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FERTILIZER QUALITY ASSESSMENT IN MARKETS OF UGANDA

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Acronyms and Abbreviations

BWS	Bag Weight Shortage
CAN	Calcium Ammonium Nitrate
Cd	Cadmium
CFDF	Cumulative Frequency Distribution Function
COMESA	Common Market for Eastern and Southern Africa
CRH	Critical Relative Humidity
DAP	Diammonium Phosphate
EAC	East African Community
FDF	Frequency Distribution Function
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
IFDC	International Fertilizer Development Center
IP	Impermeable Inner Layer
KEBS	Kenya Bureau of Standards
kg	kilogram
KS	Kenya Standard
MAAIF	Ministry of Agriculture, Animal Industry, and Fisheries
mg	milligram
mL	milliliter
N	Nitrogen
NPK	Nitrogen, Phosphorus, and Potassium
OL	Laminated Outer Layer
OOC	Out of Compliance
OW	Outer Woven
ppm	parts per million
PVoC	Pre-Export Verification of Conformity
RH	Relative Humidity
S	Sulfur
TL	Tolerance Limit
USAID	U.S. Agency for International Development
WTL	Weight Tolerance Limit
Zn	Zinc

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Executive Summary

With funding from the United States Agency for International Development (USAID), the International Fertilizer Development Center (IFDC) is conducting a series of fertilizer quality assessments in Eastern and Southern Africa. Despite Uganda's relatively small fertilizer market and low fertilizer consumption, it was selected for the assessment because the small fertilizer market and simple value chains exhibit characteristics that may influence fertilizer quality. In addition, there is potential for increasing consumption as imports have been increasing for the last decade with substantial fertilizer trade activity across its borders, mainly Kenya and Tanzania.

The objectives of these studies are to conduct fertilizer quality diagnostics that reveal detailed quality conditions in the value chains of country members of the Common Market for Eastern and Southern Africa (COMESA) and East African Community (EAC) and to use this information to recommend policy solutions for the problems identified. These solutions are targeted at reforming regulations and policies both at country and regional levels. Crafting solutions only for in-country quality problems would be insufficient given the existence of significant fertilizer trade between neighboring countries.

The IFDC fertilizer quality assessment team first trained a group of 29 oficials of the Uganda Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) to perform the role of quality inspectors and collect samples from fertilizer markets in various regions of the country. Then, a random approach was used to select fertilizer dealers and collect fertilizer samples for chemical analyses. Data were also collected on fertilizer markets, dealers, physical properties of the products, and storage conditions from the sample of dealers. After conducting chemical analyses on fertilizer samples in the labs, the estimated nutrient content for fertilizers and cadmium (Cd) content were then incorporated into the dataset for analysis.

Based on the number of samples collected from the fertilizers available in the markets, the fertilizers were classified as "large trade" or "low trade." The large trade fertilizer group included diammonium phosphate (DAP), urea, NPK 17-17-17, calcium ammonium nitrate (CAN), NPKS 25-5-5+5S, and ammonium sulfate. The low trade fertilizer group included numerous products with nutrient content in a wide range of grades and in the form of granulated, liquid, crystal, and powder fertilizers.

Nutrient content shortages in fertilizers were quantified in terms of frequency (how often they occur) and severity (the extent to which the shortages are out of compliance). The total nitrogen contents out of compliance (OOC) for DAP, 17-17-17, and 25-5-5+5S were 0%, 13%, and 27%, respectively; the severities for total nitrogen OOC in the same fertilizers were 0%, -1.7%, and -3.9%, respectively. Available phosphorus (P_2O_5) shortages OOC for the same fertilizers were 6%, 0%, and 12%, respectively, and the shortage severities were -2.5%, 0%, and -2.3%, respectively. Soluble potassium (K_2O) OOC shortage frequencies were 9% and 0% for 17-17-17 and 25-5-5+5S, respectively, and the OOC severities for the same nutrient and fertilizers were -5.5% and 0%, respectively. Total nitrogen OOC shortages in urea and ammonium sulfate were 10% and 0%, respectively. Total nitrogen OOC shortages occurred in four CAN samples out of 10. The OOC shortage severities of total nitrogen in urea, ammonium sulfate, and CAN were -1.25%, 0%, and -1.01%, respectively.

The liquid fertilizers had significantly higher frequencies and severities of nutrient shortages OOC than the granulated fertilizers; among the granulated products, the set of fertilizers of low commercialization presented higher frequencies and severities of nutrient content shortages OOC than

the set of fertilizers of high commercialization. This difference suggests the volume or market share of the products is related to the quality, that products with higher market share show evidence of being manufactured with more care than products of low market share, and/or products with higher market share are less affected by quality-influencing factors along the distribution chain.

Ten percent of the fertilizer bags used for weight verifications presented weight shortages beyond the 0.5-kilogram (kg) tolerance limits. Since Uganda has negligible re-bagging of 50-kg bags, the weight shortages must originate in the manufacturing plants or in the in-country bagging of fertilizers that are imported in bulk.

Most storage areas used by wholesalers and retailers do not regulate the temperature and relative humidity (RH) to the level required for the preservation of the physical and chemical properties of fertilizers, but due to appropriate granulation and the good quality of the bags used, cases of moist fertilizers, caking, and granular degradation in the fertilizers found in Ugandan markets were identified with low frequency. For these reasons, the nutrient content shortages found can hardly be attributed to degradation of physical properties.

No evidence of fertilizer adulteration was found in the sampling and inspection of 50-kg bags, which make up more than 90% of fertilizers traded in Uganda. Exiting literature reports that have identified adulterated fertilizers in bags containing 1-5 kg base their conclusions only on chemical lab results. Additional verification to identify and quantify foreign materials that may have been used to dilute nutrient content is needed to ensure that the out-of-compliance shortages are not due to manufacture deficiencies or uncontrolled variability in chemical analysis. Even if adulteration in small fertilizer packs is proven, it is far from being a significant source of fertilizer quality problems in Uganda given the small fraction of the total trade represented by these small packs. Only 8% of smallholder farming households use inorganic fertilizers,[1] and their use is very low at about 1 kg of nutrient per hectare per year.[2]

After discarding degradation of physical properties and adulteration in 50-kg bags as reasons for fertilizer nutrient content shortages, then what is left as the most likely cause is deficient manufacture of some of the imported fertilizers and inadequate port inspection.

Cadmium is a toxic element that can accumulate in soil and crop products. The maximum cadmium content found in fertilizers containing P_2O_5 in Uganda was in a DAP sample with 23 parts per million (ppm) of Cd or 10.7 milligram (mg) Cd per kg P_2O_5. These two values are below the Kenya tolerance limit of 30 ppm and the European tolerance limit of 20 mg Cd/kg P_2O_5. The relatively small difference between the maximum Cd found in the fertilizers commercialized in Uganda and the international tolerance limits (TLs) justify continuing to monitor closely the Cd content and the origin of the phosphate rock used in the manufacture of fertilizers, since Cd content in phosphate rock varies with the location and type of deposit.

On the regulatory side, the findings of this study point to the need for quality inspections at both domestic and international levels, because some of the quality issues identified may be connected to manufacture or points on the value chain outside of Uganda. It is also important to teach farmers that even with good quality fertilizers, raising yields to desirable levels requires a holistic approach to crop management that includes fertilizer use at rates suggested by soil characteristics and crop balance nutrition needs and the use of good quality seeds and crop protection inputs at the right rates and times.

[1] Okoboi, G., and M. Barungi. 2012. "Constraints to Fertilizer Use in Uganda: Insights from Uganda Census of Agriculture 2008/09," *Journal of Sustainable Development*, 5(10):99-113.

[2] MAAIF. 2014 (March draft). *Uganda National Fertilizer Sub-Sector Development Strategy and Investment Plan (NFS): 2014/15 - 2018/19*, Republic of Uganda, Ministry of Agriculture, Animal Industry and Fisheries (MAAIF).

1. Introduction

Uganda's economy depends on agriculture. It employs 72% of the population, contributes 22.2% of the gross domestic product, and generates 42% of the national income from exports. From the 34.9 million inhabitants of Uganda (2014), 4.2 million people, or 12% of the population, are smallholder farmers (Godfrey and Dickens, 2015).[3]

While Uganda has one of the highest soil nutrient depletion rates in the world, its farmers use less than 1 kg of inorganic fertilizers per year (Henao and Baanante, 2006).[4] Better access to crop production support services and facilities, such as credit, irrigation, and storage, as well as access to input and output markets that will significantly increase fertilizer adoption (Okoboi and Barungi, 2012),[5] but most farmers in Uganda do not use fertilizer due to its high cost and lack of information and technical advice on its use. Fertilizer use is increasing as imports were 53,447 metric tons in 2013, an increase of 9% from 2012 (Godfrey and Dickens, 2015).[3]

To increase the growth rate of Uganda's agricultural sector from 2.6% to the desirable 4% per year, research is needed to determine how best to increase the use of productivity-enhancing inputs, such as inorganic fertilizer. Fertilizer has been and continues to be a key ingredient in intensified agricultural systems and has helped farmers in other parts of the world overcome land constraints and improve aggregate production (Bumb and Baanante, 1996).[6]

Over 70% of smallholder farmers in Uganda practice subsistence agriculture with limited incomes and poor purchasing power to stimulate effective demand. Most of these farmers lack the requisite knowledge on how to use fertilizer properly (Godfrey and Dickens, 2015).[3]

The International Fertilizer Development Center (IFDC) conducted this fertilizer quality assessment with funding from the United States Agency for International Development (USAID). The objective was to make a quality diagnostic and identify factors associated with fertilizer properties and with distribution chain characteristics that contribute to the quality of fertilizers found in the markets. A report of the findings from this assessment will be provided to the Uganda Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) to guide the government in developing or making the necessary reforms to strengthen the regulatory system. The report also will be shared with the Common Market for Eastern and Southern Africa (COMESA) to support the development of a regional fertilizer quality regulatory system for the member states of the economic community.

1.1 The Regulatory and Policy Environment

Fertilizer has not played a significant role in boosting agricultural production in Uganda due to very low adoption and consumption rates[7] compared to neighboring countries. The soils in Uganda are depleted at an average of 80 kg of nutrients per hectare annually.[8] Less than 8% of households use fertilizers and at low application rates. A major constraint is poor knowledge at the farm level on the benefits of fertilizer and agronomic practices required to achieve high productivity. This has led to low adoption rates.

In order to provide an organized framework for stakeholders in the industry, the Ugandan Cabinet

[3] Godfrey, S., and Dickens, O. 2015. *Fertilizer Consumption and Fertilizer Use by Crop in Uganda*, Ministry of Agriculture, Animal Industry and Fisheries.
[4] Henao, J., and C. Baanante. 2006. *Agricultural Production and Soil Nutrient Mining in Africa: Implications for Resource Conservation and Policy Development*, IFDC Technical Bulletin.
[5] Okoboi, G., and M. Barungi. 2012. "Constraints to Fertilizer Use in Uganda: Insights from Uganda Census of Agriculture 2008-9," *Journal of Sustainable Development*, Vol. 5 No. 10.
[6] Bumb, B.L., and C.A. Baanante. 1996. *World Trend in Fertilizer Use and Projection to 2020*. IFPRI 2020 Vision, Brief 38.
[7] IFDC. 2014. "Uganda Fertilizer Assessment," https://ifdc.org/country-fertilizer-market-assessments/.
[8] Uganda National Fertilizer Policy. 2016. http://eprcug.org/research/agriculture/405-maaif-eprc.

approved the National Fertilizer Policy in 2016 after a consultative process led by the Economic Policy Research Center (EPRC) of Makerere University and MAAIF with financial support from the Alliance for a Green Revolution in Africa (AGRA). The consultations with stakeholders, including policymakers, began in 2010 with the objective to improve regulations, policy, and strategies, highlighting the importance of fertilizer use for improved soil fertility and agricultural yields.

