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FERTILIZER QUALITY ASSESSMENTS IN BENIN, BURKINA FASO, AND LIBERIA

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Fertilizer Quality Assessments in Benin, Burkina Faso, and Liberia

Executive Summary

The fertilizer quality assessments (FQAs) in Benin, Burkina Faso, and Liberia were conducted between 2015 and 2017 as part of the activities of the USAID-funded West Africa Fertilizer Program (WAFP), implemented by IFDC. FQAs in these three ECOWAS Member States were conducted to develop a fertilizer quality diagnostic that would provide the countries and the ECOWAS Commission with the information needed to develop policies and regulations associated with the domestication and harmonization of the regulatory systems in the countries assessed. The ECOWAS legal and regulatory framework for fertilizer trade and quality control was developed by the IFDC MIR Plus project and WAFP during 2010-2016. The MIR Plus project was able to get *Regulation C/REG.13/12/12*, which related to fertilizer quality control in the ECOWAS region, adopted by the Community Council of Ministers in December 2012. At the end of the MIR Plus project in December 2013, WAFP took over and ensured the review and adoption of four implementing regulations in 2016 to support *Regulation C/REG.13/12/12*. At the request of the ECOWAS Commission to IFDC in 2013, WAFP worked to facilitate implementation of this harmonized regional legal and regulatory framework at the national level. The main purpose of this report is to identify and discuss the fertilizer quality problems found in the fertilizer markets of these countries in order to assist regulatory authorities in the development of policies that could remediate the problems.

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

The main fertilizer quality problem found in Benin and Burkina Faso was the low quality of bulk blends. The problem is generalized to all blends commercialized in these two countries and is particularly pronounced in terms of frequency and severity of shortages regarding P_2O_5, K_2O, secondary nutrients, and micronutrients. Segregation of the bulk blends may explain some of the nutrient shortages, but the main origin of the problem likely is insufficient nutrient inputs at the time of blending. Solving the quality problems of bulk-blended fertilizers in West Africa is urgent considering that bulk blends will be the dominant way to deliver the balanced fertilizer formulations needed for increased crop productivity. This objective can be achieved through the reinforcement of components in the ECOWAS regulatory framework that relate to the manufacture and trade of bulk blends.

Some of the imported NPK compounds traded in the three countries surveyed are of good quality. These include NPK 15-15-15 traded in Benin and Burkina Faso and NPK 23-10-5+3S+2MgO+0.3Zn, which is highly commercialized in Burkina Faso. Some of the imported NPK compounds are of low quality, such as NPK 14-23-14+5S+1B in Benin and NPK 15-15-15+6S+1B in Burkina Faso. No fillers or foreign substances that suggest adulteration by dilution of nutrients were found, not even in re-bagged fertilizers. The only plausible explanation remaining for the nutrients being out of compliance in these imported products is that the nutrient deficiencies originated during the manufacture. Therefore, effective inspection of imported products in ports is necessary.

Cadmium (Cd) content in phosphate fertilizers from Benin, Burkina Faso, and Liberia, expressed as milligrams (mg) of Cd per kilogram (kg) of P_2O_5,

falls under the safety limits established by European and U.S. regulations.

Thirty-one percent of the bags weighed in Benin and 23% of the bags weighed in Burkina Faso were underweight by at least 0.5 kg. There were no underweight bags among the 31 bags weighed in Liberia.

External factors not directly associated with the characteristics of fertilizer products, such as rural markets, isolated dealers, periodic markets, and lack of dealers' knowledge about fertilizers, have been found to have a significant association with nutrient content out of compliance.

Fertilizer caking has a significant association with management factors; this indicates that chances of fertilizer caking increase when storage conditions do not reduce relative humidity, when bag stacks have 20 or more bags, and when pallets are not used. Similarly, chances of adequate fertilizer moisture content increase when fertilizer bags are impermeable, either through a double layer (a plastic inner and a woven outer layer) or by using plastic laminated bags.

Laboratories in West Africa have demonstrated low accuracy and precision of their analytical outputs; therefore, training personnel and updating equipment are urgent actions needed to ensure the implementation of the ECOWAS fertilizer quality framework is effective.

1. Introduction

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

1. Improve the physical environment for the optimal use of fertilizers.
2. Improve the institutional, regulatory, and business environment of the regional fertilizer market.
3. Stimulate effective demand.
4. Stimulate supply.

To achieve the second specific objective, ECOWAS is focusing on creating favorable conditions for the development of the fertilizer sector. Currently, West African national fertilizer markets are underdeveloped and too narrow to generate 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 in December 2012.

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

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

There are very few systematic studies on the quality of fertilizers marketed in West Africa. The most recent[2] were conducted by IFDC between 2010 and 2013 covering five countries – Ghana, Nigeria, Togo, Côte d'Ivoire, and Senegal. The assessments 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% 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 represented 86% of the NPK 20-10-10 blends, 12% of the NPK 6-20-10 blends, 96% of the NPK 15-10-10 blends, 31% of the 23 samples of Asaase Wura (NPK 0-22-18+9CaO+7S+5MgO), and 26% of the Cocoa Feed (NPK 0-30-20) samples. Nutrient shortages among the fertilizer blends in the current study could be explained by segregation of fertilizer components due to uneven granule size or insufficient input of nutrients during fertilizer manufacture.

In contrast to the blended products, the only compound products that failed to meet the ECOWAS quality standard were 10% of the 356 samples of the compound NPK 15-15-15, 16% of the 162 samples of ammonium sulfate (NPK 21-0-0 +24S), 15% of the 162 samples of compound NPK

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

16-16-16, 1% of the 103 samples of compound NPK 23-10-5, and 4% of the 90 samples of Sulfan (NPK 24-0-0+6S). The proportions of non-compliance in the compound products were lower than those observed in the blended products but are still considered high for imported products. This result confirms the finding of an assessment by IFDC in West Africa in 1995,[3] which indicated that 10 out of 29 NPK samples examined were nutrient deficient.

An analysis of the weight of 1,055 fertilizer bags collected from the five countries indicated that there was a 41% chance that the bag weight does not comply with the ECOWAS tolerance limit in Nigeria, a 28% chance in Côte d'Ivoire, 13% in Senegal, 12% in Ghana, and 7% in Togo. The only cases of proven adulteration were seven samples of single superphosphate from Nigeria that had zero P_2O_5 content.

High percentages of nutrient-deficient samples in some NPK blends can be attributed either to deliberate insufficient input of nutrients during manufacturing or to poor control of blending procedures due to the use of inadequate blending technology. Further research is needed to quantify these two sources of nutrient shortages in bulk blends.

Research results and discussion among soil fertility and crop production experts since the publication of the first large-scale fertilizer quality assessment in the ECOWAS region (Sanabria et. al, 2013) have resulted in the development of a relatively new idea, i.e., quantitative increases in fertilizer use in sub-Saharan Africa will not be enough to achieve the increases in crop production needed to achieve food security or income increases required to improve the livelihoods of small-scale farmers. Significant increases in the quantity of fertilizers used by crop growers must coincide with qualitative improvements of the fertilizers in order to provide balanced nutrition both to the crops and the humans that consume the crops. For optimal soil and crop nutrition, fertilizers must not only provide macronutrients but also secondary and micronutrients. There are important challenges to overcome to achieve large-scale use of balanced fertilizers. Some of the challenges are related to identifying crop needs and site-specific soil nutrient deficiencies. Detailed mapping of soil nutrient deficiencies is lacking in most African countries.

Manufacturing bulk-blended fertilizers is probably the most convenient way to produce nutritionally balanced fertilizers that address the specific needs of crops and site-specific nutrient deficiencies of soils. Therefore, manufacturing good quality bulk blends is critical. This is especially important in West Africa where problems have occurred in the manufacture of bulk blends since the beginning of their production, resulting in widespread occurrence of poor-quality blends. The current ECOWAS regulatory framework, which focuses primarily on the truth-in-labeling of any type of fertilizer, must develop regulatory components specific for the manufacture and inspection of bulk blends.

The main purpose of this report is to identify and discuss the fertilizer quality problems found in the markets of Benin, Burkina Faso, and Liberia, considering that the fertilizers commercialized in ECOWAS member states must comply with the quality standards established to deliver the balanced nutrition demanded by the soils, crops, and habitants of the region.

2. Methodology for Data and Sample Collection

Before conducting the field surveys in Benin, Burkina Faso, and Liberia to collect samples and data, IFDC experts conducted a three-day training session in each country for appointed fertilizer

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

inspectors or officials selected by the respective ministries of agriculture. The trainees were instructed in the theoretical and practical aspects of the scientific methodology. On the third day of training, fertilizer sampling and data collection were practiced in the classroom and then in a fertilizer dealer shop or warehouse.

The sampling methodology is diagrammed in Figure 1 and 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***. Collection of data about characteristics of fertilizer markets, dealers, products, and storage conditions is performed in parallel with the collection of fertilizer samples.

2.1 Sampling of Fertilizer Dealers

A list of fertilizer dealers was provided by the Ministry of Agriculture of each country to define a conceptual population of fertilizer dealers. The list from Benin contained 508 dealers, the list from Burkina Faso contained 174 private fertilizer dealers and 158 public distribution points, and the list from Liberia contained 31 fertilizer dealers, 16 of which were located in Monrovia.

The fertilizer dealer sample size for each country was determined based on the sampling capability of the set of inspection teams using the following equation:

$$n = t*d*s$$

Where

n is the sample of fertilizer dealers to be inspected,

t is the number of inspection teams,

d is the net number of days for performing the sampling, and

s is the average number of dealers that can be inspected per day, considering the density of the dealers in the markets and the distance between markets.

The random process for selecting the sample portion for each inspection team was weighted by the number of dealers in each department, province, or county, so that the regions with a higher number of dealers would be represented by a higher number in the sample than regions with a smaller number of dealers. The random sample of dealers in Benin was 96, equivalent to 9% of the population of dealers, distributed among three inspection teams. The random sample of fertilizer dealers in Burkina Faso was 169, equivalent to 50% of the population, distributed among six inspection teams. In Liberia, only one inspection team sampled 11 fertilizer dealers from the list of 31 dealers.

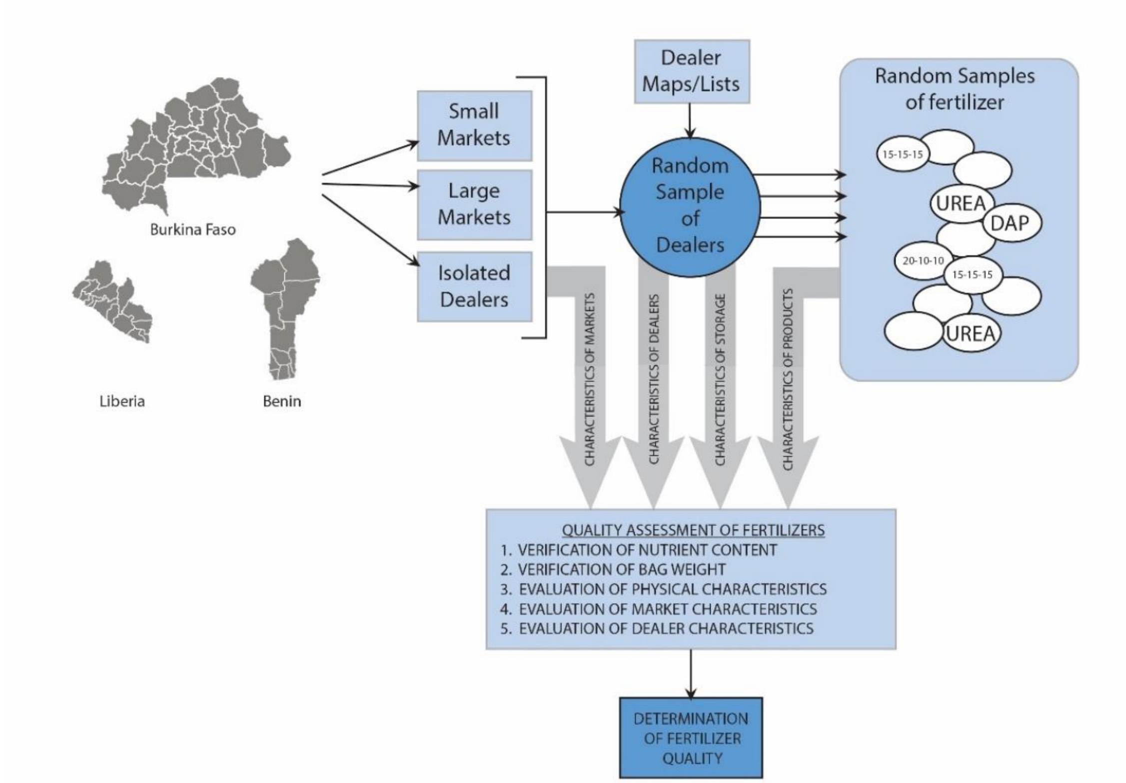

Figure 1. General Methodology for the Quality Assessment of Fertilizers Commercialized in Benin, Burkina Faso, and Liberia

Each agro-dealer in the sample was visited by an inspection team, who conducted sampling of the fertilizers available in the shop and collected data. Every inspection team received a list of the sample of dealers to which they were assigned and an additional set of dealers, also randomly selected, to substitute for dealers from the sample that could not be found or that did not have fertilizers available for sampling at the time of their visit.

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

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

- Market location and characteristics of the market: country, province, 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 in an area with a population of 20,000 or less; 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 periodic.
- Identification and characteristics of the dealer: fertilizer shop owner's or shop attendant's knowledge about fertilizers, training on fertilizer, possession of license, type of customer, and business status (see Table A2 in Appendix A). The answer options in the questionnaire are intuitive, with the exception of the shop owner's or shop attendant's knowledge

about fertilizers. This information must be deduced by the inspector from observing the dealer without asking about his/her knowledge of fertilizers.

- Characteristics of storage: approximate dimensions of the warehouse or shop storage area, qualitative assessment of ventilation, measurement of temperature and relative humidity outside and inside the building or warehouse, fertilizer handling equipment, use of pallets, height of stacks, and general housekeeping (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 in Table A4 is provided in the data collection and sampling protocol in Appendix A.
- Physical attributes of fertilizer products: segregation, granule integrity (fines and dust), presence of filler and impurities, caking, and moisture content (see Table A5 in Appendix A). A detailed description and methods for assessment of physical properties are found in Appendix B.

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

2.3 Chemical Analysis of Fertilizers

The SGS lab in Tema, Ghana, conducted the chemical analysis of the samples collected from the initial five ECOWAS countries assessed by the Marketing Inputs Regionally (MIR) Plus project,[4] but this lab was not available to perform analysis on the samples collected from Benin, Burkina Faso, and Liberia with support from the USAID-funded West Africa Fertilizer Program (WAFP).[5] Therefore, the Envaserv Research Consult (ERC) laboratory from Accra, Ghana, and the Intertek West Africa Sarl laboratory from Abidjan, Côte d'Ivoire, were evaluated with blind fertilizer samples. ERC was selected to perform chemical analysis of 326 samples out of a total of 426 samples collected from the three countries in this study. The remaining 100 samples were analyzed by the IFDC laboratory in Alabama, USA.

Nutrients determined were total nitrogen (N), available phosphate (P_2O_5), and soluble potassium (K_2O). Fertilizer samples in which sulfur (S), calcium (CaO), magnesium (MgO), zinc (Zn), and boron (B) content were claimed on the fertilizer labels were also analyzed for these nutrients.

