The opacity of international fertilizer companies: reluctance to adopt transparency and traceability systems

Janjaap Semeijn[a,*], Edwin Van Duyse[a], Wim Lambrechts[a], Cees J. Gelderman[a]

*Corresponding author: janjaap.semeijn@ou.nl

[a] Department of Marketing & Supply Chain Management, Open Universiteit, Heerlen, the Netherlands

Abstract

With the introduction of new regulations, such as the European Corporate Sustainability Due Diligence Directive, transparency and traceability have become essential for demonstrating sustainable (supply chain) management practices. This study aims to explore the reluctance of fertilizer companies to disclose the origins of their materials, despite significant environmental, health, safety, and food quality implications of fertilizer use. To achieve this, we analysed sustainability reports to assess how these companies publicly account for their traceability and transparency efforts. Additionally, semi-structured expert interviews with high-level managers were conducted to uncover their perceptions, motivations, and their (limited) willingness to adopt comprehensive transparency and traceability systems. Our findings indicate that fertilizer companies primarily react to legislative requirements and political risks rather than proactively embracing traceability. Internal and external stakeholder perspectives diverge significantly: while some managers view existing quality systems as sufficient for ensuring product safety, others recognize traceability as a critical component of quality assurance. Few managers are willing to expand transparency unless mandated by regulation or stakeholder pressure. Perceived risks, such as potential liability and competitive disadvantage, further hinder progress toward full traceability. This study highlights the tension between regulatory demands and common business practices. For the industry, embracing traceability and transparency not only aligns with evolving regulatory requirements, but also enhances stakeholder trust and secure a competitive edge in increasingly sustainability-focused markets.

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Fertilizers rarely make the headlines, with the recent blast in Beirut, Lebanon (August 2020) being a notable exception. Every year millions of tons of phosphate rock and potassium nitrate are being mined and shipped from low income to high income nations, using considerable energy and resources, including natural gas, for processing. The final product affects animal feed and our own food in myriad ways. Entire food chains have become heavily dependent on the use of chemical fertilizers, yet the fertilizer footprint in CO2, SO2 and NOx is rarely discussed (Mosier, Syers & Freney, 2004). While new supply chain transparency regulations emerge, the fertilizer industry has been relatively slow in adopting traceability and transparency (Schäfer, 2022). Fertilizer companies could play a key role in the sustainability of the entire food system, but are often seen as opaque rather than transparent (Gardner et al., 2018).

Due to growing public demands regarding safety and quality in supply chains, the last decades have seen a rise in transparency among producers and their supply chains (Grunert, 2005; UN, 2014). Supply chain transparency and traceability are closely related to food safety (Luo et al., 2018) and sustainability (Lambrechts, 2021). Transparency refers to the practice of sharing information about procedures and practices regarding transactions between buyers and suppliers, thereby ensuring consistency and stakeholder trust (Budler, Quiroga & Trkman, 2023). Traceability can be defined as the ability to track the provenance and journey of products and their inputs from the origin of the supply chain through the end-use. Traceability enables companies to monitor and verify the origins, history, locations, and applications of the products in their supply chain (Norton & Conlon, 2019).

Global initiatives have been launched to encourage traceability in commodities such as beef, cocoa, fish, palm oil, and sugar (UN, 2014; Olsen & Borit, 2013). Much academic research is focused on the feed and food industry (Luo et al., 2018; Bosona & Gebresenbet, 2013; Zhang & Kraisintu, 2011), including demands for organically grown food (e.g. Misra & Singh, 2016; Hsu, Chang & Lin, 2016). The intensified use of fertilizers has well-documented devastating effects on environmental sustainability and our ecosystems (e.g. Xiang, Malik & Nielsen, 2020; Rawnsley et al., 2020; Thrän et al., 2020). However, the transparency and traceability practices of global fertilizer companies are still under-researched.

The chemical fertilizer industry can be characterized as both capital-intensive and polluting. It is also a high-risk industry – due to the production of (explosive) nitrates, for example. The use of chemical fertilizers entails many hidden dangers to the environment and human health, including groundwater contamination and the disrupted development of infants (Buckler, 2017). Many scholars in the agricultural and chemical sciences have studied sustainability risks of chemical fertilizers. However, these issues are rarely explored from a supply chain management perspective, leaving a critical gap in understanding how supply chain managers handle the security-safety dilemma: the use of fertilizers increases food security but decreases food safety through deteriorated environmental quality (e.g. Xiang, Malik & Nielsen, 2020).

