Quality Assessment of Fertilizers Traded in Mali

Joaquin Sanabria[1] and Emmanuel Alognikou[2]

1. IFDC Headquarters, 2. IFDC Togo

Introduction

In 2006, prior to the Africa Fertilizer Summit and in collaboration with the West Africa Economic and Monetary Union (UEMOA), ECOWAS adopted a fertilizer strategy[1] with the general objective of promoting their increased and efficient use with a view to sustainably improving agricultural productivity. This regional strategy hinges on four pillars or specific objectives:

1. Improving efficiency and environmental safety of fertilizers.
2. Improving the institutional, regulatory and business environment of the regional fertilizer market.
3. Stimulate effective demand.
4. Stimulate supply.

Through the second specific objective, which is to improve the regulatory, institutional and business environment of the regional market of fertilizers, ECOWAS is focusing on creating favorable conditions for the development of the fertilizer sector. Indeed, West African national fertilizer markets are underdeveloped and too narrow to generate a sufficient dynamism and competitiveness. The extension of national markets to the ECOWAS region through the harmonization of national regulatory frameworks is likely to further stimulate private investment in this sector. The effective implementation of a regional framework that harmonizes national regulatory frameworks governing the production and trade of fertilizers and instituting and organizing quality control will protect farmers and render fertilizer trade more attractive to private investment by expanding national markets beyond national borders and by stimulating fair competition with quality products. An ECOWAS legal framework for fertilizer trade and quality control in West Africa was adopted by all state members of the economic community in December 2012.

The liberalization of the importation and distribution of fertilizers in most West African countries without appropriate control has led to the emergence of quality problems in products traded in the region. These problems could impede efforts to boost agricultural productivity and to restore or maintain soil fertility, for this reason systematic quality assessments following the requirements in the recently adopted ECOWAS regulatory system at country and regional levels are a priority.

There are very few systematic studies on the quality of fertilizers marketed in West Africa. The most recent,[2] conducted by IFDC between 2010 and 2013 made quality assessments in five countries –Ghana, Nigeria, Togo, Côte d'Ivoire and Senegal – showed large quality differences between countries, but in general, the NPK fertilizers manufactured through blending presented the most frequent cases of poor quality compared with compound products. More specifically, 51 percent of the 106 samples of the NPK 15-15-15 blend were out of compliance with the then newly adopted ECOWAS tolerance limits for nutrient content deviations. Similarly, other products that failed to meet the ECOWAS quality standards were 86 percent of the 90 samples of the NPK 20-10-10 blend, 12 percent of the 30 samples of the NPK 6-20-10 blend, 96 percent of the 27 samples of the

[1] ECOWAS. 2006. *Stratégie Régionale de Promotion des Engrais en Afrique de l'Ouest*.

[2] Sanabria, J., G. Dimithe, and E. Alognikou. 2013. "The Quality of Fertilizer Traded in West Africa: Evidence for Stronger Control". Special Publication IFDC – SP-42.

NPK 15-10-10 blend, 31 percent of the 23 samples of Asaase Wura (NPK 0-22-18+9CaO+7S+5MgO) and 26 percent of the 27 samples of Cocoa Feed (NPK 0-30-20). Data from the study indicated that nutrient shortages among the blended fertilizers can be explained by segregation of fertilizer components due to uneven size of granules in some cases and by insufficient input of some of the nutrients during manufacture in other cases.

In contrast to the blended products, the only compound products that failed to meet the ECOWAS quality standard were 4 percent of the 534 samples of urea, 10 percent of the 356 samples of the compound NPK 15-15-15, 16 percent of the 162 samples of AS (NPK 21-0-0 +24S), 15 percent of the 162 samples of compound NPK 16-16-16, 1 percent of the 103 samples of compound NPK 23-10-5 and 4 percent of the 90 samples of Sulfan (NPK 24-0-0+6S). While the proportions of non-compliant samples observed in the compound products are lower than the ones observed in blended products, these can still be considered high for imported products. This result confirms the finding of a previous assessment IFDC carried out in West Africa in 1995[3] indicating that 10 of the 29 samples of NPK compounds examined were nutrient-deficient.

An analysis of the weight of 1,055 fertilizer bags collected from all five countries indicated that there was a 41 percent chance that the bag weight does not comply with the ECOWAS tolerance limit in Nigeria, a 28 percent chance in Côte d'Ivoire, 13 percent in Senegal, 12 percent in Ghana and 7 percent in Togo. The only cases of completely proven adulteration are seven samples of SSP from Nigeria that were found to have no P_2O_5 content. While high percentages of nutrient deficient samples in some NPK blends found in some countries could be interpreted as fraud during manufacturing or along the distribution chain, this was not substantiated by findings of this study; the lack of or poor control of blending procedures and use of inadequate blending equipment can be also possible explanations.

The fertilizer quality assessments conducted between 2010 and 2013 were part of the activities of the IFDC MIR-Plus project[4]. Following adoption of the Regulation C/REG.13/12/12 relating to fertilizer quality control in the ECOWAS region, the ECOWAS Commission gave IFDC through the USAID-funded West Africa Fertilizer Program (WAFP)[5] the mandate to facilitate its implementation in member States. The fertilizer quality assessment in additional ECOWAS Member States like Mali, Burkina Faso, Benin and Liberia is part of WAFP's efforts. A fertilizer quality assessment study has been conducted in Mali between July 2014 and May 2015 and its findings are presented in this report.

The main objective of this project was to assess the quality of fertilizers in the markets of Mali, classify the problems according with their origin and identify factors that contribute to the quality problems. This information is expected to be used by the Government of Mali and ECOWAS as baseline to work toward domestication of the ECOWAS regulatory system to improve the Mali regulatory system in terms of efficacy and harmony with the regional regulatory system.

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[3] Visker, C., Rutland, D. and K. Dahoui. 1995. "The Quality of Fertilizer in West Africa (1995)," IFDC. *Miscellaneous Fertilizer Studies No. 13*.

[4] The MIR Plus project is a joint ECOWAS-UEMOA project implemented by IFDC with the overall objective of facilitating the development of a regional agro-input market in West Africa in support of the implementation of their regional agricultural policies. The project ended in December 2013.

[5] The WAFP project is a USAID/West Africa-funded project implemented by IFDC with the strategic objective of increasing regional availability and use of appropriate fertilizer in West Africa in support of the implementation of the regional agricultural policies.

Section 1. Methodology

1.1. Capacity Building of Fertilizer Inspectors

Prior to the field work, the project technical staff trained a group of fertilizer inspectors of the Direction Nationale de l'Agriculture (DNA) in Bamako for two days to work as fertilizer quality inspectors in the fertilizer dealer shops/warehouses that were part of the sample. Participants in the training, also included supervisors of the data/sample collection. The majority of participants in this training were DNA supervisors and fertilizer quality inspectors that make habitual fertilizer quality inspections in Mali as part of the existing regulatory system.

The training covered the theoretical concepts associated with fertilizer chemical and physical characteristics that define quality, the methodology for collecting fertilizer samples and data about markets, dealers, storage conditions. There was practice of the procedures to collect the different types of data as well as the protocols to take fertilizer samples from closed and open bags. During the practical component of the capacity buildings the trainees exercised the use of the equipment needed for the different data/sample collection activities. The sampling equipment is composed by the following implements:

- Main questionnaire, Sample labels and Physical Properties Format
- Digital camera with memory card
- Bag sampler probe (trier)
- Scoop to sample open bags
- Sieve boxes for assessment of fertilizer physical attributes
- Weight Scale
- Bucket, funnel, and dusting rag
- Clip board
- Tape to seal bag holes left by sampler
- Re-sealable (zip-lock) plastic bags for fertilizer samples
- Carton board boxes to carry sets of fertilizer samples

All the implements in the list were either directly provided to the inspection teams by the WAFP project or funds were given to DNA to buy implements locally.

1.2. Data and Fertilizer Sample Collection

The sampling methodology used is diagrammed in Figure 1. It consists of two sampling steps: (1) obtaining a random sample of fertilizer dealers in each country and (2) collecting random samples of fertilizers and data from each of the warehouses or shops included in the sample of distributors in the first step.

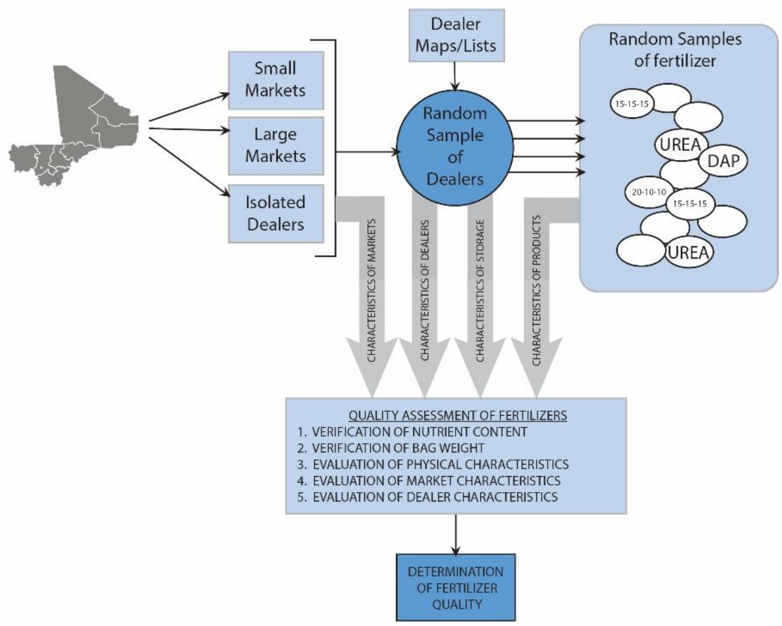

Figure 1. General Methodology for the Quality Assessment of Fertilizers Commercialized in Mali

1.2.1. Sampling of Fertilizer Dealers

A database of agro-dealers built by DNA in 2010 was the data source used for development of the sample of fertilizer dealers. The database contained 1151 agro-dealers from which 770 traded fertilizers. This set of 770 fertilizer dealers distributed through all the Mali regions was assumed as the conceptual population of fertilizer distributors to be sampled.

The fertilizer dealer sample size was determined calculating the sampling capability of the two inspection teams using the following equation:

$n = t * d * S_d$ (1)

Where n is the number of dealers that make up the delar's sample, t is the number of inspector teams that will go to the field to collect data and fertilizer samples (t =2), d the number of days available for sampling (d=10), and S_d is the average of fertilizer dealers expected to be visited per day (S_d=5).

