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Abstract

Fertilizer use remains below recommended rates in most of Sub-Saharan Africa, contributing to poor crop yields and poverty. Farmers voice suspicion that available fertilizer is often adulterated, but these concerns are not backed by reliable evidence. In fact, an insight from industry but absent from academic literature is that profitable fertilizer adulteration is difficult. We surveyed all fertilizer sellers in Morogoro Region, Tanzania and tested 633 samples of their fertilizer. We also conducted a willingness-to-pay assessment with farmers. We find that fertilizers meet nutrient standards but that belief of rampant product adulteration persists among farmers. We find evidence of a quality inference problem in the market: 25% of fertilizer has deteriorated in observable ways and farmers rely on these observable attributes to (incorrectly) assess unobservable nutrient quality. We show that this misperception likely reduces technology adoption beyond the effect of nutrient quality being unobservable.

JEL Codes: Q12, D82, O13

1 Introduction

New agricultural technologies in developing countries can increase yields, profits, and improve living standards. Nonetheless, when such technologies are introduced, adoption may not occur quickly or readily. Farmers may follow a pattern of gradual adoption, or abandon these improvements, or not try them at all (Besley and Case 1993, Feder et al. 1985, Sunding and Zilberman 2001). In Sub-Saharan Africa, fertilizer adoption remains well below profit maximizing levels (Sheahan and Barrett 2017; Sanchez 2002). Tanzanian and Kenyan farmers, for example, apply 10 only kilograms of fertilizer per hectare, in contrast with Brazilian and Indian farmers, who apply 175 and 165 kilograms per hectare, respectively (World Bank, 2014).[1] While recent literature points to heterogeneity in the yield response function to fertilizer; i.e., variation due to soil, weather and market conditions (see, among others Suri 2010, Hurley et al. 2018), a central question remains: What determines adoption and effective use of these fertilizers?

An extensive literature has emphasized the role of prices, farmer characteristics (such as income, risk-aversion, time preferences, education, etc.), and attributes of the technology itself as important predictors of adoption (see Feder et al. 1985 and Foster and Rosenzweig 2010 for an overview; and Duflo et al. 2011 for an analysis of time-inconsistent preferences and fertilizer adoption in Kenya). More recently, researchers have focused on the importance of social networks and information. Conley and Udry (2010), for instance, observe that farmers in Ghana learn about the optimal application of fertilizer on pineapple, a new crop in the region, from their network contacts (see also Foster and Rosenzweig 1995 and Munshi 2014 on the adoption of improved crop varieties during India's green revolution). In addition, incomplete and imperfect markets may increase both the direct costs and risks of adoption (Chirwa 2005; Minten et al. 2013; Croppenstedt et al. 2003; Karlan et al. 2014; Dercon and Christiaensen 2011).

In this paper, we explore another possibility for apparent under-use of fertilizer: a belief among farmers that the product available to them at local markets is of poor quality. The quality of fertilizer, its nutrient content, is not observable. Combined with a weak regulatory framework and limited enforcement of product standards, this problem of unobservable quality does provide opportunity for Akerlof's (1970) "dishonest sellers", who "wish to pawn bad wares as good wares and thereby tend to drive the good wares out of the market" (p. 495); and awareness of this possibility can decrease the demand among farmers.

We selected Tanzania as the focus for our study. Anecdotal evidence indicates that farmers in Tanzania believe that the fertilizer available in local shops is substandard, and regional newspapers have published dramatic stories of adulteration. Farmers report suspicions about fertilizer sold past its expiration date,

[1]High use rates in India and China are associated with high government fertilizer subsidies (Li et al. 2013, Fan et al. 2008)

along with concerns about purchasing urea fertilizer that has been mixed with table salt, or Di Ammonium Phosphate (DAP) diluted with powdered concrete. Such concerns are reinforced by stories in the popular press. For example, The Citizen, a major Tanzanian English Language newspaper, reported that the Tanzania Fertilizer Regulatory Authority (TFRA) had discovered "fake" fertilizer in markets across the country and that 40% of fertilizer for sale in the country was counterfeit (Kasumuni, 2016). In 2014 the same newspaper reported a seizure and destruction of counterfeit fertilizer (Lugongo 2014).

Thus farmers believe the quality of fertilizer on the market is poor. Poor quality fertilizer has direct effects on yields. Mather et al. (2016) calculate a linear maize-nitrogen response rate for Tanzania of 7.6 kilograms of maize per kilogram of nitrogen applied; 10% nitrogen missing from the fertilizer means a 10% loss in production.

In this paper, we use quantitative and qualitative data on a sample of farmers in the Morogoro Region in Tanzania, and a census of fertilizer sellers within the same region to ascertain the facts and to measure the concerns and market response of small-scale farmers.

We interviewed 165 farmers, collecting quantitative and qualitative information on fertilizer use and their perceptions regarding the quality of fertilizer. To assess demand for fertilizers, we set up a "store" at a central village location, with three samples of urea fertilizer which we purchased in the local market (we will return to these three samples later, for now it suffices to say that they differed in terms of physical attributes) and tested to ensure that they all met the required industry standards. Urea is the most commonly purchased and used fertilizer in Tanzania; in our sample, 92% of farmers had purchased and used urea in the twelve months prior to the survey, and 98% of retailers in the region have it for sale. For each urea sample, we ask the farmer to state their willingness-to-pay, first without providing any additional information about the nutrient content, and then when informed that the fertilizer had certified by a reputable laboratory as meeting industry standards.[2] Because this type of hypothetical willingness-to-pay exercise is a standard method for establishing demand (for a recent overview, see Penn and Hu 2018), it is well suited to establish the demand in the absence of asymmetric information in this context.

Consistent with expectations of low quality, we find that farmers are willing to pay considerably less for untested fertilizers in the market than they are for lab-certified fertilizers: The willingness-to-pay for one kilo of urea fertilizer in the absence of information about its nutrient content proved to be 32% lower than the post-information willingness-to-pay (1489 TZS versus 2201 TZS; or 0.65 USD versus 0.96 USD). The prevailing market price for one kilo of urea at the time was 1500 TZS: post-information

[2] In this case, the samples all contained 46% nitrogen (meeting industry quality standards).

willingness-to-pay is 48% higher than that price.

Even so, are these farmers correct in their assessment of (average) fertilizer quality?

While fertilizer quality is unobservable, farmers assume that sellers know more about the quality, an assumption we confirm in interviews with 225 sellers: sellers report pre-testing fertilizer on their own fields and test-plots; they know the supply chain and suppliers; and they accumulate feedback from farmers who praise or critique what they purchase. Another reason that farmers suspect sellers to have more information: they might be doing the adulteration, as suggested by Bold et al. (2017).

To establish fertilizer quality in the market, we visited all sellers in the Morogoro Region. We interviewed these sellers, and collected qualitative and quantitative information on the individual, their business and the local market. We used mystery-shoppers to purchase 633 fertilizer samples from 225 fertilizer sellers and recorded prices and other features of the transaction, including price, and seller and market characteristics. We tested the fertilizer in laboratories in Kenya and the United States (a randomly selected subset were double tested in both laboratories) and confirmed that the quality of fertilizers in the market is good, with only two out of 300 urea samples out of compliance with industry standards and a mean percent nitrogen deviation of 0.28%. We find mean deviations for other common fertilizer types in our sample, such as calcium ammonium nitrate (CAN) and Di Ammonium Phosphate (DAP) are also modest: 5.9% and 3.0% respectively. The finding of adequate nutrient content in marketed fertilizer, especially for urea, is consistent with recent large-scale assessments undertaken by the International Fertilizer Development Corporation (IFDC) across Sub-Saharan Africa (Sanabria et al. 2013).[3] Thus farmers' beliefs regarding the quality of fertilizer in the market are incorrect, in this case.

Further analysis of the willingess-to-pay data sheds additional light on these incorrect farmers' beliefs about quality: we find that willingness-to-pay depends on physical characteristics of the samples. The willingness-to-pay exercise included three samples purchased in the market: one sample was in pristine physical condition; the second sample contained large caked aggregates; and the third included visually-obvious foreign material and impurities. The impact among farmers of these observed physical attributes is clear. Pre-information, the willingness-to-pay for the pristine sample is, on average, 1490 Tanzanian Shillings (TZS), while the willingness-pay for sample B and C are significantly lower: 752 and 702 TZS, respectively. When presented with information on the true nutrient content, farmers revise their willingness-to-pay upwards for all samples, but mostly for samples B and C. This shift is suggestive of a learning process in which farmers use the physical attributes as signals of the underlying quality.

[3] In contrast, Bold et al. (2017) finds considerable nutrient deviations in urea in Uganda, with tested urea lacking, on average, 30% of its advertised nitrogen content. Ashour et al. (2017) find no evidence of quality problems in fertilizer. We discuss the breadth of results on fertilizer nutrient quality and the fact that Bold et al. (2017) uniquely find large average nitrogen deviations in Section 4.

When we split the sample of respondents according to their self-reported concerns about fertilizer quality, we find that quality-sensitive farmers are significantly more attentive to the physical attributes of the mineral fertilizer and respond significantly more strongly to the provision of information compared with the farmers who do not report that fertilizer quality is a primary concern.

Our results are evidence of a quality inference problem in the market. While physical degradation is common in the market (25% of the fertilizer samples our mystery shoppers purchased exhibited some degradation in physical attributes, whether it was caking, powdering, foreign material like bugs or small bits of dirt, or discoloration), there is no (statistically significant) correlation between a fertilizer's physical characteristics and its unobservable nutrient content.

While incorrect farmer beliefs may persist because of the difficulty of assessing quality in a stochastic production environment (Bold et al., 2017) and possibly because farmers might underinvest in complementary inputs such as labor if they believe the fertilizer is poor, why is there no response among sellers to these misconceptions? It would seem that sellers could compete with regard to the physical appearance of fertilizer, achieving market advantage for consistently good-looking merchandise. Our qualitative work, however, which included visits to the Dar es Salaam port to assess the quality of fertilizer as it arrives in the country and bagging facilities where it is packaged for sale, suggests that problems related to physical attributes likely begin upstream in the supply chain, in or near the port and thereby affecting retailers through the national market. These issues are generally attributable to poor manufacturing, transport and storage conditions. Our analysis shows that problems related to physical attributes affect 57% of sellers in the Morogoro Region. We do find evidence that some sellers are willing to offer farmers a discount for fertilizer with highly compromised physical condition, consistent with results of the farmer willingness-to-pay assessment.

Nonetheless, if sellers cannot change the perceptions of farmer clients easily, why isn't adulteration at the retail level more widespread? One key insight, well established in industry yet absent from the academic literature is that successful, profitable adulteration of fertilizer is actually difficult (Joaquin Sanabria, personal communication, March 27, 2018). Substantial quantities of low-value fillers must be included for a palpable effect on profits; and only farmers with minimal knowledge of fertilizers are likely to be deceived. Urea presents particular problems: the small prills are relatively uniform in size and color and very few plausible fillers are at a cost lower than urea itself. For example, kaolin clay will coat the prills and change their opacity but costs significantly more than urea by weight and sodium hydroxicide (lye) micro beads, while visually plausible before combining - is both reactive with urea and also more expensive than urea. Salt is both inexpensive and non-reactive with urea but with granuales that are considerably smaller than urea prills and easily visually detectably to all but the extremely inexperienced buyer. Given that small farmers currently represent only a small share of the Sub-Saharan Africa fertilizer market in terms of purchase quantities, such deception is unlikely to pay off at the retail level. Moreover, large-scale fraud at the product bagging stage runs higher risks of detection. Nonetheless concern about product quality and potential adulteration persists in these markets.[4]

To conclude, our results suggest that asymmetric information afflicts the Tanzanian market for fertilizer but not in the way that either farmers or researchers commonly expect, and that farmers' beliefs about quality impact willingness-to-pay. In addition, we find that farmers make incorrect inferences about the quality of the fertilizer based on physical characteristics. When presented with information about the quality, farmers frequently revise their beliefs and willingness-to-pay.

Crop yields have remained largely stagnant over the past 50 years in most of Sub-Saharan Africa. While cereal yields in South America and Asia have at least doubled since the 1960s and now average 4–4.5 metric tons per hectare, cereal yields in Sub-Saharan Africa lag far behind, averaging 1.2–1.7 metric tons per hectare (World Bank 2014; Ray et al. 2012). In the long-term, uncertainty regarding fertilizer quality could have major consequences for the persistence and growth of mineral fertilizer demand, hampering efforts to increase adoption of fertilizer as a means of raising regional agricultural productivity and improving household and national food security (McArthur and McCord, 2017). Increasing small farmer use of fertilizer and hybrid seeds is key but use of these inputs remains relatively low. Our results suggest that farmer quality perceptions are an important missing piece of the puzzle.