Much of the raw material for producing commercial fertilizers – crushed rock containing nitrogen, phosphorus, and potassium – is sourced from low income

countries. These countries typically face challenges regarding heavy-metal contamination (e.g. cadmium and lead) (Wu et al., 2015; Steffan et al., 2018). Therefore, the European Commission (EC) has set several regulations (EC, Article 8 and 26, 2003; EC, Article 43, 2008; EC Article 552, 2009) to avoid detrimental outcomes associated with compromised food safety and security, and fertilizer companies must implement traceability systems to comply with these regulations. The reluctance of these companies to disclose information on their suppliers and production processes could be driven by concerns about competitive advantage, political risks, or simply a lack of incentives to invest in these systems (Gardner et al., 2018). Despite recent regulatory frameworks mandating traceability and transparency, there is limited research on why fertilizer companies are hesitant to comply. Therefore, the aim of this study is to shed light on underlying causes for this apparent reluctance to expand on traceability and disclose information about their suppliers.

LITERATURE REVIEW

The growth of the global food system has relied heavily on the use of chemical fertilizers, but their production and use also entails vast environmental and social impacts. Several studies have examined the challenges and risks of chemical fertilizers, including their energy-intensive production, greenhouse gas emissions, soil degradation, water pollution, and human health impacts (Ray et al., 2020; Raklami et al., 2019; Bade et al., 2017).

DEFINITION OF TRACEABILITY

The literature offers a range of perspectives on the topic, and the definition of traceability appears inconsistent (Luo et al., 2018; Olsen & Borit, 2013), e.g. by referring to product properties, instead of governance methods for (sustainable) supply chain management. Most limitations and shortcomings in the definition of traceability systems stem from being considered key functions and properties of traceability, which appear to be: 'tracing', the identification of what has to be traced; and 'tracking', record keeping of gathered data and access to information (Olsen & Borit, 2013). According to Schwägele (2005), and specifically related to food supply chains, tracking is related to the provision of information downstream in the supply chain, and tracing is related to the gathering of information upstream in the supply chain.

In addition to academic definitions of traceability, institutional definitions have been developed, mentioning an ability to either find, follow or verify information through a supply chain. Influential definitions originate from the International Organization for Standardization (ISO), the EC, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations. ISO define traceability as: "the ability to trace the history, application or location of that which is under consideration" (ISO 9000, article 3.5.4, 2000). The EC defines food product traceability as: "the ability to trace and follow a food, feed, food-producing animal or substance through all stages of

production, processing and distribution" (European Parliament Regulation EC178, article 18, paragraph 1, 2002). The standards used by the WTO are established by the WHO and the FAO in the Codex Alimentarius (WTO, 2019). Traceability has become part of the Codex Alimentarius Commission (CAC) procedure manual, which defines it as "the ability to follow the movement of a food through specified stage(s) of production, processing and distribution" (WHO, 2006).

Logging historic data related to time and position of identifiers seems to be the main target of traceability systems (Dabbene & Gay, 2011). Olsen and Borit (2013) state that very few definitions – institutional or academic – try to combine the most important properties of traceability or to define the concept 'to trace', and provide the following definition: "the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (p. 148). This definition distinguishes between having traceability and verifying the claims in a traceability system, such as record keeping of properties and verification of these properties by means of analytical tools and methods.

PERCEIVED USE OF TRACEABILITY IN THE FERTILIZER INDUSTRY

Sustainability perspectives within the fertilizer industry are diverse and often conflicting. On one hand, sustainability in this sector is often related to the expansion of global food production (particularly through the "Green Revolution"), which addressed food scarcity challenges (e.g. Childers et al., 2011). Research in this domain has emphasized the sustainable provision of scarce raw materials (Cordell & White, 2013; 2008; Withers et al., 2015), e.g. by interlinking it to circular economy principles. On the other hand, the industry faces criticism for its fundamentally unsustainable and unethical practices, particularly regarding its environmental and social externalities which disproportionally affect the global South (Hsu, Chang & Lin, 2016; Xiang, Malik & Nielsen, 2020; Rawnsley et al., 2020).

Research on traceability predominantly centers on (end) consumer perceptions and demands (e.g. Liu et al., 2019; Loureiro & Umberger, 2007; Ubilava & Foster, 2009; Rodriguez-Salvador & Dopico, 2020; Chang, Tseng & Chu, 2013) and on (individual) farmer's or producer's perspective (e.g. Liao, Chang & Chang, 2011; Monteiro & Caswell, 2009; Stranieri et al., 2016; Zhao & Chen, 2012). Trust has emerged as a recurring theme in these studies, reflecting the reliance of farmers (e.g. Monteiro & Caswell, 2009) and consumers (e.g. Matzembacher et al., 2018)- on fertilizer companies and their products. Farmers, for instance, often purchase fertilizer in bulk without the ability to pre-test its performance. Therefore, trust in product quality and company reliability is high. Moreover, farmers' willingness to engage in traceability systems is often linked to their awareness of benefits, such as improved product quality control and food safety (Liao, Chang & Chang, 2011; Monteiro & Caswell, 2009; Zhao & Chen, 2012).

