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Drivers for the Adoption of Eco-Innovations in the German Fertilizer Supply Chain

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Abstract: Use of fertilizers has enabled a massive increase in crop production yields. However, this has come with severe negative externalities (e.g., greenhouse gas emission; eutrophication of non-agricultural ecosystems). Eco-innovations are one option to reduce the environmental impact of fertilizers without compromising fertilizer productivity. Although numerous eco-innovations in the domain of fertilizers are available, they have not yet seen a sufficient adoption rate. In this paper we explore main drivers for adoption of eco-innovations in the German fertilizer supply chain based on empirical investigations at three levels of the fertilizer supply chain: producers, traders, and farmers. We strive to take a "chain perspective" on environmental concerns and knowledge of fertilizer specific eco-innovations. The study was carried out in two steps: initially we conducted exploratory expert interviews with eight actors of the fertilizer supply chain. The statements generated thereby fed into a questionnaire answered by 57 participants stemming from fertilizer production ($n = 12$), traders ($n = 34$) and farmers ($n = 11$) level. Findings suggest that drivers for eco-innovations are perceived differently by the various actors in the fertilizer supply chain. Overall knowledge on eco-innovations decreases downstream the chain. By taking a chain perspective on the adoption of eco-innovation, our paper contributes to the emerging body of literature on drivers for eco-innovation, and also maps out managerial implications of fostering the implementation of eco-innovations in the fertilizer supply chain.

Keywords: innovation adoption; innovation network; knowledge exchange; innovation system thinking

1. Introduction

Along with the projected global population increase to more than nine billion in 2050, the demand for food is growing rapidly [1]. Up to now, food production has kept up with population growth through the use of new agricultural techniques, including plant breeding, plant protection, cultivation techniques, use of irrigation, and fertilization. However, at the same time as these changes in agricultural productivity occurred, consumer behavior concerning food and the political economy of farming also changed [2,3]. Agricultural systems are nowadays increasingly recognized as a significant source of environmental damage [4–6].

Nearly 50% of the increase of agricultural output, especially from cereal production, is based on fertilizer use [7]. Fertilizers help to maintain soil fertility and productivity through supplying essential plant nutrients. Fertilizers also present negative externalities, especially the emission of greenhouse gases during the production process as well as during and after field application [8,9]. Overall 12% of the greenhouse gas emissions worldwide are related to agriculture [10] with 38% stemming from the use of organic and mineral fertilizers alone [11]. Additionally, nutrient leaching into ground and surface waters are resulting in eutrophication of aquatic ecosystems with increased growth of algae and finally decreasing the levels of oxygen [7]. Also the decline of non-renewable resources (e.g., phosphorus or potassium; [12,13]) is connected to the use of mineral fertilizers.

Today, concerns about sustainability focus on the need to develop agricultural technologies and practices that (1) do not have negative effects on the environment; (2) are available to and effective for farmers; and (3) lead to both improvements in food productivity and have positive side effects on environmental goods and services [4]. To meet the challenges of global food security in a sustainable way requires the intensification of knowledge-based approaches and the use of modern agricultural practices [14], which can be classified as eco-innovative. More precisely, eco-innovations are defined as innovations that reduce the environmental impact or the use of natural resources [15–17] leading to a more responsible application of fertilizers in order to achieve low input/high output farming systems. Kemp and Pearson [18] defined eco-innovation as *"(...) the production, application or exploring of a good (...) that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resource use (including energy use) compared to relevant alternatives"* (p. 11). Ekins [15] even went one step further and defined eco-innovations as " ... *a change in economic activities that improves both the economic and the environmental performance of society*" (p. 269). In the present study we focus on eco-innovations in the field of fertilizers that have already existed for some time, but that are not yet well adopted by farmers and other actors in the fertilizer supply chain. Due to this fact, we draw upon the reasoning of Carruthers and Vanclay [19] who stated that " ... *even though an idea or a technology may have been in use for some time, it is the novelty of the concept to the new user that is critical in understanding something as innovative*."

One focus of this study is to explore the reasons for the limited innovation adoption reflected by missing drivers and the lack of knowledge sharing between the different actors in the fertilizer supply chain. Numerous studies have shown that only a combination of innovation system thinking and a proper knowledge sharing leads to a higher level of adoption of new or improved technologies or practices [20–24]. An innovation system in this context is the combination of different factors—economic, social, political, organizational, institutional—that influence the development, diffusion, and adoption of innovations [25]. An innovation system can be defined as the set of all individual and organizational actors that are relevant to innovation in a particular sector [23,26–28]. For innovation in supply chains this approach highlights the importance of information exchange across multiple links in the chain, which is enabled by partnerships between upstream and downstream actors [29]. As a result these innovation networks have become more and more complex due to the development of agriculture (diversification or specialization of producers and products [30]).

Aguilar-Gallegos et al. [20] concluded that the structure of agricultural networks leads to different rates of innovation adoption. Studies in management literature [31–33] and agricultural economics [21,34,35] also examined adoption as a function of learning orientation. Different parts of production systems and of the environment in which they are embedded (e.g., the value chain, the market, the policy environment) need to develop simultaneously in order to enable innovation. This requires interactions amongst multiple actors to acquire and assimilate new knowledge [23,36]. As the broad majority of agricultural innovations are developed outside the farm, the development of the absorptive capacity highly depends on more than internally directed and funded innovative activities, both inside and outside the agricultural production systems [22,31,37]. Although widespread services and agricultural consultation have become increasingly common in the diffusion of information for agricultural technology, the awareness of the applicability of many agricultural technologies and practices may still not be homogeneous [30,38].

