Assessment of the Agroecological Potential of Biostimulatory Effects

– Originating from Effective Microorganisms (EM) in terms of Environmental and Socioeconomic Aspects

Einschätzung des agrarökologischen Potenzials der Biostimulanzeffekte von Effektiven Mikroorganismen (EM) in Bezug auf Umwelt- und sozioökonomische Aspekte

Tania Schwarzer

Degree project • 30 credits

Swedish University of Agricultural Sciences, SLU

Agroecology – Master's Programme

Alnarp 2022

For my sister Lydia

Assessment of the Agroecological Potential of Biostimulatory Effects – Originating from Effective Microorganisms (EM) in terms of Environmental and Socioeconomic Aspects

Einschätzung des agrarökologischen Potenzials der Biostimulanzeffekte von Effektiven Mikroorganismen (EM) in Bezug auf Umwelt- und sozioökonomische Aspekte

Tania Schwarzer

Supervisor:	Jean Yong, Swedish University of Agricultural Sciences, Department of Biosystems and Technology
Co-supervisor:	Anna María Pálsdottír, Swedish University of Agricultural Sciences, Department of People and Society
Examiner:	Iman Raj Chongtham, Swedish University of Agricultural Sciences, Department of Biosystems and Technology

Credits:	30 credits
Level:	Second-cycle, A2E
Course title:	Independent Project in Agricultural science
Course code:	EX0848
Programme:	Agroecology – Master's Programme
Course coordinating dept:	Department of Biosystems and Technology

Place of publication:	Alnarp
Year of publication:	2022
Online publication:	http://stud.epsilon.slu.se

Keywords:	effective microorganisms, agroecology, biostimulants, beneficial microorganisms, lactic acid bacteria, bokashi, semi-structured interviews, interpretative phenomenological approach

Swedish University of Agricultural Sciences

Faculty of Landscape Architecture, Horticulture and Crop Production Science

Department of Biosystems and Technology

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file.

If you are more than one author you all need to agree on a decision. Read about SLU's publishing agreement here: https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.

Abstract

Environmental pollution, resource depletion and climate change are related to imbalances in the farming system. Effective microorganisms are seen as a possible solution to these problems. They are a consortium of microorganisms, which positively influence the decomposition of organic matter and create a favorable environment for plants, promoting their health and growth by stimulating physiological processes, including the efficiency of photosynthetic and stress resistance pathways. The study aims to accomplish an understanding of whether, which and how effects of EM observed in scientific research can be achieved in practice, while collecting new information on social and economic effects. Furthermore, answering the research question of how the application of effective microorganisms (EM) complies with the agroecological principles. Therefore, eight semi-structured interviews with German and Austrian farmers were conducted and subsequently analyzed using an interpretative phenomenological approach. Furthermore, the author assesses the sustainability of the EM practice by applying the disciplinary approach of agroecology by relating the finding to the 13 principles established by the Food and Agriculture Organisation of the United Nations (FAO).

The practitioners reported that as an experienced-based and knowledge-intensive practice, the application of EM requires farmer-to-farmer contact. Farmers are included in the product development of the preferably used ready-made EM solutions. Meanwhile, there is a lack of support from academia and official associations. The application of EM is limited by their input costs, increased labor, climatic conditions, and integration with other work processes and farming inputs, which is facilitated by their non-toxicity. The purpose, state and growth stage of the crop also needs to be considered. Proactively applied EM can successfully preoccupy, compete and positively interact with other microorganisms. Susceptible, special, high-risk and niche crops benefit most from the improved resistance to extreme weather conditions, pests and diseases induced by EM. Additionally, EM make organic fertilizer more competitive by improving the timing due to accelerated decomposition. Through the application of EM, pesticides and synthetic fertilizers can be reduced and sometimes replaced. Therefore, increased economic returns are possible due to reduced losses and improved input efficiency as well as increased yield, crop quality, earlier bloom, and non-toxicity, which additionally draws the consumer’s attention. The application of EM often comes with an understanding of responsibility by the producers.

With the support of EM, natural cycles can be restored, and degraded soils can be ameliorated. By reducing losses and improving their use efficiency, farming inputs can be reduced and, in some cases, even replaced. However, a nutrient source for the EM needs to be added, which however can be local resources applied using existing machinery and labor. Meanwhile, the additional management is compensated by the easy handling due to the non-toxicity of EM. This safety for non-target species besides the aforementioned effects supports soil and animal health as well as biodiversity and the related synergies. In addition, biodiversity in particular benefits from the environmental benefits originating from the input saving. Endorsing farmers for the ecosystem services related to the application of EM would create an additional source of income. Besides, the increased abiotic and biotic stress resistance supports the diversification of cultivation and leads to season extension due to earlier bloom and later infestation, which not just economically diversifies the farm, but also local diets, supporting cultural identity. Further marketing benefits arise, while the increased marketability and shelf-life additionally contribute to the reduction of food waste. These are just some of the effects of EM application benefitting food security, safety and sovereignty. Besides, yield stability and the resulting income security create an incentive for high-risk, high-return investments in innovation. The novelty of EM application itself encourages exchange between practitioners and producers of EM solutions, but also farmer-to -farmer contact. However, although EM application is a knowledge-intensive and experience-based practice, the necessary involvement from academia is lacking. On the other hand, customer interest is induced, while neighborhood relationships are improved due to the reduction of negative externalities. By mitigating abiotic and biotic stress as well as negative environmental externalities, EM contribute to the protection of the groups most vulnerable to these effects, fostering gender and social equity. Further, the access to nutrient sources facilitated through EM application is especially important for remote small-scale farmers. Additionally, work safety associated with EM is crucial for fair working conditions. Meanwhile, the use of local, renewable resources is promoted, protecting other resources in addition to the increased efficiency of the resources already in use. The reduced outflow of money and employment opportunities due to increased self-sufficiency can empower the local community.

In conclusion, due to the variety of benefits arising from the EM's biostimulatory effects, e.g. the plant's increased resistance to abiotic stress, the application of EM functions as a climate change adaptation strategy. Additionally, the invasion by alien species driven by climate change can be better managed due to the increased biotic resistance of the crops after EM application. Furthermore, the EM application contributes to climate change mitigation by reducing emissions by increasing input efficiency. Simultaneously, the economic risk-resilience of farming businesses is increased since self-sufficiency is strengthened, mainly through the promoted use of local resources, making the farming community less vulnerable to external market disruptions.

However, many uncertainties exist around the practical implementation of EM treatments in terms of their effectiveness and effects due to the complexity of natural processes as well as the socioeconomic impacts due to a lack of studies.

Keywords: effective microorganisms, agroecology, biostimulants, beneficial microorganisms, lactic acid bacteria, bokashi, semi-structured interviews, interpretative phenomenological approach

Zusammenfassung

Umweltverschmutzung, Ressourcenverknappung und Klimawandel stehen im Zusammenhang mit Ungleichgewichten im landwirtschaftlichen System. Effektive Mikroorganismen werden als eine mögliche Lösung für diese Probleme angesehen. Dabei handelt es sich um ein Konsortium von Mikroorganismen, welche die Zersetzung organischer Stoffe positiv beeinflussen und ein günstiges Umfeld für Pflanzen schaffen, indem sie deren Gesundheit und Wachstum durch die Stimulierung physiologischer Prozesse fördern, einschließlich der Effizienz von Abläufen der Photosynthese und Stressresistenz. Das Ziel dieser Studie ist es Kenntnisse darüber zu erlangen, ob, welche und wie die in der wissenschaftlichen Forschung beobachteten Effekte von EM in der Praxis realisiert werden können, und gleichzeitig neue Informationen über die sozialen und wirtschaftlichen Effekte zu sammeln. Darüber hinaus soll die Forschungsfrage beantwortet werden, inwieweit der Einsatz von effektiven Mikroorganismen (EM) mit den agrarökologischen Prinzipien vereinbar ist. Dazu wurden acht halbstrukturierte Interviews mit deutschen und österreichischen Landwirten geführt und anschließend mit einem interpretativ-phänomenologischen Ansatz ausgewertet. Des Weiteren bewertet die Autorin die Nachhaltigkeit der EM-Praxis, indem sie den disziplinären Ansatz der Agrarökologie anwendet und die Ergebnisse mit den 13 Prinzipien der Ernährungs- und Landwirtschaftsorganisation der Vereinten Nationen (FAO) in Beziehung setzt.

Die Praktiker berichteten, dass die Anwendung von EM als erfahrungsbasierte und wissensintensive Praxis den Kontakt von Landwirt zu Landwirt erfordert. Die Landwirte werden in die Produktentwicklung der vorzugsweise verwendeten EM-Fertiglösungen einbezogen. Gleichzeitig mangelt es an Unterstützung durch die Wissenschaft und offizielle Verbände. Die Anwendung von EM wird durch ihre Einsatzkosten, den erhöhten Arbeitsaufwand, die klimatischen Bedingungen und die Integration mit anderen Arbeitsprozessen und landwirtschaftlichen Betriebsmitteln begrenzt, was durch die nicht vorhandene Toxizität erleichtert wird. Auch der Zweck, der Zustand und das Wachstumsstadium der Pflanzen müssen berücksichtigt werden. Proaktiv eingesetzte EM können erfolgreich anderen Mikroorganismen verdrängen, mit ihnen konkurrieren und positiv mit ihnen interagieren. Anfällige, Sonder-, Risiko- und Nischenkulturen profitieren am meisten von der verbesserten Widerstandsfähigkeit gegen extreme Wetterbedingungen, Schädlinge und Krankheiten, die durch EM hervorgerufen wird. Darüber hinaus machen EM organischen Dünger wettbewerbsfähiger, aufgrund des verbesserten Timings durch eine Beschleunigung der Zersetzung. Durch den Einsatz von EM können Pestizide und synthetische Düngemittel reduziert und manchmal ersetzt werden. Daher sind höhere wirtschaftliche Erträge aufgrund geringerer Verluste und einer verbesserten Effizienz des Einsatzes sowie höherer Erträge, besserer Pflanzenqualität, früherer Blüte und toxischen Unbedenklichkeit möglich, was zusätzlich die Aufmerksamkeit der Verbraucher auf sich zieht. Die Anwendung von EM geht häufig mit einem Verantwortungsbewusstsein der Erzeuger einher.

Mit der Unterstützung von EM können natürliche Kreisläufe wiederhergestellt und geschädigte Böden verbessert werden. Durch die Verringerung von Verlusten und die Verbesserung der Nutzungseffizienz können landwirtschaftliche Betriebsmittel reduziert und in einigen Fällen sogar ersetzt werden. Allerdings muss eine Nährstoffquelle für die EM beigefügt werden, diese kann jedoch aus lokalen Ressourcen stammen unter Einsatz von bereits vorhandenem Equipment und Arbeitskräften. Der zusätzliche Managementaufwand wird durch die einfache Handhabung aufgrund der toxischen Unbedenklichkeit von EM kompensiert. Diese Unbedenklichkeit für

Nichtzielarten unterstützt neben den oben genannten Effekten auch die Gesundheit von Böden und Tieren sowie die biologische Vielfalt und die damit verbundenen Synergieeffekte. Darüber hinaus profitiert vor allem die biologische Vielfalt von dem Nutzen für die Umwelt, welcher sich aus der Einsparung von Betriebsmitteln ergeben. Die Anerkennung der Ökosystemleistungen, die Landwirte im Zusammenhang mit der Anwendung von EM erbringen, würde eine zusätzliche Einkommensquelle schaffen. Außerdem unterstützt die erhöhte abiotische und biotische Stressresistenz die Diversifizierung des Anbaus und führt zu einer Saisonverlängerung durch frühere Blüte und späteren Befall, was nicht nur den Betrieb wirtschaftlich diversifiziert, sondern auch die lokale Ernährung und die kulturelle Identität fördert. Des Weiteren ergeben Vorteile sich bei der Vermarktung, während die verbesserte Marktfähigkeit und Haltbarkeit zusätzlich zur Verringerung der Lebensmittelverschwendung beitragen. Dies sind nur einige der Effekte der EM-Anwendung, die der Lebensmittelsicherheit und -souveränität zugutekommen. Außerdem schaffen die Ertragsstabilität und die daraus resultierende Einkommenssicherheit einen Anreiz für risikoreiche und ertragreiche Investitionen in Innovationen. Die Neuartigkeit der EM-Anwendung selbst fördert den Austausch zwischen Praktikern und Herstellern von EM-Lösungen, aber auch den Kontakt von Landwirt zu Landwirt. Obwohl es sich bei der EM-Anwendung um eine wissens- und erfahrungsintensive Praxis handelt, fehlt es jedoch an der notwendigen Beteiligung der Wissenschaft. Andererseits wird das Interesse der Kunden geweckt und die nachbarschaftlichen Beziehungen werden durch die Verringerung der negativen externen Effekte verbessert. Durch die Abschwächung von abiotischem und biotischem Stress sowie von negativen Umwelteffekten tragen EM zum Schutz der Gruppen bei, die von diesen Auswirkungen am stärksten betroffen sind, und fördern so die Gleichstellung der Geschlechter und die soziale Gerechtigkeit. Darüber hinaus ist der durch EM-Anwendung erleichterte Zugang zu Nährstoffquellen besonders für abgelegene Kleinbauern wichtig. Des Weiteren ist die mit EM verbundene Arbeitssicherheit entscheidend für faire Arbeitsbedingungen. Gleichzeitig wird die Nutzung lokaler, erneuerbarer Ressourcen gefördert, was neben der gesteigerten Effizienz der bereits genutzten Ressourcen auch andere Ressourcen schont. Der geringere Abfluss von Geldmitteln und die Beschäftigungsmöglichkeiten, die sich aus der erhöhten Selbstversorgung ergeben, können die lokale Gemeinschaft stärken.

Zusammenfassend lässt sich sagen, dass aufgrund der vielfältigen Vorteile, die sich aus den biostimulierenden Effekten von EM ergeben, z. B. der erhöhten Widerstandsfähigkeit der Pflanzen gegen abiotischen Stress, die Anwendung von EM als Anpassungsstrategie an den Klimawandel fungiert. Außerdem kann die durch den Klimawandel bedingte Invasion gebietsfremder Arten aufgrund der erhöhten biotischen Resistenz der Pflanzen nach der EM-Anwendung besser bewältigt werden. Darüber hinaus trägt die EM-Anwendung zur Abschwächung des Klimawandels bei, indem sie die Emissionen durch eine höhere Inputeffizienz reduziert. Gleichzeitig wird die Widerstandsfähigkeit der landwirtschaftlichen Betriebe gegenüber wirtschaftlichen Risiken erhöht, da die Selbstversorgung gestärkt wird, vor allem durch die Förderung der Nutzung lokaler Ressourcen, wodurch die Landwirte weniger anfällig für externe Marktstörungen sind. Bei der praktischen Umsetzung von EM-Behandlungen bestehen jedoch aufgrund der Komplexität der natürlichen Prozesse sowie der sozioökonomischen Auswirkungen aufgrund fehlender Studien viele Unsicherheiten hinsichtlich ihrer Wirksamkeit und Wirkungen.