Analysis of cadmium (Cd) was performed on a group of fertilizers containing P_2O_5 based on concerns about the natural content of Cd in phosphate deposits and the potential of heavy metal accumulation in soils following long-term application of fertilizers. Results of Cd concentration in fertilizers were expressed as milligrams of cadmium per kilogram of available phosphate (mg Cd kg^{-1} P_2O_5) to allow for comparison with data from the literature (Roberts, 2014).[6]

Analytical methods used at the ERC laboratory were the Kjeldhal method for total N; spectrophotometry for P_2O_5; flame photometry for K_2O; colorimetry for S, Zn, and B; and titration for Ca and Mg. Methodologies used in the IFDC laboratory were combustion analysis for total N and S, spectrophotometry for P_2O_5, and inductively

[4] The MIR Plus project was 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] WAFP 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.

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

coupled plasma-optical emission spectrometry (ICP-OES) for K, Ca, Mg, Zn, B, and Cd.

2.4 Physical Analysis of Fertilizers

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

2.5 Data Analysis and Interpretation

2.5.1 Nutrient Content Compliance

Nutrient content compliance was assessed using the ECOWAS tolerance limits (TL) as summarized in Table 1.

Frequency analysis was used to estimate the frequency of out of compliance of the nutrients listed on the fertilizer label. 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 = macronutrient content in label – TL – 0.1; **x** can also be called the out-of-compliance boundary (OOCB), and

f is the OOCF.

For secondary and micronutrients, **x** = nutrient content on the label – TL.

The OOCB or x for secondary and micronutrients is x = nutrient content on the label – TL.

The $OOCS = \bar{x}_{(OOC)} - TL$, meaning that the TL is subtracted from the mean of the values out of compliance.

Table 1. ECOWAS Maximum Tolerance Limits for Nutrient Content in Fertilizers

Nutrient Type	Number of Nutrients	Nutrient	Tolerance
Macronutrient	Multinutrient Fertilizers	Total Nitrogen (N)	1.1%
		Phosphorus (P_2O_5)	1.1%
		Potassium (K_2O)	1.1%
		Deviation from Total Macronutrient Content	-2.5%
	Single Nutrient Fertilizers	Nutrient Content Guarantee ≥ 20%	0.5%
		Nutrient Content Guarantee < 20%	0.3%
Secondary Nutrient		Calcium (Ca)	0.2 unit + 5% of guarantee
		Sulfur (S)	0.2 unit + 5% of guarantee
		Magnesium (Mg)	0.2 unit + 5% of guarantee
Micronutrient		Boron (B)	0.003 unit + 15% of guarantee
		Cobalt (Co)	0.0001 unit + 30% of guarantee
		Molybdenum (Mo)	0.0001 unit + 30% of guarantee
		Chlorine (Cl)	0.005 unit + 10% of guarantee
		Copper (Cu)	0.005 unit + 10% of guarantee
		Iron (Fe)	0.005 unit + 10% of guarantee
		Manganese (Mn)	0.005 unit + 10% of guarantee
		Sodium (Na)	0.005 unit + 10% of guarantee
		Zinc (Zn)	0.005 unit + 10% of guarantee

Example:

The total nitrogen OOCF of urea in Benin (Figure A1) is $F(N_{Urea} \leq 46–0.5–0.1)=F(N_{Urea} \leq 45.4) = 22\%$. And the $OOCS=\overline{x}_{(OOC)}–TL = (45.4+45.3+45.3+45.3+45.3)/5–45.5 = -0.2$

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 lines on the CFDF indicate the percentage of samples associated with the values for total N, available P_2O_5, or soluble K_2O content or bag weights that are below the TL. Figure 5, Figure 6, Figure 7C, and Figure C1 to Figure C11 are CFDFs.

2.5.2 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:

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

In Figure 6, for example, it can be established that the frequency of bags with shortages higher than 1.0% of the bag weight is 32% in Burkina Faso and 34% in Benin.

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

Given the categorical nature of some of the fertilizer physical property variables, such as caking or moisture content, as well as the characteristics of markets, dealers, and some of the storage and packing characteristics, the frequencies associated with the different categories of these discrete variables were obtained directly from the frequency distribution function (FDF). Figures 3 and 4 and Figures 7 (A,B,D) through 11 are FDFs. In Figure 3A, for example, the frequency of rural markets in Burkina Faso is 60%.

2.5.4 Factors Influencing Fertilizer Quality

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

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).[7] The response variable in the models associated with the three initial relationships was nutrient content compliance, and the explanatory variables were the set of physical properties, the set of storage characteristics, and the set of market and dealer characteristics.

The nutrient content compliance was transformed into a binomial variable with values "Yes" and "No"; the value of the variable was "Yes" when the nutrient content values (either for N, P_2O_5, or K_2O) were equal to or higher than the TL, and the value of the variable was "No" when the nutrient content values were 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 had "No" compliance.

Then, models of the nutrient content compliance as a function of physical properties, storage conditions, and market and dealer characteristics were fit to the data, 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 magnitude of influence of the significant variables on the nutrient content compliance. For example, in Table 4, for fertilizer caking the odds ratio associated with the effect of stack height on fertilizer caking is 4.5 times higher when the fertilizer stacks are "High" than when the stacks are "Medium" or "Low."

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

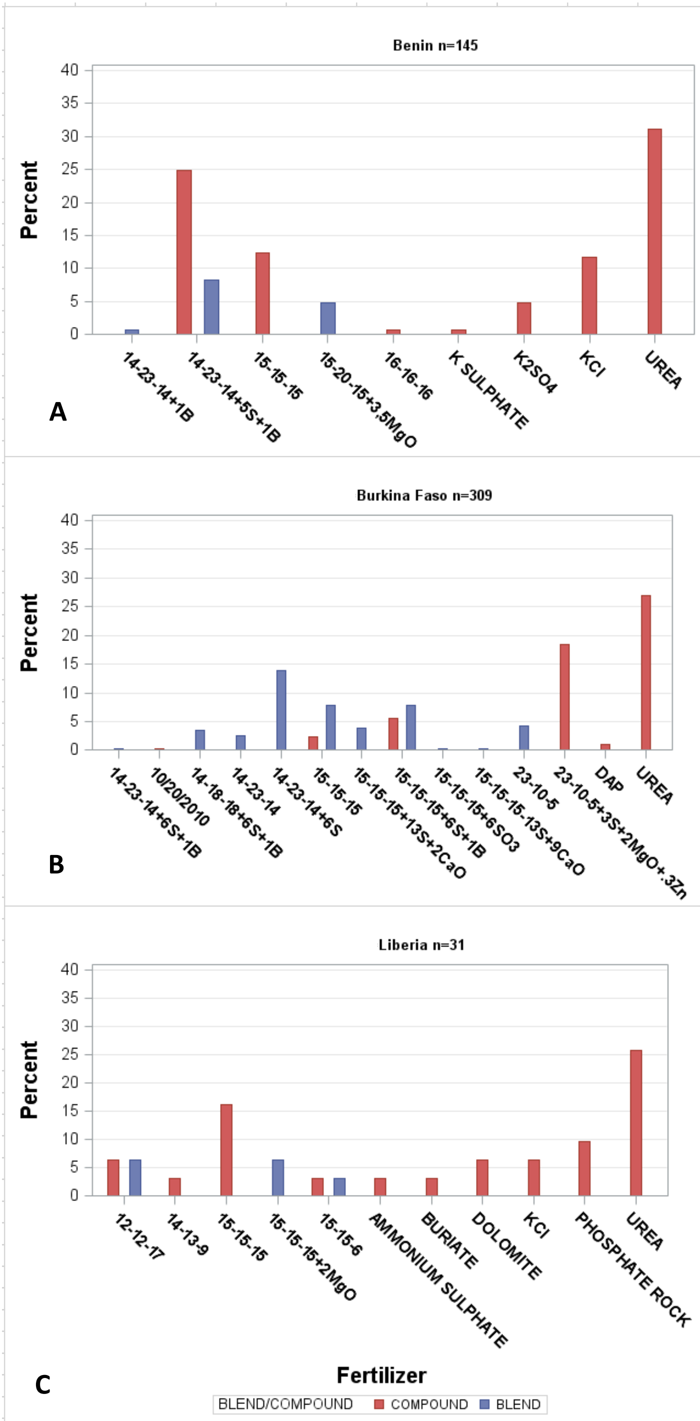


Figure 2. Distribution of Samples by Type of Fertilizer Found in the Markets for the Three Countries

3. Results

3.1 Distribution of Fertilizer Samples

A total of 485 fertilizer samples were collected in Benin, Burkina Faso, and Liberia (Figure 2), which indicates the relative fertilizer market size of the three countries. The largest market of the three countries is Burkina Faso. Benin has about half of the market size of Burkina Faso. Liberia has a market that is just starting to develop. The distribution of fertilizers sampled from the markets of the three countries (Figure 2) is expected to reflect the consumption importance of the different fertilizer products in each country. Across the three countries, urea is the most used fertilizer, accounting for 31%, 26%, and 25% of the fertilizers traded in Benin, Burkina Faso, and Liberia, respectively. The urea sampling percentages in Figure 2 are affected by sampling restrictions to avoid excessive urea samples to analyze. The second and third fertilizers most important in Benin are the compounds NPK 14-23-14+5S+1B and NPK 15-15-15. In Burkina Faso, the second most important fertilizer is the compound NPK 23-10-5+3S+2MgO+0.3Zn, and the third is the bulk-blended NPK 14-23-14+6S. In Liberia, the second most used fertilizer is 15-15-15, followed by several fertilizers and amendments with about 7% of the market share each. The fertilizer market in Burkina Faso has 10 bulk blends of commercial importance that represent around 40% of the market, while Benin has three bulk blends that represent around 14% of the market, and Liberia has four bulk blends. NPK 15-15-15 is found both as compound and blended fertilizers in the markets of Burkina Faso and Liberia but only as a compound fertilizer in Benin.

The number of fertilizer dealers surveyed in Benin and Burkina Faso and the number of fertilizer samples collected from the most important products in the two countries allow strong inferences to be made about the reality of the various aspects of fertilizer quality in these two countries. The same cannot be said about the fertilizer quality evaluations done in Liberia due to the small number of fertilizer dealers (31) involved in this assessment and the reduced number of samples collected from individual fertilizers. The few dealers surveyed and the small sample size from the few fertilizers available in Liberia are indicators of the incipient stage of Liberia's fertilizer market, which is concentrated in the capital city of Monrovia.

3.2 Characteristics of Fertilizer Markets and Dealers

The characteristics of fertilizer markets and fertilizer dealers potentially have an indirect effect on the quality of the fertilizers traded, while fertilizer chemical and physical properties as well as the storage conditions have a direct effect on fertilizer quality. The type of market, either rural or urban (Figure 2A); the concentration of dealers in the markets – high, low, or isolated (Figure 2B); and the market location, either periodic or permanent (Figure 2C), can influence the quality of the fertilizers found in the markets. The rural markets, periodic markets, and markets with isolated dealers are expected to have fertilizer quality problems with higher frequency and higher severity than urban markets, permanent markets, and markets with a high concentration of dealers. Rural markets, itinerant markets, and isolated dealers have three characteristics associated with fertilizers of low quality: less scrutiny from regulatory authorities, less competition or no competition among dealers, and less or no freedom of choice for farmers to select dealers and/or fertilizers.

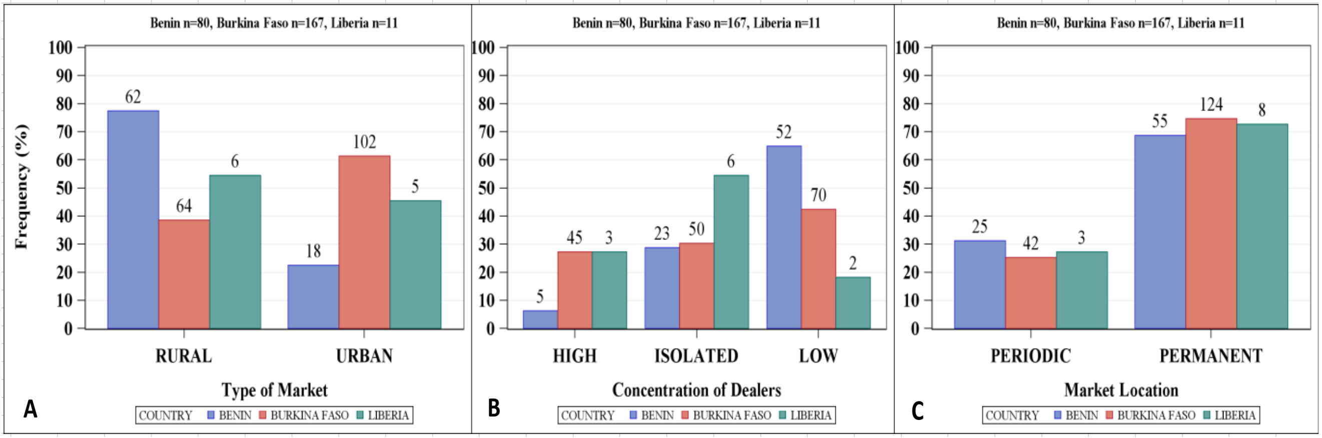


Figure 3. Frequency Distribution of Fertilizer Market Characteristics: Type of Market, Concentration of Dealers, and Market Location

In Benin, Burkina Faso, and Liberia, 78%, 38%, and 54%, respectively, of markets are rural, located in the countryside or in towns of less than 20,000 habitants. The remaining 22%, 62%, and 46%, respectively, of markets are urban (Figure 3A). The majority of the markets in Benin (62%) and Burkina Faso (41%) have a low density of fertilizer dealers, and the majority of the markets in Liberia (53%) are made up of isolated dealers, operating in areas where there are no other dealers (Figure 3B). The vast majority of the fertilizer markets in Benin, Burkina Faso, and Liberia are permanent (Figure 3C) at 69%, 72%, and 71%, respectively.

Some fertilizer dealer characteristics also have the potential to affect the quality of fertilizer in an indirect way. One of those is the degree of the dealer's knowledge about fertilizers, his/her understanding of the association between the chemical and physical properties with the fertilizer nutritional characteristics; and his/her understanding of the appropriate environmental and management conditions for the conservation of good quality of the fertilizers (Figure 4A). In Benin, 78% of the dealers have good knowledge about fertilizers, while the majority of Burkina Faso's dealers (41%) have limited knowledge about fertilizers, and eight of the 11 dealers surveyed in Liberia demonstrated good knowledge about fertilizers.

The status of the dealer, either as a wholesaler, a retailer, or both wholesaler and retailer, can have an effect on the quality of the fertilizer products found in shops or warehouses (Figure 4B). The majority of the dealers in both Benin and Burkina Faso, 76% and 58%, respectively, are fertilizer retailers. Retailers are more likely to distribute products of substandard quality than wholesalers. This phenomenon may be explained by three factors. First, the retailer is located at a low point in the distribution chain and receives products that have passed through several hands, which raises the possibility the products have undergone changes (some of which can be intentional to cause adulteration) that degrade their physical and/or chemical characteristics. Second, retailers have customers who are less likely to demand higher quality standards compared to wholesalers' customers. Third, unlike wholesalers, retailers are less likely to interact directly with importers and/or manufacturers who may share knowledge with the fertilizer dealer on how to maintain the quality of fertilizers.

The type of customer associated with the fertilizer dealers can also influence the quality of fertilizers traded by the dealers (Figure 4C). The majority of Burkina Faso's dealers (40%) sell fertilizers only to small-scale farmers, while the majority of the dealers in Benin (92%) sell fertilizers both to small-scale farmers and to commercial farmers. Dealers that sell fertilizers mainly to small-scale farmers are more likely to trade fertilizers with quality problems than dealers that sell to commercial farmers, to all types of farmers, or to retailers. Small-scale farmers are less quality demanding than commercial farmers or fertilizer retailers, mainly due to their limited knowledge about fertilizers and how they provide nutrients to crops. In Benin, Burkina Faso, and Liberia, 92%, 52%, and 40% of the dealers, respectively, sell fertilizers to small-scale farmers and to other customers, and 3%, 40%, and 20% of the dealers, respectively, sell fertilizers only to small-scale farmers.

