



# FEED THE FUTURE

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

## FERTILIZER QUALITY ASSESSMENT IN MARKETS OF ZAMBIA

**Joaquin Sanabria<sup>1</sup>, Joshua Ariga<sup>2</sup>, Dennis Mose<sup>3</sup>, and Job Fugice<sup>1</sup>**

<sup>1</sup> IFDC, Muscle Shoals, USA; <sup>2</sup> IFDC, Muscle Shoals, USA (former position) and Bill & Melinda Gates Foundation (current position); <sup>3</sup> IFDC, Nairobi, Kenya

October 2019



**USAID**  
FROM THE AMERICAN PEOPLE



## **ACKNOWLEDGEMENTS**

IFDC and the authors of this report would like to thank USAID - Bureau of Food Security Program (BFS) for funding the Fertilizer Quality Assessment in Markets of Zambia. We thank Mr. Geoffrey Siulemba from ZARI for the field coordination of the project. We would also like to thank the Zambian inspection team members that collected fertilizer samples and data across the fertilizer markets, and the IFDC Nairobi office for their assistance with the project logistics.

## Table of Contents

Executive Summary .....	1
1. Introduction .....	3
2. Methodology for Data and Sample Collection.....	3
2.1 Training of Fertilizer Quality Inspectors .....	3
2.2 Sampling Methodology.....	4
2.2.1 Random Sample of Dealers .....	5
2.2.2 Random Sample of Fertilizers and Data Collection Inside Shops/Warehouses.....	6
2.3 Chemical and Physical Analysis of Fertilizer Samples .....	7
2.3.1 Chemical Analysis of Fertilizers .....	7
2.3.2 Physical Analysis of Fertilizers, Conditions of Storage, and Characteristics of Markets and Dealers.....	7
2.4 Data Analysis and Interpretation .....	7
2.4.1 Nutrient Content Compliance.....	7
2.4.2 Bag Weight Verification .....	9
2.4.3 Fertilizer Physical Properties, Characterization of Markets and Dealers, and Qualitative Storage Conditions .....	9
2.4.4 Factors Influencing Fertilizer Quality .....	9
2.5 Data Collection System.....	10
3. Results .....	10
3.1 Distribution of Fertilizer Samples.....	10
3.2 Nutrient Content in Fertilizers .....	12
3.2.1 Fertilizers of High Market Trade: Urea, 10-20-10+6S, CAN 27%, 11-22-16+4S, and Ammonium Nitrate.....	12
3.2.2 Fertilizers of Intermediate to Low Market Trade .....	15
3.3 Cadmium Content in Fertilizers.....	19
3.4 Verification of Bag Weight.....	20
3.5 Fertilizer Storage, Packing Conditions, and Physical Properties of Fertilizers .....	20
3.6 Adulteration of Fertilizers.....	26
3.7 Market and Dealer Characteristics with Potential to Influence Fertilizer Quality .....	26
3.8 Effect of Fertilizer Physical Properties and Market and Dealer Characteristics on Macronutrient Content of Fertilizers .....	28
4. Conclusions and Recommendations.....	30
5. References .....	31
Appendix A. Procedures for Data Collection and Fertilizer Sampling .....	33
Appendix B. Assessment of Physical Properties .....	40

## Tables

Table 1.	Fertilizer Dealer Sample Size per Province .....	6
Table 2.	ECOWAS Maximum Tolerance Limits for Nutrient Content in Fertilizers .... <b>Error! Bookmark not defined.</b>	
Table 3.	Fertilizers of High Market Trade in Zambia .....	11
Table 4.	Fertilizers of Secondary and Low Market Trade in Zambia .....	11
Table 5.	Cadmium Content in Phosphatic Fertilizers.....	20
Table 6.	Test for the Effect of Market and Dealer Characteristics on Fertilizer Macronutrient Content Compliance .....	30
Table A1.	Location and Market Characteristics.....	36
Table A2.	Characteristics of the Dealer .....	37
Table A3.	Storage Conditions .....	37
Table A4.	Characteristics of Fertilizer Products .....	38
Table A5.	Physical Properties of Fertilizers.....	39

## Figures

Figure 1.	General Methodology for the Quality Assessment of Fertilizers Commercialized in Zambia.....	5
Figure 2.	Cumulative Frequency Distribution Function for Total Nitrogen Content of Urea in Zambia.....	12
Figure 3.	Cumulative Frequency Distribution Function for the Nutrient Content of 10-20-10+6S in Zambia .....	13
Figure 4.	Cumulative Frequency Distribution Function for Nutrient Content of CAN in Zambia.....	13
Figure 5.	Cumulative Frequency Distribution Function of Ammonium Nitrate .....	14
Figure 6.	Cumulative Frequency Distribution Functions for Nutrient Content of 11-22-16+4S in Zambia.....	15
Figure 7.	Cumulative Frequency Distribution Function for Nutrient Content of Granulated Fertilizers With Intermediate to Low Market Trade in Zambia .....	16
Figure 8.	Cumulative Frequency Distribution Functions of Macronutrient Content in the Set of Bulk Blended Fertilizers Traded in Zambia.....	17
Figure 9.	Cumulative Frequency Distribution Functions for Macronutrient Content in Foliar Fertilizers.....	18
Figure 10.	Cumulative Frequency Distribution Functions for Secondary and Micronutrient Content in All Fertilizers Traded in Zambia .....	19
Figure 11.	Cumulative Frequency Distribution Function of Fertilizer Bag Verification in Zambia.....	20

Figure 12.	Cumulative Frequency Distribution Function of Relative Humidity Inside Storage Facilities (A) and Reduction of Relative Humidity Inside Storage Facilities With Respect to the Relative Humidity Outside (B) in Zambia.....	21
Figure 13.	Cumulative Frequency Distribution Function of Temperature Inside Storage Facilities (A) and Temperature Reduction in Storage Facilities Relative to the Temperature Outside (B) in Zambia .....	22
Figure 14.	Frequency Distributions of Ventilation Categories Inside Storage Facilities (A) and Pallet Use Categories in Storage Facilities (B) in Zambia.....	22
Figure 15.	Frequency Distributions for Fertilizer Caking (A), Moisture Content in Fertilizers (B), and Granule Integrity of Fertilizers (C) in Zambia.....	24
Figure 16.	Frequency Distributions of Fertilizer Bag Type (A), Torn Bags (B), and Bag Seam Condition (C), and Number of Bags in a Stack (D) in Zambia.....	25
Figure 17.	Frequency Distributions of Type of Fertilizer Market (A) and Abundance of Fertilizer Dealers in Fertilizer Markets (B) in Zambia .....	27
Figure 18.	Frequency Distributions of Dealer’s Fertilizer Knowledge Level (A), Dealer Training (B), and Shop License Possession (C) in Fertilizer Markets of Zambia ..	27
Figure 19.	Frequency Distributions of Type of Dealer (A) and Type of Buyer (B) in Fertilizer Markets of Zambia .....	29
Figure A1.	Sampler for Solid Bagged Fertilizers .....	35
Figure A2.	Sampling Technique for Solid Bagged Fertilizers .....	35

# Fertilizer Quality Assessment in Markets of Zambia

## Executive Summary

With funding from the United States Agency for International Development (USAID), the International Fertilizer Development Center (IFDC) has conducted fertilizer quality assessments in Eastern and Southern Africa. IFDC conducted the assessment in Zambia because of the country's increasing trend in fertilizer consumption, large land areas with the potential for agricultural production, and the government's current programs to reduce poverty and food insecurity. In addition, Zambia does not have a National Fertilizer Quality Regulatory System; findings of this study can be used as a baseline to build a National Fertilizer Quality Regulatory System that can be harmonized with a regional regulatory system for member states of the Common Market for Eastern and Southern Africa (COMESA).

The IFDC fertilizer quality assessment team first trained a group of 23 officials from government agencies dealing with agricultural research, standardization, and environmental preservation. Then, a random approach was used to select a sample of fertilizer dealers and collect fertilizer samples for chemical analyses. Data on fertilizer markets, dealers, physical properties of the products, and storage conditions were also collected from the sample of dealers. After conducting chemical analyses on fertilizer samples in the labs, the estimated nutrient content and cadmium (Cd) content of the fertilizers were incorporated into the dataset for analysis.

Out-of-compliance (OoC) shortages of macro and secondary nutrients in the most traded fertilizers (urea, 10-20-10+6S [Compound D], calcium ammonium nitrate [CAN] 27%, 11-22-16+4S, and ammonium nitrate) occurred with high frequencies and severities. These shortages likely will cause nutrient deficiencies in crops. Considering that there was no evidence of adulteration in the samples from these fertilizers and that the degradation of physical properties was minimal, the expected origin of the nutrient shortages OoC is in the manufacturing of the products.

The combined analysis of granulated compound and straight fertilizers of intermediate to low market trade also showed frequent and severe  $P_2O_5$  and  $K_2O$  OoC shortages. Again, there was no evidence of adulteration and only mild degradation of physical properties, which suggest that the nutrient shortages originated in the manufacture of the products.

The combined analysis of the 23 bulk blends identified in Zambia showed frequent but low severity of total N shortages OoC, together with no shortages of  $P_2O_5$  OoC, and highly frequent and severe  $K_2O$  shortages OoC. It is apparent that segregation attributed to the use of crystalline, instead of granular, KCl explains the  $K_2O$  shortages in the bulk blends. Nutrient shortages in Zambian bulk blends are mild compared with nutrient shortages in bulk blends manufactured in other regions of Africa. All samples analyzed for Cd showed values well under the international tolerance limit but it is recommended to continue monitoring Cd content in fertilizers and the origin of the phosphate rock used in fertilizer manufacture.

Nineteen percent of the 50-kilogram (kg) bags weighed had OoC shortages of at least -0.5 kg, and 10% of the bags had weight shortages of at least 1 kg. Additional investigation is needed to identify where and how this fraud is committed.

Inspections conducted before imported fertilizers enter Zambia should become stricter. It is important to establish a system that ensures pre-export verification of conformity (PVoC). This should be followed by confirmatory inspections at the points of entrance to Zambia. As Zambia's fertilizer consumption grows, a regulatory framework specific to fertilizers needs to be developed. An agency within the Ministry of Agriculture should be provided with the funds, trained personnel, laboratories, and other physical resources to conduct quality inspections along the value chain, analysis of samples, and administration of the regulation's legal aspects.

Interaction and good relations between the government and private sector are essential to establish an environment of good fertilizer quality in the markets. Implementation of the regulatory system by government officials should go together with self-regulation by the private sector.

# 1. Introduction

Agriculture in Zambia employs 60% of the national labor force and accounts for one-fifth of the country's gross domestic product (GDP). With this participation in the country's economy, the agriculture sector is extremely important in the reduction of poverty by generating incomes and increasing food security (Government of the Republic of Zambia, 2004).

The key role of fertilizers in a program to reduce poverty is well understood by the government of Zambia; 29% of the national agricultural budget is allocated to the Farmer Input Support Programme (FISP) fertilizer subsidy. Unfortunately, the program has not been effective in reducing poverty due to targeting problems. Its focus on maize fertilization discourages production of other crops. Maize growers owning large land areas benefit disproportionately more than smallholder growers (Mason et al., 2011).

Zambia's fertilizer consumption must increase by 248,000 product tons – to approximately 500,000 mt – to meet the agricultural growth targets set in the Comprehensive Africa Agriculture Development Programme (CAADP) country investment plan. This increased fertilizer consumption has implications on the development of all types of stakeholders in the fertilizer value chain to deal with the pressure resulting from the higher volumes of fertilizers required to achieve the agricultural targets (IFDC, 2013).

There are serious obstacles to achieve the fertilizer consumption targets and the agricultural productivity that are expected to reduce poverty in Zambia. Some of these obstacles are the high cost of fertilizers originating in elevated port and road/rail transportation expenses, low market development due to low fertilizer demand, and fertilizer quality problems that result from the lack of quality regulation.

The existing legal framework and regulatory institutional agencies in Zambia remain weak, distorted, and unclear, such that there is almost no enforcement of the current Agriculture (Fertilizers and Feed) Act No. 51 of 1966; amended No. 13, 1994, Cap 226 of the Laws of Zambia (ZARI, 2012). The situation leaves farmers vulnerable, because the use of substandard fertilizer materials negates any gains made from efforts and strategies designed to develop the agriculture industry (Sokotela, 2014).

IFDC conducted this fertilizer quality assessment with funding from USAID and with cooperation from the Zambia Agricultural Research Institute (ZARI) and the Zambia Ministry of Agriculture and Livestock (ZMAL). The objective of the project was to make a national fertilizer quality diagnostic and identify factors responsible for the quality problems. A report of the findings from this assessment will be provided to ZMAL and ZARI to be used as a baseline to continue with the efforts initiated by the Alliance for a Green Revolution in Africa (AGRA) in 2012 to develop a Fertilizer Quality Regulatory Authority. IFDC would be interested in offering support to ZMAL, AGRA, and COMESA to achieve the establishment of an effective Fertilizer Quality Regulatory System in Zambia and a harmonized regional regulatory system for COMESA member states.