Schlüsselwörter: effektive Mikroorganismen, Agrarökologie, Biostimulanzen, nützliche Mikroorganismen, Milchsäurebakterien, Bokashi, teilstrukturierte Interviews, interpretativer phänomenologischer Ansatz

Preface

This thesis is part of a master's degree in agroecology at the Swedish University of Agricultural Sciences. The focus of the program reaches beyond the cultivation stage by applying a holistic view and systems thinking, including not solely environmental and economic aspects, but also a social lens. Therefore, agroecology considers how farming practices fit in with the local conditions while recognizing national and international forces, in order to create a sustainable food system.

I have an undergraduate degree in Agricultural Sciences (Humboldt-Universität zu Berlin). So, with an academic background in natural science, the social science approach as part of this multi-disciplinary graduate degree has been particularly challenging and contributed to most of my learning progress. Especially the consideration of socio-political and socioeconomic perspectives and principles has increased my awareness of the complexity of the food system. It has made me more open to different opinions and approaches apart from my own biases, while it also made my critical thinking more considerate and reflective.

I gained my practical experience in farming through an internship in animal husbandry at a biodynamic farm, where the size of livestock is adapted to the local area cultivated. This sparked an interest in issues of overfertilization and the lack of closure in the nutrient cycle and consequently the greater picture of soil health. In combination with concerns related to food security and sovereignty the necessity for closed agroecosystems with minimized dependency on external inputs is evident. For this transition, the human factor needs to be included, not just from a natural science point of view, but also from a social perspective.

During voluntary work at an organic farm in Sweden, I got to know about bokashi and effective microorganisms, and I was asked about information since most field reports, on which these farmers relied, were published in German, which lead me to pursue this topic. Although I have been hesitant to put the focus of the thesis on the social science part, because of my lack of experience compared to the natural science approach, the limitations due to the outbreak of the COVID-19 pandemic pushed me to extend my skills in this area and move out of my comfort zone. Further, the gap between academia and practitioners, as well as the importance of local knowledge has been discussed in my studies. So, the motivation for this study was the aim to achieve some representation of farmers by documenting their experiences. Because I have been taught that the real innovators are the farmers (Tasin, 2018).

Table of Contents

Abbreviations

DSGVO	Datenschutz-Grundverordnung
EBIC	European Biostimulants Industry Council
EM	Effective Microorganisms
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
GA	Gibberellic acid
HLPE	High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security
IAA	Indole-3-acetic acid
IPA	Interpretative Phenomenological Analysis
LAB	Lactic Acid Bacteria
PRA	Participatory Approach
SAR	Systemic Acquired Resistance
SLU	Swedish University of Agricultural Sciences

1. Introduction

The challenges faced by industrial agriculture worldwide are an increasing depletion of resources, such as the ming of mineral phosphorus, and the degradation of ecosystems, driven by a growing demand for food, feed, fiber, energy, and raw materials (Colla et al. 2014). This pressure and population growth force agricultural production to expand onto marginal lands or into protected areas, destroying natural habitats. (Lamont et al. 2017, Gliessman 2014, p. 15). Since the Green Revolution, the efforts to meet the demands partially concentrated on increasing crop yields with synthetic fertilizers. This proved successful in the short run since the decoupling of animal husbandry and crop production and the separation of sewage treatment and farming activities have led to a lower return rate of nutrients (Ashley et al. 2011). Meanwhile, sewage treatment has increasingly become a problem since an excess of nutrients builds up in ecosystems outside of the agroecosystem (Abdullah et al. 2011). Besides synthetic fertilizers, the main parameters managed in industrial agriculture are pests and diseases by applying pesticides and the water household regulated through irrigation. If irrigation water is applied without a good drainage system or despite a high salinity content, the latter leads to salinization, which is additionally caused by unreasonable chemical fertilizer application and strong surface evaporation (Xiaohou et al. 2008). Another downside is that along with phosphorus and nitrate, pesticides are the main pollutants from agriculture, having harmful effects on the environment and human health (Nardi et al. 2016, Lamont et al. 2017). Improvements only focused on minimizing these effects through improved use efficiency, optimizing application methods and schedules, and controlling the release rates, amounts and timing. So, the efforts to meet the increasing demands for agricultural produce can only slow down resource depletion and ecosystem degradation. In the long run, the application of chemical fertilizers alone may not be successful in sustaining high yields, while if not well-managed it is associated with nutrient leaching and negative effects on soil physical properties and organic matter content, which are important factors in the crop's response to the fertilizer (Dou et al. 2012, Khaliq et al. 2006). Further, synthetic fertilizers can reduce soil fertility by altering biochemical cycles, since the abundance and biodiversity of microorganisms can be influenced (Raya-Hernández et al. 2020, Glaser et al. 2015, Fatunbi and Ncube 2009). Therefore, increased problems with root and other soil-borne diseases, reducing yields, can be observed (Shin et al. 2017) as well as excessive soil erosion due to poor soil structure (Abdullah et al. 2011). Meanwhile, leaching causes eutrophication and together with contamination from pesticides makes some water resources unsuitable for human use (Raya-Hernández et al. 2020, Abdullah et al. 2011). Therefore, especially the usage of chemical control methods has been restricted over the past years (Shin et al. 2017). And while the natural environment is deteriorated (Abdullah et al. 2011), agriculture is facing additional challenges regarding climate change and associated stresses (Lamont et al. 2017, Xiaohou et al. 2008). To maintain crop production under the given and expected circumstances of climate change and increasing food demand, degraded soils must be ameliorated and natural nutrient cycles must be restored. Strategies for soil remediation and reclamation and the promotion of plant health and resilience recently started to recognize the importance of soil microbial communities (Lamont et al. 2017). The goal is to move away from synthetic fertilizers and towards organic materials as the main source of nutrients for crops. The microorganisms' role in the decomposition and mineralization of organic materials is important in bridging the time between the application and release of nutrients, especially during short-term plunges in the transition from conventional to organic farming (Fatunbi and Ncube 2009). The scientific literature describes microorganisms as a tool to manage the additional stress from climate change whilst maintaining soil productivity at low input and environmental impact (Lamont et al. 2017). Consequently, effective microorganisms (EM), beneficial for soil and plant health and growth, as well as products obtained with them, like bokashi and some biostimulant formulations have gained interest.

1.1. Aim and Research Question

In terms of sustainability of the global food system not just the environmental performance of a practice has to be considered, but also its social and economic effects. As an interdisciplinary practice, agroecology recognizes the importance of all these dimensions of the food system.

Till date, EM have mostly been examined in research with an experimental study design or in studies that collect and review the results of those studies. No investigation involving interviews could be found. So, no information exists on the practical implementation and observations by farmers as well as the effects on their livelihoods. But those are important factors in moving from theory to practice. Therefore the resulting research question is:

How does the application of effective microorganisms (EM) comply with the agroecological principles?

In this study, the existing literature on EM will be reviewed. The results will be compared against findings from semi-structured interviews conducted with German and Austrian farmers applying EM. So, the study is expected to accomplish an understanding of whether, which and how effects of EM observed in scientific research can be achieved in practice, while collecting new information on social and economic effects.

1.2. Study Objectives

The main purpose of the research is to determine the agroecological potential of EM by assessing the compliance of the application of EM to the farming system with the 13 agroecological principles established by the FAO (HLPE 2019). Consequently, the specific objectives are:

1. Identify the issues in the practical implementation of EM in the farming system
2. Identify the social and economic effects of EM

2. Materials, Methods, and Procedures

A literature review was carried out prior to conducting semi-structured interviews, which were then analyzed using interpretative phenomenological analysis (IPA). The results were discussed based on the principles of agroecology defined by the Food and Agriculture Organisation of the United Nations (FAO).

A qualitative study layout was chosen over a quantitative study layout since the descriptive information in combination with an interpretation of the available quantitative data is expected to be adequate for decision-making. Furthermore, an understanding of the farmers' attitudes affecting the practical implementation of EM is needed as a guide for more elaborate and comprehensive studies on a larger and broader scale. These aspects can be collected through participatory approach (PRA) (Hoffny-Collins 2018b). The advantage of using a PRA for assessing the sustainability of EM from an agroecological perspective is that the approach itself follows the agroecological principles, which will be elaborated on in the Discussion section. And since only limited understanding and information can be gained without good sensitive interviewing at the heart of PRA, semi-structured interviews are conducted (Hoffny-Collins 2018a).

2.1. Data Collection

The research focuses on arable production systems instead of grassland areas or animal husbandry because the underlying interest of this report is to explore EM in the context of supporting the productivity of soils and plants with an additional outlook on climate change. The group targeted as interview partners were farmers applying EM irrespective of the form, application method, and area of application. While contacting farmers, those using EM in arable farming were prioritized over applications in the horticulture sector or animal husbandry for the reasons previously mentioned. Further, no contact details of farmers were collected from academic institutions, because this group was assumed to already be represented in agricultural studies although not under the same framework. But the researcher was more interested in finding underrepresented individuals. The means by which the farmers were contacted and their response rate are illustrated in Figure 1.

On the other hand, the limited organization of farmers applying EM and the small number of individual reports makes this group difficult to reach. Therefore, in an attempt to practice the snowballing sampling method, farmers were asked in the first contact and also when an interview was rejected if they could bring the researcher in contact with practitioners that the contacted farmers might know of. Potential respondents were found through blog posts, newspaper articles, and posts in German-speaking farmers' Facebook groups. The reason for deciding on farmers in Germany and Austria was the minimization of the language barrier since the interviewer's mother tongue is German. And from working with Swedish farmers wanting to introduce EM in the form of bokashi to their fields, it was known by the author that there are already some experienced practitioners in the field of EM from those regions. From personal experience of interviewing Swedish farmers in English, it was claimed that some words or concepts are not transferable nor translatable between languages. Further, during those interviews, farmers who got introduced to EM, claimed that reports in German were most available and helpful. Relying on farmers with good English skills would further downsize the pool of potential respondents. Additionally, minimizing the obstacles in the communication between interviewer and interviewee facilitates the analysis and interpretative work later on.

Individual interviews were chosen over group interviews or discussions to highlight the uniqueness of the different cases and to give each case the space to present itself regardless of others' experiences. Further, it can be expected that the experiences of the different members of the targeted group might vary significantly based on their production system. It is not clear how much the respondents differ in their socioeconomic status and to ensure that also those of lower status can fully participate this method was chosen.

Before the interview, the participants received and signed a declaration of consent, where they were informed about their rights and given the opportunity to reject an audio recording of the interview. The form included a statement of the interview topic and a detailed description of how the data is presented in the paper and where and which data is stored after the finalization of the paper. The data has been treated in all conscience according to the legal provisions by the DSGVO (Datenschutz-Grundverordnung), the German basic regulation on data protection. Especially, the topic description was necessary for clarification and the farmers were given the opportunity to discuss uncertainties with the researcher prior to the interview.

Most interviews were conducted via phone calls since this was more convenient for most farmers. Also, some practitioners are not experienced in video calls, by which other respondents were contacted. The means of contact are indicated in Table 1 (in Appendix). At the beginning of the interview, the researcher introduced herself briefly and stated the purpose of the interview, which is the collection of the farmer's individual experience with EM.

Based on the previous literature study, a mind map of areas on the farm affected by social and economic consequences due to the usage of EM use was created. With these main points in mind, more general questions were formulated. As can be obtained from the question guide in Table 2 (in Appendix), additional questions were listed, but only asked if there was enough time or if the respondent had not elaborated on those either directly or indirectly in their previous answers. Hence, the framework followed the semi-structured interviewing style defined as: "Guided conversation in which only the topics are pre-determined. Open questions are used to encourage discussion and allow for new issues and lines of enquiry to emerge as a result of responses given" (Hoffny-Collins, 2018a, p. 4). The reasons for conducting semi-structured interviews are the freer structure compared to questionnaires while maintaining a clearer guideline than in a dialogue or discussion (Hoffny-Collins 2018a). The aim was to efficiently use the time and to create space for co-determination by the participating farmers, giving them the possibility to share information beyond what the interviewer initially considered important for the research topic but which adds value beyond that.

As taught in the agroecology program, effective interviewing only occurs when open-ended and non-directive questions are asked, while practicing careful probing of the respondents (Hoffny-Collins, 2018a). So, the interview mainly used open-ended as well as follow-up and reflective questions, while avoiding closed-ended, leading, assumption-laden questions, and ambiguous questions. Besides follow-up and reflective questions other types of probing were practiced including: encouraging vocalizations, silence, re-questioning, echoing, specification and re-cap. Throughout the interview, the type of questions moved away from open questions to probing to take advantage of the momentum gained by starting with more generalized questions creating a comfortable atmosphere so the respondents can gain trust and confidence. Especially where more information was needed or it was assumed that richer information could be obtained by further questioning, probing was practiced. Probing is suited to get to the depth or root cause of an issue and the farmers' perception of it by encouraging a full expression of their opinion and feelings (Hoffny-Collins 2018a). However, instead of directly asking about their feelings as mentioned by Brocki and Wearden (2006) as 'minimal probes', questions about their evaluation of success and expectations were asked. The former can be perceived as too personal by the respondent. So, in order to keep an appropriate distance, create a more comfortable atmosphere for the respondents, and to strengthen their role in the proceeding of the interview onto a more personal level, the latter seemed more suitable.

One of the aims to conduct the literature review prior to the interviews is to gain the theoretical knowledge to be on the same page and maintain a good flow of the conversation with the practitioners. So, the need for phased assertion as a probing technique can be kept to a minimum to not damage the trust of the interviewee if practiced poorly by the interviewer. In the interviews conducted through video calls, the conversational flow is supported by non-verbal probing like gestures to encourage the respondents to keep on going with their reporting. In verbal probing, specification and re-caps in particular are used for the clarification of points that may be unclear or contradictory (Hoffny-Collins 2018a). Besides formulating questions, the investigator used statements, touching on details to particularise or complement the previously said or summarizing a theme the respondent talked about. Pausing afterward allows the interviewee to comment, agree, disagree, or otherwise react to the statement. This creates a more natural atmosphere and conversation flow as opposed to interrogative questioning. And instead of summarizing the interview at the end, these statements in between allowed for extending different subtopics and not overwhelm the respondent. Rather, the final questions touched upon their vision for the future and which potentials they still see unexploited. The closing question asks what they would like to share that the interviewer has not yet asked. This gives the respondent the opportunity to codesign the interview by becoming the interviewer and interviewee. Further, it is a way for the interviewer to evaluate the work of asking the elementary questions and improve for the next interview, which is also an advantage of conducting a semi-structured interview.

There was no set time limit for the interview, as presented in Table 1. Based on how the interviewer interpreted the tone of the respondent's voice the conversation was ended. The time of the day, the background noises, as well as the length of the answers, also were indicators for ending an interview. In the case of a video call interview, mimics and gestures like looking at the clock were also taken into account. Taking up no more than an hour of the interviewee's time felt appropriate.