Statistical associations of market and dealer characteristics with nutrient content shortages in fertilizers are discussed in Section 2.10 of this report.

3.3 Nutrient Content of Granulated Fertilizers

The nutrient content of a fertilizer is probably its most important quality characteristic. Table 2 shows the OOCF and OOCS for each of the macronutrients and the deviations from the total macronutrient content in the most important fertilizers traded in Benin, Burkina Faso, and Liberia. The cumulative frequency distribution functions used for the development of OOCF and OOCS for each macronutrient in each fertilizer are shown in Appendix C, Figure C1 to Figure C11.

3.3.1 Urea

The ECOWAS tolerance limit for total nitrogen content in urea is 0.5%, which means that any urea sample with 45.4% or lower total nitrogen content is out of compliance. Five samples, or 22% of all urea samples, analyzed from Benin are out of compliance with an average total nitrogen shortage of -0.2% (Table 2, Figure C1). Similarly, five samples, representing 13% of the urea samples, analyzed from Burkina Faso are out of compliance for total nitrogen content with an average total nitrogen content shortage of -0.2% (Table 2, Figure C1). No total nitrogen content shortage was found in the eight urea samples from Liberia (Table 2, Figure C1). The large frequencies of total N out of compliance and the relatively low severity of the total N shortages in samples from Benin and Burkina Faso likely result from precision and accuracy problems with the analytical methods used by the laboratory in West Africa and confirm the urgent training needs for the laboratories in the region, particularly those designated by national governments to test official fertilizer samples under the newly adopted regulatory programs.

The unlikely manufacture or adulteration problems for urea leave random variability due to chemical analysis as the dominant source of variability. Urea analysis results can be used to make some judgment of analytical capabilities of the labs. The cumulative frequency distribution of total nitrogen in urea must have a slight asymmetry toward values higher than 46%, explained by the biuret impurities (around 1%) formed during manufacture. Large departures from symmetry with respect to 46%, such as those that occurred in Benin and Burkina Faso (Figure C1), are additional evidence of low accuracy and precision of analytical methods.

3.3.2 NPK 15-15-15

NPK 15-15-15 is commercialized in Benin, Burkina Faso, and Liberia. It is found in the form of a compound and bulk blend in Burkina Faso but only as a compound in Benin and Liberia.

The NPK 15-15-15 compound in Benin presented total nitrogen OOCF and OOCS of 22% and -0.2%, respectively; the P_2O_5 OOCF and OOCS were 5.6% and -0.05%, respectively; the K_2O OOCF and OOCS were 11% and -0.03%, respectively; and the deviations from total macronutrients OOCF and OOCS were 0.1% and -2.6%, respectively (Table 2, Figure C2). The very mild macronutrient shortages might be explained by the random variability in the chemical analytical outputs. The imported NPK 15-15-15 compound traded in Benin can be considered a product of good quality.

The NPK 15-15-15 compound in Burkina Faso had only seven samples. All of these samples showed total nitrogen compliance, and one of the samples presented P_2O_5 and K_2O out of compliance with very mild shortages of -0.2% and -0.1%, respectively (Figure C1B and Figure C1C). Analysis of the seven samples shows some evidence that the imported NPK 15-15-15 compound commercialized in Burkina Faso is of good quality.

The NPK 15-15-15 bulk blend in Burkina Faso presented total nitrogen OOCF and OOCS of 67% and -2.4%, respectively; the corresponding P_2O_5 OOCF and OOCS were 30.4% and -5.15%, respectively; the K_2O OOCF and OOCS were 25% and -5.5%, respectively; and the deviations from total macronutrient content were 38% and -12%, respectively (Table 2, Figure C3). The high frequency of samples out of compliance together with the high values of nutrient shortages may be explained in part by granule segregation associated with extremely asymmetrical particle size distribution (Figure 10F), causing uneven distribution of fertilizer granules in the bags. However, severe nutrient shortages are most likely due to insufficient inputs during the manufacture of the fertilizers that contribute the three macronutrients.

The NPK 15-15-15 compound in Liberia had only five samples. All five samples complied with the total nitrogen content, and two samples were out of compliance for P_2O_5 and K_2O with OOCS of -0.4% and -3.4%, respectively (Table 2, Figures C2B C2C). The high K_2O shortage in the imported NPK 15-15-15 compound traded in Liberia seems to be associated with difficulty adding the KCl to the fertilizer granule during manufacture.

3.3.3 NPK 14-23-14+5S+1B in Benin

This cotton-grade fertilizer is found as a compound and bulk blend in Benin. Thirty-six samples were collected of the compound, which ranked second after urea in terms of volume of fertilizer marketed in Benin. The corresponding total nitrogen OOCF and OOCS were 13.9% and -0.3%, respectively; the P_2O_5 OOCF and OOCS were 5.9% and -6.8%, respectively; the K_2O OOCF and OOCS were 20% and -1.4%, respectively; and the deviations from total macronutrient content OOCF and OOCS were 11% and -7.5%, respectively (Table 2, Figure C3). The sulfur OOCF and OOCS were 23.5% and -1.6%, respectively (Table 3). P_2O_5, total macronutrient, and sulfur shortages were severe and can be explained only by defective manufacture, since none of the fertilizer quality inspectors reported evidence of fertilizer adulteration.

Twelve samples were collected of the NPK 14-23-14+5S+1B bulk blend in Benin. The total nitrogen OOCF and OOCS were 50% and -0.9%, respectively; the P_2O_5 OOCF and OOCS were 25% and -5%, respectively; the K_2O OOCF and OOCS were 16.7% and -0.9%, respectively; and the deviations from total macronutrients OOCF and OOCS were 23% and -10%, respectively (Table 2, Figure C4). The sulfur OOCF and OOCS were 85.7% and -2.3%, respectively (Table 3). The severe P_2O_5 and sulfur shortages of the NPK 14-23-14+5S+1B bulk blend may be explained in part by the uneven distribution of nutrients in bags that results from segregation of the different granule sizes of the blend (Figure 10A) and also by insufficient nutrient input during manufacture of the fertilizer blend.

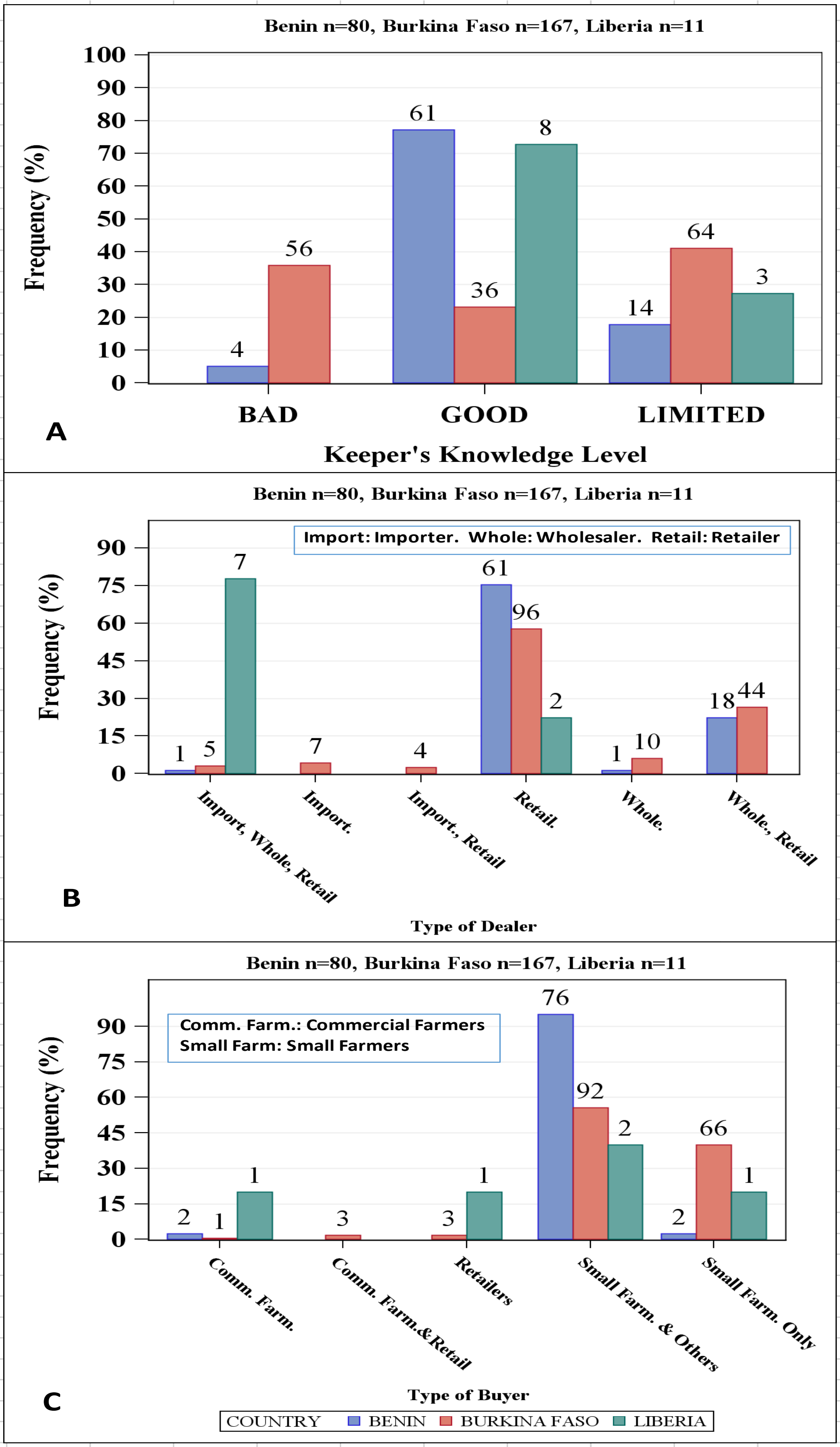


Figure 4. Frequency Distribution of Fertilizer Dealer Characteristics: Shop Keeper's Knowledge about Fertilizers (A), Type of Dealer (B), and Type of Buyer (C)

Table 2. Frequency and Severity of Nutrient Content Out of Compliance for Total N, P_2O_5, K_2O, and Deviation from Total Macronutrient Content in the Main Fertilizers Commercialized in Benin, Burkina Faso, and Benin

			Total N (%)			P_2O_5 (%)			K_2O (%)			Total NPK Nutrient Content (%)		
Country	**Fertilizer**	**BLEND / COMPOUND**	**CB[1]**	**OOCF[2]**	**OOCS[3]**	**CB[1]**	**OOCF[2]**	**OOCS[3]**	**CB[1]**	**OOCF[2]**	**OOCS[3]**	**CB[1]**	**OOCF[2]**	**OOCS[3]**
BENIN	NPK 14-23-14 + 5S + 1B	BLEND	12.9	50.0	-0.93	21.9	25.0	-5.05	12.9	16.7	-0.90	-2.5	23	-9.96
BENIN	NPK 14-23-14 + 5S + 1B	COMPOUND	12.9	13.9	-0.32	21.9	5.9	-6.80	12.9	20.0	-1.42	-2.5	11	-7.47
BENIN	NPK 15-15-15	COMPOUND	13.9	22.2	-0.20	13.9	5.6	-0.05	13.9	11.1	-0.03	-2.5	0.1	-2.63
BENIN	UREA	COMPOUND	45.4	36.4	-0.22	.	.	.		.	.	-2.5	.	.
BURKINA FASO	NPK 14-18-18 + 6S+ 1B	BLEND	12.9	29.0	-0.15	16.9	36.4	-2.52	16.9	27.3	-3.82	-2.5	25	-8.32
BURKINA FASO	NPK 14-23-14 + 6S	BLEND	12.9	9.3	-0.15	21.9	58.1	-4.34	12.9	30.2	-1.11	-2.5	30	-4.89
BURKINA FASO	NPK 15-15-15	BLEND	13.9	66.7	-2.44	13.9	30.4	-5.15	13.9	25.0	-5.47	-2.5	38	-11.96
BURKINA FASO	NPK 15-15-15	COMPOUND	13.9	.	.	13.9	14.3	-0.20	13.9	0.0	0.00	-2.5	.	-2.84
BURKINA FASO	NPK 15-15-15 + 13S + 2CaO	BLEND	13.9	41.7	-0.07	13.9	66.7	-1.55	13.9	18.2	-2.48	-2.5	28	-6.75
BURKINA FASO	NPK 15-15-15 + 6S + 1B	BLEND	13.9	58.3	-1.63	13.9	33.3	-4.70	13.9	25.0	-4.19	-2.5	38	-11.91
BURKINA FASO	NPK 15-15-15 + 6S + 1B	COMPOUND	13.9	41.2	-0.87	13.9	23.5	-0.50	13.9	25.0	-1.44	-2.5	17	-4.86
BURKINA FASO	NPK 23-10-5	BLEND	21.9	46.2	-1.15	8.9	15.4	-1.29	3.9	25.0	-0.49	-2.5	13	-5.30
BURKINA FASO	NPK 23-10-5 + 3S + 2MgO + 0.3Zn	COMPOUND	21.9	14.5	-0.42	8.9	1.8	0.00	3.9	3.9	-0.15	-2.5	0	0.00
BURKINA FASO	UREA	COMPOUND	45.4	43.2	-0.17	.	.	.	.	.	.	.	.	.
LIBERIA	NPK 15-15-15	COMPOUND	13.9	25.0	0.00	13.9		-0.40	13.9	50.0	-3.43	-2.5	.	.
LIBERIA	UREA	COMPOUND	45.4	12.5	0.00		.	.	.	.	.	.	.	.

[1] CB: Compliance Boundary

[2] OOCF: Out of Compliance Frequency

[3] OOCS: Out of Compliance Severity

3.3.4 NPK 23-10-5+3S+2MgO+0.3Zn Compound in Burkina Faso

Fifty-seven samples were collected from this compound fertilizer applied on cereals, mainly maize, in Burkina Faso, which accounts for the largest quantity after urea. The total nitrogen OOCF and OOCS were 14.5% and -0.4%, respectively; the P_2O_5 OOCF and OOCS were 1.8% and -0.1%, respectively; the K_2O OOCF and OOCS were 3.9% and -0.1%, respectively; and the deviation from total macronutrient content was in compliance (Table 2, Figure C5). Sulfur was in compliance, magnesium had a shortage of -0.05 (Table 3), and Zn presented 66% of the samples below the 0.3% guarantee. Shortage of nitrogen likely originated in the manufacture of this imported fertilizer. Shortages of the other macronutrients and magnesium were negligible, probably as a result of the variability associated with the chemical analytical outputs. The other factor against the quality of this imported fertilizer is the very high frequency of samples with Zn below the label guarantee. In addition, the serious challenge of maintaining uniform distribution of the 0.3% zinc concentration in the 50-kg bags must be considered.

3.3.5 NPK 14-23-14+6S Bulk Blend in Burkina Faso

Forty-three samples were collected from this fertilizer blend, which has the third largest commercialization importance in Burkina Faso. The total nitrogen content OOCF and OOCS were 9.3% and -0.15%, respectively; the P_2O_5 OOCF and OOCS were 58.1% and -4.3%, respectively; the K_2O OOCF and OOCS were 30.2% and -1.1%, respectively; and the deviations from total macronutrient content OOCF and OOCS were 30% and -4.9%, respectively (Table 2, Figure C6). Sulfur OOCF and OOCS were 31% and -0.77% (Table 3). Large P_2O_5 and K_2O shortages may be partially explained by the segregation of the blend with disparity in granule sizes (Figure 10E) that causes uneven distribution of nutrients inside the fertilizer bags. Shortage of these two macronutrients also suggests insufficient input of both nutrients during the blending manufacture.