## 2. Methodology for Data and Sample Collection

### 2.1 Training of Fertilizer Quality Inspectors

Before conducting the field survey to collect data and fertilizer samples in the fertilizer markets of Zambia, the IFDC team of experts conducted a five-day training session for 23 participants affiliated with ZARI, Zambia Bureau of Standards, Zambia Weights and Measures, and a Zambia Environmental Management Agency. The

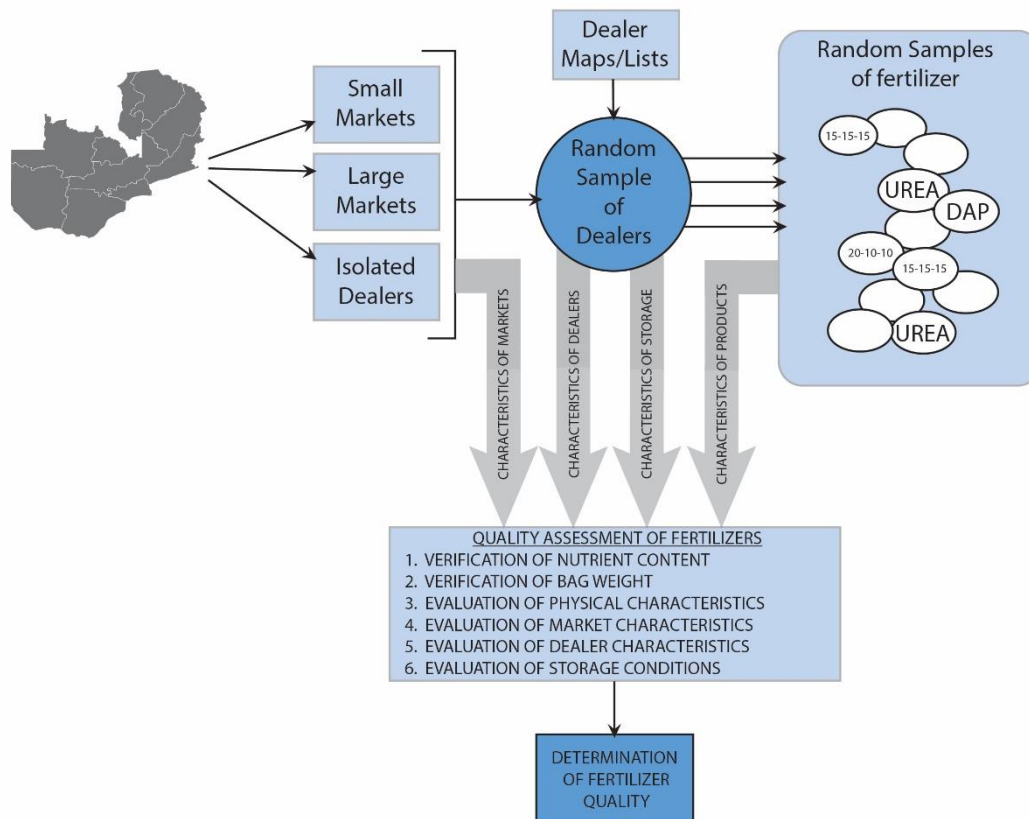
participants were trained to operate as fertilizer quality inspectors during this study and to continue in this role during the future implementation of quality assurance policies. Those trained are also expected to become trainers of additional fertilizer quality inspectors as part of the implementation of government policies. The training addressed key topics, including:

1. Description and quantification of chemical and physical fertilizer properties that define the quality of the products.
2. Description and assessment of management practices that affect fertilizer quality: conditions of storage, bagging, and handling.
3. Method for sampling in fertilizer dealer shops/warehouses (wholesalers and retailers of various sizes).
4. Methods for sampling granulated and liquid fertilizer products.
5. Use of a digital system for collection of data associated with product characteristics, management conditions, and value chain characteristics that influence fertilizer quality.
6. Basic statistical methods for data analysis and identification of factors associated with fertilizer quality problems.
7. Concepts about fertilizer quality policies and fertilizer quality regulatory systems.

## 2.2 Sampling Methodology

The sampling methodology employed for this assessment 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 market; 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.*



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

The weighted random sampling of dealers throughout the agricultural areas of Zambia 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 Zambia.

Collection of data about characteristics of fertilizer products, management, markets, and dealers is performed while visiting the dealer to sample fertilizers.

### **2.2.1 Random Sample of Dealers**

A list of 562 fertilizer dealers classified by province, provided by ZARI, 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, depending on the net number of sampling days – discounting travel time – 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. Random numbers generated from a uniform probability distribution were used to choose the dealer members. The process for selecting the sample in each province was weighted by the number of dealers in each province to ensure that provinces with a high number of dealers were represented by a larger sample size than provinces with a smaller number of dealers (Table 1). The final random sample included 112 dealers, equivalent to 19% of the total number of dealers listed. The dealer sample was distributed to four sampling teams. Team 1 conducted the survey in the Central and Copperbelt provinces, Team 2 surveyed the Eastern province, Team 3 surveyed Lusaka and part of the Southern province, and Team 4 surveyed the rest of the Southern province.

Each fertilizer dealer in the sample was visited by an inspection team that conducted fertilizer sampling of the products available in the shop and collected data about fertilizer characteristics, conditions of storage, characteristics of the market, and characteristics of the dealer. Each team received a list containing the sample of dealers assigned to the team and an additional set of randomly selected dealers to substitute for dealers that could not be found or that did not have fertilizers available for sampling at the time of their visit.

**Table 1. Fertilizer Dealer Sample Size per Province**

PROVINCE	DEALER POPULATION	SAMPLE
SOUTHERN	188	33
COPPERBELT	143	32
CENTRAL	69	11
LUSAKA	60	12
LUAPULA	54	10
EASTERN	22	6
NORTH-WESTERN	15	4
NORTHERN	6	2
WESTERN	3	1
MUCHINGA	2	1
<b>Total</b>	<b>562</b>	<b>112</b>

### 2.2.2 Random Sampling 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 the same appendix.

- Market location and characteristics of the market: country, region, county, town, market name, type of market, concentration of dealers, and 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, and general housekeeping conditions (see Table A3 in Appendix A).

- Characteristics of fertilizer products: grade, lot, type, blend/compound, bag characteristics, bag weight, bottle characteristics, and evidence of quality problems (see Table A4 in Appendix A). Detailed information about the data collection 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, and 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 shops/warehouses visited, fertilizer products were sampled, labeled, and packed using the sampling protocol described in Appendix A.

## 2.3 Chemical and Physical Analysis of Fertilizer Samples

### 2.3.1 Chemical Analysis of Fertilizers

The 305 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), or zinc (Zn) contents were reported were also analyzed for these nutrients.

Analysis of cadmium (Cd) was performed on a subset of fertilizers containing  $P_2O_5$  due to concerns about the natural content of Cd in phosphate deposits and the potential of heavy metal accumulation in soils with fertilizers that have been applied season after season. Results of Cd concentration in fertilizers were expressed as milligrams of cadmium per kilogram of available phosphorus ( $mg\ Cd\ kg^{-1}\ P_2O_5$ ) for comparison with international reports in the literature (Roberts, 2014).

Analytical methodologies used at the IFDC laboratory included combustion analysis for total N and S (AOAC International, 2012a), spectrophotometric analysis for  $P_2O_5$  (AOAC International, 2012b), and inductively coupled plasma-optical emission spectrometry (ICP-OES) for  $K_2O$ , CaO, Zn, and Cd (AOAC International, 2012c).

### 2.3.2 Physical Analysis of Fertilizers, Conditions of Storage, and Characteristics of Markets and Dealers

An assessment of fertilizer moisture content, caking, granule integrity, and segregation (in bulk blends) was conducted as specified in Appendix B. Tables A1, A2, A3, A4, and A5 from Appendix A were loaded on the smartphones used by the inspectors to capture market characteristics, dealer characteristics, storage conditions characteristics of fertilizer products, and the physical properties of fertilizers.

## 2.4 Data Analysis and Interpretation

### 2.4.1 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 (CFDFs) 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 (percentage) 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<sub>2</sub>O<sub>5</sub>, or soluble K<sub>2</sub>O 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:

$$F(X \leq x) = f \quad [1]$$

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 on the bag label or the 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 for urea (Figure 2) is:

$$F(N_{\text{Urea}} < -0.5) = 4\%$$

The shortage severity (SS) is calculated as follows:

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

Where **X<sub>i</sub>** is the nutrient shortages lower than the TL, and **p** is the number of values lower than the TL.

Example: SS for total N in urea is -0.63% (Figure 2).

Tolerance limits for compound and blended fertilizers were taken from the Zambian Standards ZS 431:2014 and ZS 327:2005 respectively (Zambian Bureau of Standards, 2014 and Zambian Bureau of Standards, 2005).

### 2.4.2 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 smartphone 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 (percentage) in the ordinate. A bag weight tolerance limit (WTL) was not found in Zambia Standards, a WTL of 1% of the weight specified on the fertilizer label will be used to calculate the frequency of bag weight shortages out of compliance with the following expression:

$$F(\text{BWS} \leq \text{WTL}\%) = f$$

In Figure 11, for example, it can be established that the frequency of 50-kg bags with shortages larger than - 0.5 kg is 19%.

### 2.4.3 Fertilizer Physical Properties, Characterization of Markets and Dealers, and Qualitative Storage 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 conditions, the frequencies associated with the various categories of these discrete variables were obtained directly from the frequency distribution function (FDF). Figures 14 through 19 are FDFs. In Figure 14A, for example, the frequency of storage facilities with no ventilation is 19%.

### 2.4.4 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 kept. External factors, such as 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, the location of the markets and shops, the type of dealer, and the type of customers that the dealers have. 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 listed 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 for the three initial relationships were the set of physical properties, the set of storage characteristics, and the set of market and dealer characteristics.

The nutrient content compliance was transformed into a binomial variable with values “Yes” and “No”; the variable was “Yes” when the nutrient content value (either N, P<sub>2</sub>O<sub>5</sub>, or K<sub>2</sub>O) was equal to or higher than the TL, and the variable was “No” when the nutrient content value was lower than the TL. A global nutrient content compliance was also created; its value was “Yes” when the compliance for the three macronutrients was “Yes” and “No” when at least one of the macronutrients’ compliance was “No.”

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. Significance 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 listed above, a response variable for each of the physical properties was assigned; 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.

## 2.5 Data Collection System

A digital system using smartphones was utilized to gather data about market and dealer characteristics, fertilizer management, storage conditions, and fertilizer properties at every shop visited. Data were temporarily stored in the smartphones, then transmitted to the system platform using a Wi-Fi connection 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 the data to be checked and the work of the inspectors to be supervised in real time as the data is collected from each dealer shop.

## 3. Results

### 3.1 Distribution of Fertilizer Samples

The 324 fertilizer samples collected in Zambia were grouped into three sets based in the number of samples collected. The first group of five fertilizers collected with 9 samples or more were named the fertilizers of High Market Trade and accounted for 77% of all the samples collected (Table 3). Then a second group of 14 fertilizers, including bulk blends like 20-10-5+9S, compounds like 17-17-17, and straight fertilizers like MOP, accounted for 12% of the samples and were designated fertilizers of intermediate market trade. A third group of 36 fertilizers, each with only one sample collected, accounted for 11% of the total samples were classified as fertilizers of low market trade. The intermediate and low marked trade were combined in Table 4.

**Table 2. Fertilizers of High Market Trade in Zambia**

Fertilizer	n	Type
Urea	141	ST <sup>†</sup>
10-20-10+6S Compound D	69	CM <sup>‡</sup>
CAN 27%	22	ST
11-22-16+4S	11	CM
Ammonium Nitrate	9	ST

<sup>†</sup> Straight Fertilizer. <sup>‡</sup> Compound Fertilizer.

Since the low number of samples from fertilizers in Table 4 does not allow analysis of frequency for individual fertilizers, the analysis of frequency for nutrient content was performed separately for three groups of fertilizers: compound granulated and straight in one group, bulk blends in a second group, and foliar fertilizers in a third group. In the day-to-day implementation of a fertilizer quality regulatory system in Zambia, every fertilizer of interested must be sampled with at least 20 samples to develop the CFDF and obtain solid estimates of the compliance or lack of it for every nutrient claimed by the fertilizer label.

The bulk blends and the compound fertilizers made up for 42.6% and 29.6% respectively, of all the fertilizer samples collected during the survey. The high market share of the bulk blend fertilizers suggests a good position of Zambia to achieve the balanced crop nutrition objectives pursued worldwide.

**Table 3. Fertilizers of Secondary and Low Market Trade in Zambia**

Fertilizer	n*	Type	Fertilizer	n*	Type
16-0-24	6	BB	19-19-19	1	BB
14-18-18+6S	4	CM	19-6-26	1	BB
21-0-32	4	BB	19-8-15	1	BB
10-10-20	3	BB	2-3-2 (22), Zn 5g/Kg	1	BB
10-23-4.5	3	BB	14 12 12	1	BB
20-10-5+9S Compound X	3	BB	21-0-32+4S	1	BB
KAN/LAN 28	2	ST	23-21-0	1	BB
MOP	2	ST	24-0-0+S15+7.5CaO	1	CM
17-17-17	2	CM	35-0-0+26S+N26S4 Ca5	1	CM
8-24-16+5S+0.5Zn+0.1B	2	CM	40-0-0+5.6S	1	CM
10-20-10+7s	2	BB	6-16-32+2S	1	CM
10-15-15	2	BB	Ammonium Sulfate	1	ST
10-20-11	2	BB	Calcium Nitrate	1	ST
12.3-6.8-20.3	2	BB	Humic acid (85%), K (11%), Fe (1%)	1	OR
20-10-0+7S+15CaO	1	CM	20-12-20	1	CM
6-18-12+8S+0.1B Compound C	1	CM	14.5-14.5-20 +8S+3Zn+3B	1	BB
10-18-24+7S	1	CM	10:20:10+5S+0.15Zn+0.15B	3	LQ
10-30-10+6S	1	CM	NPFZnCuMnaAuxinsCytokinines	1	PW
11-52-0 MAP	1	CM	12:10:08	1	PW
20-12-20	1	CM	NPKZnFeCuMnMo AminoAc	1	LQ
10-20-10+6s+0.5 Zn+0.1B	1	BB	14-11-33+0.03B+0.05Cu+0.1Fe+0.05Mn+0.001Mo+0.06Zn	1	LQ
10-20-10	1	BB	13.5-0-38.4	1	LQ
11.2-17.3-23.43	1	BB	1.52-0-0+ 1.59Zn+3.9Cu+0.67B	1	LQ
12 12 12	1	BB	27-10-16+BCuFeMnMoZn AmminoAc.	1	LQ
13 12 12	1	BB	1.52-0-0+ 1.59Zn+3.9Cu+0.67B	1	LQ

\* Number of samples  
 BB: Bulk Blend  
 CM: Compound  
 OR: Organic  
 ST: Straight  
 LQ: Liquid  
 PW: Powder

## 3.2 Nutrient Content in Fertilizers

### 3.2.1 Fertilizers of High Market Trade: Urea, 10-20-10+6S, CAN 27%, 11-22-16+4S, and Ammonium Nitrate

#### Urea

The tolerance limit for total N shortages in urea is -0.5%. International standards set tolerance limit for total N content in urea lower than in compound or blend fertilizers, due to the lower random variability of N content at the time of both adding the nutrient during manufacture and quantifying the nutrient in the lab. Four percent (six samples) of the 141 urea samples were out of compliance (OoC), and the OoC shortage severity was -0.63% (Figure 2). Considering the difficulty of reducing the 46% nitrogen content of the urea molecule during manufacture, the small N shortages are likely associated with impurities in the urea samples and/or small precision errors in the chemical analysis. Adulteration of urea by adding filler materials to dilute total N content is unlikely. Any filler material would be conspicuous due to the sharp contrast with the crystalline urea particles, and a synthetic material resembling urea likely would be more expensive than urea.