Despite the recognized importance of traceability in food and feed supply chains, fertilizer companies (situated upstream in the supply chains) are often overlooked in academic research on traceability initiatives. Research among

supply chain managers and experts has highlighted that traceability is often viewed as a tool for improving food safety, food quality and supply chain efficiency (Zhang & Kraisintu, 2011; Heyder et al., 2010; Kher et al., 2010). Some managers recognize the potential of traceability systems to enhance company and supply chain performance (Shankar, Gupta & Pathak, 2018; Pagell & Wu, 2009), others treat these systems as marketing tools to increase their company's public image (Delmas, Etzion & Nairn-Birch, 2013). For example, supply chain managers may try to use ratings and certification as evidence of their companies' environmental performance outcomes, but this "evidence" appears to be used as a "window dressing" practice for marketing purposes rather than a means of improving environmental performance.

In addition, many supply chain managers are reluctant to provide full transparency through traceability systems due to fears that disclosing information may expose their company to reputational risks (Delmas, Etzion & Nairn-Birch, 2013; Van den Brule, 2008; Pullman, Maloni & Carter, 2009; Styles, Schoenberger & Galvez-Martos, 2012). For example, revealing environmental and social impacts in the supply chain may lead to negative public perceptions and potential customer backlash toward the focal company, a phenomenon referred to as 'guilt-by-association' in supply chain context (Veit et al., 2018). Related to this issue, some managers' unwillingness to share information through traceability seems to stem from a lack of trust regarding certain parties within the supply chain (Lam et al., 2018; Sarpong, 2014).

MATERIALS AND METHODS

DATA COLLECTION

Given the sensitive nature of the topic, we anticipated that respondents might be hesitant to share detailed information. To supplement our primary data collection, we also analysed voluntary disclosures by other companies in the same sector. Secondary data were sourced through the Global Reporting Initiative (GRI) Disclosure Database. Companies were selected based on the following criteria: (i) the company's primary focus and activities should be within the fertilizer industry; (ii) the sustainability report should be accessible through the GRI database in PDF format; (iii) the report should fall within the timeframe of 2015-2018. Using these criteria, we identified ten companies for analysis. The first criterion was particularly significant, as many fertilizer-related activities are conducted by broader chemical corporations. For instance, BASF was excluded from the sample because its operations encompass various sectors beyond fertilizers. The second criterion ensured the accessibility and consistency of the disclosed information. While many companies also provide data in HTML format, we found that the associated web links frequently led to general or non-functional pages, limiting their usefulness for analysis. The third criterion specifically delineates the timeframe because the period aligns with significant developments in global sustainability (such as the Paris Agreement and the Sustainable Development

Goals), while avoiding potential distortions in disclosure due to the COVID-19 pandemic. Furthermore, setting a specific timeframe ensures consistency in the data set, which is essential for cross-case analysis.

The second part of our study focused on exploring the subjective realities of managers working in the fertilizer industry, a perspective about which little is currently known (Zhang & Kraisintu, 2011). We employed semi-structured interviews in order to target specific case study topics, provide nuanced explanations, and capture individual perspectives, including perceptions, attitudes and meanings. Semi-structured interviews were particularly suitable for our study, as prior literature emphasized the critical role of supply chain managers' perceptions in shaping traceability practices (Yin, 2014). A key advantage of this method is its flexibility, which allows for deeper exploration of responses to uncover the underlying reasons behind particular perceptions (Saunders, Lewis & Thornbill, 2015). The interviews were conducted face-to-face, ensuring a more personal and engaging interaction, and were recorded using a Dictaphone for accuracy and subsequent analysis. Each interview was guided by a list of operationalized themes, which ensured consistency across interviews while allowing respondents to elaborate on their experiences and viewpoints (see Appendix 1).

To ensure relevance and depth of insights, only managers with a minimum of three years of experience in the fertilizer supply chain were selected for the interviews. Respondents were primarily identified at industry conferences organised by fertilizer company associations, such as the International Fertilizer Association (IFA), the Ammonium Nitrate & Nitric Acid producers group (ANNA) and Urea Know How group. A pilot test involving three semi-structured interviews was conducted to identify potential flaws, limitations, or weaknesses in the interview design and to refine the research questions for greater clarity and focus.

The selection of posed significant challenges, as many companies and individuals were unwilling to provide detailed information on the topic. Additionally, four respondents withdrew from the study due to management decisions halting participation once sensitive topics, such as 'window dressing' and corporate social performance, were introduced. This withdrawal highlights the industry's broader reluctance to engage with issues surrounding traceability and sustainability.

All interviews were conducted face-to-face, typically at the respondents' (home) offices, to facilitate open communication in a familiar setting. The final sample included seven respondents based in the Netherlands (NL) and one in Belgium (B) (see table 1). Before each interview, participants were informed about the study's, and their consent was obtained for recording and transcribing the interviews. After transcription, the interview transcripts were shared with the respondents for review and approval to ensure accuracy and mutual agreement on the content.