On the regulatory side, the Agricultural Chemicals (Control) Act of 2006 provides guidelines on the control and regulation of agricultural chemicals from manufacture, import, and distribution to retail. The Act details the roles of management and inspection units in making sure farmers access good quality fertilizers. The policy and regulatory frameworks are important pieces in the overall strategy to provide an enabling environment that will encourage private sector participation and investment in the fertilizer sub-sector accompanied with appropriate government oversight. The findings from this survey will hopefully contribute to informing MAAIF on areas to focus attention in the implementation of regulatory activities, including inspections.

1.2 Methodology for Data and Sample Collection

1.2.1 Training of Fertilizer Quality Inspectors

Before conducting the field survey to collect data and fertilizer samples in the fertilizer markets of Uganda, the IFDC team of experts conducted a four-day training session for 29 employees of MAAIF working in different agricultural areas of the country and in activities related to agriculture extension, agriculture inspection, or administration. The title or specialty of fertilizer quality inspector, as such, does not exist within MAAIF. The 29 participants were trained to operate as fertilizer quality inspectors during the study and to potentially continue in this role during the implementation of existing or to-be-developed fertilizer quality assurance policies. Those trained are also expected to become trainers for additional fertilizer quality inspectors as part of the implementation of government policies. The key topics addressed in the training were:

- Description and quantification of chemical and physical fertilizer properties that define the quality of the products.
- Description and assessment of management practices that affect fertilizer quality: conditions of storage, bagging, and handling.
- Method for sampling fertilizer dealers (wholesalers, retailers of different sizes).
- Methods for sampling granulated and liquid products in warehouses or retailer shops.
- Digital system for collection of data associated with product characteristics, management conditions, and value chain characteristics that influence fertilizer quality.
- Basic statistical methods for data analysis and identification of factors associated with fertilizer quality problems.
- Concepts about fertilizer quality policies and fertilizer quality regulatory systems.

1.3 Sampling Methodology

The sampling methodology employed for the Uganda Fertilizer Quality Assessment is diagrammed in Figure 1. It basically 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 Uganda and the random sampling of fertilizers inside dealers' shops result in the collection of data and fertilizer samples that are representative of the fertilizer quality in the markets of Uganda.

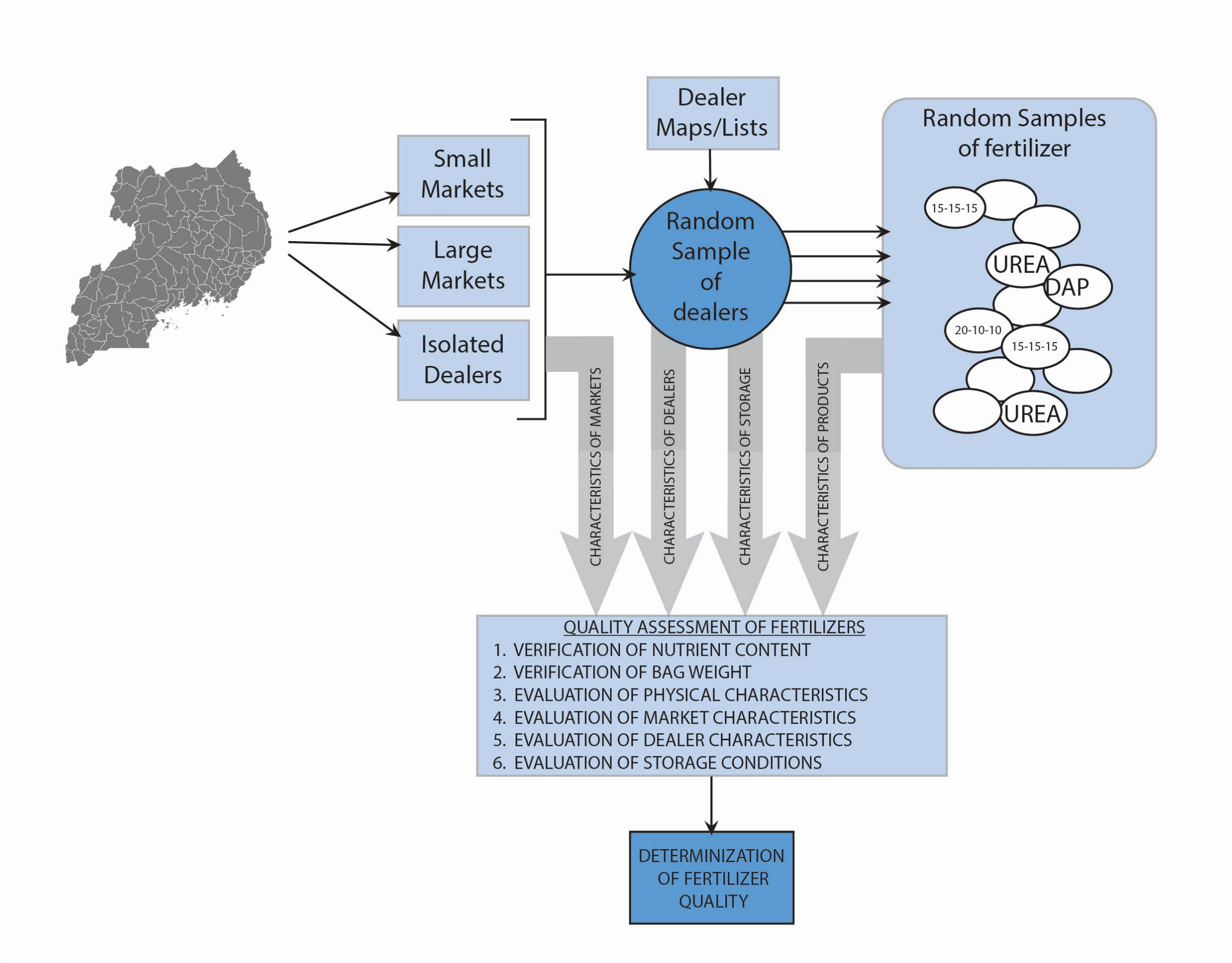


Figure 1. General Methodology for the Quality Assessment of Fertilizers Commercialized in Uganda

Collection of data about characteristics of fertilizer products, management, markets, and dealers is performed in parallel with the fertilizer sampling during the visits to sample fertilizer dealers.

1.3.1 Random Sample of Dealers

A list of 642 agro-dealers classified by region (Central, Eastern, Northern, and Western) provided by the MAAIF was the basis to define a conceptual population of fertilizer dealers in the country. The fertilizer dealer sample size was determined based on the sampling capability of four 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 distance between dealers. The random process for selecting the sample portion for each inspection team was weighted per the number of dealers in each region, 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 120 dealers, equivalent to 18% of the total number of dealers listed. The sample comprised 47 dealers from the Central Region, 27 from the Eastern Region, 25 from the Northern Region, and 21 from the Western Region. Each agro-dealer in the sample was visited by an inspection team that conducted sampling of the fertilizers available in the shop and collected data. Each 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 for dealers that could not be found or that did not have fertilizers available for sampling at the time of the inspectors' visit.

1.3.2 Random Sample of Fertilizers and Data Collection Inside Shops/Warehouses

Fertilizer sampling and data collection were performed in each of the dealer shops that made up the sample. The inspection teams collected fertilizer samples following the sampling procedures specified in Appendix A and collected data about the following aspects using the procedures outlined in Appendix A.

- Market location and characteristics of the market: country, region, 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 outside a city or town; 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 owners' or shop attendants' knowledge about fertilizers, training level on fertilizers, possession of a license to sell fertilizers, type of customer, and business status (see Table A2 in Appendix A). The answer options in the questionnaire are intuitive, except for the shop owners' or attendants' 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, manual or mechanized fertilizer handling, use of pallets, height of stacks, general housekeeping conditions (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 properties: 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.

1.4 Chemical and Physical Analysis of Fertilizer Samples

1.4.1 Chemical Analysis of Fertilizers

There are just a few laboratories able to analyze fertilizers in Kampala; one of them is owned by the Ministry of Health but the team was not able to observe the facilities due to safety protocols. The other lab with fertilizer analysis capabilities belongs to the School of Agricultural Sciences in Makerere University. After conversations with the professor in charge of the lab and with the lab manager, the team was able to verify the lab's extensive experience in analyzing fertilizers as part of university research activities and services provided to the government and commercial farmer organizations. The lab manager provided evidence of being an expert in the methodologies used for the analysis of the different nutrient groups found in fertilizers and showed us the equipment available in the laboratory. The equipment is antiquated and allows the lab to analyze no more than ten samples a day. Seventy samples out of 201 samples collected in Uganda were left to be analyzed at the Makerere

University laboratory to meet the objective of building local capacity in the country. The rest of the fertilizer samples collected by the study were analyzed at 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), magnesium (MgO), or zinc (Zn) contents were reported were also analyzed for these nutrients.

Analysis of cadmium (Cd) was performed in a subset 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.

Analytical methodologies used at the IFDC laboratory included 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, MgO, Zn, and Cd.

1.4.2 Physical Analysis of Fertilizers

The assessment of the physical properties of fertilizers was conducted as specified in Appendix B. Table A5 was loaded in the smart phones used by the inspectors to capture the physical properties of fertilizers.

1.5 Data Analysis and Interpretation

1.5.1 Nutrient Content Compliance

Frequency analysis was used to estimate the frequency of out of compliance shortages of total N, P_2O_5, K_2O, S, and CaO content. The severity of nutrient content shortages was estimated as the average nutrient content of the samples out of compliance.

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 black lines on the CFDF indicate the TL and the projection of the colored lines toward the Y axis indicate the frequency or 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.

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:

$$F(X < TL) = f \quad (1)$$

Where **F** is the CFDF.

X is the variable associated with the difference between nutrient content determined by the lab and the nutrient content specified in the bag label, or actual bag weight minus label-specified weight.

X is a shortage if $X < 0$

TL is the shortage tolerance limit for a particular nutrient

A shortage is Out of Compliance (OOC) **if X < TL**

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

Example: The frequency of total N content out of compliance in Figure 3 is:

$F(N_{17\text{-}17\text{-}17} < -1.1) = 14\%$

$F(N_{25\text{-}5\text{-}5} < -1.1) = 28\%$

$F(N_{18\text{-}46\text{-}0} < -1.1) = 0\%$

The shortage severity (SS) is calculated as follows:

$$SS = (\sum_{p}^{i=1} X_i/p) \quad (2)$$

Where X_i are the nutrient shortages lower than TL and p is the number of values lower than TL.

Example: SS for total N in 17-17-17 is -1.71% (Figure 3A); SS for P_2O_5 in DAP is -2.47% (Figure 3B).

