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Review

Drivers for the Adoption of Different Eco-Innovation Types in the Fertilizer Sector: A Review

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Abstract: Numerous innovations have been developed in the fertilizer and plant nutrition area in recent decades. However, the adoption of many new products and techniques at farm level is still low. In this paper, based on a literature review, we explore the main drivers for innovation adoption or rejection. By splitting up the extant research landscape into disruptive and continuous innovations and innovation types (product, process and innovation of other types), we aim to identify drivers explaining innovation adoption in the fertilizer sector in particular and in the agricultural sector in general.

Keywords: plant nutrition; technology acceptance; environment; innovation diffusion

1. Introduction

World food production has rapidly grown during recent decades and now it feeds over 7.5 billion people. However, the continuing growth of the global population, coming to a plateau at approximately 9 billion people by 2050, will result in a greater competition for land, water and energy [1]. To feed the world population, the intensity of the production on agricultural land has to be significantly increased [2]. Concurrent with the recent increase in agricultural productivity, agricultural systems are now also recognized to be a significant source of environmental damage [3,4]. During the last five decades worldwide fertilizer consumption has grown approximately fourfold; for nitrogen fertilizers even sevenfold [5]. However, unlike pesticides or other agricultural inputs, plant nutrients cannot be substituted by other products. Nevertheless, a better adoption of the necessary plant nutrients to the actual requirement and a better use efficiency can be reached with new fertilizer products or better tailored application and cultivation methods [4,6]. Products, services or management strategies with the purpose of improving the environmental impact and increasing economic value can be classified as eco-innovations [7]. Numerous eco-innovations have been developed in the fertilizer sector in recent decades, but none of them have seen a successful market adoption leading to higher market shares [8,9]. Nevertheless, identifying the main reasons can help policy makers and other decision-makers to implement instruments which are effective and efficient enough to promote eco-innovations in the fertilizer sector [10]. Numerous publications have reviewed the literature on firm-level determinates of eco-innovations [10–12]. All reviews have identified main determinants, such as regulatory pressures, firm size or firm age. However, a company and a single farm are not in all cases completely comparable [11,13]. Additionally, even models specifically tailored to eco-innovations [14,15] seem not sufficient enough to explain the low adoption of eco-innovations at farm level [16]. It seems that well-established models explaining innovation adoption such as

Rogers' theory of innovation diffusion or Davis' technology acceptance model are more suitable [17,18]. Therefore, as a basic model for innovation adoption, the seminal technology acceptance model (TAM) of Davis (1989) was selected to guide this literature review [17,19]. By reviewing the literature the model was extended by external precursors, factors suggested by other theories and contextual factors. To our best knowledge, this is the first attempt to explain the low adoption of innovations within a sector not by only by firm-specific factors, but on a more individual level, putting the farmer and therefore the innovation adopter into the focus. Additionally, this literature review combines innovation adoption in agricultural supply chains with the lens of innovation typologies, to reach a better understanding of the reasons for the low adoption rates of eco-innovations. Therefore, the innovations found within this review are categorized in six cases: First, the eco-innovations were divided into disruptive (changing the way of farming or fertilizer application; [20]) or continuous (not changing the complete fertilizer management; [21]) innovations. Here we used the division of Garcia and Calantone [22] claiming that disruptive or, in their terms, radical innovations, combining a new technology and a new market, make the adoption a much more difficult task. Continuous or incremental innovations present only new features, benefits or improvements to existing technologies in existing markets. Or more precisely for the agriculture environments: disruptive innovations change the working process and the everyday situation, need new or advanced technology, information or support and are not easy to adapt to the existing management strategy [23]; continuous innovations change only the yield or the quality of agricultural products, are easy to adapt [24]. Afterwards, the reviewed publications were divided into different types of innovations. This division was made because we assume that different eco-innovations types are facing specific difficulties in the innovation diffusion process, because of their various particularities. We build our analysis on different types of innovations: disruptive process innovations (1) and innovations of other types (2) and continuous process (3) and product innovations (service (4) and goods (5)). According to our best knowledge, this is the first attempt to review the innovation adoption literature by the characteristics and types of innovations in agriculture. Here the different characteristics of specific eco-innovations types have been used to come to more general conclusions of the eco-innovation adoption in the fertilizer area and the entire agricultural sector.

The remainder of this paper is structured as follows. Section 2 focuses on the analytical framework and gives an overview about the theoretical approaches. Section 3 presents the systematic literature review, while results are discussed in Section 4. First, a basic description of the aggregated publications is performed, followed by more systematic descriptions for the five cases (disruptive process and other type of innovations, continuous process and product (services and goods) innovations. Finally, the paper closes with the syntheses of the main drivers of fertilizer innovation adoption in general and for the specific environments.

