for the Most Common Fertilizers in Kenya

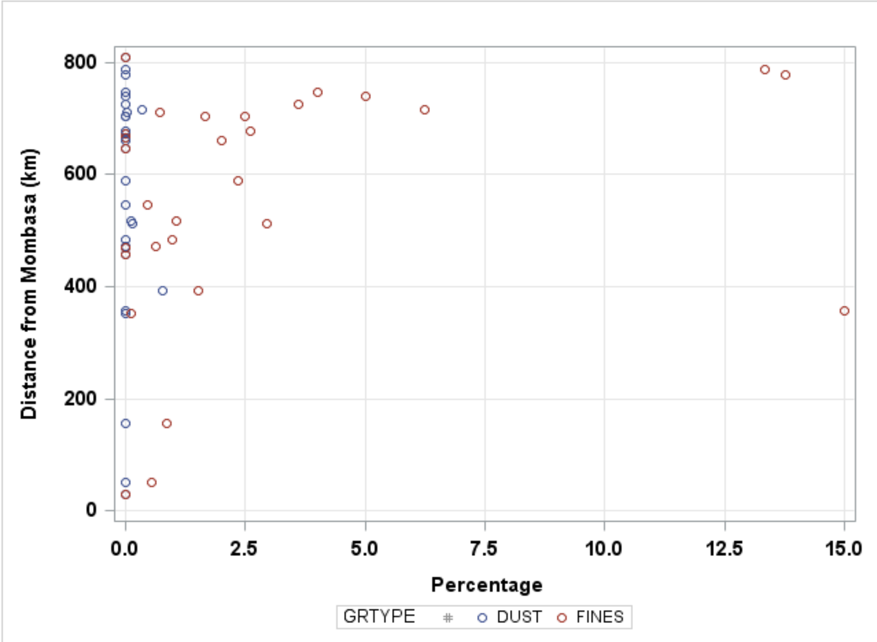


Figure 19. Effect of Fertilizer Handling on Granule Integrity Along the Distribution Chain

Figure 19 provides an illustration of the effect of transportation and handling of granulated fertilizers on degradation of the granule. The figure shows an increasing pattern of percentage of granule fines as the fertilizers move from the port of entrance in Mombasa to distant points in the distribution chain. Further granule degradation to dust remains at very low percentages.

The only bulk blend fertilizer found in Kenyan markets was the NPK 10-26-10; granule segregation was not found in six fertilizer samples tested with the Sylvite® Sieve Boxes.

2.9. Adulteration of Fertilizers

The presence of fillers or foreign materials that can be used to dilute the nutrient content of granulated fertilizers were not found in fertilizers packed in original bags or in rebagged fertilizers. Impurities that could indicate tampering of fertilizer bags were not found either. Fertilizer quality inspectors were asked to record any evidence of adulteration found in each of the fertilizer bags inspected. There was not one record related to adulteration of granular fertilizers.

There are anecdotal reports of adulteration within the fertilizers distributed by the Kenya Government subsidy program. These reports were not supported by the lack of adulteration evidence in two samples of NPK 17-17-17 and two samples of DAP collected and analyzed from the NCPB depot located in the Kissi county, and one SSP, one DAP, one NPK 23-23-0 and one NPKSCa 26 0 0 + 5S 10Ca samples collected and analyzed from the NCPB depot in the Narok county. Only these two depots had fertilizers for distribution at the time of the FQA sampling in Kenya. Extensive sampling at the NCPB depots nationwide is needed to identify the possible adulteration among the subsidized fertilizers.

2.10. Effect of External Factors and Fertilizer Physical Properties on Moisture and Nutrient Content of Fertilizers

Ventilation in the storage area, fertilizer bag type, bag seam condition, fertilizer bag condition, and use of pallets in storage were used as predictors of fertilizer moisture content using logistic models (Table 4). The condition of the bag seam and the use of pallets were the only factors showing some significant effect on the moisture content of fertilizers. The probability from the chi-square distribution equal to 0.0277 indicates a significant effect of the seam condition on the moisture content of fertilizers; similarly, the chi-square value of 0.1037 from pallet use is marginally significant and suggests that there is some effect of pallet use on fertilizer moisture content. The odds ratio for the seam condition indicates that getting moist fertilizers has 6.07 times higher odds when the bag seam is loose than when the bag seam is tight. And the odds of getting moist fertilizers when no pallets are used is 1.5 times higher than when pallets are used in sufficient quantity. Loose bag seams allow moisture from the air to get in contact with the fertilizers while the lack of pallet use in the storage area reduces the air circulation and promotes increased relative humidity and temperature inside the fertilizer storage warehouses. External factors, such as market type, dealer density, market periodicity, dealer's knowledge about fertilizers, status of the dealer, and type of buyers, were used together with fertilizer physical properties such as moisture content and caking to predict the nutrient content compliance of fertilizers (Table 5) with a logistic model. From all the set of predictors, only the type of market (rural or urban) and the type of buyers (dealer's customers) showed significant effect (Pr>Chi-Sq = 0.0151 and Pr>Chi-Sq = 0.0503, respectively) on the macronutrient content compliance of fertilizers. The odds of nutrient content compliance in rural markets, relative to urban markets, are just 0.28, nearly one out of four. The fertilizer dealers that sell fertilizers to all types of farmers and to fertilizer retailers have odds of complying with the macronutrient content in fertilizers 3.27 times higher than dealers that sell fertilizers only to small-scale farmers.