Existing research has shown that a firm's decision to introduce eco-innovations is influenced by a variety of factors, including regulation (as the "regulatory push/pull effect"), technology push, market pull (e.g., the concept of customer benefits), policy (changing laws), and firm-specific aspects (such as knowledge transfer mechanisms and involvement in networks) [39–44]. Based on these studies we consider the following three drivers as highly relevant for the adoption of eco-innovations: market pull (measured by "perceived need for action"); regulation (measured by "regulation awareness"); and firm-specific aspects (measured by "knowledge on eco-innovation" and "markets pull" or "technology push"). We strive to explore to what extent these three drivers differ among the three aforementioned supply chain actors. To this end, by focusing on the adoption of innovations from a supply chain perspective, the paper at hand seeks to contribute to the emerging literature on eco-innovations. So far, to our best knowledge, this is the first paper looking at eco-innovation adoption and diffusion of knowledge using a supply chain perspective. Additionally, we were able to show that it is not only users of eco-innovations (farmers) who are blocking the diffusion process, but also the traders or/and producers of fertilizers. We aim to provide recommendations to improve knowledge sharing and collaboration within agricultural supply chains to stimulate the development and implementation of eco-innovations.

2. Theoretical Framework

We draw upon the following definition of eco-innovation: "*The production, application or exploring of a good (...) that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resource use*" [15]. Further, an eco-innovation must have a benefit linked to both the environmental impact of a product or service and to the economic performance [17]. Additionally to the definitions of Kemp and Pearson [18] and Ekins [15] it does not matter if environmental improvements have been the declared goal or came along as by-product or simply by chance. That means that eco-innovations can be the result of other economic decisions such as reducing costs, and not have been predominantly motivated by environmental concerns [39].

In line with our overall research goal (i.e., understanding the drivers for the adoption of eco-innovations) we strive to explore (1) if innovations are pulled by farmers or pushed by other actors within the fertilizer supply chain; (2) the perceived need for action to mitigate climate change; (3) the regulation awareness; and (4) the knowledge on eco-innovations among different fertilizer supply chain actors.

2.1. Technology Push or Market Pull

Generally speaking, an innovation process can either be initiated upstream through the enhanced involvement of farmers in innovation development planning (market pull; [45]) or downstream "pushed" from innovative fertilizer producers (technology push; [46]). Most farms in Germany are family-based with minor changes over the years, and most farmers tend to think about their work pretty much as they always have done. Sivertsson and Tell [47] claimed that the request for innovation is closely linked to the human capital on farms, leading in many cases to the so called "locked-in syndrome" where no further changes are taken into account. Additionally, most environmental problems represent negative externalities of food production, such as emissions into the atmosphere, so that for many farmers there is no clear economic stimulus to adopt eco-innovations as long as the end-consumer does not want to pay extra for such products [48]. Thus, we strive to understand if the innovation system in the fertilizer supply chain is more pushed by producers or pulled by farmers.

2.2. Perceived Need for Action to Mitigate Climate Change

In a very early state of innovation adoption stands the awareness of the problem or opportunity. In this context, awareness means not just knowing that an innovation exists, but that it is potentially of practical relevance to the user [49]. Awareness and relevance can be linked to the so called "perceived need for action" [43]. As long as the farming system and the agricultural environment do not modify significantly, the perceived need for action at the farmers' level should be very low. However, with predicted changes due to climate change in Germany there could be some massive effects on plant yields and fertilization periods (like modified rainfall, changes in total seasonal precipitation or in its pattern of variability, and extreme weather scenarios such as spells of high temperatures or droughts [50]). Furthermore, the continuing environmental discussion, influenced by information coming from customers, suppliers, competitors or consultants, conferences and exhibitions, universities and other public research institutions or (scientific) journals could create a higher awareness of the perceived need for action [39,43]. This could lead to the conclusion that eco-innovations are seen as possible solutions for the upcoming problems.

Here we seek to explore if the fertilizer supply chain position and the perceived necessity to adopt eco-innovation differ through the supply chain by detecting how the different fertilizer supply chain actors comprehend the changes in fertilization patterns due to climate change.

2.3. Regulation Awareness and Knowledge on Eco-Innovations

Woolthuis et al. [51] reviewed the commonly occurring types of innovation system failures and designed a framework for structured analysis of constraints in innovation processes. The innovation system framework consists of a matrix of system elements: barriers that may block learning and innovation and the actors who reproduce the barriers [51,52]. Our research design classified the following two barriers:

- Institutional failure being failures in the framework of regulation and the general legal system [53].
- Network failures [54], i.e., the "blindness" that evolves if actors have close links to each other and, as a result, miss out on new outside developments.