2. Material and Methods

2.1. The Research Setting: Eco-Innovations in the Fertilizer Sector

To meet the challenges of global food security and the environmental impact of agriculture in a sustainable way requires the use of modern agricultural practices [25]. One solution to stop the continuing world food crisis might be the suggestion of a substantially greater use of (fertilizer) inputs. However, there is growing evidence that fertilizer use has already reached critical environmental limits, and that the aggregate costs in terms of lost or foregone benefits from environmental service are too high for the world to bear [26,27]. Here the implementation of so called environmental or eco-innovations could solve a wide range of the above-mentioned problems. Eco-innovations are defined as innovations that reduce the environmental impact or the use of natural resources [7,28,29]. This can lead to innovations targeting a more responsible application of fertilizers. A widely used definition is the one of Kemp and Pearson [30], who defined eco-innovation as production, application or exploring of a good or service that is novel to a firm or user. Additionally, it results in a reduction of environmental risk, pollution and the negative impacts of resource use compared to relevant alternatives. Ekins [29] even went one step further by mentioning eco-innovations as a change in economic activities that improves both the economic and the environmental performance of society. In the present review the focus lays on eco-innovations in the field of fertilization and plant nutrition. Here we are especially interested in the interaction between the innovation type and the drivers for the adoption. The overall goal is to elucidate factors driving the adoption of eco-innovations. In the fertilizer sector, most eco-innovations are encircling a better adjustment of fertilization to the agricultural environment, closing nutrient cycles or to improve nutrient and cultivation managements [8].

2.2. Classification of Eco-Innovations

In order to provide a more in-depth understanding of how the adoption of eco-innovations may differ according to type of innovation, the main characteristics of eco-innovations need to be distinguished. By separating the innovations in disruptive and continuous innovations it was aimed to get a better understanding in the adoption process of more radical and less radical innovations. Disruptive innovations are innovations which create a new market or displace or disrupts existing markets [20]. Disruptive innovations tend to be produced by outsiders and entrepreneurs, rather than existing market-leading companies [31]. The business environment of market leaders does not allow them to pursue disruptive innovations when they first arise, because they are not profitable enough at first and because their development can be fundamentally different from the normal production process and can need different resources [31]. A disruptive process can take longer to develop, therefore the risk associated to it is higher than by other types of innovations [32]. Continuous innovations are ongoing advancement of existing technologies or products. They do not fundamentally change the market dynamics and therefore they do not typically require end users to change in behavior [33].

Furthermore, innovations can be divided into different types. This distinction between different innovation types has found to be essential, because the types have different characteristics and their adoption is not affected identically [34–36]. The variety of different innovation types is outstanding, the best known and widest study typology of innovations is the distinction between product and process innovations [37,38]. Edquist [39] expands these two established typologies by including two types of product innovations ("in goods" and "in services") and two types of process innovations ("technological" and "organizational"). Whereby the technical process innovation compromises things such as customer services, logistics and procurement and organizational innovations things such as strategic planning, project management and employee assessment [40]. For the fertilizer supply chain the following four types of innovations could be distinguished as relevant: (3) disruptive process innovations, such as advanced consultation, which can be needed within a sustainable intensification, (2) disruptive innovations of other types of innovations which have more than one specific characterization, such as precision farming, (3) continuous process innovations such as intercropping or nutrient management decisions, (4) product innovation resulting in new goods or products, such as stabilized nutrients and (5) product innovations resulting in new service options, such as online diagnose tools for nutrient status.

2.3. Technology Acceptance Models

There are numerous models to describe technology acceptance and use, for example Rogers's theory of innovation diffusion [18], the Concerns-Based Adoption Model (CBAM; [41,42]) or the technology acceptance model (TAM; [17]). Because of its simplicity and frequent use, the TAM was used as model for innovation adoption in the context of this article (Figure 1).

The TAM bases on studies and models of empirical social sciences, especially the model of theory of reasoned action developed by Ajzen and Fishbein [43]. Davis [17] and Davis et al. [19] thereof developed the TAM to provide an explanation that intended the acceptance of computer usage across a wide range of end-user. According to Straub (2009) Davis identified two perceived characteristics about new technologies that, in his belief, could predict the actual use. Those are the perceived ease of use (PEU) and the perceived usefulness (PU).

However, because of its simplicity, its origin in the IT-sector and the attitude-behavior gap the TAM often fails to actually describe the way of innovation acceptance in agriculture [44–46]. Additionally, because of their specific nature, eco-innovations are facing more acceptance problems than other innovations. Here, the classic factors pushing innovations like technology push or market pull mostly fail to fully explain the low diffusion of eco-innovations [47–49]. Due to other external problems, such as the level of technological capabilities acquired through R&D activities, impulses for eco-innovation creation from the demand side is rather low [50]. Additionally, a lack of knowledge transfer mechanisms and involvement in networks [49,51,52] leads to the conclusion that the traditional discussion of innovation economists has to be extended. King and He [53] found in a meta-analysis several variables, which can improve the forecasting quality of the TAM without changing the simple characteristic of it. The inclusion of external precursors [54–57], the incorporation of factors suggested by other theories, the inclusion of contextual factors [16,55,58] and the inclusion of consequence measures [17,59,60] are found to be most useful to describe the innovation adoption in a larger scale. For the agricultural sector, the inclusion of consequence measures (such as attitude, perceptual usage and actual usage) is only rarely investigated in scientific publications and was therefore excluded.