Table 1. Respondents' demographics and compliance overview

#	Role	Company tier	Management tier	Office country	Gender	Age	Seniority in role
1	Director track, trace & recall	Producer	Corporate	B	M	50-59	20-29
2	Planning manager loading & logistics	Producer	Middle management	NL	M	40-49	10-19
3	Site manager loading & logistics	Producer	Site management	NL	M	40-49	3-9
4	Senior operations supervisor	Wholesale	Middle management	NL	M	30-39	3-9
5	Director supply chain	Producer	Corporate	NL	M	50-59	10-19
6	Manager logistics and QHSE	Wholesale	Site management	NL	M	60-69	30-39
7	Project manager operations & logistics	Producer	Site management	NL	M	30-39	10-19
8	Production planner operations	Producer	Middle management	NL	M	60-69	20-29

Note: B: Belgium; NL: the Netherlands; M: male.

DATA ANALYSIS

The content of the sustainability reports was analysed through a key term analysis, focusing on terms such as traceability, transparency, supply chain, and risk. This analysis allowed us to evaluate how companies communicate with stakeholders and the extent to which they disclose information about their activities.

The semi-structured interviews were coded using the code-tree (Appendix 2) that was developed iteratively, moving back and forth between empirical findings and relevant theoretical frameworks (Miles & Huberman, 1994; Strauss & Corbin, 1998). All interviews transcripts were uploaded into the qualitative analysis software MAXQDA to facilitate systematic coding. To enhance reliability, the coding of the transcripts was independently reviews by a second researcher. The comparison between expected and observed patterns was conducted using pattern matching (Yin, 2014), a technique that identifies and evaluated discrepancies between theoretical expectations and empirical results.

A potential methodological issue lies in assessing the genuine social performance of transparency and traceability. To address this, we implemented a strategic approach to mitigate respondents' reluctance to discuss sensitive topics, such as 'window dressing' or personal opinions. If a respondent hesitated to address such issues, examples from other industries were introduced, framing window dressing as a common business practice to normalise the discussion. If reluctance persisted, anonymized examples of other companies were presented to

encourage open dialogue (Gelderman, Semeijn & De Zoete, 2008). This strategy helped create a more open environment for detailed and meaningful responses.

RESULTS

SUSTAINABILITY REPORTS

The sample consisted of ten companies with headquarter (as stated in the GRI Disclosure Database) in Austria (1), Canada (2), Germany (1), Norway (1), the Russian Federation (2), the Netherlands (1), and the United States of America (2). It should be stated that all companies are multinationals with regional and local plants located in other countries and continents. The length of the sustainability reports varied. Some of the companies only disclosed short, brochure-like reports with reference to other reports, while others disclosed reports of more than 200 pages. The average length of the reports analyzed was 109,3 pages, and the mean length was 93,5 pages (see Table 2).

Table 2. Overview of sustainability reports sample and analysis

Company	Country*	Year	# pages	Language	Traceability	Transparency	Supply Chain	Risk
Agrium	CA	2017	87	English	-	-	✓	✓
Borealis	AT	2018	213	English	✓	✓	✓	✓
CF Industries	US	2015	26	English	-	✓	-	✓
Eurochem	RU	2017	48	English	-	✓	✓	✓
K+S Gruppe	DE	2017	222	German	-	✓	✓	✓
OCI	NL	2018	100	English	-	✓	✓	✓
Potash Corp.	CA	2016	19	English	-	✓	✓	✓
Mosaic Company	US	2016	14	English	-	-	-	-
Uralkali	RU	2016	192	English	-	✓	✓	✓
Yara International	NO	2016	172	English	-	✓	✓	✓

Note: * as stated in GRI Disclosure Database; AT: Austria; CA: Canada; DE: Germany; NL: Netherlands; NO: Norway; RU: Russian Federation; US: United States of America

Only one company explicitly references 'traceability' in its sustainability report. Borealis describes its use of Teams SR, an integrated environmental data management system, and reporting software package, emphasizing its role in ensuring comprehensive data control: "This ensures control of data flows from varied sources, in multiple formats and on different schedules, as well as traceability and transparency required for reporting" (Borealis, p. 79).

In contrast, eight out of ten companies address 'transparency', but predominantly within the broader context of corporate social responsibility (CSR) and good governance, rather than as it relates to traceable supply chains:

> *"Proactive and transparent corporate governance is crucial for aligning the interests of shareholders, management, employees, and other stakeholders" (Yara International, p. 23)*

OCI highlights transparency as a key business value that facilitates sustainable growth and stakeholder engagement:

> *"We believe in the importance of business transparency and stakeholder engagement as a tool to effect change and sustainably grow our business" (OCI, p. 46)*

References to supply chain-related aspects appear in most reports, but the depth of information varies. Some companies briefly mention their relationships with suppliers:

> *"The Company strives to ensure alternative suppliers and contractors are available for all its needs" (Uralkali, p. 44)*

> *"We promote sustainable agriculture and nutrient stewardship through our supply chain, which begins with sourcing natural gas and ends at our agricultural and industrial customers. We work diligently to ensure every aspect of our business operates optimally, and promote best practices through our Supplier Code of Conduct" (OCI, p. 51)*

> *"Businesses need to engage with their upstream and downstream supply chains and wider 'communities of interest'" (Eurochem, p. 33)*

> *"To ensure responsible sourcing throughout its supply chain, in 2017 Borealis took up the voluntary obligation to be annually assessed according to the systematic Ecovadis Standard" (Borealis, p. 26)*

The sustainability reports reviewed lack detailed disclosures about supply chains, partners, or suppliers. For instance, Potash Corporation emphasizes that customer priorities center on supply reliability: Potash Corporation, for example, states that what matters most to their customers is supply reliability (Potash Corp., p. 8). While the company refers to its own plants as sources of raw materials, it also notes that some materials are "purchased from other locations" (Potash Corp., p. 9). Other reports offer only vague references to suppliers, avoiding transparency about operational specifics.