Regulatory instruments include all political interventions that formally influence social and economic action through binding regulations [55]. They suggest norms, rules, and acceptable behaviors while limiting certain activities in a society [56]. Encouraging soft environmental measures (e.g., guidelines or memorandums) by governments, such as environmental accounting systems, eco-labels or eco-auditions may improve the information base for eco-innovations [57]. The analysis of institutional barriers in this article builds upon the problems which would arise with the amendment of the German fertilizer ordinance. Environmental regulatory instruments and environmental policy instruments (especially soft regulations) are highly relevant drivers for the adoption of eco-innovations [40,48,58]. Therefore, we included environmental policy and restrictions as a second important determinant for the adoption of eco-innovations in our study, also known as the "regulatory push/pull effect" [17,59,60]. Regulation is not always seen as an undesirable cost-increasing factor but also as an activator for innovativeness that could lead to a first-mover advantage [61]. As a result, the impact of regulation as a driver for eco-innovations might differ depending on how actors deal with regulatory changes, taking a pro- or reactive approach [62]. We utilize the possible reduction of nitrogen and phosphorus use (extracted from the expert interviews as a potential solution) as precursor for presumable eco-innovations in fertilization. In a further step we asked all members of the supply chain to what extent they presume further restriction. We assumed that more critical answers lead to a higher possibility for the consideration of eco-innovations. Thus, we strive to explore the different perception of regulatory change as a driver for eco-innovations in how the different actors of the fertilizer supply chain anticipate changes in regulation.

The analysis of the network failures is based on the assumption that agricultural supply chains in general and the German fertilizer supply chain in particular are very closely linked with trusted and long-lasting relationships. Additionally, we assumed that farming has retained many of its traditional characteristics (large number of small producers, family-based enterprises, etc.), but has more and more fertilizer types or technical equipment being available for agriculture production. Selecting these options became a specialized task and farmers started to rely on external consulting which might lead to an uneven distributed knowledge [46]. However, a fluent up- and downstream flow of information is fundamental for achieving coherence among the chain actors and increasing the capabilities of the chain (e.g., [63–65]). The adoption of innovation is a dynamic learning process with can be broken down into stages, always starting with the awareness of the problem or opportunity (e.g., [43,49,66]. Porter and van der Linde [67] claimed that firms do not see the potential of eco-innovations because they are "*(. . .) still inexperienced in dealing creatively with environmental issues*" ([67], p. 99). Environmental and economic friendly innovations are not realized because of incomplete information, organizational and/or coordination problems [67], and firms are not able to recognize the cost saving potentials of eco-innovation. Additionally, Garbade et al. [68] concluded that knowledge enhancement also offers the possibility for bridging the gap between exploration and exploitation of research results. In the present study our focus lies on the knowledge transfer mechanism. Therefore, we explore the knowledge distribution along the fertilizer supply chain in the following research question: Does the level of knowledge on eco-innovations differ among the actors in the fertilizer supply chain?

3. The Fertilizer Supply Chain and Its Existing Eco-Innovations

3.1. The Fertilizer Supply Chain in Germany

Although there exists a diversity of supply chain structures, we conceptualize the fertilizer supply chain as consisting of three main participants: producers, traders, and farmers consuming the fertilizer in their arable crop farming practices. Due to high market entry barriers such as capital and energy costs, only nine fertilizer producers are still operating in Germany at present (one plant for fertilizer production containing mainly phosphorus, one large company for potassium-based fertilizers, and seven production plants for nitrogen, multiple nutrient fertilizers, or special fertilizers [69]).

In most areas in Germany, fertilizer (as well as other agricultural products) are traded in a two-step supply chain starting at wholesale which sells to several smaller local agro-traders (see comparison in Figure 1). In 2000, there were still 18 wholesalers operating in Germany with a tendency for further structural change [69]. Thus, the second step of the fertilizer supply chain mainly consists of agro-traders. These traders are not only selling fertilizer, but also other agricultural input factors (e.g., seeds or pesticides). In most cases they even purchase the entire harvest from arable farmers and are offering facilities for storage and logistics. In the year 2000 there were approximately 4000 agro-traders operating as single trading companies or in larger cooperatives [69], but in the last couple of years this number has been constantly decreasing. At present ca. 287,500 farmers are operating in Germany [70].

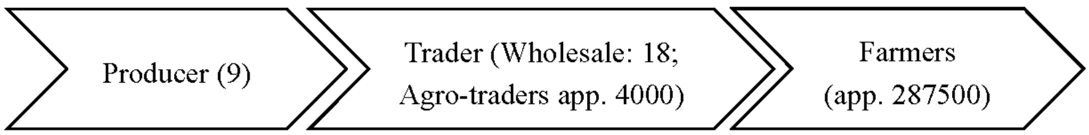

Figure 1. German fertilizer supply chain—number of supply chain partners in brackets [69].

3.2. Eco-Innovations in the Fertilizer Supply Chain

Information on eco-innovations in the German fertilizer sector was gathered through expert interviews and analyses of secondary data (spring 2013). In the last decade a high number of eco-innovations were generated changing fertilizer application techniques and fertilizer properties [71]. However, many of them are only useful in extreme cultivation areas (e.g., genetically modified plants (GMOs) with a higher tolerance to salinity or drought), and others are made for specific agricultural practices (e.g., special urea coatings for rice production [71]). Recently developed eco-innovation in the German fertilizer related area are: GMOs, strip till, in-field variable fertilization (precision farming), foliar fertilization, stabilized nitrogen fertilizer (SNF), fertigation (FG), fertilizer made from secondary raw material (FSRM), and fermentation residues from biogas production. We excluded most of these eco-innovations from our research due to the following reasons: the use of GMOs is highly controversial discussed in German society and between consumers [72], and strip till, foliar fertilization, and area specific fertilization will change the application technique, and therefore the agriculture system, and fermentation residues from biogas production are too closely linked to the original organic fertilization. Finally, we arrived at three specific fertilizer eco-innovations with a high relevance for the fertilizer sector (SNF, FG, and FSRM). Additionally, all experts during the interviews mentioned all three of them (together with GMO and improved organic fertilization) as relevant in association with legal and environmental changes within the German agriculture surroundings. All three innovations are only incremental and don't change the whole fertilization system. Furthermore, we decided to get deeper insights into these eco-innovations, because they might alleviate the problems associated with climate change in Germany. Due to the expected increase of temperatures, more humid winters, and more frequent extreme weather events [73], it could become necessary to modify the nitrogen fertilizer product to avoid undesirable losses to the environment. Additionally, an increasing number of drought periods in some areas of Germany [73] could lead to an increased use of irrigation systems. In association with the amendment of the German fertilizer ordinance, it could become even more important to close nutrient cycles and to use existing raw materials as fertilizers.