Equation 1 was used to come out with the dealer's sample of size of 100. Each of the inspector's team received 50 dealers to visit. The dealers assigned to each team were randomly selected using random numbers generated by a uniform probability distribution. The dealer's list given to each team also contained a number of dealers randomly selected to make substitutions when a dealer in the sample is not found or does not have fertilizers to be sampled.

1.2.2. Collection of Data and Random Sampling of Fertilizers in each Distribution Points included in the Sample

When the inspection teams visited the dealers that were part of the sample, they recorded location of the shop or warehouse and characteristics of market in Table A1, characteristics of the dealer in Table A2, characteristics of the storage facilities in Table A3, characteristics of each fertilizer product sampled in Table A4. Tables A1 to A4 as well as the protocol for collecting samples, packing the samples and labeling them are in Appendix A.

1.3. Chemical and Physical Analyses of Fertilizer Samples

1.3.1. Chemical Analysis of Fertilizers

From a set of laboratories, the SGS Environmental Laboratory of Tema in Ghana had been selected to make the chemical analysis of fertilizers collected during the MIR-Plus study conducted between 2010 and 2013. The same laboratory was selected to make analysis of fertilizers samples from Mali.

The priority in the chemical analysis of the fertilizer samples focused on determination of primary plant nutrient content: total nitrogen (N), available phosphorus (P_2O_5) and soluble potassium (K_2O). However, a few samples were considered for determination of sulfur (S) and Zinc (Zn). Total N content in the fertilizer samples was determined with the Kjeldahl[6] procedure. P_2O_5, K_2O, S, CaO and MgO determinations were done with Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES)[7].

1.3.2. Physical Analysis of Fertilizers

Description of the fertilizer physical properties is done in Appedix B.
Sylvite® sieve boxes[8] were used to quantify segregation and granule integrity, and qualitative scales were employed for caking, moisture content, presence of fillers, and presence of impurities assessments. Procedures are explained in Appendix B. Data was recorded in Table A5 for statistical analysis.

1.4 External Factors with Potential to Influence Fertilizer Quality

Characteristics of markets, dealers, and storage conditions are factors that have the potential to affect quality of the fertilizers. The market characteristics that were evaluated and recorded in Table A1 are Type of Market referring to whether the market is located in a rural or urban area, the fertilizer dealer concentration which establishes if the concentration of dealers in a market is high, low, or if the dealer is located in an isolated location without other dealers around. The other market characteristic recorded is the location stability of the dealer whether it is located permanently in one location or its location changes from season to season.

The dealer characteristics that were recorded in Table A2 are the status of the dealer as importer wholesaler, or retailer or combinations of any of these three categories. The level of knowledge about fertilizer from the shop attendant which is qualified as good, limited or bad. This characteristic is judged by the fertilizer quality inspectors and is recorded in Table A2 at the end of the visit to the dealer after interacting with him/her during the inspection. Whether the shop attendant of the shop have training for the sale of fertilizers. And the type of buyers that the dealer has, they can be small-scale farmers, large-scale farmers, farmer organizations, other dealers, or combinations of these four categories. A qualitative evaluation of storage conditions is done

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[6] AOAC. 2014. Determination of Kjeldahl Nitrogen in Fertilizers by AOAC Official Method 978.02. Gaithersburg, MD, USA.
[7] AOAC International. 2012c. Official Methods of Analysis 19th Ed., Modified AOAC Official Method 955.06. Gaithersburg, MD, USA.
[8] Sylvite SGN Scale. https://www.sylvite.ca/agriculture/products/scale

estimating the quality of ventilation, temperature, relative humidity, the high of the fertilizer stacks, and the use of pallets, these data is recorded in Table A3.

1.5. Data Analysis and Interpretation

1.5.1. Nutrient Content Compliance

The cumulative frequency distribution function (CFDF) together with ECOWAS tolerance limits (Table C1, Appendix C) were used to assess nutrient content compliance in fertilizers. A nutrient content is out of compliance (OOC) when it is under the out of compliance boundary (OOCB) in the CFDF.

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 vertical line on the CFDF is the OOCB and the dotted horizontal line indicates the frequency (percentage) of samples with nutrient content or bag weight OOC. Figure 2-8 are CFDFs.

Any nutrient out of compliance is judged with the combination of the out-of-compliance frequency (OOCF) and the out-of-compliance severity (OOCS). The OOCF is obtained from the cumulative frequency distribution function (CFDF) developed for the quantitative continuous variables of the nutrient content of fertilizers as follows:

$F(X \leq x) = f$

Where **F** is the CFDF,

X is the variable associated with a nutrient content or weight difference,

x is the out-of-compliance boundary (OOCB), x = nutrient content on the label – TL

f is the OOCF

The OOCS= $\bar{X}_{(OOC)}$ – OOCB

Example: The OOCF and OOCS for of total N content in DAP (Figure 3A) are:

F(Total N ≤ 18-1.1) = F(Total N ≤ 16.9) =17% , OOCF=17%

OOCS=((15.4+15.7+16.8)/3) – 18 – 1.1 = -3.13% , OOCS=-3.13% .

1.5.2. Bag Weight Verification

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

BWS = Label Weight – Actual Weight

TL=-1% of Label Weight

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

1.5.3. Evaluation of Fertilizer Physical Attributes

Given the discrete nature of some of the fertilizer physical attribute variables like caking, moisture condition, presence of impurities, and presence of fillers, the frequency statements associated with the different categories of the physical attributes were obtained from the frequency distribution (FDF), which is represented by a bar graph with the physical attributes categories in the abscissa (X) and the frequencies (percent) in the ordinate (Y). Numbers on top of columns indicate number of samples.

Segregation of the bulk blend fertilizers and granular integrity of all granulated products were estimated using sieve boxes for the separation of fertilizer particles of different size. The distribution of fertilizer particle size allows to establish whether there is segregation or not. And the presence of fines and dust located in columns to the left of whole granule columns allows to quantify the percentages of fines and dust that were produced as result of granule degradation by crushing or abrasive forces.

The quality of data recorded in the field from the use of the sieve boxes did not allow quantification of segregation and granular degradation. Segregation of blend fertilizers was estimated using departures from the TL for the total nutrient content.
The frequency distribution from the scale categories used for the qualitative evaluation of caking, moisture content, and presence of fillers and impurities were used to know the severity of caking, the degree of moisture content in the fertilizers, and the frequency with which presence of fillers and impurities were found.

1.5.4. External Factors Influencing Fertilizer Quality

Characteristics of markets, dealers and storage were analyzed with analysis of frequency to obtain the frequency distributions (FDF). The frequency distribution figures have the characteristic categories in the abscissa and the frequency (percentage) in the ordinate.

Example: In Figure 9A, for ventilation in storage facilities, 14% (9 samples) of the storage facilities inspected had sufficient ventilation, and 86% (54 samples) of the facilities inspected had limited ventilation.

Section 2. Results and Discussion

2.1. Distribution of Fertilizer Samples

A total of 106 fertilizer samples were collected in 5 of the 8 regions[9] of Mali in addition to the capital District of Bamako using the methodology presented in Section 1. These samples represent 12 different fertilizer products and their distribution by grade is shown in Table 1. The six top fertilizers in Table 1 which are among the products of highest commercialization in Mali represented 90.6% of the fertilizer's sample. The three forms of NPK 15-15-15 (Products # 3, 5, and 10) sampled account for 25.4% of the total sample, suggesting that the random sampling of this NPK has about the same representation as Urea and DAP in the Mali markets.

Table 1. Distribution of samples per fertilizer product

Product #	Fertilizer Grade	Number of Samples	Percent of Samples	Cumulative Percent
1	Urea	26	24.5	24.5
2	DAP	25	23.6	48.1
3	NPK 15-15-15	16	15.1	63.2
4	NPKSZn 16-26-12+4.5S+0.3Zn	14	13.2	76.4
5	NPK 15-15-15+4S	10	9.4	85.8
6	NPKSZn 16-26-12+4.5S+0.5Zn	5	4.7	90.6
7	NPKSB 14-18-18+6S+1B_2O_3	3	2.8	93.4
8	NPKMgS 12-11-18+4Mg+8S	2	1.9	95.3
9	NPK 17-17-17	2	1.9	97.2
10	NPK 15-15-15+6S+1B	1	0.9	98.1
11	NPKSMgZn 23-10-05+3S+2Mg+0.3Zn	1	0.9	99.1
12	NPK 23-10-05	1	0.9	100.0
	Total	106	100.0	

[9] Gao, Kidal and Tombouctou were excluded from the sampling due to security reasons.

2.2. Fertilizer Nutrient Content Compliance

2.2.1. Urea

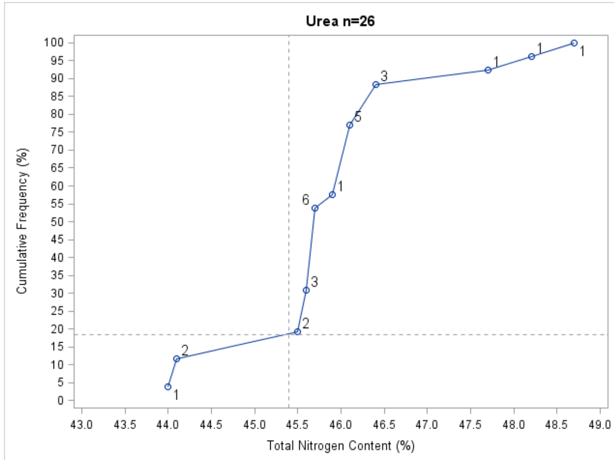

Figure 2. Cumulative frequency distribution for total nitrogen content in urea

A total of 26 samples of Urea were collected in Mali and used in the statistical analysis. The ECOWAS tolerance limit of 0.5% was used to identify cases of urea samples out of compliance for total nitrogen content, meaning that total nitrogen contents of 45.4% or lower are out of compliance with the ECOWAS regulation. The cumulative frequency distribution in Figure 2 makes a little overestimation (it happens when the samples are scattered along the CFDF line) of the out-of-compliance frequency because the 45.4% critical value for total nitrogen content cuts the cumulative distribution at 18%, but in reality, only 3 out of 26 samples, thus the OOCF of total N content in urea is 11%. The OOCS for total N was -1.4%, this means that the urea samples that were out of compliance had a total N shortage average of -1.4%. The 3 samples that were out of compliance for total nitrogen content can be explained by the sum of random variability during manufacture and chemical analysis. From these two sources of variability we would expect the chemical analysis to have a higher likelihood because the nitrogen content in the urea molecule is nearly impossible to be altered during manufacture.