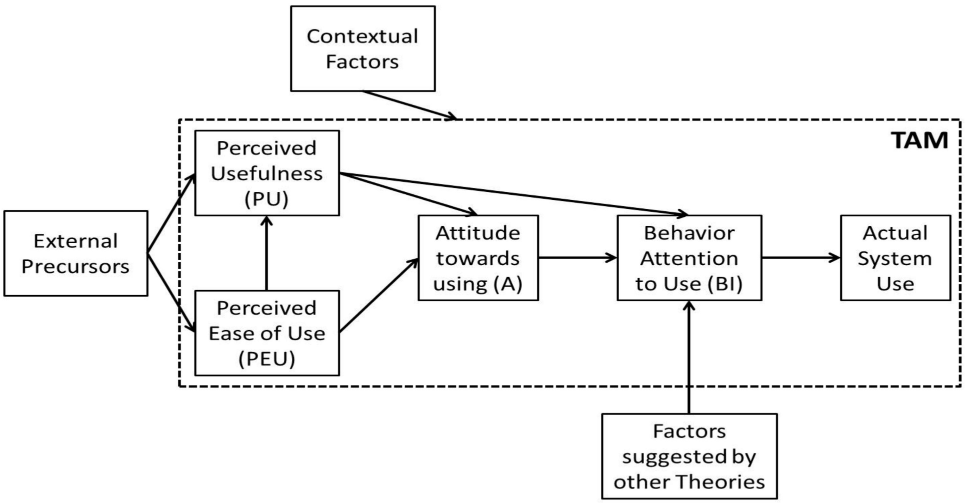

Figure 1. The technology acceptance model and its extension for the literature review.

We extend the TAM with respect to:

(1) The inclusion of external precursors such as situational involvement (like the involvement in external groups or co-operations; [54]), pressure by regulation [16], observability [57,61], quality of support [56,62], information [16,56] and compatibility [63].

(2) The incorporation of factors suggested by other theories that are intended to increase TAMs predictive power; these include expectation [64], task-technology fit [16,65], access to credit [16] and market access [16].

(3) The inclusion of contextual factors such as gender, age, education, farm size and land-ownership that may have moderator effects [16,53,58,64,66].

In the following section, the external precursors and factors suggested by other theories are shortly explained, starting with the external precursors:

- The involvement of external groups (like co-operations, organizations, advisory council or association) can be a good source and distribution of information, knowledge and application of new technologies or products [54]. External groups can provide their participations with external resources and regular meetings and can therefore stimulate farmers to try something new [67].
- Regulations can stimulate the need to adopt certain innovations faster [9,16]. They suggest norms, rules and acceptable behaviors through binding regulations [9].

- Farmers need to see an improvement by using new methods and technologies. Therefore, the observability of the effects of these new methods or technologies on the yield, yield quality or harvest material is important for the acceptance [57,61].
- The quality of support can have a strong influence on the eco-innovation adoption [56,62]. This is especially important for innovations with a more technical origin. Here the support must not only provide a platform for buying and selling, but also for learning, repair, assistance and training [68,69]. Also the adoption of process innovations can be stimulated by a good technical or personal support [70,71].
- Information and knowledge exchange can be a strong precursor for innovation adoption [16,56]. According to Carlsson and Jacobsson [72] it is essential to form an exchange of information throw-out in a network to get a better understanding of innovations and therefore a higher willingness to expose innovations.
- Compatibility is especially important for innovations concerning more technical solutions with the need to be fitted to the existing farm equipment [63]. Therefore, it plays a more significant role for disruptive innovations. New technologies or management systems raise definite expectation by the users, in this case farmers [64].

Factors suggested by other theories can be outlined as followed:

- In our literature review expectations are mainly expressed in higher yields or better yield qualities [73,74], followed by the reduced use of fertilizers [75] or less fertilizer costs [61]. Therefore the variable expectation can be multi-dimensional. In order to regard that fact, we only include expectations referring to the yield and yield quality, because these are the main factors influenced by fertilizers.
- The variable task-technology fit can be a good trigger to describe the adoption of more disruptive innovations. If an innovation involves a large number of different technologies (e.g., IT, agricultural machinery, measuring devices), all these technologies need to be controlled by the farmer [16,65]. Here a better understanding of the underlining technology and a more open attitude towards new technologies can trigger a positive adoption.
- Access to credit can stimulate more expensive eco-innovations with a potential in cost-saving in the near future (e.g., some precision farming technologies [16]).
- Market access combines the fact, that an eco-innovation must be available for the user and the end-products, created with new technologies, must be disposable on markets [16].

2.4. Systematic Literature Review Methodology

First, we limited our search to fertilizer literature using the web-based search engine ISI Web of Knowledge(SM). Topic search (TS) was used to identify publications that refer to fertilizer in title, abstract, author, keywords and keywords plus®. The reach was further narrowed down to English language articles including peer-reviewed research papers, review papers, proceeding papers and book chapters published, between January 1945 and January 2017. The goal of this search was to get a broad overview about the publications within the fertilizer and plant nutrient sector. That search resulted in 58,650 publications in the field of fertilizer and plant nutrient (Table 1). Additionally, we included papers concerning precision agriculture or precision farming, because this is one major development in the area of plant nutrient and fertilizer application in the last decade. Many papers however do not include the words fertilizer or plant nutrient in the abstract or heading. In order to get these publications as well, we additionally include the keywords precision agriculture and precision farming. Here the search results in 2389 publications. To come to a combination of innovation adoption and plant nutrient or the use of fertilizers, we now combined these two studied areas with the concept of innovation adaption, diffusion, transfer and acceptance. A combination of the innovation keywords and the fertilizer or the precision agriculture and precision farming topic results in 100 publications. By screening references in the selected documents and applying “snowballing”, 48 documents were added to the final review. Papers on precision farming were only included if they have a major focus on fertilizer application, reduction or use. General precision farming papers were excluded from this review. After screening the abstracts of the 148 publications, 9 precision agriculture publications and 48 publications with fertilizer as topic were excluded from the review because of their limited relevance (e.g., urine separation, soil fertility in general, improved seeds or irrigation) coming to a total of 91 publications. All publications were evaluated by the main eco-innovations, publication type, the publication year, the journal, the country of research, the first author background and the main drivers.