#### 10-20-10+6S

This product is also identified as Compound D. It is the compound fertilizer of highest market trade in Zambia during the second semester growing season, as suggested by the 69 samples collected.

The tolerance limit for total N is -1.0%, -1.1% for  $P_2O_5$  and -1.0% for  $K_2O$ , and -0.49% for 6% S in compound fertilizers (Zambian Bureau of Standards, 2014). Twelve percent of the samples were OoC for total N content, with a total N shortage severity of -1.41% (Figure 3A). The  $P_2O_5$  shortages OoC occurred in 21% of the samples, with a severity of -2.85% (Figure 3B).  $K_2O$  shortages OoC occurred in 20% of the samples, with a severity of -2.82% (Figure 3C). S shortages OoC occurred in 29% of the samples, with a severity of -1.49% (Figure 3D). The combination of high frequency shortages with shortage severities that may cause nutritional deficiencies in crops, indicate a serious quality problem in this fertilizer. No filling materials were found in this fertilizer, consequently, the nutrient shortages are highly likely originated in the manufacture of the fertilizer.

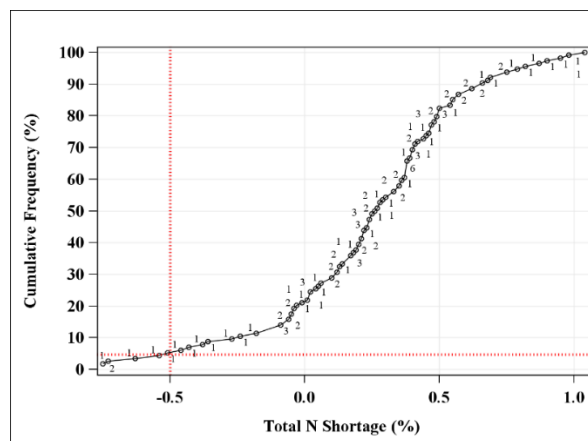
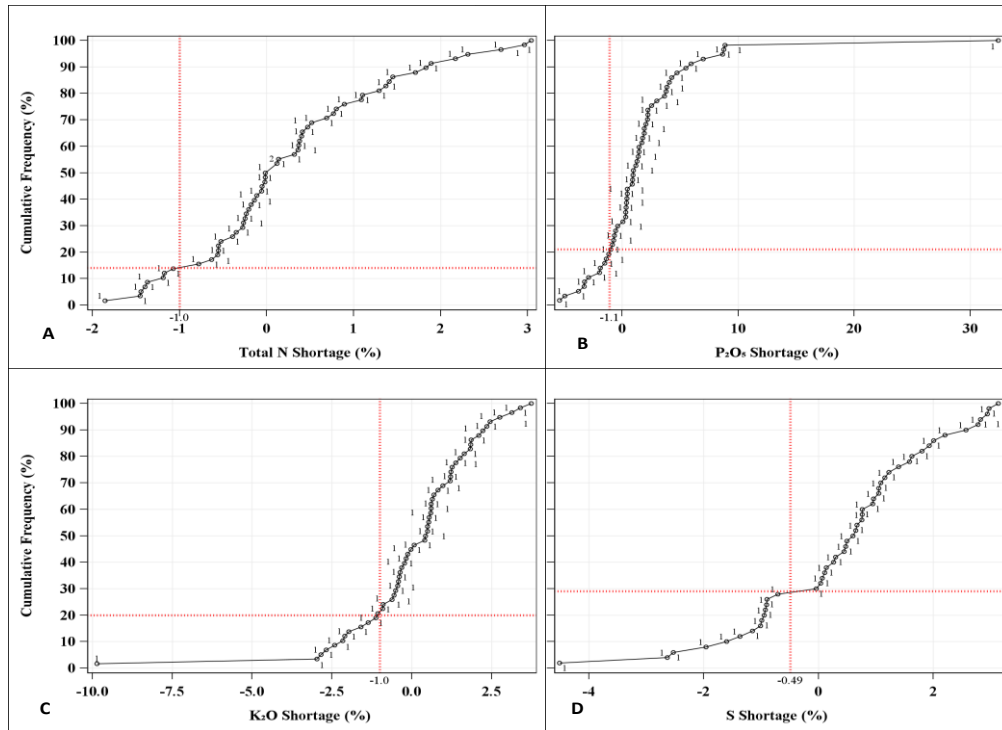


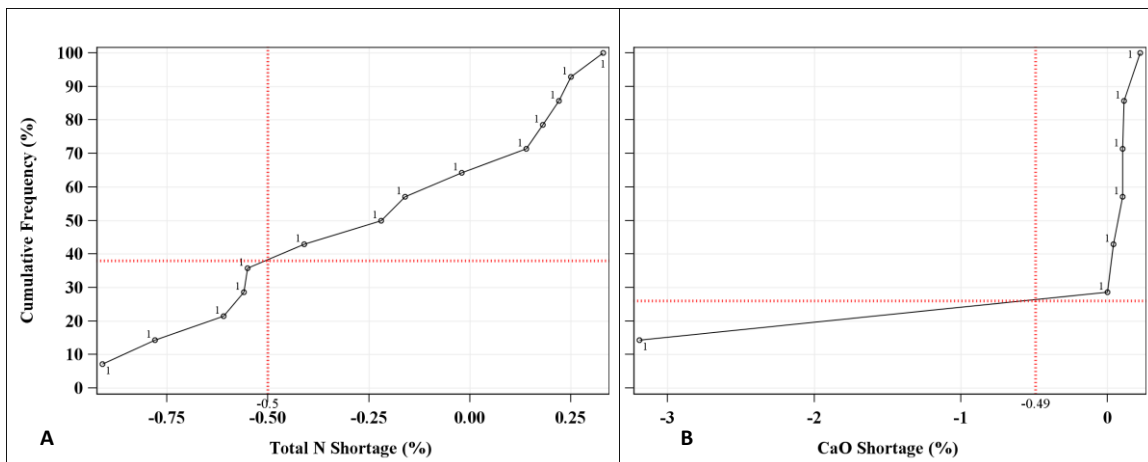
Figure 2. Cumulative Frequency Distribution Function for Total Nitrogen Content of Urea in Zambia



**Figure 3. Cumulative Frequency Distribution Function for the Nutrient Content of 10-20-10+6S in Zambia**

### CAN 27%

The tolerance limit for total N content in a straight fertilizer like CAN is -0.5%. Total N shortages in CAN 27% occurred in 39% of the samples, and the total N shortage severity was -0.7% (Figure 4A). CaO shortage tolerance limit is -0.49%. Twenty six percent of the samples had a CaO content shortage OoC. Only one CaO value under the tolerance limit does not allow the calculation of a reliable CaO shortage severity (Figure 4B). The high frequency of total N shortages OoC combined with a severity OoC of -0.7%, plus the high frequency of CaO shortages OoC point out to a serious quality problems in this fertilizer. The no presence of filler materials in the samples of CAN suggests that the nutrient shortages likely originated in the manufacture.

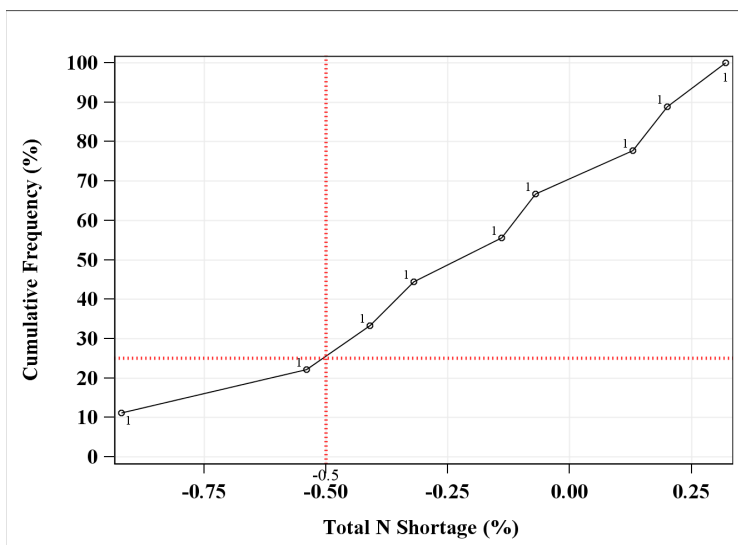


**Figure 4. Cumulative Frequency Distribution Function for Nutrient Content of CAN in Zambia**

## Ammonium Nitrate

The CFDF of ammonium nitrate was built with only nine samples collected (Figure 5). The inferences derived about total N content in the ammonium nitrate traded in markets of Zambia from only nine samples are weak and only indicate a tendency of the fertilizer quality. A larger sample size is required to develop stronger ideas about the quality of this fertilizer in Zambia.

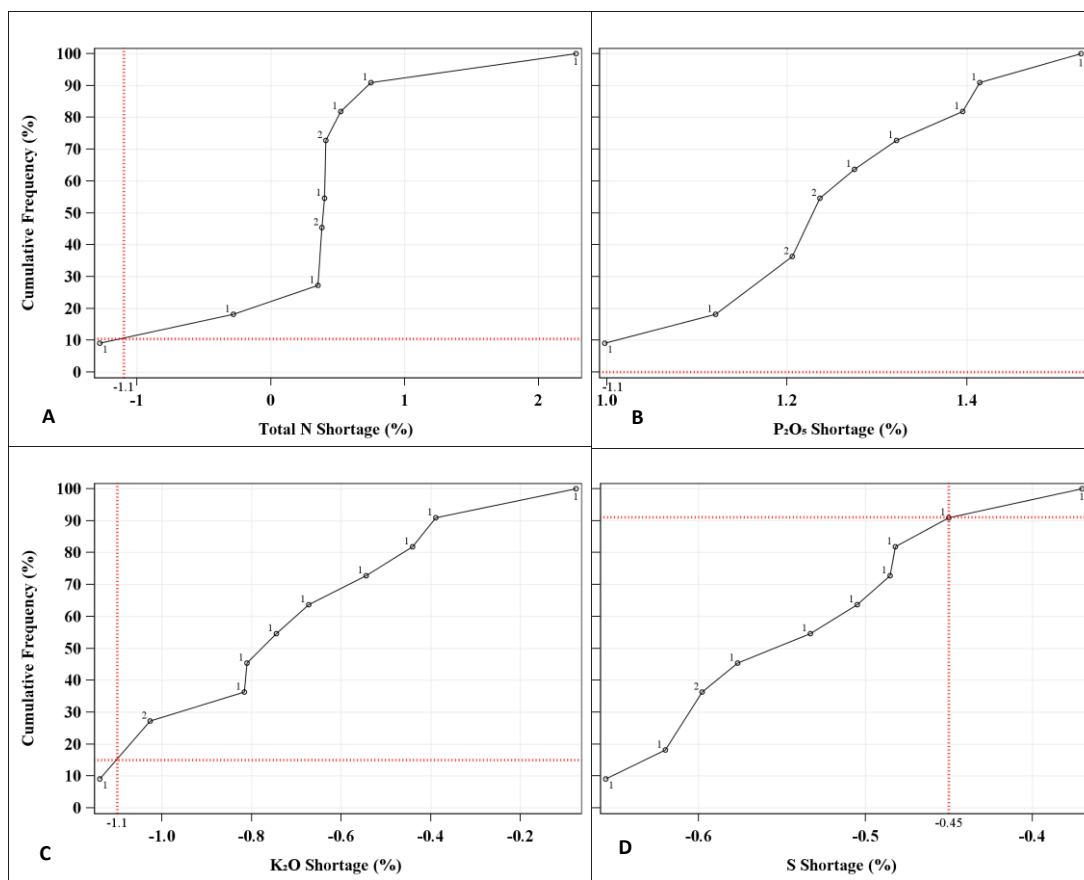
Twenty four percent of the samples, were OoC for total nitrogen content, lower than the -0.5% tolerance limit of this straight fertilizer. The severity of the total N shortages OoC was -0.73%. The high frequency of total N and CaO shortages deserves further investigation to determine the origin of the problem.



**Figure 5. Cumulative Frequency Distribution Function of Ammonium Nitrate**

## 11-22-16+4S

Eleven samples were collected from this compound fertilizer. The CFDF built with this small number of samples provides a very general idea of the quality of the fertilizer. A larger number of samples is required to develop strong inferences from the CFDF about the nutrient content conditions of the fertilizer. Eleven percent of the samples showed total nitrogen shortages OoC, and the severity of the total N shortage was -1.28% (Figure 6A). There were no  $P_2O_5$  shortages; all 11 samples presented “positive” shortages, meaning that all samples had a  $P_2O_5$  content higher than the 22% specified on the label (Figure 6B). Fifteen percent of the samples, presented  $K_2O$  shortage OoC. The  $K_2O$  OoC shortage severity was -1.14% (Figure 6C). S shortages OoC occurred in 91% of the samples, and the S shortage severity was -0.48% (Figure 6D). Shortages of N,  $K_2O$ , and S could be explained in part by the excessive addition of  $P_2O_5$  during manufacture. Shortages of N and  $K_2O$  may cause mild deficiencies in crops, but the -0.48% deficiency of S can result in important yield reductions.