Table 4. Test for Effect of Storage and Bag Conditions on Fertilizer Moisture Content

Effect	DF	Wald Chi-Sq	Pr > ChiSq	Odds Ratio	
				Label	Estimate
VENTILATION	2	1.2148	0.5448		
BAG TYPE	3	2.4164	0.4906		
SEAM CONDITION	1	4.8468	0.0277	SEAM CONDITION Loose vs. Tight	6.076
BAG INTEGRITY	1	0.004	0.9496		
PALLETS USE	2	4.2626	0.1037	PALLETS USE None vs. Sufficient	1.542

Table 5. Test for Effect of Market, Dealer, and Fertilizer Physical Characteristics on Global Nutrient Content Compliance of Fertilizers

Effect	DF	Wald Chi-Square	Pr > ChiSq	Odds Ratio	
				Label	Estimate
MARKET TYPE	1	**5.9002**	**0.0151**	**Rural vs. Urban**	**0.28**
DEALERS DENSITY	2	0.6707	0.7151		
MARKET PERIODICITY	1	0.8954	0.6543		
DEALER'S FERT KNOWLEDGE	2	0.0909	0.9556		
STATUS	1	0.9294	0.335		
BUYERS	1	**3.832**	**0.0503**	**All Frmrs + Rtlrs vs. Smll Frmrs Only**	**3.27**
MOISTURE CONTENT	2	1.83	0.4005		
CAKING	3	3.4487	0.3275		

Section 3. Conclusions

3.1. Market and Dealer Characteristics

- Using the distribution of fertilizers sampled during the survey, it can be estimated that conventional granulated fertilizers represent 96% of the fertilizers traded in Kenyan fertilizer markets, while crystal and liquid fertilizers represent 2.6% and 1.4% of the traded fertilizers, respectively.
- DAP represents 46% of the fertilizers traded. Urea, CAN, NPK 23-23-0, and NPK 17-17-17 represent 23%, 13%, 7%, and 5% of the market, respectively.
- Sixty percent of the markets in Kenya are rural markets, and 40% are urban markets; 90% of the markets are located in a permanent location, and 10% are itinerant markets. Fifty percent of the markets have high concentration of dealers, while 39% have low concentration, and 6% of the markets consist of isolated dealers.
- Eighty percent of the fertilizer dealers in Kenya are small retailers, and 70% of the dealers sell fertilizers only to small-scale farmers. Thirty percent of the fertilizer dealers have limited or no knowledge about fertilizers characteristics related to quality, and 34% of the dealers have never received any training about fertilizers.

3.2. Nutrient Content Compliance of Most Common Fertilizers

- Four percent of the DAP samples were out of compliance with respect to total N content, and 12% of the samples were out compliance with respect to the P_2O_5 content. There were no urea samples out of compliance for total N content.
- The CAN fertilizer presented 14% of samples with total N content out of compliance and 2% of the samples with CaO content out of compliance.
- NPK 23-23-0 presented 12% of samples with total N content out of compliance and 23% of the samples out of compliance for P_2O_5 content.
- NPK 17-17-17 presented 31% of samples out of compliance for total N content, 36% of the samples presented P_2O_5 content out of compliance, and 63% of the samples showed K_2O content out of compliance.
- Average severity for nutrients out of compliance expressed as nutrient shortages for the main fertilizers were: 1.5% N, and 4.3% P_2O_5 in DAP. 4.4% N in CAN. 4.7% N and 4.6% P_2O_5 in NPK 23-23-0. 3.3% N, 3.3% P_2O_5 and 2.4% K_2O in NPK 17-17-17.
- No evidence of adulteration or severe degradation of physical properties were found in any of the granulated fertilizers. This suggests that the cases of total N, P_2O_5, or K_2O content out of compliance likely originated in the manufacture of the imported fertilizers.
- Of the main six granulated products assessed, significant relationships were identified (with a logistic model) between nutrient content compliance and the type of market (rural or urban) and type of customers the fertilizer dealer serves (all farmers and retailers or small-scale farmers only). The odds ratio of nutrient content compliance for a rural market is 0.28 times that of an urban market, and the odds ratio of nutrient content compliance is 3.27 times higher for the dealers that serve all types of farmers and retailers than those with only small-scale farmer customers.

3.3. Quality of Crystal and Liquid Fertilizers

- The number of samples (n ranging from two to eight) from the different crystal and liquid fertilizers were insufficient to develop frequency distribution functions and make reliable inferences about the frequency of nutrient content compliance. Global nitrogen shortage severity in crystal products ranged between 1.5% and 7.6%. In liquid products, the nitrogen shortage severity ranged between 3.6% and 22.5%.

- Combining all fertilizers within fertilizer types, it was possible to identify that the severity of nutrient shortages in liquid fertilizers is four times higher than the granulated fertilizers, and crystal fertilizers have a nutrient shortage severity two times higher than granular fertilizers.
- Labels on crystal or liquid products sometimes report content of secondary and/or micronutrients but never identify the nutrient or specify the quantities of secondary or micronutrients contained in the fertilizers.

3.4. Cadmium Content in Fertilizers

- The maximum Cd contents were found in three DAP samples with 12.5, 11.8, and 6.2 mg Cd kg^{-1} P_2O_5. These Cd contents are lower than the maximum content allowed by the European Union in fertilizers, which ranges from 20 to 60 mg Cd kg^{-1} P_2O_5. These amounts are far lower than the maximum allowed by the state of California, which is 180 mg Cd kg^{-1} P_2O_5.