Table 1. ISI web of knowledge keyword search to come to the reviewed articles.

	Fertilizer and Plant Nutrients	Precision Agriculture	Innovation Adoption
Search keywords	#1: TS=((fertilizer) or (fertilizer) or (“Plant nutrient”) or (plant + nutrient) or (“Plant nutrition”) or (plant + nutrition))	#2: TS=(“precision agriculture” or ”precision farming”)	Within #1 and #2: TS=(((Innovation) AND (Adoption OR Diffusion OR Transfer OR acceptance) or ((Eco-Innovation) AND (Adoption OR Diffusion OR Transfer OR acceptance)))
Number of results	58,650	2389	148
Connection to the theoretical framework	Basic research setting to get information about the fertilizer and plant nutrient sector	Addition to the basic research setting, because many publications are not specifically tailored to the word fertilizer or plant nutrient	Combination of the basic research setting and the extended TAM in order to come to more general conclusions

3. Results

3.1. Different Eco-Innovations in the Fertilizer Sector

All analyzed 91 publications have a clear perspective on innovation in the fertilizer or plant nutrient area. Some of them are only changing single production steps, some change the whole way of farming. In the following, the main eco-innovations are shortly outlined. These are namely: (1) conserve farming (2) diagnose tools for nutrient status (3) fertigation (4) fertilizers made from secondary raw materials (5) intercropping with (leguminous) crops (6) knowledge training (7) nanotechnology (8) new cultivation methods (9) nutrient management technologies (10) precision farming (11) stabilized nutrients (12) sustainable intensification (see Table A1, Appendix A). All these eco-innovations were divided according to their specific type. First they were split in disruptive and continuous innovations. An innovation was categorized as disruptive, if the farming management system needs to change, the technology used is modified and/or it requires more or a more specific information flow, knowledge exchange or education. Additionally, it was considered, that the existing supporting or trading system is not sufficient enough to fully support the adoption of these special innovations. Continuous innovations require only minor changes in the farming management system, they are easy to integrate within the existing technology, supporting or trading network and only need a minimum of specific information, knowledge or education (see definition in introduction). Furthermore, all eco-innovations were split to their main characteristic, meaning if they are a process or product innovations or innovations of other types. Process innovations only change the process of, in our chase e.g., the application, but not other parts of the fertilization, product innovations represents new fertilizer products. Innovation of other types change the whole way of fertilizer usage and therefore mostly include more than one innovation characteristic. A high number of publications, classified as disruptive innovations, deal with new cultivation or farming methods regarding the application, use and management of fertilizers (e.g., [76–78]). In developing countries, these new cultivation methods even estimate the use of mineral fertilizers only. In more developed countries, the publications are aiming to come to new cultivation methods reducing the fertilizer input. All publications are circling around new ways of farming and crop production, with a higher technical input or a different training and service, wherefore all were categorized as disruptive innovations. Precision farming or precision agriculture is another widely published topic regarding eco-innovations in the fertilizer sector. Only publications with a focus on fertilizer application via precision farming were included in this review. Here especially the agricultural production in developed countries lies in the focus (e.g., [69,75,79]). These innovations are disruptive, because they need specific technology equipment and different types of fertilizers. The same holds true for conservative farming methods. Here the application of fertilizer and plant nutrients is a much more difficult and technical task, because of the different soil conditions and technical aspects, such as impossible soil tillage after the fertilization. Therefore, the whole farming system must be adapted to the new farming management regime, including the purchase of new farming technique (e.g., [80–82]). Another more disruptive innovation is the implementation of so called sustainable intensification in agricultural production. Here the use of fertilizers and plant nutrients is higher at regions with high yields and yield potentials and lower in areas with a less optimal farming area. Consequentially, high productive systems are producing at the yield maximum and low productive systems as environmental friendly as possible. That could also mean to shift certain cultivars to better fitted areas making agricultural environments more specialized (e.g., [78,83]). One publication estimated the influence of nanotechnologies on the fertilizer use and production [84].

Many publications concern specific crops where the cultivation should be optimized with better fertilization strategies or new ways of fertilizers application (e.g., [85–87]). These eco-innovations are classified as continuous process innovations. Product eco-innovations concerning the establishment of new goods all aim to lower the environmental impact of fertilization. Here in particular the stabilization of the nutrients in the soil, closing the nutrient cycles, or a more efficient use of the fertilizer nutrients are discussed (e.g., [9,88]). Other publications have the use of mineral fertilizer in developing countries in focus (e.g., [89,90]). Furthermore, tools for diagnosis to enable a better estimation of the crop nutrient status are evaluated by a number of publications (e.g., [91,92]). A well-established way to maintain soil fertility is the intercropping with, mostly leguminous, intermediate crops. In this review, many publications are concerned about optimizing these intercropping, especially in developing countries (e.g., [70,93,94]). Another, more service oriented eco-innovation can be the implementation of knowledge training methods for all members of the fertilizer supply chain (e.g., [95,96]). This implies the dissemination of production technologies or information of specific innovations to a large number of farmers, making fertilization more sustainable.