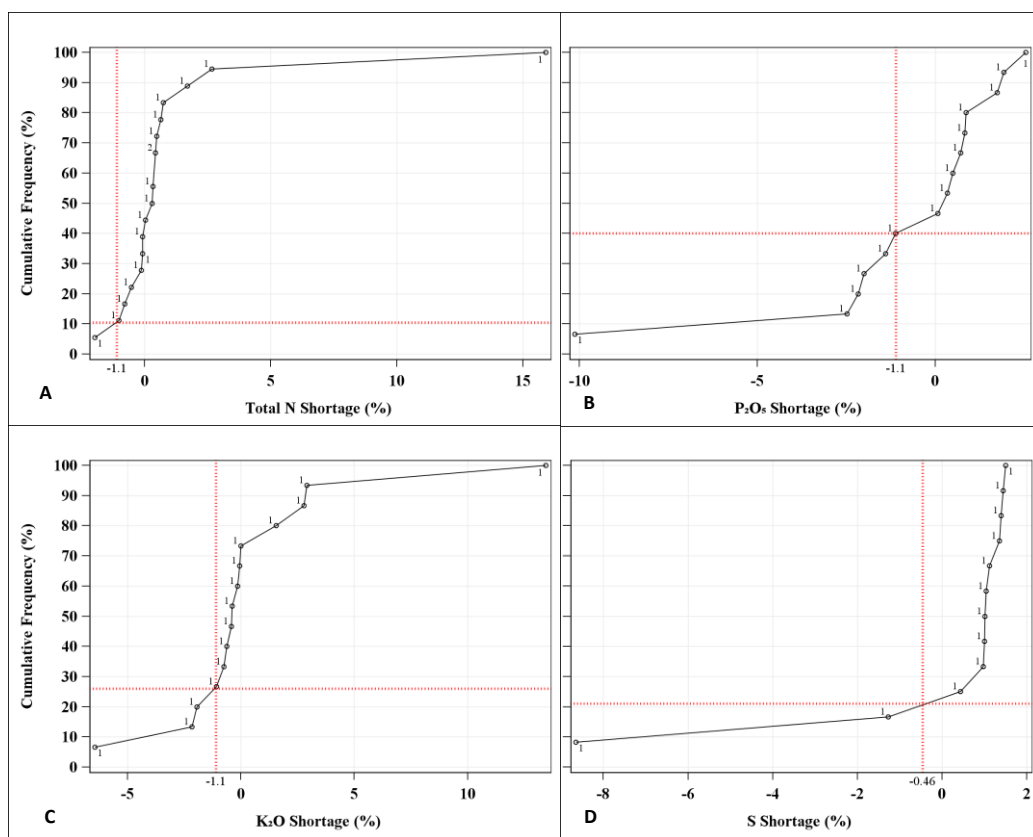
**Figure 6. Cumulative Frequency Distribution Functions for Nutrient Content of 11-22-16+4S in Zambia**

### 3.2.2 Fertilizers of Intermediate to Low Market Trade

#### Compound and Straight Granulated Fertilizers

The compound and straight fertilizers in Table 2 were pooled to produce the CFDF and study the compliance of macronutrient content. The single or few samples of the fertilizers in this group do not allow individual analysis per fertilizer. The pooled analysis is useful to obtain a general idea of the nutrient content conditions of this set of fertilizers. During implementation of a regulatory system, every fertilizer of interest will need to have enough samples (at least 20) collected to make robust inferences about quality.

OoC shortages for total N were found in 11% of the samples, with an OoC shortage severity of -1.5% (Figure 7A). OoC shortages for P<sub>2</sub>O<sub>5</sub> were found in 40% of the samples, with an OoC shortage severity of -3.1% (Figure 7B). OoC shortages of K<sub>2</sub>O were found in 26% of the samples, with an OoC shortage severity of -3.5% (Figure 7C). The OoC S shortages were found in 21% of the samples. The frequent OoC shortages for the four nutrient in the fertilizer together with severe shortages of P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, and S are evidence of considerable nutrient shortages in the fertilizers of medium to low commercialization in Zambia. Nutrient deficiencies are expected to take place in crops where these products are applied. Nutrient shortages OoC in this set of fertilizers probably occurred during the manufacture of the products given that adulteration through dilution of nutrients was not found, and the degradation of physical properties was minor.



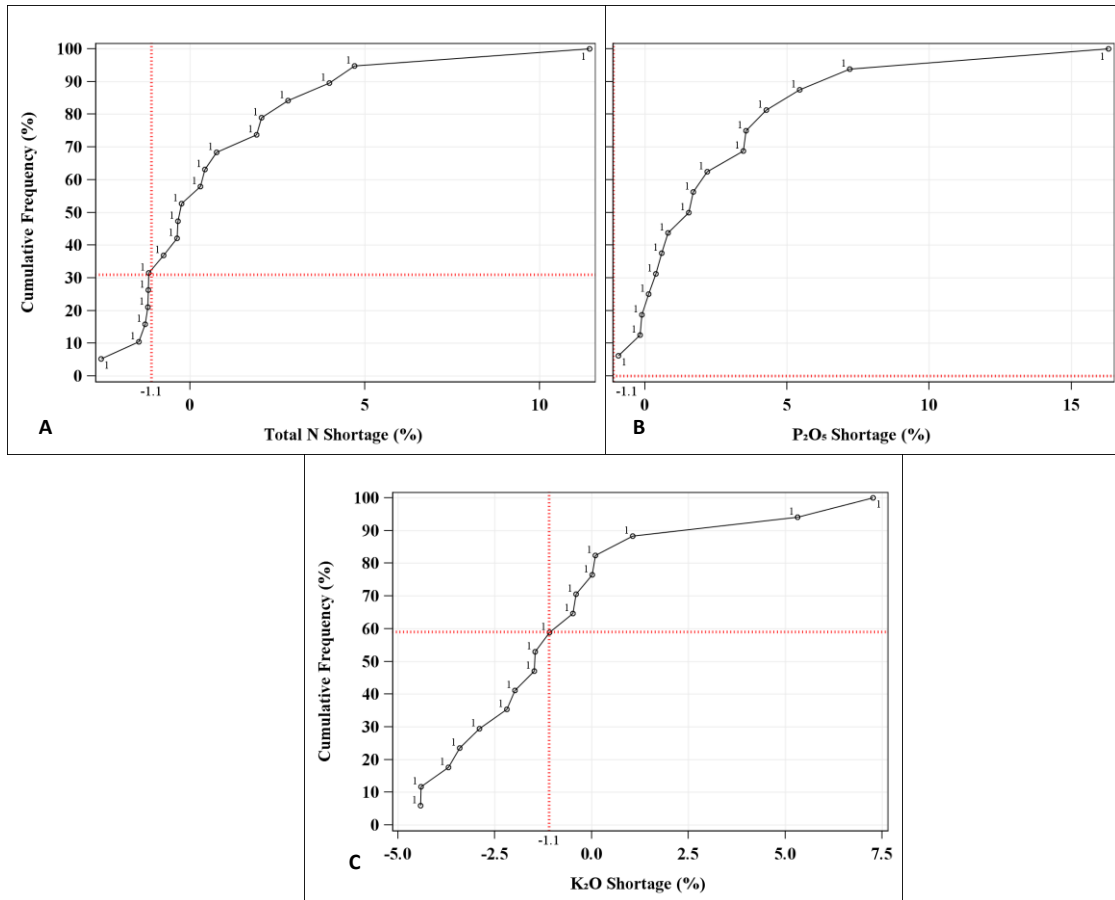
**Figure 7. Cumulative Frequency Distribution Function for Nutrient Content of Granulated Fertilizers with Intermediate to Low Market Trade in Zambia**

### Bulk Blend Fertilizers

The combined analysis of 23 bulk-blended grades (most of them with only one sample) found in Zambia provides a general view about the quality of this type of fertilizer in the country. During the eventual implementation of a National Fertilizer Quality Regulatory System, an assessment must be conducted for each individual blend after at least 20 samples per fertilizer grade are collected.

Shortages OoC for the total N content in the combination of blends was found in 32% of the samples with an OoC shortage severity of -1.54% (Figure 8A). No OoC shortages for  $P_2O_5$  were found in the combination of bulk blends (Figure 8B). OoC shortages of  $K_2O$  were found in 59% of the samples, with an OoC shortage severity of -2.9% (Figure 8C). Evidently, the  $K_2O$  OoC shortage is the main nutrient content problem in bulk blends traded in Zambia given the highly frequent and severe K shortages, as a consequence, the likelihood of  $K_2O$  deficiency in crops that are treated with bulk blends is high. A frequent cause of  $K_2O$  shortage in bulk blends is segregation, especially when the  $K_2O$  source is crystalline (< 2 mm diameter) rather than granulated (2-4 mm diameter) KCl. Crystalline KCl particles migrate toward the bottom of the fertilizer bags during the handling of the fertilizer, and often fertilizer samples extracted have fewer KCl particles than granules from the other blend components. It is apparent that the void left by KCl particles in the samples collected was filled by  $P_2O_5$  granules as is evidenced by the positive  $P_2O_5$  shortage values. Segregation of particles causes segregation of nutrients inside the bags, and non-homogeneous distribution of nutrients in the fields when the fertilizers are applied to crops. Further investigation should be conducted to identify the reason for the serious  $K_2O$  shortages

in bulk blends marketed in Zambia.  $K_2O$  shortages and segregation of  $KCl$  particles in the 16-0-24+S blend is discussed in Section 3.5.



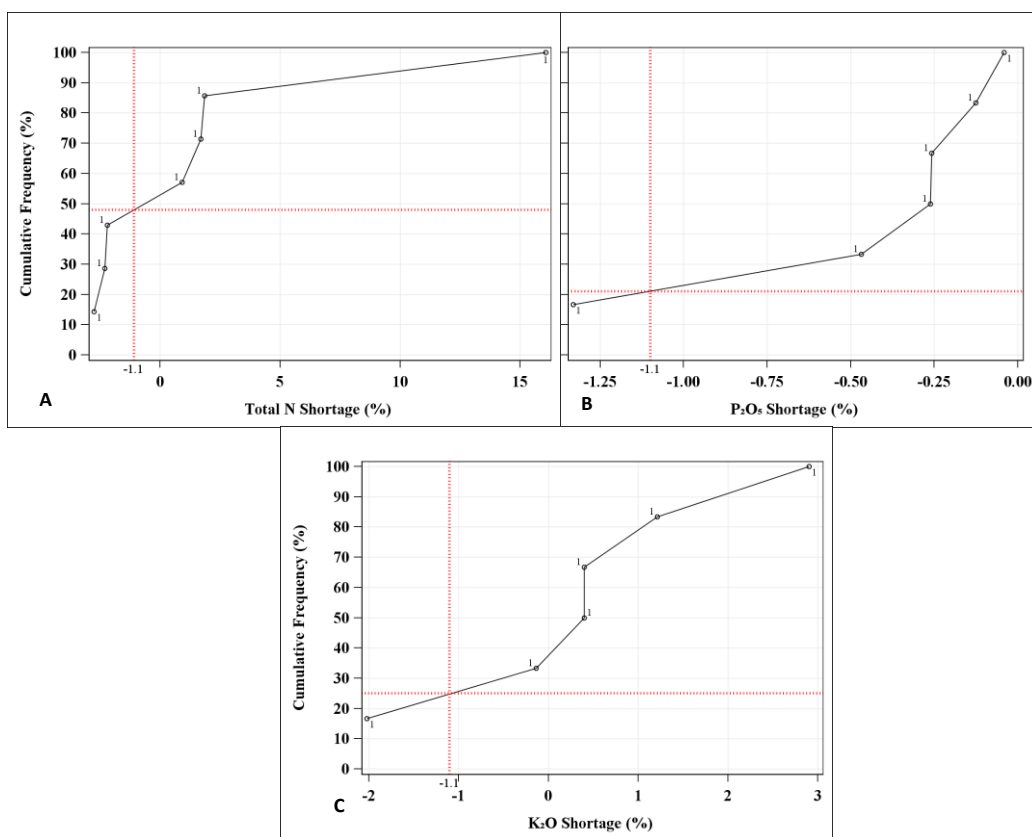
**Figure 8. Cumulative Frequency Distribution Functions of Macronutrient Content in the Set of Bulk Blend Fertilizers Traded in Zambia**

### Fertilizers for Foliar Application

Nine fertilizers for foliar application were sampled in markets of Zambia; seven were liquids and two were powders (Table 4). These fertilizers were combined to produce a CFDF per nutrient to learn about the macronutrient content condition. As part of the implementation of national regulations in the near future, enough samples should be collected from each foliar fertilizer available in the market to make quality assessments of individual fertilizer products.

The CFDFs in Figure 9 allows a very general assessment of the macronutrient content conditions of fertilizers for foliar application in Zambia. Forty-nine percent of the samples showed total N shortages OoC (Figure 9A), 21% of the samples presented  $P_2O_5$  shortages OoC (Figure 9B), and 25% of the samples had  $K_2O$  shortages OoC (Figure 9C).

High frequency of nutrient shortages in fertilizers for foliar application require intervention of regulatory authorities supervising manufacture of these products.