2.2. Data Analysis

The researcher opted for IPA, which as an idiographic focus tends to specify in opposition to a nomothetic approach, which tends to generalize (Smith et al. 1999). As stated in the Preface, the motivation for the study was to give farmers a representation in academic works. In order to not cut out information that can only be collected from practical experience versus scientific studies, the uniqueness of individual cases was prioritized, on which claims for the group were made. Hence, the number of interviews was limited to 8, because the idiographic approach recommends a smaller sample of up to 10 respondents (Smith et al. 1999) in order to notice subtle nuances and inflictions of meaning (Brocki and Wearden 2006). Further, IPA was chosen because the study is interested in how farmers view the experiences they made applying EM rather than what has led to this view (cf. narrative analysis). It prioritizes the meaning of the communicated content over the content itself and how it is communicated (cf. content analysis and discourse analysis). The phenomenological approach recognizes that the objective reality is not passively perceived and that the subjective reports of individuals originate from their process of interpreting and understanding their world (Brocki and Wearden (2006). Therefore, the application of EM not just depends on their performance in the field, but also on an individual's personal perception or account of the performance of EM (Smith et al. 1999). The individual in this case is the farmer, the decision-maker, who also takes into account processes like the workflow and socioeconomic factors and is influenced by societal forces. In addition to describing how farmers experience the current performance of EM on their farms, IPA aims to map the process the participants have been through to make sense of their own experiences (Brocki and Wearden 2006). Hence, if their beliefs, aims, expectations and criteria can be aligned with the observations in the practical implementation. So, the analytical process engages in the accessing of a particular respondent's thoughts, which are assumed to not be transparently available but the underlying cognition of verbal reports. And the paper does not aim at formulating a new theory (cf. grounded theory), but rather documents what was said and places it into context in order to understand ”personal experiences as opposed to social processes” (Smith et al. 1999, p. 100). Meanwhile, interpretative research recognizes that the insider perspective of a practitioner is not directly and completely accessible from the perspective of the researcher and that the interpretative process of attempting to understand an individual's personal perception is complicated by the researcher's own conceptions (Smith et al. 1999).

The work with the text follows the guidelines by Smith et al. (1999) and is a mix of a case-study approach and an exploratory approach. The difference to the case-study approach described is that during the transcription process the researcher was already familiar with reoccurring themes, keywords, and concepts, as well as similarities and particularities between the cases. After marking and noting these in the transcripts, general categories are created by taking into account the literature review. The exploratory approach recognizes that the literature is a useful backdrop against which to consider personal accounts, especially since measurable results are less influenced by the researcher's cognition (Smith et al. 1999). After the themes were sorted into categories by color coding, the subthemes emerged in the process of writing up the Interview Analysis and Results section. The methodology allows multiple labels for themes and pronounced cross-category coding was emphasized in the results. For example, themes like the increased labor demand were coded under workload but also under cost structure, since higher labor costs can be expected. Further, the category Inputs Replaced could also be coded under Costs and Cost Structure, but the author wanted to highlight this section since they not only have economic but also environmental implications. The author frequently went back to the original transcript to ensure that the actual meaning is not altered during the summarizing. And because the meaning was not taken from single sentences but from whole passages, the referencing in the section Interview Analysis and Results is done through consecutive numbering of these passages "y" per interview. These are then referenced in combination with the number of the interview "x" in the form "x.y". For example, the second passage of Interview 1 would be referenced "1.2". For Interview 6 only the "x", the number of the interview, which is "6", is referenced because the respondent did not approve of a transcription of the interview. This is perceived by the author as simplifying the process and small adjustments like these are in accordance with the methodology. Since IPA is more accessible and a dynamic process compared to other qualitative methodologies (Smith et al. 1999, Brocki and Wearden 2006), it is suitable for the researcher who is inexperienced in bundling together multiple interviews. So, the flexibility of IPA leaves room for adjustments along with the researcher's improved abilities during the process. The researcher's role in the interpretation of the data is further reflected in the Discussion, while the theoretical preconditions that she brings to the data can be extracted from the Preface. Besides a critical examination of the methodology, the Discussion reviews the results from the interviews and literature study based on the principles of agroecology defined by the FAO (HLPE 2019).

3. Literature Review

3.1. Biostimulants

Firstly, it is necessary to clarify the terminology. Especially in the category of biostimulants where an unclear legislation framework has led to confusion, affecting registration procedures (D´Addabbo et al. 2019). A very comprehensive definition by Nardi et al. (2016, p. 18), similarly to Colla et al. (2014), Caballero et al. (2020), and Brown and Saa (2015), states that biostimulants are "materials that contain one or more substances and/or microorganisms able to stimulate nutrient uptake and use efficiency by plants, increase plant tolerance to abiotic/biotic stress and improve crop quality when applied in small amounts", benefitting plant vigor and yield (EBIC 2021b). By definition, microorganisms contained in a biostimulant preparation can be called biostimulants as well as substances produced by them that affect soil microorganisms or the plant in a way that positively influences growth parameters or resistance of the crop. Additionally, biostimulants are mainly defined by their effect rather than their mode of action (du Jardin 2015). Therefore, microorganisms that suppress phytoparasitic nematodes by nematicidal microbial metabolites, as well as those competing with those nematodes for nutrients and space, are classified as microbial biostimulants (D´Addabbo et al. 2019).

The specific mode of action of biostimulants mostly remains unknown, but the general mechanism of action can enhance photosynthetic and senescence processes, modulate phytohormones, and influence water and nutrient uptake as well as the abiotic stress resistance, morphology and phenology of plants (Yakhin et al. 2017). Some of these mechanisms are mediated by different metabolic pathways, which are influenced by enzymes expressed through genes, which can be activated by biostimulants (Nardi et al. 2016). Gates et al. (2012) and Blaszczak et al. (2012) reported that fermentation metabolites of biostimulants up-regulated genes involved in the plant's response to abiotic stress and the activation of Systemic Acquired Resistance (SAR), improving their resistance to abiotic and biotic stress. Besides gene expression in plants, some biostimulants can also enhance the production of hormones or growth regulators or both in the soil by promoting microbial activity (Nardi et al. 2016). This emphasizes that the signaling molecules regulating the stress response of plants can be produced by the plant itself or the associated microorganisms (Brown and Saa 2015). Biostimulants discourage a yield loss due to stress response by altering how it is experienced by the plant, reducing the diversion of assimilates to non-productive stress response metabolism (Brown and Saa 2015).

Although biostimulants contain small amounts of plant nutrients, their main stimulatory effect is independent of their nutritious value. The contained hormones and other signaling molecules rather trigger a nutrient acquisition response, increasing the absorptive surface area, which favors the uptake of nutrients (Nardi et al. 2016). This was also observed by Colla et al. (2014) in the form of an extensive root apparatus and the process of nitrogen assimilation being stimulated. Besides the nutrient acquisition, the translocation of photosynthates to the sinks is improved (Colla et al. 2014). Therefore, to efficiently achieve positive effects, biostimulants should be paired with a source of nutrients, which was also observed by Brown and Saa (2015), noting that a biostimulant from microbial fermentation performed better under nutrient supply than under low nutrient supply conditions. Gates et al. (2012) also emphasize the combination with nutrients. On the other hand, since biostimulants increase the nitrogen use efficiency, the application of nitrogen fertilizer can be decreased significantly (Colla et al. 2014).

In terms of their biotic stress alleviation, some biostimulants fall under the regulations for phytochemicals, so the market is limited to products inducing plant resistance improvement since the registration procedures for pesticides are more complex and expensive (D´Addabbo et al. 2019). Biostimulant producers already face enough challenges when registering commercial products due to the lack of standardized raw materials and manufacturing processes. Additionally, toxicological screenings can be difficult (D´Addabbo et al. 2019). Based on the EU Fertilising Products Regulation (2019/1009) the effectiveness of a biostimulant has to be demonstrated by the producers through parameters relevant to the claimed effects, e.g. mode of action or the ratio and amount of its components (EBIC 2021a), which is complex. Therefore, the market price for biostimulants is currently high, so their combinability with other control measures is important (D´Addabbo et al. 2019), and benefit-cost analyses should take into account the additional effect of abiotic stress tolerance.

3.2. Effective Microorganisms

The term effective microorganisms (EM) originates from Prof. Dr. Teruo Higa's consortium of about 80 different microorganisms, which positively influence the decomposition of organic matter (Abdullah et al. 2011, Mayer et al. 2010) and create a favorable environment for plants, promoting their health and growth (Olle 2019). This consortium can be seen as part of the biostimulants. EM can improve the yield and quality (e.g. mineral content) of crops by stimulating physiological processes, including the efficiency of photosynthetic and stress resistance pathways (Olle and Williams 2013, Abdullah et al. 2011, Górski et al. 2017).

The beneficial microorganisms contained in the EM inoculant can be grouped as follows (Khaliq et al. 2006, Fatunbi and Ncube 2009, Olle and Williams 2013, Olle 2019, Mayer et al. 2010, Abdullah et al. 2011):

- Lactobacilli: e.g. *Lactobacillus plantarum*, *Lactobacillus casei*, *Lactococcus lactis*
- Yeasts: e.g. *Saccharomyces cerevisiae*, *Candida utilis*

- Photosynthetic bacteria: e.g. *Rhodopseudomonas palustris*, *Rhodobacter sphaeroides*
- Actinomycetes: e.g. *Streptomyces albus*, *Streptomyces griseus*
- Mold or rather fermenting fungi (including *Penicillium* spp.): e.g. *Aspergillus oryzae*, *Mucor hiemalis*

The first formulations have been based on naturally occurring microorganisms isolated from naturally fertile soils and further developed through trial and error, so without genetic engineering (Olle 2019, Baldotto and Baldotto 2016, Olle and Williams 2013, Abdullah et al. 2011). Nowadays the formulations can be more specific. Bionova Hygiene GmbH disclosed their EM-1 solution as a mix of colony-forming units of lactic acid bacteria, photosynthetic bacteria, and yeast in the approximate ratio of 1,000 : 2.5 : 1 (Mayer et al. 2010). However, the exact composition of the product remains unknown to the public (Boechat et al. 2013). It is assumed that the different commercially available brands and formulations use local microbial isolates (Olle and Williams 2013), making each product unique, which is why the effect can vary depending on the product and its suitability for the local conditions. Further, the subsequent processing and application method can influence the composition and effect of the microbial community (Górski et al. 2017). Mayer et al. (2010) summarized that EM-1 is the formulation commonly used for EM preparations, which can be EMA (anaerobic fermented molasses and water with EM), EM5 (like EMA with ethanol and vinegar added), or bokashi (like EMA with organic material in form of solid agricultural by-products added, Shin et al. 2017). The fermentation with added water and molasses contributes to the activation of the solution, which is distributed in a dormant state (Abdullah et al. 2011).

The application of EM alone is not effective if the amount of organic matter in the soil is too low to sustain the microbial community of the inoculant (Khaliq et al. 2006). The usage of fresh organic material high in labile organic matter is recommended over matured compost because the amount of soluble C in more stable organic matter is too low to support the decomposer community, which may lead to N immobilization (Fatunbi and Ncube 2009, Boechat et al. 2013, Khaliq et al. 2006). So, the supply of enough digestible organic matter and its quality influence the balance between microbial nutrient immobilization and mineralization (Fatunbi and Ncube et al. 2009, Boechat et al. 2013). With their rapid proliferation, the EM consume C, N, and other nutrients, accelerating the decomposition of organic matter and subsequently releasing the nutrients in a plant-available form, increasing nutrient uptake and yields (Fatunbi and Ncube 2009). Further, nutrient-rich organic acids are released by the EM (Olle and Williams 2013), which similarly to root exudates (Nardi et al. 2016) break down macro aggregates formed during the decomposition of fresh plant residues (Neuman 2017) into biologically active molecules (Nardi et al. 2016). So, the positive effects of EM application are unrelated to their intrinsic nutrient content (Olle and Williams 2013).

One of the resulting effects is the promoted production of substances acting as antioxidants (e.g. vitamin C), which additionally detoxify or inhibit substances and microbes harmful to the plant (Mayer et al. 2010). This detoxifying and purifying characteristic of EM can also be used on wastewater, sludge, and gases with the benefits of odor elimination, deoxidization, and conversion of heavy metals into organo-metallic compounds, while the toxic gases are converted into organic acids (Abdullah et al. 2011).

Besides organic acids and substances influencing antioxidant production, EM secrete other secondary metabolites, hormones, and phytochelatins, which can stimulate plant growth directly or indirectly (Górski et al. 2017). Direct effects are reported in form of promoted root growth through hormone and hormone-like compounds (Górski et al. 2017, Formowitz et al. 2005). Indirect effects include the improved development of nodules (Górski et al. 2017). Antioxidants released by EM can also positively affect beneficial microorganisms (Mayer et al. 2010). In addition, their proliferation is supported by the energy provided in the form of carbohydrates released from the organic matter by EM (Brown and Saa 2015). This is in accordance with observations of increased numbers of nitrogen-fixing and phosphorus-solubilizing bacteria after EM application (Mayer et al. 2010) and the subsequent increase in the concentration of biologically-fixed nitrogen (Olle and Williams 2013) and solubilized phosphorus (Lamont et al. 2017). So, the improved soil microbial health creates a beneficial environment for plant roots (Abdullah et al. 2011), which positively influences associated soil structure characteristics (Olle and Williams 2013). In the context of plant immunity, carbohydrates activate molecular patterns that are pathogen-, damage-, and microbe-associated, beneficially altering the plant's metabolism by intervening in signaling pathways (Brown and Saa 2015). The latter is especially associated with lactic acid bacteria (Lamont et al. 2017).

Other effects connected to EM's interaction with the naturally occurring microorganisms, besides the control of decomposition processes, include the inhibition of pathogenic factors and other agents of diseases and pests (Olle and Williams 2013, Abdullah et al. 2011, Górski et al. 2017). Their activities against vectors threatening plant health are either natural competitive or antagonistic processes or both (Olle and Williams 2013, Fatunbi and Ncube 2009, Sales et al. 2020). Therefore, and because no evidence of toxicity for ladybirds, spiders, dragonflies, and frogs, they are not classified as a pesticide and are regarded as environmentally safe (Olle and Williams 2013).

Besides the economic returns from increased yields and crop quality, EM can accelerate seed germination and lead to an earlier bloom (Górski et al. 2017), which gives farmers the competitive advantage of season extension and could allow them to charge a higher price in case of an earlier harvest. If the stimulation of seed germination and earlier growth is not selective for the crop, EM could reduce the seed bank of weeds in the long term. First, the infestation with weeds is expected to increase followed by a decline, partially due to the stunting of perennation and asexual reproduction organs of the weeds. Therefore, weed's competition with the crop is reduced, increasing the crop's access to production factors, quality, and yield, while concerns about weed's resistance to herbicides and agrochemical pollution are eliminated (Javaid 2010). Overall, the intrinsic natural power of agricultural soils is strengthened by maintaining microbial and ecological balance (Olle 2019, Olle and Williams 2013, Khaliq et al. 2006). Further, the accelerated breakdown of organic matter minimizes the time between organic fertilizer application and the fertilizing effect, facilitating management processes (Abdullah et al. 2011, Khaliq et al. 2006). Additionally, the losses from on-farm recycling and other processes (e.g. transplanting, Olle 2019) are minimized, contributing to the reduction of inputs required (including cost and capital) and ecological compatibility. The environmental state is improved alongside the farm's profitability due to the reduced need for chemical pesticides and fertilizer (Abdullah et al. 2011, Khaliq et al. 2006). Further, if only plant-based organic material is used in the formulation of the EM preparation, this technique also appeals to communities with dietary preferences like halal or vegan in cases where it replaces manure, representing a niche market with promising profits due to its exclusivity (Abdullah et al. 2011).