In the next section, we provide additional background and context for the study. The third section provides an overview of the data collected. We present the empirical analysis and results in Section 4. In Section 5 we discuss these results. We conclude with reflections for policy and further research.

2 Background

Agriculture is a critical sector for employment and food security in Tanzania but its growth has lagged the rest of the economy in recent years. Low-input and rain-fed subsistence farming dominates the sector and the use of fertilizer is extremely low. Primary fertilizers used in the country include urea, and the blends Di Ammonium Phosphate (DAP), calcium ammonium nitrate (CAN), and nitrogen-Phosphorous-Potassium fertilizer (NPK). In 2010, urea and DAP accounted for half of the fertilizer used in Tanzania with NPK

[4] This fact contrasts with the findings of Kroll and Rustagi (2017) who tested the quality of buffalo milk in New Delhi (for the presence of water) and investigated motives for dishonesty. They find, on average, a 17% water content in the tested milk and note that dishonest milkmen consequently earn, on average, 210 USD more per year, compared to honest ones.

consisting of about 20% and CAN 9% (Sanabria 2013). While the official government recommendation for one acre of maize production is 50 kg of urea and 50 kg of DAP, farmers on average apply fewer than nine kilograms of fertilizer per acre (Tanzania Fertilizer Assessment 2012).

Nearly all fertilizer in Tanzania is imported to the port in Dar es Salaam. Fertilizer quality is only minimally monitored. The Fertilizer Act of 2009 established the Tanzania Fertilizer Regulatory Authority (TRFA) to enforce policies related to fertilizer manufacturing, importation, and use of fertilizer but a 2017 report by the African Fertilizer and Agribusiness Partnership (AFAP 2017) noted:

> "TFRA remains under-funded with few professional staff...it depends on 100 "inspectors" (who) do not provide reliable inspection (and testing) services to TFRA as they have multiple responsibilities and lack the resources (transport, testing equipment) and technical skill (proper taking of samples) to do their job properly...What should be an important regulatory body is, therefore, quite weak due to a lack of institutional and human resource capacity." (p. 11)

Upon arrival at the port, the fertilizer is removed from the shipping containers (where it is transported loose and in bulk) and bagged in 25 and 50 kg manufacturer bags. Tanzania's fertilizer trade association included ten firms in 2011 but only three of these consistently imported fertilizer into the country; the remaining seven companies obtained their product from these importers (Benson et al. 2012). From Dar es Salaam, fertilizer begins its trip inland, passing through the hands of multiple wholesalers and sellers before reaching rural farmers. Large companies either sell to intermediate wholesalers or transport the fertilizer inland themselves to storage depots used to supply the large number of retailers, i.e. agro-dealers, selling agricultural inputs (referred to henceforth as sellers). These small sellers operate independently of the large fertilizer companies; that is, they are not subsidiaries of specific companies though they sometimes receive stock on credit or negotiate an exclusive relationship with a brand.

We conduct this work in Morogoro, an agricultural region with a reasonably developed market system. The region's fertilizer sales market is geographically disperse, reaching far out into rural areas along major roads, but locally concentrated, with small clusters of sellers located in a large number of market centers. The seller census we conducted in Morogoro Region identified 102 market centers with shops selling fertilizer. Of these, 54 had only one seller, 23 had two sellers, 11 had three, and 14 had four or more. The mean within-market center Herfindahl index[5] is 0.75 (0.25 is considered a high market concentration threshold); for the subsample of market centers with more than one seller, the mean Herfindahl index is

[5] A measure of market concentration calculated by squaring the market share of each firm competing in a market and then summing the squares.

slightly lower, 0.63. Nearly all sellers are open year round rather than running seasonal operations. In urban areas, sellers tend to cluster along major roads or thoroughfares. In rural areas, sellers tend to be located along the road in clusters with other village shops. It is uncommon for sellers to be located in isolated areas far from major roads or other shops and businesses.

3 Data collected

Between November 2015 and May 2016, we collected data from 225 sellers in the Morogoro region of Tanzania and a sample of 165 farmers in the same region. We collected qualitative and quantitative data from these sellers and farmers using surveys, including information on prices, beliefs, and willingness-to-pay; laboratory tests of sampled fertilizer provided information on fertilizer quality. We first introduce the seller and farmer samples and then discuss these data collections in turn.

3.1 Seller sample

We conducted a census to identify all sellers with operations in the Morogoro Region and then proceeded to survey these 225 sellers.[6] We interviewed the sellers and collected qualitaive and quantitative information about the scale, seasonality, and history of the operation, participation in government programs, wholesalers where the shop sourced fertilizer, and types of fertilizer stocked and in which months.

Table 1 presents descriptive statistics for the sellers (Panel A). About one quarter of sellers reported sourcing their fertilizer direct from a wholesaler in Dar es Salaam. Sellers operated businesses in clusters of other sellers, with an average of 2.22 sellers per market location in the sample. Finally, sellers tend to source fertilizer from between one and two suppliers.

In addition to the survey visit, enumerators operating as mystery shoppers visited each surveyed shop twice to purchase fertilizer – once in November or December 2015 before the start of the primary growing season and once during planting and cultivation in March and April 2016. The enumerator followed a pre-defined script: he greeted the shopkeeper and asked the shopkeeper to buy 1 kg of urea, DAP, and CAN. If the shop had all three types available, the enumerator purchased all three. If the shop had only two types or one type available, the enumerator purchased the type(s) that were available. Enumerators dressed in the way that a farmer would dress if he was making a visit to town; enumerators were all

[6]To our knowledge no census had before been conducted of the number of fertilizer sellers operating in Morogoro or Tanzania. The 2009 Fertilizers Act requires that all fertilizer sellers and sales locations must be registered with the government but few of the sellers we found in our regional census had the required registrations. This is an important methodological point: any researcher exclusively using the government's licensing lists as a sampling frame would have missed the majority of the sellers operating in the region.

male and wore collared shirts, trousers, and sandals. In the case that enumerators were asked additional questions by the seller, they were prepared to respond with locally appropriate responses. For example, on occasion, our enumerators were asked by sellers on which crop they intended to apply the fertilizer(s). Enumerators were aware of the major crops grown in the location, and, as such, were able to engage the sellers.

Table 1: Fertilizer seller and farmer descriptive statistics.

Panel A: Fertilizer sellers (n=225)	Mean (SD)	Min	Max
Sell fertilizer all months of the year (share)	0.80		
Sell urea fertilizer (share)	0.98		
Have an exclusive relationship with a fertilizer manufacturer (share)	0.19		
Source fertilizer directly from Dar es Salaam (share)	0.27		
Licensed by the government to sell fertilizer (share)	0.41		
Report selling the largest amount of fertilizer to small farmers (share)	0.91		
Distance from Dar es Salaam (km)	269.93 (86.84)	127.49	441.24
Number of fertilizer sellers per market location	2.22 (2.52)	1	21
Number of suppliers where seller sources fertilizer	1.66 (0.93)	1	4
Years in business	4.18 (4.34)	0.1	30
Panel B: Farmers (n=165)			
Male (share)	0.61		
Ever purchased mineral fertilizer (share)	0.98		
Purchased urea fertilizer in the past 12 months (share)	0.90		
Grew maize in 2016 season (share)	0.76		
Grew rice in 2016 season (share)	0.84		
Grew beans in 2016 season (share)	0.56		
Grew vegetables in 2016 season (share)	0.06		
Purchasing high quality fertilizer among top two concerns at season start (share)	0.24		
Believe $\geq$ 50% of the fertilizer in the market adulterated (share)	0.18		
Believe >0 but $<50\%$ of fertilizer in the market adulterated (share)	0.18		
Age (years)	45.93 (11.34)	22	79
Land owned (acres)	5.84 (10.50)	0	100

Source: authors' own calculations from seller and farmer surveys.

Enumerator mystery shoppers purchased 300 samples of urea, 137 DAP, and 196 CAN, a total of 633 samples of fertilizer. When purchasing the samples, we also recorded information on features of the transaction such as whether the seller was the owner of the establishment, the price, the brand, whether the fertilizer was scooped from an open bag (and if so whether it was agitated before scooped) or repackaged previously by the seller, and whether the transaction (the fertilizer scooping) occurred in front of the enumerator.

3.2 Farmer sample

We worked with the International Institute of Tropical Agriculture's (IITA) Africa RISING initiative to select a sample of 12 villages in Mvomero District, Morogoro Region. These villages were purposively selected as villages where at least some farmers were regularly using fertilizers. All farmers with prior fertilizer experience were invited to participate in our survey. In total, we surveyed 165 farmers and collected qualitative and quantitative data on farmer demographics, crops grown, previous experience purchasing and using fertilizer, and general perceptions of fertilizer quality in markets.

Table 1 (Panel B) introduces the farmers' sample. Farmers in the sample are more likely to be male, are 46 years of age on average and have mean landholdings of 5.84 acres. On average, farmers in the sample had at least completed primary school; only one percent of the farmers reported no schooling. Farmers grow a range of crops and nearly all had purchased mineral fertilizer previously and 90% had purchased urea in the 12 months previous to the survey. 24% of the farmers interviewed listed purchasing high quality fertilizer among their top two concerns as they prepared for the start of a typical agricultural season (other options included the start and duration of the rains, purchasing high quality seeds, and access to financing for inputs). Moreover, 36% of the farmers reported concerns about adulterated fertilizer in markets, with 18% of farmers believing that more than 50% was likely adulterated and 18% believing that between zero and 50% was adulterated.

Farmers also provided us with a small (0.25 kg) sample to the research team of fertilizer from their home and answered questions about the source and use of that fertilizer.[7] The objective of collecting these samples from the farmers was to compare the quality of the fertilizer we purchased from sellers with the quality of fertilizer that farmers bought themselves.

Finally, we completed a willingness-to-pay exercise. We turn to an explanation of this exercise next.

3.3 Eliciting willingness-to-pay

We elicited farmers' willingness-to-pay (WTP) using a series of hypothetical questions based on the contingent valuation method commonly used to value environmental public goods (for an introduction

[7]On the day of the survey, the research team arrived earlier than the agreed-upon time. This ensured that the team would be able to observe the behavior of the extension officer, lead farmer, or other participants and to verify that none of the fertilizer samples had been divided or shared among participants. In each village, the survey was conducted at the local village government office. As participants arrived, the research field supervisor began a screening process of each of the participants and their fertilizer. The field supervisor asked each of the participants a set of questions about their fertilizer sample/s, including: (1) What type of fertilizer did you bring? (2) To which crop/s did you apply this fertilizer? (3) Did you apply this fertilizer during the planting stage or the cultivation stage? (4) Where did you buy this fertilizer? (5) What was the original amount of fertilizer purchased? (6) How much did you pay for it? Participants who were able to answer these questions easily and confidently were invited to participate in the survey. Five participants were excluded from the survey as a result of the screening process.

see Mitchell and Carson 1989; and Bateman and Willis 2001). The method is hypothetical – i.e., the farmers did not actually purchase any fertilizer from the enumerators. It is, however, a common method to establish demand for yet unavailable goods and services in developing country contexts (see, among others, Matuschke et al. (2007), Vargas et al. (2013), and Penn and Hu (2018) for an overview on the method). In our case, we use the method to create a counterfactual scenario for the fertilizer market: What would the demand be if the farmers had no concerns about fertilizer quality? Using a willingness-to-pay exercise to gain insight into this counterfactual scenario is not uncommon in this literature. Sanogo and Masters (2002), for instance, present mothers in Mali with a choice experiment of infant food.[8]

We used an open-ended elicitation of the farmer's valuation of the fertilizer, which has been shown to better elicit values than methods based on dichotomous choice (Lybbert 2006, Balistreri, et al. 2001, List and Gallet 2001).

We showed farmers three samples of urea fertilizer that we had previously purchased from sellers in the Morogoro region and which had been lab-tested for nutrient content. All samples were of nutrient content that had been tested and met international fertilizer standards and can therefore be considered good quality in terms of their unobservable (to the farmer) nutrient content. However, the three samples differed in terms of their physical attributes. Figure 1 presents pictures of the three samples: Sample A was of good appearance (bright white and clean with no caked aggregates or foreign material present); Sample B included large hard caked clumps and discoloration; and Sample C included the presence of foreign material making it appear to have been mixed with darkly colored pebbles or prills of another kind of fertilizer.