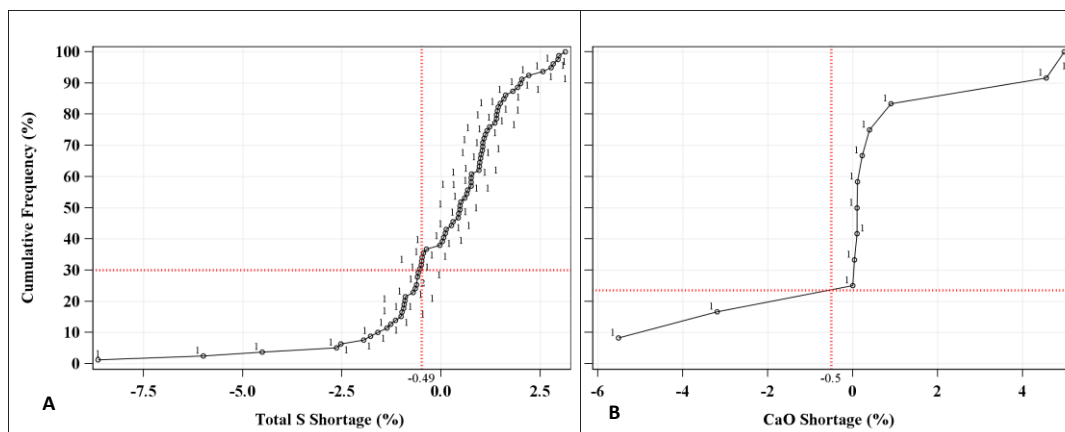
**Figure 9. Cumulative Frequency Distribution Functions for Macronutrient Content in Foliar Fertilizers**

### Secondary Nutrient Content

Number of samples containing micronutrients was too low to develop any valuable conclusion about this type of nutrients. Evaluation of the content compliance of secondary and micronutrients is important to understand the capability of fertilizers traded in Zambia to deliver the balanced nutrition for crops to achieve high yields and nutritional value. There were not enough samples to make this assessment for individual fertilizers. Instead, all of the fertilizers containing secondary and/or micronutrients were combined to develop CFDFs and produce a general estimate of the content compliance for S, and CaO. During implementation of a regulatory system, every fertilizer containing secondary or micronutrients should be surveyed with a sufficient number of samples to develop reliable CFDFs.

Tolerance limits for shortages of S and CaO vary depending on the nutrient guarantee value reported on the label, as shown in Annex D of the Zambian standard ZS 431:2014 (Zambian Bureau of Standards, 2014). An average tolerance limit calculated from the content reported on the fertilizer label is used in Figure 9. The S content shortages across all fertilizers containing this nutrient were OoC in 30% of the samples, with an OoC shortage severity of -2.04% (Figure 10A). The OoC CaO shortages occurred in 35% of the samples, with an OoC shortage severity of -3.0% (Figure 10B). Both the frequency and severity of the nutrient shortages OoC for the two

secondary nutrients can produce nutrient deficiencies in crops that are treated with the fertilizers having these nutrient shortages.



**Figure 10. Cumulative Frequency Distribution Functions for S and Ca Content in all Fertilizers Traded in Zambia**

### 3.3 Cadmium Content in Fertilizers

Cadmium is a non-nutrient element naturally found in the phosphates used in fertilizer manufacture. Its concentration in phosphate rock deposits of sedimentary origin is significantly higher than in phosphate deposits of igneous origin (Roberts, 2014). This heavy metal has been associated with serious damage to human vital organs (U.S. Department of Health and Human Services, 2012; Institute of Health and Consumer Protection, 2007).

Fifteen samples selected at random from the fertilizers containing  $P_2O_5$  were analyzed for Cd content. Five of the samples contained Cd with values below the minimum detection level of the determination method; the Cd contents of the remaining 10 phosphatic fertilizers are shown in Table 5.

The European Union (EU) is the world leader in the establishment of tolerance limits for the content of heavy metals in fertilizers. The EU has proposed a tolerance limit of  $60 \text{ mg Cd kg}^{-1} P_2O_5$  as the maximum Cd content in fertilizers to avoid Cd buildup in soils where phosphatic fertilizers are used (European Parliament, 2003). This tolerance limit will be gradually reduced, making it stricter; the TL is expected to be set at  $20 \text{ mg Cd kg}^{-1} P_2O_5$  a decade after the initial tolerance limit was recommended (Safer Phosphates, 2017).

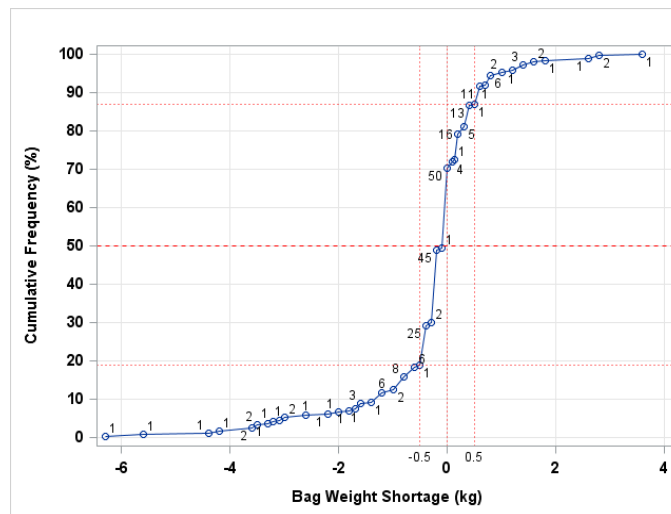
Zambia's Cd maximum tolerance limit is  $20 \text{ mg kg}^{-1} P_2O_5$ . Even the highest value of  $16.01 \text{ mg Cd kg}^{-1} P_2O_5$  from the compound 11-52-0 (Table 5) is below the Zambia's tolerance limit. The Cd content in the 10-20-10+6S, the most used compound fertilizer in Zambia, shows wide variability, ranging from  $0.128$  to  $4.34 \text{ mg kg}^{-1} P_2O_5$ . Such variability may be explained by the high variability of the heavy metal content across different phosphate rocks, it's known that Cd concentration can vary widely even within phosphate rock samples from the same deposit (Van Kauwenbergh, 2001; Roberts, 2014). Although the Cd values found in this study are below Zambia's tolerance limit, monitoring Cd content in locally manufactured or imported fertilizers must be a routine practice in Zambia.

**Table 4. Cadmium Content in Phosphatic Fertilizers**

Fertilizer	Cd (mg kg P <sub>2</sub> O <sub>5</sub> )
11-52-0 MAP	16.010
10-20-10+6S	4.342
10-20-10+6S	2.269
10-20-10+6S	1.492
10-20-10+6S	0.918
10:20:10+5S+0.15Zn+0.15B	0.254
10-20-10+6S	0.201
10-20-10+6S	0.151
10-20-10+6S	0.128
14-18-18+6S	0.046

### 3.4 Verification of Bag Weight

The TL for weight shortages in international regulatory systems is 1% of the weight reported on the fertilizer label. In Zambia, 50-kg bags are dominant, and the maximum weight shortage allowed is 0.5 kg. A total of 263 randomly selected 50-kg bags were weighed during the survey, and 19% of them were OoC, presenting weight shortages higher than -0.5 kg; 10% presented weight shortages of 1 kg or more (Figure 11). Underweight bags may result from random errors in the filling or weighing of bags during manufacture or bagging of bulk shipments, or from deliberate underfilling of bags. Deliberate underfilling of bags is a fraud that produces large profits for the manufacturers or distributors that practice it. The regulators must investigate this type of fraud and punish those responsible.



**Figure 9. Cumulative Frequency Distribution Function of Fertilizer Bag Weight Verification in Zambia**

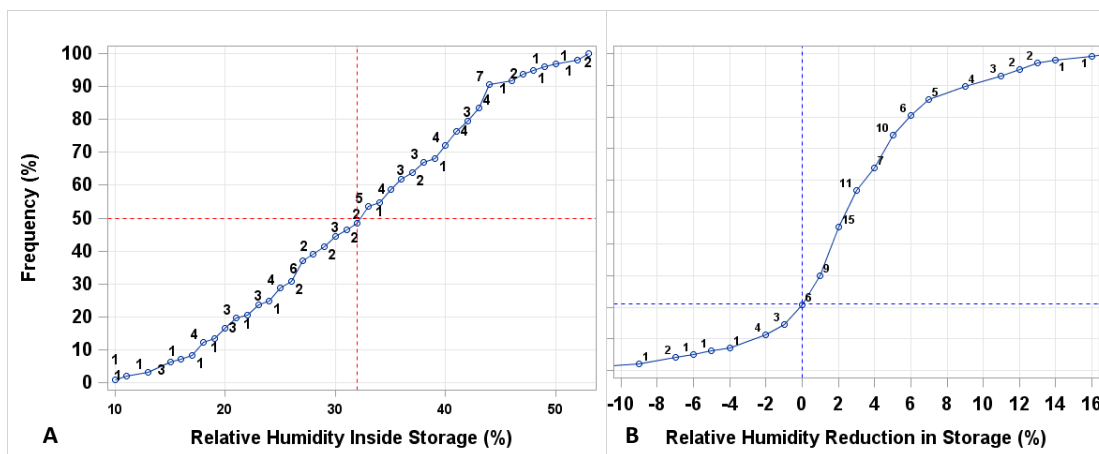
### 3.5 Fertilizer Storage, Packing Conditions, and Physical Properties of Fertilizers

Granulated fertilizers are hygroscopic salts that absorb moisture from the environment. For this reason, keeping granulated fertilizers in environments of low humidity and packing them in impermeable bags are essential for the preservation of the physical and chemical properties of the fertilizers. The critical relative humidity (CRH) of fertilizers is the relative humidity at which the fertilizer granules start absorbing moisture from the environment. CRH is usually measured at 30°C and depends on the constituents of the fertilizers. The fertilizers of high

commercialization in Zambia, ammonium sulfate, urea, CAN, and NPKs such as 17-17-17 or similar, have CRHs equal to 75%, 70%, 55%, and 55%, respectively.

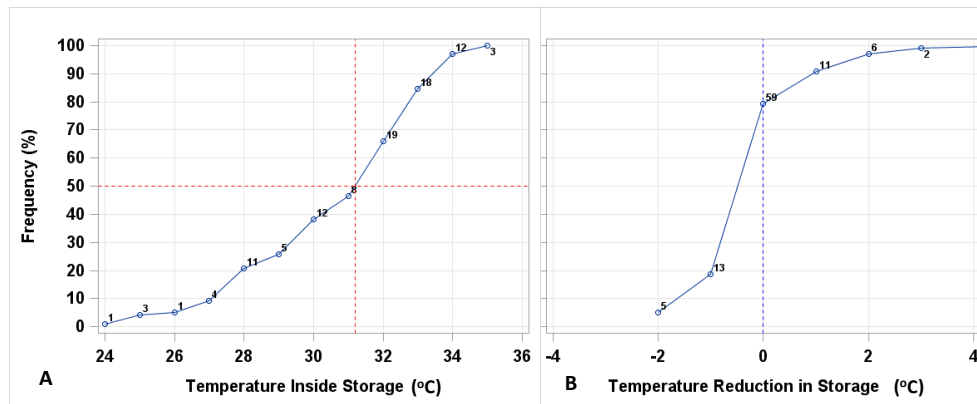
Figure 11A shows the range of relative humidity and RH frequency for a random sample of 97 storage facilities inspected. The inspection took place in October, when relative humidity is low in Zambia. The top RH in Figure 11A is 52%; thus, the CRH for NPKs or CAN (around 55%) has a low chance of occurring inside the storage rooms, and the occurrence of the CRH for ammonium sulfate and urea would be very unlikely in October. A different situation would take place in the November to January interval, when the fertilizer markets are very active, and the RH typically ranges between 70% and 80%. NPKs, CAN, and even urea and ammonium sulfate would reach their CRH if the storage facilities and the bagging materials are not set up to reduce RH and protect the fertilizers from absorbing environmental moisture.

Figure 11B indicates that only 21% of the fertilizer storage facilities had conditions to reduce the relative humidity inside the storage facilities with respect to the relative humidity outside the storage facilities. The actual protection to fertilizers would occur with RH reductions of 2% or larger, which occurs in only 10% of the facilities inspected.



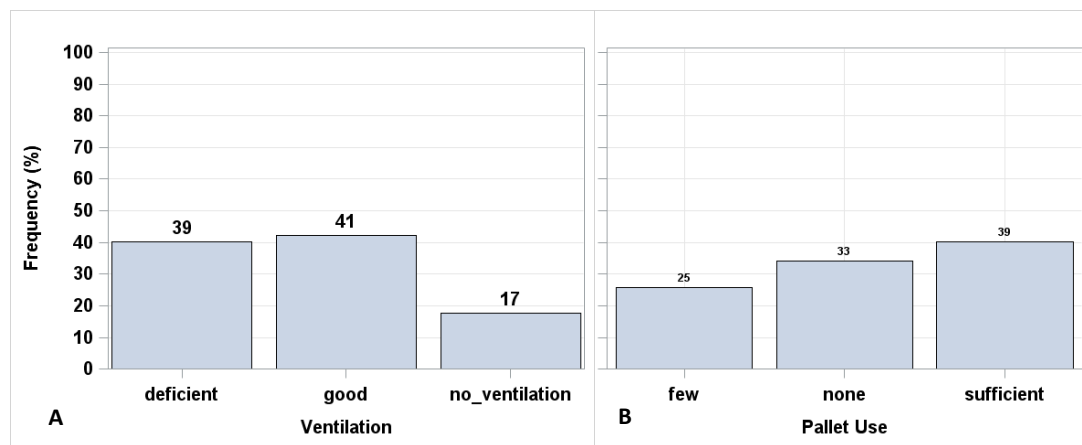
**Figure 10. Cumulative Frequency Distribution Function of Relative Humidity Inside Storage Facilities (A) and Reduction of Relative Humidity Inside Storage Facilities With Respect to the Relative Humidity Outside (B) in Zambia**

Reduction of the relative humidity in the storage facilities is achieved by reducing the temperature inside the storage area relative to the outside conditions. The average temperature in the interior of the storage areas was 31.2°C (Figure 12A). In the absence of air conditioning in fertilizer storage facilities (generalized to all sub-Saharan Africa), temperature reduction in the fertilizer warehouses and shops is achieved by eliminating direct solar radiation and creating conditions for ventilation through vents, and air circulation inside the storage areas leaving empty spaces between bag stacks and the roof, between bag stacks and walls, and between bag stack lots. The use of pallets also allows air circulation through the bag stacks. Nineteen percent of the storage facilities inspected showed no reduction of temperature relative to the temperature outside (Figure 12B).