At the time this report was written, the Ugandan Government had no provisions for the tolerance limits of nutrient content in fertilizers. Considering that there are efforts to harmonize the key elements of fertilizer quality regulatory systems among country members of COMESA, the team decided to use the Kenya macronutrient content tolerance limits established in the Kenya Standard (KS) 158:2011[9]. This Kenyan standard does not make specifications about tolerance limits for secondary nutrient content in fertilizer; for this reason, the secondary nutrient tolerance specification limits of the Economic Community of West African States (ECOWAS) regulatory framework was used in this study.[10] Total N, P_2O_5, and K_2O content shortages in solid compound fertilizers must have a maximum limit of 1.1%. The standard established for minimum content limits for secondary and micronutrients are indicated in Table 1.[11]

Table 1. Tolerance Limits Used by the Economic Community of West African States

Nutrient Type	Nutrient	Tolerance
Macronutrient	Total nitrogen (N)	1.10%
	Phosphorus (P_2O_5)	1.10%
	Potassium (K_2O)	1.10%
Secondary nutrient	Calcium (Ca)	0.2 unit + 5% of guarantee
	Sulfur (S)	0.2 unit + 5% of guarantee
	Magnesium (Mg)	0.2 unit + 5% of guarantee
Micronutrient	Boron (B)	0.003 unit + 15% of guarantee
	Cobalt (Co)	0.0001 unit + 30% of guarantee
	Molybdenum (Mo)	0.0001 unit + 30% of guarantee
	Chlorine (Cl)	0.005 unit + 10% of guarantee
	Copper (Cu)	0.005 unit + 10% of guarantee
	Iron (Fe)	0.005 unit + 10% of guarantee
	Manganese (Mn)	0.005 unit + 10% of guarantee
	Sodium (Na)	0.005 unit + 10% of guarantee
	Zinc (Zn)	0.005 unit + 10% of guarantee

[9] KEBS. 2011. Kenya Standard (KS) 158:2011. *Solid Compound Fertilizer – Specification*. Fourth Edition.
[10] Sanabria, J., G. Dimithe, and E.K.M. Alognikou. 2013. *The Quality of Fertilizers Traded in West Africa: Evidence for Stroger Control*, IFDC.
[11] ECOWAS Tolerance Limits for Plant Nutrients, Heavy Metals and Bag Weight. Ref. Implementing Regulation ECW/PEC/IR/02/03/16.

1.5.2 Bag Weight Verification

Prior to sampling the first randomly selected bag of a fertilizer lot in a shop or warehouse, the weight declared on the fertilizer label is verified by weighing the bag. The weight reported on the label and the weight obtained from the scale are entered in the phone data collection system. Bag shortage is calculated, and the CFDF is developed. The CFDF graphs have the BWS in the abscissa and the cumulative frequency (percent) in the ordinate. The frequency of BWS was determined using the following general expression and 1% of the weight in the label as the weight tolerance limit (WTL) for bag weight shortage:

$$F(BWS \leq WTL\%) = f$$

In Figure 7, for example, it can be established that the frequency of 50-kg bags with shortages higher than 0.5 kg of the bag weight is 10%.

1.5.3 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%.

1.5.4 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 TL, and the variable became "No" when the nutrient content values were lower than the TL. 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 to the frequencies 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.

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 frequencies from the categories of each physical property, and the explanatory variables are the frequencies associated with the categories from the different storage conditions evaluated. Then, models were fit and tested as described in the previous paragraph.

1.6 Data Collection System

A digital system using smart phones was utilized to gather the data about market, dealer, management, and storage characteristics and fertilizer properties at every shop visited. Data is temporarily stored in the phones, then transmitted to the system platform using Wi-Fi connections or the telephone network to form a database. The database is ready to perform analysis right after the survey is completed. The digital system allows to check the data and supervise the work of the inspectors in real time as the data is collected from each dealer shop.

2. Results

2.1 Distribution of Fertilizer Samples

Seventy-eight percent of the fertilizers sampled in Ugandan markets were granulated for soil application in field crops while 22% of them were in liquid, crystal, or powder form for foliar or fertigation application in vegetables or other intensive and high-value crops (Figure 2A).

Fertilizers that were collected with very low frequency (e.g., one sample) are not included in the frequency analysis in Figure 2B. Diammonium phosphate (DAP) and urea are the products of highest commercialization in the fertilizer markets of Uganda. Figure 2B is underrepresenting the importance of urea, because the reduction of urea sampling, in purpose, is justified by the very rare occurrences of nitrogen shortages in this fertilizer. After urea and DAP, the fertilizers of higher trade in the country are the NPKs 17-17-17 and 25-5-5+5S, as well as CAN and ammonium sulfate. The higher the frequency associated with each fertilizer in Figure 2B, the higher the probability of finding each of the fertilizers in a fertilizer store in the markets of Uganda. These six fertilizers account for 74% of the granulated fertilizers commercialized in Uganda.

2.2 Nutrient Content in Fertilizers

Nutrient content shortages in fertilizers were quantified in terms of frequency, or how often they occur, and severity or the extent to which the shortages are OOC. The total nitrogen content OOC for DAP, 17-17-17, and 25-5-5+5S were 0%, 13%, and 27%, respectively; the severity for total nitrogen OOC in the same fertilizers were 0, -1.7%, and -3.9%, respectively (Figure 3A). P_2O_5 shortages OOC for the same fertilizers were 6%, 0%, and 12%, respectively, and the shortage severities were -2.5%, 0%, and -2.3%, respectively (Figure 3B). K_2O OOC shortage frequencies were 9% and 0% for 17-17-17 and 25-25-5+5S, respectively; the OOC severities for the same nutrient and fertilizers were -5.5% and 0%, respectively.

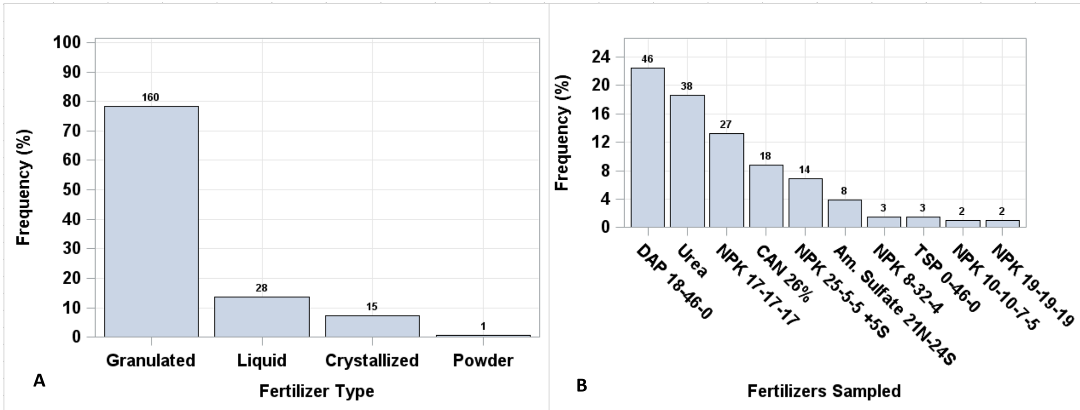


Figure 2. Relative Importance of Fertilizers Found in Ugandan Markets

Total nitrogen OOC shortages in urea and ammonium sulfate were 10% and 0%, respectively. Total nitrogen OOC shortages occurred in four CAN samples out of 10. The OOC shortage severity of total nitrogen in urea, ammonium sulfate, and CAN were -1.25%, 0%, and -1.01%, respectively (Figure 4A). The nitrogen content in urea is very difficult to alter, either during the manufacture or along the distribution chain. The three samples that apparently are OOC in Figure 4A very likely had total nitrogen content lower than the TL of 0.5% due to imprecision of the chemical analysis method. The ten samples of CAN are not enough to develop a strong statement about total nitrogen content in this fertilizer in the markets of Uganda. Sample size of ammonium sulfate, 25-5-5+5S, and CAN were not sufficient to construct reliable CFDFs for sulfur and CaO shortages in these three fertilizers.

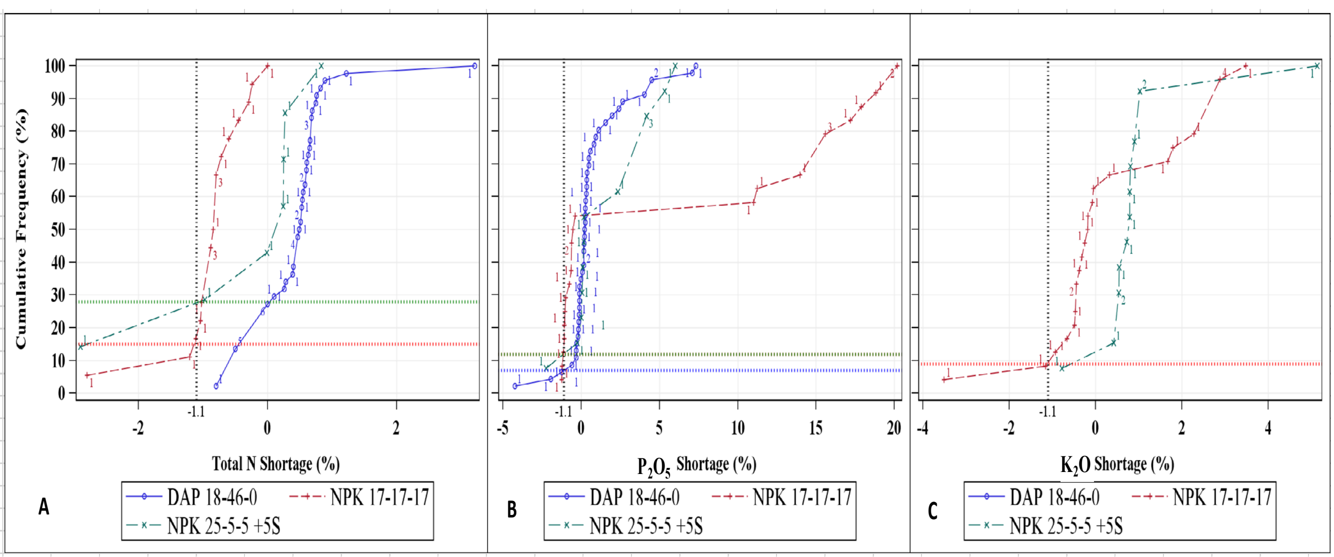


Figure 3. Cumulative Frequency Distribution Function for the Macronutrient Content of the Most Frequently Found NPK Fertilizers in Uganda

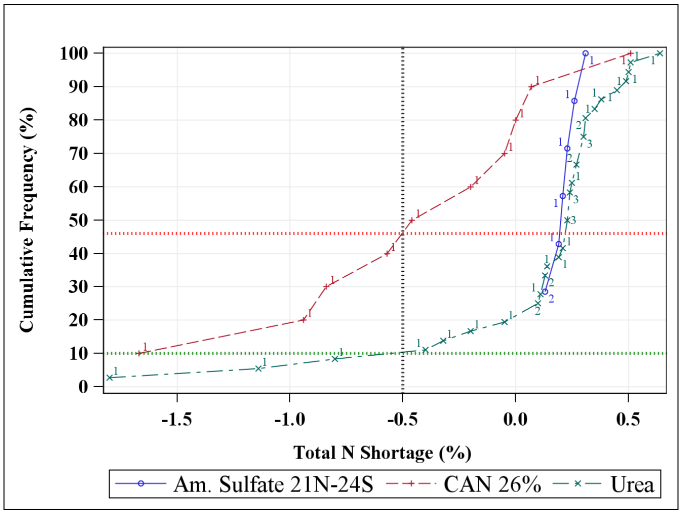


Figure 4. Cumulative Frequency Distribution Function for Total Nitrogen Content of Urea, Ammonium Sulfate, and CAN

Fertilizers other than urea, DAP, ammonium sulfate, 17-17-17, and 25-5-5+5S that are found in the Ugandan markets with low frequency (Figure 2A and Figure 2B) were grouped by type of fertilizer – granulated, liquid, or crystallized – to produce a CFDF by fertilizer type combining all the fertilizers of uncommon occurrence to analyze the frequency of shortages of total N, P_2O_5, and K_2O shortages. List of fertilizers with lower importance in Ugandan markets is in Table A6.