2.2.2. DAP

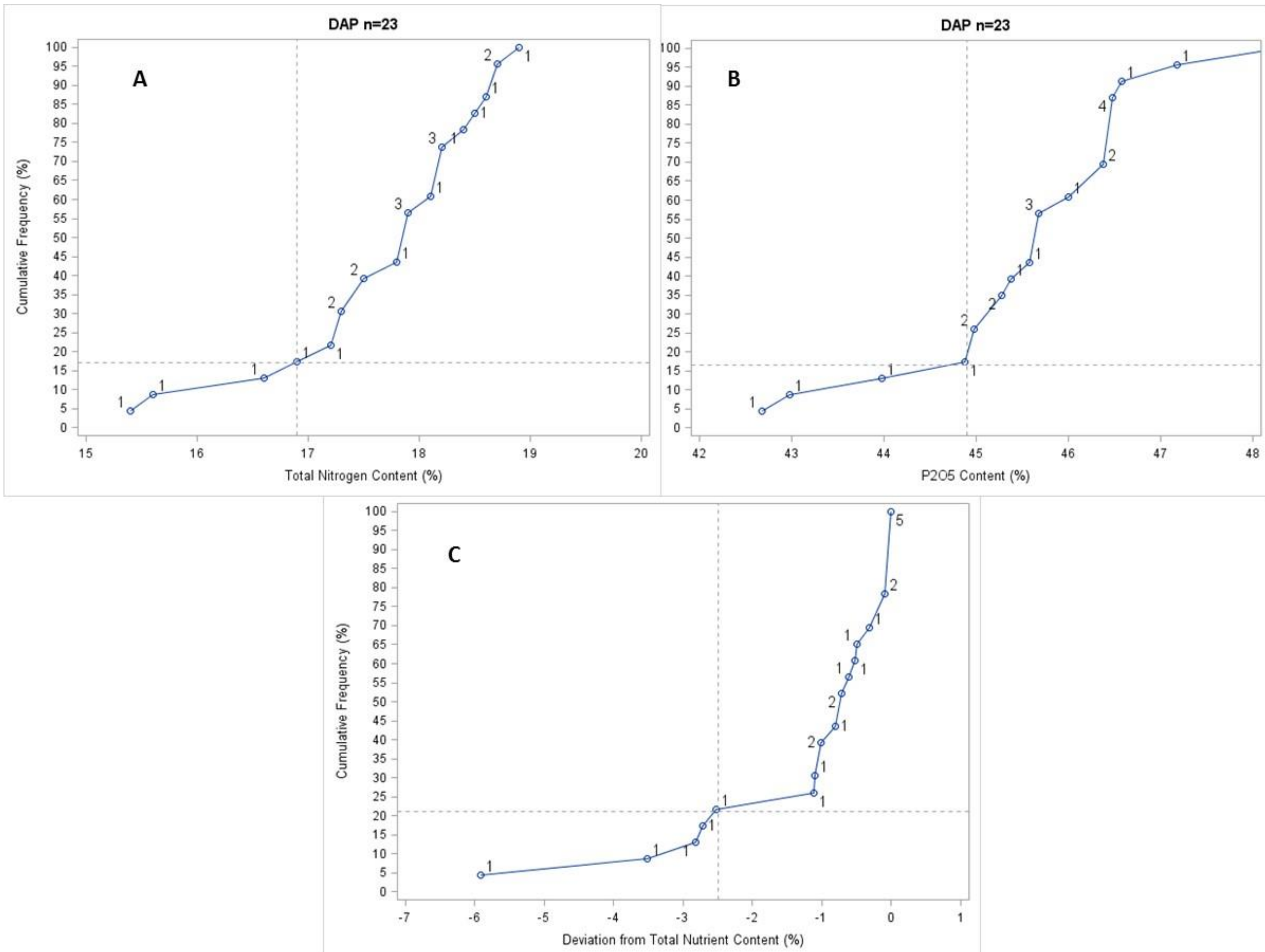

Figure 3. Cumulative frequency distributions of total nitrogen content (A), P_2O_5 content (B), and deviations from total nutrient content (C) in DAP

A total of 25 samples of DAP were collected and 23 samples were used in statistical analysis. The ECOWAS tolerance limits for individual macronutrient content in compound fertilizers like DAP is 1.1%., and for the total nutrient content is 2.5%. Figure 3A indicates that the OOCF for total N is 17% and the OOCS is -0.68%. Figure 3B shows that the OOCF for P_2O_5 is 17% and the OOCS is -1.7%. Figure 3C indicates that the deviation from total nutrient content has a OOCF of 21% and a OOCS of -3.7%. The -0.68% shortage average of total N is unlikely of causing detectable N deficiencies in crops, in contrast, the -1.7% average shortage of P_2O_5 likely will result in phosphorus deficiencies and possible yield reductions in crops where the DAP is used. The frequency and severity of the total nutrient content compliance are high enough to motivate the regulators to take measures to ensure the quality of fertilizers of high demand in the market like DAP. The most likely source of the nutrient shortages identified in DAP is the product manufacture, the Mali regulatory system should escalate up inspection of imported fertilizers at the entrance sites of the country.

2.2.3. NPK 15-15-15, NPK 15-15-15 + 4S and NPK 15-15-15 + 6S + 1B Blends

The number of samples of blended NPK 15-15-15, NPK 15-15-15 + 4S and NPK 15-15-15 + 6S + 1B collected in Mali were 16, 10 and 1, respectively. The three sample sizes were combined for the nutrient statistical analysis (Figure 4A,B,C,D). The 10 samples of NPK 15-15-15 + 4S were also used for sulfur statistical analysis (Figure 4E). The ECOWAS tolerance limit for individual macronutrient content is 1.1%, and 2.5% for the total nutrient content. The OOCF for total N is 92% and the OOCS is -2.3% (Figure 4A). The OOCF for P_2O_5 is 38% and the OOCS is -3.11%. (Figure 4B). The OOCF for K_2O is 32% and the OOCS is -2.14% (Figure 4C). The OOCF for Total Macronutrient Content is 93% and the OOCS is -6.9% (Figure 4D). There were not samples with S shortages out of compliance. The high frequencies and high severities of the three macronutrient shortages, as well as the very high frequency and severity of the total nutrient content are strong evidences of very serious nutrient shortages in the NPK 15-15-15 blends. Crops fertilized with this fertilizer would experience severe nutrient shortages and yield reductions.

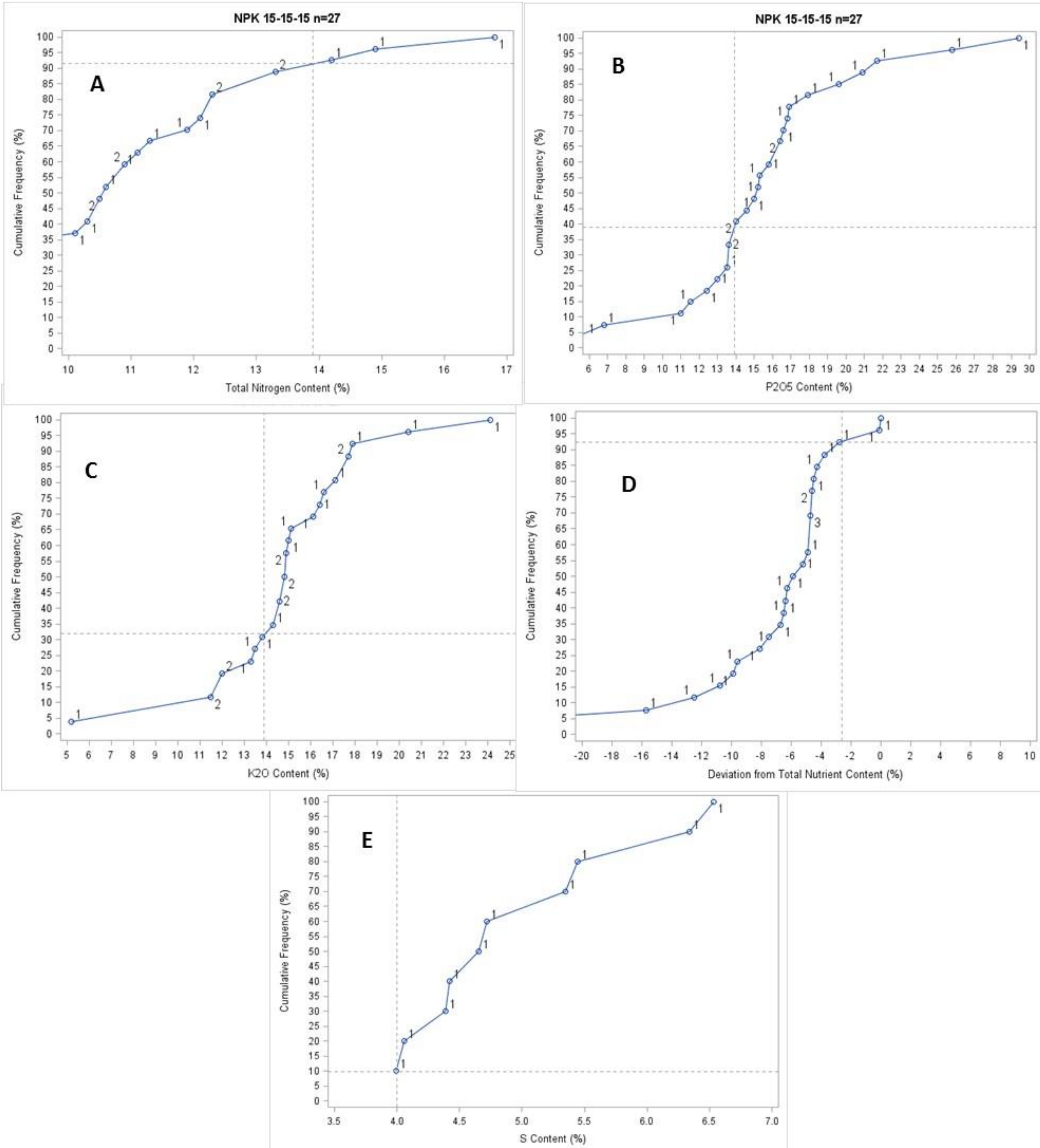

Figure 4. Cumulative frequency distribution for total nitrogen content (A), P_2O_5 content (B), K2O content (C), deviations from total nutrient content (D) and sulfur content (E) of NPK 15-15-15, NPK 15-15-15 + 4S and NPK 15-15-15 + 6S + 1B Blends