3.3.6 NPK 15-15-15+6S+1B in Burkina Faso

This fertilizer is found in Burkina Faso both as a compound and a bulk blend. Seventeen samples were collected from the compound fertilizers. The total nitrogen OOCF and OOCS were 41.2% and -0.9%, respectively; the P_2O_5 OOCF and OOCS were 23.5% and -0.5%, respectively; the K_2O OOCF and OOCS were 25% and -1.4%, respectively; and the deviations from total macronutrient content OOCF and OOCS were 17% and -4.9%, respectively (Table 2, Figure C7). The sulfur OOCF and OOCS were 11% and -1.17%, respectively (Table 3). All of the boron concentrations from the 17 samples presented values lower than 0.85% (B OOCS). High frequency and severity values of K_2O and S shortages, as well as lower boron content than the guarantee, are strong evidence of manufacturing problems in these compound fertilizers. Adding KCl during granulation is a frequent problem in fertilizers with a high K_2O content.

The NPK 15-15-15+6S+1B bulk blend had 24 samples in Burkina Faso. The total nitrogen OOCF and OOCS were 58.3% and -1.6%, respectively; the P_2O_5 OOCF and OOCS were 33.3% and -4.7%, respectively; the K_2O OOCF and OOCS were 25% and -4.2%, respectively; and the deviations from total macronutrient content OOCF and OOCS were 38 and -11.9, respectively (Table 2, Figure C8). The sulfur OOCF and OOCS were 11.1% and -0.35%, respectively (Table 3). All 24 samples presented B concentrations lower than the 0.85% (B OOCS).

Large frequencies and severities of shortages out of compliance for all macronutrients, sulfur, and boron are strong evidence of the low quality of the fertilizer blend. The input fertilizers likely were used in insufficient quantities to reach the grade specified on the label. Severe granule segregation (Figure 10H) also seems to play a role in the severe nutrient shortages of this fertilizer.

3.3.7 NPK 15-15-15+13S+2CaO Bulk Blend in Burkina Faso

Twelve NPK 15-15-15+13S+2CaO samples were collected in Burkina Faso. The related total nitrogen content OOCF and the OOCS were 41.7% and -0.1%, respectively; the P_2O_5 OOCF and OOCS were 66.7% and -1.5%, respectively; the K_2O OOCF and OOCS were 18.2% and -2.5%, respectively; and the deviations from total macronutrient content OOCF and OOCS were 28% and -6.8%, respectively (Table 2, Figure C9). The calcium content was in compliance, and the sulfur OOCF and OOCS were 71.4% and -3.94%, respectively (Table 3). Large out of compliance frequencies and severities for P_2O_5 and K_2O and deviations from total macronutrient content and sulfur content are strong evidence of the low quality of this bulk-blend fertilizer. Insufficient phosphorus, potassium, and sulfur likely were used to manufacture the blend grade. Unequal particle size of the constituents of the blend that resulted in granule segregation (Figure 10G) and uneven distribution of nutrients in the fertilizer bags may have played a part in the severe deficiencies of phosphorus, potassium, and sulfur observed with the fertilizer samples.

3.3.8 NPK 23-10-5 Bulk Blend in Burkina Faso

Thirteen samples were collected from this bulk blend in Burkina Faso. The total nitrogen content OOCF and OOCS were 46.2% and -1.2%, respectively; the P_2O_5 content OOCF and OOCS were 15.4% and -1.3%, respectively; the K_2O content OOCF and OOCS were 25% and -0.5%, respectively;

and the deviations from total macronutrient content OOCF and OOCS were 13% and -5.3%, respectively (Table 2, Figure C10). Total N and P_2O_5 shortage severities are large enough to create serious quality problems in this blended fertilizer. Shortage of potassium in this fertilizer is not as serious as in other blends, probably due to the low K_2O in the fertilizer grade. Insufficient input of nitrogen and phosphorus during manufacture of the blend likely is the main cause of nutrient shortages in this fertilizer. Granule segregation due to the uneven granule sizes (Figure 10I) of the blended fertilizers may also play a part in the nutrient deficiencies.

3.3.9 NPK 14-18-18+6S+1B Bulk Blend in Burkina Faso

Eleven samples from this bulk blend were collected in Burkina Faso. The total nitrogen OOCF and OOCS were 29% and -0.2%, respectively; the P_2O_5 OOCF and OOCS were 36.4% and -2.5%, respectively; the K_2O OOCF and OOCS were 27.3% and -3.8%, respectively; and the deviations from total macronutrient content OOCF and OOCS were 25% and -8.3%, respectively (Table 2, Figure C11). The sulfur OOCF and OOCS were 50% and -0.26%, respectively (Table 3). All 11 samples produced B concentrations lower than 0.85% (B OOCS). The large frequency of out-of-compliance and large shortage severity values, especially for P_2O_5, K_2O, total macronutrient content, and B, are strong evidence of the low quality of this fertilizer blend. A combined effect of insufficient nutrient input during the blending manufacture and granule segregation due to a wide range of granule sizes (Figure 10C) explain the severe nutrient shortages of this fertilizer product.

Low quality of the bulk blends in West Africa is a sensitive issue, considering that this kind of fertilizer is probably the only way to deliver the balanced nutrition grades combining the macro-, secondary, and micronutrients required for specific crops and soil characteristics. Bulk-blend fertilizers dominate the fertilizer manufacture and trade in West Africa and the entire world. Now with the advent of balanced nutrition concepts, Africa must increase its fertilizer consumption quantitatively and qualitatively in order to respond to the food demand of a growing population.

The way to start changing the current poor-quality bulk blend in West Africa is to introduce specific regulatory components in the ECOWAS regulatory system that address all aspects of the manufacture and trade of fertilizer bulk blends.

3.4 Cadmium Content in Fertilizers

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

Table 3. Frequency and Severity of Nutrient Content Out-of-Compliance for Secondary Nutrients from the Main Fertilizers Commercialized in Benin and Burkina Faso

Nutrient	Country	Fertilizer	BLEND/ COMPOUND	n	Compliance Boundary	Out of Compliance Frequency	Out of Compliance Severity
S	BENIN	NPK 14-23-14 + 5S + 1B	BLEND	12	4.55	85.7	-2.30
S	BENIN	NPK 14-23-14 + 5S + 1B	COMPOUND	36	4.55	23.5	-1.61
Mg	BENIN	NPK 15-20-15 + 3,5MgO	BLEND	7	3.125	50.0	-0.96
S	BURKINA FASO	NPK 14-18-18 + 6S + 1B	BLEND	11	5.5	50.0	-0.26
S	BURKINA FASO	NPK 14-23-14 + 6S	BLEND	43	5.5	31.3	-0.77
Ca	BURKINA FASO	NPK 15-15-15 + 13S + 2CaO	BLEND	12	1.15	0.0	0.00
S	BURKINA FASO	NPK 15-15-15 + 13S + 2CaO	BLEND	12	12.15	71.4	-3.93
S	BURKINA FASO	NPK 15-15-15 + 6S + 1B	BLEND	24	5.5	11.1	-0.35
S	BURKINA FASO	NPK 15-15-15 + 6S + 1B	COMPOUND	17	5.5	11.1	-1.17
Mg	BURKINA FASO	NPK 23-10-5 + 3S + 2MgO + 0.3Zn	COMPOUND	57	1.7	5.0	-0.05
S	BURKINA FASO	NPK 23-10-5 + 3S + 2MgO + 0.3Zn	COMPOUND	57	2.65	0.0	0.00

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

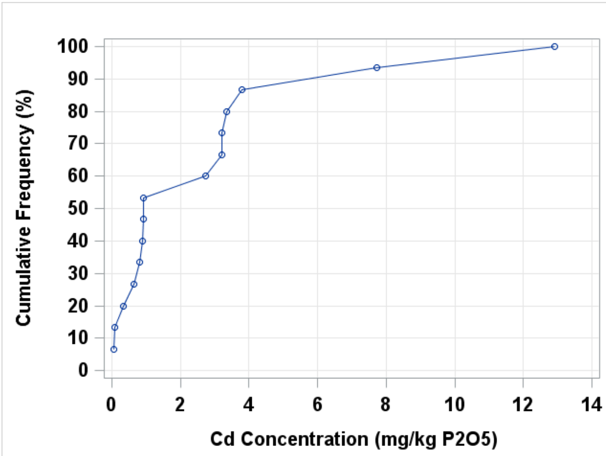
Fifteen fertilizer samples containing phosphorus were analyzed for cadmium. The two highest cadmium values in Figure 5 are from phosphate rock sampled in Liberia, but these two cadmium values are well below the European Union tolerance limits of 20-40 mg/kg P_2O_5 or the U.S. tolerance limits in the range of 180-889 mg/kg P_2O_5.

3.5 Bag Weight Verification

Most of the fertilizer marketed in West Africa is packaged in 50-kg fertilizer bags. The ECOWAS bag difference tolerance between the weight specified on the label and the actual weight of the bag is 1%, or 0.5 kg for 50-kg bags.

Thirty-one percent of the 136 bags weighed in Benin and 23% of the 277 bags weighed in Burkina Faso were underweight by at least 0.5 kg. There were no underweight bags among the 31 bags weighed in Liberia. From the symmetric distribution of bag weight shortages, we can estimate the average random error committed filling and weighing the bag from the right size of the distribution, assuming that the overfilling/overweighing happens completely at random. The average random error in Benin is 0.9 and in Burkina Faso is 0.4. If the random error is subtracted from the frequency of underweight bags by more than -0.5 kg, we can estimate the frequency of deliberately underweight bags, which would be 30.1% in Benin and 22.6% in Burkina Faso.

The Liberia cumulative frequency distribution of bag weight shortage is not symmetric with respect to the 0 weight difference to 50% frequency relationship (Figure 6). All of the bags seem to be overweight either because of a procedure that is overfilling the bags or a bias scale that is measuring weight higher than the actual weight.



Country	Fertilizer	Cd
BURKINA FASO	NPK 15-15-15 + 6S + 1B	0.63
BURKINA FASO	NPK 23-10-5 + 3S + 2MgO + 0.3Zn	0.69
BURKINA FASO	NPK 15-15-15 + 13S + 2CaO	1.39
LIBERIA	12-12-17	5.02
BURKINA FASO	NPK 15-15-15 + 6S + 1B	5.67
BURKINA FASO	NPK 23-10-5	5.87
BURKINA FASO	NPK 15-15-15	6.21
LIBERIA	NPK 15-15-15	6.41
BURKINA FASO	NPK 14-23-14 + 6S	12.94
BURKINA FASO	NPK 14-18-18 + 6S + 1B	13.15
BENIN	NPK 14-23-14 + 5S + 1B	13.55
LIBERIA	PHOSPHATE ROCK	13.84
BURKINA FASO	NPK 14-23-14 + 6S	14.41
LIBERIA	PHOSPHATE ROCK	27.06
LIBERIA	PHOSPHATE ROCK	33.27

Figure 5. Cumulative Frequency Distribution of Cadmium Content in 15 Phosphate Fertilizers

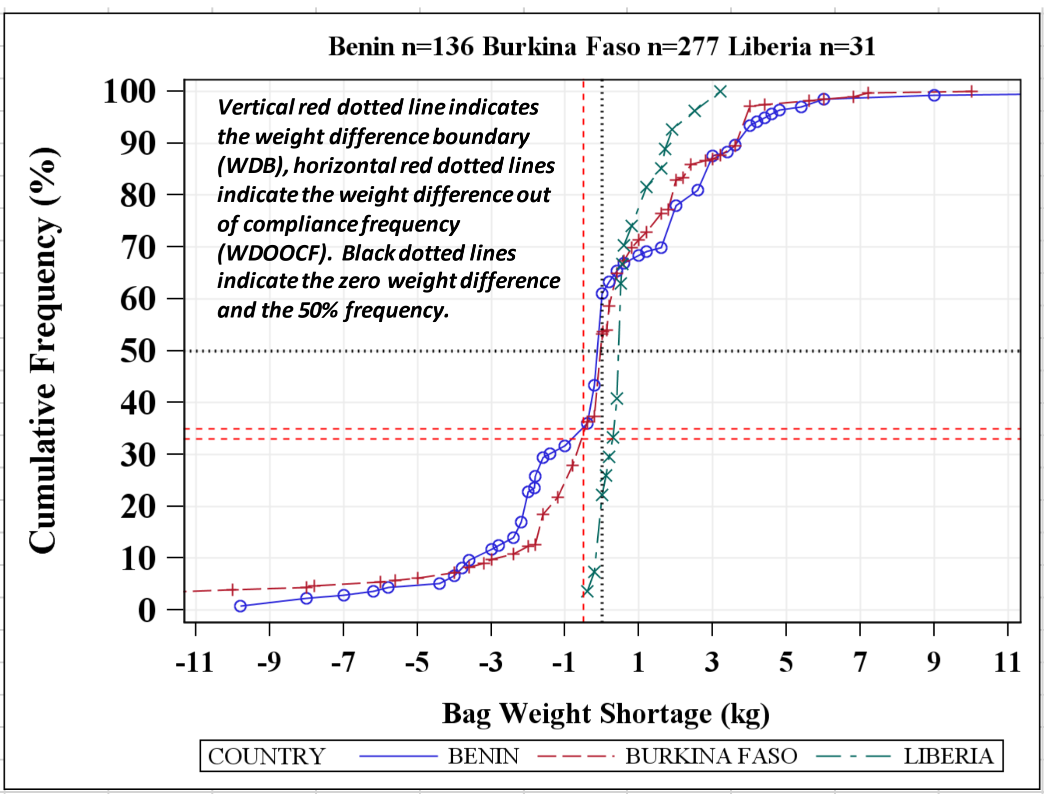


Figure 6. Cumulative Distribution of Fertilizer Bag Weight Verification in Benin, Burkina Faso, and Liberia

3.6 Storage and Bagging Conditions

Physical properties of fertilizers, such as moisture content, caking susceptibility, and integrity of the granules, are highly affected by the temperature and relative humidity (RH) of the storage areas. In general, high temperature and high RH during the storage period are detrimental to the fertilizers' physical properties. Critical relative humidity (CRH), a property of individual fertilizers involving the interaction of temperature and relative humidity, is determined by the hygroscopic characteristics of the constituent materials of the fertilizer. The CRH of NPK 17-17-17 is 45% at a temperature of 30°C. Similar fertilizers commonly found in Benin, Burkina Faso, and Liberia, such as the different forms of NPK 15-15-15, are expected to have a CRH near 45%, which makes this fertilizer very susceptible to integrity degradation and caking. Storage conditions that do not reduce the high RH and temperature (Figure 7A and Figure 7B), typical of the tropical climate in the three countries studied, easily reach the CRH of several of the most common NPKs found in the markets.

Another detrimental storage condition is bags stacked too high. The frequency of storage facilities having 20 or more bags as the maximum number of bags in the stacks is 40% in Liberia, 27% in Benin, and 3% in Burkina Faso (Figure 7 C). Not using pallets or insufficient use of pallets also contributes to caking of fertilizers, especially urea (Figure 7D).

The lower frequency of fertilizer stacks with 20 or more bags in Burkina Faso (Figure 7C) explains the low urea caking of about 15% (Figure 8B), as compared with 23% urea caking with stacks higher than 20 bags (Figure 7C) and 68% urea caking, adding the medium and high caking categories, in Benin (Figure 8A). Other factors contributing to reduced urea caking in Burkina Faso relative to Benin are the higher frequency of pallet use (Figure 7D) and the higher frequency of storage conditions that reduce relative humidity (Figure 7B).