3.2. Results of the Literature Review

Only 148 (0.2%) of the 61039 fertilizers, fertilization and precision agricultural related publications address the problem of innovation adoption or diffusion in this area. However only 91 are can be related to the use, application and management of fertilizers and plant nutrients. The annual linear increase of publications in the fertilizer area is 5.8%. For publications concerning innovation adoption and diffusion, this increase is notable higher (9.6%); for publications regarding innovation adoption and diffusion in the fertilizer area, it is even 10.3% (Table 2).

The publications were analyzed for their reference elements on the different characteristics (disruptive or continuous) and the different types (process, product, other type, according to the classification in the introduction). Most publications could be found for disruptive innovations of other types (n = 26; 28%), closely followed by continuous process innovations (n = 24; 26%). Twenty publications (22%) deal with disruptive process innovations. The remaining types of continuous product innovations (goods and service) are slightly smaller (n = 10, 11% and n = 10; 11% respectively; Table 3).

Table 2. Search analysis for fertilizer and precision agriculture publications and the share of publications concerning innovation adoption.

	Fertilizer and Plant Nutrients	Precision Agriculture	Innovation Adoption
Range of pub. years	1946–2017	1994–2016	1993–2017
Avg. pub. per year (1994–2016)	2110	100	5.3
Avg. linear increase of pub. per year (1994–2016)	5.8%	9.6%	10.3%
Top-3 source titles	Commun Soil Sci Plant Anal (3.2%) Agron J (2.8%) Plant Soil (2.4%)	Comput Electron Agric (10%) Precis Agric (5.8%) Transac ASAE (3.7%)	Agric Sys (7%) Precis Agric (7%) J Agric Econ (5%)

Table 3. Eco-innovations in the fertilizer sector with their publication quantity and classification as disruptive or continuous and classification of the type of innovation (several publications regarding more than one innovation).

Innovation Found in the Literature	Number of Publications	Innovation Type	
		Disruptive	Continuous
Conserve farming	11	Other type	
Diagnose tools for nutrient status	10		Product (service)
Fertigation	6		Product (good)
Fertilizers made from secondary raw materials	3		Product (good)
Intercropping with (leguminous) crops	13		Process (technological)
Knowledge training	6		Product (service)
Nanotechnology	1	Other type	
New cultivation technologies	28	Process (technological)	
Nutrient management technologies	13		Process (technological)
Precision farming	17	Other type	
Stabilized nutrients	14		Product (good)
Sustainable intensification	5	Process (technological)	

Of the analyzed publications, eight reviews dealing with different aspects of the adoption of fertilizer innovations and development of fertilizer innovations were found. 74% of the analyzed publications were published between 2007 and 2016, the oldest one has been published at 1993 (Figure 2). The top-3 journals in which 19% of the publications where published are: Agricultural System, Precision Agriculture and Agricultural Economics which all have a wider focus on agricultural research result and policy assessments.

Regarding the geographical orientation, 135 different countries where counted within the 91 publications. The share of publications focusing on agriculture in developed countries (Australia, North America and Europe; n = 36; 26%) is much lower than the share of publications focusing on agriculture in developing countries (Asia, Africa, Latin and Mid America; n = 88; 65%). The remaining publications (n = 11, 10%) have a more global orientation.

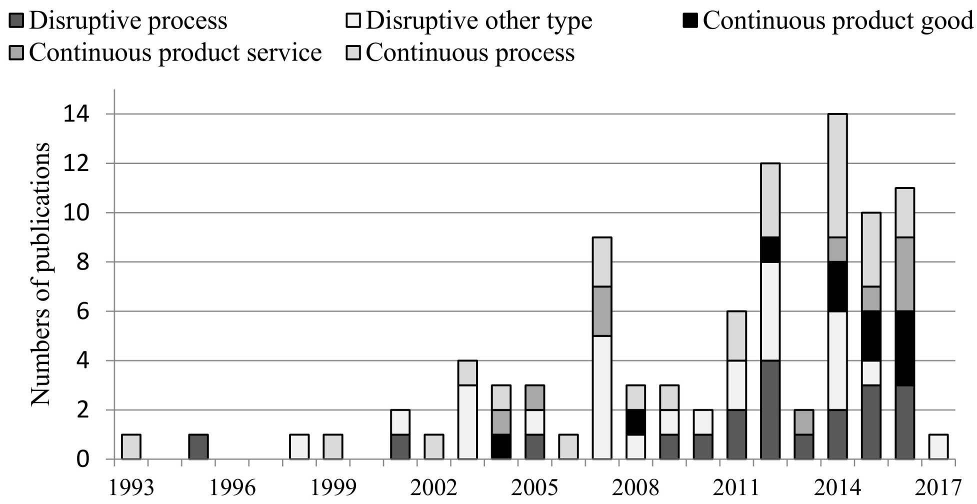

Figure 2. Number of publications per year and approach from 1993 till 2017.