However, legislative and political risks are explicitly addressed in several reports. For example, Yara International as well as OCI highlight the growing regulatory pressures and their potential economic impact:

> *"There is an increasing trend of stricter governmental regulations impacting both production economics (Emission trading system in Europe) and application of fertilizer related both to the environmental aspects and safety related aspects of handling and applying fertilizer. These regulations could have a substantial impact on Yara's earnings (…) Our investments and operations may be affected as a result of changes in political leadership, policies and regulations as well as political and social instability in a country or a region. Such changes could represent threats as well as opportunities for Yara" (Yara International, p. 43)*

> *"Risks related to changes in laws and regulations, including HSE, tax, and financial reporting, and other legislation that may require changes in the way we do business" (OCI, p. 86)*

Borealis also acknowledges potential challenges stemming from non-compliance with product stewardship obligations:

> *"In addition to these risks to people and the environment, Borealis' failure to comply with its product stewardship obligations could lead to the loss of market share because its products are non-compliant" (Borealis, p. 74)*

Despite the recognized importance of traceability as a pillar of sustainability in a global supply chains, the reports fail to provide specific details on the issues at stake. This omission highlights companies' reluctance to disclose traceability data, likely due to concerns over confidentiality or competitive advantage.

EXPERT INTERVIEWS

The results of the interviews are structured according to the coding process (see Appendix 2 for theoretical categories and dimensions). Statements have been coded and clustered regarding different issues of (i) definition and interpretation; (ii) product quality and safety improvement; (iii) supply chain efficiency; and (iv) image and adoption.

Traceability and transparency

Traceability allows companies to provide critical information to their customers, demonstrating accountability and control. As one respondent explained:

> *"You can easily demonstrate to a customer, OK, the ship was loaded then and these are the corresponding shipping samples. And we can also show when it was produced and what the production analyzes were of that day" (Respondent 1).*

However, the link between traceability and transparency is not always straightforward. According to two supply chain managers from mid-sized fertilizer companies (Respondents 4 and 8), the extent to which traceability fosters transparency depends on the degree of its implementation. Respondent 4 emphasized that implementing traceability is a time-intensive process, requiring careful planning and execution. Similarly, Respondent 8 noted that the level of transparency achieved also hinges on whether clear agreements are established with all stakeholders involved in the supply chain.

Furthermore, Respondent 5 highlighted that enhancing transparency is often the primary objective when companies adopt traceability practices. This perspective underscores the potential of traceability systems to improve visibility and trust within supply chains, provided they implemented effectively.

Improving product quality and safety

Respondents expressed mixed perceptions regarding the impact of traceability and transparency on product quality and safety. On one hand, traceability data is a valuable tool for conducting root cause problem analysis, enabling companies to trace quality issues back to their origin. However, opinions differ on what is necessary to achieve this:

> *"You need to get the mindset right so everybody minds quality. People should be aware that all that can contribute to a deviating product gets reported" (Respondent 2)*

> *"In order to improve quality it is important to know who delivered a product in case of complaints. We need to know from which supplier that product has come otherwise we cannot improve the product, so there you need traceability." (Respondent 6)*

The benefits of improved product quality and safety also vary across the supply chain. When closer to feed and food production, guaranteed agricultural product quality becomes a critical asset. Producers of agricultural products bear the liability for ensuring the quality of the final product, whereas fertilizer producers are only responsible for the quality of the ingredient used. This dynamic suggests that the middle-tier of the supply chain, such as fertilizer producers, may gain the most from traceability, as it helps ensure quality for downstream stakeholders and customers.

While traceability is essential for identifying problems within the supply chain, it also carries risks. For instance, incidents occurring upstream or downstream could result in reputation damage for producers or wholesalers due to increased transparency. This potential for "guilt by association" highlights tensions between internal benefits (such as quality and safety improvements) and external risks tied to transparency initiatives:

> *"One gets suspicious when somebody doesn't want to be transparent, when he can't say where his product or raw materials come from. I understand that you don't give your process free as a producer because it is your way to produce. But a raw materials producer who doesn't want to reveal where his product or raw materials come from, that's suspicious of course" (Respondent 8)*

According to Respondent 8, excessive external traceability could reveal sensitive information about methods, commodities, and sources, creating risks for companies. Therefore, achieving an optimal balance between internal and external traceability is crucial. This balance enables efficient product checking, rapid response to issues, root cause analysis, and the implementation of effective solutions without compromising competitive advantages.