Key Conclusions

Conventional granulated fertilizers represent 96% of the fertilizers traded in Kenya, while crystal and liquid fertilizers represent 2.6% and 1.4%, respectively.
DAP represents 46% of the fertilizers traded. Urea, CAN, NPK 23-23-0, and NPK 17-17-17 represent 23%, 13%, 7%, and 5% of the market, respectively.
No evidence of adulteration or severe physical degradation were found in any of the granulated fertilizers. This suggests that cases of total N, P_2O_5, or K_2O content out of compliance likely originated in the manufacture of imported fertilizers.
The odds ratio of nutrient content compliance for a rural market is 0.28 times that of an urban market.
The odds ratio of nutrient content compliance is 3.27 times higher for dealers that serve all types of farmers and retailers than for those with only small-scale farmer customers.
The severity of nutrient shortages in liquid fertilizers is four times higher than granulated fertilizers. Crystal fertilizers have a nutrient shortage severity two times higher than granulated fertilizers.
The cadmium content found is lower than the maximum content allowed by the European Union, which ranges from 20 to 60 mg Cd kg^{-1} P_2O_5.
The chances of finding an intentionally underweight bag are 33.5% (one out of three), 23.5%, and 14.5% for 10-kg, 25-kg, and 50-kg bags, respectively.
50% of the warehouses evaluated did not reduce temperature relative to temperature outside during the hottest hours of the day. 37% did not reduce the relative humidity with respect to the relative humidity outside.
The odds ratio of having moist fertilizers is six times higher when the bag seam is loose than when it is tight. The odds ratio of having moist fertilizers is 1.5 times higher when pallets are not used than when sufficient pallets are used.
The percentage of fines increases with distance from Mombasa, the port of entrance. The crushing, impact, and abrasive forces that produce granule degradation accumulate as the products are handled along the distribution chain.

3.5. Bag Weight Verification

- The three most common bag sizes in Kenya are 50 kg, 25 kg, and 10 kg. The chances of finding an underweight bag were found to increase as the bag size decreases. The chances of obtaining an intentionally underweight bag can be estimated by subtracting the filling/weighting random error, which is 4.5%. The chances of getting intentionally underweight bags are 33.5% (one out of three), 23.5%, and 14.5% for bags with 10-kg, 25-kg, and 50-kg labels, respectively.

3.6. Storage Conditions

- Fifty percent of the warehouses evaluated did not reduce temperature relative to temperature outside during the hottest hours of the day, and 37% of the warehouses did not reduce the relative humidity with respect to the RH outside. This is mainly explained by no ventilation or limited ventilation and by the insufficient use of pallets.
- Due to the limited control of temperature and RH in the storage facilities, the 45% Critical Relative Humidity (CRH) of the 7-17-17 fertilizer at 30°C is expected to be exceeded in 80% of the warehouses. The 55% CRH of CAN at 30°C is expected to be exceeded in 51% of the warehouses.

3.7. Physical Properties of Fertilizers

- The high moisture content found in 7% of the DAP samples, 10% of the CAN samples, and 16% of the 23-23-0 samples can be explained by the significant relationship (determined with a logistic model) between fertilizer moisture content and bag seam conditions and the use of pallets. The odds ratio of having moist fertilizers when the bag seam is loose is six times higher than when the seam is tight, and the odds ratio of having moist fertilizers when pallets are not used is 1.5 times higher than when enough pallets are used.
- High caking was observed in 1%, 4%, 6%, and 2% of the DAP, CAN, 23-23-0, and urea bags, respectively. Data collected did not allow the assessment to identify significant relationships with factors that may explain caking frequencies, but possible causes are high moisture content, the absence or rare use of pallets, permeable bags, torn bags, and loose bag seams. The near 1% of warehouses with bag stacks higher than 20 bags is another factor that has the potential to produce caking because of the high pressure exerted on bags at the bottom of the stacks.
- Granular integrity in the six most common fertilizers is not a major concern. All six fertilizers have at least 90% of the material with granule sizes between 1.0 mm and 4.0 mm. A maximum 15% of fines (1.0-2.8 mm) was observed in urea, DAP, and 23-23-0. The percentage of fines increased with distance from Mombasa, the port of entrance. The crushing, impact, and abrasive forces that produce granule degradation accumulate as the products are handled along the distribution chain.
- Only one bulk blend product was found in the markets, NPK 10-26-10. None of the three samples analyzed showed granule segregation.

3.8. Recommendations on Quality Regulations

- Quality control of liquid and crystal fertilizers during manufacture must be imposed, and regular inspection both at the manufacture and sale points must be included in the country's fertilizer quality regulations.
- To deal with quality problems that can be linked to the manufacturing process will require more stringent inspection arrangements at the origin and, if locally manufactured, at the plant before distribution takes place. This means that selecting international companies for pre-shipment inspection has to be more stringent, and local inspection agencies need to focus on eliminating importation or local manufacture of substandard fertilizer products. Regular training of inspectors to update their skills and knowledge should be emphasized in quality assurance plans.

- Products that have been identified to have quality problems should also receive heightened inspection on arrival at the destination port of Mombasa.

- Updating of country regulatory framework, coupled with regional harmonization of regulations and standards, could contribute to making it more difficult for poor-quality fertilizer to be traded in the region. Therefore, current efforts toward achieving this goal should be supported by all countries in the region.

- Training of dealers in proper handling and storage should be part of the process of strengthening regulatory oversight and improving quality. Re-bagging of products should be handled carefully to eliminate weight shortages.

Section 4. References

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Stokes, E.M., C.S. Davis, and G.G. Koch. 2009. *Categorical Data Analysis Using the SAS System.* Second edition. SAS Institute, Cary, NC.

Acknowledgements

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Appendix A.