For our analysis of the main determinates we first identified all relevant drivers within in the publications and included these in a database (Table 4). Each driver is than applied, by searching with specific keywords, to the specific eco-innovation type to provide a more insight view of the most common drivers (for each innovation type) and to give more insights to the specific adoption problems.

Concerning the first authors' affiliation the following research background could be detected: universities (n = 54; 59%), international research institutes (n = 23; 25%), national research institutes (n = 7; 7%), governments (n = 3; 3%), development associations (n = 3; 3%), consultancy companies (n = 2; 2%) and one farmer (n = 1; 1%).

Table 4. Keywords that were used to analyze the main drivers.

Theoretical Approach	Keyword
Drivers: External precursors	1. Group 2. Network 3. Co-operation 4. Farm Neighborhood/Environment 5. Regulation 6. Law 7. Rules 8. Observability Visibility 9. Outcome 10. Result 11. Support 12. Help 13. Service 14. Information 15. Media 16. Communication 17. Compatibility 18. Consistency

Table 4. *Cont.*

Theoretical Approach	Keyword
Drivers: Factors suggested by other theories	1. Expectation 2. Concept 3. Performance 4. Imagination 5. Yield 6. Yield quality 7. Task-technology 8. Computer 9 IT 10. EDV 11. Credit 12. Bank 13. Financial Institute 14. Loan 15. Market 16. Store 17. Retailer
Drivers: Contextual factors	1. Gender 2. Age 3. Education 4. Farm size 5. Land ownership

In the following, the main drivers for the different types of innovations are shortly outlined. Because of the wide range of the publications in geographic and agriculture surrounds, it was assumed that at least 25% of all publications need to mention a driver to be relevant

3.2.1. Drivers for Disruptive Process Innovations

The involvement in groups, co-operations or in advisory council could stimulate the consideration of disruptive process innovations [67,78,97–100] (Table 5). Furthermore, it can provide a good information exchange, which is also an important trigger for the adoption of disruptive process innovations [67,78,83,97,99,101,102]. To push a new production technology, farmers need to have access to a market where they can buy the technology or the knowledge about this specific technology and where they can get a credit for this particular purchase. Therefore, access to credit [67,76,78,98,103–106] and a market access [67,97–99,104,106,107] are important. Disruptive process innovation seems to be sooner adopted by male farmers than by female ones [76,78,97–100,103,107]. One reason could be the higher risk tolerance of male people [100]. Age is seen by many publications as a influencing factor where a younger age positively influences innovation adoption [76,78,98–100,104,106–108]. Younger farmers have longer planning horizons and therefore have a bigger stimulus to consider new equipment investments or a change management practices than older farmers. Nearly all publications mentioned the importance of education [67,76,78,99–101,103,104,106,107]. Higher education levels can have a stimulation effect because they can provide the farmer with a higher willingness for live long learning and cooperation. A bigger farm size can give farmers a better foundation for finical investments and can therefore trigger the eco-innovation adoption [67,76,78,83,98–100,106–108]. If the land is additionally owned by the farmers themselves, the willingness to invest in new technologies to maintain soil fertility and soil quality is much higher [97,99,104–106].

Table 5. Main drivers for disruptive process innovations (*n* = 20).

Drivers	Disruptive Process Innovations
Involvement in external groups or co-operations	6
Information	7
Access to credit	8
Market access	7
Gender	8
Age	9
Education	10
Farm size	10
Land ownership	5

3.2.2. Drivers for Disruptive Innovations of Other Types

One major driver mentioned as important by almost all publications is the quality of support [68,69,73,74,79,81,84,109–115]. Reichardt et al. [68] declared that farmers need more information about the different farming tools and more training opportunities as well as a better advisory service. Watcharaanantapong et al. [69] even observed that farmers who obtained farming information from farm dealers, crop consultants, university extension, other farmers, trade shows, the internet, and/or news media were more likely to adopt complex disruptive innovations. Information can be seen as important precursor for innovation adoption. That goes in line with many publications for this particular type of innovation [68,69,74,79–81,84,109–111,113–115]. One source of information could be agricultural events such as field days, exhibitions and trade fairs, seminars or workshops [113]. More publications can be found for the variable expectations. Batte and Arnold [73], Marra et al. [61], Adrian et al. [75], Aubert et al. [79], Tey and Brindal [57], Busse et al. [74] and Handford et al. [84] all declare that farmers with high expectations are more willing to adopt new technologies. Disruptive innovations of other types are mostly orbiting around conserve or precision farming practices. These kinds of innovations are mostly technologies with a specific focus on new computer-based technologies (e.g., variable fertilizer application or IT farm management systems), which require a minimum comprehension of these technologies. Therefore, most publications see the technology task fit as an important driver for the adoption [44,57,68,69,73–75,79,80,109,111,115–117]. A higher education level seems to stimulate the adoption of new technologies [57,68,69,74,75,80,112,113,118]. Davidson et al. [110] particularly mentioned the importance of education for private sector retailers and crop advisors on the most up to date nutrient management practices through professional certification programs because these persons play a dominate role in knowledge diffusion. Because of the investment costs of these technologies, farm size can be seen as important variable, while larger farms sooner reach the break-even point of the investments [57,61,68,69,75,79–82,109,113,119] (Table 6).

Table 6. Main drivers for disruptive innovations of other types (*n* = 28).