Supply chain efficiency

The added value of traceability lies in its ability to create structures for real-time databases that capture processes and events, offering a detailed view of the

supply chain. This enhanced visibility can lead to improved product delivery and customer service. However, implementing traceability can also increase administrative burdens:

> *"The business efficiency mainly comes from looking into information and process flows, so you identify things to improve or act different. We go for that, we have decided to invest in automation via the use of barcodes, RFIDs and other techniques" (Respondent 1)*

> *"You have a much better overview of where stock sits, it is better to steer, especially if you are in a tight market. You can deliver much more efficient. We can act very fast on questions about where it has been produced and where it comes from. Every complaint we can track back to production circumstances" (Respondent 2)*

Customer service also benefits from traceability, as tracking and tracing data can serve as evidence when addressing problems or complaints. Moreover, it is a valuable tool for root cause analysis, helping identify deviations in product, production, or packaging:

> *"Suppose a certain shift has packaged that final product, then we can track it back to that shift and almost to the operator who has worked on it. And then in any case you can talk to him and discuss what went wrong and where improvements are possible" (Respondent 4)*

Respondents had differing perspectives on who benefits the most from improved supply chain management efficiency. According to one respondent, the extent of these benefits depends on the product type, its position in the supply chain, and its destination. For logistics involving bulk fertilizers, the advantages appear uniform across all tiers. However, for products destined for feed and food, the benefits are more pronounced for companies involved, due to their higher liability (Respondent 1).

Image and adoption

Perspectives on transparency and traceability vary significantly, particularly between "old school" and "new school" managers. "Old school" managers often exhibit a cautious approach, perceiving transparency as a potential threat. They prefer to avoid changes that could disrupt established practices: "we don't need this, boys we can do anything we want, we know that, right?".

These perceptions may also be influenced by the manager's role and position within the supply chain:

> *"Transparency can be a larger threat to traders than to producers. Their added value lies precisely in the fact that you cannot see what they do and from where they get their materials" (Respondent 1)*

In contrast, "new school" managers recognize more distinct advantages of transparency and advocate for its genuine adoption, viewing it as an opportunity rather than a threat. They emphasize using transparency and traceability as tools to drive meaningful improvements rather than merely for appearances. Being proactive and transparent can create a competitive advantage:

> *"Yes, but wait a minute, we cannot turn our back on this. We can try using window dressing and construct a story around it, but we can also say no, let's take care of the core and really do something about it (…) It is the companies' policy and interest to be transparent. We can show what we do and we want to comply to legislation. At the end traceability on fertilizers is targeted to tracking and tracing which is absolutely no threat, on the contrary, it is just fine!" (Respondent 5)*

> *"If we have it under control and our competitors have not, then we have an advantage (…) if you show you have it under control it is no longer a threat" (Respondent 2)*

The fertilizer industry faces increasing pressure to adopt traceability due to EU directives and local legislation. Over time, traceability is expected to become a "license to operate", though its adoption has been slow as companies require time for implementation. Respondents universally denied engaging in window dressing within their own companies but expressed suspicion that some competitors might use such tactics, albeit without concrete evidence.

Regional differences in market maturity also influence the degree of legislative and customer pressure to adopt traceability. In more mature markets, companies are compelled to meet higher expectations. In addition to legislative compliance, transparency has a positive impact on corporate image, particularly in the context of social responsibility. Companies that can demonstrate effective traceability systems build trust with both governments and stakeholders, aligning with broader expectations of accountability and sustainability:

> *"In France you have to reply within 24 hours. England is a market where since* quite *some time the pressure is high, while in Brazil it is far less. But you cannot go to a government if you cannot show you get things under control. To a government, it only creates trust if you can show very fast you have things under control" (Respondent 2)*

SYNTHESIS: OPACITY OF TRACEABILITY INITIATIVES

While the sustainability reports recognize traceability as important in the broader context of sustainability, they provide limited transparency about supply chains. Fertilizer companies focus on governance and Corporate Social Responsibility, while detailed traceability and transparency disclosures are sparse. The findings reflect an industry-wide reluctance to disclose detailed traceability data.

The expert interviews revealed a nuanced perspective on traceability, with respondents acknowledging its potential to improve product quality, supply chain efficiency, and transparency. However, concerns about competitive advantage, administrative burden, and the risk of reputational damage were prevalent. These

factors, and concerns over confidentiality and competitive advantage most likely explain the reluctance to engage in, and report about traceability initiatives.