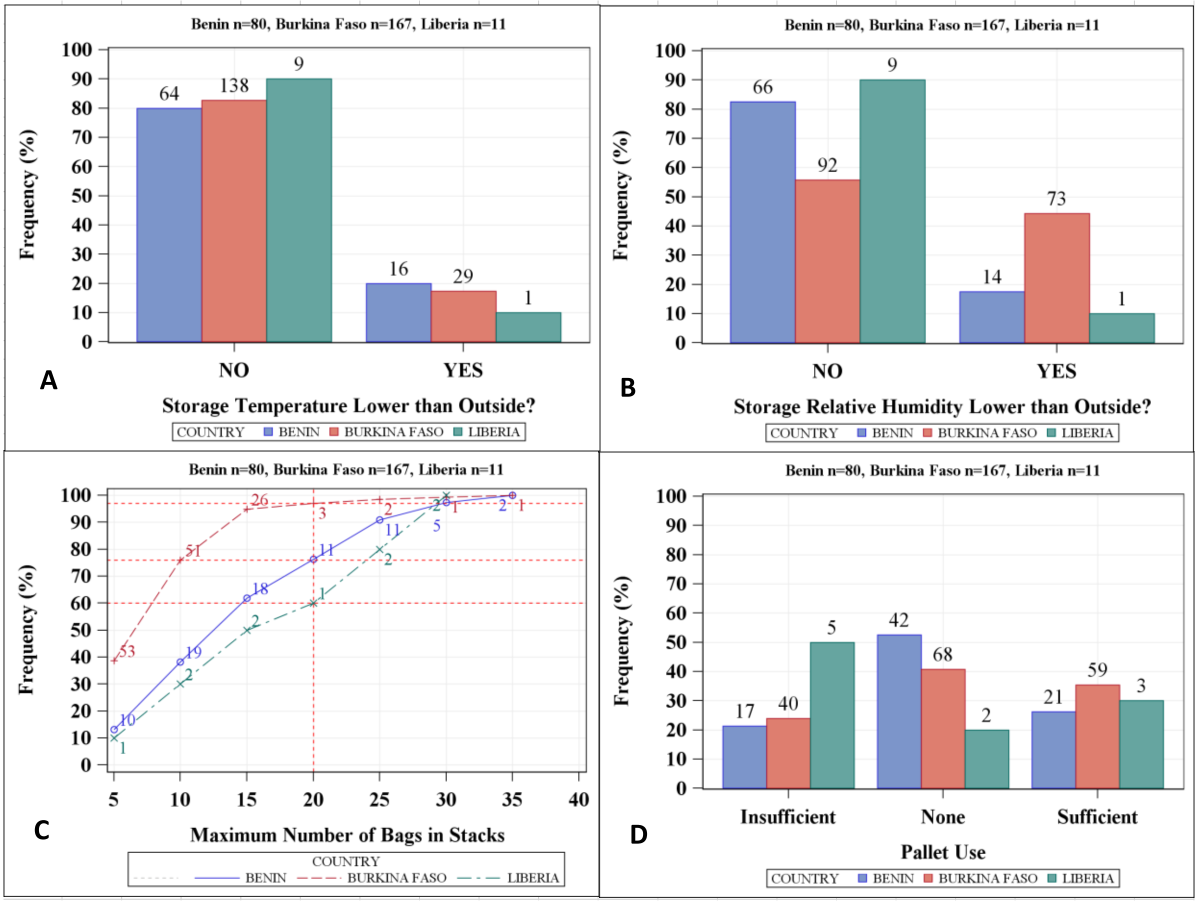


Figure 7. ***Frequency Distribution for Storage Conditions: Storage Temperature (A), Storage Relative Humidity (B), Maximum Number of Bags in Stacks (C), and Pallet Use (D) in Benin, Burkina Faso, and Liberia***

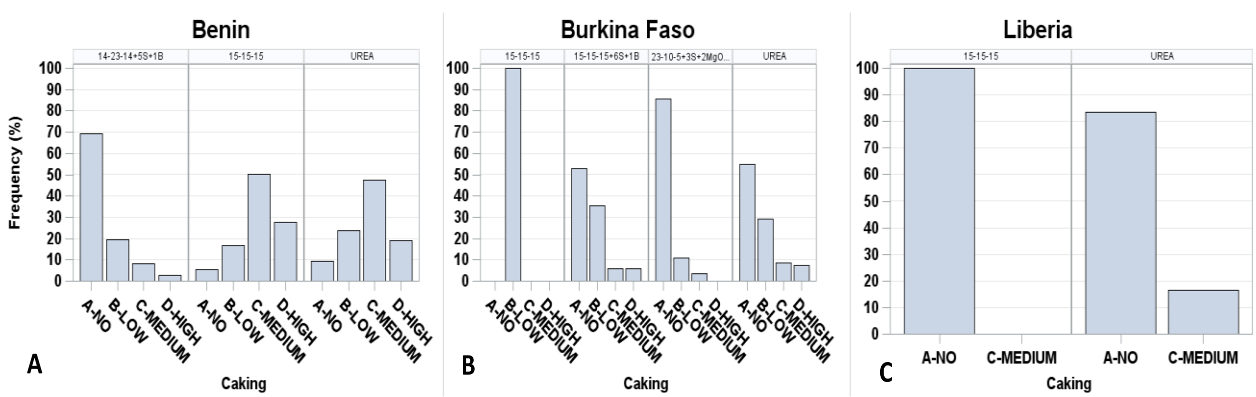


Figure 8. ***Frequency Distribution of Caking for Fertilizers Sampled in Benin, Burkina Faso, and Liberia***

Waterproof bags of good quality and in good condition are the best resource dealers have to protect the fertilizers from damage caused by high relative humidity during fertilizer storage. The great majority of bags in Benin and Burkina Faso are impermeable through the combination of outer woven and inner impermeable plastic layers (Figure 9A and Figure 9B). Of the 31 storage areas examined in Liberia, about nine had bags with an outer woven layer without the inner impermeable layer (Figure 9C). Torn bags that allow moisture to penetrate the bags and degrade the quality of fertilizers occur frequently in Benin, ranging from 29% to 67% of the samples (Figure 9D). Torn bags were found in Burkina Faso with frequencies ranging from 7% to 12% (Figure 9E). No torn bags were found in Liberia (Figure 9F). Loose bag seams, which are frequent in Burkina Faso (between 18% and 28%; Figure 9H) and Liberia (between 61% and 81%; Figure 9I), have an effect similar to torn bags, allowing moisture to affect fertilizer quality.

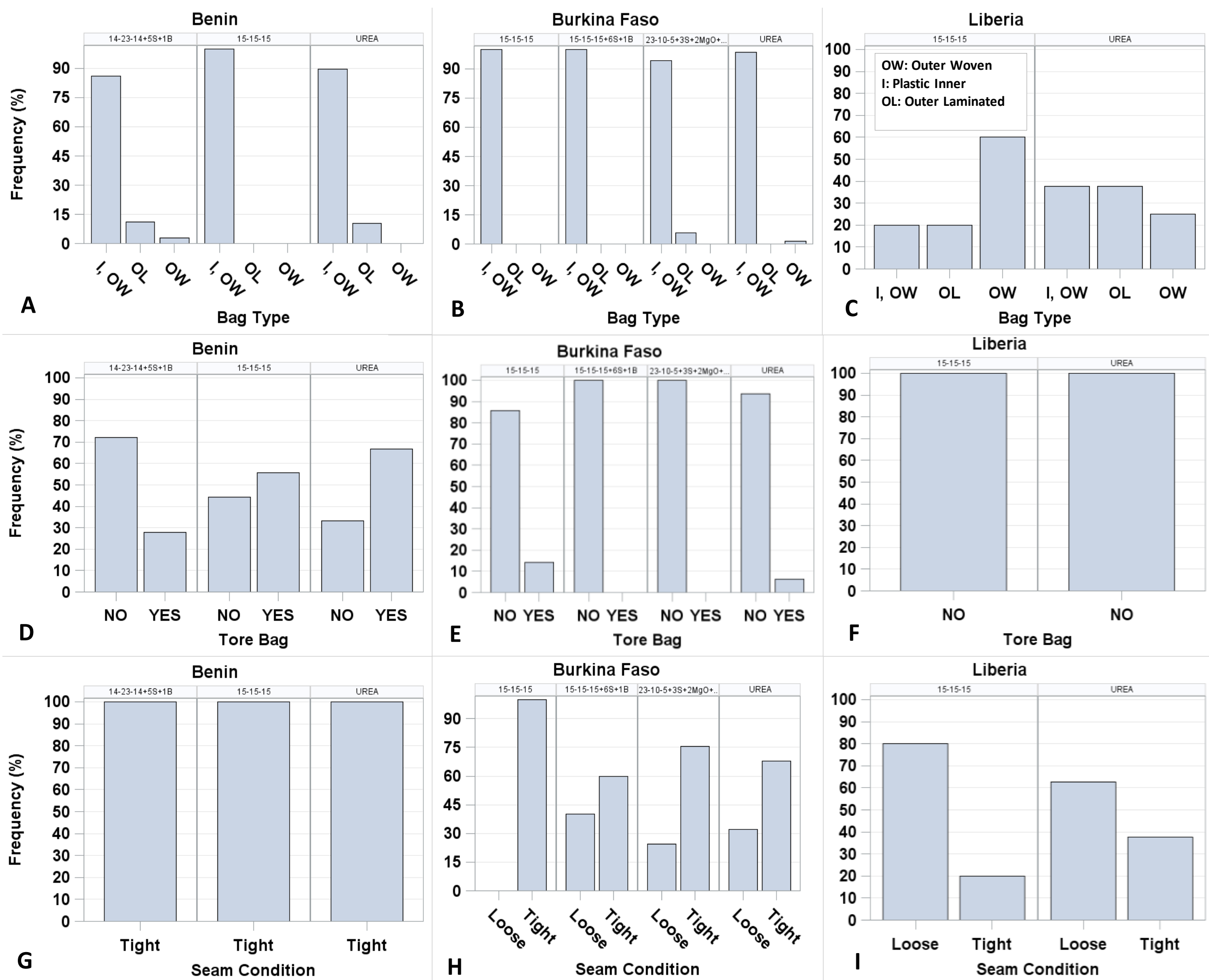


Figure 9. Frequency Distribution for Bag Characteristics: Type (A-C), Integrity of the Bag (D-F), and Condition of the Bag Seam (G-I) in Benin, Burkina Faso, and Liberia

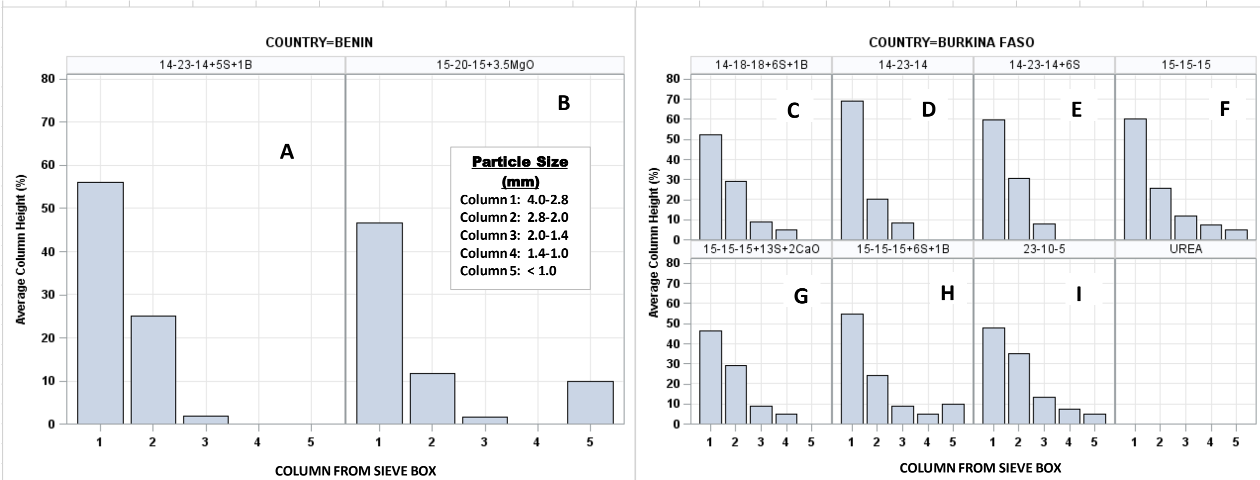


Figure 10. Granule Segregation of Bulk Blends in Benin and Burkina Faso

The particle size distribution of non-segregated bulk blends (Figure B2B in Appendix B) would show granules of all blend components in one or few columns arranged in a symmetrical distribution. Figure 10A shows the great majority of fertilizer particles within 2-4 mm average diameter. The low percentage of particles with an average diameter lower than 2 mm indicates no segregation concerns, while Figures 10B to 10I present particles with an average diameter lower than 2 mm at frequencies of 10% or higher, indicating segregation that can produce segregation of nutrients inside the fertilizer bags.

Granular integrity of the most commonly traded fertilizers in Benin, Burkina Faso, and Liberia (Figure 11) is not a major concern. For all fertilizers analyzed, the regular size granules, by far, make up the largest proportion of granules. The NPK 15-15-15 and urea in Benin present small quantities of fines and dust, with similar situations for the two NPK 15-15-15 products and urea in Burkina Faso and urea in Liberia. The production of fines and dust likely resulted from the manual and individual handling of fertilizer bags, when three types of forces – crushing, impact and abrasion – interact to cause fracture and abrasion of the original whole granules. The granule hardness determines the capability of the granules to withstand the three forces that may degrade them. This hardness is a manufacturing characteristic that is preserved by avoiding contact of fertilizer granules with environmental moisture.

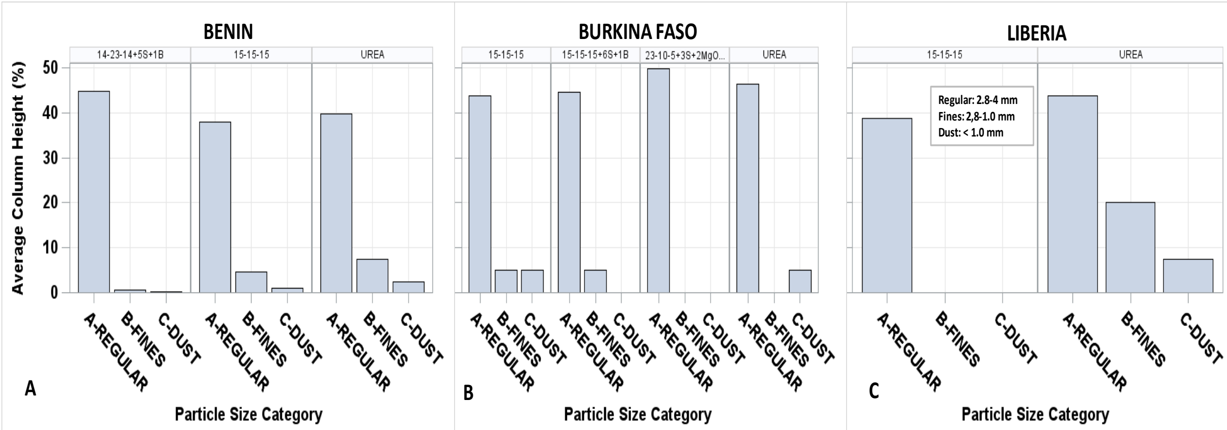


***Figure 11.** Granule Degradation of Fertilizers in Benin, Burkina Faso, and Liberia*

3.7 Effect of Storage Conditions on Fertilizer Physical Properties

The effect of storage conditions, such as ventilation, temperature, relative humidity, bag stack height, use of pallets, and the type of bag, on fertilizer caking and adequate fertilizer moisture content was tested using regression logistic models. The odds ratio for storage RH indicates that the fertilizer caking odds are 1.6 times higher in a storage facility with no RH reduction than in a storage facility with RH reduction. The stack height odds ratio indicates that fertilizer caking odds are 4.5 times higher when the stacks are high than when the stacks have medium or low height. The odds ratio for pallet use is 1.6 times higher when no pallets are used than when a sufficient number of pallets are used (Table 4). The significant effect of RH reduction together with the use of pallets indicates the importance of RH reduction inside the storage areas along with low to medium stack heights to reduce fertilizer caking. The higher magnitude of the stack height odds ratio indicates a greater importance of the other two factors to reduce fertilizer caking.