3.2.1. Bokashi

As previously mentioned, EM should be applied together with organic materials. If those are added during the fermentation process, so prior to field application, the resulting product is called bokashi. There is no coherent formulation of bokashi at present, most often the organic material added (to molasses, water, and EM) is wheat or rice bran and optionally some kind of manure (e.g. Mayer et al. 2010, Andreev et al. 2016, Dou et al. 2012, Xiaohou et al. 2008, Sales et al. 2020). EM treatment in bokashi form can be more effective than the solution form. The same positive effects on vegetative growth, yield and fruit quality apply, as well as effects in the soil, like the number of soil microflora and macro and microelements (Sahain et al. 2007). However, as mentioned before, EM activity is influenced by the quality of the added organic material. Boechat et al. (2013) state that N immobilization occurs due to a high C:N ratio of the organic material added together with the EM, in which case the microorganisms use the mineral nitrogen. Under optimal conditions with labile organic fractions however organic matter degradation is accelerated, including N mineralization, becoming available to plants through microbial consumption. An initial immobilization of nitrogen could however contribute to a better distribution of the amount of nitrogen mineralized over time (Boechat et al. 2013).

If wastes like agricultural by-products can be treated for recirculation through the fermentation process, this contributes to a reduction of the nutrients lost from the agroecosystem while substituting mineral fertilizer (Raya-Hernández et al. 2020). According to Xiaohou et al. (2008), the amount of chemical fertilizer applied can sufficiently be reduced through bokashi treatment, promoting environmental and sustainable development. There are multiple reasons for the reduced requirement of nutrient supplements. Boechat et al. (2013) account it to the enhanced availability of nutrients due to accelerated organic matter degradation. While the provision of those nutrients as organic chelates additionally supports their availability for plants (Baldotto and Baldotto 2016). Meanwhile, Dou et al. (2012) ascribe it to the bokashi-induced use efficiency of fertilizer, which additionally prevents excesses of nitrogen fertilizer to nitrify or contribute to soil salinization.

Salinization of the soil among other growth parameters is additionally influenced by bokashi's positive effect on the soil characteristics, raising soil fertility (Xiaohou et al. 2008). Andreev et al. (2016), who applied EMA in combination with animal manure and rice bran, reported that soil bulk density was reduced, while nutrients availability, soil permeability and porosity were increased. The same observations together with increased soil microbial biomass, cation exchange capacity, and leaching of salts have been made by Xiaohou et al. (2008) for the same preparation. Especially marginal land like deforested areas can benefit from soil quality improvement due to bokashi application (Karimuna et al. 2020, Jaramillo-López et al. 2015). Similar treatments led to an improved root system, increased soil organic matter, and yield (Dou et al. 2012). Baldotto and Baldotto (2016) relate positive effects on rooting, nutrient- and chlorophyll content in shoots to the humic acid contained in bokashi. The hormone-like stimulation of enzymatic pathways proved to be especially important in the initial performance of crops. And a higher use efficiency of fertilizer is supported by the increased root biomass (Baldotto and Baldotto 2016). Furthermore, other authors add improved crop quality and protection to the list of advantages of bokashi (Pandit et al. 2020).

Partly, crop protection is improved by the microbial carriers in the bokashi, which create favorable conditions in the soil, promoting the settlement of microorganisms (Xiaohou et al. 2008) and potentially work together with native microorganisms (Boechat et al. 2013). The fermentative environment due to the beneficial microorganisms, which are introduced to the soil with the application of bokashi, further increased the multiplication and performance of existing beneficial soil microflora (Baldotto and Baldotto 2016). Bokashi improves for example AMF root colonization under high P supply conditions, mitigating its suppressiveness on plant growth when hosting the symbiont costs the plant photosynthesis-derived sugars while no benefits from improved P uptake arise due to N being the limiting factor (Raya-Hernández et al. 2020). Sales et al. (2020) note that ericoid mycorrhizal fungi are also supported in their colonization of roots by biochar-bokashi.

3.2.2. Lactic Acid Bacteria

According to Lamont et al. (2017), the group which is most active and dominant in matured EM preparations is lactic acid bacteria (LAB). This is consistent with Boechat et al. (2013) and Pandit et al. (2020), who both state that lactic fermentation is the main process of bokashi production. Since they are the major part of the EM consortium, the application of LAB ferment application shows similar effects to bokashi. These effects include increased organic acid content (e.g. amino acid), nutrient availability (e.g. of soluble phosphate due to lactic acid stimulating soil enzymatic activities, Caballero et al. 2020) and nutrient uptake, as well as improved plant growth, seed germination and soil characteristics, alleviating abiotic and biotic stresses.

Microbe-associated molecular patterns produced by lactic acid bacteria, e.g. in form of polyamines, are thought to be the main mechanism behind the plant's increased resilience to abiotic and biotic stresses after inoculation with EM (Lamont et al. 2017). Protein hydrolysates released by LAB from the organic matter as well as the lactic acid stimulate the enzymatic activity in the soil, shaping the composition of bacterial communities. Further, these protein hydrolysates promote nutrient uptake, particularly nitrogen assimilation, with beneficial effects for yield parameters (Caballero et al. 2020). These pathways are usually activated by phytohormones like IAA and GA (Brown and Saa 2015). Some LAB species also produce IAA and cytokinin (Lamont et al. 2017). Additionally, they act as chelating agents and promote salt tolerance (Caballero et al.

2020). Further, LAB-produced compounds can initiate morphological changes in the plant, making it for example less vulnerable to mechanical damage (Lamont et al. 2017). In particular, the SAR is promoted. Meanwhile, LAB also increase the presence of organic acids like proline, which adjust the osmotic potential of cells in case of abiotic stresses (Lamont et al. 2017). In the plant, lactic acid prevents the phytotoxic effects of hypoxia (Caballero et al. 2020). The increased tolerance to abiotic stress is also connected to LAB themselves having a high drought and salt tolerance (Lamont et al. 2017).

Carbohydrate-rich environments are beneficial for LAB and their production of organic acids, through which they outcompete other microbes since they acidify their environment, which is the reason for their superiority in EM mixtures. In particular, the lactic acid released shifts the population of soil microorganisms towards plant growth-promoting bacteria. Further, LAB suppress other microbial communities through antimicrobial compounds, bacteriocins, and reactive oxygen species, as well as the preoccupation of plant tissues and the aforementioned alteration of plant immune response. On the other hand, LAB's modulation of the microbe composition is limited by the quick breakdown of organic acids and by the ability of the plant community to shape the microbial community through root exudates depending on the plant species and age (Lamont et al. 2017). The initial acidification of the environment, potentially reducing the bacterial biodiversity, disappears when the lactic acid is consumed by soil microorganisms. However, some of the taxonomic changes persist according to Caballero et al. (2020).

LAB are well understood due to their long use experience, also for human consumption, which cuts the cost and time regarding regulation. Therefore, LAB are regarded as safe and effective biocontrol agents (Lamont et al. 2017). On the other hand, Shin et al. (2017) state that in terms of the effectiveness in pathogen suppression, a consortium of microorganisms is more desirable, leading to more consistent and reproducible results than performing biocontrol using a single strain, which is limited by an established community of soil microorganisms and limited to a particular pathogen. This is consistent with Caballero et al. (2020), where the application of only LAB decreased the biodiversity by favoring plant growth-promoting bacteria. Further, due to the complexity of the nutritional requirements, a consortium of complimentary microorganisms, which satisfies these needs by their metabolites, is more effective than a pure culture of LAB (Lamont et al. 2017). In conclusion, a product is not defined by an individual component since its effect might be dependent on or influenced by combinations of its ingredients and synergetic effects (EBIC 2021a). Therefore, conversations on the effectiveness of bokashi formulations and EM application cannot exclusively focus on LAB, making assessments complex and causing varying results.

LAB have beneficial effects associated with farm management. According to Andreev et al. (2016), LAB fermentation is the most efficient form of transforming organic material into humus. Therefore, LAB can make organic fertilization schemes compatible with mineral fertilization, while shifting the focus on renewable resources (Lamont et al. 2017). On the other hand, since LAB stimulate not just the availability of nutrients, but also their uptake by the plants, the combination with mineral fertilizer was successful in increasing yields (Glaser et al. 2015), facilitating management.

3.3. Uncertainties of EM Treatments

Short-term values can vary due to a priming effect hence an increase in soil organic matter decomposition upon application due to high microbial activity, which was observed for unfermented EM treatment as well as for LAB-fermented organic fertilizer (Fatunbi and Ncube 2009, Andreev et al. 2016). Further, in the example of LAB treatment, different changes in the plant's morphology could be observed simultaneously, which is another factor for inconsistency between studies (Lamont et al. 2017). For EM treatments in bokashi form and in solution form, positive effects on vegetative growth, yield, and fruit quality could be observed, but simultaneously fruit firmness was slightly reduced (Sahain et al. 2007).

Some studies solely add EM to the field, which is possible when the organic matter content, especially the labile organic matter, is high enough to sustain the microorganisms. And if enough raw material from which they release nutrients, organic acids, protein hydrolysates and other compounds is provided. Otherwise, no effects of EM application could be observed without a carrier substrate (Mayer et al. 2010). Therefore, EM should be applied together with some sort of organic material as a source (Olle and Williams 2013).

Besides the effectiveness of EM being so closely tied to the addition of organic material, organic material addition itself has effects on the structure of the soil, increasing water holding capacity (Jaramillo-López et al. 2015) and the microbial community (Mayer et al. 2010). Boechat et al. (2013, p. 257) state that „organic wastes enhanced soil chemical properties and increased nitrogen concentration in soil" while making the connection to the role of the C : N ratio and incubation time. So, the increase of nitrogen in the soil can either be attributed to the organic material from which the N originates or to the activity of microorganisms that release the N from the organic amendment through decomposition. This combined positive effect of bokashi and high-quality organic waste on net N mineralization and the fertility of the soil is recognized by Boechat et al. (2013). So, distinguishing between the effect of organic matter amendment and the effect of EM remains difficult (Jaramillo-López et al. 2015). Therefore, when the treatment with EM in combination with organic material shows a neglectable yield increase compared to a control with autoclaved EM, promoted plant growth is mainly attributed to the fertilizing effect of the nutrients contained in the organic carrier substrate, which are released by the indigenous microorganisms (Mayer et al. 2010). However, the sterilization was done after the fermentation process, so the autoclaved treatment might still contain some biostimulatory metabolites produced by the EM during bokashi preparation. Jilani et al. (2007) state regarding non-fermentative EM treatment, that organic material can increase the microbial population and inoculation can increase their effectiveness.

On the other hand, the previously mentioned quality of the organic material accessible to EM is important (Boechat et al. 2013). Attention should be paid to the quantity of easily hydrolyzable carbon, high in fresh material, promoting interaction between nitrifiers and heterotrophic microorganisms, consequently accelerating mineralization. Because, although the content of labile mineral N can be higher in composted materials, due to the more stable carbon and related high C : N ratio, N immobilization occurs. So, more mineral N can comparably be detected after the application of fresh materials (Fatunbi and Ncube 2009). Therefore, varying study results are partially observed due to differences in the C : N ratio, causing the effect of EM on the nitrogen content to be multidirectional (Górski et al. 2017). Consequently, although EM stimulate the release of nutrients from organic sources, the effects are still not immediately visible. More than one season might still be needed since the nutrient absorption and uptake of microorganisms is more energy-efficient compared to plants. The re-mineralization of initially immobilized N is long-term (Khaliq et al. 2006). For these reasons, bokashi made with waste needs to be prepared in an adequate ratio otherwise the fermentation process can be disrupted (Baldotto and Baldotto 2016).

Further, results are rarely replicable because of the diversity of other influence factors, including the formulation, subsequent processing, preparation quality, application form, and application frequency in addition to the general environmental variations (Górski et al. 2017). In the formulation, the provision of nutrients and the mixture with ingredients serving as wetting agents or adhesives are favorable (Abdullah et al. 2011). Even between batches of commercial EM products, variations in the bacterial composition occur, resulting, inter alia, in inconsistencies in studies on the disease suppressiveness of EM (Shin et al. 2017). As an example in processing, subsequent vermicomposting of LAB-fermented organic material might cause some of its effect on yield to be lost but gains a greater influence on germination and other morphological changes (Andreev et al. 2016), which emphasizes the importance of purpose-oriented preparation. Baldotto and Baldotto (2016) suggest that the isolation of humic acid from bokashi increases the biostimulant effect of the solubilized bioactive substances. In terms of distribution method, due to the high levels of organic acids in bokashi, attention should be paid to plant roots during application since those could otherwise be damaged (Olle and Williams 2013). The application method of EM influences the volume of increase (Górski et al. 2017), which is additionally dose-dependent, while strain-, host- and environmental dependencies of some mechanisms (e.g. LAB) exist as well (Lamont et al. 2017). Baldotto and Baldotto (2016) reported decreasing increments with increased concentration. Further, incompatible strains in an unsuitably formulated plant growth-promoting bacteria inoculum could enter into inhibitory competition (Lamont et al. 2017).

Besides the composition of the EM solution, the most important biotic factor is the soil fauna, especially the soil microorganisms. Their activity alters the soil pH and is part of their influence on the suppressiveness of microbial inoculants (Fatunbi and Ncube 2009). One of the aspects of the soil microbial community impacted by the application of EM is its enhanced heterogeneity and biodiversity (Fatunbi and Ncube 2009, Raya-Hernández et al. 2020, Olle and Williams 2013), increasing its suppressiveness against soil pathogens (Shin et al. 2017). This was not the case when the experimental soil was artificially infested directly after the inoculation with EM. So, there was no time for the microorganisms to establish and suppress soil-borne disease through the main mechanism of preoccupation and competition. This explains the inconsistent results documented by Shin et al. (2017), who reported that the added EM did not affect the composition of the bacterial community in terms of diversity, total microbial activity, or bacterial community composition. The authors concluded themselves, when comparing their failed control of *Pythium ultimum* to successful results by other authors reducing the infestation with *Phytophthora cinnamomi* through a bokashi application, that the amendment should be applied preventative several weeks before the disease exposure. Similarly, the soils in the experiment of Sales et al. (2020) were infected before the bokashi-biochar application, which could explain why an improvement in some plant growth parameters could be observed for uninfected plants but not for infected ones.