The liquid fertilizers have substantially higher frequencies of OOC nutrient shortages than the granulated fertilizers for the three macronutrients. The OOC shortage frequencies from liquids were 72%, 78%, and 48%, and the OOC shortage severities were -5.2%, -9.3%, and -7.4% for total N, P_2O_5, and K_2O, respectively. The OOC shortage frequencies from granulated fertilizers were 36%, 26%, and 26%, and the OOC shortage severities were -4.2%, -3.2%, and -2.2% for total N, P_2O_5, and K_2O, respectively. The crystalized products do not have enough samples for developing firm conclusions about nutrient shortages (Figure 5). The frequency of nutrient OOC shortages from the uncommonly found fertilizer products is substantially higher than in the commonly found products. This difference suggests that the importance of the products in the market has some effect on the quality, meaning that products of high commercialization show evidence of being manufactured with more care than products of low commercialization, and/or products of high commercialization are less affected by quality-degrading changes, mainly associated with management, along the distribution chain.

There were not sufficient fertilizer samples containing micronutrients to develop frequency distributions and to establish the frequency and severity of micronutrient shortages.

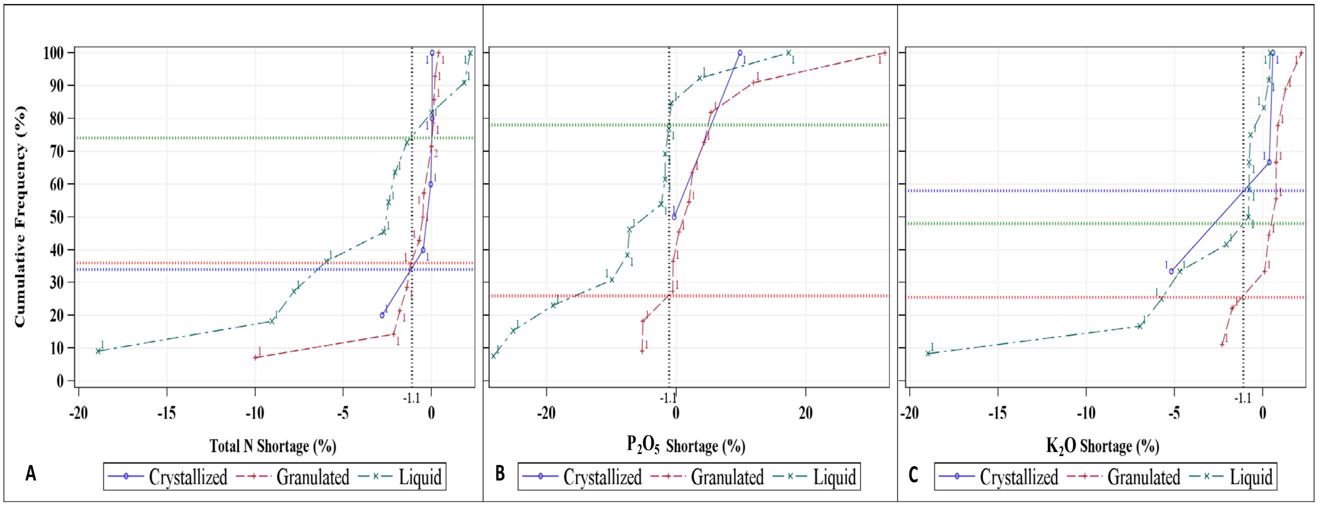


Figure 5. Cumulative Frequency Distribution Frequency from Combining Fertilizers Found with Low Frequency in Markets of Uganda for Frequency Analysis of Total N, P_2O_5, and K_2O Shortages

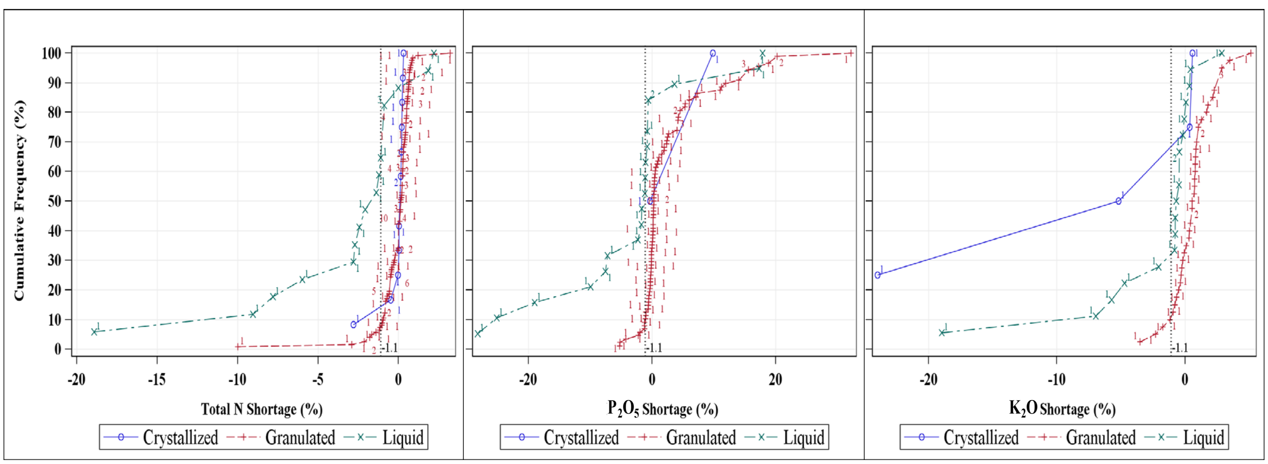


Figure 6. Comparison of Fertilizer Types with Respect to Total N, P_2O_5, and K_2O Shortages

Classification of the fertilizers sampled in Ugandan markets, according with their physical presentation as granulated, crystalized, or liquid (Figure 6), shows that the granulated products have considerably lower occurrence of OOC nutrient content shortages (number of points at the left of the -1.1 TL). Six percent and 60% were OOC for total N; 6% and 50% were OOC for P_2O_5; and 8.5% and 30% were OOC for K_2O from granulated and liquid fertilizers, respectively. OOC severities were also considerably lower in granulated fertilizers than in liquid fertilizers. There were not enough samples from crystalized fertilizers to develop well-grounded comparisons against the other two types of fertilizers.

2.3 Cadmium Content in Phosphatic Fertilizers

The maximum cadmium content found in phosphatic fertilizers traded in Uganda was in a DAP sample with 23 ppm of Cd or 10.69 mg Cd/kg P_2O_5 (Table 2). These two values are below the Kenya tolerance limit of 30 ppm and the European tolerance limit of 20 mg Cd/kg P_2O_5. The two highest Cd concentrations are not far from the international standards for Cd; this justifies continuing to monitor closely the Cd content in fertilizers and their origin since Cd content in phosphate rock varies with the location and type of deposit. Some of the highest Cd content found in phosphate originated in sedimentary rock deposits from Morocco.[12]

Table 2. Cadmium Content in Phosphatic Fertilizers Traded in Uganda

Fertilizer	Cd* (mg Cd*kg $P_2O_5^{-1}$)
DAP	10.69
DAP	8.64
DAP	1.39
DAP	1.24
DAP	1.21
DAP	1.18
DAP	1.16
DAP	1.11
DAP	1.05
DAP	1.02
14-14-20	0.09
23-10-5+3S+2MgO+0.3Zn	0.07

*From 27 samples analyzed, 15 had Cd contents below the detection limit.

2.4 Bag Weight Verification

The TL for weight shortages in international regulatory systems is 1% of the weight reported on the fertilizer label. In Uganda, 50-kg bags are dominant, and the maximum weight shortage allowed is 0.5 kg. A total of 120 randomly selected 50-kg bags were weighed during the survey, and 10% of them presented weight shortages higher than 0.5 kg OOC (Figure 7). Underweight bags may result from random errors in the filling or weighing of bags during manufacture or debagging, or they can be the result of deliberately putting less fertilizer in the bags. Unfortunately, the CFDF in Figure 7, with higher deviations toward overweighting than toward underweighting, does not allow to estimate the random error of filling/weighing the bags in order to estimate the frequency of deliberate filling of underweighted bags.

2.5 Fertilizer Storage, Packing Conditions, and Physical Properties of Fertilizers

Adequate moisture content was found in 80% of the fertilizers sampled; 15% of the sampled fertilizers had high moisture content and 5% had low moisture (Figure 8A). Most fertilizers sampled in Uganda had adequate moisture content mainly because appropriate bags were used to pack the fertilizers; 90% of the fertilizers were packed in bags that have a fiber woven outer (OW) exterior combined with a plastic impermeable inner (IP) layer, and 9% of the bags were laminated (OL), which is completely impermeable (Figure 8B). The OW exterior protects the bag from tearing or perforations that may occur during handling, and the IP layer protects the fertilizers from contact with free water and/or moisture vapor suspended in the air. The impermeable bags, either IP+OW or OL, were used in 99% of the bags sampled. These bags keep the moisture of fertilizers at appropriate levels (1.5% moisture or lower) even under storage conditions of high relative humidity (RH). An average of 55% RH was measured during the afternoon in the storage facilities visited in Uganda (Figure 10A). Sixty percent of the warehouses/shops inspected did not show RH reductions with respect to outside conditions during the afternoon (Figure 10B). The 20% of fertilizer bags with low or high moisture content could be explained by the use of torn bags (Figure 8C), bags with loose seams (Figure 8D), or bags with IP layers made with polyethylene that is too thin and allows water vapor to enter.

[12] Roberts, T.L. 2014. "Cadmium and Phosphorous Fertilizers: The Issues and the Science," *Procedia Engineering*, 83(2014):52-59.