The assessment was conducted in a central location in each village but each farmer completed the assessment individually with an enumerator separate from the rest of the respondents. We proceeded in three steps[9]:

1. First, farmers were provided with the samples to inspect as they wished. Farmers were asked to assess the quality and to report their willingness-to-pay for 1 kg of urea of equivalent quality for each of the three samples. Enumerators were asked to explain to the farmer that he should respond with a price (in Tanzanian Shillings) reflecting not what he thought the urea would cost, but instead a price reflecting what the urea is worth to the farmer.

2. Second, the enumerator presented farmers with test results on the nitrogen content of each of the

[8] Other methods are also possible. Bai (2015) uses an experimental approach, and provides quality certification labels and branding in the watermelon market in China. Anagol (2016) contrasts two markets for cows in India: an open market, which is subject to adverse selection, and within-social network market, where asymmetric information is less present.

[9] Further details about the elicitation are available in the appendix.

Figure 1: Pictures of samples shown to farmers for the willingness-to-pay assessment. Sample A represented. All three 1 kg samples of urea were purchased as shown by the research team in the market. All three samples were tested by Thornton Labs in the United States and were found to contain 46% nitrogen. Sample A was clean with no caking; Sample B included two large, hard caked aggregates; and Sample C included the presence of foreign material mixed in the urea.

three urea samples. Farmers were informed that nutrient content tests were conducted in a lab in the United States, and that the sample met industry standards for nitrogen.

3. Finally, the farmer was asked to rate the quality and report his (post-information) willingness-to-pay.

Enumerators reported that questions, despite being hypothetically framed, were well understood by the farmers, all of whom were literate and had experience purchasing fertilizer from the market. Showing the actual samples of urea to the farmer to inspect as he or she saw fit added a measure of realism to the exercise, partly compensating for the hypothetical nature of the assessment. Some farmers touched the fertilizer, others placed a small amount on their tongues. As discussed, urea is a familiar, commonly used fertilizer in the region, and 90% of the participating farmers had purchased and used urea in the previous 12 months.

As urea fertilizer is available in local markets, the local market price plus farmer transaction costs should serve as an upward bound on the willingness-to-pay (that is, before the farmers are informed about the quality of the product). We find that this is the case: less than 3% (15 out of 494 responses to the pre-information willingness-to-pay) of farmers' reported willingness-to-pay estimates exceeding the highest per kg market price for fertilizer we observed in markets. However, the second half of our assessment exercise introduces a good that is not currently available in markets: there is no market currently for fertilizer with nutrient quality certified by an independent third party (here, a research team using a United States lab).

All farmers were asked to report willingness-to-pay for sample A, followed by the willingness-to-pay of sample B and then willingness-to-pay for sample C. All samples were shown to each farmer simultaneously to reduce the possibility of anchoring or ordering effects.[10] In the analysis, we will focus on differences in willingness-to-pay between farmers and samples, which avoids some of the primary concerns associated with order effects, should they be present.

As mentioned above, the willingness-to-pay questions were hypothetical; farmers did not actually purchase the urea fertilizer bags we presented to them. This decision to elicit hypothetical willingness-to-pay was made for logistical reasons – in order to make between-farmer comparisons it was essential that the exact same products were presented to each farmer, i.e., fertilizer of the same color, with the same number of caked aggregates and the same amount of foreign material. Hence, selling the fertilizer to one particular farmer would have prevented us from using the same product in the next village.

The effect of using hypothetical payments as opposed to real payments has not yet been settled in the literature. The validity depends on the nature of the context and elicitation method. In the literature focused on risk-preferences, some studies have found evidence of differences between the two methods (as in Holt and Laury 2002) while others have found no such discrepancies (Binswanger 1983). Kahneman and Tversky (1979) argued that "the subjects have no special reason to disguise their true preferences" (p. 265) in hypothetical elicitations and Beattie and Loomes (1997, pp. 165) conclude "the absence or presence of financial incentives is not a crucial factor in encouraging or discouraging violations of standard axioms in pairwise risky choice problems". Less evidence is available for the elicitation of willingness-to-pay of agricultural technologies in developing country contexts. Our exercise was explicitly framed as a fertilizer-buying scenario with experienced fertilizer purchasers, and respondents expressed and displayed little trouble imagining how they would react. While the exercise has some limitations, it provides the first insights into farmer assessment of fertilizer quality and response to information about unobservable nutrient content.

3.4 Testing the fertilizer samples

We collected a total of 633 fertilizer samples from sellers and 187 samples from farmers. Purchased samples were stored in their original plastic bag packaging and labeled with the store and purchase information for the purposes of creating unique sample identifications. Samples were packed and sealed in doubled Ziploc bags immediately after purchase and placed in airtight plastic bins for storage until

[10] We recognize that order effects might still be a concern, and farmers might benchmark their valuation of samples B and C to what they stated for sample A. We have however no prior as to the degree to which order effects would be present in this setting as the literature has reported cases with significant order effects (as in Holt and Laury 2005) and cases without any evidence of order effects (as in Alpizar et al. 2011, Harrison et al. 2005).

testing. The Soil-Plant Diagnostics Spectral Lab at the World Agroforestry Centre (ICRAF) in Nairobi, Kenya, conducted the nutrient content testing for all of the fertilizer samples. Details on the testing are provided in the appendix. [11] A randomly selected subsample of the fertilizer was sent to Thornton Labs in the United States.[12] The correlation coefficient between the nitrogen content of the 59 samples tested at both ICRAF and Thorton is 0.97 and all samples had a difference between the measures of less than 1%.

Samples were tested for the degree to which they deviated from what is known as their fertilizer grade – the guaranteed content of nutrients.[13] The nutrient content is expressed as a percentage of the fertilizer weight. For example, urea is 46% nitrogen and is referred to as a straight fertilizer because it only contains one nutrient, whereas DAP contains two nutrients and is 18% nitrogen and 46% phosphate.

In addition, we took photographs of all samples acquired from sellers and farmers on the day of purchase, and used these to visually code physical attributes: caking, discoloration, presence of foreign material (ex: dirt, grass, maize grains, stones), and powdered granules. These are readily observable, physical attributes. Because photographs were taken the day of purchase, observable characteristics were not impacted by transport or storage. Two independent coders (one in Tanzania and one in the United States) completed visual coding with a correlation across the characteristics of 0.96. Details of the physical attributes are as follows:

- Fertilizer caking occurs when fertilizer granules fuse together to form larger aggregates. In the most extreme cases, the entire bag can fuse into a single, hard aggregate.

- Fertilizer discoloration, in the case of DAP and CAN, implies a discernibly darkening of the color of the fertilizer, sometimes accompanied by an oily film that can secrete through the packaging, leaving a residue on the outside of the bag. Urea can similarly become dirty and pick up a gray discoloring.

- The inclusion of foreign material, such as, dirt, sand, insects, or grains of maize.

- Fertilizer powdering implies the breaking of the small aggregate prills into smaller, powdery fragments.

[11] ICRAF, a CGIAR center, has contributed to advancing spectroscopy techniques and methodologies for measuring soil (Terhoeven-Urselmans et al. 2010, Towett et al. 2015) and plant (Towett et al. 2015) chemical composition. ICRAF utilized two methods to determine the nitrogen content: Mid-infrared diffuse reflectance spectroscopy (MIR) and portable X-ray fluorescence (pXRF) spectroscopy. In general, spectroscopy measures the quantities of chemical elements (ie., nitrogen), by analyzing how infrared radiation responds to physical matter (ie., fertilizer). Although spectroscopy is used widely in many fields, ICRAF has been a world leader in developing and utilizing these technologies for agricultural applications.

[12] Thornton Labs used the traditional Kjeldahl wet chemistry method for sample analysis.

[13] International standards specify maximum moisture content by weight, nutrient content by weight, particle size, and packing guidelines.

While nutrient quality – specifically fertilizer missing nutrients – can result from either manufacturing impurities or adulteration by wholesalers or sellers, degradation of physical quality generally results from poor supply chain management and logistics problems: poor handling at port, poor transport conditions, storage, exposure to high temperatures and humidity and product aging (Sanabria et al. 2013).[14]

Physical quality characteristics are discussed in seller technical training manuals (Rutland and Polo 2015) and fertilizer standards and analysis manuals (Sanabria et al. 2013, Yara 2012).[15] To our knowledge, there is no literature, either acadamic or technical, which considers the relationship between physical attributes and nutrient content.[16]

4 Analysis and Results

We begin by presenting evidence on sampled fertilizer nutrient content from the results of the laboratory tests. We tested all samples for nutrient content and also documented their physical attributes and we present results of an analysis of the relationship between fertilizer nutrient content and physical attributes We analyze the farmers' beliefs using the willingness-to-pay exercise. We then proceed with a review of some of the qualitative evidence documenting the beliefs of both sellers and farmers.

4.1 Fertilizer quality and characteristics

Table 2 presents the results of the laboratory tests. The top panel presents the results for the sellers' samples, the bottom panel is the farmers' samples. Column (1) presents the manufacturer standard for the nitrogen content for each fertilizer. Column (2) presents the share of the samples found to be out of compliance based on the guidelines for nutrient compliance from the Economic Community of West African States (ECOWAS), which are the standards used in Tanzania. Column (3) presents the mean and the standard deviation (in parentheses) of the tested nitrogen. Column (4) presents the mean deviation

[14]Caking is often a result of the fertilizer having been exposed to water or high humidity during initial packaging and handling of manufacturer bags as well as subsequent transportation and storage (Sanabria et al 2013). Caking is especially sensitive to temperature and humidity, pressure in piles and stacks, and storage time (Rutland and Polo 2015). Discoloration is also the result of moisture or high humidity. In the case of foreign materials, while deliberate adulteration can be one source of the presence of foreign material, more incidental cases result from the way that fertilizer is imported and prepared for wholesalers and sellers in Tanzania.While at port, the fertilizer is often exposed to humidity and high temperatures, as well as sand, dust, and dirt. Fertilizer sold from opened bags or sold in informally repackaged parcels is also vulnerable to the inclusion of foreign material. Foreign material decreases the per weight nitrogen content of the fertilizer; the quality dilution can be incidental (in the case of fertilizer which includes a handful of maize kernels or insects) or more harmful if the fertilizer has been deliberately and significantly adulterated. Fertilizer powdering is the result of poor handling and storage or excessive handling or product aging.

[15]IFDC agro-dealer training manuals mention the importance of a range of physical attributes and guidelines for storage and transport to preserve quality. For example, on caking: "Caking can cause many handling and application problems and is considered by most fertilizer producers to be the single biggest physical quality problem in fertilizers." (p. 7)

[16]One explanation for the lack of literature may be the fact that few quality problems exist now in industrial countries but it is surprising that few papers have considered these issues in developing countries.

from nitrogen standard. This was calculated as follows: the nitrogen content standard was subtracted from the measured nitrogen content. The difference was divided by the nitrogen content standard, resulting in deviation from nitrogen standard as a percent of the standard. A negative figure represents a nitrogen deficiency, whereas zero represents adequate nitrogen content relative to the manufacturing standard.

On average, among the sellers' samples, urea contained 45.9% nitrogen rather than 46%, CAN contained 24.5% nitrogen rather than the standard 26%, and DAP contained 17.5% rather than the standard 18%. Comparing farmers' with seller samples, note that while only 2% of the seller urea samples, 6% of the farmer urea samples are out of compliance; the difference is small but significant, with a p-value of 0.042.

As our focus is understanding the validity of farmers' beliefs, we focus the rest of the discussion on the seller samples. We note that urea fertilizer available from sellers is largely in accordance with international standards, with only 2% of samples out of compliance and 0.03% of samples exhibiting a fractional deviation exceeding 20%. Consistent with the findings of the IFDC (Sanabria et al. 2013), more CAN and DAP are out of compliance, but the deviations from industry standards are small, in the order of 5.9% and 3.0%, respectively.

Figure 2 presents a histogram of the fractional deviation in nitrogen for the seller samples[17]. Figure 3 presents the fractional deviations for the 146 seller samples found to be out of compliance, by fertilizer type. A handful of samples have fractional deviations exceeding 20%: two CAN samples, five DAP samples, and one urea sample.