According to Olle and Williams (2013), the EM have to become established for desired effects to appear. So, for lasting results, the EM consortium has to dominate the microbial community in order to remain stable and active in the soil. An early establishment is supposedly supported by a repeated application (Olle and Williams 2013). Mayer et al. (2010) however found that no long-term effects could be observed even after repeated application since the EM could not alter the structure of the microbial community in the soil and outcompete the indigenous microorganisms. This dominance of endemic microbial communities has also been demonstrated for other biocontrol agents according to Shin et al. (2017). Additionally, even the expectation that the inoculated microorganisms would at least stimulate the activity of the indigenous microbial community was not the case (Mayer et al. 2010). In the case of Shin et al. (2017), the genera *Pythium* competes with EM for non-stabilized matter serving as a food source. The same applies to *Rhizoctonia solani*, but contrary to *P. ultimum* this variety is very sensitive to low oxygen conditions, so less competitive with EM. Additionally, while the control mechanism for *Pythium* is general suppression through competition, *R. solani* is suppressed by specific microorganisms and other biocontrol agents. Because of this multitude of control mechanisms and although a high microbial activity and diversity in the soil reduce EM survival, the competitiveness and effect of EM cannot be predicted (Shin et al. 2017). The claim that beneficial effects are observable at relatively low application rates seems to mainly apply to treatments of degraded soils (Andreev et al. 2016). Pandit et al. (2020) for example reported that the bokashi application was only effective at a high enough dosage.

Confusion about the optimal product concentration and frequency of applications can arise, especially since recommendations have to be adjusted to the local conditions. Simultaneously, environmental distortions, including precipitation and temperature, can lead to contradictory results influencing e.g., nutrient availability and leaching (Nardi et al. 2016, Andreev et al. 2016). For example, the C : N ratio was found to increase with increasing moisture and decreasing temperature (Yamakura and Sahunalu 1990), which is an important factor for the effectiveness of EM as mentioned previously. Further, the local conditions can vary even in a very confined area, e.g. heterogenic soil properties, which are on the other hand influenced by management practices like tillage, loosening, and airing of the soil while incorporating crop residues (Mayer et al. 2010). Especially the soil organic carbon and clay content correlate with soil microbial parameters like soil respiration and consequently the yield (Mayer et al. 2007). In addition to the soil type influencing the effect of EM, Pandit et al. (2020) also mention the vegetation as an important factor, which is consistent with studies on LAB, reporting that the crop influences the microbial community (D´Addabbo et al. 2019, Lamont et al. 2017). Li et al. (2016) noted based on their own and previous studies that the soil characteristics are more important in the formation of the bacterial community than the plant species. However, the composition of the plant community is still one of the major drivers of belowground biota communities and their activity (Vincent et al. 2018). Because, in addition to directly influencing microbial population, root exudates also influence soil characteristics as well as root growth (Li et al. 2016).

But since the major component the microbial composition of the product is not specified in detail, farmers purchasing EM products are limited in their ability to evaluate the effectiveness for their local conditions (Mayer et al. 2010). Therefore, self-produced microorganism formulations could be more attractive to farmers if effective screening methods would be accessible and affordable. One example is Glaser et al. (2015), who used microorganisms extracted from local forest soil. In the study, the local microorganism consortium was combined with maize silage and digestate and optionally biochar. This treatment showed the highest yield increase compared to other treatments, including compost, pure biogas digestate, and mineral fertilizer, raking highest or among the highest in total N uptake and concentration in the plant as well as plant-available phosphorus in the soil (Glaser et al. 2015). The increased availability of P is related to the higher adaptability of some EM to acid conditions compared to native microbes (Boechat et al. 2013), which is reflected by the usually very low pH of bokashi due to the LAB in the EM mixture (Glaser et al. 2015). However, these results are unpredictable, since the key component, the soil pH, is influenced by many factors. So, the effect on the soil pH is little (Sales et al. 2020). For example, the increased ammonification due to the activity of *Streptomyces* spp. which are also contained in the mix increases the soil pH (Fatunbi and Ncube 2009). The added organic material and promoted humus formation additionally buffer this effect, while the organic acids released by the LAB do not persist long in the soil (Lamont et al. 2017). On the other hand, the translocation of nutrients can be improved as suspected for a biostimulatory plant-derived protein hydrolysate by Colla et al. (2014). In the trials of Glaser et al. (2015), the P uptake of the treatment without biochar was reported among the lowest, but P concentration in the plant was among the highest, which might be related to this process.

Many studies besides Glaser et al. (2015) examine bokashi and EM in combination with biochar, which might distort the results and leads to false conclusions if no control group is included in the study. Some ways in which biochar influences treatments with EM are explored in the following. In the case of Glaser et al. (2015), the addition of biochar to fermented biogas digestate decreased the yield, N uptake and concentration in the plants. It increased the P uptake but not the P concentration in the plants compared to the same treatment without biochar. The increased P availability is related to lactobacilli-induced organic degradation, overcoming the P deficiency symptoms displayed by e.g. bokashi without biochar. However, the sole bokashi application still showed a higher available P concentration compared to NPK treatment (Pandit et al.

2020). Further, although all bokashi treatments showed higher NO_3^- concentrations than recorded after mineral fertilizer application, post-mixed and co-composted biochar addition increased NO_3^- significantly as well as the soil moisture (Pandit et al. 2020). Other nutrients, whose availability was increased include exchangeable base cations like K^+, Ca_2^+, Mg_2^+, improving soil CEC, which were increased in all bokashi treatments compared to the NPK treatment though higher with biochar addition and highest if co-composted (Pandit et al. 2020). Further, Pandit et al. (2020) reported increased biomass with biochar addition, both co-composted and post-mixed, compared to mineral fertilizer but also compared to sole bokashi application. The same trends could be observed for N, P, K, and Mg in leaves, and organic matter by Sales et al. (2020), when bokashi was combined with biochar. But also treatments without biochar showed similar results for N, P, K, and Ca contents in leaves when seeds and soil were inoculated and irrigated with EM, improving growth, health and quality of transplants (Olle 2019). Several authors observing contradictory results of enhanced nutrient uptake with biochar are listed by Glaser et al. (2015). This is a result of biochar addition affecting the properties of the soil (Glaser et al. 2015), for example by improved water holding capacity and reducing leaching. Therefore, the treatment's effectiveness to increase the yield can become less dependent on weather conditions, regarding LAB-fermented organic amendments compared to mineral fertilization (Andreev et al. 2016). Further, the addition of biochar to bokashi, both post-mixed and co-composted, increases the soil pH, which tends to be relatively low after sole bokashi application, although it is still higher than the soil pH after NPK fertilizer application (Pandit et al. 2020). This effect in combination with the high C : N ratio and low nutritional value of biochar influence the microbial activity, shifting it towards N immobilization (Sales et al. 2020, Glaser et al. 2015). Furthermore, biochar can retain nutrients through temporary sorption (Sales et al. 2020) and possibly biostimulatory compounds as well. Microorganisms can be hosted in its pores, which provide protection (Sales et al. 2020), and it is unclear whether that is beneficial or not for EM treatments. Overall it seems that if inorganic fertilizer is applied in addition to bokashi (Dou et al. 2012), the application of biochar can be favorable since biochar optimizes the use efficiency of inorganic fertilizer. Otherwise, the combination of biochar and bokashi achieves lower yields than the sole application of bokashi (Dou et al. 2012, Glaser et al. 2015). Further, the results observed by Glaser et al. (2015) suggest that biochar should be added to bokashi after the fermentation process during field application.

Results between studies additionally vary because the effect of plant growth promotion due to improved nutrition is more pronounced under previously nutrient-limited conditions (Sales et al. 2020). Otherwise, at an optimal soil and nutrient status, biostimulatory effects are only observable at abiotic or biotic stress (Lamont et al. 2017, Brown and Saa 2015). For example, Jaramillo-López et al. (2015) observed that seedlings infested with fungi that had been planted in bokashi grew taller than those that were not infected. So, maybe the production of certain plant hormones in response to the pathogenic attack caused a threshold in the concentration of signaling molecules to be reached, which have been previously promoted by biostimulants from the bokashi.

Overall, the complexity of sources with a variety of bioactive components and their potentially synergetic relations result in several modes of action, which remain unknown

(Nardi et al. 2016, Brown and Saa 2015). Therefore, EM treatments cannot replace sustainable management practices like crop rotation, incorporation of N-fixing crops, or crops in general that beneficially interact and sustain the microbial community formed by EM application. EM should be seen as an additive for optimizing other components of farming (Khaliq et al. 2006).

3.4. Competitiveness and Socioeconomic Implications

Besides the effectiveness of EM technology, the practical adoption of inoculated organic fertilizer depends on the performance compared to other agricultural inputs and the socioeconomic compatibility. Due to the variety of plant protection products, the literature review focuses on the performance of EM compared to synthetic fertilizer. Further, study results on the effectiveness of EM in controlling pests and disease vary. So, since abiotic stress is one of the main causes of yield reduction in crops (Gates et al. 2012), EM's effectiveness to mitigate abiotic stress is prioritized over biotic stress relief.

The main mechanism by which EM increases the use efficiency of organic and mineral fertilizers is the transformation of insoluble phosphate into the soluble form (Boechat et al. 2013, Pandit et al. 2020), mainly through acidification (Jilani et al. 2007). The P-solubilizing microorganisms in the EM mixture include *Bacillus, Pseudomonas,* and *Aspergillus* (Jilani et al. 2007). In the following, the issues associated with phosphorus fertilizer are described in order to elucidate the linked alleviation of problems by replacement with EM preparations.

The main problem of phosphorus fertilizer application is the pressure on water resources by causing eutrophication due to discharge into water bodies and consumption of water during the fertilizer production stage (Amann et al. 2018, Schröder et al. 2010). The mining stage generates economic as well as environmental costs. The pace at which phosphate rock is currently mined leads to the depletion of the resource and to the point of peak phosphorus being reached, where the supply can no longer satisfy the demand. Moving towards this point, the accessibility and quality decline, which makes sourcing and purification more energy-intense (Cordell et al. 2009). Therefore, costs and waste generation show an accelerated increase due to peak oil and carbon pricing efforts, while competition with other oil-dependent industries increases (Cordell et al. 2009, Schröder et al. 2010). Sulfuric acid reserves are also significant since it is used to process phosphate ore into phosphoric acid for further processing into phosphorus fertilizer. In this step radioactive phosphogypsum is formed (Tayibi et al. 2009). Other toxic materials are released, including heavy metals and fluoride (Amann et al. 2018, Schröder et al. 2010). The heavy metals with the highest concentrations in phosphorus fertilizer are mainly Cd, but also Zn and Cr, while N and K fertilizer show comparably low concentrations of heavy metals (Kühnen and Goldbach 2004). In European agricultural soils, the input of trace metals through fertilizer application is in some cases even higher than the input from atmospheric deposition, or at least as high (Nziguheba and Smolders 2008). Therefore, NPK fertilizer application leads to an increase in heavy metal contamination of the soil (e.g. Cd, Pb, As), especially in the case of overapplication as well as some pesticides (Atafar et al. 2010). While some countries have imposed restrictions and regulations on the quality of the rock phosphate that can be used for fertilizer production (Kühnen and Goldbach 2004), the increasing scarcity of phosphorus might create an incentive for using low-grade and low-quality phosphate rock under unregulated circumstances. With higher contamination, there is additionally a higher risk of overexposure of workers along the production chain (Cordell et al., 2009).

The increasing scarcity of phosphorus reserves creates a position of power for exporting countries. According to Schröder et al. (2010), almost 90% of the economically exploitable phosphate rock reserves were located in 5 countries in 2009, including some of the 8 countries holding 65% of the global sulphuric acid reserves. This issue of power concentration due to oligopoly has socioeconomic implications. Long transport distances are associated with losses and greenhouse gas emissions (Schröder et al. 2010). So, the reduction or replacement of mineral fertilizer with EM fertilizer protects the environment. On one hand, through reducing eutrophication and land degradation, e.g. heavy metal contamination associated with the mining as well as with the field application (Amann et al. 2018). On the other hand, by reducing the carbon footprint. In addition to the absence of geographical limitation, the preparation of EM treatments can be done using very simple technology and infrastructure. This increases the local availability of phosphorus-containing fertilizer by promoting regional value chains and natural nutrient cycles (Egle et al. 2016). Besides reducing transportation, this creates independence for importing countries from exporters in mostly geopolitically unstable regions, making importers less vulnerable to market forces like supply disruptions and fluctuating market prices (Egle et al. 2016, Schröder et al. 2010, Amann et al. 2018).

EM preparations are compatible with different production systems regardless of scale and approach towards organic farming (Baldotto and Baldotto 2016), the application in addition to herbicide has been performed (Khaliq et al. 2006). Since the bokashi preparation is so versatile and not source-specific, though the resulting effect is influenced by the kind and quality of organic material, it can be sourced sustainably by using by-products (Jaramillo-López et al. 2015). LAB have already proven advantageous in waste treatment and the valorization of by-products, adding value to low-bioavailable compounds (Caballero et al. 2020). Also, indigenous microbial populations are used in composting, silage, and anaerobic digestion processes (Lamont et al. 2017). Jaramillo-López et al. (2015) and Glaser et al. (2015) showed that bokashi can be prepared using local soil and yeast instead of commercial EM inoculum, which is more accessible to isolated areas, like those of indigenous communities. It fosters community involvement in the preparation and simplifies the process and lowers the costs of this already quite inexpensive technology (Jaramillo-López et al. 2015). Family farms can also produce handmade bokashi with recyclable organic waste at a low cost (Baldotto and Baldotto 2016). Additionally, the cost of externalities can be reduced if sewage sludge is used as organic matter in the EM preparation, its treatment provides a social as well as an environmental service, preventing its disposal in an unsafe way. However, this requires proper infrastructure, minimizing emissions, management and transportation costs (Amann et al. 2018). On the other hand, economic benefits from the prevention of environmental externalities and the additional recovery of water, nitrogen and other nutrients should be considered (Molinos-Senante et al. 2011, Amann et al. 2018). Compared to other phosphorus recycling technologies, the treatment with EM can be assumed to have fewer trade-offs between low environmental risk, good fertilizing effect, and economic efficiency (Egle et al. 2016).

Additionally, since treatment of organic waste via EM technology produces cheaper fertilizer compared to products from other phosphate recycling processes like sewage sludge ash, it is also economically more accessible to developing countries. And while developed countries usually have P-saturated soil conditions, soils in developing countries often have a phosphorus deficiency (Steffen et al. 2015). So, international equity is promoted when developing countries have access to P recycling because not just the resource's lifetime is prolonged, but the share of the resource by developing countries is increased simultaneously (Weikard and Seihan 2009). Especially, since mineral fertilizer use intensity in developing countries is positively correlated with dependency on international investment (Jorgenson and Kuykendall 2008). This allocation of phosphorus further contributes to food security and food sovereignty (Mayer et al. 2016), potentially boosting global crop production (Steffen et al. 2015). The same unequal distribution can also be observed for nitrogen, which contributes to acidification in addition to eutrophication (Steffen et al. 2015).