**Figure 11. Cumulative Frequency Distribution Function of Temperature Inside Storage Facilities (A) and Temperature Reduction in Storage Facilities Relative to the Temperature Outside (B) in Zambia**

Temperature reductions are not achieved more frequently in storage facilities due to limited ventilation and air circulation; 19% of the storage facilities had no ventilation and 40% had deficient ventilation (Figure 13A). The use of pallets produces air circulation across the bag stacks, however, 32% of the storage facilities did not use pallets, and 27% use only a few pallets (Figure 13B). Highly frequent obstacles for air circulation in warehouses and shops are the lack of open spaces between fertilizer bags and the roof, no space between bag stacks and walls, and no free space between stack lots. The extremely limited ventilation and air circulation inside the fertilizer warehouses and shops in Zambia and most of sub-Saharan Africa result in no reduction or only a small reduction of temperature inside the storage areas. Temperature reduction is needed to reduce relative humidity inside the fertilizer storage facilities.



**Figure 12. Frequency Distributions of Ventilation Categories Inside Storage Facilities (A) and Pallet Use Categories in Storage Facilities (B) in Zambia**

This fertilizer quality survey was conducted during a period of low relative humidity in Zambia, which is one of the factors that helps to explain the high frequency (92%) of fertilizers with adequate moisture content (Figure 14A) which is inferred from the full flowability of granulated fertilizers through the sampling probe. Fertilizer samples that did not flow down the sampling probe were qualified with high moisture content, and samples presenting slow flowability

through the sampling probe were classified as containing low moisture. The moisture content at which fertilizers start reducing their flowability changes with the fertilizer type, most NPKs remain flowable at moisture contents of 1.5% or lower. ZS 431-2014 requires the granular fertilizer to be free flowing (Zambia Bureau of Standards, 2014), but does not make particular specification of moisture content.

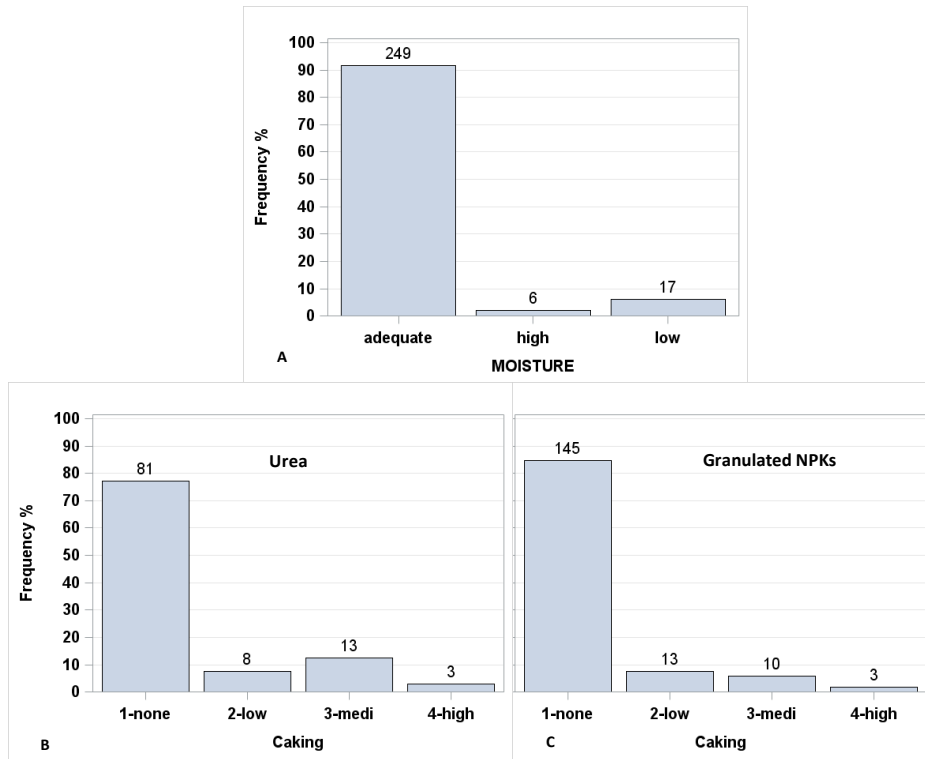
Granule degradation in Figure 15 is minimum for the fertilizers of highest market trade in Zambia. The great majority of the granules from the examined samples have remained at the regular granule size of 2-4 mm in diameter, and all fertilizers in this set presented particles with diameter lower than 1 mm in percentages lower than 10% to be in compliance with ZS 327-2005 (Zambia Bureau of Standards, 2005) which requires that a minimum of 90% of the granules be retained by a 1.00 mm sieve. Manufacture of the fertilizer granules with enough hardness to stand the forces associated with manual handling of the bags is the main factor explaining the low granule degradation in Zambia.

Caking in urea (Figures 14A) and granulated NPKs (Figure 14B) are shown in Figures 14A and 14B respectively. Twenty four percent of the urea samples presented some degree of caking, while 17% of the granulated NPKs showed some degree of caking. Elevated bag stacks with more than twenty layers in 13% of the warehouses (Figure 16D) and the use of insufficient or no use of pallets in 60% of the warehouses contribute to explain the relatively high frequency of caking in urea.

The good quality and integrity of the fertilizer bags (Figures 16A, 16B and 16C) along with the low relative humidity in October, are factors that help to explain the low moisture content of the fertilizers (Figure 14A) and the minimum granule degradation (Figure 15). Ninety-one percent of the bags inspected were impermeable due to their manufacture with an impermeable plastic inner layer and a woven fiber outer layer, or with a plastic laminated material (Figure 16A). Only 4% of the bags were torn (Figure 16B), and 3% of the bags had loose seams Figure 16C). A small proportion of the fertilizers stored in Zambia may have granule degradation associated with granule contact with environmental moisture that penetrates the bags through holes or cuts in torn bags or through loose bag seams. The predominant good quality and integrity of fertilizer bags are expected to protect the fertilizers against the high relative humidity inside the storage facilities during the hot and humid periods of the year in Zambia.

Segregation of bulk blend components was observed in only two samples out of 33 (6%). The first segregated sample was from the fertilizer identified as 16-0-24+S. The sieve box processing of a sample of this fertilizer indicated that the majority of the fertilizer sample was distributed in the first three compartments (diameter range 1.4-4.0 mm ). Most of the granules in these three compartments were ammonium sulfate, with a few reddish KCl granules. Few of the KCl particles with diameter < 1.4 mm were found in the right end compartments for fines and dust (diameter < 1.0 mm). It was evident that KCl was underrepresented in the sample from a fertilizer with 24% K<sub>2</sub>O, the chemical analysis of this fertilizer sample indicates an average K<sub>2</sub>O shortage of -3.3%. The KCl used for the blend was in crystalline form and segregated by moving down to the bottom of the fertilizer bags, KCl segregation could have been avoided by using granulated KCl.

The other sample showing segregation of blend components in the sieve box is the 10-20-10. The three first box compartments for granule diameters in the 1.4-4.0 mm range show a symmetrical distribution of granules with white, red, and green granules at about the same proportions. In the the compartment for dust-size particles ,<1.0 mm, there is 6% of a mixture of all the granules that form the blend. The granules in the dust compartment seem to be pieces of fractured granules and particles of the filler. The chemical analysis did not show OoC shortages for any of the three macronutrients.



**Figure 13. Frequency Distributions for Moisture Content Condition in Fertilizers (A), Urea Caking (B), and Granulated NPKs Caking (C).**

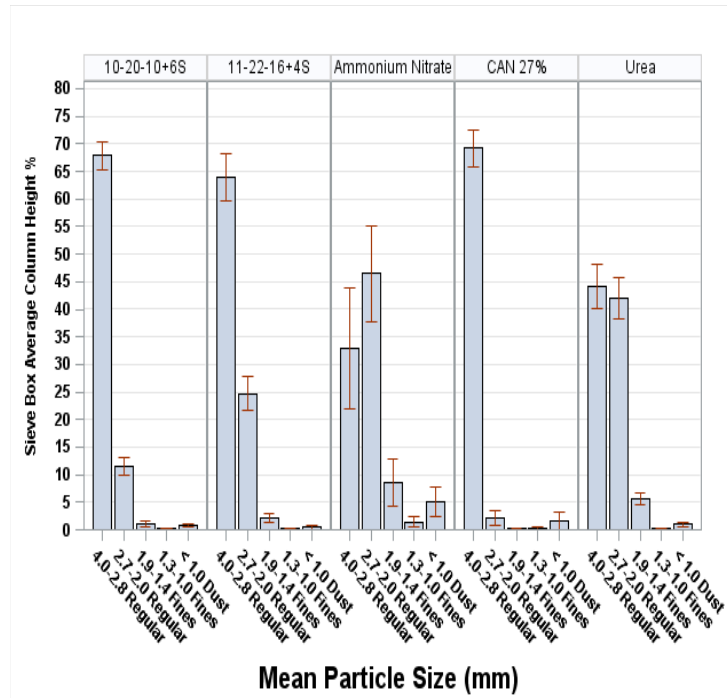


Figure 14. Granule degradation for the fertilizers of highest market trade in Zambia

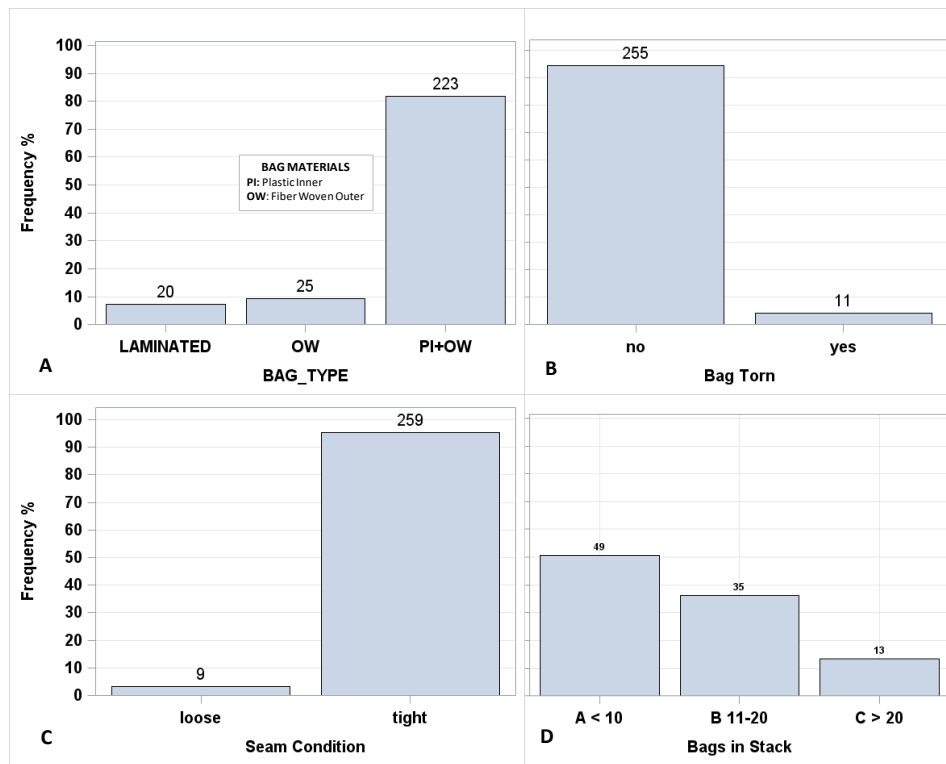


Figure 15. Frequency Distributions of Fertilizer Bag Type (A), Torn Bags (B), and Bag Seam Condition (C), and Number of Bags in a Stack (D) in Zambia

### 3.6 Adulteration of Fertilizers

The most common definition of adulteration is the addition of fillers or materials with no nutritional characteristics to a fertilizer product. The purpose of diluting the nutrient content reported in the fertilizer label is to increase the volume of the product to multiply the profit. Selling materials with no nutritional properties packed in fertilizer bags is another type of fraud that can be encountered in the fertilizer markets.

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 indicators 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. Chemical analysis is used to confirm possible adulteration after physical observation of the fertilizer in question.

Fertilizer inspectors did not find evidence of adulteration in any of the 305 fertilizer bags that were sampled and analyzed. This is consistent with findings in ECOWAS member countries, Kenya and Uganda (Sanabria et al., 2013; Sanabria et al., 2018a; Sanabria et al., 2018b). The belief that adulteration of fertilizer is the most important source of fertilizer quality problems also has been disproven by authors like Ashour et al. (2019) in Uganda and Michelson et al. (2018) in Tanzania. These findings contradict anecdotic statements about the rampant adulteration of fertilizers and the epidemic presence of “fake” fertilizers in countries of Africa.

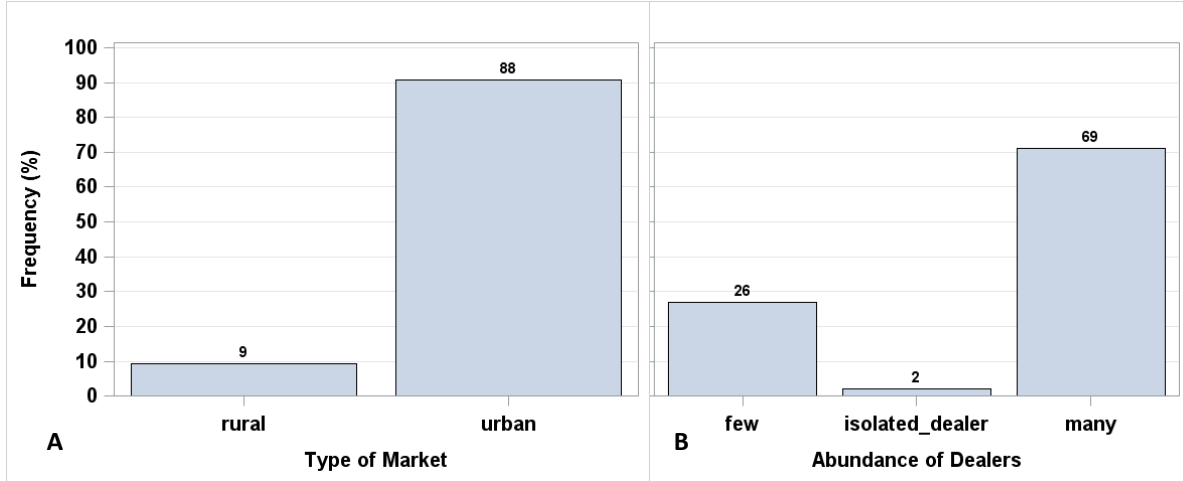
The overestimation of fertilizer adulteration in African markets may be explained by several factors (Sanabria et al., 2018b):

- Poorly designed fertilizer quality assessments that wrongly qualify quality problems that originate in faulty manufacture or poorly conducted chemical analysis as adulteration.
- Magnification of isolated cases of adulteration by the media.
- Complaints made by farmers due to poor crop response that cannot be directly linked to the fertilizer used but to an interaction of crop management problems.