These results differ from Bold et al. (2017), who find highly variable nutrient content and average nitrogen deviations of 30% in urea in Uganda. Our results are consistent with the findings of IFDC (Sanabria et al. 2013) as well as a 2015 policy brief funded by the Alliance for a Green Revolution for Africa and undertaken by the Ugandan Ministry of Agriculture which similarly found that urea was largely in compliance in Uganda, with an average deviation of 5% across 44 samples (Mbowa et al. 2015). Ashour et al. (2017) also found that urea and NPK fertilizers met standards for nutrient content in Uganda with one out-of-compliance sample out of 220 tested. The IFDC methodology is carefully documented and includes random stratified sampling of sellers; our samples are a census of the region's fertilizer sellers. In short, while Bold et al. (2017) find much higher deviations than other studies, we suspect the difference with IFDC could be attributed to sampling strategy, while the difference with our study might also be

[17]We use the guidelines for nutrient compliance from the Economic Community of West African States (ECOWAS): single nutrient fertilizer with more than 20% nutrient content max .5 units (.5% for nitrogen in urea) and max 1.1 units for individual nutrients (that means 1.1% for DAP and CAN nitrogen).

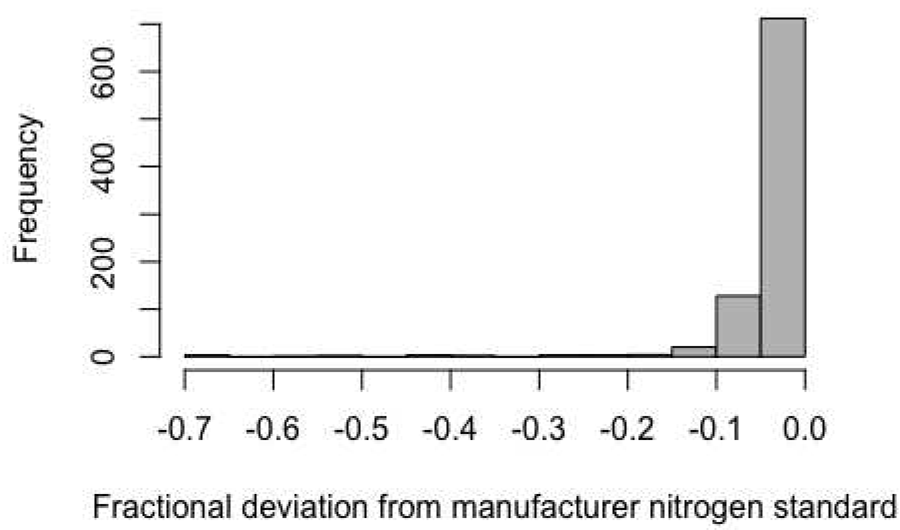

Figure 2: Fractional deviation from manufacturer Nitrogen standard in samples of mineral fertilizer purchased from fertilizer sellers in the Morogoro region of Tanzania. On average, mineral fertilizer is missing 3% of the advertised nitrogen (n=633).

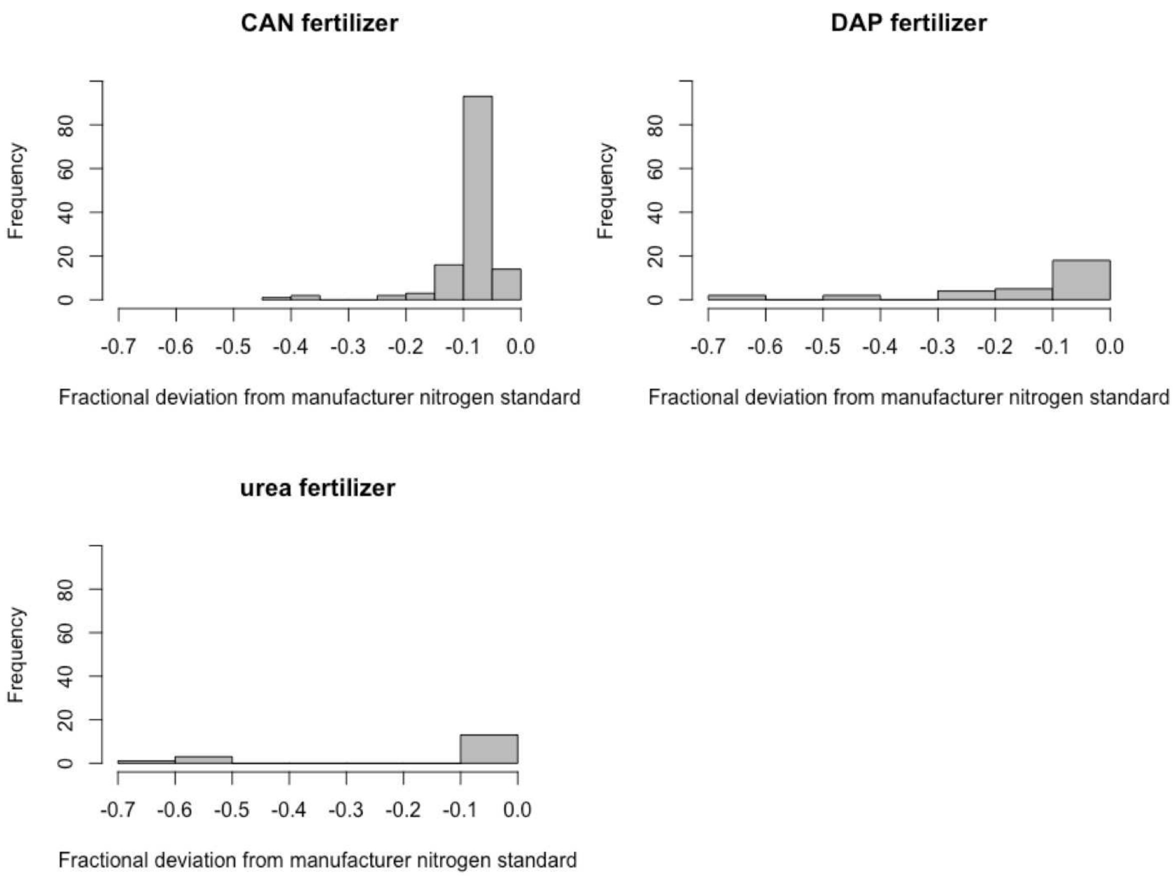

Figure 3: Fractional deviation from manufacturer Nitrogen standard in samples of mineral fertilizer purchased from fertilizer sellers in the Morogoro region of Tanzania for the 146 seller samples out of compliance based on ECOWAS tolerance limits, by fertilizer type.

due to features of Ugandan fertilizer supply chains, and perhaps the testing method.[18]

Table 2: Measured nitrogen content, deviation from industry standard and industry standards by fertilizer type. Top panel is fertilizer seller sample and bottom panel is farmer sample.

	Nitrogen Standard (Minimum %)	Samples Out of Compliance (%)	Mean Nitrogen Content (%)	Mean Deviation from Nitrogen Standard (share)
urea (n=300)	46	2	45.9 (1.5)	-0.003 (0.03)
DAP (n=137)	18	10	17.5 (1.1)	-0.03 (0.06)
CAN (n=196)	26	64	24.5 (1.2)	-0.06 (0.05)
Farmer samples				
urea (n=121)	46	6	45.4 (3.6)	-0.01 (0.08)
DAP (n=55)	18	27	16.7 (2.4)	-0.07 (0.13)
CAN (n=5)	26	40	23.7 (2.5)	-0.09 (0.96)

Notes: Tests conducted by the World Agroforestry Center (ICRAF). Out of compliance designations use ECOWAS tolerance limited for plant nutrients: maximum 0.5 units for single nutrient fertilizers with more than 20% nutrient content; complex fertilizers maximum 1.1 units for individual nutrients.

Moving on to the physical attributes, Table 3 presents the results of the visual coding of the physical attributes. Column (1) refers to the farmers' sample while Column (2) refers to the sellers' sample.

We observed caking in 15% of farmer samples and 28% of samples obtained from sellers. Approximately 6% of farmer samples were discolored, compared to 10% of sellers' samples. 9% of farmer samples had foreign material present, as opposed to 5% of seller samples. 8% of both samples contained powdered granules. Overall, one quarter of the fertilizer samples had physical quality issues such as caking, discoloration, powdering, or the presence of foreign material. These rates are consistent with the IFDC report documents comparable incidence rates of physical quality issues in West Africa (Sanbria et al 2013). We present the observed rates of physical attributes disaggregated by fertilizer type in the appendix (Tables A1-A3). Urea has the highest incidence of caking, with 42% of the seller samples exhibiting the presence of hard clumps and 17% of farmer samples. CAN and DAP are more likely to be discolored and CAN samples are the most likely to contain powdered particles.

To assess the relationship between fertilizer physical condition, characteristics that are observable before, or shortly after, the transaction, and nitrogen content, which is never observable to the farmer, we present the results of analyses in which we regress the fractional nitrogen deviation on the four physical attributes for all fertilizer samples purchased from sellers: caking, powdering, foreign material,

[18]Bold et. al used a lab in Uganda relying on the Kjeldahl method and took the average of three test results for each sample. Ashour et. al (2017) use two labs in Uganda using two methods - Kjeldahl and a method based on combustion - to double test 187 fertilizer samples and find the Kjeldahl method results unreliable, with a low correlation between test-retest results for the same samples. We rely both on Kejldahl (conducted in Florida, USA) and pXRF methods (in Nairobi) but find a high correlation across the methods for our tests.

and discoloration. Table 4 Column (1) presents the results using standard OLS with robust standard errors. Column (2) adds a market location fixed effect and Column (3) a seller fixed effect. Column (4) runs a linear probability model on a binary measure - whether the sample is out of compliance (OOC) based on the ECOWAS standards. In columns (1)-(3) the standardized nitrogen share has been multiplied by 100 so that it is expressed in change in percentage points to ease interpretation of the coefficients.

Table 3: Prevalence of poor physical attributes of fertilizer samples.

	Farmer samples (%)	Seller samples (%)
Presence of clumps/caking	15.3	27.84
Discolored	6.01	10.38
Presence of foreign material	9.29	4.78
Presence of powdered granules	7.65	7.91
n	187	633

In short, the observed properties of the fertilizer exhibit no relationship with the nitrogen quantity. That is, physical quality can exhibit degradation without underlying degradation in the nutrient content.[19] This is expected, given the low magnitudes and frequencies of missing nitrogen that we found based on the lab tests and the high rates of poor physical attributes. The magnitudes of the coefficients are all relatively small and none are statistically significant; a coefficient of -0.5 indicates that the presence of powdering would be associated with the fertilizer missing an additional 0.5 percent of the nitrogen (in percentage terms). For urea this would be a sample with 43.7% nitrogen instead of 46%. We also run the Column (3) specification for each type of fertilizer separately; these results are available in the appendix (Table A4).[20]

The fertilizer in our samples from farmers and sellers is of good nutrient quality but with some problems with poor physical attributes. We find that the physical attributes do not provide an informational signal regarding the unobservable nutrient content of the fertilizer.

[19] As a check, we also analyze the relationship between the measured moisture content of the samples and observed quality characteristics; moisture content is directly related to caking and powdering of granules (powdering makes the fertilizer likely to more readily and quickly absorb moisture). As expected, evidence of powdering is positively associated with moisture content and caking is similarly associated with higher moisture content. Discoloration and the presence of foreign material have no relationship with the measured moisture content. Details available on request.

[20] An IFDC study of fertilizer quality in West Africa found caking to be correlated with low nutrient content in a particular blend of NPK (Sanabria et al. 2013).

Table 4: Regression of the fractional deviation of nitrogen from the manufacturer standard on observable mineral fertilizer quality characteristics (seller samples).

VARIABLES	(1) N standardized (percentage points)	(2) N standardized (percentage points)	(3) N standardized (percentage points)
Clumping	0.0309	0.0936	0.125
	(0.0561)	(0.0735)	(0.154)
Powdering	-0.566	0.146	-0.534
	(0.861)	(0.963)	(1.072)
Discoloration	-0.489	-0.282	-0.512
	(1.025)	(1.256)	(1.145)
Debris/foreign material	-0.0467	0.0352	0.763
	(0.470)	(0.543)	(0.986)
DAP	2.812***	2.949***	3.037***
	(0.670)	(0.700)	(0.749)
urea	5.393***	5.539***	5.561***
	(0.399)	(0.402)	(0.367)
Constant	-5.715***	-5.394***	-6.340***
	(0.310)	(1.439)	(0.367)
Observations	606	606	606
Market location FE		Y	
Seller FE			Y
R-squared	0.229	0.322	0.578

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

4.2 Willingness-to-pay for fertilizer

To gain a better understanding of what drives farmer willingness-to-pay (henceforward WTP) for fertilizer we regress WTP on physical attributes (clean sample, samples with impurities and caked sample) and whether or not the farmer received information about the nutrient quantity (this variable takes the value 0 prior to the information and 1 after the information was provided).