Procedures for Data Collection and Fertilizer Sampling

1. Equipment

- Main questionnaire (MQ) and physical properties format (PPF)
- Computer tablet with camera
- Thermometer/hygrometer
- Bag sampler probe and scoop
- Transfer pipettes to sample liquid fertilizers
- Sieve box
- Weight scale
- Bucket, funnel, scissors, and dusting rag
- Tape to seal bag holes left by sampler
- Re-sealable (Ziploc) 0.5-kg plastic bags for fertilizer samples
- 50-mL plastic jars
- Carton board boxes to carry sets of fertilizer samples

2. Data Collection

The procedure for data collection and sampling of fertilizers in each of the dealer's warehouses or shops visited is described step-by-step as follows:

1. Introduction of inspectors to the shop owner or keeper.
2. Fill out the following questionnaire sections: General identification and characteristics of the market in Table A1. Enter the "Time in" in Table A1. Record identification and characteristics of the dealer in Table A2.
3. Enter characteristics of storage in Table A3. Ventilation is judged based on the size, number, and location of the ventilation vents and whether the vents are free or obstructed by fertilizer bags. For temperature and relative humidity outside and inside the storage area, use the hygrometer provided. Take pictures of the storage area.
4. Locate the fertilizers and the different lots of each fertilizer in the shop/warehouse. For this survey, the lot of a particular fertilizer product is defined as all of the product of that fertilizer that was ordered from a particular source at the same time and supplied to the agro-dealer on the same container or vehicle.
5. List products and lots in the first column of the table "Characteristics of Fertilizer Products" in Table A4. A product can be listed more than once if there is more than one lot of that fertilizer or if there is one open bag of the same product for retailing in small quantities. The list may be restricted only to the most important fertilizers as discussed in the inspector's training.
6. Fill out the section "Characteristics of Fertilizer Products" in Table A4 for every product and lot listed.
7. In each lot, pick a random bag from each product listed in the questionnaire for weight verification. Take a picture of the bag label. Weigh the bag. Record in the questionnaire the weight on the label and actual weight of the bag.
8. Take a sample from every product listed in the questionnaire applying the procedures described below for solid and liquid fertilizers:

3. Fertilizer Sampling

Taking a Sample from Closed Bags

Fertilizer bags must be in a horizontal position. Subsamples are taken directly from bags in the stacks. You may need a ladder to reach high bags.

- Insert the sampling probe or bag sampler (Figure A1) through a corner of the bag (Figure A2). The sampling probe must have the slots down during the insertion. When the sampling probe has reached the opposite bag corner, turn it 180° to get the slots upward. Extract the sampling probe.
- Empty the content of the sampling probe in a bucket. That is a subsample.
- Patch with tape the hole left by the sampling probe in the bag.
- Repeat this operation in each of the bags selected at random from the lot. The accumulated subsamples in the bucket make up the sample.

The number of subsamples that make up a fertilizer sample is determined using the following table.

Fertilizer Type	n Bags in lot	n bags to sample
Solid	5 or less	1
	6 to 20	2
	21 to 50	4
	51 to 100	6
	> 100	1 from every 20
Liquid	**n jars in lot**	**n jars to sample**
	20 or less	1
	21 to 50	2
	> 50	2 from every 50

- Use part of the sample in the bucket to evaluate physical properties using the "Sieve Boxes" and observation. Fill out Table A5.
- Transfer the sample from the bucket to a plastic bag using a funnel. Seal the bag perfectly to avoid moisture loss.
- Fill out the sample label using the format T#A#F#. T#: for team number, A#: for agro-dealer number, and F#: for fertilizer number from Table A4. Stick the label to the first plastic bag containing the sample.
- Place sample and label in a second bag. Seal the bag perfectly to preserve moisture content in the sample.
- Wipe sampling probe, bucket, and funnel with a dry rag to remove any fertilizer residue.
- Move to another lot of the same product or to a lot of different product and repeat the sampling procedure.
- Place all the fertilizer samples from a dealer's shop in a cardboard box.
- Take pictures of any condition in the shop or any practice of the dealer that you believe can affect the quality of fertilizers (e.g., spreading products on the ground to sun-dry them, blending of products, mixing of fertilizer with other materials, rebagging).
- Record the "Time at end" at the top of the questionnaire.

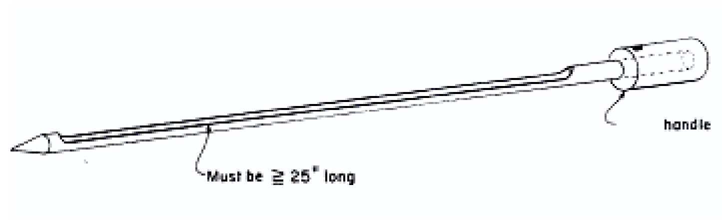


Figure A1. Sampler for Solid Bagged Fertilizers

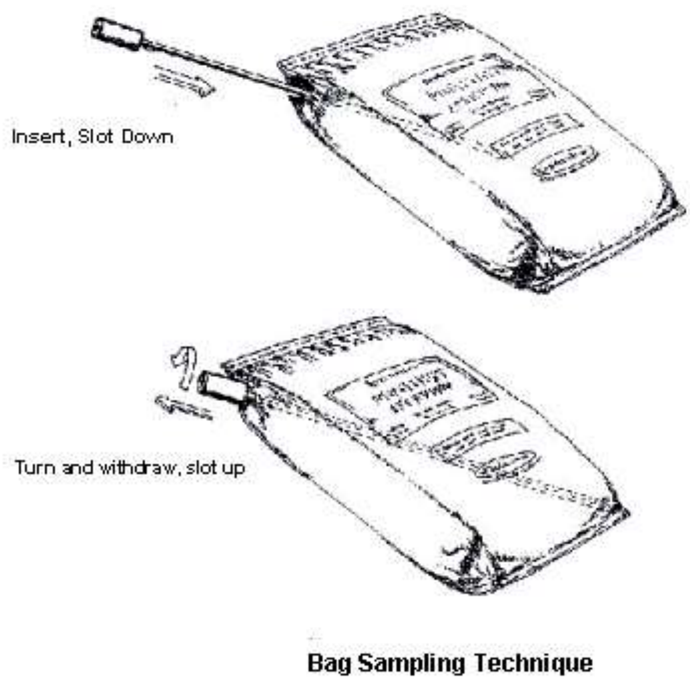


Figure A2. Sampling Technique for Solid Bagged Fertilizers

Taking a Sample from an Open Bag

- Scoop out three subsamples: one from the top, another from the middle, and another from the bottom of the bag (Figure A3). Place the three subsamples in a bag. Seal bag perfectly.
- Fill out the sample label. Stick it on the sample bag. Make sure to mark the "Open Bag" box on Table A4.
- Place sample bag in a second larger bag. Seal it perfectly.
- Take a picture of the open bag showing the product in the top (usually moist from humidity absorbed from the air). Take another picture showing the fertilizer bag label.