In short, the threats of non-stored excess nitrogen consist of water pollution, eutrophication, loss of biodiversity, soil acidification, global warming potential, and stratospheric ozone destruction besides the direct health impact, causing harm to wildlife and humans. The multitude of impacts originates from the diversity of sources through which nitrogen enters the agricultural system, some more controllable than others, including nitrogen fertilizers, animal manure partially in form of excreta of grazing animals on pastures, atmospheric deposition, and biological dinitrogen fixation. Additionally, the different forms and compounds as well as a variety of influence factors and interrelations determine its environmental effect (Velthof et al. 2014). Similar to phosphorus fertilizer, the reduction or exclusion of nitrogen fertilizers beneficially affects the energy efficiency of organic as well as conventional farming systems in terms of primary energy input, simultaneously reducing indirect energy inputs associated with pollution treatment (Hoeppner et al. 2006, Khaliq et al. 2006). So far, due to the multitude of sources of nitrogen emissions and the long-term nature of the damages of excess nitrogen, their pollution potential is often underestimated, leading to the assumed mitigation costs being higher than the costs of damage, so shareholders stay inactive (Sutton et al. 2011). This is in addition partially based on the statement by Clarke and Tilman (2017) that the environmental gains of improving the efficiency of a system are reduced or even canceled out when economic costs occur in form of resource investment, which is the case in already more efficient systems. But EM technology not only reduces mineral fertilizer use but also contributes to higher net revenues. For example, using a fermentative liquid mainly containing LAB, Pandit et al. (2020) estimated that there would be a net benefit of about 6% of the benefits of the yield increase when the total cost for the production of bokashi with co-composted biochar is subtracted. Likewise, EM addition to a NP fertilizing scheme increased the net return although the production costs were slightly higher compared to sole NP application. But due to the higher yield, the income was increased (Jilani et al. 2007).

Similarly, the cost-benefit ratio of bokashi treatments was reported to be low, the main cost factor being the cost of application, while the preparation costs are neglectable (Baldotto and Baldotto 2016). The input costs can be reduced when the practice is more developed. As a consequence of the economic viability of the technique, the promotion of EM as a mitigation strategy is low-cost for the government. Otherwise, compensation would be necessary to create an incentive for farmers to adopt this technique (Schulte et al. 2017). Zhang et al. (2016) mention that the implementation of regulations on nitrous oxide emissions from mineral fertilizers could create a negative perception due to historical governmental promotion of these fertilizers, the promotion of EM offers an alternative strategy for reducing environmental damage. The removal of barriers is essential for the adoption of EM technology and can be promoted by adequate policies, especially regarding legislative issues like product authorization and patenting of commercial EM solutions.

The ecosystem services provided by nitrogen and phosphorus fertilizer reduction include protection of aquatic life, mitigation of climate change through reduced greenhouse gas emissions and improved human health. In addition, business opportunities in tourism and recreation can be created (Schulte et al. 2017). And besides reducing agricultural emissions, a more efficient resource use offers considerable potential for increasing the resilience of rural livelihoods partially due to the increased agricultural incomes. Further, most of the production increase to meet increasing global demands for agricultural products needs to come from increased productivity. Due to its accessibility and affordability, simplified EM technology contributed to the crucial productivity and income increase in the smallholder production sector. The strengthening of small-scale farming contributes to the transformation of the food system beyond food security through production increase towards food sovereignty (Lipper et al. 2014).

Overall, significant effects on the environment and human health, energy conservation, soil quality and health due to EM treatment can be expected (Khaliq et al. 2006). However, the key argument to keep in mind is that microbial populations play an important part in plant nutrition beyond NPK fertilizers, which requires further investigation. Not just nutrients are released from the organic materials upon microbial degradation but also biostimulatory compounds, like phytohormones, enzymes, organic acids, antioxidants, and other metabolites. This is visible when comparing the effects of the application of mineral NP fertilizer with and without EM addition. The yield, nutrient uptake of N, P and K and count of microflora fixing nitrogen or solubilizing phosphate are increased, although N-fixing bacteria were not part of the inoculant they are positively affected. Sole mineral NP fertilizer was investigated instead of the commonly used NPK fertilizer since no potassium solubilizing bacteria have been disclosed in EM solutions. However, combining EM with an inoculum containing K-solubilizing bacteria is possible (Jilani et al. 2007). But so far, the main socioeconomic effects of EM that have been reported in the literature are only related to input substitution and other effects have mostly been neglected.

4. Interview Analysis and Results

Of the eight participants in the study, three respondents are located in three different Federal States in South-West Germany. The five Austrian farmers came from three different areas in the North-East of Austria. Among the participants four farm organically, three of them exclusively without any conventional fields. The remaining farms are operated conventionally. The period of experience varied among the respondents but was evenly distributed between conventional and organic farmers, with three years for the least experienced farmer (respondent 5), and 25 and 16 years of experience in one of their production areas for the most experienced farmers (respondent 4 and 2). The other respondents had an experience of around 6 years. No correlation between the type of farming system or demography and negative reports or report of success with the EM practice could be observed.

From the interviews, 13 themes emerged based on which components of the farm management are influenced by the application of EM according to the literature with adjustments due to additional information given by the respondents. The final themes include:

1. Communication and Information Acquisition with the subthemes:
   - EM EM Industry Contact,
   - Peer Contact,
2. Product and Product Combination,
3. Method and Frequency of Application,
4. Product and Application Criteria,
5. Aim of Application and Expected Effects,
6. Observations,
7. Assessment Criteria,
8. Inputs Replaced,
9. Costs and Cost Structure,
10. Workload and Work Safety,
11. Setbacks and Areas of Conflict with the subthemes:
    - Related to EM,
    - Related to Farming in General,
12. Ideology, Motivation and Drivers of Change,
13. Future Aspirations and Potential.

4.1. Communication and Information Acquisition

First of all, it is important to know how the farmers found out about EM and from which sources they get their information. Especially, the balance between information provided by the producing companies in form of written content but also through advisors, and the information acquired from peers including practitioners farming with EM and contacts via academic institutions for example through field trials is important.

4.1.1. EM Industry Contact

In terms of direct contact with the EM industry, two of the respondents are friendly with producers of EM products (1.6, 7.18, 7.49). They as well as other respondents get support and recommendations from advisors (1.6, 2.5, 4.27, 7.49, 8.17) and in some cases those consultants actively take part in developing an application strategy (1.11, 2.5). One of the farmers is even involved in trials from one of the EM producers (1.6), while another is contacted on the topic of areas of interest based on his experiences (4.29). Further, another farmer is included in strategy meetings of an EM producing company, which additionally point out his mistakes to him and contribute to the improvement of his practice (7.23).

Besides the personal contact with the industry, a third of the farmers got introduced to EM through promotional activities of EM producers at talks, fairs, or online (5.23, 6, 8.41). And two of those farmers said that they apply EM according to the recommendations, for example, those given in product and branded brochures (6, 8.4).

4.1.2. Peer Contact

If not introduced to EM through industry contacts, farmers come across EM through readings, peer contact, or other independent information sources. One of the farmers criticized that there are not enough consultants available (3.18), while he also stated that he preferred an exchange between EM practitioners in an online community engaging with each other via WhatsApp (3.23). On the other hand, also sales partners in consultation seem to be practice-oriented, in one case providing the contact to a practitioner who solved the problems encountered by one of the farmers (2.27). One farmer said that he is actively contacted by phone by inexperienced farmers, asking him about his experiences (5.20).

Some farmers empathized that the exchange between farmers is very important (7.49, 8.49). Mostly they in praticular actively visit talks, presentations, and seminars (7.49, 8.20). One of them even hosts seminars and knows other seminar organizers (7.23, 7.49). Furthermore, two interviewees are members of associations with EM in their agenda (2.27, 7.49). This brings them in contact with other farmers applying EM, therefore respondent 8 is familiar with respondent 5 from hearsay (8.52). But respondent 8 also criticized that the industrial vegetable grower association has not officially discussed about EM (8.50). There seems to be a gap between practitioners and institutions. Half of the respondents see a lack of communication between practitioners and academic institutions (2.27, 5.34, 7.50, 8.50) although one farmer even held lectures at an university (7.49).

Those who do not actively search for a group of peers in terms of EM application still have their local farming community for information exchange. Two of the farmers take over some of the cultivation or harvest operations of a neighbor or several regional farms through which they get a comparison to how crops perform on the other farms. In the case of respondent 1, it is a comparison to another farm applying EM and in the case of respondent 4, it is a comparison to farming systems without EM application (1.31, 4.77). Meanwhile, other farmers did not have regional role models and described their work as pioneering (4.8, 7.46, 8.41). Some of those first got inspired to try out EM treatment from a book (4.2, 8.43). One of them used regional livestock holdings applying EM as a model for his non-animal production due to the lack of example cases (8.41), while the other extended EM application from their animal husbandry to other farming sectors (4.1). Only one farmer said that there is no experience exchange with other farmers (6)

4.2. Product and Product Combination

Because of the broad definition of EM, it is important to look at what products are applied and what are common additives to the solution. Three out of the eight farmers multiply EM from a stock solution (2.4, 3.5, 4.5), combining it with additives like micronutrients (3.21), other solids (4.18), or combination preparations (ready-made mixtures) with EM (2.2). In most cases, the products used are those combination preparations containing EM and other additives (1.7, 7.15 8.18, 8.34) like humic acids, seaweed extracts, chili extracts, garlic extracts, micronutrients, or other not specifically classified substances. Most of these additives seem to fall under the definition of biostimulants. Respondents 5 and 6 also use these ready-made combination preparations with EM, though they did not elaborate on the preparation process. These combination preparations are further mixed with solid components like ceramic powder (2.25, 6, 8.18, 8.34), zeolite (1.7, 7.31) commonly known as rock flour (4.18), charcoal or leonardite (4.18), lime as well as whey powder (8.18, 8.34) or micronutrients in addition to those contained in the combination preparations (7.12). In terms of dosage, the amounts per hectare mentioned were 200 and 400 liter per hectare (7.10, 8.34).

Often EM products are not the only new inputs incorporated into the farming practices. Some farmers reported that they developed their farming business parallel to incorporating EM, for example by adopting a food waste composting scheme (8.22) or actively integrating beneficials (5.7) or homeopathic treatments like globules (1.11) into the system. Three of the farmers use EM treatments in addition to foliar application of compost tea (3.1, 7.12, 8.21).

4.3. Method and Frequency of Application

Besides what product and combination are applied, the effects of EM are determined by the way they are applied. Not just in the introduction phase, where two farmers mentioned that they gradually increased the EM treatment, while reducing conventional treatments (3.14, 8.6, 8.42), but also in terms of frequency. Respondent 3 is the only farmer who does not apply EM regularly (3.3.) and then only once as soil application before sowing (3.16). On the contrary, two farmers mentioned regular foliar applications in intervals that vary from 2 weeks (2.6) to around every 12 days or after rain (8.3). In some horticultural crops, this only amounts to two foliar applications after planting (8.3, 8.30). Foliar applications can be combined with pesticides (4.25, 4.51, 4.74, 6) or compost tea (7.12). And soil applications can also be combined with compost tea (3.1, 7.32, 8.23).

Respondent 1 does not adjust the application process to whether a conventional or organically managed field is treated (1.15). The timing depends on the crops, which is before flowering and before harvest in the viticultural crop (1.12) and before ground coverage and as foliar application later on in the horticultural crop (1.17). Especially the soil application (5.11, 7.2) needs to be done while the soil is still accessible, so preferably before sowing (8.3, 8.30) or during planting (4.24, 6), done as dipping of young plants before transplantation in viticulture (2.2, 7.5). Therefore, EM are also used in combination with milling (2.3) to terminate winter catch crops (7.2, 7.32, 8.23). The subsequent fermentation in the field processes the green manure for the following crop.

In all cases the equipment used is a conventional sprayer (3.28, 4.24, 4.25, 5.12, 6, 8.29), sometimes with adjustments (1.5, 2.21, 7.32). In the case of animal husbandry, the feed is sprayed with EM before entering the bunker silo (4.14), while the amount of EM added later is successively reduced over the production cycle based on the performance of the livestock (4.15). If required due to high disease pressure, an additional might be given with the water (4.46). As a combined animal and arable production system, the peculiarity is that the manure spread to the field has indirectly been treated with EM through their application to fodder (4.51).

4.4. Product and Application Criteria

The Product and Product Combination as well as the Method and Frequency of Application are determined by what farmers perceive as influence factors and consider in their decision-making.

The selected product and application method are based on the type of crop and variety (8.12, 8.27). A decision factor can be the infestation potential, which is expected to be low in arable farming compared to horticultural farming (4.56). But EM also seem to be preferably used in special crops. Special crops are crops, whose cultivation demands and is limited to particular site conditions and whose production is very labor- and cost-intensive. Special crops include for example viticultural crops, soft fruits, and most vegetables like asparagus, onions, and salad (1.1, 2.1, 5.1, 6, 7.4, 7.29). Therefore, producers can demand higher prices. Further, some crops are classified as high-risk crops by the insurance industry or produced in a niche (e.g. onion, salad, oil squash, runner beans, chokeberry; 1.19, 4.21, 8.49). And although respondent 4 does not treat his horticultural crops with EM (4.51), he recognized that EM are of particular interest for special crops in that production segment (4.55). In this interview series, only respondent 3 does not grow crops that fit into either of these categories.

Otherwise, specific crops which the farmer has an expertise in or high value cash crops as a main source of income might preferably be treated with EM (4.50, 4.51, 4.30), these can but do not have to correlate with the previous section. Further, the aim of the application dictates which EM products are prioritized in the application e.g., treatments for pest prevention are prioritized over soil conditioners (1.22, 1.30). In terms of pest and disease prevention, the product and related application method used also depends on the origin of the problem e.g., root or leaf (4.56). In addition, some farmers emphasized that the synergy between different EM and different additives should not be disregarded (1.22, 4.23, 7.21). In one case, for instance, additives to the EM mixture are excluded towards the harvest time for aesthetic reasons at retail (2.5).

Meanwhile, one farmer reported that the state of the crop is not of concern but the integration with other work processes (4.49), such as sowing or planting, working the soil or spraying. In other cases, farmers who also find it important that the EM treatment integrates well or smoothly fits in with the workflow (1.5, 1.33, 3.15, 6), nonetheless consider the state and growth stage of the crop in the application timing (1.12, 1.17, 3.19, 3.24, 6). The growth stage seems to be the main criteria since it determines the accessibility of the soil. In the context of in-field fermentation, this is important because according to two respondents it requires enough biomass from the greenery (2.3, 2.6, 2.23, 7.25). Similar to growth stage considerations in the field application, the treatment in animal husbandry is adapted for each flock, younger more susceptible individuals receive a higher dosage which is later reduced following good growth and low losses (4.43).