The intuition behind this empirical strategy is the following: If the farmer is risk-averse, and if crop performance (positively) depends on the quality of fertilizer, then both decreasing the uncertainty regarding nutrient quantity (which is what information does) and increasing its expected value (which is also what information does) will increase WTP. In contrast, the physical attributes of the non-clean samples might decrease the expected quality, and hence decrease WTP. We outline a simple model below which captures this intuition.

Define x^i as the yield outcome of fertiliser sample i, θ^i the true nutrient quantity of sample i and P^i as the physical attributes of sample i - we assume that a larger value of P^i corresponds to a better looking sample. Then:

$$x^i = x(\theta^i, P^i) + \mu^i \tag{1}$$

Where μ^i is a random variable with mean 0 and standard deviation σ_μ. Assuming a linear yield function, we write:

$$x^i = \alpha\theta^i + \beta P^i + \mu^i \tag{2}$$

With both $\alpha > 0$ and $\beta > 0$. In writing expression (2), we allow for P^i to impact the yield, independently of the nutrient quantity (while the impact is likely limited). We assume that the parameters of this yield function (2), α and β, are known to the farmer. But while P^i can directly be observed in our assessment exercise, θ^i is unknown and will be the object of learning. We turn to this learning process next.

Assume that the farmer j has a prior belief about θ^i. This prior belief is normally distributed with mean $\bar{\theta}_j$ and variance $\sigma^2_{j,\theta}$. We assume that the prior belief is farmer-specific, hence the introduction of the subscript j. In addition, the mean of this prior belief may depend on the physical attributes: $\bar{\theta}_j(P)$.

In our assessment exercise, the farmer receives a signal $s^i$of the nutrient quantity θ^i: the statement by the research team. This is an unbiased signal, and assumed to be drawn from a normal distribution with mean θ^i and variance $\sigma^2_{j,\epsilon}$:

$$s^i = \theta^i + \epsilon^i, \qquad \epsilon^i \sim N(0, \sigma^2_{j,\epsilon}) \tag{3}$$

Note that $\sigma^2_{j,\epsilon}$ measures the credibility of the information (to farmer j), and in the extreme, this variance can be zero, that is, if the information from the research team is taken at face value. So far, the setup above corresponds to a standard Bayesian learning model with normal priors and signals. It can be shown in such a model that as the variance of the farmers' belief distribution decreases, it in effect can collapse into θ^i as $\sigma^2_{j,\epsilon}$ decreases (see, for instance, Chamley 2003). The distribution is updated from $N(\bar{\theta}_j, \sigma^2_{j,\theta})$ to $N(\theta_{j,post}, \sigma_{j,post})$ with:

$$\sigma_{j,post} = \frac{\sigma^2_{j,\theta} * \sigma^2_{j,\epsilon}}{\sigma^2_{j,\theta} + \sigma^2_{j,\epsilon}} \tag{4}$$

$$\theta_{j,post} = \frac{\sigma_{j,post}}{\sigma^2_{j,\epsilon}} s^i + [1 - \frac{\sigma_{j,post}}{\sigma^2_{j,\epsilon}}] * \bar{\theta}_j \tag{5}$$

To summarize, the expected yield outcome $E[x^i]$ is:

$$E[x_i] = \alpha E[\theta^i | s^i, P^i] + \beta P^i \tag{6}$$

And the variance of the yield outcome $Var[x^i]$ is:

$$Var[x^i] = \alpha^2 Var[\theta^i | s^i, P^i] + \sigma_\mu \tag{7}$$

With the (farmer dependent) mean and variance function defined as specified above. The farmer states his or her WTP on the basis of these beliefs. To ensure tractability, let us assume that farmer j maximizes the following linear mean-variance utility function:[21]

$$w_j + o_j = E[w_j - WTP^i_j + x_i] - \phi Var[w_j - WTP^i_j + x_i] \tag{8}$$

Where w_j = initial wealth of farmer j and o_j = the yield without any fertilizer (which we assume, for simplicity, has no uncertainty associated with it). Writing out the expectation/variance operators yields:

$$w_j + o_j = w_j - WTP^i_j + E[x_i] - \phi Var[x^i] \tag{9}$$

Now, plug in equations (6) and (7):

$$w_j + o_j = w_j - WTP^i_j + \alpha E[\theta^i | s^i, P^i] + \beta P^i - \phi[\alpha^2 Var[\theta^i | s^i, P^i] + \sigma_\mu] \tag{10}$$

And rewrite as:

$$WTP^i_j = -o_j + \alpha E[\theta^i | s^i, P^i] + \beta P^i - \phi[\alpha^2 Var[\theta^i | s^i, P^i] + \sigma_\mu] \tag{11}$$

We take the partial derivatives with respect to s^i and P^i to obtain:

$$\frac{\partial WTP^i_j}{\partial s^i} = \alpha \frac{\partial E[\theta^i | s^i, P^i]}{\partial s^i} - \phi \alpha^2 \frac{\partial Var[\theta^i | s^i, P^i]}{\partial s^i} \tag{12}$$

$$\frac{\partial WTP^i_j}{\partial P^i} = \alpha \frac{\partial E[\theta^i | s^i, P^i]}{\partial P^i} + \beta - \phi \alpha^2 \frac{\partial Var[\theta^i | s^i, P^i]}{\partial P^i} \tag{13}$$

[21] Where we normalized the output price to one and ignore other farming costs.

Note that the partial derivative with respect to s^i consists of two terms. Recall that we had assumed that $\alpha > 0$. The first term $(\alpha \frac{\partial E[\theta^i|s^i,P^i]}{\partial s^i})$ is therefore positive, as is the second term, i.e., $\frac{\partial Var[\theta^i|s^i,P^i]}{\partial s^i}$ is negative - in effect, Bayesian learning implies that any signal would decrease the variance of one's posterior beliefs. The second partial derivative, with respect to P^i consists of three terms. Recall that we had assumed that $\beta > 0$. The signs of the other two terms are undetermined, as they depend on how the farmer constructs a link between physical condition and quality as per his/her prior beliefs. If this link is assumed to be non-existent, $\frac{\partial WTP_j^i}{\partial P^i} = 0$.

Similarly, the overall sign on the cross derivative (14) will be zero under the latter condition, but can be expected to be positive if poor physical attributes are perceived to be correlated with nutrient content.

$$\frac{\partial WTP_j^i}{\partial s^i \partial P^i} = \alpha \frac{\partial E[\theta^i|s^i, P^i]}{\partial s^i \partial P^i} - \phi \alpha^2 \frac{\partial Var[\theta^i|s^i, P^i]}{\partial s^i \partial P^i} \tag{14}$$

In Table 5 - Column (1), we approximate the WTP using a linear model. We estimate:

$$WTP_j^i = a + b_1 s^i + b_2 P^i + b_3 s^i P^i + \eta_j + e_j^i \tag{15}$$

Where WTP_j^i is the WTP of farmer j for sample i with physical attributes P_i and s^i indicates whether the WTP was stated pre or post information. Column (2) adds a farmer fixed effect (each farmer completed six assessments, three before and three after the information was provided).

As a benchmark for the reported willingness-to-pay, the average per kilo price of urea in the region during the time of the assessment was 1500 Tanzanian Shillings (TZS).

Analysis of the WTP assessment yields two important insights. First, farmer WTP for perfect quality fertilizer (both in terms of nitrogen content and physical condition) exceeds the market price. Farmers' mean pre-information WTP for Sample A, the sample in good physical condition, is 1489 TZS, approximating the prevailing market price in the region at the time. However, after receiving information about the lab-tested nutrient quality of the urea, farmers' mean WTP increases by 48% to 2,201 TZS, well exceeding the market price. The post-information WTP on Sample A provides a counterfactual – what farmers in our sample would pay for fertilizer without uncertainty about nitrogen content. This increase indicates that credible information works.

Table 5: Willingness-to-pay assessment; effect of information about unobservable nitrogen content on WTP.

VARIABLES	(1) WTP TZSh	(2) WTP TZSh
Sample B (clumps)	-748.2***	-737.7***
	(96.8)	(75.6)
Sample C (foreign material)	-795.5***	-787.5***
	(100.8)	(79.4)
post information	712.2***	712.2***
	(71.5)	(71.4)
Sample B * post information	282.5***	282.5***
	(105.2)	(105.0)
Sample C * post information	252.9**	251.0**
	(109.4)	(109.2)
Constant	1,503.5***	1,489.2**
	(61.27)	(454.4)
Farmer FE		Y
Observations	855	855
Adj R-squared	0.30	0.30

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. We omit from these estimations the responses in which farmers reported zero WTP for both pre and post information; these 150 responses comprise 13% of the sample and were nearly all for the sample that appeared to have the presence of foreign material (Sample C). Results hold with the inclusion of these zero WTP estimates and are included in the appendix (Table A1).

Second, the assessment establishes that farmers' WTP for fertilizer responds to the physical condition of the fertilizer. Recall that Sample A is the pristine, white urea; Sample B included several large, hard caked aggregates; and Sample C included the presence of dark-colored foreign material, perhaps small stones or another fertilizer like DAP. Prior to the provision of the lab tests on nitrogen content, farmers discounted Sample B and Sample C relative to Sample A by 763 and 806 TZS, respectively. Farmers' WTP increases significantly for all three samples after farmers are provided the lab results. Post-information WTP increases for Sample B and Sample C are approximately 1000 TZS; resulting in a post-information WTP for these samples which, again, exceeds the prevailing market price.

It is notable however that even post-information, farmers continue to report a lower WTP for the samples with bad physical attributes relative to pristine Sample A. Farmers may care about the physical condition both as a signal of unobservable nutrient (nitrogen) quality and as a separate quality dimension related to ease of application and storage; hence, resolving uncertainty around unobserved quality obviously does not fully resolve the physical condition quality problems and post-information willingness-to-pay is still below that of Sample A. Pre-information willingness-to-pay therefore captures not only the farmer uncertainty about nutrient quality and inference about that nutrient content based on physical condition, but also an expected cost of dealing with poor physical attributes. Our post-information willingness-to-pay estimates help decompose these costs (assuming that the information was credible); what remains after the uncertainty is resolved can be interpreted in lost time and resources from addressing physical quality problems – including the costs of lost fertilizer if the caked aggregates are discarded. For example, caked fertilizer must be broken up by the farmer before application; powdered fertilizer is difficult to apply and can result in losses during handling or storage; unwanted foreign material needs to be sorted out.

Overall, results of the WTP exercise suggest that farmers are - on average - suspicious about unobservable fertilizer quality and use the physical attributes as a signal of unobservable nutrient content. As presented (Table **??** in Section 4.1, we find no evidence of a relationship between physical attributes of the fertilizer and the nitrogen content. We return to the possible reasons for the existence and persistence of these incorrect beliefs in the discussion section.

We conclude with a note on the further implications of this incorrectly perceived correlation between physical attributes and nutrient content. While farmers who do not perceive such correlation are expected to rate Samples A, B, and C similarly; farmers who do, being confronted with the significant share of poor looking samples in the market, might have an overall lower WTP, and might even be reluctant to update their beliefs when presented with credible information about unobserved quality (here, the lab results).

To test this claim, we divide the farmers in two samples, a group that is highly sensitive to fertilizer quality and a group that did not report this sensitivity. The quality sensitive group is the group that listed "purchasing high quality fertilizer" among their top two concerns at the beginning of an agricultural season. Respondents were asked to rank four options (identified through farmer interviews) in order of concern; other options included "purchasing high quality seeds" , "access to financing for inputs" , and " the start and duration of the rains". Of the 165 farmers, 39 (24%) listed high quality fertilizer as among their top two concerns out the four provided.

We run an extension of Equation (15), interacting an indicator for these quality-concerned farmers with the pre-post-information signal indicator, the physical attributes indicator (we pool samples B and

C to increase power), and with the interaction between the physical attributes and information indicators:

$$WTP_j^i = a + b_1 s^i + b_2 P^i + b_3 s^i P^i + b_4 Q_j + b_5 s^i Q_j + b_6 P^i Q_j + b_7 s^i P^i Q_j + \eta_j + e_j^i \qquad (16)$$

Where, as above, WTP_j^i is the reported WTP of farmer j for sample i physical attributes P_i and s^i indicates whether the WTP was stated pre or post information. Q_j is the indicator of whether the farmer identified him or herself as concerned about purchasing high quality fertilizer.