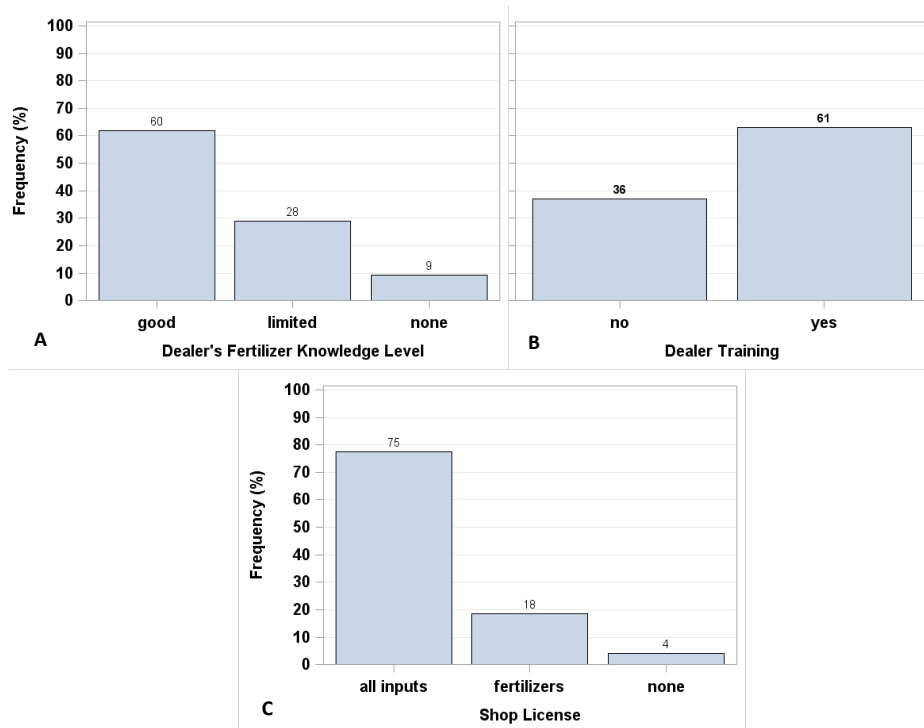
### 3.7 Market and Dealer Characteristics with Potential to Influence Fertilizer Quality

The market classification as urban or rural (Figure 17A) and the abundance of dealers operating in a fertilizer market (Figure 17B) have been found by Sanabria et al. (2013) to influence fertilizer quality. The location of the market in an urban area and the operation of many dealers in a market are expected to be associated with good fertilizer quality. The urban market characteristics that promote good fertilizer quality are a high chances of observation by authorities, large competition between dealers, customers demanding a high quality fertilizers, and customers who have freedom of choice to select the best dealers and the best fertilizer products. Rural markets are expected to have the opposite characteristics. Markets with ‘Many’ dealers trading in a market also create an appropriate environment for good fertilizer quality through competition between dealers to attract customers and freedom of choice for the customers. Markets with isolated dealers or few dealers would be expected to have characteristics opposite to the markets with many dealers, and may create conditions that favor the trade of poor quality fertilizers. Ninety-one percent of the fertilizer markets in Zambia are

rural (Figure 17A), and 71% of the markets in Zambia have many dealers (Figure 17B). Whether the 10% of rural markets and the 29% of the markets with few or isolated dealers have a negative effect on the quality of fertilizers was tested, and the results are shown in Section 3.8.



**Figure 16. Frequency Distributions of Type of Fertilizer Market (A) and Abundance of Fertilizer Dealers in Fertilizer Markets (B) in Zambia**



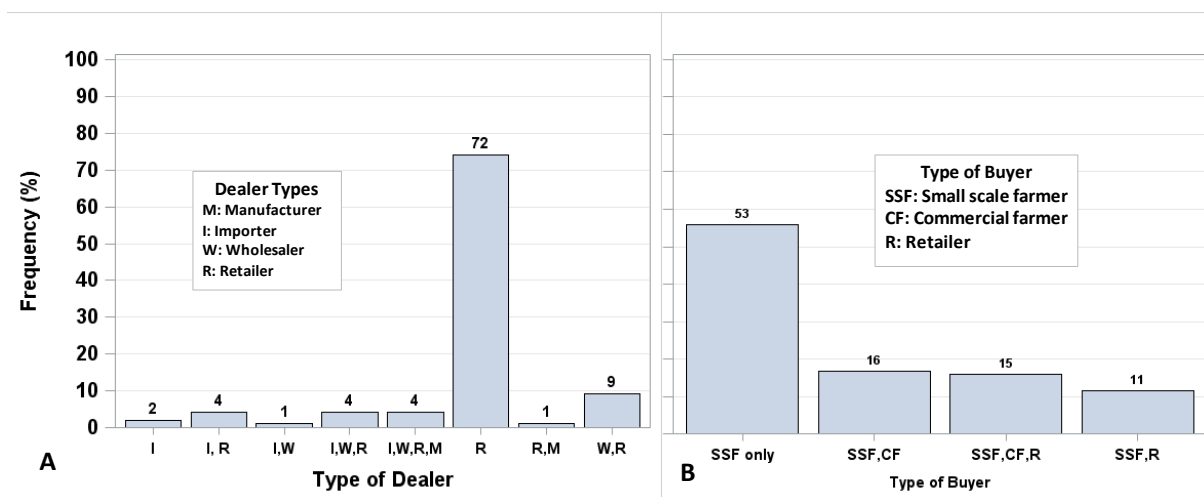
**Figure 17. Frequency Distributions of Dealer's Fertilizer Knowledge Level (A), Dealer Training (B), and Shop License Possession (C) in Fertilizer Markets of Zambia**

The dealer's knowledge about fertilizers has a potential effect on the quality of the fertilizers being sold. This type of knowledge may affect the quality of the product the dealer buys from importers and wholesalers, the management provided to the fertilizers in the shop/warehouse, and the advice given to farmers. In Zambia, 61% of the dealers have limited or no knowledge about fertilizers (Figure 18A). Dealers' access to training also could affect the quality of fertilizers sold, since training remediates knowledge deficiencies; 38% of Zambian dealers have not received training about fertilizers (Figure 18B). Four percent of the dealers do not have a license to sell fertilizers or agricultural inputs in general. The high frequencies of dealers with limited or no knowledge about fertilizers and without training are factors that could be detrimental to fertilizer quality in Zambia.

The type of dealer from which farmers buy fertilizers, either an importer, wholesaler, or retailer, can affect the quality of the products that the farmer gets to apply to the crops. Retailers are more likely to distribute products of substandard quality than wholesalers, and small retailers that work with small fertilizer quantities and provide them to smallholder farmers are at higher risk of selling low-quality fertilizer. This phenomenon may be explained by three factors. First, the retailer is located at the lowest point in the distribution chain and receives products that have passed through many hands. These products likely experience changes (some of them may be deliberate) 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 and wholesalers, retailers have less opportunity to learn about fertilizer properties through direct training or interaction with manufacturers, importers, and wholesalers. Seventy-two percent of the dealers in Zambia are retailers (Figure 19A). The type of customers that a dealer has also can influence 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 fertilizer retailers. Small-scale farmers are less likely to demand high quality than commercial farmers or fertilizer retailers. Fifty-six percent of the Zambian dealers sell only to small-scale farmers (Figure 19B). Statistical testing of associations of fertilizer physical properties, fertilizer management conditions, and market and dealer characteristics with fertilizer nutrient content compliance is discussed in Section 3.8.

### **3.8 Effect of Fertilizer Physical Properties and Market and Dealer Characteristics on Macronutrient Content of Fertilizers**

The results of tests to identify the possible effect of caking, moisture content, and fertilizer granule integrity on nutrient content compliance were non-significant. Physical properties data did not have enough variability, the great majority (> 80%) of the fertilizer samples studied did not show caking, and most (> 90%) of the fertilizer samples presented an adequate moisture content. Similarly, the granule integrity analysis presented very low percentages of fine particles or dust; regular-size granules dominated in all samples analyzed.



**Figure 18. Frequency Distributions of Type of Dealer (A) and Type of Buyer (B) in Fertilizer Markets of Zambia**

From the market and dealer characteristics that have the potential to affect fertilizer macronutrient content compliance, only the type of buyer that fertilizer dealers have as customers showed significant effect on macronutrient content compliance (Table 6). Compliance with the macronutrient content occurs with significantly higher frequency among samples taken from dealers that have all types of customers than samples taken from dealers that have only small-scale farmers as customers. The odds ratio of 2.35 indicates that the chances of a fertilizer sample being compliant with respect to macronutrient content is 2.35 times higher when samples come from a dealer that sells fertilizers to all types of farmers (smallholders plus commercial farmers) than when samples come from dealers that have small-scale farmers as their only customers. The dealer that sells only to small-scale farmers may not be aware of the low-quality fertilizers in his/her shop, or the dealer could be conscious of the low quality of the products in the shop but taking advantage of the low quality awareness of his/her customers.

This finding indicates the need for education, both for the fertilizer dealers, specialty retailers, and smallholder farmers. Dealers should be educated as part of private sector strengthening programs on the subjects of fertilizer quality and good business practices. Smallholder farmers should be educated about fertilizer quality concepts and the effect of fertilizer quality on crop productivity, soil fertility, environment conservation, and human nutrition.

**Table 5. Test for the Effect of Market and Dealer Characteristics on Fertilizer Macronutrient Content Compliance**

Effect	DF	Chi-Square	Pr > ChiSq	Odds Ratio		
				Label	Estimate	0.95 Confidence
Type of Market	1	1.258	0.262			
Abundance of Dealers	1	1.200	0.273			
Type of Dealer	1	1.888	0.170			
Type of Buyer	1	3.641	0.056	All Farmer Types vs Only Small Scale Farmers	2.35	1.25 4.42
Dealer's Fertilizer Knowledge	1	0.112	0.738			

## 4. Conclusions

- OoC shortages of macro and secondary nutrients occurred with high frequency and severity in the fertilizers traded in Zambia. Considering that there was no evidence of adulteration in the samples from these fertilizers, and that the physical properties degradation was minimal, the expected origin of the nutrient shortages OoC is in the manufacture of the products.
- The combined analysis of the 23 bulk blends identified in Zambia showed frequent but low severity of total N OoC shortages, no P<sub>2</sub>O<sub>5</sub> OoC shortages, and highly frequent and severe K<sub>2</sub>O OoC shortages. It is apparent that the K<sub>2</sub>O OoC shortages are due to use of crystalline KCl instead of granulated KCl. Segregation of small KCl particles explains the K<sub>2</sub>O shortages in the bulk blends.
- The most plausible explanation for the nutrient shortages out of compliance in the granulated products is that the nutrient deficiencies originate in the manufacture. Inspection before imported fertilizers enter Zambia should become stricter. It is important to establish a system that ensures pre-export verification of conformity (PVoC). This should be followed by confirmatory inspection and analysis before the imported products reach the markets.
- Cadmium content in 15 phosphatic fertilizer samples was below Zambia standard. Continued monitoring of the Cd content in fertilizers and the origin of the phosphate rock used in fertilizer manufacture is recommended.
- Nineteen percent of the 50-kg bags weighed had OoC shortages of at least -0.5 kg, and 10% of the bags had weight shortages of at least 1 kg. Additional investigation is needed to identify where and how this fraud is committed.
- No severe degradation of granule integrity that could cause uneven distribution of nutrients inside the fertilizer bags was identified; fertilizers seem to be manufactured with sufficient granule hardness to withstand the manual handling of individual fertilizer bags. Caking and high moisture content, which have the potential to affect nutrient distribution inside the bags, were found with low frequencies. Good quality bags were found to protect fertilizer granules from absorbing moisture in storage facilities.

## 5. Recommendations

- As Zambia's fertilizer consumption grows and the national fertilizer markets expand, the existing laws that regulate fertilizers and feeds must be reviewed. A regulatory framework specific to fertilizers needs to be developed, and an agency within the Ministry of Agriculture should be provided with the funds, trained personnel, laboratories, and other physical resources to conduct continuous quality inspections along the value chain, analysis of samples, and legal enforcement of the standards developed by ZABS.
- Interaction and good relations between government and the private sector are essential to establish an environment of good fertilizer quality in the markets. Implementation of the regulatory system by the government should go together with self-regulation by the private sector.
- Finally, implementing updated regulatory and policy frameworks will provide the necessary environment to encourage investment and build trust in the fertilizer sub-sector. Then, regional harmonization of fertilizer quality regulation will lead to a larger market, reduced costs, and increase access to quality fertilizers.
- The random fertilizer sampling in this study indicated that just five fertilizer products make up for 77% of the total sampling. This can be interpreted as a fertilizer market with low product diversity for matching the nutritional needs of crops growing in the highly diverse soils and agroecosystems of Zambia.
- Fertilizer recommendation research programs would identify the crop nutritional needs across the country and additional fertilizers that should be present in the markets.
- ZABS should consider developing standards for fertilizer contamination with additional heavy metals like Cr, Ni, As, specially for fertilizers that contain organic materials. There are evidences of heavy metal contamination in fertilizers manufactured in China, the organic materials used in some of these fertilizers are collected from areas with heavy industrial or mining activity.