However, one of the farmers considering the growth stage of the crop argued that within the labor limitations the climatic conditions are the main factors determining the application timing (3.11), in this particular case EM are applied ahead of frost to relieve stress (3.12). Others agree that the climatic conditions are a relevant application criterion for EM (1.32, 3.15). It was reported that cold (7.8) and dry (3.4) conditions cancel the processes of EM. Especially the sun and its UV light are important factors in the application of EM products and should be avoided (1.4, 2.6). Therefore, EM products are often applied early in the morning, late in the evening, or at night (1.4, 8.46). This is mainly the case in combination with a pesticide agent (4.25, 6). In this context, one practitioner explained that an application under mulch film is preferable because of a better absorption (4.76). In addition to this form of application, soil spraying during planting is independent of the sun according to respondent 4 (4.73). The wind is also considered, not just when EM products are applied in combination with pesticides but also without them due to targeting to preserve inputs also for financial reasons (2.6, 8.46). This touches upon what was mentioned by two farmers, that input costs are a criterion (4.47, 3.5). Additionally, rain is a factor mainly because it influences the driving conditions (1.12, 2.6), but some farmers also think it is favorable to apply EM to those anaerobic soil conditions (3.3, 8.3).

Practitioners usually know these indicators but make decisions based on how they "experience" the state of the field or flock and what makes sense to them, so it is based on experience, knowledge and monitoring (3.19, 3.24, 4.43, 5.6, 5.16, 5.17, 6, 8.13). With that in mind, comparisons to other measures are made (5.21) or trials of different dosages evaluated (4.7). In animal husbandry, farmers can also consult veterinarians during regular check-ups (4.35). And due to a lack of independent experts (3.18), for some farmers the recommendations given by EM producers and their advisors are important in the selection of the product, its dosage and application (8.2, 8.4, 8.17, 6). The reasons mentioned for trusting the recommendations of those companies are: identification with their approach, gut feeling (8.2), and trust in their expertise (1.13, 4.28, 5.4, 6, 8.4). Respondent 1 said that based on their experience the system developed with the EM producers has proven its effectiveness and referred to the phrase "never change a running system" (1.10). Proximity to the producers in the case of respondent 1 further favors the use of ready-made EM products (1.6, 1.13). Additionally, it was also mentioned that there is a guaranteed safety implied for a company-certified product (7.17) as well as quality (1.13, 4.6, 3.5), functionality, and adequate packaging, facilitating storage (1.13). On the other hand, this correlates with some setbacks already mentioned, including the initial investment cost for an own reproduction (1.13), failures due to missing experience and amateur technical setup (4.6) as well as a perceived high difficulty of the EM production (8.20) keep farmers from making their own EM solution.

4.5. Aim of Application and Expected Effects

As mentioned in Product and Application Criteria the aim of the EM application can determine which area of treatment is prioritized. Proactive farmers use EM as a preventive measure (2.14, 3.10, 3.25, 4.54, 5.19) often to keep unfavorable or unwanted microorganisms under control (2.10, 4.36), for example by steering the rotting process (1.27, 2.3, 3.17) or combating disease (2.12, 5.11, 8.5) or pests (1.7). From the perspective of respondent 4, EM are preferential, because conventional insecticides are not selective between beneficials and pests (4.58). Otherwise, the treatment is expected to generate overall vital plants (2.10) mainly due to healthy soil life (1.7, 4.32) leading to better performance (5.11), and yield (1.28). The same goes for animal husbandry, the usage of EM aims at an overall healthy stock and good performance in terms of feed conversion (4.3, 4.12). In general, the system is expected to be more resistant (6) and less vulnerable to extreme weather conditions (3.13) due to the stress-relieving properties of EM (3.7, 3.12). On the other hand, the use of EM as an additive in manure or pesticides aims at minimizing the burning of plants (4.22, 4.25).

Respondent 3 expects that frequent EM applications are not necessary in the long run, because he sees the treatment more as an initial introduction of soil life, including it into the operating decisions and transformation of the system (3.9). Long-term positive effects on the soil structure and humus content (7.37) are expected by some farmers, hoping that the activated soil life would counteract soil compaction and make the working of the fields easier (1.26). Fertile soils are also the main goal for respondent 7, applying EM in the notion that more energy in the form of nutritious biomass including carbon, can be brought into the soil through an extended vegetation period of the catch crop. It can be terminated later, while not interfering with the subsequent crop because EM speeds up the decomposition process (7.24, 7.34). Further, by dipping young plants before the transplanting he aims at increasing the microbial diversity at the root and the nutrient efficiency (7.6). The same farmer uses EM to facilitate the conversion of the organic mass and corresponding sugars of the catch crops (7.6). This acceleration of the nutrient cycling by the ferments will immediately make the contained nutrients available to the subsequent crop (7.24). Efficient use of nutrient reserves prevents the attraction of parasites caused by excesses (7.14), which through the fermentation of green manure are built into clay-humus complexes according to the farmer (7.26). Further, he declares there are change in the habitat, suppressing weeds like pioneer plants as well as nitrogen-indicating plants, no matter how great the seed bank, so there would be no outbreaks and sprouting (7.26).

4.6. Observations

Many of the expectations from Aim of Application and Expected Effects can be met through observations. The plants are overall vital, strong, and less susceptible to pests and disease (2.9, 3.13, 8.25). For example, EM treatment counteracts losses from root-bound pests by stimulating root growth (4.33). In another case, EM performed well in terms of plant protection (8.7) with little to no disease cases in the EM-treated areas (8.15). And while one farmer reported that EM are more effective against fungal diseases than against pests (5.21), EM treatments still controlled pests for another farmer and even better than other biological plant protection (7.11, 7.13). In the first case concerning pest control, there was a higher number of beneficials observed over the years, which could also be due to an active distribution by the farmer in the previous years (5.8). Even if EM only delay the infestation compared to systems without treatment, it already extends the period of healthy growth and this form of season extension further leads to higher yields (1.8, 1.18, 6, 8.9). In one case EM treatment sped up the growth of the crop (8.25) but did not lead to an increase in the yields, quality, or an extension of the season (8.35). Meanwhile, in the case of respondent 4, who uses pesticides, the amount of some of those pesticides could be reduced (4.57), while the addition of EM reduces sunburn and made the crop more tolerant to the conventional pesticides (4.26, 4.75). But there is also less sunburn and healthier plants in viticulture independent of pesticide application (7.30). This observation of crops tolerating extreme weather conditions better (3.13, 4.65), especially drought (7.36, 8.39), could be due to SAR to drought (1.23). Since the health of crops contributes to yield security (4.63) as for respondent 4, who reported that they “are on the safe side regarding weather conditions and pests” (4.62). They never had a collapse or total crop failure with EM treatment and are always at the forefront due to consistent upper performance in terms of efficiency and quality and not due to intended yield increases

(4.63). The consistent higher performance of crops, which was also observed by respondent 7 for their fields (7.36) was further achieved with less input (4.63) since the manure from animals with EM in their diet contained higher levels of nitrogen providing for more area (4.20). Incorporating EM in the feed of animals immediately improved the air in the stable and its smell, which was reflected in low NO_x measurements (4.9, 4.11, 4.16, 4.38) as well as the feed utilization and the animal health (4.16, 4.40). No more salmonella issues occurred, which is again coherent with the suppression of pathogens (4.37).

Healthy crops also correspond to good quality and a high marketable harvest (7.11, 7.36). In other cases, this quality improvement showed in a competition-winning taste (1.2) and uncontaminated product with a long shelf-life (4.16, 4.41, 4.64), which was also reported for horticultural crops if harvested at optimal conditions (2.22, 6). These observations together with other positive effects on inputs like improved sprouting of seeds (1.9) influence the Costs and Cost Structure as discussed later on.

Most observations however are long-term changes (1.20). Changes in the soil life and smell occurred after decades (4.53,.7.7) as well as a changed soil texture (7.7). And while these changes can be observed based on the indicators mentioned in the Assessment Criteria, respondent 6 just generally reports positive effects on the soil structure (6). For example, two farmers report an increased soil life based on increased sightings of earthworms and earthworm holes (1.16, 8.24, 8.25). These could be cues for the accelerated decomposition process observed (1.14, 3.22, 7.24). Changes in the habitat and plant population, especially in the weeds of which some even disappear (7.24, 7.26)

4.7. Assessment Criteria

Which criteria the farmers use to assess the effect of EM seems to be correlated with the Observations they made over the years, since those seem to be the indicators, to which they pay the most attention. At the same time, the result of the assessment using these criteria might also influence the Product and Application Criteria.

The importance of experience, knowledge and monitoring (3.19, 3.24, 4.43, 5.6, 5.16, 5.17, 6, 8.13) has been brought up in the section Product and Application Criteria. Regarding monitoring, sensory perception seems to play a major role, so visible effects in the decomposition process of green manure as well as changes in the habitat and weed population (7.24), the fraying of the soil texture as well as its smell (4.53, 7.7). A specific visual cue that was mentioned by two farmers is the number of earthworms or rather earthworm holes (1.16, 8.24) as criteria for active soil life. The evaluation of the quality of the EM product or the final product can also depend on sensory testing, like tasting (1.2, 4.71). However, non-sensory quality measurements are also considered like contamination levels (4.64) and shelf-life (2.22, 4.64, 6). Indicators specific to animal husbandry are the stable climate and air quality, which is assessed through NO_x measurements done by the farmer, the feed conversion factor, animal welfare and health, which are reflected in the growth rate (4.11, 4.12, 4.38, 4.43). Additionally, the absence of disease cases or losses (4.40, 4.43) is a positive sign. The success of disease and pest prevention in crops is mainly evaluated through comparison with other farms, especially those in the same neighborhood or region (1.8, 4.77, 7.13, 8.7, 8.25) as well as own reference areas (5.19, 7.11, 8.7).

But the assessment is complicated by the complexity and lengthiness of natural processes and systems (1.20, 6, 8.40) and the lack of comparable cases or reference areas (2.8, 4.61, 6, 7.46). And as mentioned in the Product and Product Combination section sometimes other improvements to the farming system happen parallel to the implementation of EM (8.22, 5.7), which makes it difficult to differentiate the effects and the origin of changes (8.38). Accordingly, the aforementioned higher numbers of beneficials might be due to the active placement and distribution of them by the farmer (5.8). Another criterion that can be used is the farmer's own satisfaction (1.21, 4.40). In relation, two farmers agreed that ultimately yield (3.29, 4.12), generating revenue with profit is the decision parameter.

4.8. Inputs Replaced

The profit of farming with EM is increased by the replacement of inputs, which influences the Costs and Cost Structure. How it is influenced and which inputs are potentially replaced partially depends on the Aim of Application and Expected Effects as well as on the Method and Frequency of Application. EM products seem to either reduce or replace pesticides as well as biological plant protection products (2.15, 2.26, 3.10, 3.15, 3.26, 4.57, 6, 8.6, 8.11). One farmer only sees EM as another component of his farming practices (1.25, 1.27), which can be assumed as well for respondent 5, who uses EM for strengthening the plants (5.11). Respondent 7 did not mention any specific treatments being replaced but also does not use any pesticides.

Respondent 3 said that in a conventional farming business though some farmers might hope for it, EM treatments do not replace fertilization (3.8). In contrast to that, respondent 4 reports that due to the higher nitrogen levels of the EM-treated manure and additional third of their fields can be fertilized, which in turn reduces synthetic fertilizer (4.20). Further, EM treatments replaced antibiotics (4.16, 4.35) and disinfection products except for the chlorination of the drinking water in animal husbandry (4.36).

4.9. Costs and Cost Structure

Besides the Inputs Replaced (2.15, 4.36, 6) the previous section also touches upon EM improving the efficiency of other inputs (4.63). This is a result of EM stimulating the sprouting of seeds (1.9), improving feed utilization (4.16) and manure quality (4.20), which directly or indirectly creates savings on seeds (1.9), pesticides (3.26, 4.57, 8.11), fertilizer (4.20) and antibiotics (4.16).

Regarding expenses, no new equipment seems to be necessary for the field application of EM (5.12, 6). Most farmers use a conventional sprayer (3.28, 4.24, 4.25, 5.12, 6, 8.29), and rarely small investments for the adaption of existing equipment are needed (1.5, 2.21, 7.32). But as mentioned by respondent 8, it is advantageous when replacing old equipment, to get a model that is mode fitting for the work with EM e.g., peel milling machine (8.32). Further, investing in a machine, in this case, a compost tea machine, to stir the EM solution while adding solid additives is also favorable to ensure proper dissolving and prevent the clogging of the sprayer (8.31). In terms of the reproduction of EM stock solution, investments are needed as well, which is the reason why some farmers opt for ready-made combination preparations with EM besides the guaranteed quality and safety of the product (1.13, 7.15, 7.17). Two farmers emphasized that these investments and expenses for EM products are advance payments since long-term improvement depends on these upfront inputs (5.18, 7.35). Therefore, the input costs for EM are considered in the adjustment of the dosage (1.35, 4.47) and are also mentioned as one of the limiting factors in the EM application by some farmers (2.11, 3.6, 5.9). Especially for application in conventional arable farming, the ready-made products are too expensive, but opting for self-reproduction solves this problem (3.6). If farmers self-market their produce the increased expenses can be covered by demanding a higher price at retail (5.9).

On the other hand, when the occurrence of diseases can be delayed through EM application until late in the season, not only can losses be avoided (1.8, 6, 8.9), but also higher yields can be achieved (6). Respondent 6 reports that the yield increase covers the expenses (6) and adds that there are higher costs but also a higher revenue (6). The yield increase (1.18) is expected to make the EM application economically viable (1.28) as well, according to respondent 1. Though not mentioned by the farmers, an improvement in the quality (1.2, 4.16, 4.41, 4.64, 7.36) and marketable share (7.11) of their agricultural produce gives them a competitive advantage compared to farms not working with EM, as well as the longer shelf life of their goods (2.22, 4.64, 6). In addition to the "head start" due to good crop performance (6), applying EM sets the farm apart from others, especially in a region of intensive agriculture, creating a high demand (7.39) because of a positive customer perception (6, 7.38). Further, the author speculates that the Observations, including a consistent better performance (4.63) and a certain amount of yield security regardless of weather conditions (7.36), might be advantageous in terms of insurance and futures contracts.

Only respondent 8 explicitly did not report any positive effects on the yield, quality, or season (8.35), although delayed disease incidences in his fields (8.9). But he also reported that for him the input costs for the EM product are about the same as for the chemical treatment (8.36). But the respondent also claims that it is not a one-to-one calculation (8.36). At this point Ideology, Motivation and Drivers of Change seem to be important and a belief that, as respondent 7 said, "it will pay off eventually" (7.42). With this dedication farmers are ready to put in the work for the implementation of EM into the system, which is important since respondent 5 reports that the cost increase is mainly related to the higher demand for labor (5.13), which is discussed in the next section.

4.10. Workload and Work Safety

Almost all farmers agreed that the application of EM was more labor-intensive than conventional methods and that was the main limiting factor in different contexts including their implementation but also the creation and multiplication of an own solution (2.7, 2.16, 2.24, 3.2, 3.12, 3.28, 5.5, 5.13, 5.15, 6, 7.27). The workload increased especially when a gradual transition from conventional to EM treatments is practiced (3.14).