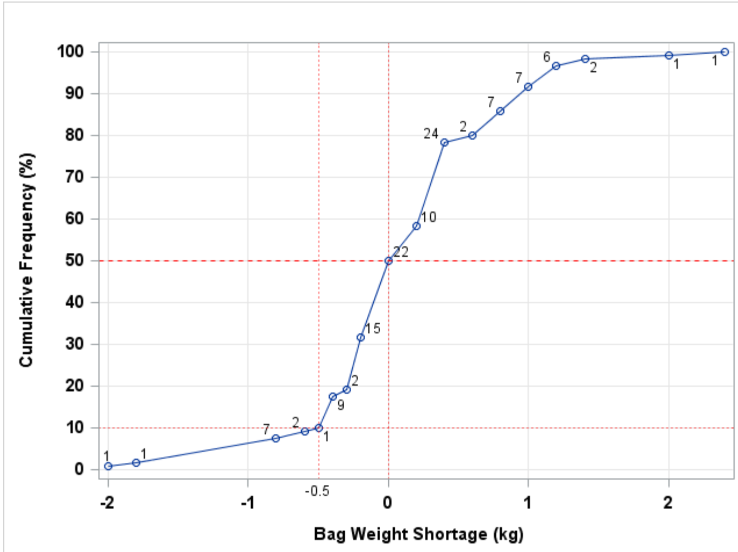


Figure 7. Fertilizer Bag Weight Verification in Markets of Uganda

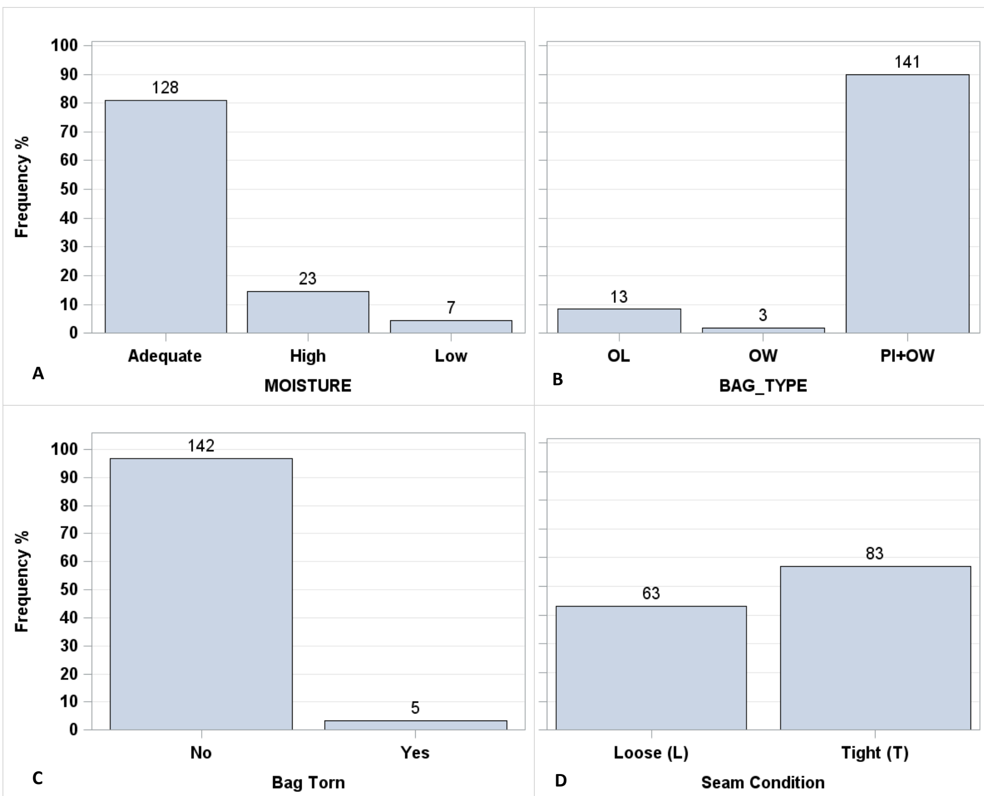


Figure 8. Frequency Analysis of Moisture Content and Fertilizer Bag Characteristics in the Fertilizer Markets of Uganda

Caking at several levels was found in 15% of the bags examined (Figure 9A); most of the high and medium levels of caking were identified in urea. The caking of fertilizers in the fertilizer markets of Uganda can be explained by the 20% of sampled fertilizer with higher than adequate moisture content in combination with the pressure exerted on fertilizer bags at the bottom of stacks that have ten bags or more. This situation was observed in 22% of the storage facilities visited in Uganda (Figure 9B). The absence or insufficient use of pallets in the storage facilities also contributes to the caking of fertilizers; 38% of the storage areas inspected in Uganda had few or no pallets in use (Figure 9C).

The elevated RH inside Ugandan storage areas, with a median of 55%, creates conditions appropriate for caking and granule degradation, particularly when other conditions, such as high bag stacks and non-impermeable bags, occur together. The 55% median RH inside storage areas coincides with the critical relative humidity (CRH) of fertilizers, such as 17-17-17, other NPK fertilizers of similar grade, and ammonium sulfate. These fertilizers start absorbing moisture from the environment when placed in an environment with 55% RH or higher and a temperature of 30°C or higher. Fifty percent of the storage facilities in Uganda meet this condition for this set of fertilizers to start caking and weakening the granule integrity (Figure 10A).

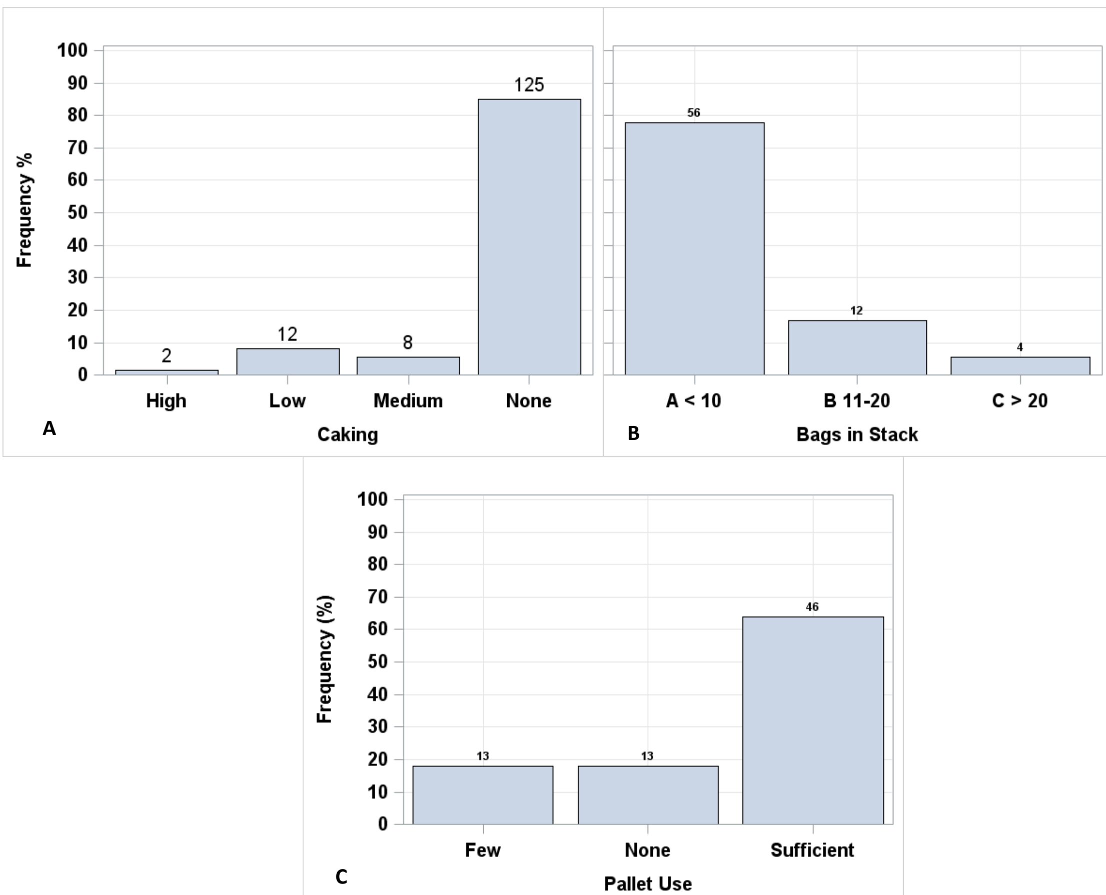


Figure 9. Frequency Distribution for Fertilizer Caking and Factors That Have the Potential to Produce Caking in the Fertilizer Markets of Uganda

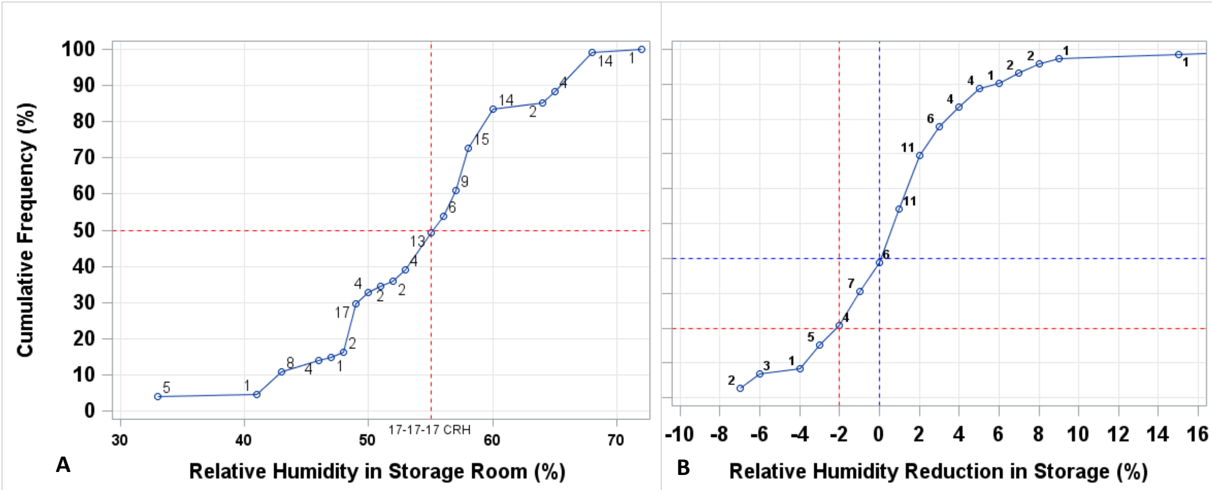


Figure 10. CFDF of Relative Humidity Inside the Storage Area (A) and Relative Humidity Reduction Inside the Storage Area with Respect to Relative Humidity Outside (B) in the Afternoon

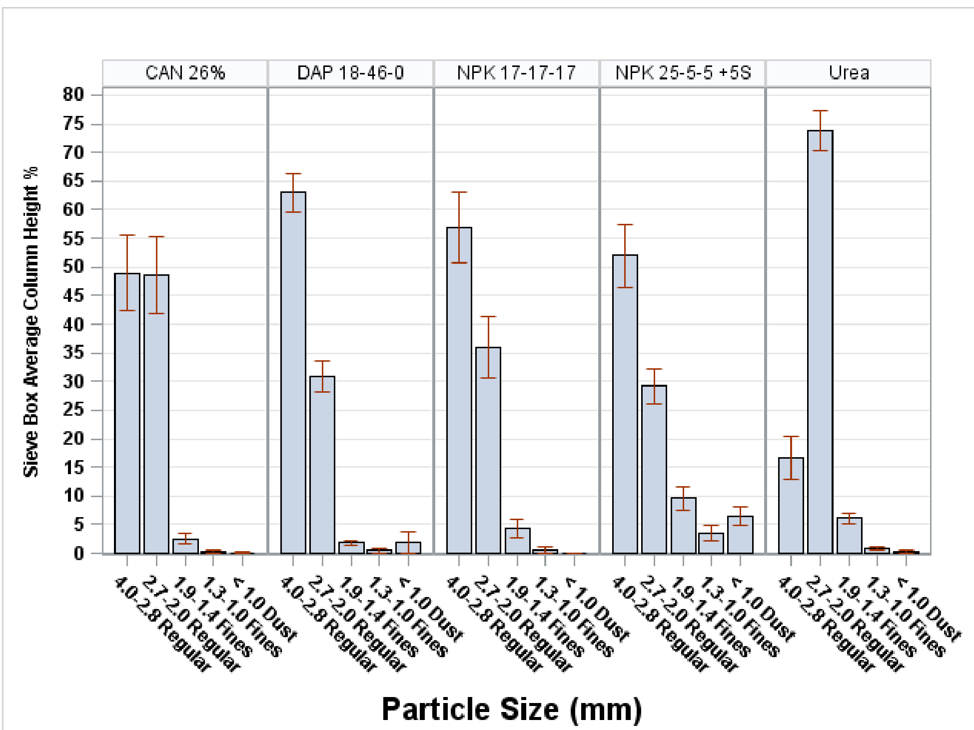


Figure 11. Analysis of Granule Integrity for Five Fertilizers of High Commercialization in Uganda Using Sylvite® Sieve Boxes.

The particle size distribution for the most commonly traded fertilizers in Uganda is largely dominated by the regular granule size (2-4 mm) (Figure 11); the average presence of fines (1.9 mm-1 mm) was lower than 5% in CAN, DAP, 17-17-17, and urea. 25-5-5+5S and DAP showed some granule degradation with 7% fines and 6% dust in the NPK and 3% dust in DAP. The granule degradation in these two fertilizers, especially in 25-5-5+5S, can cause uneven distribution of nutrients inside the fertilizer bags and non-uniform application of nutrients in crop fields. The 74% column height average of urea particles in the 2-2.7 mm range indicates the abundance of prilled urea in the Ugandan markets.