Drivers	Disruptive Innovations Other Type
Quality of support	14
Information	13
Expectation	7
Task-technology fit	14
Education	10
Farm size	11

3.2.3. Drivers for Continuous Process Innovations

Continuous process innovations are pushed by nearly the same drivers as disruptive process innovations. Only gender, age and education seem not as relevant as for disruptive process innovations. Therefore, the involvement in external groups [94,117,120–124], the quality of support [70,93,94,117,121,125,126], the information access [70,85,93,94,117,121–123,126–129], access to credit [85,120,122,124,125,127,130] and market [85–87,93,94,120,122,123,129] and the farm size [117,122,124,126,127,129,131] are most important (Table 7).

Table 7. Main drivers for continuous process innovations (n = 24).

Drivers	Continuous Process Innovations
Involvement in external groups or co-operations	7
Quality of support	7
Information	10
Access to credit	7
Market access	9
Farm size	7

3.2.4. Drivers for Continuous Product Innovations (Goods)

To evaluate the purchase of a new product, the user needs to be informed about the possibility to buy a new product and the improvements of this new product. Therefore, information is mandatory [9,88,89,132]. That goes in line with the quality of support. Here a good support or consulting could stimulate the farmers to try a new product [9,88,89,133]. New products are in need for a purchase opportunity by farmers. Hence the access to a market selling the new products is necessary. If the farm surrounding does not provide any opportunity to buy an innovative product, the farmers are less aware and have no opportunity to come in contact with these new products [89,134–136]. If a new product implies further investments, the access to credit can motivate innovation adoption [89,134,137,138]. Age and education level can also stimulate the adoption by having a longer planning horizon and a better formal training [89,134,136–138] (Table 8).

Table 8. Main drivers for continuous product innovations (n = 10).

Drivers	Continuous Product Innovations (Goods)
Quality of support	4
Information	4
Access to credit	4
Market access	4
Education	5

3.2.5. Drivers for Continuous Product Innovations (Service)

The involvement in co-operations or consultant groups can stimulate the adoption of service innovations because these groups can offer this kind of service or can establish contacts [95,139,140]. When farmers exploit services, they want to see the results in higher yields or input effort. Therefore, the observability of these services is important for the continued use [91,92,133,139]. The same holds true for the quality of the support. By providing a specific service, a continuous support is necessary [91,92,140]. Here a fluent information flow, which is also important for innovation adoption, is also ensured [91,96,133,141]. For product innovations offering new ways of services, also gender (male; [95,133,139]), age [92,95,139] farm size [92,139,142] can trigger a further adoption (Table 9).

Table 9. Main drivers for continuous process innovations (n = 10).

Drivers	Continuous Product Innovations (Service)
Involvement in external groups or co-operations	3
Observability	4
Quality of support	3
Information	4
Gender	3
Age	3
Farm size	3

4. Discussion and Conclusions

This review shows that the largest group of publications focuses on farm-level analysis. The structural analysis of multi-level interactions, which can play an important role for innovation adoption, is rarely part of the analytical framework of the considered publications. Only a few studies even mentioned level of higher dimension (e.g., national policies; [93,140]). The observed literature clearly displays that the relationship in innovation creation and adoption between farmers and researchers remains the same, with the researcher as innovation developer and farmers as innovation adopters. In the majority of the publications, the farmers have no or little influence on the innovation itself. In some studies, the (national) agricultural research and extension system have a massive impact on promoting innovation adoption [77,111]. That leads to the conclusion that within the fertilizer or agricultural sector, more individual decisions and therefore more individual drivers play important roles for the eco-innovation adoption and diffusion. Comparing it to other publications dealing with main drivers of eco-innovation adoption, the regulatory pressure, market demand, competitive pressure or stakeholder pressure seems to play a minor role [10–13]. That makes the implementation of innovations especially suited to ecosystems or eco-innovations much more difficult [14,15]. The fertilizer sector showed a clear focus on more individual determinates, such as task technology fit, age, education or gender (Tables 5–9). Therefore we assume that a model describing more individual determinates of innovation adoption, such as the TAM, is more suitable for explaining the low adoption of eco-innovations within the fertilizers sector, than classic economic models.

An additional distinction of the publications into diverse agricultural areas could be useful. For example many continuous process innovations (like nutrient management technologies) are already used in higher amounts in developed countries. By splitting the research up to more specific agricultural areas, more precise predictions about the eco-innovation adoption would be possible. The literature review done in this paper generally showed that individual factors are more important for innovation adoption at farm level than economic explanations putting the farm as firm into the focus. Additionally, the characteristics of a specific innovation can lead to different solutions supporting the adoption. Disruptive process innovations are driven by information, education, age and farm size. That leads to the conclusion, that this type of innovation requires a more radical rethinking in the farm management and production systems, making the adoption more reasonable for bigger farms with a longer planning horizon. Disruptive eco-innovations of other types are mostly pushed by factors regarding the knowledge and education of the single farmer, such as the education level, the task technology fit, information and support. Here, targeted training opportunities for farmers to enhance their skill and knowledge so that they can cope with the complexities of the systems can help to overcome adoption problems. The adoption of continuous innovation is mostly motivated by the driver information, where more training opportunities and consulting could actively simulate a positive adoption.