Table 6 presents the results of this sub-group analysis. Column (1) presents specification (16); Column (2) drops the quality-sensitivity indicator and includes farmer fixed effects.

Table 6: Willingness-to-pay assessment, sub-group analysis; effect of information about unobservable nitrogen content on WTP with interactions for quality sensitive farmers.

	(1) WTP TZS	(3) WTP TZS
Samples with poor physical attributes	-602.6***	-565.7***
	(94.65)	(73.09)
Post-information	741.6***	741.6***
	(105.5)	(79.63)
Poor phys attributes * post information	153.2	152.0
	(133.8)	((101.0)
Poor phys attributes * quality sensitive farmers	-791.8***	-876.8***
	(196.9)	(154.1)
Quality sensitive farmers * post-information	-123.7	-123.7
	(216.3)	(163.7)
Quality sensitive farmers * Poor phys attributes * post-information	513.3*	514.5**
	(278.5)	(210.2)
Quality sensitive farmers	326.5**	
	(153.0)	
Constant	1,425***	1,460***
	(74.60)	(62.75)
Farmer FE		Y
Observations	855	855
Number of farmers		165

Notes: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

We find that the quality-sensitive farmers are more attentive to the physical attributes of the samples; b_6 is large, negative, and significant. Their WTP for these samples is significantly lower than that of farmers who do not self-identify as quality-concerned. We find no evidence of belief stickiness: the quality-concerned farmers have a stronger response to the quality information provided in the WTP exercise for the poor looking fertilizer samples (b_7 is positive, and significant). Interesting, the coefficient on the quality-concerned group in the specifications without fixed effects – Columns (1) and (2) – is positive and large, indicating that the quality-concerned farmers provide a higher pre-information WTP for the clean urea (Sample A); in effect, their WTP for the clean urea pre-information approximates the prevailing urea market price.

Results suggest that farmers are attentive to the physical attributes of fertilizer, which are commonly observable. More than half of the respondents reported having purchased caked fertilizer in a previous season and 82% reported knowing someone who had purchased caked fertilizer. Similarly, farmers report suspicions that fertilizer in the marketplace is likely to be compromised: 14% reported that they suspected that they had purchased fertilizer with this problem in the past and 21% reported knowing someone who had had similar suspicions about having purchased adulterated fertilizer (Table 7). Similarly (Table 1), 18% of farmers reported that they believed that at least 50% of the fertilizer in the market adulterated; another 18% reported believing that more than zero but less than 50% of fertilizer was adulterated.

Table 7: Farmers' reported personal experience with fertilizer quality (n=165).

	Ever had mineral fertilizer with this problem? (%)	Ever known someone who had mineral fertilizer with this problem? (%)
Mineral fertilizer can be adulterated	13.9	21.2
Mineral fertilizer can be expired	29.7	57.0
Mineral fertilizer can have a nutrient content that is different from what is advertised	20.0	37.6
Mineral fertilizer can be caked and clumpy from moisture	55.2	82.4

Source: data collected by the authors.

5 Discussion

Are farmers incorrect to use physical condition as a sign of nutrient content? While the physical condition signal for unobserved nitrogen appears incorrect, it may be correct from the farmer's point of view for at least two reasons. First, farmers may respond to poor looking fertilizer and reduce complementary inputs such as labor in the presence of, for example, caking or discolored fertilizer, resulting in lower yields. Second, some physical attributes *can effect yield* – large caked aggregates can burn crops if they are not broken up for example – and farmers may attribute these yield effects of these two channels to the nitrogen rather than to the physical properties of the fertilizer.

Results from our willingness-to-pay assessment demonstrate that farmers rely on physical attributes of fertilizer to (incorrectly) assess unobservable nutrient quality and that farmers are unwilling to purchase substandard-looking fertilizer unless it is sold well below the average market price.

In this section, we consider two important questions related to sellers. First, what do *sellers* believe about nutrient quality? Second, given evidence that farmers take physical quality as a signal of nutrient content, why don't sellers respond to improve these characteristics?

5.1 Qualitative Evidence in the market: seller perceptions

Evidence from sellers suggests that sellers know more about the quality of the fertilizer they sell than farmers. Table 8 presents seller responses to the question of how he or she identifies high quality fertilizer. The sellers responded with reference to the fertilizer that they purchase for sale from their own suppliers and were permitted to choose multiple responses. Sellers report using physical attributes of the bag such as the labeling and weight as well as relational factors such as their trust in their own supplier and in the brand. Sellers also responded to open-ended questions about how they assess fertilizer quality and how they ensure that the fertilizer that they purchase for their store is of good quality. Numerous sellers mentioned paying attention to the printed expiration dates, the weight of bags (bags short weight considered a sign of adulteration), condition of the bags (whether it had been double-sewn, indicating that it had been previously opened, whether the bag had a hard plastic inner liner intact with official stamps), as well as their relationship with their own supplier and observations of the storage conditions used by their suppliers.

Table 8: Fertilizer seller responses to questions about signs of good quality fertilizer (n=225). Sellers could list multiple responses.

	Share of fertilizer sellers who report using as a sign of good quality (%)
Bag weight	0.07
Condition of package	0.22
Labeling on package (expiration date)	0.45
Trust in supplier	0.24
Trust in manufacturer	0.25

Source: data collected by the authors.

Sellers report testing the fertilizers that they sell on their own fields and small demonstration plots and explain that they rely on aggregated feedback from their farmer customers to assess the quality of the products they sell. "I depend on farmers to provide information about the performance of the fertilizer on their fields," one seller noted. A second reported, "my clients have never complained about the fertilizer I sell to them"; and another: "if you sell a quality fertilizer you will see that customers come to congratulate you and if they don't you will notice." Customers provide details on specific manufacturers that sellers report attending to: "three years ago we bought fertilizer and most of the customers said that it was not clean. Then we stopped ordering from them because we don't trust them."

Despite sellers' self-reported attention to the packaging and characteristics of the fertilizer that they source and the sellers that they source from, they voice their own suspicions about the quality of fertilizer available from their sellers and many report having purchased fertilizer with both physical and nutrient quality problems in the past: 34% report having purchased fertilizer that was past its expiration date, 58% report having purchased caked fertilizer and 21% report having purchased fertilizer that they suspected had been adulterated. Sellers, then, also suspect that the product that they purchase from suppliers has adulteration issues and that their own suppliers know more about the fertilizer quality than they do, themselves.

Profitable adulteration of fertilizer is difficult, especially non-blended fertilizers like urea whose particles are of uniform size and color. Adulteration of fertilizer blends such as NPK and CAN may be easier because particle sizes differ in the blends but still the required fillers must be used in large enough quantities that their presence is likely to be detected visually. Researchers at the IFDC argue that the presence of such extraneous material is so evident that only smallholder farmers with virtually no knowledge of fertilizers will be deceived (Joaquin Sanabria, personal communication, March 27, 2018). Smallholder farmers represent only a small share of the market (in terms of purchase quantity) in many regions and the deception is unlikely to pay off. Adulterating fertilizers in large volumes is most profitable but fraud at this scale is most likely to be caught by authorities and farmers. The 2013 IFDC report finds evidence of only ten cases out of 2,037 collected samples in which strange substances or excessive fillers were identified. All of these cases were a special Single Superphosphate fertilizer collected in Nigeria; seven of these were found based on chemical analysis to contain no phosphate.[22] Ashour et al. (2017) identify one urea sample out of compliance for nitrogen in their Uganda study and write, "this sample is easily discernible, as it does not even look like fertilizer" (p. 11).

In short: farmers and sellers are operating in a market characterized by lax government regulation and information asymmetries along the supply chain but we do not find evidence of adulteration in nutrient content analysis of fertilizers, perhaps at least in part because successful adulteration is difficult, more difficult than farmers (and perhaps some retail level sellers) suspect. Not surprisingly given the context and the widespread reports in media, however, farmers report concerns about fertilizer's unobservable and agronomically essential nutrient quality.

[22] More common in the IFDC report was fertilizer bags that were found to be short weight.

As mentioned, farmer beliefs about fertilizer quality in Tanzania are consistent with coverage in regional newspapers, which publish dramatic stories of criminal fertilizer adulteration (Kasumuni 2016; Lugongo 2014). Once a prior of low fertilizer nutrient quality in markets is established, farmers may associate bad physical quality characteristics as a signal of unobservable, compromised nutrient quality. Beliefs about compromised nutrient quality and the relationship between observable and unobservable characteristics may persist due to the difficulty of learning about true quality given considerable stochasticity in agricultural production (Bold et al., 2017) and possibly because of complementary underinvestment in labor and other critical inputs if one believes the fertilizer is poor, but also because farmers may not be purchasing and applying the right quantities or types of fertilizer, given their plot-specific nutrient limitations and prevailing government fertilizer recommendations that are inappropriate for many farmers. Harou et al. (2018) find evidence of agronomically important local within-village variability in soil nutrient needs distinct from government fertilizer recommendations among a sample of 1000 farmers in 50 villages in the same region in Tanzania where our research is conducted.

5.2 Seller response: prices and supply chain investments

We have found that that farmer willingness-to-pay responds to physical characteristics of the fertilizer, even though these characteristics appear uncorrelated with the nitrogen content. Given that farmers appear to respond strongly to the physical condition of fertilizer, we would expect that the fertilizer market price should relate to this physical condition.

Tables 9-11 presents the results of a regression of the per kilogram price of fertilizer on the fractional nitrogen deviation as well as the observed physical properties of each fertilizer sample (caking, discoloration, powdering, presence of foreign material for urea, CAN, and DAP samples, respectively. We find no statistically significant relationship between the price and the nitrogen content, except for DAP, where higher price DAP is associated with higher N. Somewhat more surprising, we find no relationship between physical condition and price. Column (2) in each table adds features of the transaction, seller, and location that might be observable to the farmer at the time of the transaction. Fertilizer purchased from open bags in one or two-kilogram quantities are significantly more expensive than fertilizer purchased in 50 or 25 kg bags, evidence of quantity discounting. Column (3) runs the model for only samples of one or two kilograms that were repacked by the seller or purchased from open bags at the time of the transaction. Few other characteristics of the business associated with formality seem associated with lower prices across markets.

In fact, overall we observe little variation in market prices for fertilizer, both within and across market centers. For example, in 58% of the market centers where we purchased urea from multiple sellers on the same day, we find no price variation across sellers – all prices are the same (40/68 market centers). These results are consistent with what farmers report in qualitative interviews; prices do not vary within a market center across sellers.

Our qualitative work does show that some sellers are willing to offer farmers a discount for fertilizer with highly compromised physical condition, consistent with results of the farmer willingness-to-pay assessment.[23] Overall, however, results find a lack of a relationship between physical quality characteristics and price, suggests that the market provides sellers with little incentive to invest in supply chain logistics such as improved storage or handling that could improve the physical attributes of the fertilizer that they sell.

On the seller side, why do observable fertilizer quality problems persist in the marketplace? Given evidence that farmers interpret caking and powdering as evidence of nutrient quality, why don't sellers compete on observables as a means of signaling **unobservable** quality to farmers?

Our evidence suggests that problems with observable quality characteristics begin upstream in the supply chain and so nearly all sellers have some chance in any given shipment of having such issues. We find that seller is most predictive of the physical attributes of a sample - with a models with lower root mean squared error than models with a market location fixed effect or a models including other geographic and supply chain factors (results in Appendix tables A6-A9). However, we find that physical condition is NOT explained by the seller's own shop infrastructure such as the use of pallets for storage, which we would expect to impact physical quality. Table 12 presents the results of these regressions. In short, fertilizer physical quality problems are presented as random shocks (though these could be based on unobserved variables at the seller level). Actions taken by sellers may prevent further degradation but they all accept some chance of receiving product from their suppliers of compromised physical attributes.