The low level of granule degradation in most of the important fertilizers in Uganda can be attributed mainly to the manufacture of fertilizer products with an adequate granule hardiness that stands the impact, crushing, and abrasion forces that occur during manual handling of individual fertilizer bags. Another contributing factor to low granule degradation in Uganda is the good quality of the bags, which minimizes contact of fertilizer granules with environmental moisture.

2.6 Adulteration of Fertilizers

Fertilizer quality inspectors were trained to identify the primary evidence of adulteration, which is the presence of fillers used to dilute the nutrient content in compound or single nutrient fertilizers. Additional evidences of adulteration are presence of impurities, re-bagging, inconsistency in bag type, sets of bags without labels or with labels that do not match the characteristics of the fertilizers, open bags, or bags with imperfect seams. Fertilizer inspectors did not find any evidence of adulteration in 50-kg bags, which account for around 90% of the fertilizer trade, during the sampling on April 2017.

An additional sampling designed for the detection of adulteration in small fertilizer packs (≤ 10 kg) destined to be purchased by small-holder farmers was conducted in June 2018 in fertilizer markets of the Central and Eastern regions by MAAIF inspectors trained by IFDC. Seventy-nine samples of fertilizers comprising NPKs, DAP, CAN and urea were collected. None of the samples contained foreign materials used to adulterate the fertilizers through dilution of the nutrients.

Some previous survey reports have found evidence of adulteration in fertilizers. One such report on urea adulteration in Uganda[13] bases its conclusions on results from nitrogen content analysis and a survey of smallholders' perception of fertilizer quality and the effect of substandard quality in yield reduction; the report does not identify or quantify the presence of materials that may be used to dilute nitrogen content in the urea samples. Dilution is the only possible way of reducing nitrogen content in urea. The nitrogen content in the samples used as evidence could be below 46% as a result of deficiencies in the use of the Kjeldahl method,[14] especially when the method is applied manually and by personnel with limited experience analyzing fertilizers. A very common mistake is assuming that a lab with experience analyzing soils will perform well analyzing fertilizers. Additionally, smallholder farmers' perception of fertilizer quality and its association with yields is very unreliable since it involves understanding scientific concepts. It is also tenuous to attribute poor yields to fertilizers without taking into account other factors.

Another report[15] bases its conclusions on results of nutrient content analysis that vary widely from the nutrient content specified on the label, e.g. lab results from nitrogen content in DAP (18% N) ranging between 6.3% and 52.8%. The same report shows severe nutrient shortages detected at importer

[13] Bold, T., K.C. Kaizzi, J. Svensson, and D. Yanagizawas-Drott. 2015. *Low Quality, Low Returns, Low Adoption: Evidence from the Market for Fertilizer and Hybrid Seed in Uganda*. Harvard Kennedy School of Government. Faculty Research Working Paper Series.

[14] The most traditional of the lab methods to analyze total nitrogen content in any material.

[15] Mbowa, S., K.C. Luswata, and K. Bulegeya. 2015. *Are Ugandan Farmers Using the Right Quality Inorganic Fertilizers?* Policy Brief No. 56, Ministry of Agriculture, Animal Industry and Fisheries.

warehouses, e.g. nitrogen content in CAN (21-26% N) ranging from 2.4% to 11.5%. Sample inspections to identify and quantify materials that could be used to dilute nutrients were not performed. Very likely, the nutrient shortages that are attributed to adulteration could be explained by deficient chemical analysis of nutrient content and nutrient shortages originating in the manufacture of imported products.

The findings of this IFDC study also contradict anecdotal affirmations that fertilizer adulteration is the dominant source of fertilizer quality problems in Uganda.

The overestimation of fertilizer adulteration in African markets may be explained by several factors:

- Poorly designed fertilizer quality assessments that overestimate the frequency and severity of nutrient shortages. Some of the main methodological problems are: lack of methodologies that integrate assessment of chemical and physical characteristics of fertilizers, use of labs with no capability and/or no experience analyzing fertilizers, overlooking nutrient shortages in some imported fertilizers, and biased sampling.
- Magnification of isolated cases of adulteration by the media.
- Confusion of adulteration with other forms of fertilizer quality problems. Likely the fertilizers denominated as "fake" have nutrient shortages originated in quality problems no related to adulteration.
- Complaints made by farmers that cannot be directly linked to fertilizer as the sole cause. Crop failure can be attributed to many causes, ranging from poor crop nutrition due to insufficient use of fertilizers to limited or absent crop protection and other crop management problems.

2.7 Market and Dealer Characteristics with Potential to Influence Fertilizer Quality

Two fertilizer market characteristics associated with location that have been found to influence fertilizer quality are the market classification as urban or rural and whether the market is permanently located in one site or if it is itinerant.[16] The effect of these two market characteristics on the quality of fertilizers traded in Uganda could not be assessed because all 72 fertilizer markets surveyed were located in urban centers and operated in permanent locations. The location of all the fertilizer markets in urban centers can be interpreted as a characteristic of a country's market in early stages of development with very limited capability to reach rural areas, mainly due to the low fertilizer consumption in areas away from cities and large towns.

[16] Sanabria, J., G. Dimithe, and E.K.M. Alognikou. 2013. *The Quality of Fertilizers Traded in West Africa: Evidence for Stroger Control*, IFDC.

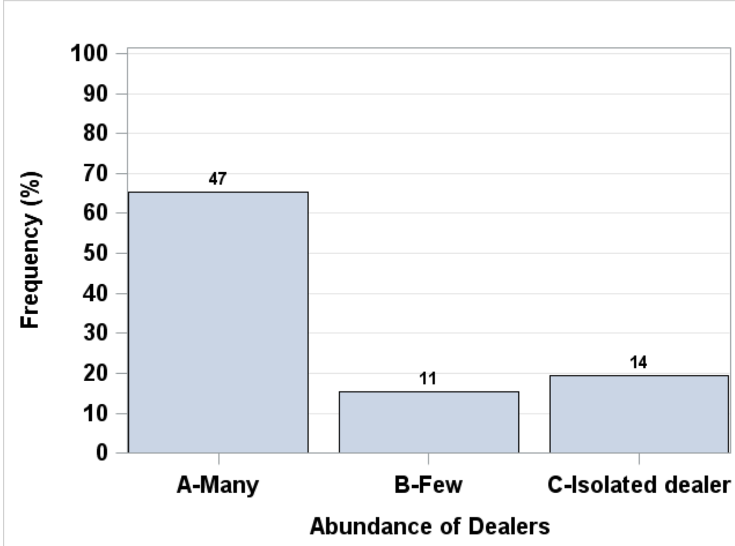


Figure 12. Frequency Distribution of Dealers' Abundance in Markets of Uganda

Another market characteristic that could affect fertilizer quality is the number of dealers in fertilizer markets (Figure 12). Markets with many dealers have a lower chance of fertilizer quality problems than markets with few dealers or dealers that operate isolated markets. Competition for customers among the dealers that operate in a market is usually a factor associated with good fertilizer quality. The opposite situation – markets with few dealers or isolated dealers with deficient fertilizer quality – is possible. Relationships between fertilizer quality factors and the abundance of dealers in fertilizer markets are tested in the next section of the report. Sixty-five percent of the fertilizer markets in Uganda have many dealers, 17% have few dealers, and 18% comprise isolated dealers that operate outside markets (Figure 12).

Some fertilizer dealer characteristics, such as their knowledge level about fertilizers, training to perform the role of fertilizer dealer, status of their fertilizer business, and type of customers, have the potential to affect the quality of fertilizer in an indirect way.

The dealer's knowledge about fertilizers, including understanding the association between the chemical and physical properties of fertilizers and their nutritional characteristics and understanding the appropriate environmental and management conditions necessary to conserve the chemical and physical properties of fertilizers, are critical for the dealer to distinguish between good and poor-quality products. This understanding is also necessary for dealers to manage fertilizers appropriately, buy good quality products from importers or wholesalers, and provide appropriate advice to farmers. In Uganda, 40% of the dealers have limited or no knowledge about fertilizers (Figure 13A). Dealers' access to training also could affect the quality of fertilizers that they sell, since training remediates knowledge deficiencies; 24% have not received training about fertilizers (Figure 13B). The high frequencies of dealers with limited or no knowledge about fertilizers and without training are factors that could be detrimental for fertilizer quality in the country.

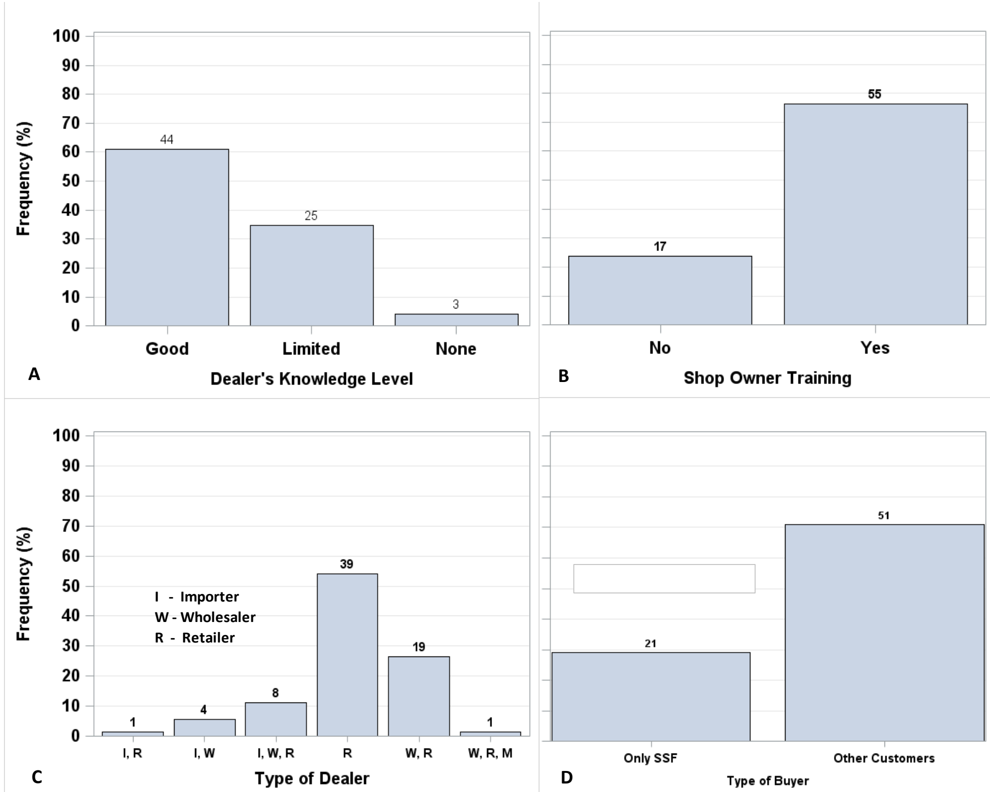


Figure 13. Frequency Distribution of Fertilizer Dealer Characteristics That Have the Potential to Affect Fertilizer Quality

The type of dealer, either as importer, wholesaler, retailer, or combinations of the three categories, can affect the quality of the products found in his/her shop or warehouse. 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, experiencing changes (some of them can be intentional) that degrade their physical and/or chemical characteristics. Second, retailers have customers that are less likely to demand high-quality standards compared to wholesalers' customers. Third, unlike importers or wholesalers, retailers have less opportunity to learn about fertilizer properties through direct training or interaction with importers and wholesalers. Fifty-four percent of the dealers in Uganda are small retailers (Figure 13C).

The type of customers can be very influential on the quality of fertilizers traded. Dealers that sell fertilizers only 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 likely to demand quality than commercial farmers or fertilizer retailers. Twenty-nine percent of the Ugandan dealers sell only to small-scale farmers (Figure 13D).

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 2.8 of this report.