Taking a Sample from Liquid and Crystal Fertilizer

- Identify the two most abundant liquid fertilizers and most abundant crystal fertilizers found in the agro-dealer store.
- List the fertilizers identified above in the "FERTILIZERS" section of the Main Questionnaire.
- Buy a small bottle of each liquid fertilizer and a small bag of the crystal fertilizer listed in the Main Questionnaire.
- Take a picture of each liquid or crystal fertilizer listed in the Main Questionnaire.
- From each liquid fertilizer, transfer 20 mL to a sample jar, using a new pipette.
- Cap the sample jar tightly.
- Write the sample label (T#A#F#) and stick it on the jar.
- Discard the rest of the fertilizer.
- Fill approximately one-quarter of a sample bag with crystal fertilizer. Discard the rest of the crystal fertilizer.
- Seal the bag perfectly.
- Write the sample label (T#A#F#) and stick it on the sample bag.
- Put the sample bag inside a second bag, and seal it perfectly.

Table A1. Location and Market Characteristics

Team	Questionnaire	Country	Province	County	District	City/Town	Market Name	Date	Time at Start	Time at End
1 to 8	T#A#F#							dd-mm-yy	hh-mm	hh-mm
		Kenya								

MARKET CHARACTERISTICS						
Mark with an X under the answer options						
Type of Market		Concentration of Dealers			Market Location	
Urban	Rural	High	Low	Isolated Dealer	Permanent	Itinerant

Table A2. Characteristics of the Agro-Dealer

AGRO-DEALER CHARACTERISTICS									
Enter text or mark with an 'X' in front of the answer options									
Ownership	Private		Government						
Business name									
Owner's name									
Keeper's name									
Address									
Telephone									
Owner's knowledge about fertilizers*	Good		Limited		None				
Keeper's knowledge about fertilizers*	Good		Limited		None				
Has owner had training about fertilizers?	Yes		No		When?		By whom?		
Has keeper had training about fertilizers?	Yes		No		When?		By whom?		
Does the business have a license?	For inputs in general		For fertilizers						
Status of the business (mark all options that apply)	Importer		Wholesaler		Retailer				
Type of customers (mark all options that apply)	Small farmers		Commercial farmers		Farmer's organizations		Retailers		

* Do not ask, judge yourself.

Table A3. Characteristics of Storage

Characteristics of Storage										
Enter text or mark with an 'X' in front of the answer options										
Approximate dimensions (m)	Length		Width		Height					
Ventilation	Good		Deficient		No ventilation					
Temperature inside the warehouse		Relative humidity inside warehouse								
Temperature outside building		Relative humidity outside building								
Handling of fertilizer bags	Manual		Mechanical							
Height of stacks	Maximum number of bag layers		Average number of bag layers							
Pallet use	Sufficient		Few		None					
Are stacks neat?	Yes		No		If no, explain					
Are other materials stored?	No		Yes		What kind					
Is the storage area clean?	Yes		No		If no, expl					

Table A4. Characteristics of Fertilizer Products

Characteristics of Fertilizer Products

Enter text or quantity, use codes especified at the bottom of table

Sequence #	Fertilizer Grade (spell out nutrients and their concentration)	Lot #	Granulated (G) Crystal (C) or Liquid (L)?	Is the granulated fertilizer a blend? (Yes or No)	Bag Characteristics					Weight (Kg)		Bottle Characteristics			Fertilizer Volume (l or ml)		Evidence of: (Yes or No)			
					Type*	Seam Condition Tight (T) or Loose (L)	Tore? (Yes or No)	Rebagged? (Yes or No)	Open Bag (Yes or No)	On Label	Actual	Material**	Bottle Condition Good (G) Bad (B)	Well sealed (Yes or No)	On Label	Less than on label % reduction	Management Problem	Manufacturing Problem	Adulteration	Explanations
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				

*** Type of Bag: Plastic Inner (I), Outer Laminated (OL), Outer Woven (OW), Paper (P), Other (OT).**

**** Bottle material: Glass (G), Plastic (P), Other (O)**

Table A5. Physical Properties of Fertilizers

ASSESSMENT OF PHYSICAL PROPERTIES										
Enter text, quantities, or mark with 'X'										
Team #		Questionnaire #:					Sequence #:			
Fertilizer			Lot							
Granular Fertilizers										
Color(s)										
SEGREGATION only for bulk blends Percentages from vertical scale in Sieve Box					**MOISTURE CONTENT**			**FILLER**		
5 - %	4 - %	3 - %	2 - %	1 - %	Adequate	Low	High	Yes		No
								% in label		
GRANULE INTEGRITY for granular compound fertilizers Percentages from vertical scale in Sieve Box					CAKING				IMPURITIES/FOREIGN MATERIAL	
5 - %	4 - %	3 - %	2 - %	1 - %	None	Low	Medium	High	Yes	No
Type of filler:					Type of impurity/foreign material:					
Comments:										
Liquid Fertilizers										
Color										
Homogeneous	Yes		No							
Sediments?	Yes		No							
Impurities?	Yes		No							
Comments:										

Appendix B.