In the following we briefly explain these eco-innovations': (1) underlying technological principle; (2) specific eco-innovation potential; and (3) current status of market adoption.

3.2.1. Stabilized Nitrogen Fertilizers (SNF)

(1) SNF, first introduced in the 1950s can be formulated in three different ways. The first is to add a coating to the granular which allows for a controlled release of the nitrogen (N). The second way is to supply Nin a less soluble from that needs to be converted chemically or biologically to a more soluble and plant available from (sometimes called "delayed release"). The third way is to add an inhibiting chemical that blocks or at least delays the transformation of urea/ammonium N into nitrate nitrogen [74].

(2) SNFs have been shown to reduce N leaching [75] and gaseous emissions leading to increased nitrogen use efficiency. Hence, they present an important eco-innovation, since the use of nitrogen fertilizer at field level is a primary source of CO_2 and N_2O emissions [76–78].

(3) It has been estimated that stabilized N fertilizers comprise only 8%–10% of the fertilizers used in Europe [79,80], 1% in the USA, and only 0.25% in the world [81]. The market share of these products in German agriculture is still very limited. Legal requirements have led to a faster adoption rate of this technology, especially in areas with high livestock intensity, while in other regions market penetration is developing rather slowly. Only about 10% of the total SNF production is used on agricultural crops [70], the remainder is used for non-agricultural markets (e.g., lawns, golf courses, fruit trees, and vegetables [80]).

3.2.2. Fertigation (FG)

(1) FG is defined as application of soluble fertilizer via the irrigation water [82]. This technology was initially developed in the 1970s in Israel [82]. As nutrients are applied in a water soluble form they are immediately accessible for plant uptake right after application, allowing the farmers greater control over nutrient availability to the crop. When nutrients are applied shortly before they are actually needed, it is possible to reduce losses of nutrients to the environment and also to make the producers less dependent on weather conditions.

(2) In Germany, the need for irrigation is not so widespread compared to Mediterranean countries, but with changes in rainfall patterns due to climate change, FG might become important to enable high yields in the future. The benefits of FG are two-fold: (1) a reduction of fertilizer and water needed for crop production; and (2) the application of nutrients can be controlled at the precise times they are needed [83,84]. However, FG also has some disadvantages like high investment costs, organic fertilizer cannot be used, and a supply of high quality water resources must be guaranteed.

(3) At the moment, market adoption of FG in Germany is rather low. Due to its high investment costs for the irrigation infrastructure, FG is only profitable for crops with high profit margins (like strawberries, tomatoes, or herbs). However, experiments in regions with frequent drought

stress periods with potatoes have shown promising results [85]. Assuming climate would become warmer and drier, FG seems to be a viable option for many regions in Europe [86].

3.2.3. Fertilizers Made from Secondary Raw Materials (FSRM)

(1) FSRM are fertilizers made from so-called "secondary raw materials", such as sewage sludge, compost or other organic substances like horn meal, crop residues, or various non-usable leftovers from food production.

(2) If these materials are used as fertilizers they need to comply with the German fertilizer regulation [87] which, at the moment, bans the use of bone meal, meat meal, animal meal, and blood-based products. However, such FSRM products are expected to become especially important when non-renewable raw materials like rock-phosphate become scarce and regulations regarding the closing of nutrient cycles become mandatory. Additionally, with new filtering, removing, or cleaning technologies [88], many of the above-mentioned materials could also be used as base materials for fertilizer production. This will result in a reduction of the use of non-renewable resources as source material for mineral fertilizer production.

(3) Overall these materials are quite often used in German agriculture, but often there is a lack of awareness of these products reflected by the fact that most farmers are neglecting them when calculating fertilizer compositions [87].

4. Methods

We sought to obtain information about the drivers, determined by the above-mentioned factors (i.e., **technology push/market pull, perceived need for action, regulation awareness** and **knowledge**) from actors of the three levels of the supply chain operating in Germany. Therefore, we apply a mixed-method research design conducted in a two-step approach, beginning with exploratory expert interviews followed by a postal questionnaire.

4.1. Step One: Exploratory Interview with Experts in the Fertilizer Sector

Experts for the interviews ($n = 8$) conducted in spring 2013 were two CEOs and two regional consultants of different fertilizer producers in Germany, the sales directors of two different fertilizer trading organizations, and two plant nutrition professors from agricultural universities in Germany. The following topics were discussed: (1) expected future supply chain developments; (2) expected political changes; (3) expected developments of new technologies; and (4) new ways of nutrient recycling. The transcribed interviews were computer-assisted encoded, in order to identify the most relevant aspects. Then, we conducted a group comparison of the different assessments of the individual supply chain actors. In a final step we summarized the statements of every supply chain level into a general opinion.