## 6. References

- AOAC International. 2012a. *Official Methods of Analysis 19<sup>th</sup> Ed., Modified AOAC Official Method 2017.08*. Gaithersburg, MD, USA.
- AOAC International. 2012b. *Official Methods of Analysis 19<sup>th</sup> Ed., Modified AOAC Official Method 958.01*. Gaithersburg, MD, USA.
- AOAC International. 2012c. *Official Methods of Analysis 19<sup>th</sup> Ed., Modified AOAC Official Method 955.06*. Gaithersburg, MD, USA.
- European Parliament. 2003. *Regulation (EC) No 2003/2003 of the European Parliament and of the Council Relating to Fertilisers*. Official Journal of the European Union L304.
- Government of the Republic of Zambia. 2004. *National Agricultural Policy (2004-2015)*. Ministry of Agriculture and Co-Operatives.

IFDC. 2013. *Zambia Fertilizer Assessment*.

Mason, N.M., W.J. Burke, A. Shipekesa, and T.S. Jayne. 2011. "The 2011 Surplus in Smallholder Maize Production in Zambia: Drivers, Beneficiaries, & Implications for Agricultural & Poverty Reduction Policies." *Working Paper No. 58 Draft, Food Security Research Project. Lusaka, Zambia*

U.S. Department of Health and Human Services. 2012. *Toxicological Profile for Cadmium*. Public Health Service. Agency for Toxic Substances and Disease Registry. Available: <http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=48&tid=15> (verified 18 January 2013).

Institute of Health and Consumer Protection. 2007. *European Union Risk Assessment Report. Cadmium Oxide and Cadmium Metal. Part 1 –Environment. Risk Assessment*.

Van Kauwenbergh, S.J. 2001. "Cadmium in Phosphate Rock and Fertilizers," Paper presented at The Fertilizer Institute 2001 World Fertilizer Conference, Chicago, Illinois.

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

Safer Phosphates™. 2018. <https://www.saferphosphates.com/fertilizers>

Sanabria, J., J. Dimithe and E. Alognikou. 2013. The Quality of the Fertilizers Traded in West Africa: Evidence for Stronger Control. IFDC report.

Sanabria, J., J. Ariga, J. Fugice, and D. Mose. 2018a. *Fertilizer Quality Assessment in Markets of Kenya*. IFDC report.

Sanabria, J., J. Ariga, J. Fugice, and D. Mose. 2018b. *Fertilizer Quality Assessment in Markets of Uganda*, IFDC report.

Sokotela, S. 2014. National Report: Zambia. "Joint Program on Fertilizer Policy and Regulatory Harmonization Programme" organized by Common Market for Eastern and Southern Africa (COMESA) Alliance for Commodity Trade in Eastern and Southern Africa (ACTESA) African Fertilizer and Agribusiness Partnership (AFAP).

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

Zambia Ministry of Agriculture. 2011. *The National Agriculture Policy 2012-2030*.

Zambia Agricultural Research Institute (ZARI). 2012. *Project for Strengthening National Institutions for Fertilizer Quality and Regulatory System in Zambia*. AGRA Grant No. 2012 SHP 010. Zambia Agricultural Research Institute, Ministry of Agriculture and Livestock, Chilanga.

Zambia Bureau of Standards. 2005. Blended (Physical Mixture) Fertilizers Specification. ZS 327:2005

Zambia Bureau of Standards. 2014. Compound Fertilizers Specification. ZS 327:2005 2<sup>nd</sup> Edition.

# Appendix A. Procedures for Data Collection and Fertilizer Sampling

## 1. Equipment

- Smartphone 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 various 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 smartphone. It will start prompting for information related to the fertilizer market where the shop is located (Table A1), followed by 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 smartphone. The next prompt will be about opening a dataset for characteristics of the first fertilizer that will be sampled; after you reply "yes", the smartphone 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 smartphone questionnaire the weight on the label and actual weight of the bag when prompted.
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*

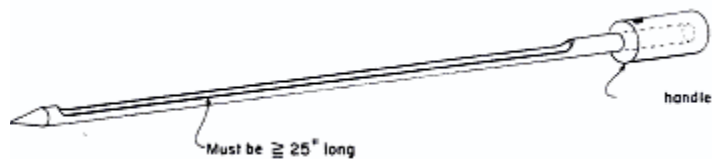
A fertilizer lot is the set of fertilizer bags that were delivered to the shop or warehouse in only one shipment. The most common situation in a fertilizer dealer warehouse is finding more than one lot of the most commercialized fertilizers.

A sample of a granulated fertilizer is usually 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.

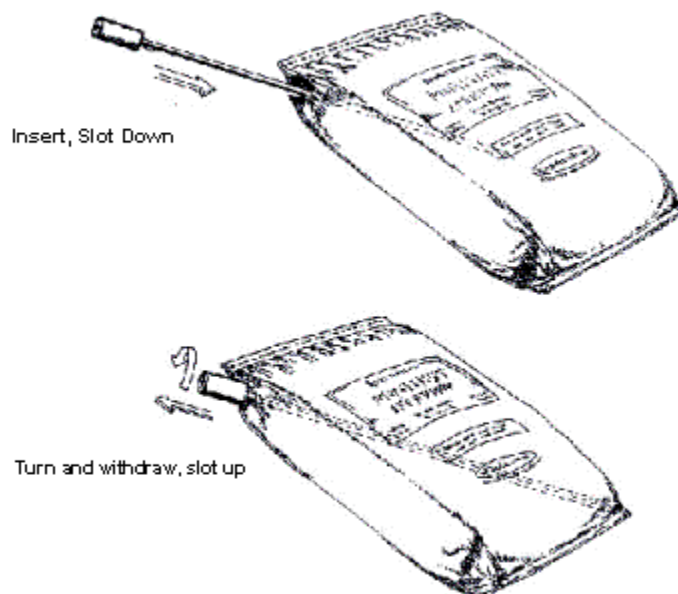
Fertilizer Type	n Bags in lot	n bags to sample
Solid	5 or less	1
	6 to 20	2
	21 to 50	4
	51 to 100	6
	> 100	1 from every 20
Liquid	<b>n jars in lot</b>	<b>n jars to sample</b>
	20 or less	1
	21 to 50	2
	> 50	2 from every 50

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 move the slots upward. Extract the sampling probe.
- Empty the content of the sampling probe in a bucket. That is a subsample.
- Patch the hole left by the sampling probe in the bag with tape.
- 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 the physical properties assessment in the smartphone data system.
- Transfer the sample from the bucket to a plastic bag using a funnel. Seal the bag completely 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. 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. Adhere the label to the first plastic bag containing the sample.
- Place sample and label in a second bag. Seal the bag completely 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 a 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, 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**



**Bag Sampling Technique**

**Figure A2. Sampling Technique for Solid Bagged Fertilizers**

**Taking a Sample from an Open Bag**

- Scoop out three subsamples: one from the top, one from the middle, and one from the bottom of the bag (Figure A3). Place the three subsamples in a bag. Seal the bag completely.
- Fill out the sample label. Adhere it to the sample bag. Make sure to mark the “Open Bag” box on Table A4.
- Place the sample bag in a second larger bag. Seal it completely.
- 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 into the smartphone system using the same procedure as with data from closed bags.

## Taking a Sample from Liquid and Crystal Fertilizers

- 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 adhere it to the jar or bag
- Enter characteristics of the fertilizer to the smartphone system in the same way as 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								
<b>MARKET CHARACTERISTICS</b>										
Mark with an X under the answer options										
<b>Type of Market</b>			<b>Concentration of Dealers</b>			<b>Market Location</b>				
<b>Urban</b>	<b>Rural</b>		<b>High</b>	<b>Low</b>	<b>Isolated Dealer</b>	<b>Permanent</b>	<b>Itinerant</b>			

**Table A2. Characteristics of the Dealer**

<b>AGRO-DEALER CHARACTERISTICS</b>									
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. Storage Conditions**

<b>Characteristics of Storage</b>									
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**

<b>Characteristics of Fertilizer Products</b>																				
Enter text or quantity, use codes especified at the bottom of table																				
Sequenc e #	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)											
<b>SEGREGATION only for bulk blends</b> Percentages from vertical scale in Sieve Box					<b>MOISTURE CONTENT</b>			<b>FILLER</b>			
5 - %	4 - %	3 - %	2 - %	1 - %	Adequate	Low	High	Yes		No	
								% in label			
<b>GRANULE INTEGRITY for granular compound fertilizers</b> Percentages from vertical scale in Sieve Box					<b>CAKING</b>				<b>IMPURITIES/FOREIGN MATERIAL</b>		
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 percentage 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 smartphone 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 colors of granules will be well separated. A non-segregated fertilizer will show all the granules in few columns, usually two or three, with 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 smartphone 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.

**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 percentage of granules of regular size (range 2.8 mm to 4 mm, contained in the 1<sup>st</sup> compartment), percentage of granules smaller than the original size or fines (between 1.0 and 2.8 mm, contained in the 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> compartments), and the percentage of dust (< 1 mm, contained in 5<sup>th</sup> 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 small amounts of fines and dust, show few or no particles in the “fines” and “dust” compartment of the sieve box. Record column heights in the smartphone 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 smartphone 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 smartphone 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.

**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 complete sealing. Pick one of the moisture content categories shown on the smartphone screen.

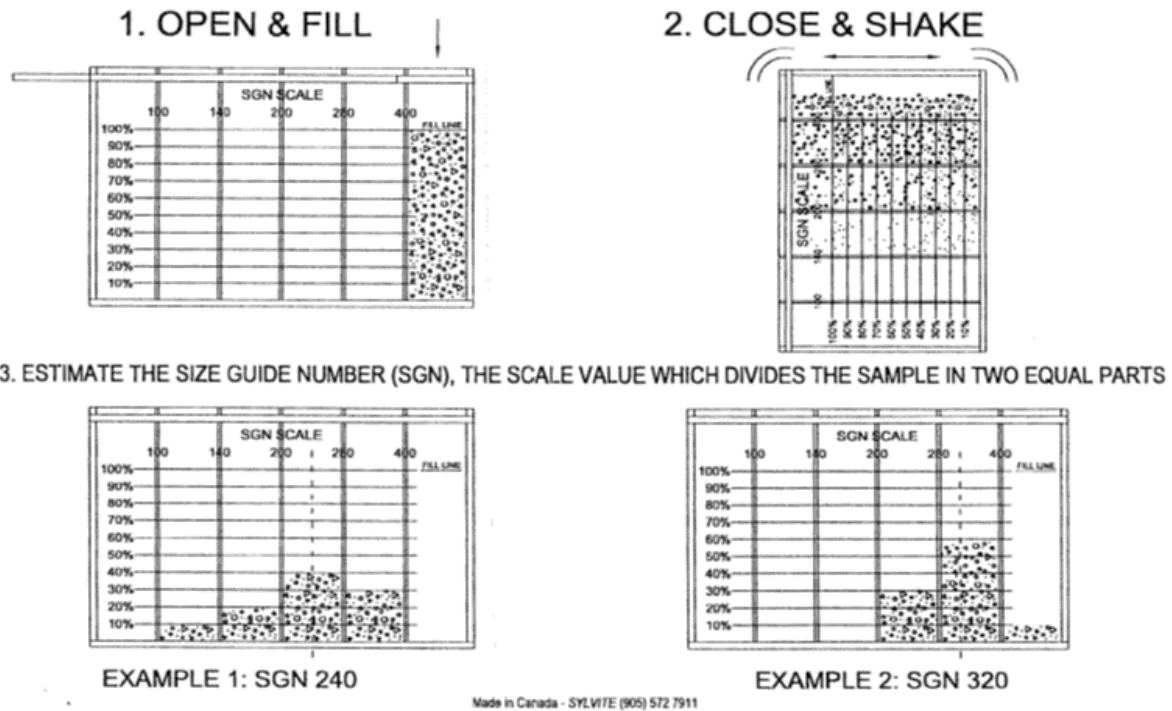
**Caking** occurs when the individual granules of the product fuse to form larger aggregates. In extreme cases of caking, entire bags become one solid body. Caking usually takes place when the fertilizer product comes into contact with water or when it absorbs moisture from the air due to storage in 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 on the smartphone 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, or to make blends), fertilizers may become contaminated with soil, plant tissue, 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 are based on the separation of granules of different size. There are other laboratory methods for high precision and accuracy.

## Operation of the Boxes



## Estimation of Segregation (Example)

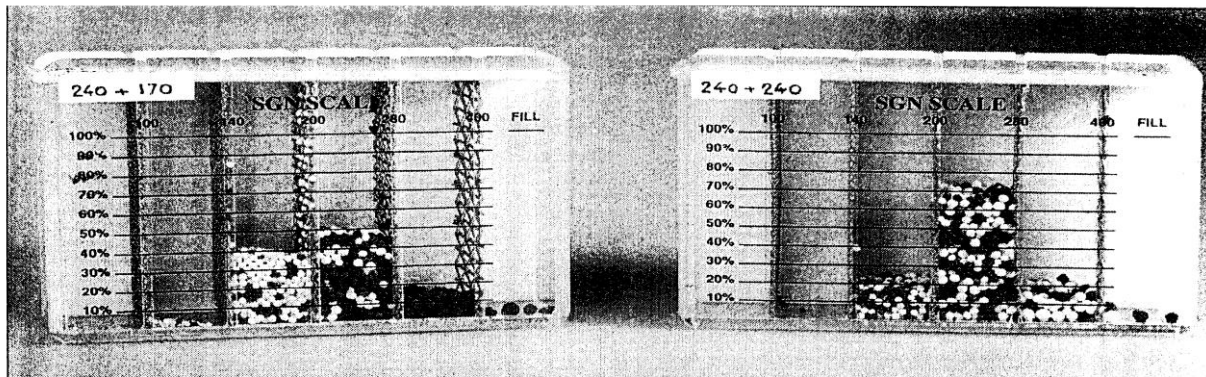


FIG. 7-2. TESTING FOR SEGREGATION

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 colors of granules will be well separated. A **non-segregated fertilizer** will show all the granules in few columns, usually three or four, with all of 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 few or no particles at the left end of the sieve box.