Table 3. Test for the Effect of Dealer Characteristics on the Nutrient Content Out of Compliance in Fertilizers of Secondary Importance

Type 3 Analysis of Effects				Odds Ratio Estimate			
Effect	**DF**	**Chi-Sq**	**Pr > ChiSq**	**Definition**	**Estimate**	**95% Conf. Limits**	
BUSINESS STATUS	1	0.7383	0.3902				
BUYER TYPE	1	0.0014	0.9705				
OWNER/KEEPER KNOWLEDGE	2	7.0047	0.0301	None vs Good	17.6	1.44	216.58

2.8 Effect of Physical Properties and Market and Dealer Characteristics on Nutrient Content of Fertilizers

The tests to identify if granule integrity (percent of regular size granules, fines, and dust) and caking had an effect on the frequencies of macronutrient shortages out of compliance were not significant. This association is explained mainly by the low levels of granule degradation and caking that were found in the fertilizers traded in Uganda.

Relationships tested between fertilizer caking and storage conditions that could result in caking (height of bag stacks), fertilizer moisture content, and fertilizer bags (type of bag, integrity of the bag, and quality of the bag seam) were not significant. Factors explaining this non-significant relationship include the following: most products did not suffer from caking; instances of high bag stacks and moist fertilizers were few; and most bags were impermeable and in good condition.

Of all the market and dealer characteristics quantified in Ugandan markets, only the dealers' degree of knowledge about fertilizers presented a significant relationship with the frequency of nutrient content out of compliance in fertilizers of secondary importance (Table 3). The odds ratio of fertilizers with nutrient content out of compliance is 17.6 times higher when the owner or shop keeper has no knowledge about fertilizers than when the owner/keeper has good knowledge about fertilizers. The same test within the set of the most important fertilizers, in which out of compliance nutrient content occurred with low frequencies, was not significant.

3. Conclusions and Recommendations

DAP, urea, 17-17-17, CAN, 25-5-5+5S, and ammonium sulfate are the fertilizers sampled with the highest frequency and represent the fertilizers most traded in the fertilizer markets of Uganda. These six fertilizers account for 74% of the samples collected in the fertilizer markets. Sampling of urea was reduced purposefully because it is uncommon to find nitrogen content out of compliance in urea. Nearly 80% of the samples collected were in the granulated form, while liquid fertilizers and crystallized fertilizers accounted for 12% and 8%, respectively.

No N shortages were identified in ammonium sulfate and DAP. Seven percent of the urea samples and 40% of the CAN samples were OOC for total N content with a severity of -1.25±0.5% and 1.01±0.5, respectively. The total N shortage OOC severity in urea and CAN are small and can be attributed mainly to the random variability of the chemical analysis around the rigorous TL of -0.5%. 17-17-17 and 25-5-5+5S presented total N shortage OOC with frequencies of 13% and 37%, respectively, and shortage OOC severities of -1.7±0.9% and -3.9±1.5%, respectively.

The P_2O_5 shortages OOC in DAP, 17-17-17, and 25-5-5+5S occurred with frequencies of 5%, 10%, and 8%, respectively, and with OOC severities of -2.5±1.6%, -5.5±6.8%, and -2.3±1.9%, respectively.

There were no K_2O shortages OOC in 25-5-5+5S. The K_2O shortages OOC in 17-17-17 took place with a frequency of 10% and a severity of -5.5±5.5%.

Total N shortages in 25-5-5+5S, P_2O_5 shortages in DAP, 17-17-17, and 25-5-5+5S, and K_2O shortages in 17-17-17 are of concern and require solutions.

No fillers or foreign substances that suggest adulteration by dilution of nutrients were found, not even in the low percentage of re-bagged fertilizers that were sampled.

No severe degradation of granule integrity that could cause uneven distribution of nutrients inside the fertilizer bags were identified; fertilizers contained granule fines or dust in very low proportions relative to the regular size granules. Caking and high moisture contents that have the potential to affect nutrient distribution inside the bags were found with low frequencies. This is remarkable because fertilizers are imported and transported on trucks by road over long distances through neighboring Kenya into Uganda.

The most plausible explanation for the nutrient shortages being out of compliance in the granulated products, both of high and low trade, is that the nutrient deficiencies originated during the manufacture. It is therefore important to establish a system that ensures pre-export verification of conformity (PVoC) is carried out by reputable and internationally accredited companies at source. This should be followed by confirmatory inspections at the destination port (or once entering into Uganda), especially for products that have a history of poor quality.

Nutrient shortages out of compliance in the fertilizers of lower trade are higher in frequency and intensity. This finding suggests that products of lower importance in markets of Uganda are manufactured with less care than products of higher importance in the market. Whether the manufacturers of the two groups of fertilizers are the same is something to identify during Ugandan ministry inspections.

The liquid products have the most serious nutrient shortages as indicated by the combination of high frequencies and severities. The OOC frequencies are higher than 50% for total N and P_2O_5 and nearly 40% for K_2O; the shortage severities range between -7% and -10%. Regulations for quality assurance of liquid fertilizers, imported or locally manufactured, must be part of a Ugandan or regional fertilizer quality regulatory system.

Ten percent of the bags weighed during the survey in Ugandan fertilizer markets are OOC for weight shortages. Re-bagging in 50-kg bags is not common at the retail level in Uganda and so this implies that this weight anomaly originates at the upstream of the value chain in the manufacturing plants or importing facilities where fertilizers imported in bulk are bagged in 50-kg bags, which justifies the recommendation to do inspections internationally, at local manufacturing plants and at importation facilities.

The maximum cadmium content found in fertilizers containing P_2O_5 traded in Uganda was in a DAP sample with 23 ppm of Cd or 10.7 mg Cd/kg P_2O_5. These two values are below the Kenya tolerance limit of 30 ppm and the European tolerance limit of 20 mg Cd/kg P_2O_5. The small difference between the maximum Cd found in the fertilizers commercialized in Uganda and the international TLs justifies continuing to monitor closely the Cd content and possibly to identify the country of origin of the phosphate rock used in the manufacture of fertilizers, since Cd content in phosphate rock varies with the location and type of deposit.

No evidence of fertilizer adulteration was found through the sampling and inspection of 50-kg bags or in 50-kg bags that were found open in the retailers' shops and used to sell fertilizers in small quantities. There is a chance that adulteration caused by the addition of fillers to dilute the nutrient content may be occurring during the repacking of fertilizers into small bags (usually 1-5 kg) bought by smallholder farmers. Because fertilizer consumption by smallholders is very low, it can be inferred that the proportion of Ugandan fertilizer trade that is compromised by adulteration is very small even if adulteration is proven to be frequent among the fertilizers packed in small bags.

Statements that smallholder farmers are discouraged to use fertilizer or to scale up fertilizer consumption because of the lack of crop response after using adulterated fertilizers are not sound; low yields or crop failure experienced by smallholders are hardly evidence of poor fertilizer quality since these farmers often use fertilizer at rates far lower than recommended and usually farm on nutrient-depleted soils. They would be at high risk for low yields or crop failure even with the best quality fertilizers. Farmers with serious financial constraints and limited knowledge about fertilizers and crop management are very likely to have low yields due to limiting factors other than poor crop nutrition, such as deficient crop protection from weeds, pests, and diseases and inadequate crop management in general.

IFDC will conduct additional sampling focused on small bags destined to be bought by smallholder farmers. The inspection will start with the identification and quantification of fillers. Then samples will be taken to the lab for analysis of nutrient content. An addendum to this report will be written, discussed with MAAIF, and published.

Low temperatures and low relative humidity are needed to maintain fertilizer quality during storage. Most of the storage areas used by retailers (53% of the Ugandan fertilizer dealers) have no means to reduce temperature and relative humidity with respect to the outside conditions during the afternoon hours. Even under this condition, caking, moisture content of fertilizers, and granule degradation are at low levels of frequency and severity. This is explained by the good quality of the bags used; 90% of the bags have an inner impermeable layer and a strong woven exterior that allows the bag to stand the rough treatment associated with manual and individual handling. The loose bag seam in 42% of the bags examined explains the medium and low caking and the high fertilizer moisture content found in some fertilizers.

As Uganda's fertilizer consumption grows, it is necessary to establish targeted and random inspections along the domestic value chain, particularly at retail, to maintain quality standards. The capacities of agencies in charge of quality regulations, including laboratory equipment and human or technical expertise, need to be improved as well. In addition, training of distributors and agro-dealers on best practices in handling fertilizers and maintaining appropriate storage facilities will provide further support. The capacity building of agro-dealers should extend to learning about the benefits of fertilizers and their composition so that they can also provide extension advice to farmers who purchase from their shops. In addition, there needs to be a mechanism in place for farmers and other stakeholders to pass quality-related complaints to relevant authorities/agencies for action.

Finally, having updated regulatory and policy frameworks in place will provide the necessary environment to encourage investments and build trust in the fertilizer sub-sector. Then regional harmonization will lead to a bigger market, reduce costs, and increase access to quality fertilizers.

Acknowledgements

Thank you to USAID, Bureau for Food Security for providing the funds to conduct this study.

Appendix A. Procedures for Data Collection and Fertilizer Sampling

1. Equipment

- Smart Telephone with data collection system loaded
- Thermometer/hygrometer
- Bag sampler probe and scoop
- Transfer pipettes to sample liquid fertilizers
- Sieve box
- Weight scale
- Bucket, funnel, scissors, and dusting rag
- Utility knife to make an opening in fertilizer bag seam
- 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. Self-introduction of inspectors to the shop owner or keeper. Inspectors should identify themselves as employees of the MAAIF, and explain the "Official Character" of the inspection they are going to conduct, with the purpose of verifying the quality of fertilizers as stipulated by existing laws.
2. Locate the fertilizers and the different lots of each fertilizer in the shop/warehouse.
3. The data collection will be performed following the questions prompted by the questionnaires loaded in the telephone. It will start prompting for information related to the fertilizer market where the shop is located (Table A1), then about characteristics of the dealer (Table A2), and then about the conditions for storage of fertilizers (Table A3). Tables A1, A2 and A3 have been previously loaded in the telephone. The next prompt will be about opening a dataset for characteristics of the first fertilizer that will be sampled, after you reply "yes", the telephone will prompt for each of the fertilizer characteristics contained in Table A4. After entering all the characteristics for the first fertilizer, the user will be prompted to open another group for characteristics of the next fertilizer.
4. In each lot, pick a random bag from each product listed in the questionnaire for weight verification first and then for sampling. Take a picture of the bag label. Weigh the bag. Record in the telephone questionnaire the weight on the label and actual weight of the bag when prompted by the telephone.
5. 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

A fertilizer lot is the set of fertilizer bags that were delivered to the shop or warehouse in only one shipment. The most common situation in a fertilizer dealer warehouse is finding more than one lot of the most commercialized fertilizers.

A sample of a granulated fertilizer is most of the time composed of several subsamples, a subsample is the fertilizer amount taken from each of the bags randomly selected in a fertilizer lot. 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

Fertilizer bags must be in a horizontal position. Subsamples are taken directly from bags in the lot 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.
- Use part of the sample in the bucket to evaluate physical properties (Table A5) using the procedures for assessment of physical properties in Appendix B. Record results from physical properties assessment in the phone data system.
- 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#. Make sure that the numbers assigned to A# identify the agro-dealers visited by a team following the sequence in which they were visited, and the numbers assigned to F# follow the sequence in which the fertilizers were sampled in every agro-dealer shop/warehouse. 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, re-bagging).
- Record the "Time at end" at the top of the questionnaire.