4.2. Step Two: Questionnaire with Actors across the Fertilizer Supply Chain

Based on the results of the interviews, a postal questionnaire was developed as a second step and sent to 250 supply chain actors in fall 2013. We selected these 250 participants for the survey from the customer lists of two agricultural trading and distribution cooperatives (Verband Deutscher Düngermischer and Raiffeisenverband) and agricultural students stemming from farms. In total, 57 individuals responded (response rate 23%). Twelve respondents (21% of the sample) were CEOs and regional consultants of the main fertilizer producing companies in Germany, 34 (60% of the sample) belonged to the supply chain level of agro-traders, and 11 were farmers, representing the final level of the fertilizer supply chain (19% of the sample).

4.3. Measurement Used in the Questionnaire

All questions concerning the four drivers for eco-innovations (technology push/market pull, perceived need for action, regulation awareness, and knowledge about eco-innovations) were measured with seven-point Likert-scales (1 = total disagreement to 7 = total agreement). Details on "technology push/market pull" were gathered by asking the participants the following items: (1) I use new technologies ahead of my competitors and (2) new technologies have a better work performance. The "perceived need for action" was measured by the items: (1) frequency of extreme weather scenarios will increase and (2) fertilization strategies have to be adapted to extreme weather scenarios. The same approach was used for the determinant of "regulation awareness". Here, participants were asked to what extent they expect further restrictions concerning the use of nutrients (i.e., the use of mineral nutrients, especially nitrogen and phosphorus, will be further restricted). To explore the knowledge distribution along the supply chain, *knowledge* regarding eco-innovations was measured with a dichotomous yes/no question (Do you know SNF? Do you know what FG is? Do you know FSRM?). Three additional open questions were used to get a deeper insight in the ideas of the different respondents about the environmental challenges the fertilizer supply chain is facing and the possible solutions in the field of eco-innovation, and if they see it as a chance or a threat. Due the small sample size, we only report average answer values, i.e., means (M) together with their standard deviation (SD). Significant differences were calculated by using ANOVA followed by multiple comparison test (Tukey) and are reported as significant with p-values of $\leqslant$5%. We only report the p-values (P) of significant differences. Statistical differences concerning the knowledge about the three eco-innovations of the different supply chain actors (producer, trader, farmer) were evaluated by using a non-parametric multiple contrast test [89]. All statistical tests were computed by tools of the software R [90]. To calculated the correlations between the questions pairwise spearman rank correlation coefficients where computed. To avoid spurious correlation we additionally decide to split the question into the three groups (producer, trader, farmer). All correlations can be found in the supplementary materials (Tables S1–S4).

5. Results

5.1. Technology Push or Market Pull

During the interviews all eight experts agreed that the agricultural sector will undergo profound changes within the next decade. Here, most of them mentioned an intensification of animal and/or crop production and assessed that small-scale low-income family-based farms seem to be a discontinued model. Especially the experts working for fertilizer producers or trading organizations expect a higher global cross-linkage, for example with the U.S. or Chinese markets. One solution nearly all experts (except the two CEOs) mentioned was that the future of agricultural businesses is based on well-educated farmers, seeing themselves as business managers. The experts working for fertilizer producers even desire a live-long-learning of all supply chain partners and more openness towards new developments.

In our questionnaire we were interested if the openness towards increase in new technologies or decrease along the supply chain. Going down the fertilizer supply chain, it seems that farmers are the most skeptical towards new technologies (Table 1). Even if the decrease is not significant, that could mean innovations are less likely pulled by farmers but rather follow a technology push approach.

Table 1. *Technology push or market pull* in the context of technology evaluation of the different supply chain actors within the fertilizer supply chain (average values and standard deviation).

	Supply Chain Position		
	Producers (*n* = 12)	**Traders (*n* = 34)**	**Farmers (*n* = 11)**
First user of new technologies	4.37/1.85	4.08/1.61	3.54/1.63
New technologies are better	5.00/1.60	4.41/1.21	4.00/1.18

All items were measured with a seven-point Likert-scale (1 = total disagreement to 7 = total agreement).

5.2. Perceived Need for Action

In the interviews all eight experts agreed that extreme weather scenarios (e.g., drought periods) might occur more often in the next couple of years. As a consequence, the period for fertilizer application might be shorter and/or the management system must be adapted to new climate conditions. Obviously the awareness of necessary changes due to climate change exists, but differs across the supply chain.

We were also interested in the question of whether environmental concerns are also perceived as a business opportunity by the different supply chain actors (producers, traders, farmers). The fertilizer producers indicate that they plan to include reflect environmental aspects in their businesses strategies (e.g., with labeling or proactive initiatives). Mostly they take that into consideration because they bear the interests of the end-consumers of agricultural goods in mind. As stated by P2: "*The Carbon Footprint in marketing will come. It will take some time, but it will come*". However, they seem to be insecure to what extent these are considered during the purchasing process of farmers. Most of the experts are convinced that farmers are not buying based on any environmental motivation. According to one producer (P1), farmers do not perceive any need to mitigate climate change: "*The whole environmental discussion is no issue for the farmer; it is more seen as harassment or political instructions. That issue has no positive meaning for farmers*". One trader (T2) is also questioning the motivation of farmers: "*Are farmers buying with environmental perspectives? I don´t think so*". However, looking at the statements of the farmers in the open question part, some of them indicated that they would buy with an environmental motivation if that would be honored and lead to a higher willingness to pay at consumer level.