DISCUSSION

Implementing traceability in the fertilizer industry presents a complex interplay of internal benefits and external challenges. Internally, traceability enhances product quality, safety, and operational efficiency. Externally, however, it introduces risks such as potential reputational damage, competitive disadvantages, and liability concerns. These tensions align with findings in prior research, which highlight the dual-edged nature of transparency (cf. Van den Brule, 2008; Pullman, Maloni, & Carter, 2009; Styles, Schoenberger, & Galvez-Martos, 2012). Managers are hesitant to disclose supply chain details, fearing exposure of unfavorable (social or environmental) outcomes (cf. Wang et al., 2009), or the revelation of proprietary information about suppliers or production processes.

Sustainability reports in the fertilizer sector rarely address traceability in depth. Only Borealis explicitly discusses traceability, reflecting a broader reluctance among companies to engage with this issue transparently. This resistance persists despite increasing legislative and stakeholder demands, particularly in Europe, where compliance with directives is becoming a "license to operate" (Luo et al., 2018; Delmas et al., 2013). Our findings suggest that fertilizer companies are opaque, meaning that they do not disclose information relevant for stakeholders to make informed decisions (cf. Bartlett, Julien & Baines, 2007).

Our study highlights a divide between "old school" and "new school" managerial mindsets regarding transparency. "Old school" managers, influenced by traditional CSR perspectives (e.g. Luke, 2013; Blaha et al., 2021), often approach traceability with skepticism, focusing narrowly on economic and techno-centric goals. They perceive transparency as a threat to competitive advantage and managerial authority. Conversely, "new school" managers are more receptive to holistic approaches, recognizing the ethical and strategic benefits of transparency and its alignment with evolving stakeholder expectations. This generational and ideological divide underscores the need for targeted change management strategies in promoting traceability adoption.

The literature demonstrates clear advantages of traceability, such as improved efficiency, accountability, and customer trust (Bosona & Gebresenbet, 2013; Lam et al., 2018; Shankar et al., 2018; Mai et al., 2010). However, our findings suggest that managers prioritize internal benefits over external transparency. Many emphasize the need for robust business cases to justify traceability investments, consistent with Wang et al. (2009), who highlight the lack of transparent and effective traceability systems in practice.

Regarding social and environmental performance outcomes, some respondents are convinced that (other) companies use traceability for window dressing purposes. Threats are perceived to come from revealing competitive

advantages towards competitors and revealing poor (social or environmental) performance. Respondents differ in views on who benefits from improvements in efficiency, product quality, and safety in the fertilizer supply chain. Some respondents perceive companies that are closer towards customers to gain the most from traceability and transparency. This is related to either having full liability towards the end product at customer level, or having limited liability for parts or ingredients in the upstream supply chain.

Managers at different positions in the fertilizer supply chain may differ in perceptions about potential threats from transparency (cf. Pullman et al., 2009; Karlsen et al., 2011). They are hesitant to engage in traceability throughout their supply chain (external perspective), referring to the possible threats it creates, such as being held responsible for problems in the supply chain, commonly referred to as 'guilt-by-association' (Veit et al., 2018). This apprehension, coupled with the potential loss of competitive advantage, shapes the varying perspectives across different tiers of the supply chain. Companies closer to the end customer may perceive greater benefits from traceability due to their liability for final product quality, whereas upstream players face fewer direct incentives to adopt transparency measures.

Our examination of sustainability reports underscores the growing importance of in managing legislative and political risks. In the fertilizer industry, where food safety and health concerns are paramount, transparency is increasingly non-negotiable (cf. Wang et al., 2009). However, achieving sector-wide adoption is hindered by its conservative nature and reluctance to embrace systemic change. The disruptions caused by the COVID-19 pandemic have further emphasized the need for resilient and responsive supply chains (Linton & Vakil, 2020), yet the sector remains slow to adapt.

A shift towards new paradigms (Mitchell et al., 2020; 2022) and radical transformation of our economic system in relation to social and environmental boundary conditions as called for by (a.o.) Elkington (2018) and Raworth (2017) seems difficult. The tensions between internal and external perspectives on traceability reveal that the fertilizer industry seems to operate in ways that are far from systemic or holistic. Sustainability governance mechanisms, such as Levers of Control in supply chain context (de Haan-Hoek et al., 2020), might help in further integrating traceability, but as a rather conservative sector, the fertilizer industry is reluctant to engage in sustainability practices.

CONCLUSIONS

Our analysis of sustainability reports and interviews reveal that the fertilizer industry is hesitant to fully embrace traceability and transparency, with companies primarily responding to legislative and political risks rather than proactively pursuing traceability measures. While sustainability reports address transparency related to governance and stakeholder relations, they largely omit detailed disclosures about traceability and supplier practices. Expert interviews

underscore the intrinsic connection between traceability and transparency but also highlight mixed perceptions regarding their benefits and drawbacks.

The interviews show that traceability potentially leads to more transparency, although it might be argued that it depends on the degree of implementation and stakeholders alignment. Respondents expressed varied views on stakeholder expectations and the steps required to meet these expectations. Respondents state that product quality and safety are key drivers for traceability, especially given the fertilizer industry's critical role in high-risk sectors such as food production. Some respondents argue that their existing quality systems and employee mindset are sufficient to ensure quality and safety, reducing the perceived need for traceability.