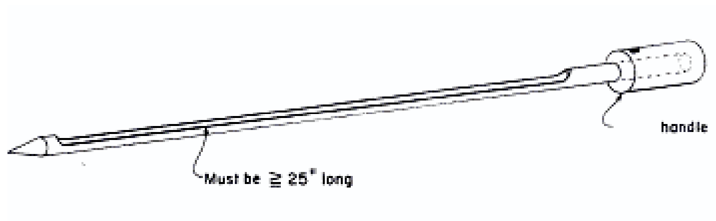


Figure A1.Sampler for Solid Bagged Fertilizers

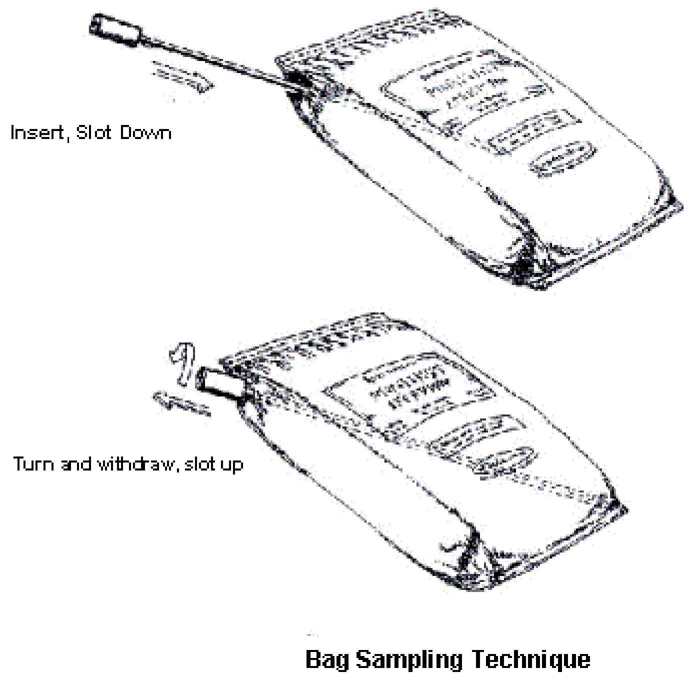


Figure A2.Sampling Technique for Solid Bagged Fertilizers

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.
- Enter data to the telephone system using the same procedure as with data from closed bags.

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.
- Write the sample label (T#A#F#) and stick it on the jar or bag
- Enter characteristics of the fertilizer to the phone system the same way it was done for the granulated products.
- Reduction of the sample quantity of liquids and powders will be done at the end of the field work in the office.

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

					Bag Characteristics					Weight (Kg)		Bottle Characteristics			Fertilizer Volume (l or ml)		Evidence of: (Yes or No)			
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)	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:					

Table A6. Fertilizers of Secondary Importance in Ugandan Markets and Their Nutrient Content

FERTILIZER	TYPE	Total N	P_2O_5	K_2O	S	CaO	MgO	Zn	Cd
NPK	Granulated	25.150	17.361	6.282	-	-	.	.	.
NPK 0-0-60	Granulated			60.103	.	.	.	.	.
NPK 0-52-34	Granulated		51.503	35.286	.	.	.	.	< DL
NPK 11-8-6	Granulated	11.000	2.754	6.746	.	.	.	.	.
NPK 12-61-0 MOP	Granulated	12.410	60.436		.	.	.	.	.
NPK 13-58-0	Granulated	13.040	57.666		.	.	.	.	.
NPK 14-14-20	Granulated	13.560	16.518	20.851	2.800	.	.	0.004	0.667
NPK 15-0-0+26CA+0.3B	Granulated	15.100	0.230	0.120	-	19.738	.	.	.
NPK 15-5-0,0[19.5]	Granulated	13.600	8.951	0.000	.	.	.	.	.
NPK 15-9-20	Granulated	12.200	18.819	14.818	.	.	.	.	.
NPK 23-10-5+3S+2MgO+0.3Zn	Granulated	22.310	10.369	5.740	3.153	-	2.023	0.268	0.678
NPK 23-23-0	Granulated	22.200	34.884		.	.	.	.	.
NPK 24-0-0 +6S	Granulated	22.860	0.295		5.781	-	.	.	.
NPK 40-0-0 +6S	Granulated	40.130			5.662	.	.	.	< DL
TSP 0-46-0	Granulated		47.978		.	.	.	.	.
TSP 0-46-0	Granulated	1.000	50.261	0.000	.	.	.	.	.
BLUE LIQUID	Liquid	3.677	2.003	2.560	.	.	-	-	-
POWER BOOSTER LIQUID	Liquid	0.591	0.000	0.009	.	.	.	.	.
BROWN LIQUID	Liquid	0.388	0.143	3.637	-	.	.	.	.
GREEN LIQUID	Liquid	8.777	8.672	5.664	.	.	.	.	.
NPK 2.35-4.44-1.75	Liquid	4.200	2.754	1.807	.	.	.	.	.
NPK 22-6-12	Liquid	14.200	9.639	6.264	.	.	.	.	.
ORANGE LIQUID	Liquid	0.591	0.000	0.012	.	.	.	.	.
ORANGE LIQUID	Liquid	0.500	0.000	0.037	-	.	.	.	.
TSP 0-46-0	Liquid		44.294	0.000	.	.	.	.	.
K2SO4	Crystallized		0.000	49.499	17.990	.	.	.	.
KNO3 13-0-46	Crystallized	12.960		46.364	.	.	.	.	.
Mg Nitrate 10.7%N, 15%MgO	Crystallized	10.220			.	.	15.534	.	.
MgSO4	Crystallized	0.500	0.230	0.241	7.900	.	.	.	.
Potassium Nitrate 13-0-46	Crystallized	13.030		46.569	.	.	.	.	.

* < DL: Under the detection limit

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 the telephone data system. A segregated fertilizer will show a very asymmetrical distribution with large granules located at the left of the box and small granules at the right. The types or color of granules will be well separated. A no segregated fertilizer will show all the granules in few columns, usually two or three, all the columns showing about the same proportion of granules (colors) in a symmetric arrangement (see Estimation of Segregation example). Record column heights in the telephone system, and take a picture of the sieve box. Inspectors will practice this assessment until mastering the procedure before going to the inspection in fertilizer markets.

The granule integrity is proportional to the resistance of granules to impact, crushing, and abrasion forces. The aggregated effect of these forces causes Granule Degradation that can be estimated quantitatively using the particle size separation obtained with the use 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. High column readings in the "fines" and "dust" sections of the box relative to the column of "regular size" granules, indicate high granule degradation. Samples with good granular integrity, meaning little amounts of fines and dust, show little or no particles in the "fines" and "dust" compartment of the sieve box. Record column heights in the telephone system. Inspectors will practice this assessment until mastering the procedure before going to the inspection in fertilizer markets.

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 telephone system.

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 telephone system.

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. Pick one of the moisture content categories shown in the telephone screen.

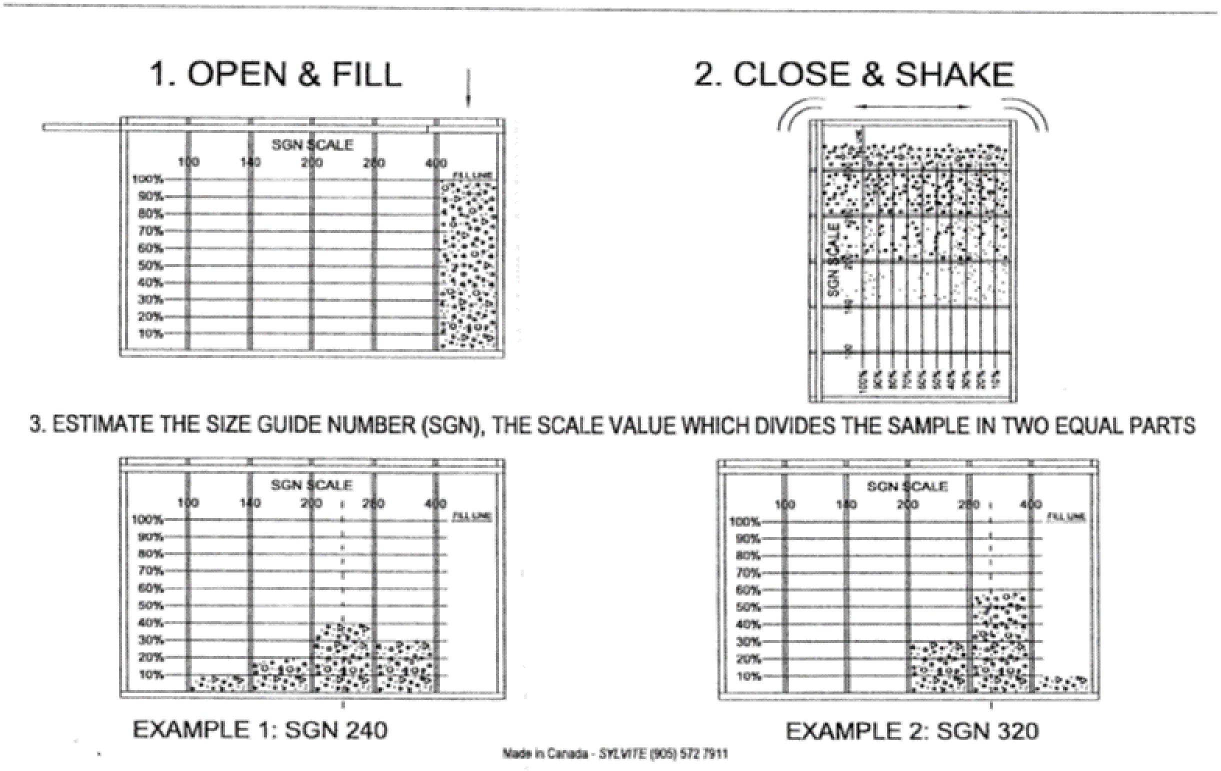
Caking occurs when the individual granules of the product fuse to form larger aggregates. In extreme cases of caking, entire bags become one solid body. Caking usually takes place when the fertilizer product gets in contact with water or when it absorbs moisture from the air due to storage in conditions 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. Pick one of the caking categories shown in the telephone screen.

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)

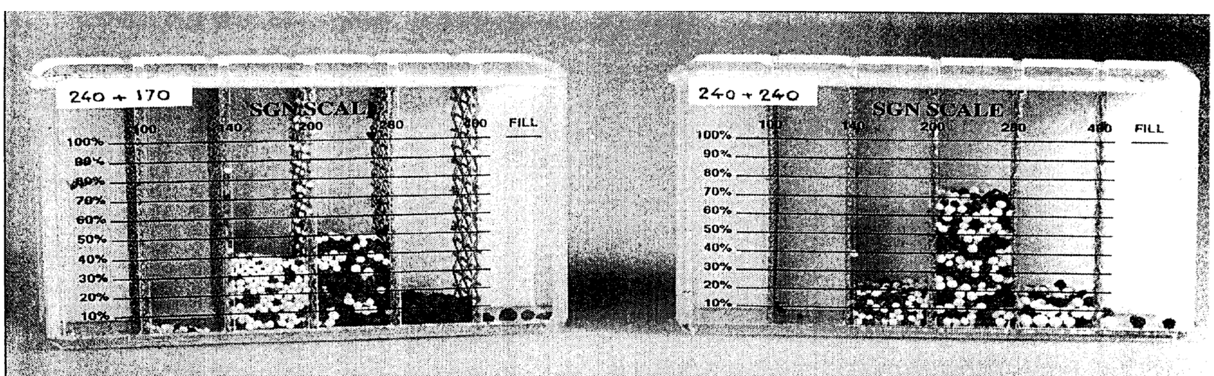


FIG. 7-2. TESTING FOR SEGREGATION

There is no segregation in the box tagged 240 + 240. But the box tagged 240 + 170 shows seg regation 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.