More research is generally needed to compare developed countries and developing countries. Some of the innovations classified as continuous innovations could be disruptive in developing countries because of a lack of market, trading opportunities or training. Additionally, it would be interesting to know whether the adoption decision might change, if the characteristics of an innovation change from disruptive to continuous (for example the use of apps to characterize the nutrient status of a plant). Here future studies seem necessary to allow for a more precise understanding of innovation adoption in the field of fertilizer and agricultural eco-innovations. However, this study provides a detailed inside view to the nature of innovation adoption at farm level by taking the different characteristics of specific innovations into account. Future studies can use this framework for different agriculture sectors in order to come to a better explanation for the low innovation adoption in the agricultural sector in general.

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Appendix

Table A1. Fertilizer innovation adoption publications categorized according to the main characteristic and innovation type (publications regarding more than one type of innovation were categorized regarding their main focus).

Innovation Type		Publications	Innovation
Disruptive	Process	Adesina and Baidu-Forson, 1995 [108]; Doss and Morris, 2001 [107]; Chianu and Tsuji, 2005 [138]; Oduol and Tsuji, 2005 [143]; Oladoja et al., 2009 [103]; Sirrine et al., 2010 [144]; Giller et al., 2011 [101]; Katungi et al., 2011 [104]; Akudugu et al., 2012 [76]; Kopainsky et al., 2012 [102]; Loyce et al., 2012 [77]; Mapila et al., 2012 [97]; Shiferaw et al., 2013 [67]; Ndiritu et al., 2014 [98]; Tey et al., 2014 [78]; Emerick et al., 2016 [105]; Mahadevan and Asufu-Adjeye, 2015 [106]; Manda et al., 2015 [99]; Stuart et al., 2015 [123]; Handschuch and Wollni, 2016 [100]; Ju et al., 2016 [83]; Roxburgh et al., 2016 [145]	New or advanced cultivation methods [76,97,99–103,106–108,138]; sustainable intensification [67,77,78,83,98,104,105,123,143–145]
	Other type	Strickland et al., 1998 [116]; Swinton and Lowenberg-Deborer, 2001 [118]; Batte and Arnold, 2003 [73]; Daberkow and McBride, 2003 [109]; Marra et al., 2003 [61]; Adrian et al., 2005 [75]; Jochinke et al., 2007 [111]; Knowler and Bradshaw, 2007 [80]; Namara et al., 2007 [81]; Ogbonna et al., 2007 [112]; Takăcs-György, 2007 [119]; Gowing and Palmer, 2008 [71]; Reichardt et al.; 2009 [68]; Rezaei-Moghaddam and Salehi, 2010 [44]; Dalton et al., 2011 [146]; Kutter et al., 2011 [113]; Aubert et al., 2012 [79]; Chauhan et al., 2012 [82]; Nikkila et al., 2012 [114]; Tey and Brindal, 2012 [57]; Busse et al., 2014 [74]; Davidson et al., 2014 [110]; Nhamo et al., 2014 [147]; Watcharaanantapong et al., 2014 [69]; Handford et al., 2015 [84]; Eastwood et al., 2017 [115]	Precision farming [44,57,61,68,69,73–75,79,109–111,113–116,119]; conserved farming [71,80–82,112,118,146,147]; nanotechnology [84]
Continuous	Process	Smale and Heise, 1993 [127]; Pandey, 1999 [85]; Haneklaus et al., 2002 [148]; Mudhara et al., 2003 [131]; Mafongoya et al., 2006 [70]; Ajayi et al., 2007 [120]; Ajayi, 2007 [129]; Akinnifesi et al., 2008 [149]; Lamba, 2009 [121]; Ajayi et al., 2011 [125]; Chen et al., 2011 [150]; Kanellolpoulos et al., 2012 [151]; Robertson et al., 2012 [117]; Siddique et al., 2012 [128]; Simpson et al., 2013 [86]; Kamau et al., 2014 [129]; Simpson et al., 2014 [87]; Wainaina et al., 2014 [122]; Weber and McCann, 2014 [126]; Lamers et al., 2015 [130]; Wossen et al., 2015 [124]; Magrini et al., 2016 [94]; Russo et al., 2016 [152]	Nutrient management [85–87,117,122,124,126,127,130,150,152]; fertilizer management [148]; leguminous intercropping [70,93,94,120,125,128,131,149]; management technologies [121,129,151]
	Product (Good)	Asfaw and Admassie, 2004 [137]; Alene et al., 2008 [134]; Khumairoh et al., 2012 [153]; Lambrecht et al., 2014 [89]; Nin-Pratt and McBride, 2014 [90]; Chang and Tsai, 2015 [132]; Ciceri et al., 2015 [135]; Hasler et al., 2016 [9]; Herrera et al., 2016 [88]; Sheahan et al., 2016 [136]	Mineral fertilizer [89,90,132,134–137,153]; fertilizer made of secondary resources [9]; stabilized nutrients [9,88]
	Product (Service)	Rerkasem, 2005 [154]; Hayman et al., 2007 [91]; Schreinemachers et al., 2007 [139]; Chianu et al., 2012 [133]; Moreau et al., 2013 [141]; Van Rees et al.; 2014 [142]; Huang et al., 2015 [140]; Abate et al., 2016 [95]; Zhang et al., 2016 [92]; Zhao et al., 2016 [96]	Knowledge training [95,96,140]; supporting service [133]; diagnose tools [91,92,139,141,142,154]

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