Across the entire sample, in general, supply chain actors agreed that extreme weather scenarios will increase and that fertilization management has to be adapted [extreme weather scenarios will be more frequent (M 5.6; SD 1.27); fertilization has to be adapted to extreme weather scenarios (M 5.72; SD 1.05)].

However, as depicted in Table 2, results differ according to the chain position. The group of fertilizer producers is very sure that climate change will affect farming activities in general and fertilization practice in Germany. They see clear opportunities for new application techniques. Also, farmers see climate change problems quite clearly. Although farmers are the ones that are directly affected, they indicated that they have no idea how to manage this problem. Traders are not so sure about the statement that climate change may affect German agriculture. As detailed in Table 2, the traders' mean values for both items of the "*perceived need for action*" category were lower than the ones of producers and farmers whereas only the item "*fertilization needs to be adapted to extreme weather scenarios*" differs significantly from producers and traders (P 0.045). Obviously concerns about climate change or global warming are seen as less critical by traders than by producers and farmers. Some of the traders even negate climate change is occurring at all in the open question part.

Table 2. *Perceived need for action* in the context of climate change of the different supply chain actors within the fertilizer supply chain (average values and standard deviation.

	Supply Chain Position		
	Producers (*n* = 12)	**Traders (*n* = 34)**	**Farmers (*n* = 11)**
Qualitative statement	*"Climate change in Germany will result in more dry periods and extreme weather scenarios (like tornados, extreme rainfall events or extreme frost events in winter)."*	*"What climate change?"*	*"Would buy with environmental motivation, if that would be honored or paid."*
More frequently extreme weather scenarios	6.00/1.10	4.96/1.74	5.82/0.87
Fertilization has to be adapted to weather scenarios	6.38/0.74 [a]	5.22/1.27 [b]	5.54/1.13 [a,b]

All items were measured with a seven-point Likert-scales (1 = total disagree to 7 = total agree); a and b indicate significant differences between the single supply chain actors at $\alpha \leqslant 0.05$ measured by ANOVA followed by multiple comparison tests.

5.3. Regulation Awareness

Most experts in the interviews agree that legal regulations linked to the program "CAP 2020" [91] will increase with the main concept of changing the agricultural subsidies from direct payments per hectare to targeted environmental programs. Furthermore, most of them are aware of these changes, but the consequences are assessed in very different ways. Producers (e.g., P3) are quite sure that in addition to the political changes, the public pressure will force farmers " … *to include ecological aspects to their decisions like nature protection, animal welfare, or environmental consideration*". Producers even expect political changes based on societal pressure and new social values. Traders agree that more regulatory constrains will occur, but they have few ideas on scope and content of these changes.

Based on our questionnaire it seems that producers, traders, and farmers are aware of regulation as a driver for eco-innovation. In the qualitative statements we find that especially producers try to anticipate these to find solutions for regulatory compliance. However, going downstream the supply chain we can observe that traders and farmers seem to be less pro-active and show a mere "wait and see" attitude to regulation. Traders and farmers perceive regulations as a given force that cannot be influenced or changed as indicated by the statement "*we have no choice*". Farmers just admitted that they have to possibly react and deal with new situations (Table 3). Especially the farmers expect further restriction of the use of nitrogen and phosphorous (M 5.18; SD 0.87). However, even though the means of the supply chain actors differ, no significant differences could be detected.

Table 3. *Regulation awareness* of the different supply chain actors within the fertilizer supply chain (average values and standard deviation).

	Supply Chain Position		
	Producers (*n* = 12)	**Traders (*n* = 34)**	**Farmers (*n* = 11)**
Qualitative statement	*"The nutrient surplus will be further regulated (finally to achieve a balanced input/output nutrient ratio) by the European government, because existing regulations have not lowered the nitrate emissions to ground water bodies."*	*" … cannot be influenced or changed."*	*"We have no choice!"*
Further restriction of N and P [1] use	4.58/1.68	4.73/1.42	5.18/0.87

All items were measured with a seven-point Likert-scales (1 = total disagree to 7 = total agree); [1] N = nitrogen and P = phosphorus.

5.4. Knowledge about Eco-Innovations and Awareness for Changes

During the expert interviews, the most-mentioned eco-innovations were those related to the use of organic fertilizers or to the closing of nutrient cycles. However, within the complete supply chain the knowledge of specific eco-innovations turned out to be rather limited and varied according to the eco-innovation itself and the different supply chain partners.

In Figure 2 the level of knowledge of the three specific fertilizer eco-innovations (i.e., SNF, FG, and FSRM) is shown. SNF is well known by all partners in the supply chain, with no significant differences in knowledge between the supply chain partners. This differs for FG and FSRM: For these two eco-innovations we found significant differences among the chain members, with knowledge levels decreasing downstream the supply chain. While FG is known by all producers, about 65% of the traders report that they are aware of this eco-innovation, and only about 30% of the farmers, whose knowledge is significantly lower. FSRM is an eco-innovation relatively well known only by fertilizer producers (60%), by contrast less than 30% of the traders and the farmers know about it. The non-parametrical comparison showed significant differences between the producers and traders and farmers. Interestingly, farmers who would directly be able to apply the eco-innovations in their daily business have the lowest knowledge about the different options.