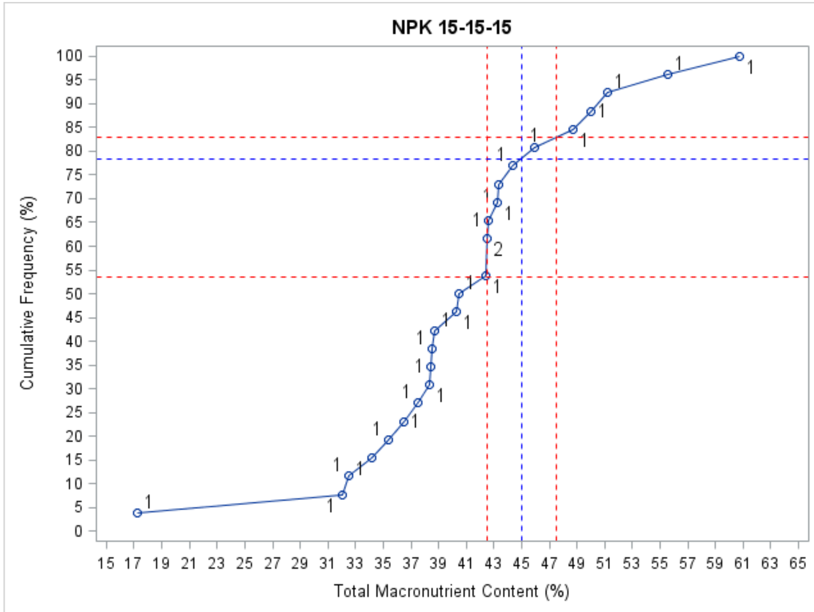

Figure 5. Cumulative frequency distribution for the total macronutrient content of the NPK 15-15-15 blend sampled in markets of Mali

The severe out of compliance for individual macronutrients and for the total macronutrient content in this fertilizer is mainly associated with the fact that the NPK 15-15-15 sampled in the Mali markets is a bulk blend. The samples between the tolerance limits for the 45% total nutrient content (red vertical lines: 42.5%, 47.5%) in Figure 5 present granular segregation, shortage of a nutrient in a sample is "compensated[10]" by excess of at least one of the other nutrients. Granular segregation occurred with a frequency of 28%. The most common explanations for granule segregation are the use of prilled urea instead of granulated urea, and the use of crystalline KCl instead of granulated KCl as source of K_2O. The smaller particles of prilled urea and the KCl crystals of considerably smaller size than granules of the other blend components move downward inside the fertilizer bags causing granule segregation. KCl crystals are also more fragile than granules of other blend components and degrade to fines or dust because the manual handling of fertilizer bags.

The 5 samples above the 47.5% (Figure 5, vertical red line on the right) can be used to estimate the magnitude of the random error in the manufacture of the NPK blend. It can be considered random error because nobody would manufacture the blend with a deliberated higher than required total macronutrient content. The frequency of the random error is18%.

The number of samples below 42.5% (Figure 5, vertical red line on the left) have a 48% frequency. If we subtract the random error 18% from 48%, we can say that 30% of the samples out of compliance are not the result of random error or segregation. The nutrient shortage of these samples can be attributed to the deliberate use of insufficient input nutrients or to the use of inappropriate or non-calibrated blending equipment.

[10] Shortage of one nutrient cannot be compensated by excess of another nutrient in reality.

Mali and ECOWAS regulators must find out about the type of equipment used in each blending plant, identify the cases associated with fraud and apply severe penalties to the responsible. There are cases in which the owners and operators of the blending plants need technical assistance for acquisition of the appropriate equipment, adequate calibration and operation of the equipment and use of the right input fertilizers.

2.2.4. NPK 16-26-12 + 4.5S + 0.3Zn and NPK 16-26-12 + 4.5S + 0.5Zn Blends

A total of 14 samples of blended NPK 16-26-12 + 4.5S + 0.3Zn and 5 samples of blended NPK 16-26-12 + 4.5S + 0.5Zn were collected in Mali. The 19 samples of the two fertilizer grades were combined for the statistical analysis of macronutrients and sulfur statistical analysis (Figure 6A,B,C,D,E). In Figure 6, vertical lines delimit the area in which a nutrient or the total nutrient content starts to be out of compliance, and horizontal lines indicate the frequency at which the out of compliance occurs. The OOCF for total N content was 97%, and the OOCS was -3.2% (Figure 6A). The OOCF for P2O5 content was 77.5% and the OOCS was -6.9% (Figure 6B). The OOCF for K2O content was 42% and the OOCS was -1.4% (Figure 6C). The OOCF for total nutrient content was 95% and the OOCS was -9.5% (Figure 6D). The nutrient shortage frequencies for the three macronutrients and for the total macronutrient content are very high, it is close to say that every bag of the NPK 16-26-12 available in the market is of undesirable quality. And the severity of the shortages ranging between -1.4% (K2O) and -9.5% (for the addition of the 3 macronutrients) indicate that almost every bag of this fertilizer used in the field would cause nutrient deficiencies and yield reductions. The OOCF of sulfur content shortages was 16% and the OOCS was -0.3% (Figure 6E), these two values suggest a very common shortage of this secondary nutrient and a severity shortage that may cause sulfur deficiencies in crops where this secondary nutrient is required.

There were only 3 cases out of 19 samples showing evidences of segregation (Figure 7, samples between the two red dotted lines), these three samples may present shortage of one nutrient that is "compensated" by at least another nutrient to add to the 54% of total macronutrient content in the fertilizer. The small number of samples with demonstrated segregation conduct to believe that the majority of the nutrient shortages in the NPK 16-26-12 originate in the insufficient use of nutrients during the blending to achieve the fertilizer grade specified on the fertilizer label. The high frequency of the nutrient shortages in the fertilizer are also evidence of no interest for correcting equipment malfunctions or calibration errors.

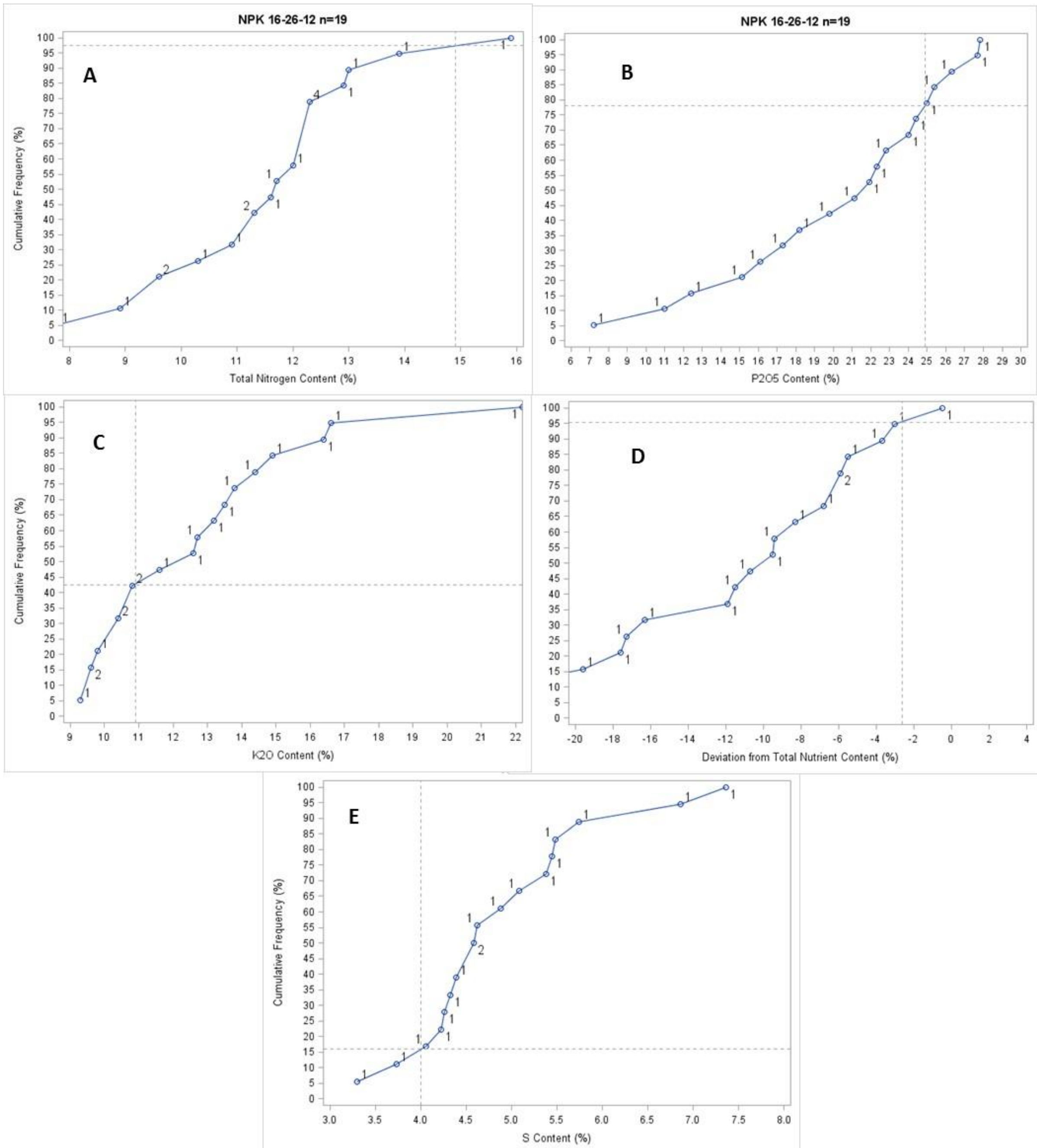

Figure 6. Cumulative frequency distribution for total nitrogen content (A), P_2O_5 content (B), K2O content (C), deviations from total nutrient content (D) and sulfur content (E) of NPK 16-26-12 + 4.5S + 0.3Zn and NPK 16-26-12 + 4.5S + 0.5Zn blends