Assessment of Physical Properties

The fertilizer physical properties that are important for the quality of the product are:

- Segregation
- Granule integrity: amount of fines, amount of dust
- Color
- Presence and percent of fillers
- Critical relative humidity
- Moisture content
- Caking
- Impurities

Segregation is the physical separation of granules from different components of bulk blended fertilizer due mainly to their particle size differences. Shaking of bags during transportation or handling in warehouses and shops produce segregation because smaller granules move downward in higher proportion than larger granules. Concentration of nutrients contained in small granules is expected to be higher in low bag sections where the quantity of small granules is higher than in the rest of the bag. Segregation can be estimated quantitatively using the sieve boxes taking advantage of the particle size separation that can be achieved with appropriate use of Sylvite® sieve boxes. After applying the procedure to separate granules of different size, the inspectors will record the height percentage at each column in Table A5. A segregated fertilizer will show a very asymmetrical distribution with large granules located at the right of the box and small granules at the left. The types or color of granules will be well separated. A no segregated fertilizer will show all the granules in few columns, usually three or four, all the columns showing about the same composition of granules (colors) in a very symmetric arrangement.

The granule integrity is proportional to the resistance of granules to impact, crushing, and abrasion forces. Granule integrity can be estimated quantitatively using the particle size separation obtained with the help of Sylvite® sieve boxes. It is measured assessing the percent of granules of regular size (range 2.8 mm to 4 mm, contained in the 1st compartment), percent of granules smaller than the original size or fines (between 1.0 and 2.8 mm, contained in 2nd, 3rd, and 4th compartments), and the percent of dust (< 1 mm, contained in 5th compartment). Poor granule integrity may indicate manufacturing deficiencies, excessive handling, or aging of the products. The smaller the height differences of the columns at the left with the columns containing the whole granules the higher the granule degradation. Samples with good granular integrity, meaning little amounts of fines and dust, show little or no particles at the left of the 1st compartment of the sieve box. Inspectors will be trained in the use of the boxes with numerous practical exercises. Record column percentages in the format for physical properties (Table A5).

Most fertilizers have typical colors: Urea is white, DAP is dark gray, NPKs are light gray or light brown, and MOP is reddish. Colors for a product may vary depending on differences in manufacturing processes or the use of color codes used by manufacturers, but a person familiar with the fertilizers commercialized in an area would be able to identify atypical colors among the most common products traded in the area. Atypical colors may be an indication of the presence of fillers, impurities, or strange materials and possible adulteration of the product. Darker colors than usual may also be an indication of high moisture content. Record fertilizer color in the format for physical properties (Table A5).

Fillers are materials added to fertilizer blends to obtain the right proportion of nutrients associated with the fertilizer grade within a given volume or weight of the fertilizer product. Usually, the straight granulated NPK products and urea do not contain fillers; the presence of fillers in bags of these products may be evidence of adulteration. The presence of filler and its percentage if specified in the bag label should be recorded in the questionnaire for physical properties (Table A5).

Critical relative humidity is the relative humidity at which a fertilizer starts absorbing moisture from the environment. The critical relative humidity is a function of temperature and depends on the hygroscopic characteristics of the constituents of each fertilizer. Tables of critical relative humidity for different fertilizers are usually reported at 30°C.

The moisture content can be qualitatively assessed by observation of color and fluidity and by feeling the fertilizer sample. Granules of a dry fertilizer sample flow freely through the sampling probe, and the dryness can be felt when touched. On the other hand, moisture present in a fertilizer can be felt when touched and can be observed since a wet fertilizer becomes darker than the original color of the product when dry. Also a wet fertilizer has lower fluidity through the sampling probe, to the point of clogging the probe when the moisture content is high. The sample must preserve the original moisture content, packing it in two plastic bags with perfect sealing. Mark with an 'X' one of the categories in the format for physical properties (Table A5).

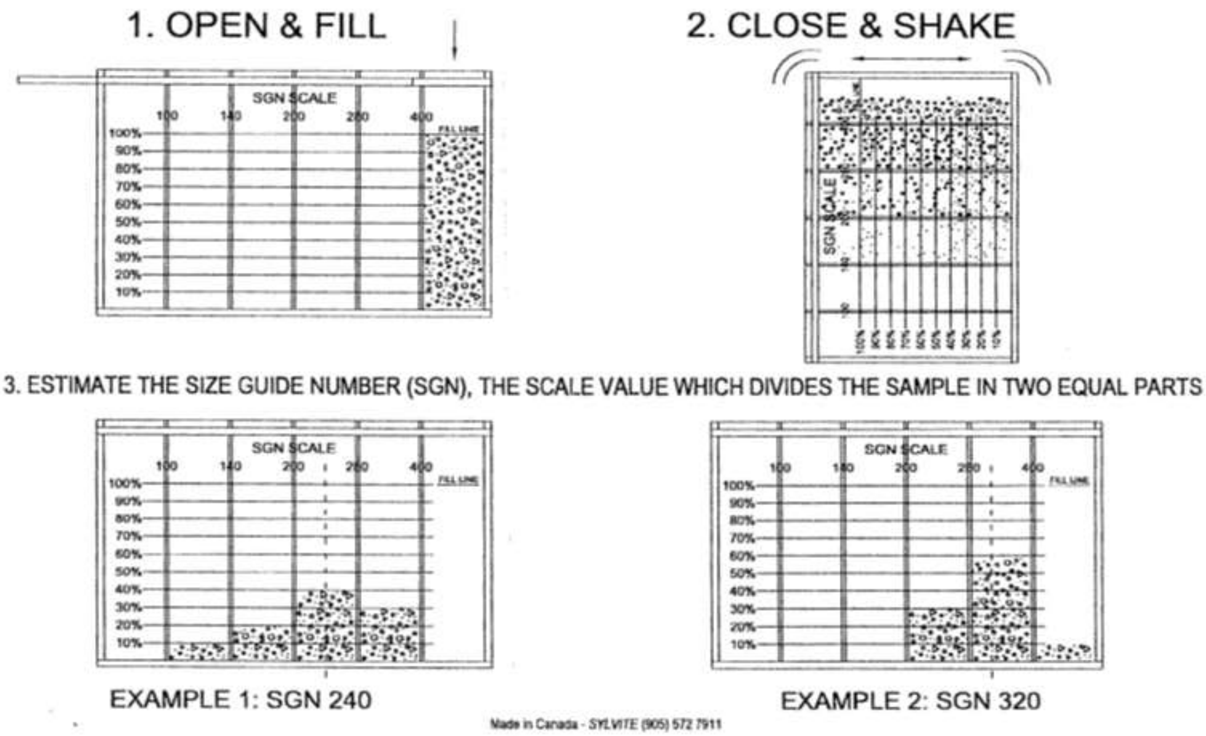
Caking occurs when the individual granules of the product fuse to form larger aggregates. In extreme cases of caking, entire bags become one solid body. Caking usually takes place when the fertilizer product gets in contact with water or when it absorbs moisture from the air due to storage in conditions of high relative humidity and permeable bagging materials. Another factor contributing to caking is the pressure exerted by stacked bags. It can be qualitatively assessed through observation of the bags and touching. Fertilizer bags usually are deformed by caked products. Mark with an 'X' one of the categories in the format for physical properties (Table A5).