Qualitative work by the research team included a 2018 visit to a bagging facility in Dar es Salaam run by one of the major fertilizer importing companies. The fertilizer comes to the bagging facility from the port and is stored there until it is packaged into 50 and 25 kilogram bags. The fertilizer was kept on a bare dirt floor that was wet at the time of the visit. Vehicles bagging and scooping the fertilizer drove over it as they worked, individuals frequently walked over it before it was bagged, and the piled fertilizer included large visible clumps. The implication is quality problems up the supply chain: nearly all sellers have some chance in any given shipment of having fertilizer that is clumped, powdered, or

[23] Farmers indicate that they do not tend to observe physical properties until they arrive home and open the purchased package of mineral fertilizer. Qualitative evidence based on farmer interviews indicates that a handful will return to fertilizer sellers if they find that purchased fertilizer has physical quality problems such as severe clumping.

includes foreign material.

Table 9: Regression of the per kilo price on observable mineral fertilizer quality characteristics, urea samples from sellers. Column (3) runs the model on only samples purchased from open bags.

	(1) price per kg (TZS)	(2) price per kg (TZS)	(3) price per kg (TZS)
Nitrogen fractional deviation	-0.255	0.557	1.378
	(1.030)	(1.429)	(1.255)
Number of clumps	-3.170	-1.514	-1.270
	(5.118)	(4.943)	(4.985)
Powders present in sample (Y=1)	25.51	16.44	27.87
	(29.15)	(33.67)	(33.70)
Sample discolored (Y=1)	4.534	-13.34	-14.45
	(56.51)	(55.12)	(56.36)
Foreign material present in sample (Y=1)	35.99	57.30	61.62
	(38.64)	(48.27)	(48.74)
Purchase made from open bag	149.7**	129.3*	
	(64.12)	(66.46)	
Constant	1,054***	1,208***	1,319***
	(234.5)	(101.1)	(82.32)
Observations	290	267	255
R-squared	0.827	0.848	0.868
Market FE	Y	Y	Y
Enumerator FE	Y	Y	Y
Seller Controls		Y	Y

Notes: Robust standard errors in parentheses; Seller controls include store sign visible, number of governments present during the transaction, gender of respondent, age of respondent, years business has been in operation, and whether fertilizer is sold every month of the year. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10: Regression of the per kilo price on observable mineral fertilizer quality characteristics, CAN samples from sellers. Column (3) runs the model on only samples purchased from open bags.

VARIABLES	(1) price per kg (TZS)	(2) price per kg (TZS)	(3) price per kg (TZS)
Nitrogen fractional deviation	-5.955	-10.48	-10.49
	(4.538)	(6.346)	(6.477)
Number of clumps	2.135	6.231	5.829
	(5.826)	(6.637)	(6.993)
Powders present in sample (Y=1)	56.75*	64.03	74.18*
	(33.30)	(41.28)	(42.95)
Sample discolored (Y=1)	-35.04	-51.17	-23.72
	(39.90)	(48.62)	(50.35)
Foreign material present in sample (Y=1)	9.097	14.09	59.64
	(34.63)	(72.87)	(80.81)
Purchase made from open bag	301.9***	291.3***	
	(74.48)	(78.01)	
Constant	1,119***	883.9***	1,125***
	(109.8)	(222.3)	(195.0)
Observations	180	167	160
R-squared	0.813	0.817	0.814
Market FE	Y	Y	Y
Enumerator FE	Y	Y	Y
Seller Controls		Y	Y

Notes: Robust standard errors in parentheses; Seller controls include store sign visible, number of governments present during the transaction, gender of respondent, age of respondent, years business has been in operation, and whether fertilizer is sold every month of the year. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 11: Regression of the per kilo price on observable mineral fertilizer quality characteristics, DAP samples from sellers. Column (3) runs the model on only samples purchased from open bags.

	(1) price per kg (TZS)	(2) price per kg (TZS)	(3) price per kg (TZS)
Nitrogen fractional deviation	16.65***	15.02***	15.88***
(3.301)	(2.833)	(2.955)	
Number of clumps	23.82	40.50	37.86
	(31.57)	(33.79)	(35.81)
Powders present in sample (Y=1)	162.0	10.10	44.19
	(98.86)	(123.5)	(128.0)
Sample discolored (Y=1)	-2.939	-66.11	-39.37
	(51.54)	(55.38)	(59.38)
Foreign material present in sample (Y=1)	9.755	-6.808	-2.303
	(47.54)	(48.92)	(50.09)
Purchase made from open bag	279.6***	305.1***	
	(63.47)	(69.86)	
Constant	1,723***	1,897***	2,253***
	(80.01)	(129.0)	(87.64)
Observations	127	114	108
R-squared	0.760	0.838	0.841
Market FE	Y	Y	Y
Enumerator FE	Y	Y	Y
Seller Controls		Y	Y

Notes: Robust standard errors in parentheses; Seller controls include store sign visible, number of governments present during the transaction, gender of respondent, age of respondent, years business has been in operation, and whether fertilizer is sold every month of the year. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 12: Relationship between physical attributes of mineral fertilizer and shop infrastructure.

VARIABLES	(1) caking present	(2) powders present	(3) foreign material	(4) discolored
Concrete floor	0.00786	0.0031	-0.0211	0.00162
	(0.0336)	(0.02)	(0.0136)	(0.0194)
Shelving	-0.00427	0.0638**	0.00529	-0.0133
	(0.0401)	(0.0256)	(0.0199)	(0.0241)
Pallets	0.0141	0.0435	-0.0432	-0.00947
	(0.0623)	(0.0336)	(0.0295)	(0.0347)
DAP	-0.269***	-0.0577***	-0.0652***	0.213***
	(0.0476)	(0.0175)	(0.0179)	(0.0382)
CAN	-0.257***	0.0856***	-0.0643***	0.113***
	(0.0395)	(0.0308)	(0.0184)	(0.0285)
sample collected 2016	-0.00433	0.0347	0.00789	0.101***
	(0.0353)	(0.023)	(0.0159)	(0.0264)
Constant	0.405***	0.0114	0.109***	-0.0214
	(0.0664)	(0.0336)	(0.0331)	(0.0333)
Observations	605	605	605	605
R-squared	0.085	0.059	0.029	0.106

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6 Conclusion

In terms of fertilizer quality, a 2013 report from the International Fertilizer Development Corporation (IFDC) - a public international organization - presents and discusses the results of tests of 2,037 fertilizer samples collected from 827 wholesalers, government depots and retailers in five West African countries. The study finds that nitrogen problems in urea are highly infrequent,[24] with only 4% of more than 500 tested urea samples out of compliance with standards.[25] Forthcoming IFDC reports from Uganda and Kenya find no nutrient issues in urea; all urea sampled and tested by IFDC in these studies is in compliance. The 2013 IFDC report notes that farmer **beliefs** about urea fertilizer are not consistent with the evidence of its good nutrient quality, however:

> "With a probability of out of compliance of 0.04, the total N content compliance of urea was good. Yet, there is a perception that urea is being mixed with non-fertilizer materials in the region, which the study results did not confirm. A specific assessment is required to

[24]Quality problems are more significant for some of the fertilizer blends and the report discusses that such problems could be due to a number of factors including settling particles, blending problems, or manufacturing issues. Overall, they characterize evidence of adulteration in mineral fertilizer in the region as "weak".

[25]The Nitrogen shortage tolerance limit in urea is just 0.5% due to the low variability expected for N content in urea.

further verify this claim." (p. 39)

We find evidence that the quality of fertilizers for sale in retail shops in an important agricultural region of Tanzania largely meets national manufacturing standards for nutrient content but that belief of rampant product adulteration persists among farmers in these markets.

We make a distinction between two types of fertilizer quality: we find widespread evidence of degradation in physical quality characteristics and we find that these physical quality characteristics do not provide information about unobservable nitrogen. Moreover, we find evidence that farmers are attentive to the physical attributes of fertilizer, that they are using physical attributes to infer unobservable nutrient quality, and that this inference directly impacts their willingness-to-pay for fertilizer in a way that suggests broader market implications. For example, farmers' average reported willingness-to-pay for caked urea was well below the market price. We find that farmers' quality ratings and willingness-to-pay respond to information about the tested nutrient quality of the fertilizer but assessments of bad-looking samples continue to trail assessments of the good-looking sample.

We find that the nitrogen content is not reflected in price. Surprisingly, we also find that fertilizer market price does not respond to physical quality characteristics, evidence that sellers currently have little incentive to invest in improvements to their supply chains in ways that could improve physical attributes of fertilizer transacted in these markets.

Given that conditions in fertilizer markets are conducive to adverse selection - minimal regulation and asymmetric information - farmer beliefs about bad nutrient quality are likely a response to market circumstances, reducing the demand of farmers at prevailing prices. Slow learning about true quality by farmers may be due to stochasticity in agricultural production, reduction in complementary inputs investment, and purchase and application of fertilizers based on inaccurate government recommendations. Smallholders grow crops under conditions that include many potentially yield-limiting factors: without soil analysis to understand plot-specific nutrient limitations; insufficient financial resources to purchase fertilizer in the quantities required or to manage weeds, pests, and disease; variable or inadequate rain. They may attribute low yields to nutrient problems in the amounts fertilizer they do apply, especially if the fertilizer has compromised physical attributes that they can readily see.

Given farmer suspicions about adverse selection and our finding that farmer willingness-to-pay responds to credible information about unobservable nitrogen content, is nutrient content certification or labeling a viable solution for information problems in this market? Product labeling is common in developed countries, and increasingly used in the developing world as a strategy to bridge the information gap between consumers and producers regarding product contents, product safety and quality, and the production process (child-labor free, organic, GMO free etc.).[26]

Numerous studies have analyzed the effects of labeling on consumers. Results suggest that labeling can effectively inform consumers about product attributes (for an overview see Messer et al. 2017, Henson and Caswell 1999, Verbeke 2005, Grunert 2005, Costa-Font et al. 2008). Less attention has been given to the question in developing countries, where regulatory enforcement is weaker. Hoffman et al. (2017) use a randomized control trial in Kenyan markets to study labeling for aflotoxin and find that labeling affects consumer demand in the short term but not in the long term. Similarly, Garrido et al (2017), study the effects of labeling groundnut aflotoxin-free and find little impact on farmers' behavior, even when the label was associated with a price premium.

Few studies have focused on the effects of labeling agricultural inputs in developing countries, though there is a small literature on labeling information on farm input choice by farmers in the United States (Hasing et al. 2012). Auriol and Schilizzi (2015) propose conditions for the design and funding of certification schemes in developing countries and consider how various options might impact market structure. Ashour et al (2017) present some initial evidence on an e-verification scheme for seeds implemented by USAID in Uganda through a Feed the Future (FTF) initiative.[27]

In general, whether or not certification increases welfare depends on the willingness-to-pay for higher quality, the costs of implementing, monitoring, and enforcing the certification, and how fast farmers update their beliefs, as well as their initial beliefs (as this will determine how quickly reputation can be established; see also Marinovic et al. 2018 who theoretically establish the presence of bad and good equilbria depending on the cost and benefits of certification). Bai (2015) uses an experimental approach, and provides quality certification labels and branding in the watermelon market in China but finds that profit increases may not justify certification investments for individual sellers. In the case of Tanzania, our results suggest that farmers are willing to pay a significant amount for quality fertilizer, and that they are willing and able to update their beliefs quickly.

The prospects for fertilizer labeling and credible nutrient content certification in Tanzania are limited at this stage for at least two reasons, however. First, current government bodies charged with the task of regulating fertilizer sales and importation such as the Tanzanian Fertilizer Regulatory Authority (TFRA) and Tanzanian Bureau of Standards (TBS) lack the financial support and manpower to enforce their existing mandates. A labeling initiative could come from the private sector but margins in fertilizer

[26] See Leyland (1979) for an introduction on certification.

[27] See also Sanogo and Masters (2002) on certification of infant foods in Mali and Bai (2015) on watermelons in China.

are extremely thin and any undertaking that increases the fixed costs of fertilizer sales seems unlikely to succeed.[28] A third-party certification by an independent group may have more promise but it is unclear who might assume such a task.

Labeling could resolve the uncertainty around unobservable nutrient content, and helping farmers to learn not to infer unobservable quality from the physical condition. However, in the absence of credible labeling, we expect that farmers will continue to use observables as a signal of nutrient content. Our ongoing work suggests that supply chains in the region moving fertilizer from port to rural input shops are capital constrained and limited in their logistics and storage capabilities (Fairbairn et al., 2016) and our findings suggest that poor supply chain management may be leading to degradation of physical quality characteristics in fertilizer in the market. Our results therefore suggest that capital constraints for small sellers can have direct consequences for agricultural input adoption, agricultural productivity, and farmer investment, all of which of course impact market investment and development: in particular, physical quality problems in a context of asymmetric information could depress demand for fertilizer and complementary agricultural investments.