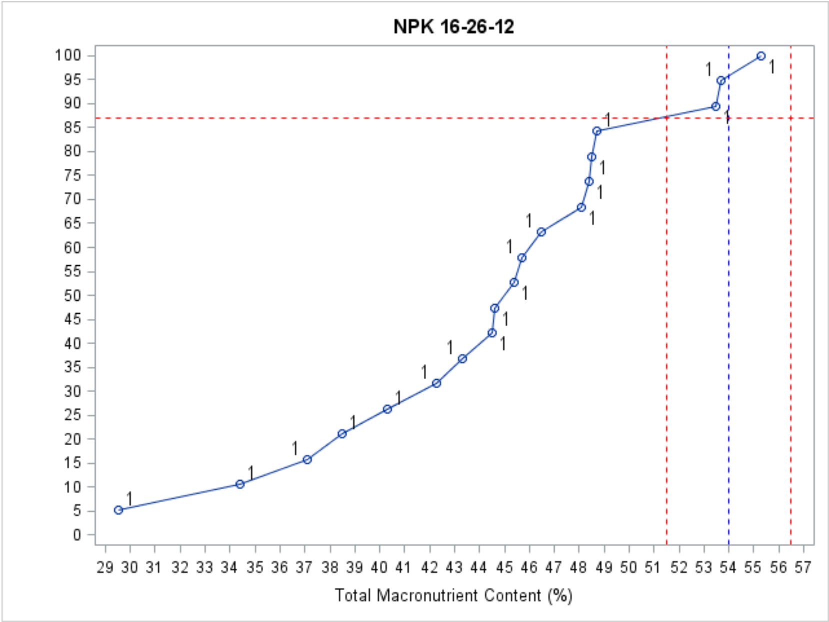

Figure 7. Cumulative frequency distribution for the total macronutrient content of the NPK 16-26-12 + 4.5S + 0.3Zn and NPK 16-26-12 + 4.5S + 0.5Zn blends sampled in markets of Mali

2.3. Bag Weight Verification

A total of 79 non-open 50 kg fertilizer bags were weighed in Mali. By ECOWAS standards, the assessment of bag weight compliance should be made using 1% of the weight on the label weight shortage as the tolerance limit. The maximum weight shortage tolerated in a 50 kg bag is 0.5 kg or 500 g. Unfortunately, during data collection in Mali bag weights were recorded without decimals. Consequently, the frequency analysis of bag weight shortages was done using 1 kg as the weight at which a bag starts to be out of compliance.

Values at the left of the first vertical red line in Figure 8 are associated with underweighted bags, and values at the right of the second red vertical line are associated with overweighed bags. The frequency of overweighed bags is used to estimate the random error associated with the combined operations of filling and weighing the bags, it is a good estimate of random error considering that nobody would overfill or overweigh a bag deliberately. The OOCF for bag weight shortage was 13%, and the OOCS was -1.0 kg.

Underweight bags are the result of lack of control in the process of filling and weighing of bags during the manufacture or re-bagging, and in some cases it is possible that the underweight bags are the result of a deliberate act. If the random error in filling the bags affects 6% of the bags (Figure 8) we can subtract this quantity from the 13% underweight bags and estimate that the percentage of deliberately underweighted bags is 7%. Further investigation by the regulators is required to determine where and how the bag weight reduction takes place – at the manufacturing plants or along the distribution chain.

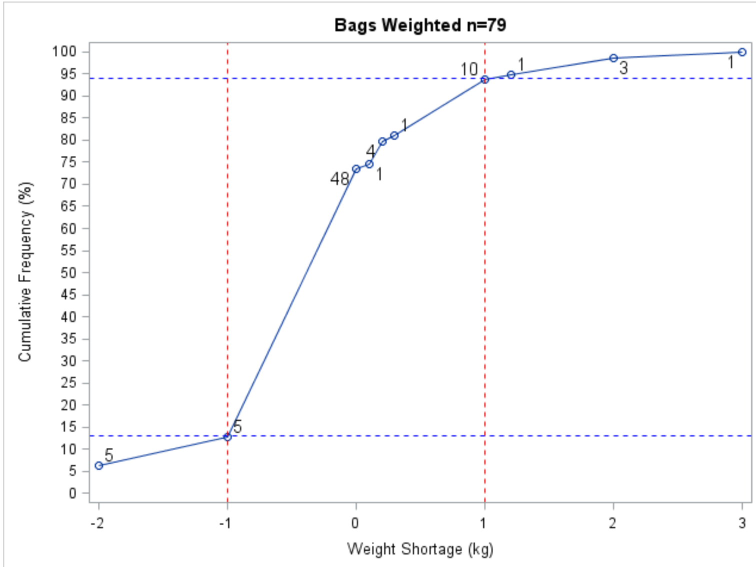

Figure 8. Cumulative frequency distribution of deviations from weight in fertilizer label

2.4. External Factors with Potential to Influence Fertilizer Quality

2.4.1. Storage Conditions

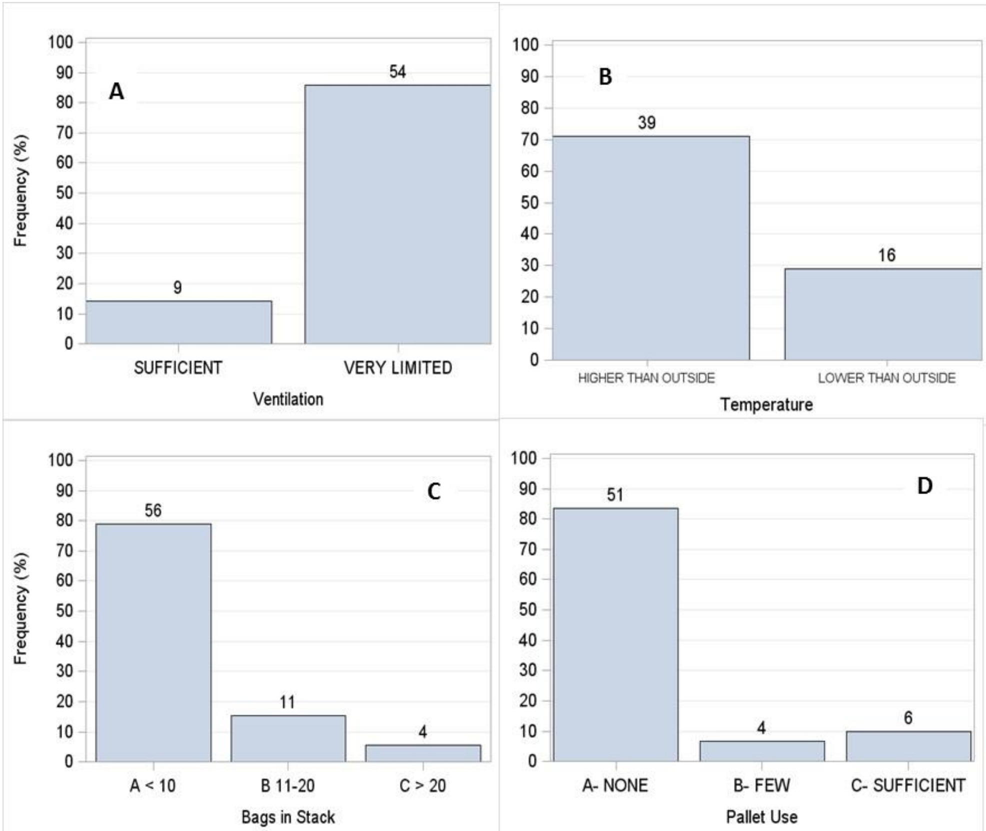

Figure 9. Qualitative evaluation of storage conditions in Mali fertilizer markets.

The 87% frequency of very limited ventilation in storage warehouses/shops (Figure 9A), together with 72% frequency of high temperature inside the storage facilities (Figure 9B) and the very high frequency of no use of pallet (83%) plus 7% of few use (Figure 9D) and the manual handling of individual fertilizer bags are conditions conductive to degradation of granule integrity that could end in non-homogeneous distribution of nutrients inside the fertilizer bags.

Adequate ventilation in storage warehouses have radical importance in the hot and humid tropical climates of West Africa. The dominant condition of very limited ventilation of the fertilizer storage facilities in Mali likely results in high temperature and high relative humidity inside the storage area. These two environmental conditions produce high moisture content in the fertilizers if they are not packed in impermeable and well-sealed bags. Caking, high moisture content and granular degradation also result from hot and humid storage conditions.

Previous assessments of storage conditions in other West African countries have identified inadequate storage conditions across all categories of fertilizer dealers including government owned storage facilities[11]. Many of the fertilizer dealers and government officials involved in fertilizer distribution or trade do not have a clear understanding of the relationship between the conditions of handling and storage of the fertilizer products with the physical and chemical characteristics of the products. For many of them the quality of the fertilizer is good as long as all the fertilizer product and the nutrients that it contains are inside the bag. Training of public and private fertilizer distributors to make them understand the fragility of fertilizers and their susceptibility to environmental conditions and inappropriate handling is essential to motivate them to start investing in appropriate storage facilities and handling equipment.