Impurities are strange substances that get mixed with the fertilizer during deficient manufacturing procedures or as a result of management practices that compromise quality. When products are spread on the ground, a common practice among small retailers (to dry, to break conglomerates, to make blends), fertilizers may become contaminated with soil, plant tissues, or other materials. Fillers and impurities should not be confounded. Fillers are present in relatively large quantities and tend to be uniformly distributed in the entire volume of fertilizer. Impurities are present in small quantities and their distribution is not uniform. Record the presence or absence of impurities in the format for physical properties (Table A5).

Sieve Boxes for Quantification of Segregation and Granular Degradation

Proxy methods for assessment of these two physical properties in the field, they are based on the separation of granules of different size. There are other laboratory methods of high precision and accuracy.

Operation of the Boxes



Estimation of Segregation (Example)

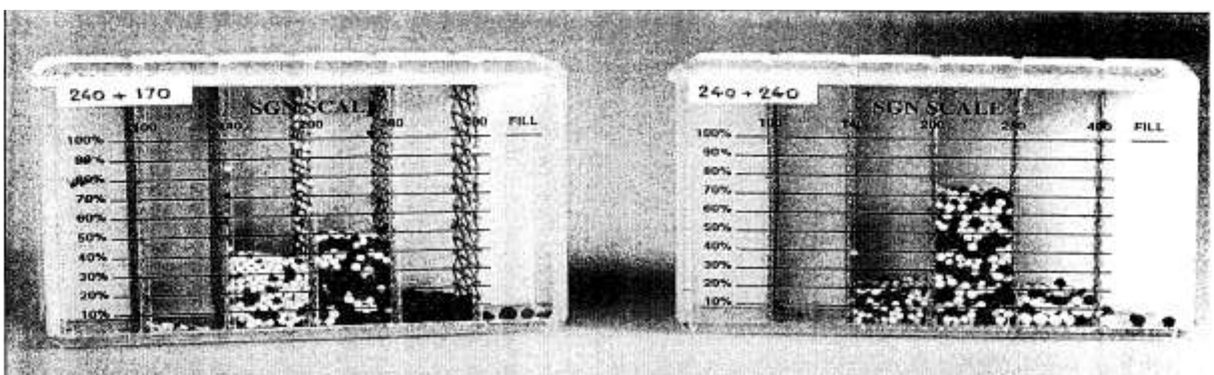


FIG. 7-2. TESTING FOR SEGREGATION

There is no segregation in the box tagged 240 + 240. But the box tagged 240 + 170 shows segregation between the white material SGN 170 and the grey material SGN 240.

- **A segregated fertilizer** will show a very asymmetrical distribution with large granules located at the right of the box and small granules at the left. The types or color of granules will be well separated. **A non-segregated fertilizer** will show all the granules in few columns, usually three or four, all the columns showing about the same composition of granules (colors) in a symmetric arrangement.
- After the sample is processed, the fines and dust will be located at the extreme left of the whole granule column or columns. The smaller the height differences of the columns at the left with the columns containing the whole granules the **higher the granule degradation**. Samples with **good granule integrity**, meaning very little amounts of fines and dust, show little or no particles at the left end of the sieve box.