Overall, farmer suspicions about quality may partially explain the slow uptake of the use of fertilizer in Tanzania. In the long-term, uncertainty regarding fertilizer quality could have widespread consequences for the functioning and growth of fertilizer demand. Such problems could hamper efforts to increase adoption of fertilizer as a means of raising regional agricultural productivity and improving household and national food security. As a result, it is critical for policy to understand not merely the determinants of quality and quality degradation but also how farmers are assessing fertilizer quality, what attributes they care about, and how they decide whether a purchase has those attributes. Increasing small farmer use of fertilizer and hybrid seeds is key to improving regional agricultural productivity and raising incomes and food security but use of these inputs remains relatively low. Our results suggest variable quality – both physical attributes and unobservable nutrient content – is an important missing piece of the puzzle.

[28]For example, YARA introduced small one and two kilogram packs of fertilizer to the Tanzanian market for a few years leading up to this research but quickly discontinued them citing the additional cost that maintaining two bagging and supply lines added to their operations.

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Appendix

Table A1: Prevalence of poor physical attributes of fertilizer samples. CAN

	Farmer samples (%)	Seller samples (%)
Presence of clumps/caking	20.0	15.5
Discolored	0.0	13.8
Presence of foreign material	0.0	1.7
Presence of powdered granules	0.0	14.9
n	5	181

Table A2: Prevalence of poor physical attributes of fertilizer samples. DAP

	Farmer samples (%)	Seller samples (%)
Presence of clumps/caking	9.3	14.6
Discolored	1.9	23.1
Presence of foreign material	7.4	1.5
Presence of powdered granules	0.0	1.0
n	54	130

Table A3: Prevalence of poor physical attributes of fertilizer samples. urea

	Farmer samples (%)	Seller samples (%)
Presence of clumps/caking	16.9	42.0
Discolored	7.6	2.4
Presence of foreign material	11.0	8.2
Presence of powdered granules	11.0	6.8
n	118	293

Table A4: Regression of the fractional deviation of nitrogen from the manufacturer standard on observable mineral fertilizer quality characteristics (agro-dealer samples), by fertilizer type.

	(1) UREA N standardized	(2) DAP N standardized	(3) CAN N standardized
Clumping present	6.89e-05	-0.00297	-0.000500
	(6.17e-05)	(0.00535)	(0.00266)
Powders present in sample	0.000188		0.00539
	(0.000300)		(0.0281)
Sample discolored	0.000536	-0.00856	-0.0113
	(0.000725)	(0.0159)	(0.0308)
Foreign material present in sample	-0.00309	0.0162	0.0444***
	(0.00304)	(0.0256)	(0.00529)
Constant	-0.00277***	-0.0275***	-0.0583***
	(0.000157)	(0.00359)	(0.00355)
Observations	293	130	181
R-squared	0.013	0.011	0.026
Number of agro_n	167	80	115
Seller FE	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A5: Willingness-to-pay assessment; effect of information about unobservable nitrogen content on WTP.

	(1) WTP TZS	(2) WTP TZS
Sample B (clumps)	-861.5***	-861.5***
	(77.63)	(77.66)
Sample C (foreign material)	-973.2***	-972.7***
	(77.77)	(77.80)
post information	707.9***	707.9***
	(77.63)	(77.66)
Sample B * post information	142.1	142.1
	(109.8)	(109.8)
Sample C * post information	10.82	10.23
	(109.9)	(109.9)
Constant	1,493***	1,493***
	(69.59)	(54.91)
Farmer FE		Y
Observations	989	989
R-squared		0.438

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A6: Regression of physical attributes on seller fixed effect (Column 1), market fixed effect (Column 2), and supply chain and source characteristics (Column 3): Powdering

	(1)	(2)	(3)
VARIABLES	powdering present	powdering present	powdering present
DAP	-0.0301	-0.0549*	-0.0564**
	(0.0292)	(0.0288)	(0.0280)
CAN	0.0839***	0.0815***	0.0821***
	(0.0260)	(0.0258)	(0.0252)
Distance to Dar es Salaam			-0.000211
			(0.000166)
Primary supplier in Morogoro			-0.0622**
			(0.0302)
Primary supplier in Ifakara			0.0339
			(0.0426)
Primary source is a tertiary market			0.00227
			(0.0450)
Number of suppliers in the marketplace/village			-0.00236
			(0.0129)
Constant	0	-0.00886	0.154**
	(0.248)	(0.151)	(0.0601)
Agrodealer FE	Y		
Village FE		Y	
Observations	605	605	605
R-squared	0.409	0.215	0.049
RMSE	0.248	0.260	0.265

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A7: Regression of physical attributes on seller fixed effect (Column 1), market fixed effect (Column 2), and supply chain and source characteristics (Column 3): Caking

	(1) caking present	(2) caking present	(3) caking present
DAP	-1.127***	-1.167***	-0.972***
	(0.193)	(0.198)	(0.192)
CAN	-0.864***	-0.923***	-0.894***
	(0.173)	(0.177)	(0.173)
Distance to Dar es Salaam			-0.000659
			(0.00113)
Primary supplier in Morogoro			-0.128
			(0.207)
Primary supplier in Ifakara			0.614**
			(0.292)
Primary source is a tertiary market			-0.0680
			(0.308)
Number of suppliers in the marketplace/village			-0.111
			(0.0883)
Constant	0	0.697	1.669***
	(1.645)	(1.036)	(0.412)
Agrodealer FE	Y		
Village FE		Y	
Observations	605	605	605
R-squared	0.464	0.238	0.080
RMSE	1.645	1.785	1.818

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A8: Regression of physical attributes on seller fixed effect (Column 1), market fixed effect (Column 2), and supply chain and source characteristics (Column 3): Caking

	(1) discoloration present	(2) discoloration present	(3) discoloration present
DAP	0.254***	0.244***	0.217***
	(0.0348)	(0.0326)	(0.0309)
CAN	0.114***	0.112***	0.113***
	(0.0311)	(0.0293)	(0.0279)
Distance to Dar es Salaam			-0.000137
			(0.000183)
Primary supplier in Morogoro			-0.0697**
			(0.0334)
Primary supplier in Ifakara			-0.0250
			(0.0472)
Primary source is a tertiary market			-0.00277
			(0.0498)
Number of suppliers in the marketplace/village			-0.0215
			(0.0143)
Constant	-0	0.215	0.136**
	(0.296)	(0.171)	(0.0665)
Agrodealer FE	Y		
Village FE		Y	
Observations	605	605	605
R-squared	0.339	0.211	0.088
rmse	0.296	0.295	0.294

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A9: Regression of physical attributes on seller fixed effect (Column 1), market fixed effect (Column 2), and supply chain and source characteristics (Column 3): Foreign material

	(1)	(2)	(3)
	foreign material present	foreign material	foreign material
DAP	-0.0778***	-0.0785***	-0.0676***
	(0.0236)	(0.0234)	(0.0222)
CAN	-0.0682***	-0.0672***	-0.0645***
	(0.0211)	(0.0210)	(0.0200)
Distance to Dar es Salaam			-0.000214
			(0.000132)
Primary supplier in Morogoro			-0.0218
			(0.0240)
Primary supplier in Ifakara			-0.0494
			(0.0339)
Primary source is a tertiary market			0.0149
			(0.0358)
NUM_suppliers			-0.0103
			(0.0102)
Constant	0	0.0486	0.172***
	(0.201)	(0.123)	(0.0478)
Agrodealer FE	Y		
Village FE		Y	
Observations	605	605	605
R-squared	0.378	0.170	0.038
rmse	0.201	0.211	0.211

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Fertilizer testing

The Soil-Plant Diagnostics Spectral Lab at the World Agroforestry Centre (ICRAF) in Nairobi, Kenya, conducted the nutrient content testing for all of the mineral fertilizer samples. ICRAF utilized two methods to determine the nitrogen content: Mid-infrared diffuse reflectance spectroscopy (MIR) and portable X-ray fluorescence (pXRF) spectroscopy. In general, spectroscopy measures the quantities of chemical elements (ie., nitrogen), by analyzing how infrared radiation responds to physical matter (ie., fertilizer). Although spectroscopy is used widely in many fields, ICRAF has been a world leader in developing and utilizing these technologies for agricultural applications. Namely, ICRAF has contributed to advancing spectroscopy techniques and methodologies for measuring soil (Terhoeven-Urselmans et al. 2010, Towett et al. 2015) and plant (Towett et al. 2015) chemical composition. As the spearhead of the African Soil Information Service, a project to generate new and precise soil maps for the continent, the next focus for ICRAF is to develop and test methodologies for rapidly testing mineral fertilizer. This rapid testing would enable the fertilizer industry to ensure that high quality mineral fertilizer is supplied and provide the ability for area-specific blending that accommodates and addresses the soil conditions of that particular area.

The MIR technology relies on predicting the chemical values based on a set of previously calibrated data. In our case, ICRAF instructed us to test 59 of our fertilizer samples externally, the results of which would be used as reference data to measure the nitrogen content of the remaining fertilizer samples. The nitrogen content of these 59 samples was analyzed with a traditional wet chemistry method, the Kjeldahl method, at Thornton Laboratories in the United States.[1] For the MIR measurement of nitrogen content, ICRAF relied on Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES) methods.[2] For reference, the prediction capability of MIR technology for total nitrogen content for soil is good: Towett et al. (2015) find that using MIR can predict total nitrogen with a R^2 greater than 0.80.

The pXRF method is a technology that has exciting field-based applications. Unlike MIR technologies, the pXRF is a handheld device, meaning that it can be used directly in the field. The pXRF analyzes the total elemental composition of the physical matter being measured. For example, in the case of mineral fertilizer, this technology has the ability to serve two main purposes. First, it has the ability to rapidly test whether the fertilizer nutrient content has degraded and/or whether it has been adulterated. Second, if area-specific fertilizer blends becomes widespread, the technology is sensitive enough to measure whether

[1] The specific procedure used was AOAC 955.04. More information is available here: http://www.eoma.aoac.org/methods/info.asp?ID=29898

[2] The method was developed by KU Lueven University, additional information can be found here: https://www.mtm.kuleuven.be/equipment/ICP-OES/ICP-OES

the fertilizer is the appropriate chemical composition. Our fertilizer samples were the first set of samples to be tested with ICRAF?s pXRF and will serve as reference data for subsequent fertilizer analyses.

Willingness-to-pay elicitation

In the assessment, we showed farmers three samples of fertilizer that the survey team had purchased from agro-dealers in the Morogoro region and which had been lab-tested for nutrient content. All samples were of a nutrient content that met FAO and Tanzanian government fertilizer standards and can therefore be considered good quality, despite the variation in their physical characteristics. We showed participants three samples of Urea fertilizer: Sample A, good appearance (bright white and prilled) and good nutrient quality; Sample B, bad appearance (caked clumps with discoloration) and good nutrient quality; Sample C, bad appearance (presence of foreign material; perhaps mixed with some DAP) and good nutrient quality.

Participants were provided with all three samples to inspect at the same time. They were given one minute to examine the three samples however they chose (for example, participants were free to open the bag, touch the fertilizer, etc.). Participants were then asked to provide the enumerator with the highest price that they would be willing to pay for the sample. After obtaining the initial willingness to pay, participants were provided with information on the measured (unobserved) nutrient quality of each sample. The following script was used for each sample:

Now, I would like to provide you with information on the nutrient and moisture content of these fertilizer samples. Fertilizers, including Urea, have nutrient and moisture standards that ensure that the fertilizer will improve soil fertility and help the crops to grow. For example, in Urea, the most important element is Nitrogen and samples of Urea should contain 46% Nitrogen. Also, Urea should not have moisture content greater than 1%. We tested the nutrient and moisture content of these Urea samples to ensure that they meet industry and national standards. We tested the fertilizer samples at a laboratory in Florida, USA. This particular laboratory tests the nutrient and moisture content of fertilizers for farmers and agricultural companies in the United States. We have the results of those tests and would like to share them with you. This sample has a Nitrogen content of X% and a moisture content less than Y%. According to the results from the laboratory, this sample meets industry standards and when applied correctly, will improve soil fertility and help crops grow.

Note that "X" and "Y" represent the actual values of the measured nutrient and moisture content, and the statement was repeated for Sample A, Sample B, and Sample C. After receiving the nutrient quality information, participants were again asked to provide their maximum willingness-to-pay for each fertilizer sample.