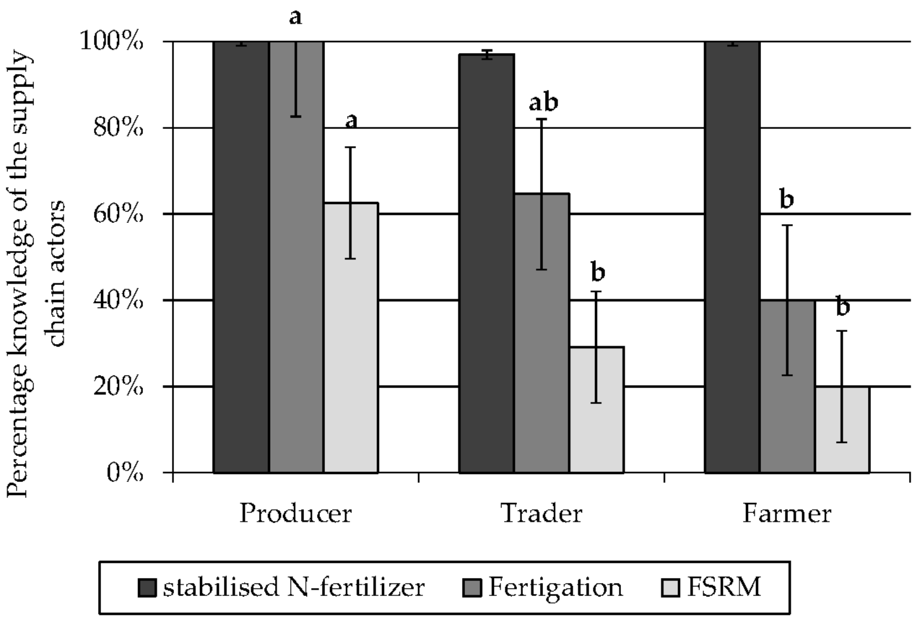

Figure 2. Knowledge of three fertilizer eco-innovations (bars show standard deviations; a and b indicate significant differences between the single supply chain actors at $\alpha \leqslant 0.05$, measured with non-parametrical-comparison using global ranks; FSRM: fertilizer made from secondary raw material).

6. Discussion and Conclusions

This paper contributes to the empirical literature focusing on the drivers of eco-innovation in the agricultural sector in general and the fertilizer supply chain in particular. Additionally, we include the influence of the supply chain position as drivers of eco-innovation and also consider the possibility that the effects differ across the supply chain levels by using basic principles of the innovation system framework. Furthermore, we take an in-depth view on the adoption of eco-innovations within a supply chain position to get a better understanding on the dynamics and innovation capacity of eco-innovations in the fertilizer area.

Our empirical findings indicate that the adoption of eco-innovation is motivated by **technology push** rather than a strong **market pull** of farmers, which might change if retail or consumers would honor the use of eco-innovations with a higher willingness to pay. Farmers are positioned at the beginning of the food supply chain, but their market power is rather weak due to the dominance of the retail sector. Although they are the producers of agricultural goods, they have relatively little influence on consulting or production companies. As a consequence, farmers actively adopt only a few changes themselves because they rather passively depend on their suppliers and their customers. There are evidently significant gaps between expert expectations (policy-makers, researchers, extension workers, etc.) and farmers' perspectives, needs, and opportunities [24]. That leads to the conclusion that it is sufficient to motivate "technology push" and "market pull" within the whole downstream fertilizer supply chain by creating a pull for eco-innovations accompanying the technology push of the research intense producer level. Clearly, much can be done with existing resources and already-developed techniques, but a wider transition towards a more environmental friendly agriculture will not occur without some external incentives (from government or R & D). Hence, market pull factors play only a moderate roll for the adoption of eco-innovations. The farmers alone are neither in the position to trigger the use nor pro-actively develop any eco-innovations.

To assess the **perceived need** for action across the supply chain as a driver for eco-innovations we conclude that market demand—measured by the awareness to take action—is moderate and differs according to supply chain position. In contrast to Heemskerk [45], in our study fertilizer producers and traders estimate the demand of the farmers for more environmental friendly innovations as very low. In general, fertilizer producers and farmers are aware that changes in the production and application of fertilizers are necessary, because fertilization is, as nearly all agricultural practices, highly depended on environmental conditions. Climate change will affect the German fertilizer market (see [50]). More extreme weather conditions (e.g., drought conditions within the periods when fertilizers are applied [73]) could lead to a shorter timeframe for fertilization or different application strategies and/or forms of fertilizers. However, although farmers indicate that they are aware of the need for action, they will not move as long as there is no clear economic stimulus. Here all members of the supply chain should be aware of the need for improvements. All supply chain partners in our investigation agree that environmental **regulations** will become stricter, which could lead to a faster adoption of eco-innovations. These findings confirm previous studies in the field of eco-innovation [40,59] indicating that environmental regulations have a positive impact on adoption. The respondents are sure that with the implementation of CAP 2020 [91] political change will occur that may lead to restrictions in mineral fertilization to reduce unwanted nutrient losses. However, stricter regulations can also result in a situation where a product like FSRM cannot be used in Germany any longer (e.g., hygienic aspects, lower threshold values for heavy metals, or organic pollutants). The technical progress in this area indicates that most of the basic materials are useable in the next couple of years [88]. One solution could be that the government might step in by honoring these technical processes and/or by providing some sort of guarantee for the needed extra investments. Moreover, as far as we concerned, legal regulation could go further to promote public-private certification such as EMAS (European Management and Audit Scheme) or ISO 14001 [92,93], instead of relying only on subsidies or tax incentives to encourage the use of eco-innovations. However, literature indicates [94] that the promotion of standards require changes in forms of collective action and must include the whole fertilizer supply chain.