Our findings have important implications for both policymakers and companies striving to enhance traceability and transparency across industries, particularly in sectors with significant environmental and social impacts like fertilizers.. Policymakers hold a pivotal role in promoting traceability and transparency as tools for improving sustainability and governance. In addition to regulatory frameworks, policymakers might want to incentivize adoption of traceability, e.g. through supporting industry-specific initiatives of providing incentives for companies that do invest in traceability technologies such as block chain. Furthermore, policymakers should actively promote multi-stakeholder collaborations, such as issue networks or learning communities, to align goals and share best practices for implementing traceability. Companies are encouraged to consider traceability as a strategic investment, rather than merely a compliance requirement. Traceability should be integrated into broader corporate strategies to enhance decision-making, improve operational efficiency, and reduce costs. Investing in advanced traceability systems, such as block chain, RFID, and real-time monitoring tools, will enhance data accuracy and trust in the supply chain. In addition, investing in human capital by training employees and raising awareness to externalities in the supply chain (social and ecological impact) is important to improve sustainability efforts.

Further research could explore how full traceability and transparency can be effectively implemented in the fertilizer supply chain while balancing business and social interests. With growing demands from consumers, public institutions and governments for greater supply chain transparency, understanding how to meet these expectations is critical. The application of block chain technology could be an important step in improving supply chain transparency (cf. Francisco & Swanson, 2018; Creydt & Fischer, 2019). This study did not include respondents from raw material suppliers, leaving a gap in understanding how upstream stakeholders perceive the risks and benefits of traceability and transparency. In addition, conducting similar studies in other supply chains, particularly those with varying degrees of complexity and regulatory requirements (e.g. pharmaceuticals; electronics; apparel), could broaden our understanding of how traceability and transparency- are perceived and implemented, ultimately contributing to the development of resilient, sustainable, and ethically aligned supply chains.

ABBREVIATIONS

ANNA, Ammonium Nitrate & Nitric Acid producers group; CAC, Codex Alimentarius Commission; CSR, Corporate Social Responsibility; EC, European Commission; EU, European Union; FAO, Food and Agriculture Organization; GRI, Global Reporting Initiative; IFA, International Fertilizer Association; ISO, International Organization for Standardization; WHO, World Health Organization.

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DATA STATEMENT

Due to the confidential nature of the data supporting the findings of this study, they are not publicly available.

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APPENDIX 1. OPERATIONALISATION OF CONSTRUCTS

Concept	Definition
Perceived benefits	"degree to which a person believes that using traceability would bring benefits" (Davis, 1989, p. 320)
Traceability	"the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen & Borit, 2013, p. 148)
Transparency	"the extent to which all its stakeholders have a shared understanding of, and access to, the product-related information that they request, without loss, noise, delay and distortion" (Trienekens et al., 2011, p. 55)
Window dressing	"activities that serve to alter public perceptions by communicating positive social behaviour, while companies' activities are not necessarily in line with corporate communications and code of conduct" (Van den Brule, 2008, p. 2)
Real social performance outcomes	"policies and practices of corporations that reflect business responsibility for some of the wider societal good" (Matten & Moon, 2008, p. 405)
Efficiency and inefficiency of supply chain management	"an organizations' or persons' behaviour is judged efficient or inefficient by comparing input and output, in terms of some units chosen arbitrarily, such as money, effort, physical resources, etc." (Baldamus, 2013, p. 1)
Product quality (product or service point of view)	"the degree to which a set of inherent characteristics fulfils all requirements" (BSI-ISO 9000, 2000, p. 1)
Product quality (customer point of view)	"the fitness of that product or a service for meeting or exceeding its intended use as required by the customer" (Mitra, 2016, p. 8)

APPENDIX 2. CODING PROCESS MAXQDA

First-order Codes	Theoretical Categories	Theoretical Dimensions
Statements about interpretations and perspectives of traceability and transparency	Traceability is associated with transparency	Relation between traceability and transparency
Statements about advantages and threats of traceability	Traceability is associated with threats to reveal real (social; environmental) performance outcomes	Benefits and threats of traceability; External traceability
Statements about window dressing		
Statements about legislation and compliance		
Statements about improvement of product quality and safety	Traceability is associated with improved product quality and safety	Traceability improves product quality, safety and packaging; Internal traceability
Statements about packaging quality		
Statements about improvement of supply chain management efficiency	Traceability is associated with improved supply chain efficiency	Traceability improves supply chain efficiency; Internal versus external traceability
Statements about customer service and handling complaints		
Statements about improved production and logistics		
Statements about the position in the supply chain (high – middle – low tier)	Perceived benefits of traceability depend on the position in the supply chain; The higher the position (tier), the lower the perception of benefits of improved product quality; The higher the position (tier), the higher the perception of supply chain management efficiency	Traceability benefits differ depending on supply chain position; Internal versus external traceability
Statements about who benefits from quality improvement		
Statements about supply chain management efficiency		