Among the factors that potentially affect the adequate moisture content of fertilizers (Table 4), the only significant one was the type of bag. The laminated bags or bags with a plastic inner layer have a 17 times higher chance of maintaining an adequate moisture content in fertilizers than bags that have only the permeable woven exterior material without an impermeable plastic inner layer.

3.8 Effect of Fertilizer Physical Properties and Characteristics of Markets and Dealers on Nitrogen Content Compliance

Table 5 shows the factors that have a significant effect on finding nitrogen content out of compliance. The predictor variables of the logistic model are binomial (two options), such as market type and periodicity; multinomial (more than two options), such as dealer density or shop keeper’s knowledge about fertilizers; or continuous (infinite options), such as percentage of fines.

Table 4. Effect of Conditions of Storage on Fertilizer Physical Properties

Response Variable	Effect	DF	Wald Chi-Square	Pr > ChiSq	Odds Ratio Estimates and Wald Confidence Intervals: Label	Estimate	95% Confidence Limits	
Fertilizer Caking	Storage ventilation	1	0.76	0.38				
	Storage temperature	1	0.05	0.82				
	Storage RH	1	4.53	0.03	No RH reduction vs RH reduction	1.6	1.039	2.541
	Stack height	2	10.00	0.01	High vs Medium or Low	4.5	1.755	11.603
	Use of pallets	2	4.69	0.10	No use or Insufficient vs Sufficient use	1.6	0.998	2.621
Adequate Fertilizer Moisture Content	Storage ventilation	1	0.89	0.35				
	Storage temperature	1	0.32	0.57				
	Use of pallets	2	5.83	0.17	Use of Pallets vs No use or insufficient use	9	0.605	144.1
	Type of bag	2	3.60	0.05	Laminated or inner plastic vs Outer Woven only	17	0.879	335.78

The odds ratio for market type indicates that the odds of a rural market having nitrogen content out of compliance are 1.8 times higher than in an urban market. The density of dealers odds ratio indicates that the odds of finding nitrogen content out of compliance in an isolated dealer shop are 1.2 times higher than in a market with a high density of dealers. The market periodicity odds ratio indicates that the odds of finding nitrogen content out of compliance in an itinerant market is 0.6 times higher than in a permanent market (Table 5). Dealers operating in rural markets, isolated dealers, and dealers working in markets that do not have a permanent location have a tendency to be less knowledgeable about fertilizer management conditions and have customers that are less knowledgeable and less quality-demanding than dealers operating in urban markets, dealers located in markets of high dealer density, or dealers operating in permanent markets.

The shop keeper's knowledge about fertilizers odds ratio indicates that the nitrogen content out of compliance in a shop where the keeper has no knowledge or limited knowledge about fertilizers is 2 times higher than in a shop where the keeper has good knowledge about fertilizers (Table 5). A dealer with no knowledge or limited knowledge likely results in the purchase of poor-quality fertilizers and inappropriate management of the products traded.

The odds ratio for the percentage of granule fines indicates that the odds of nitrogen content out of compliance increases by 1.3 for every unit increase in the percentage granule fines (Table 5). The likelihood of finding nitrogen shortages increases with the granule degradation of the fertilizer, because the distribution of nitrogen inside the bags becomes non-uniform, and some sections of a bag may have a lower nitrogen concentration than the label specification.

The significant factors identified in Table 4 and Table 5 can be used by ECOWAS regulators to develop policy provisions with respect to fertilizer storage and management as well as market and dealer regulations. Results discussed above also are useful for designing sampling and inspection strategies that focus on factors associated with fertilizer quality risk, such as rural markets, itinerant markets or dealers, isolated dealers, non-impermeable bags, and bag stacks that are too high.

Table 5. Test of the Effect of Market, Dealer, Physical Properties, and Storage Conditions on Nitrogen Content Out of Compliance, Caking, and Moisture Content using Logistic Models

					Odds Ratio Estimates and Wald Confidence Intervals			
Response Variable	**Effect**	**DF**	**Wald Chi-Square**	**Pr > ChiSq**	**Label**	**Estimate**	**95% Confidence Limits**	
Nitrogen Content Out of Compliance	Market type	1	5.80	0.02	Rural vs Urban	1.8	1.112	2.808
	Dealer's density	2	8.48	0.01	Isolated dealer vs Medium or High density	1.2	0.708	1.899
	Market periodocity	1	3.15	0.08	Itinerant vs Permanent	0.6	0.35	1.054
	Status of dealer	5	1.60	0.90				
	Type of buyers	4	1.97	0.74				
	Store Keeper's knowledge about fertilizers	2	7.62	0.02	No or limited Knwledge vs Good Knowledge	2	1.02	3.974
	Dealer's fertilizer license	1	0.33	0.57				
	Percentage of fines	1	3.33	0.07	Fines Increase	1.3	0.98	1.754
	Percentage of dust	1	1.95	0.16				
	Caking	1	0.99	0.32				
	Fertilizer moisture content	2	1.77	0.41				

4. Conclusions and Recommendations

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

1. The main fertilizer quality problem found in Benin and Burkina Faso is the low quality of the bulk blends. The problem is generalized to all blends commercialized in these two countries and is especially serious in terms of frequency and severity of shortages with regard to P_2O_5, K_2O, secondary nutrients, and micronutrients.
2. Solving the bulk blend quality problems in West Africa is urgent, considering that bulk blends will be the dominant way to deliver the balanced nutrition needed for regional food security, improvement in smallholders' living standards, and economic development of the countries.
3. Segregation of the bulk blends may explain some of the nutrient shortages, but the main origin of the problem proved to be insufficient nutrient inputs at the time of blending. ECOWAS must identify the various factors involved in the production of extremely low-quality bulk blends and establish provisions to stop the production and distribution of poor-quality products inside countries and across international boundaries.
4. Some of the imported NPK compounds are good quality, such as the NPK 15-15-15 in Benin and Burkina Faso and the NPK 23-10-5+3S+2MgO+0.3Zn in Burkina Faso. Other imported compound NPKs are low quality, such as the NPK 14-23-14+5S+1B in Benin and the NPK 15-15-15+6S+1B in Burkina Faso. No evidence of adulteration was found in the manufacture of these two fertilizers, and the only reason for their severe nutrient shortages is deficient nutrient input during manufacture. Imported products of substandard quality reach the markets due to ineffective control by regulatory authorities at ports of entry. Facilitating the professionalization of inspectors and ensuring laboratories can conduct good and quick analysis of all nutrients and heavy metals are essential.

5. Some granulated fertilizers presented granule fines and dust at levels that can cause uneven distribution of nutrients inside the bags and on the crop fields. Production of fines and dust, in most cases, is a result of manual handling of individual bags. Mechanical equipment and use of pallets would reduce granule degradation.
6. Caking and moist fertilizers in Benin and Burkina Faso are the result of storage problems, such as bag stacks that are too high (> 20 layers), no use of pallets, and the use of non-impermeable bags. ECOWAS should establish specific regulations to ensure the appropriate storage and management of fertilizers.
7. Cadmium content in phosphate fertilizers from Benin, Burkina Faso, and Liberia is well under the safety limits established by European and U.S. regulations, but monitoring of heavy metals must continue on a regular basis.
8. The frequent and severe underweight bags in Benin and Burkina Faso are associated with fraud. ECOWAS should investigate where and how the underweighting occurs and establish severe penalties for the infractors.
9. Some characteristics of markets and dealers have the potential to affect the quality of fertilizers. Rural and itinerant markets as well as isolated dealers and dealers with limited knowledge about fertilizers can be detrimental to the quality of fertilizers. Further investigation of these factors should be conducted by ECOWAS.

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.

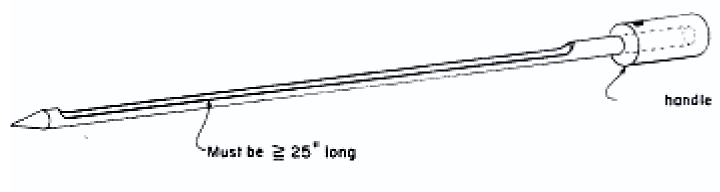


Figure A1.Sampler for Solid Bagged Fertilizers

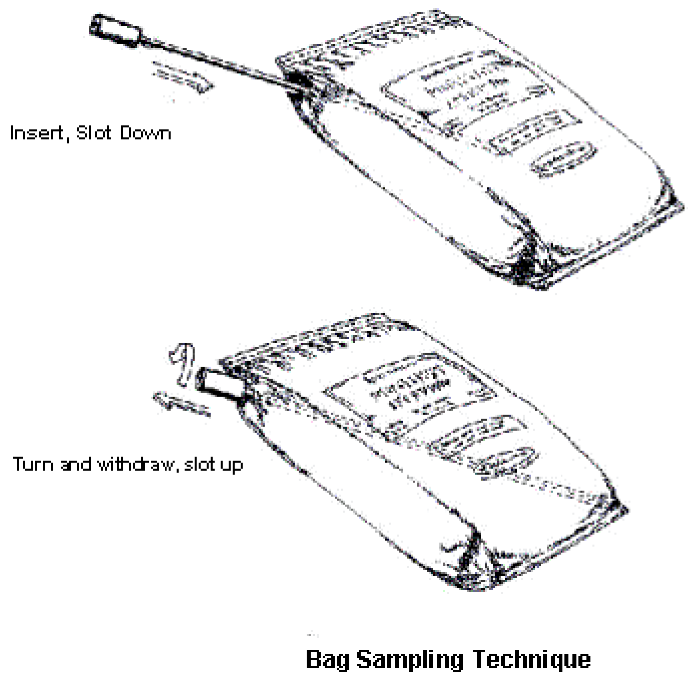


Figure A2. Sampling Technique for Solid Bagged Fertilizers

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 Agro-Dealer

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

* Do not ask, judge yourself.

Table A3. Characteristics of Storage

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

Table A4. Characteristics of Fertilizer Products

Characteristics of Fertilizer Products

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

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

<table>
<tr><th colspan="11">ASSESSMENT OF PHYSICAL PROPERTIES</th></tr>
<tr><td colspan="11">Enter text, quantities, or mark with 'X'</td></tr>
<tr><td>Team #</td><td></td><td colspan="2">Questionnaire #:</td><td colspan="3"></td><td colspan="2">Sequence #:</td><td colspan="2"></td></tr>
<tr><td>Fertilizer</td><td colspan="2"></td><td>Lot</td><td></td><td colspan="6"></td></tr>
<tr><td colspan="11">Granular Fertilizers</td></tr>
<tr><td>Color(s)</td><td colspan="4"></td><td colspan="6"></td></tr>
<tr><td colspan="5">SEGREGATION only for bulk blends
Percentages from vertical scale in Sieve Box</td><td colspan="3">MOISTURE CONTENT</td><td colspan="3">FILLER</td></tr>
<tr><td>5 - %</td><td>4 - %</td><td>3 - %</td><td>2 - %</td><td>1 - %</td><td>Adequate</td><td>Low</td><td>High</td><td colspan="2">Yes</td><td>No</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>% in label</td><td></td><td></td></tr>
<tr><td colspan="5">GRANULE INTEGRITY for granular compound fertilizers
Percentages from vertical scale in Sieve Box</td><td colspan="4">CAKING</td><td colspan="2">IMPURITIES/FOREIGN MATERIAL</td></tr>
<tr><td>5 - %</td><td>4 - %</td><td>3 - %</td><td>2 - %</td><td>1 - %</td><td>None</td><td>Low</td><td>Medium</td><td>High</td><td>Yes</td><td>No</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Type of filler:</td><td colspan="6">Type of impurity/foreign material:</td></tr>
<tr><td colspan="11">Comments:</td></tr>
<tr><td colspan="11"></td></tr>
</table>

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.

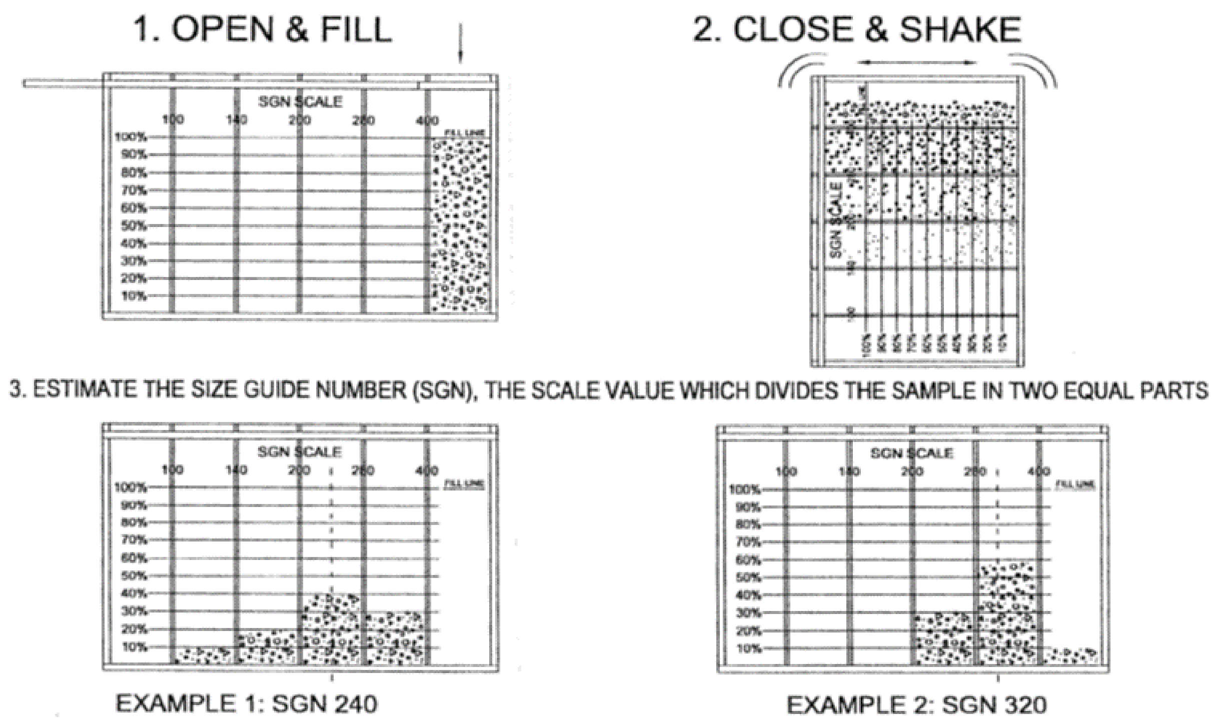


Figure B1. Operation of the Sylvite® Sieve Boxes

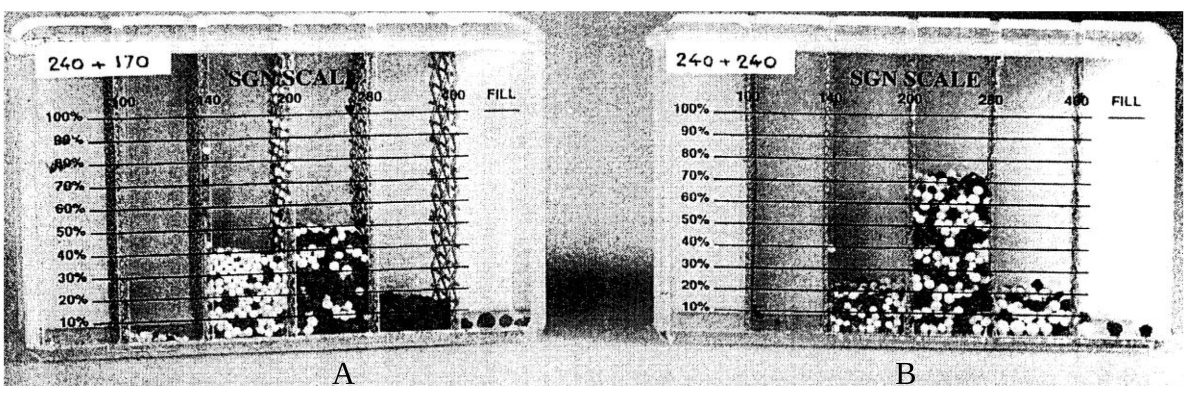


Figure B2. Identification of Granule Segregation in Bulk Blends using Sieve Boxes (Box A shows granule segregation; Box B shows no granule segregation)

- **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.