Appendix C

Table C1. Frequency and Severity of the Three Macronutrients in All Fertilizers Samples Analyzed

		Total N					K_2O		
TYPE	FERTILIZER	n Samples	% ooc[1]	Shortage Mean (%)[2]	% ooc[1]	Shortage Mean (%)[2]	n Samples	% ooc[1]	Shortage Mean (%)[2]
GRANULATED	DAP 18-46-0	215	3.7	-1.5	22	-4.3	.	.	.
	CAN 26-0-0	62	14.5	-4.4	.	.	.	.	.
	NPK 23-23-0	34	11.8	-4.7	8	-4.6	.	.	.
	UREA	31	6.5	-1.2	.	.	.	.	.
	NPK 17-17-17	22	31.8	-3.3	8	-3.3	22	63.6	-2.4
	NPK 10-26-10 Mavuno	9	0	0	1	-2.4	9	22.2	-2.8
	AS 21 0 0 24	4	25.0	-2.5	.	.	.	.	.
	KCl	4	.	.	.	.		.	-3.1
	NKP 15-15-15	3	33.3	-1.4	1	-4.7	3	0	0.0
CRYSTAL	NPK 14-11-33 EASY GROW	8	50	-1.5	3	-1.9	8	87.5	-2.6
	NPK 27-10-16 +TE EASY GROW	7	71.4	-2.3	2	-3.4	7	85.7	-2.2
	NPK 18-20-21 +TE EASY GROW	6	66.7	-2.3	1	-9.5	6	66.7	-1.7
	NPK 13-2-44 Multi-NPK	5	20	-2.8	0	0.0	5	40	-1.4
	NPK 15-5-35 +MgO+TE AGRIGROW	4	25	-7.6	0	0.0	4	50	-4.1
	NPK 15-9-20 Omex	2	50	-1.5	0	0.0	2	0	0.0
LIQUID	NPK 12-10-8 + TE AGROFEED	5	100	-3.6	4	-4.3	5	100	-3.2
	NPK 20-20-20 Diamond Plant	5	100	-9.1	5	-11.3	5	100	-14.3
	NPK 10-10-10 Crop Sta	3	33.3	-5.4	0	0.0	3	66.7	-3.1
	NPK 14-12-8 Booster Extra Foliar Feed	3	66.7	-8.7	2	-9.8	3	100	-4.2
	NPK 22-21-17 Murphy Foliar Feed	2	100	-4.3	2	-3.8	2	100	-2.2
	NPK 25-5-5 +Na+Se Booster	2	100	-22.5	2	-4.8	2	100	-4.3
	NPK 12-10-8 Osho Agrofeed	2	100	-6.3	1	-9.8	2	100	-4.8
	NPK 19-19-19 +Te Super Nguvu	2	100	-18.6	1	-18.8	2	100	-18.8
	NPK 19-19-19 Tomex	2	100	-10.7	2	-11.5	2	100	-15.4
	NPK 19-19-19 Laibuta	2	100	-16.4	2	-18.2	2	100	-16.7
	NPK 22-20-20 Beta Booster	2	100	-21.1	2	-19.5	2	100	-19.6

[1] Out of Compliance. [2]Tolerance Limit is 1.1%

Table C2. Geographical Distribution of Total N Shortages in Fertilizers Sampled Across Kenya

Province	County	n	N Defficiency %
CENTRAL	KIAMBU	2	-5.7
CENTRAL	KIRINYAGA	6	-10.1
CENTRAL	MURANGA	6	-2.8
CENTRAL	NYERI	5	-4.1
COAST	KILIFI	3	-2.4
COAST	TAITA TAVETA	1	-2.2
EASTERN	EMBU	1	-22.9
EASTERN	KITUI	1	-1.2
EASTERN	MACHAKOS	2	-9.6
EASTERN	MAKUENI	4	-0.8
EASTERN	MERU	2	-2.7
NYANZA	KISII	4	-2.5
NYANZA	KISUMU	1	-1.4
NYANZA	MIGORI	1	-12.7
NYANZA	NYAMIRA	1	-0.7
NYANZA	SIAYA	1	-1.9
RIFT VALLEY	BARINGO	1	-1.2
RIFT VALLEY	ELGEYO MARAKWET	3	-2.5
RIFT VALLEY	NAKURU	2	-0.9
RIFT VALLEY	NANDI	2	-4.3
RIFT VALLEY	NAROK	2	-0.6
RIFT VALLEY	UASIN GISHU	5	-8.8
WESTERN	BUNGOMA	7	-6.5
WESTERN	KAKAMEGA	3	-1.0
WESTERN	VIHIGA	5	-8.3

Table C3. Geographical Distribution of Bag Weight Shortages Across Kenya

Province	County	Shortage %	n
WESTERN	BUNGOMA	2 to 12	6
NYANZA	KISII	1 to 6	5
RIFT VALLEY	NAROK	1 to 6	4
RIFT VALLEY	NAKURU	1 to 6	2
RIFT VALLEY	UASIN GISHU	1 to 5	4
WESTERN	KAKAMEGA	3 to 4	2
WESTERN	VIHIGA	2 to 5	4
RIFT VALLEY	ELGEYO MARAKWET	2 to 5	3
EASTERN	MAKUENI	1 to 4	3
EASTERN	MACHAKOS	1 to 4	3
COAST	KWALE	8	1
RIFT VALLEY	BARINGO	6.4	1
CENTRAL	NYERI	4	1
RIFT VALLEY	NANDI	4	1
CENTRAL	MURANGA	3	1
COAST	KILIFI	2.4	1
CENTRAL	KIRINYAGA	2	1

Table C4. Differences of Secondary and Micronutrient Contents Relative to the Label Specification in Granulated Fertilizers

		Differences relative to Label especification			
FERTILIZER	n Samples	S	Ca	Zn	B
SOLUBOR 20.5%B	1				-1.6
NITRABOR 15.5%N+18%Ca+0.3%B	1		7.4		
CAN 26 0 0 6%CaO	62		0.4		
AS 21 0 0 24%S	4	-0.3			
NPK 23 10 5 3%S 0.3%Zn	3	-0.3		-0.2	
NPK 14-0-2+13%Ca	1		7.5		
NPK 15-9-20+3%S	1	1.1			
NPK 23-10-5 +3%S+0.3%Zn	1	-0.3		0.0	
NPK 23-10-5+3%S	1	0.1			
SSP 18%/21.5%P 12%S 24%Ca	2	-4.1	-6.9		
Sulfan 24%N 6%S	2	-0.2			