2.4.2. Market Characteristics

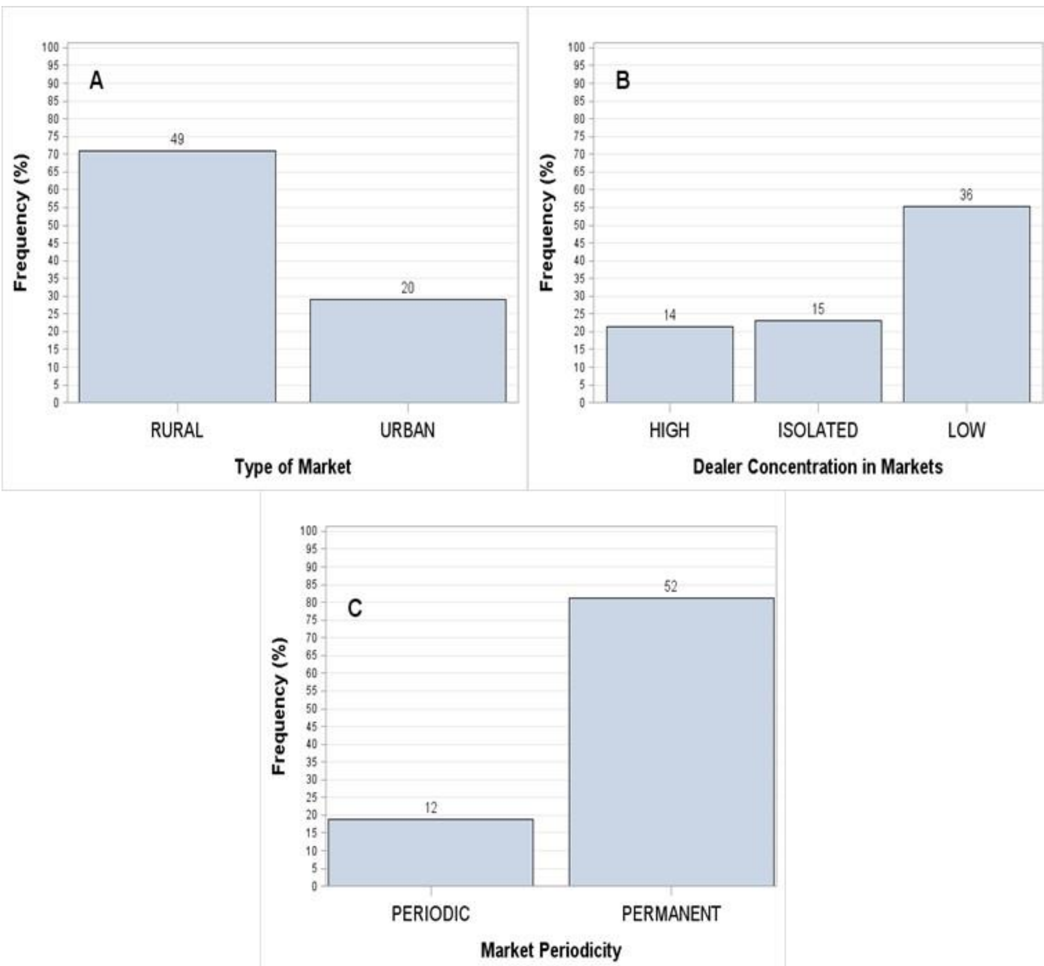

Figure 10. Frequency distribution of several market characteristics in Mali with respect to type od market (A), density of dealers in the market (B) and market periodicity (C)

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[11] Sanabria, J., G. Dimithe, and E. Alognikou. 2013. "The Quality of Fertilizer Traded in West Africa: Evidence for Stronger Control". Special Publication IFDC – SP-42.

Rural markets are located in small towns or in country side locations by roads or trails, while urban markets are located in large towns or cities with populations of at least few tens of thousands of inhabitants. Seventy percent of the markets in Mali are rural (Figure 10A), around 55% of the markets have low density distribution of the dealers (Figure 10B), and nearly 80% of the markets are permanent meaning that season after season the majority of the markets are located in the same site.

Fertilizer quality assessment in West Africa countries have showed relationships between quality of fertilizers, especially with respect to compliance of nutrient content, and the market characteristics depicted in Figure 10. Rural, isolated, and periodic markets show a trend of association with higher frequency of quality issues than urban, high density, and permanent markets.

This kind of association could not be tested with data collected in Mali markets mainly due to small sample size for the different market categories and low variability in nutrient content compliance in the individual fertilizer products. The low variability in nutrient content compliance refers to Urea and DAP having few cases of out of compliance, and the NPK blends presenting dominant out of compliance with respect to nutrient content.

2.4.3. Dealer Characteristics

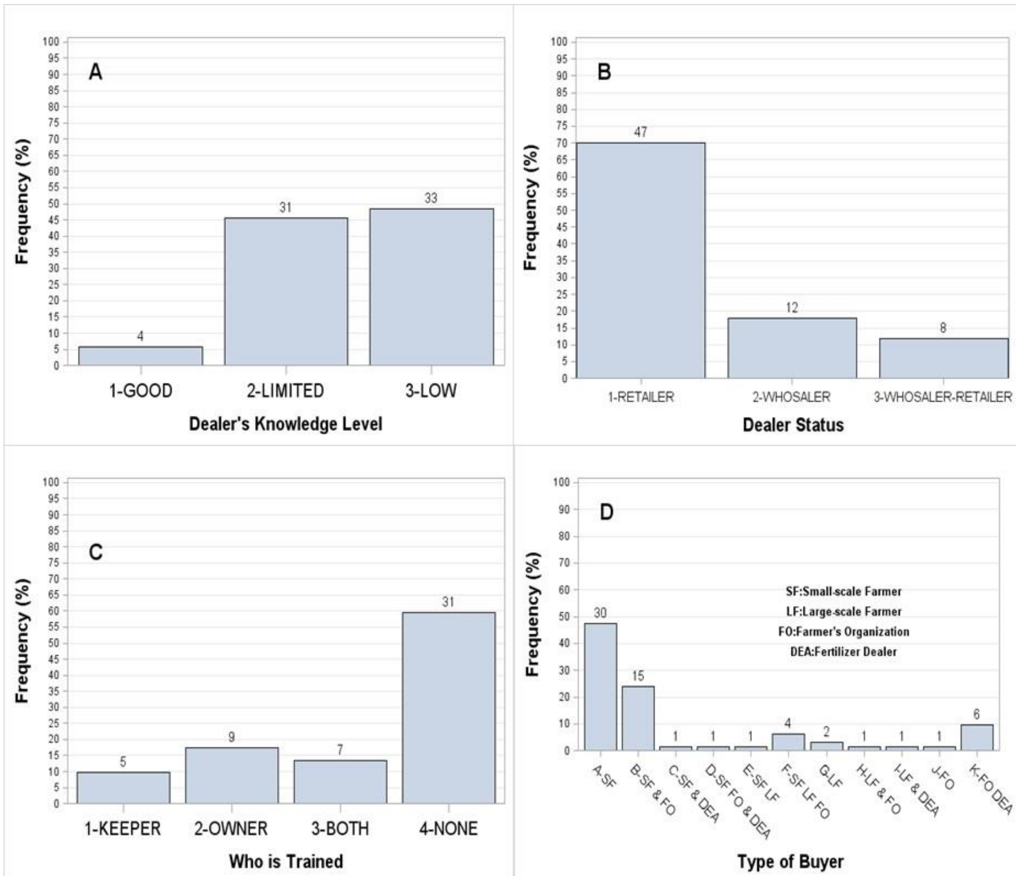


Figure 11. Frequency distribution of several dealer characteristics with respect to knowledge about fertilizers by the shop keeper (A), dealer status (B), training of the dealers (C), and type of fertilizer buyers (D).

Low knowledge about fertilizers, retailer status, absence of training for distributors and small scale farmers as the main customers in Figure 11 have been identified as the dealer characteristics with the highest potential to affect fertilizer quality in West Africa. In Mali, nearly 50% of the fertilizer dealers have low knowledge about fertilizers and their characteristics, and about additional 45% of the dealers have limited knowledge about fertilizer products (Figure 11A). Seventy percent of the dealers are retailers (Figure 11B); in about 60% of the dealer shops neither the owner nor the keeper have received any training to commercialize fertilizers (Figure 11C); and about 48% of the dealers sell fertilizers to small-scale farmers (Figure 11D). Data collected from Mali markets did not allow to evaluate relationships between dealer characteristics and quality of fertilizer products. However, high percentages from these critical factors are expected to be associated with frequent fertilizer quality problem in Mali.

The storage conditions is another of the factors that have the potential to affect quality of fertilizer products. The effect of storage conditions on fertilizer quality was discussed in section 2.4.1.

2.5. Evaluation of Physical Attributes of Fertilizers

2.5.1. Moisture Content and Caking

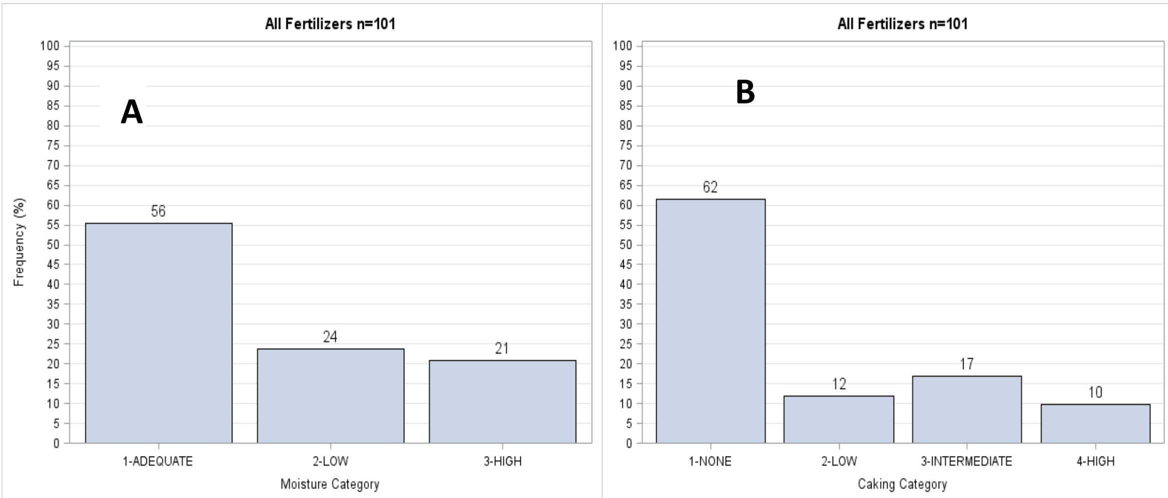


Figure 12. Qualitatively evaluation of caking and moisture content of fertilizers sampled in markets of Mali

Sample size of individual fertilizers was not large enough to make analysis of moisture content and caking per fertilizer product, instead, all the fertilizer products sampled were combined for the frequency analysis of these two physical characteristics. The qualitative evaluation of moisture in 101 fertilizer samples (Figure 12A) indicates that 21% of the samples presented high moisture contents, and nearly 27% of the samples presented intermediate or high caking degrees (Figure 12B). Both, the frequent cases of high moisture content and caking can be explained by inadequate storage conditions with very limited ventilation and high temperature (Figure 9A & B). The fertilizer inspectors reported 100% presence of bags with impermeable layers but still there was 21% of samples with high moisture content. This may be explained by bag seams that do not seal the bags completely or by tore bags that allow the hygroscopic fertilizer to get exposed to the moisture in the air.