The general **knowledge** about fertilizer eco-innovations seems to strongly decrease downstream the fertilizer supply chain. One possible explanation for the relatively low knowledge concerning the eco-innovations SNF, FG, and FRSM at farmers' level is that the market diffusion of these technologies is relatively low. All three of them are fully developed, but all are facing acceptance problems. There might be various reasons for that: FSRM can only be used in accordance with the German fertilizer regulations concerning organic materials as base material for fertilizer production or fertilizer usage, which excludes rather cheap materials like blood, bone, and animal waste [87]. Furthermore, the basic materials are traded from other sources, bypassing the original fertilizer supply chain, especially skipping the fertilizer producers. This means that producers in particular are not willing to promote these fertilizer materials. FG requires extra capital for irrigation equipment and the irrigation infrastructure is necessary—both are connected with high investment costs at farmer's level. The fertilizer products which can be used in FG needs to be processed differently (to avoid clogging), which leads to extra investments in production. SNF has the highest market share, but still is a niche product because of its higher costs (ca. 20%–60% more expensive) and lower availability at trader level compared to other fertilizer products. Additionally, the production of these fertilizer products is much more complex and requires proper technical know-how and a more specialized production factory, which could lead to production places in Europe or other Western countries with higher salaries and ecological standards making the production even more high-priced. All three eco-innovations could expand their market shares if regulation or society pressure will further restrict the acceptable nutrient surplus at farm level. For policy makers interested in growing innovative activity in agriculture, we find that building a farm's adoption capacity through knowledge acquisition and assimilation is very likely to increase the adoption of eco-innovations.

Moreover, because of the complex agricultural working situation, farmers heavily rely on consulting and therefore may have a lower knowledge of eco-innovations. The trader level especially seems to act as a bottleneck. Traders can play an essential role in asking for new ways of plant production and fertilizer application by only accepting agricultural goods under certain prerequisites (cultivation contracts, priority trading, etc.). However, at the moment there seem to be few incentives for traders to be involved in the environmental discussion. In addition, the multiple players in the German fertilizer supply chain are not very well connected; they are rather fragmented and mostly act very regionally. To create a stimulating environment for the adoption of eco-innovations it is absolutely necessary for the whole supply chain to encourage lifelong education and an active information exchange. As agricultural production worldwide continues to increase in complexity, this indicates there may be greater value in establishing networks with peers, local suppliers, and customers as well as other local institutions for gaining awareness of new technologies and practices [30,95,96]. Many eco-innovations are already in a very developed stage of the innovation life cycle, but because of lack of knowledge and communication channels, they are often not well-known. Education and knowledge sharing among all actors of the supply chain would be necessary to improve the overall environmental performance. Regular seminars and workshops on new technological and market developments in agriculture for farmers and traders would therefore be more than desirable. Mylan et al. [29] showed that the effectiveness of various eco-innovation mechanisms is shaped by pre-existing supply chain structures. They claimed more integrated supply chain and existing degrees of collaboration make it easier to promote eco-innovations. Additionally, their studies showed that the distribution of eco-innovations needed a shift in supply chain governance modes (more cooperative) and the effective use of innovation coordination mechanisms (information exchange, collective framing of sustainability issues, etc.). Solutions at farm level for adoption of eco-innovations might be practice sharing, flagship projects, and guidance documents. However, due to the relatively small size of agricultural trading organizations and the rather local focus, every single trader must find a solution which is suitable for their surroundings.

All eco-innovations described in this paper can be used to improve the overall supply chain performance and lower the environmental impact of fertilizer use, but all of them have one main barrier, namely that in the first phase they are more expensive than existing alternatives. Numerous other eco-innovations are already on the market (e.g., precision farming technologies), but the pressure of using them is still too low. All four drivers investigated in our paper have the potential to force the use of these eco-innovations, but there are at least not yet strong enough to achieve real differences.

In conclusion, our study can be seen as a first step to understanding the adoption of eco-innovations from a supply chain perspective. However, this study still has a mere exploratory character as it is restricted in sample size and questionnaire design (stemming from exploratory statements). Additionally, we only focus on incremental eco-innovations which do not change the agricultural system and fertilization itself. It would be interesting to evaluate if the low knowledge and engagement of farmers are also true for more fundamental innovations (e.g., GMOs). Hence, a follow up study based on a larger sample and a more focused questionnaire design that looks at only one specific driver (e.g., knowledge) would be desirable.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/8/8/682/s1, Table S1: Pairwise spearman rank correlation coefficient between variables (questions) without group effects, Table S2: Pairwise spearman rank correlation coefficient for producers, Table S3: Pairwise spearman rank correlation coefficient for traders, Table S4: Pairwise spearman rank correlation coefficient for farmers.

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Abbreviations

The following abbreviations are used in this manuscript:

FG	Fertigation
FSRM	Fertilizer made from secondary raw materials
GMO	Genetically modified plants
SNF	Stabilized nitrogen fertilizer
N	nitrogen

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