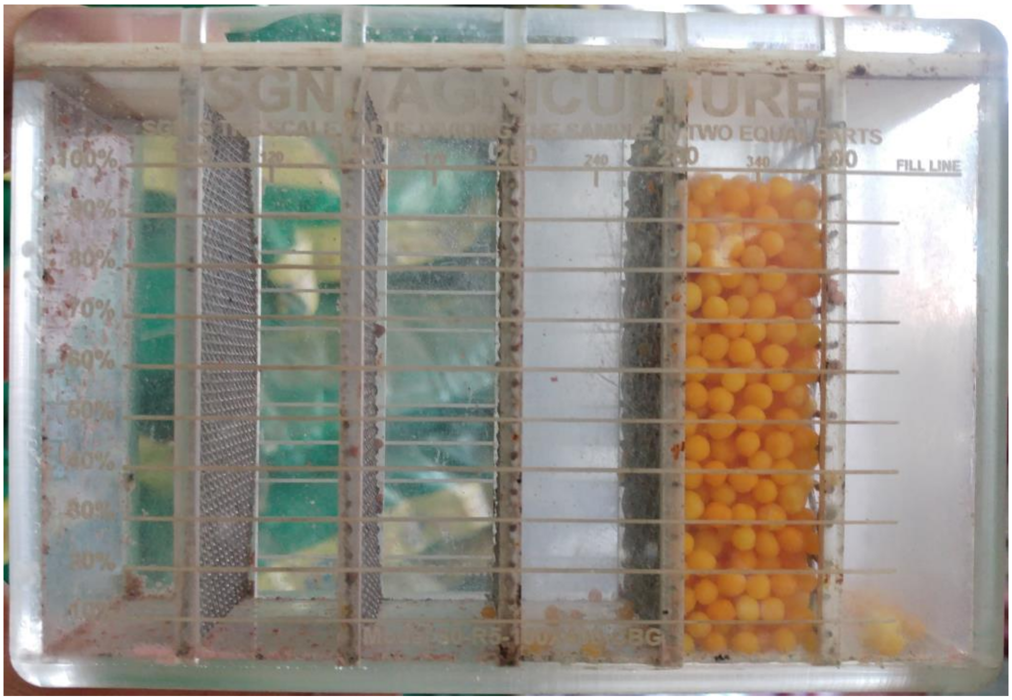


Figure B3. Typical Case of No Granule Degradation – Near 100% of the Granules Have an Average 4 mm Diameter

Appendix C. Frequency Distribution Functions of Nutrient Content in Main Fertilizers

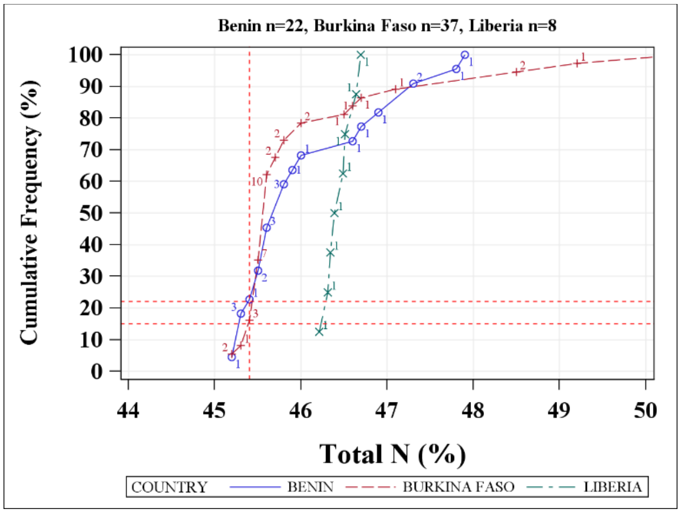


Figure C1. Cumulative Frequency Distribution Function of Urea in Benin, Burkina Faso, and Liberia

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

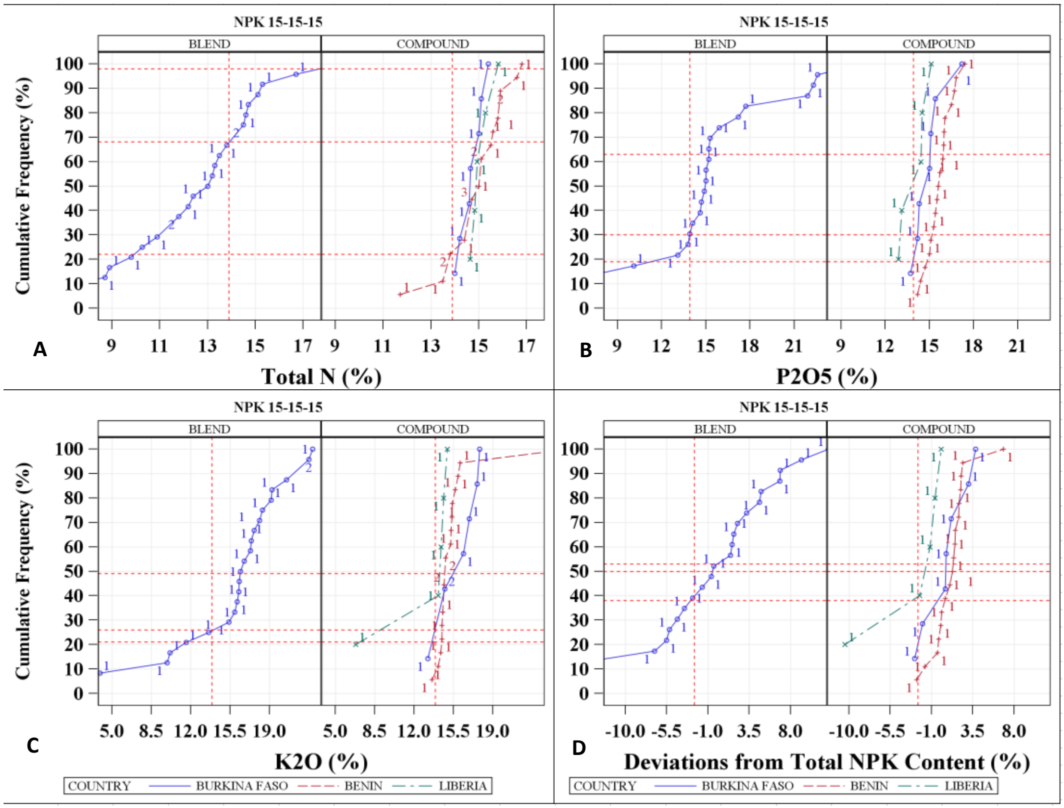


Figure C2. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 15-15-15 Compound and Bulk Blend in Benin, Burkina Faso, and Liberia

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

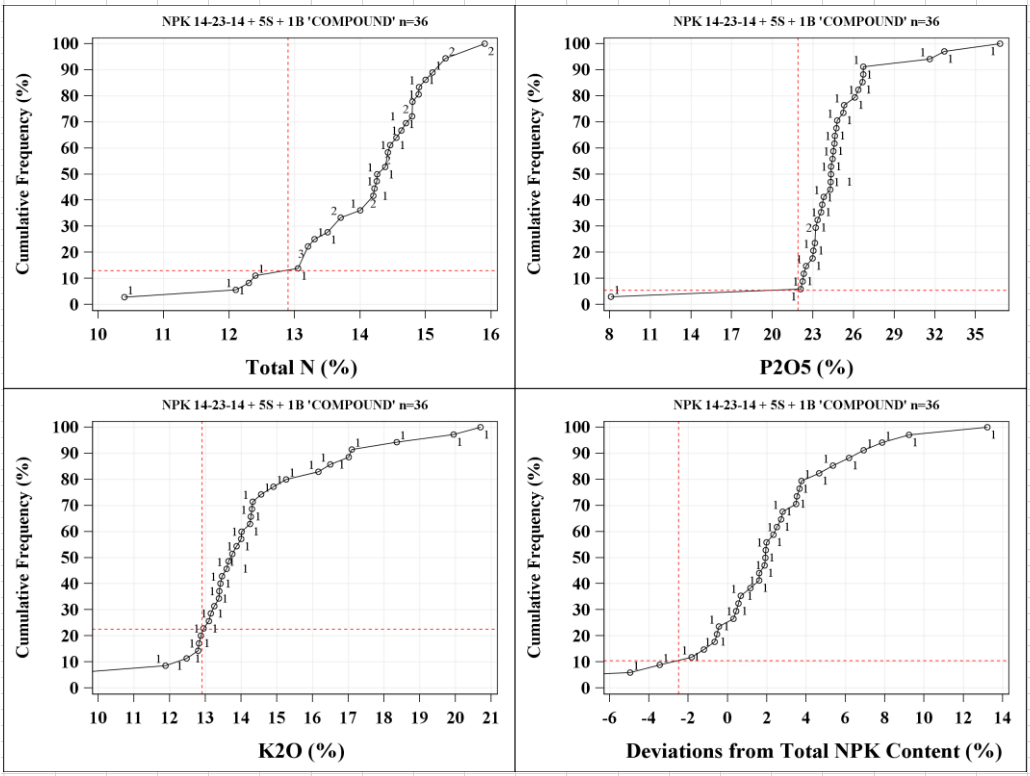


Figure C3. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 14-23-14+5S+1B Compound in Benin

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

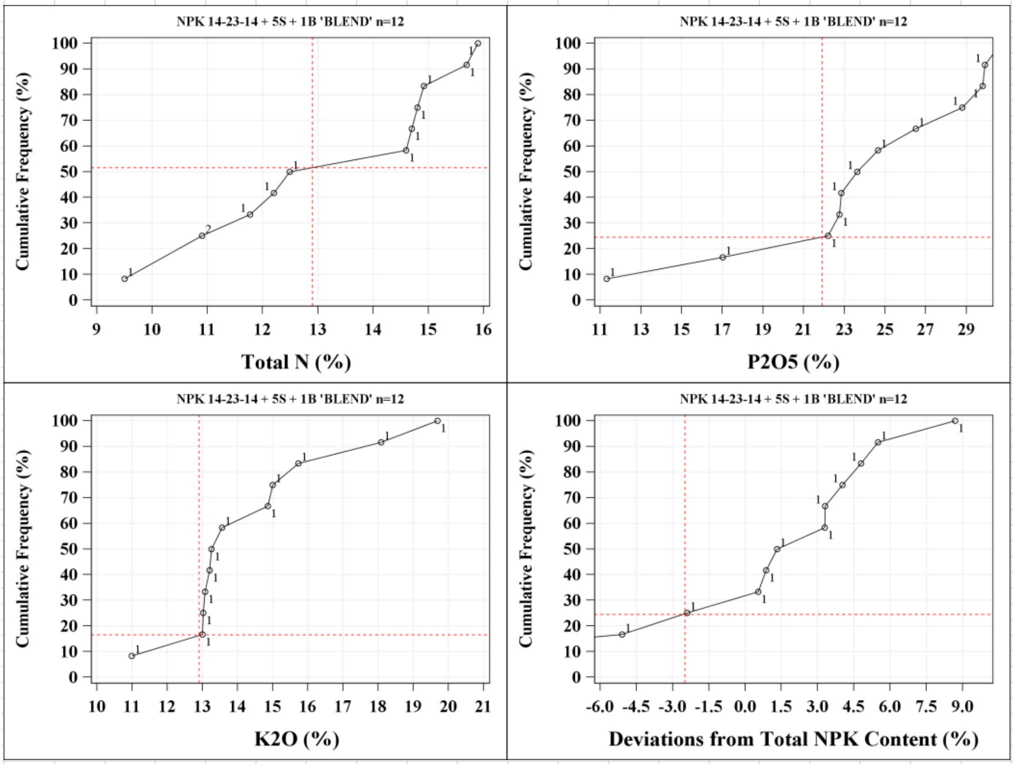


Figure C4. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 14-23-14+5S+1B Bulk Blend in Benin

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

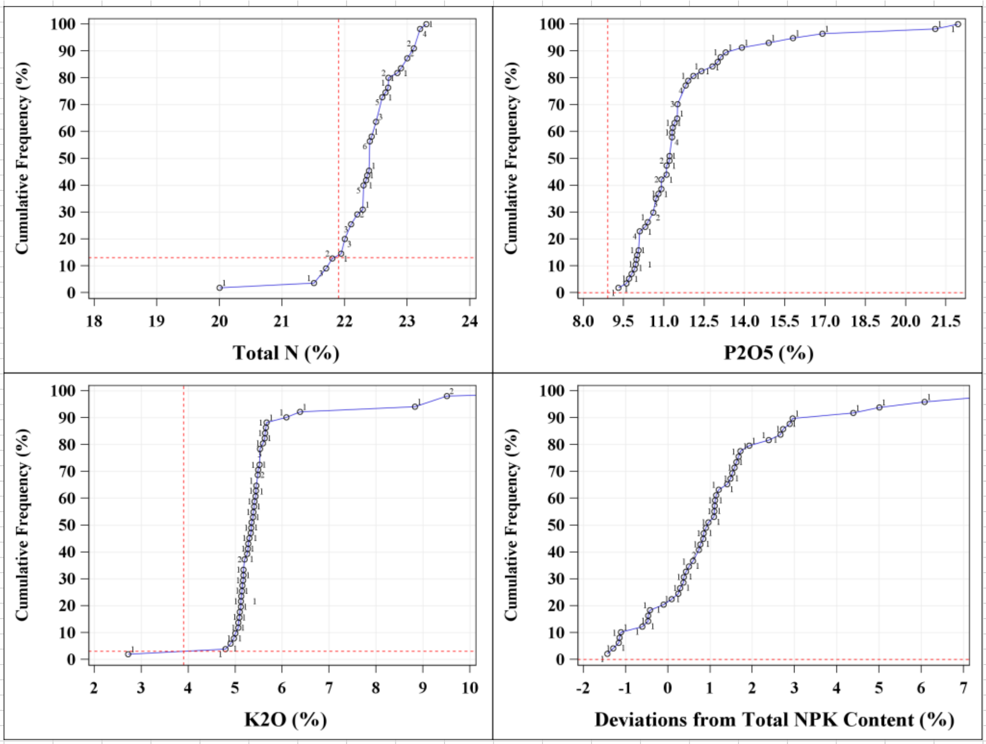


Figure C5. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 23-10-5+3S+2MgO+0.3Zn Compound in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