An additional factor that helps to explain the high frequency of caking is the low use of pallets (Figure 9D) in the storage facilities. When pallets are not used the air circulation through the stacks is absent or extremely low, this condition very often results in high relative humidity in the storage area. Another function of pallets is to relieve bags at the bottom of the stacks from the pressure exerted by bags on the top. When pallet use is insufficient or absent, fertilizer bags at the bottom of the stacks are subject to large pressure and the possibilities of caking in these bags increases even when the bag stacks are not too high (Figure 9C).

2.5.2. Segregation and Granule Integrity

Data from segregation and granule integrity evaluations using the SGN sieve boxes was not usable for quantitative estimation of these physical properties from the fertilizer products sampled in Mali. Instead, the segregation of blended NPKs was analyzed using the total macronutrient content (Figures 5 and 7) and were discussed in Sections 2.2.3 and 2.2.4.

2.6. Adulteration of Fertilizers

There was no case of adulteration completely documented in this fertilizer quality assessment in Mali. However, the sale of underweight bags, which is estimated to occur for 8 percent of the fertilizer bags traded in the country, could be considered fraudulent. Similarly, cases of nutrient deficiency (for which the most likely explanation for nutrient content shortage is insufficient use of nutrients during the blending manufacture or nutrient dilution along the distribution chain) could be considered fraudulent as well.

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

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

Conclusions and Recommendations

The main findings of this assessment can be summarized as follows:

Adulteration

The perception that fake or adulterated fertilizers in West African markets is a dominant quality concern is not supported by the findings of this study in Mali. However, the 7% of the deliberate underweighted fertilizer bags traded in the country is fraudulent. Similarly, 30% of the out of compliance nutrient content of the NPK 15-15-15 blends can be attributed to fraudulent insufficient input of nutrients during the manufacture of these blends.

Urea

Only three of the 26 samples of Urea (11%) collected in Mali were out of compliance for total N content with respect to the ECOWAS tolerance limits for individual nutrient content. The three samples OOC are likely the result of error in the lab analysis.

DAP

Only four out of the 25 samples of DAP (17%) collected in Mali were out of compliance for total N content and for P_2O_5 contents.

NPK Blends

The severity of the nutrient shortages, in many cases higher than 5% relative to the label specification, and the high frequency of the nutrient shortages indicate a very serious problem in the manufacture of NPK blends commercialized in Mali. Only very few cases of the nutrient content out of compliance may be attributed to segregation of the blend components, the great majority of the cases can be attributed to lack of control in the blending procedures or to fraudulent production of fertilizers with insufficient nutrient input. The Mali and ECOWAS regulators should supervise the blending plants to find out the reasons for the frequent and severe nutrient shortages. Specific penalties should be included in the ECOWAS framework to discourage fraudulent manufacture of bulk blends. Some fraction of the nutrient shortage in the bulk blends can be attributed to the use of deficient or non-calibrated equipment in the blending plants, ECOWAS experts should identify these cases and design technical assistance programs to manufacturers in order to correct the quality problems in the fertilizer blends.

Bag Weight

Thirteen percent of the bags are underweighted, part of the bag weight shortage may be attributed to lack of control in filling and weighing bags during manufacture or re-bagging. Data also suggest that about 7% of the weight shortages are deliberate. The Mali and ECOWAS regulators should develop investigations to identify where and when the bags are deliberately reduced in weight, and apply penalties to discourage this fraud.

Storage Conditions and Fertilizer Physical Properties

The 20% of fertilizer samples presenting high moisture content and the 27% of samples presenting caking between medium to high degrees are likely associated with the very limited ventilation found in 87% of the storage facilities, 72% frequency of high temperature inside the storage facilities, and 83% of no use of pallets. Data collected did not contain enough cases of good storage conditions to be able to test statistically the relationships between storage conditions and degradation of fertilizer physical properties.

Dealer characteristics

Nearly 95% of the fertilizer dealers visited in Mali markets either have no knowledge or very limited knowledge about fertilizer characteristics, and in about 60% of the shops neither the owner nor keeper of the business have had any training for management and selling of fertilizers. Seventy percent of the dealers are retailers and 48% of the dealers sell fertilizers only to small-scale farmers. All the above dealer characteristics and their high frequency of occurrence have been associated with high frequency of fertilizers out of nutrient content compliance from previous studies in West Africa, but the data collected from Mali was insufficient for validating this relationship with statistical methods.

The results of this study indicate that the quality of fertilizers in Mali can be enhanced through a series of actions:

1. Enforcing of the national fertilizer law and supporting regulations, and implementing the newly adopted ECOWAS regulatory system in Mali will create the environment for solving the fertilizer quality problems in the country markets.
    a. Since the main quality problems in the country are connected with the bulk blends, this sector of the fertilizer manufacturing needs special attention with respect to identify the origin of the quality problems, take appropriate corrective measures, and to train the personnel involved in the blending manufacture.
    b. Registration of fertilizer distributors using GPS technology for developing frequently updated geo-referenced databases and maps is a critical administrative requirement for effective implementation of the regulations.
2. Conducting studies to identify the origin of the quality problems of bulk-blended fertilizers and proposing appropriate solutions.
3. Analyzing the economic impact of the high frequencies of poor quality fertilizer found in Mali both at farmer and country levels.
4. Enhancing manufacturing knowledge and equipment for manufacturing blends, including:
    a. Sufficient use of NPK inputs for proper blend formulation.
    b. Maintenance of equipment/calibration.
    c. Implementation of technical knowledge and training.
    d. Use of high-quality and appropriate granule size for the ingredients of the blends to minimize segregation.
5. Standardization of blending plants as part of the implementation of a regulatory system.
6. Training of distributors on the following topics:
    a. Appropriate handling of fertilizer products. Fines and dust in compound fertilizers can be reduced with less manual manipulation. Use of pallets and mechanical equipment for handling bags can reduce degradation.
    b. Physical and chemical properties of fertilizers.
    c. Appropriate storage of fertilizer products.
7. Improving labeling of fertilizer products in conformity with the newly adopted ECOWAS regulatory system as a response to incomplete label information found in Mali to ensure that labels contain the following minimum information:
    a. The fertilizer grade.
    b. The guaranteed analysis, with special attention to a breakdown of the various forms of nitrogen.
    c. The net weight.
    d. The sources of nutrients.
    e. The name and address of manufacturer or re-packing agent.

8. Developing the fertilizer market. The low variability of fertilizer found in the market, six of them represent 90% of the fertilizers traded in the country, indicates the need of market development. Promoting fertilizer demand may be the most effective way to produce market

growth. Soil mapping and fertilizer recommendation programs have resulted in fertilizer market expansion in West Africa countries like Ghana. Complete liberalization of the importation and national fertilizer trade is also key for the growth of the fertilizer market.

Appendix A. Procedures for Data Collection and Fertilizer Sampling

1. Equipment
    - Main questionnaire (MQ) and physical properties format (PPF)
    - Bag sampler probe and scoop
    - Sieve box
    - Weight scale
    - Bucket, funnel, scissors, and dusting rag
    - Tape to seal bag holes left by sampler
    - Re-sealable (Ziploc) 0.5-kg plastic bags for fertilizer samples
    - Carton board boxes to carry sets of fertilizer samples

2. Data Collection

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

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

3. Fertilizer Sampling

Taking a Sample from a Closed Bag

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

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

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

Fertilizer Type	n Bags in Lot	n Bags to Sample
Solid	5 or less	1
	6 to 20	2
	21 to 50	4
	51 to 100	6
	> 100	1 from every 20

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

- Record the “Time at end” at the top of the questionnaire.

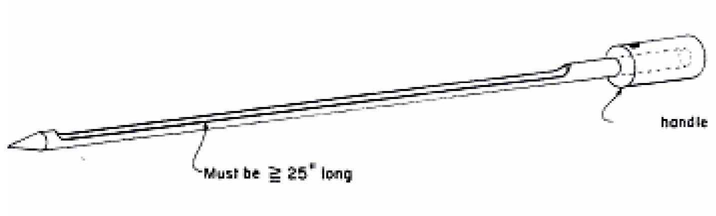
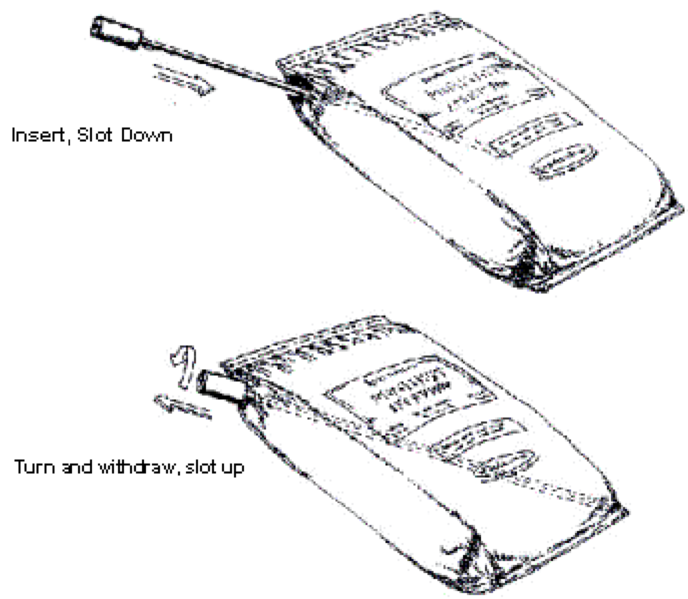


Figure A1. Sampler for Solid Bagged Fertilizers



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, another from the middle, and another from the bottom of the bag (Figure A3). Place the three subsamples in a bag. Seal bag completely.
- Fill out the sample label. Stick it on the sample bag. Make sure to mark the “Open Bag” box on Table A4.
- Place sample bag in a second larger bag. Seal it 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.

Table A1. Location and Market Characteristics

Team	Questionnaire	Country	Region/ Department	County	City/Town	Market Name	Date	Time at start	Time at end
	T#A#F#						dd-mm-yy	hh-mm	hh-mm

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

Table A2.Characteristics of the Fertilizer Dealer

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

* Do not ask, judge yourself.

Table A3.Characteristics of Storage

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

Table A4.Characteristics of Fertilizer Products

Characteristics of Fertilizer Products

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

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

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

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

Table A5.Physical Properties of Fertilizers

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

Appendix B. Assessment of Physical Properties

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

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

Segregation is the physical separation of granules from different components of bulk-blended fertilizer due mainly to their particle size differences. Shaking of bags during transportation or handling in warehouses and shops produce segregation because smaller granules move downward in higher proportion than larger granules. Concentration of nutrients contained in small granules is expected to be higher in low bag sections, where the quantity of small granules is higher than in the rest of the bag. Segregation can be estimated quantitatively using the sieve boxes, taking advantage of the particle size separation that can be achieved with appropriate use of Sylvite® sieve boxes. After applying the procedure to separate granules of different size, the inspectors will record the height percentage at each column in Table A5. A segregated fertilizer will show a very asymmetrical distribution with large granules located at the right of the box and small granules at the left. The types or 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 the columns showing about the same composition of granules (colors) in a very symmetric arrangement.

The granule integrity is proportional to the resistance of granules to impact, crushing, and abrasion forces. Granule integrity can be estimated quantitatively using the particle size separation obtained with the help of Sylvite® sieve boxes. It is measured assessing the percent of granules of regular size (range 2.8 mm to 4 mm, contained in the 1st compartment), percentage of granules smaller than the original size or fines (between 1.0 and 2.8 mm, contained in 2nd, 3rd, and 4th compartments), and the percent of dust (< 1 mm, contained in 5th compartment). Poor granule integrity may indicate manufacturing deficiencies, excessive handling, or aging of the products. The smaller the height differences of the columns at the left with the columns containing the whole granules, the higher the granule degradation. Samples with good granular integrity, meaning small amounts of fines and dust, show few or no particles at the left of the 1st compartment of the sieve box. Inspectors will be trained in the use of the boxes with numerous practical exercises. Record column percentages in the format for physical properties (Table A5).
Most fertilizers have typical colors: Urea is white, DAP is dark gray, NPKs are light gray or light brown, and MOP is reddish. Colors for a product may vary depending on differences in manufacturing processes or the use of color codes used by manufacturers, but a person familiar

with the fertilizers commercialized in an area would be able to identify atypical colors among the most commonly traded products in the area. Atypical colors may be an indication of the presence of fillers, impurities, or strange materials and possible adulteration of the product. Darker colors than usual may also be an indication of high moisture content. Record fertilizer color in the format for physical properties (Table A5).

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

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

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. Mark one of the categories in the format for physical properties with an “X” (Table A5).

Caking occurs when the individual granules of the product fuse to form larger aggregates. In extreme cases of caking, entire bags become one solid body. Caking usually takes place when the fertilizer product 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. Mark with an “X” one of the categories in the format for physical properties (Table A5).

Impurities are strange substances that get mixed with the fertilizer during deficient manufacturing procedures or as a result of management practices that compromise quality. When products are spread on the ground, a common practice among small retailers (to dry, to break conglomerates, 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.

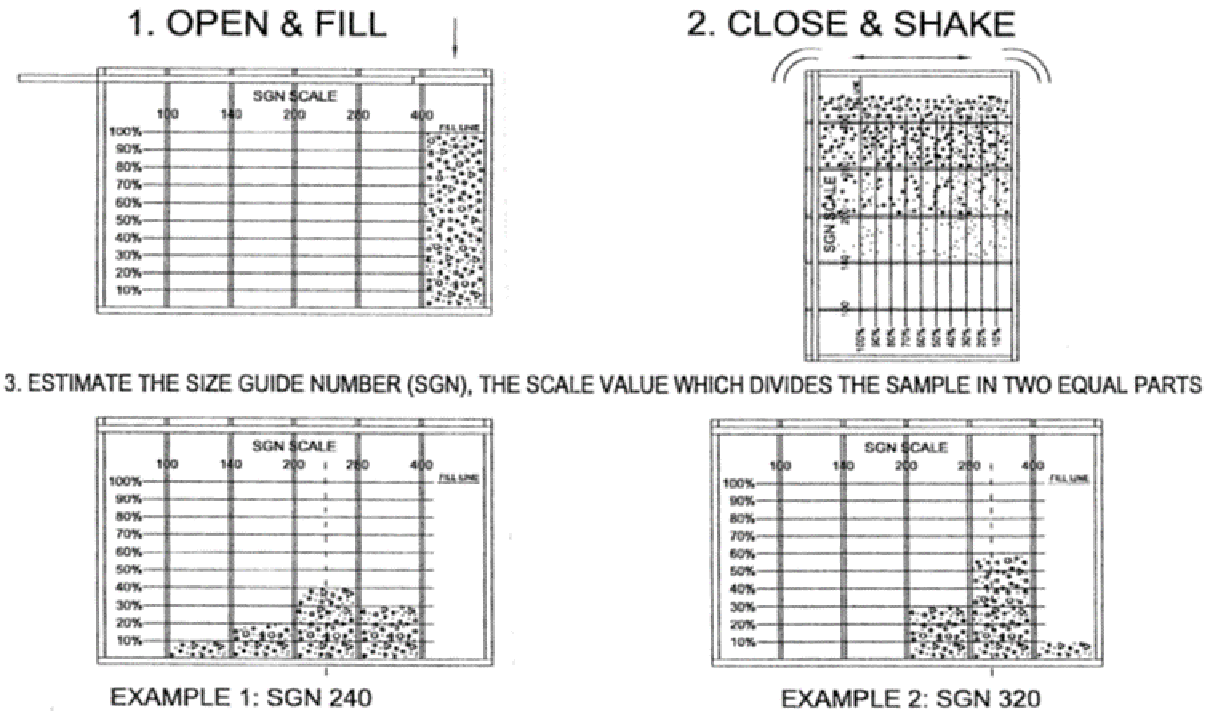


Figure B1. Operation of the Sylvite® Sieve Boxes

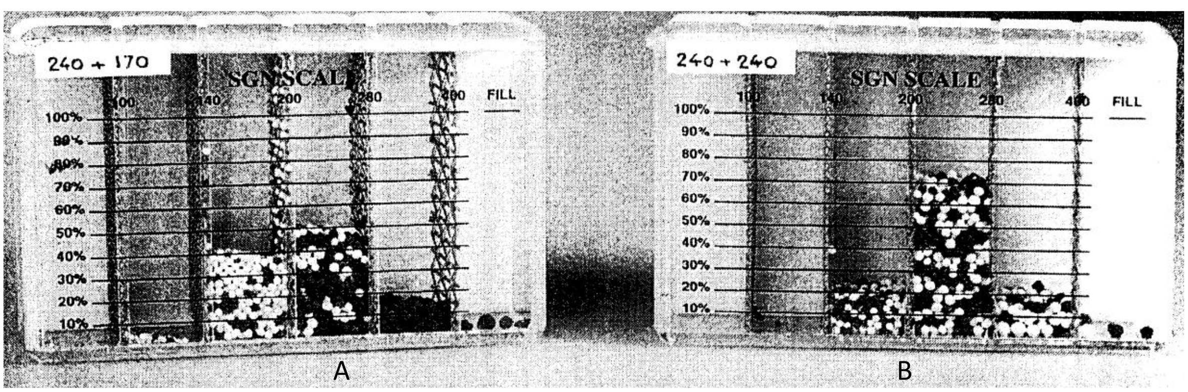


Figure B2. Identification of Granule Segregation in Bulk Blends using Sieve Boxes (Box A shows granule segregation; Box B shows no granule segregation)

- **A segregated fertilizer** will show an asymmetric distribution, with large granules located at the right of the box and small granules at the left (Figure B2A). The types or colors of granules will be well separated. **A non-segregated fertilizer** will show all the granules in few columns, each showing about the same composition of granules (colors) in a symmetric arrangement (Figure B2B).

- 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 (Figure B3)**, meaning a very small amounts of fines and dust, show few or no particles at the left of the whole grain columns.

Figure B3. Typical Case of No Granule Degradation – Near 100% of the Granules Have an Average 4 mm Diameter

Appendix C. ECOWAS Tolerance Limits

Table C1. ECOWAS tolerance limits for fertilizer nutrient content and bag weight

<table>
<tr><th>Nutrient Type</th><th>Number of Nutrients</th><th>Nutrient</th><th>Shortage Tolerance</th></tr>
<tr><td rowspan="6">Macronutrient</td><td rowspan="4">Multinutrient Fertilizers</td><td>Total Nitrogen (N)</td><td>1.1%</td></tr>
<tr><td>Phosphorus (P_2O_5)</td><td>1.1%</td></tr>
<tr><td>Potassium (K_2O)</td><td>1.1%</td></tr>
<tr><td>Deviation from Total Macronutrient Content</td><td>-2.5%</td></tr>
<tr><td rowspan="2">Single Nutrient Fertilizers</td><td>Nutrient Content Guarantee ≥ 20%</td><td>0.5%</td></tr>
<tr><td>Nutrient Content Guarantee < 20%</td><td>0.3%</td></tr>
<tr><td rowspan="3">Secondary Nutrient</td><td rowspan="12"></td><td>Calcium (Ca)</td><td>0.2 unit + 5% of guarantee</td></tr>
<tr><td>Sulfur (S)</td><td>0.2 unit + 5% of guarantee</td></tr>
<tr><td>Magnesium (Mg)</td><td>0.2 unit + 5% of guarantee</td></tr>
<tr><td rowspan="9">Micronutrient</td><td>Boron (B)</td><td>0.003 unit + 15% of guarantee</td></tr>
<tr><td>Cobalt (Co)</td><td>0.0001 unit + 30% of guarantee</td></tr>
<tr><td>Molybdenum (Mo)</td><td>0.0001 unit + 30% of guarantee</td></tr>
<tr><td>Chlorine (Cl)</td><td>0.005 unit + 10% of guarantee</td></tr>
<tr><td>Copper (Cu)</td><td>0.005 unit + 10% of guarantee</td></tr>
<tr><td>Iron (Fe)</td><td>0.005 unit + 10% of guarantee</td></tr>
<tr><td>Manganese (Mn)</td><td>0.005 unit + 10% of guarantee</td></tr>
<tr><td>Sodium (Na)</td><td>0.005 unit + 10% of guarantee</td></tr>
<tr><td>Zinc (Zn)</td><td>0.005 unit + 10% of guarantee</td></tr>
<tr><td colspan="3">Bag Weight</td><td>1% of weight on the label</td></tr>
</table>