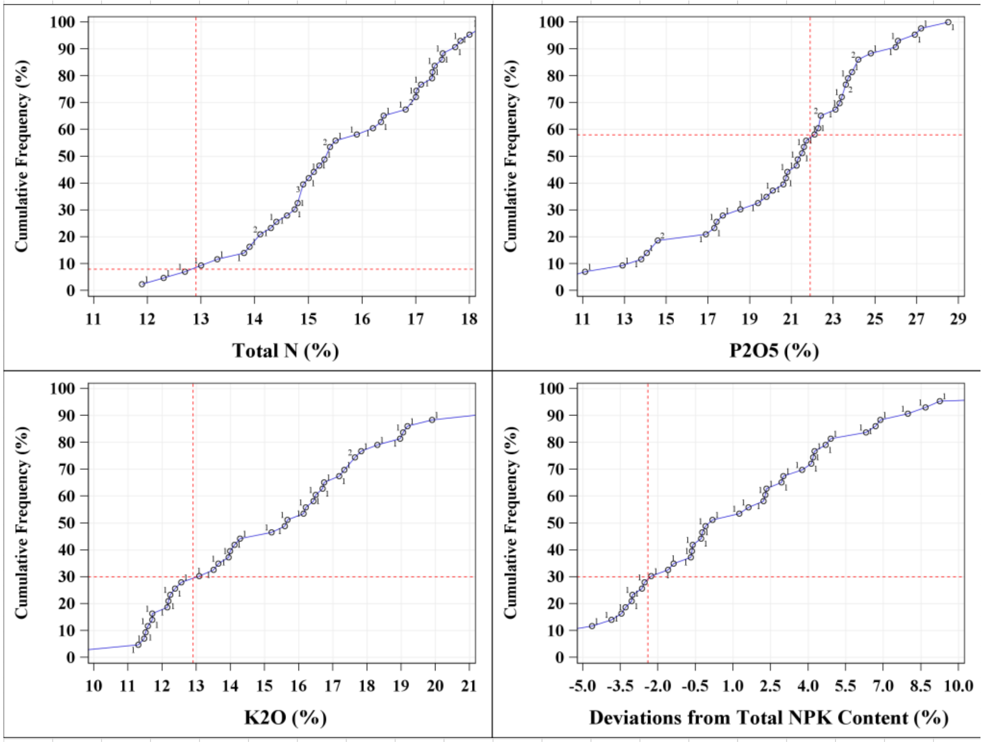


Figure C6. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 14-23-14+6S Bulk Blend in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

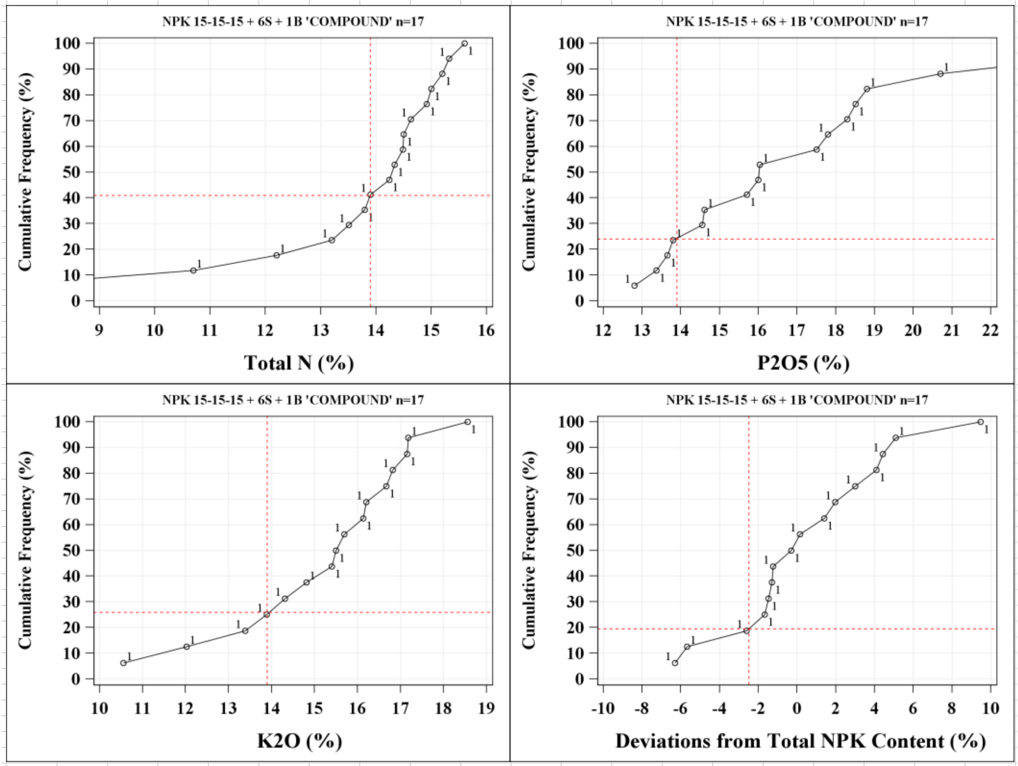


Figure C7.Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 15-15-15+6S+1B Compound in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

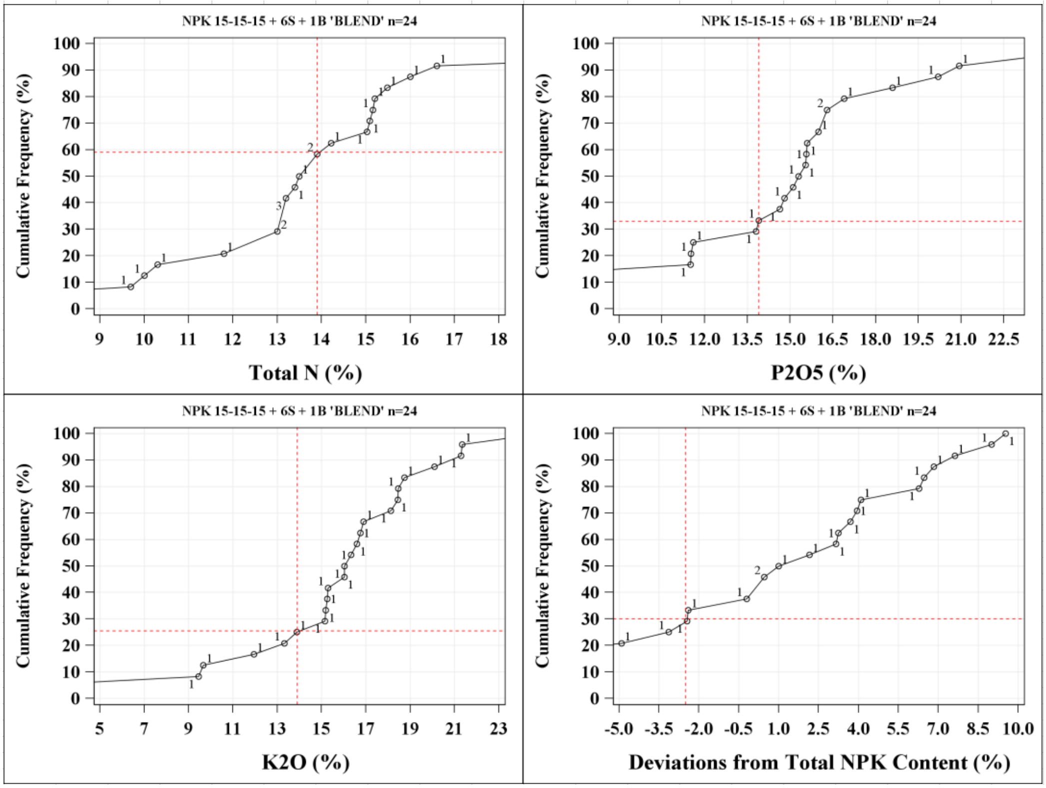


Figure C8. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 15-15-15+6S+1B Bulk Blend in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

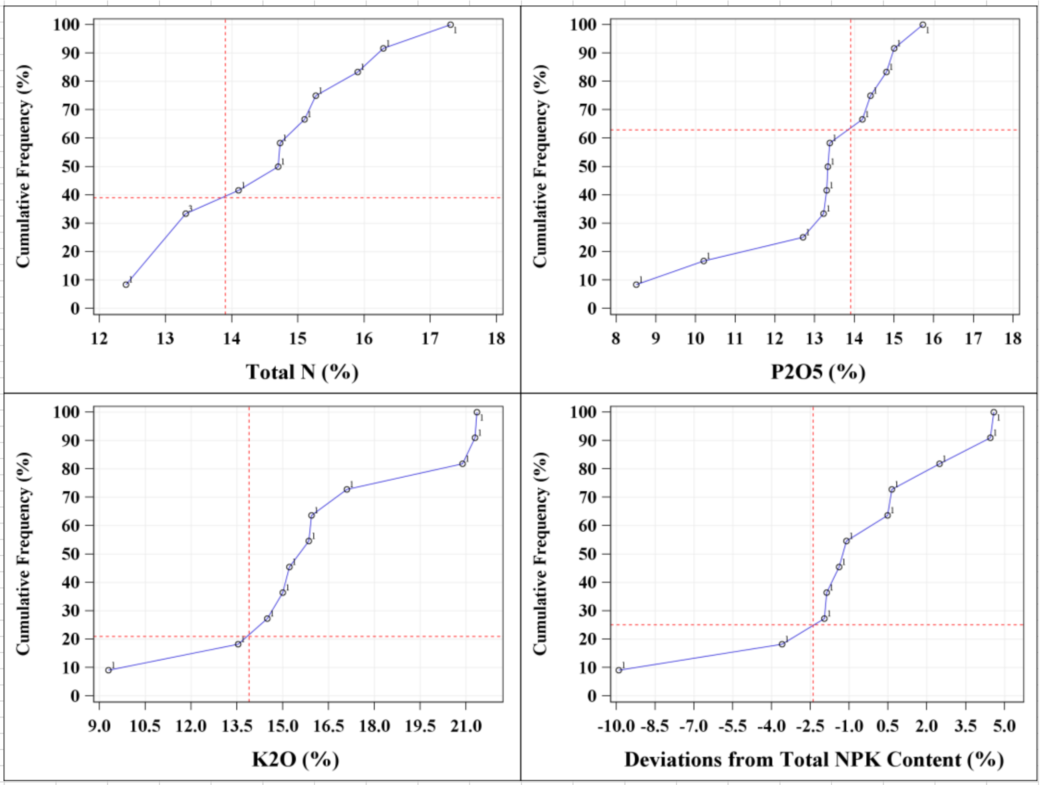


Figure C9. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 15-15-15+13S+2CaO Bulk Blend in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

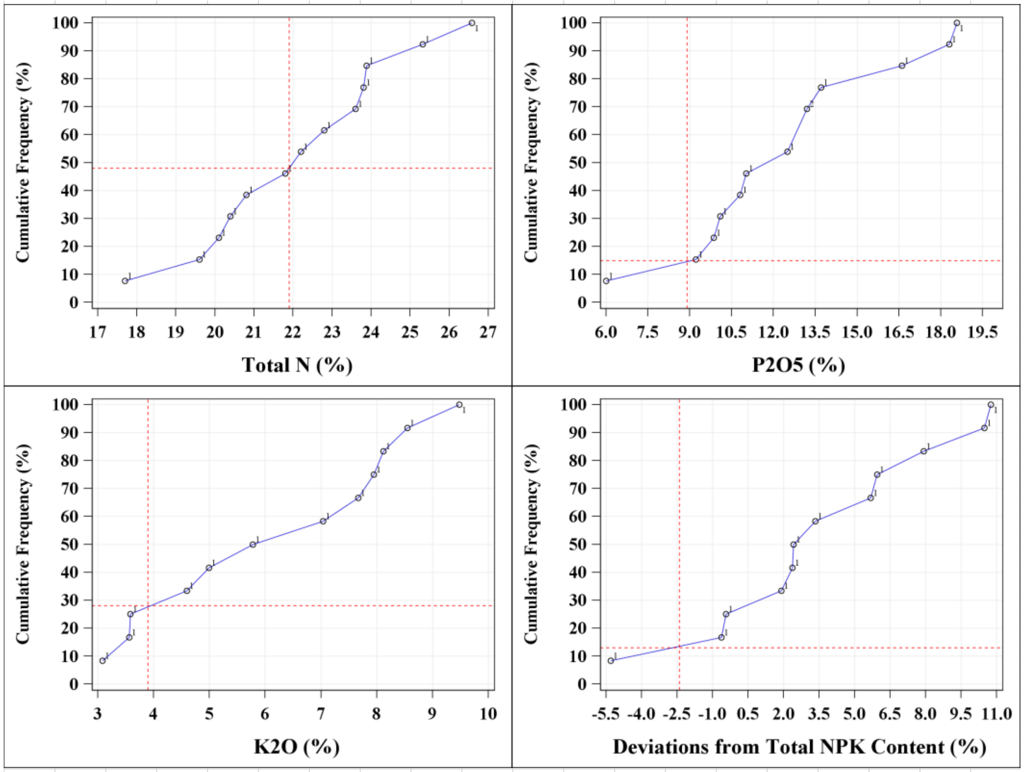


Figure C10. Cumulative Frequency Distribution Function for the Macronutrients and Deviations From total NPK Content of the 23-10-5 Bulk Blend in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.

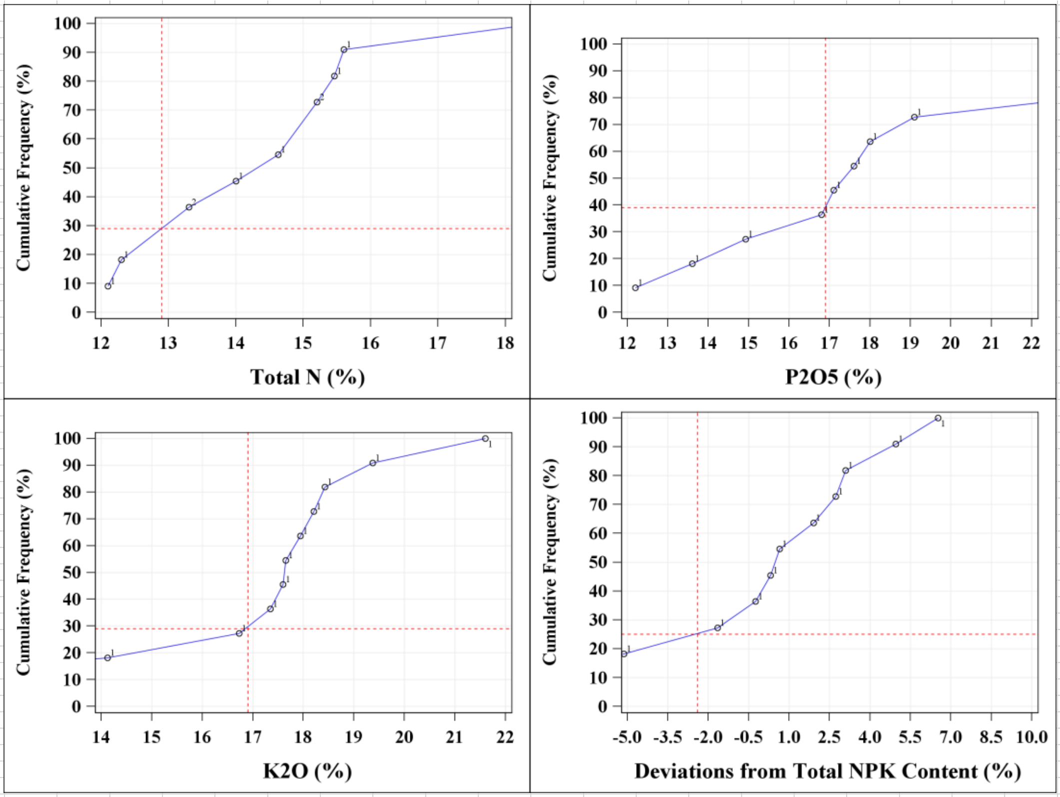


Figure C11. Cumulative Frequency Distribution Function for the Macronutrients and Deviations from Total NPK Content of the 14-18-18+6S+1B Bulk Blend in Burkina Faso

Vertical dotted line indicates the out of compliance boundary (OOCB), and horizontal dotted lines indicate the cumulative frequency associated with the OOCB in each country.