Simultaneously, the EM treatment integrates well with the workflow, so more operations or passes are not needed (1.5, 2.21, 4.52, 6, 7.32, 8.29) with the right machinery (1.29). But as mentioned earlier, the conventional sprayer can be used (3.28, 4.24, 4.25, 5.12, 6, 8.29), with only small adjustments of the equipment needed (1.5, 2.21, 7.32). Further, respondent 1 mentioned that working the fields will be easier due to the expected benefits of EM on improving the soil conditions (1.26). Contrary to the integration into the workflow, respondent 5 claims that the farming business needs to be structured in a way that accounts for the EM treatment in terms of managing the labor (5.14, 5.35). In accordance, you need to be flexible in your work process when taking into account the climatic conditions (3.20).

In terms of work safety and storage, there are no regulations and risks associated with EM (2.18, 8.33). There are no toxic dosages of EM (4.47, 8.47). Therefore, on one of the farms, EM are not stored over winter and are rather used up and re-ordered for each season, simplifying storage (2.20). And even if the EM product spoils it does not become harmful it just loses its positive attributes (4.70). Further, a safer work environment for the employees and in the publicly accessible fields reduces the liability of the farmer like putting up warning signs and the need for insurance coverage (8.33). However, if EM are combined with pesticides, the regulations on pesticides and work safety measures have to be complied with (6).

4.11. Setbacks and Areas of Conflict

In this section, complications in the application of EM are discussed. Since these can be more pronounced or otherwise related to general issues that farmers are facing, the subtheme Related to Farming in General was created in addition to the one Related to EM.

4.11.1. Related to EM

As previously mentioned, there are limitations due to the labor intensity of EM practices (2.7, 2.16, 2.24, 3.2, 3.12, 3.28, 5.5, 5.13, 5.15, 6, 7.27). The related labor costs (5.13, 5.15) contribute to the financial limitations in addition to the investment costs for own reproduction (1.13) and the input costs of the EM (1.35, 2.11, 3.6). There can also be practical mistakes and accidents like tipping over a container of EM as for any other input. Or if the storage area is not well isolated it might affect the quality of EM, which should be protected from freezing, direct sunlight, and high temperature to keep the pH stable and avoid expiration (2.19, 4.69). Therefore, the price of the EM preparations can be a major drawback (2.11). Especially since it might not always be possible for the farmer to allocate the higher production costs to the consumer when they cannot demand a higher price at retail due to the lack of self-marketing (5.9).

In addition, a lot of input upfront in form of equipment like a stirrer, demanding advance payment (5.18, 7.35), but also in terms of knowledge are needed. EM treatment as well as their preparation is knowledge-intensive also requires skills for its practical implementation (4.6, 4.50, 5.16, 7.15, 7.16, 7.22, 7.35, 8.20). This drawback is reinforced by the novelty of the practice (5.20) and a lack of comparable cases (7.46), creating the image of a lone fighter (7.44). So, while the availability of information situation is improving through exchange with the few experienced farmers, there is still a lot of pioneering involved (4.8, 8.41). Moreover, the author assumes that the initial trial and error phase, including failings in the reproduction of EM or administering the EM with the water for animals clogging the pipes (4.6, 7.15, 4.13), can add to the upfront costs.

This information situation was summarized by respondent 3 calling the practice a blind flight (3.30). And even if there are many opportunities for trials because of short vegetation cycles, there is no time and labor available on the farm for supervision, self-documentation, and evaluation (8.51). This relates to the lack of contact with academic institutions.

Therefore, courage is needed to trust in treatment and prioritize it over common practices and keep trying, because sometimes there might not be any effects due to the dosage being too low (4.48, 4.45). Further, it can lead to uncertainty about whether the EM treatment can be fully implemented (7.43), especially since two farmers reported a need for flexibility and the ability to structure the operations around the EM application (3.20, 5.14, 5.35). This can be difficult at the outset, especially if EM are part of a conversion of the farming system (7.20) and all aspects of the EM practice have to be considered because of the synergies between the different components of farming (7.21). One farmer switches some fields back and forth with neighboring farmers, which limits his ability to completely structure and transform the system in favor of the EM (8.1).

In addition, the trust in EM can be challenged since naturally phases of declined growth still occur, in animal husbandry as an exemplary case the flock catches up eventually (4.39). Further, the effects can also vary with the variety and type of crop, which the EM are applied to (8.12, 8.27). The results are not predictable due to the limited information available but also due to the complexity of natural systems (1.20, 6, 8.40).

And while a fastened decomposition process due to EM might be favorable in some cases (4.14, 7.24, 7.34), in other cases it is seen as negative assuming that there will not be enough biomass left for other soil organisms like earthworms (3.22). On the other hand, this is contradicted by the increased spotting of earthworms by some farmers (1.16, 8.24). In another contradictory account, respondent 3 wants to reduce his dependency on external inputs (3.27), while another farmer mentioned that EM are not traded any different from other inputs (4.28). So, only if EM show long-term effects without a need for reapplication or buying EM products can be opted for an own EM reproduction, this self-sufficiency can be achieved. Own EM reproduction and developments of the EM technique like bokashi production instead of in-field fermentation and its usage also have to follow the regulations of organic farming if the produce treated with it is to be sold as organic. So, the biomass for the bokashi has to be certified as organic (2.29).

Prevalent site-specific climatic conditions interfere with the EM's ability to relieve abiotic stress (1.24, 2.13). Under extreme weather conditions like floods and hail (8.10), especially when the crop is mechanically damaged (8.8, 8.16), EM cannot combat disease and pesticides (8.28). So, the field conditions and weather conditions remain the main factors in the season, the yield and its quality (5.10). For example, soil compaction influences how the EM-stimulated root growth unfolds (4.59). The effectiveness of EM treatment against infestation can also vary depending on the crop treated (8.12) as well as the type of biotic stressor. It was reported by two farmers that EM are more effective against fungal diseases than against pests (5.21, 8.19).

In conclusion, though no setbacks with EM were reported by respondent 6, the price, workload, and the climatic constraints are reasons why cheaper conventional inputs might be seen as an easier alternative by other farmers (2.16).

4.11.2. Related to Farming in General

Due to climate change, farmers find it harder and harder to achieve sufficient biomass with a winter catch crop, or they need to opt for components that freeze off because of a tightened spring schedule due to an increasing scarcity in the water supply (3.22). Together with more frequent extreme summer droughts killing undersown catch crops, establishing a reliable cover crop becomes more and more challenging (7.33). This interferes with the farmers' ability to implement in-field fermentation even with EM accelerating the process and since EM also need biomass (2.3, 2.6, 2.23, 7.25).

According to respondent 5, there is missing transparency in the agricultural market regarding cross-country standards. He criticized that local producers have to compete with imported goods while fulfilling high standards which do not apply to the competition (5.32). In addition, respondent 1 experienced that conventional crops are no longer viable (1.1), probably due to the fierce competition. This can be an additional burden on small-scale farms, which are already under pressure (6).

Another general problem reported by respondent 5 is the increasing responsibility that farmers have to carry (5.27) when inputs retrospectively are classified as unsafe, which was partially mentioned concerning EM being a new practice (5.28). Meanwhile, even though increasing raw material prices and consequently an increased cost of living is already foreseeable for respondent 5 (5.31), farmers are not included in political decision-making (5.29). Therefore, respondent 7 claims that there is a need for support from society (7.40) with regards to taking responsibility for sustainable development. According to respondent 5, the mindset of the general public has to change to seeing the social service behind the provision of food besides the economic interests of farmers, and more understanding needs to be created through information, education, and reconnecting people with agriculture (5.25, 5.30, 5.33).

This also applies to professionals in academia. Two farmers reported that they observed a lack of practical understanding by scientists in their interactions (5.34, 7.50). So, studies do not address challenging crops (7.50). As mentioned in Communication and Information Acquisition regarding Peer Contact, this lack of communication does not just apply to academic institutions, but also official associations (8.50)

Further, three farmers mentioned lobbying as an impediment to development (4.66, 5.26, 8.45). One of them had an experience related to the implementation of EM in animal husbandry, where he was falsely accused of illegal use of antibiotics, which entailed a house search and which he blames the pharmaceutical lobby for (4.66). Another mentioned the general “greed for money” (5.26), while the third farmer expressed that EM strengthen the self-sufficiency of farmers which conflicts with the interests of the “chemical lobby” (8.45). According to him, this self-sufficiency is also inhibited by technical limitations, and he sees the responsibility but a lack of interest with the manufacturers (8.45).

4.12. Ideology, Motivation and Drivers of Change

Respondent 7 sees EM as one practice to combat climate change (7.28) and feels a “responsibility for the future”, which leads to an “unconditional” commitment to EM as part of regenerative farming (7.41). Besides this and other socioeconomic motivations, awareness and will to produce nutritious food (7.38, 7.28). This participant is driven by his beliefs. Respondent 7 described that an agricultural turnaround cannot rely on politics (7.38), to him it is important to become a beacon and promote participation (7.51). This system could be interpreted as Corporate Social Responsibility (7.48) because he describes collaboration with consumers based on visibility, cooperatives, and participation (7.38). In his opinion, the system he describes is not possible to achieve in “conventional and agrochemical agriculture” (7.38). In consistency with that, two participants mentioned that opting for EM treatment is perceived as positive by customers (6, 7.38). For example, the farm of respondent 4 is located close to a village due to reduced smell pollution they have fewer conflicts with neighbors (4.10). In addition to that, respondent 6 listed the “headstart” due to EM treatment compared to other farmers as a reason to apply EM. Meanwhile, some practitioners mentioned that without EM their farming system (2.12) like the implementation of cover crops (7.9, 7.25) would not work or that EM have become “indispensable” (4.17, 4.34)

Farmers explicitly mentioned the term “philosophy” with this way of farming (8.1, 8.48), while the term “conviction” or “believe” was also mentioned (2.8, 8.1, 8.37, 5.36) as well as “ideology” (4.60). For example, it was said that conventional methods like fungicide do not fit the latter (2.17) or that prophylactic antibiotic treatments are not wanted (4.4). Statements such as “I know it’s the right system (…) it will now pay off eventually” (7.42), emphasize the “will to change” or “want for change” (7.28, 8.44, 7.51) of a few of the participants. One farmer seems to see EM as a gateway to independent thinking and to “learn to observe the field situation by yourself” (3.24) in the context of why he does not want classical consulting (3.23).

The savings on conventional pesticides (3.26, 5.2, 5.36, 6, 8.1, 8.14, 8.37) as well as on classical biological plant protection treatments (2.15) are perceived as positive by the farmers. Either because they are leaning towards a more ecological production system (4.19) or implementing regenerative farming practices, because of the missing progress and limitations of other farming systems (7.19, 7.45). One farmer mentioned the “big picture” that chemicals would disturb the positive climate on the plant and soil surface and later on referred to the necessity to switch to renewables without wasting environmental resources, which he seems to include EM in (8.26, 8.44). This is in line with the attitude of respondent 4 to respect and support natural mechanisms and rather focus on building soil fertility than on plant fertilization (4.79), which includes partially allowing for natural losses (4.60). Others are motivated by continuous restrictions on plant protection products (3.27, 5.22, 6), aiming to reduce their dependency on a single component and external inputs (3.27). While they are aware of the negative effect of conventional pesticides or antibiotics, they recognize that the management and dosage is the crucial factor (5.23, 4.42). And although EM are the main priority and used before those (5.36, 4.68), their necessity as last resort before animals suffer, the stock is devastated (4.42) or the harvest is disrupted so loans or employees cannot be paid (5.36).

4.13. Future Aspirations and Potential

While one of the practitioners said that he has already exploited the full potential of EM application (1.34), another said the same in terms of labor allocated to the implementation of the EM (2.7). Although later on it was mentioned that there is still potential for applications in the initial stage of their arable farming, for shortening the intervals in their soft fruit cultivation, and for extending the EM application to other types of soft fruit as well as other EM products e.g., bokashi (2.28). Similar to the latter, respondent 7 voiced the goal to produce their own regional EM mixture with local plants mixed into the fermentation process together with their cooperative after closing the knowledge gap (7.16, 7.47). Other product developments requested by a respondent included an EM product that can be applied in a solid form, like a powder or granulate, while the current EM mixture could already be combined with trace elements (4.78). The general hope was expressed that the long-term process of building a healthy soil structure could be sped up (4.78). In contrast to further product development respondent 3 first demands that an evaluation system for the quality and effectiveness of this type of input is developed to solve what he called a “biological blind flight” (3.30, 3.31).

Unrelated to what has been mentioned, respondent 6 said that they could transform their farming system further towards ecological farming by omitting herbicides (6). Additional mechanic weed control was mentioned as well, so it is unclear whether EM are assumed to support this change. Other potentials for the future that were mentioned though not clearly connected to EM were technical solutions to enable farmers to use more of their own resources in farming, e.g tractors run on biogas (8.45). Respondent 5 seemed satisfied with his farming system, the only areas of potential for future improvement mentioned are related to a general reform of the agricultural system.

5. Discussion

5.1. Compliance of EM Treatments with the Agroecological Principles

Agroecology is defined as "the integrative study of entire farm and food systems, embracing environmental, economic and social dimensions" (Tasin 2018, p. 6). It involves systems thinking and a transdisciplinary, participatory, and action-oriented approach (Tasin 2018, Gliessman 2018). In practice, this is realized by the "design of individual farms (…) with emphasis on uniqueness of place and the people and other species that inhabit that place" (Francis et al. 2003). Based on this framework the FAO established 13 agroecological principles (HLPE 2019), which are used in this study to assess the EM treatment.

5.1.1. Resource Efficiency

The respondents are mostly aware of the increasing demand, scarcity and costs of raw materials. So, improved resource efficiency through closing cycles, including prioritizing renewable resources and minimizing external inputs through self-sufficiency is one of the three operational principles of agroecology.

Principle 1: Recycling

EM's potential to restore natural cycles and ameliorate degraded soils anticipated by the initial literature (Lamont et al. 2017) was confirmed in the interviews. But the potential recycling of nutrients from sewage sludge proposed is not done in practice. Regarding waste treatment, one farmer uses leftovers from the biogas plant (3.22), and another brings bio-waste back onto the field (8.22), but this was mentioned as unrelated to the EM treatment. However, the benefits documented for sludge treatment are indirectly experienced for manure, including the reduction of odor elimination and nitrogen being lost to the atmosphere. The economic performance compared to other waste treatments was not investigated. On the other hand, EM improve the use efficiency and timing of nutrients release from biomass, observed in practice as an amelioration and facilitated management of green manure, promoting the use of local renewable resources. For LAB, in particular, research (Lamont et al. 2017) highlights the renewability of the resource as well as the complexity and synergy of the associated processes, benefitting from the combination with a nutrient source. The combination of EM with a nutrient source is a focal point in the literature (Gates et al. 2012). In practice, EM are combined with prepared mixtures for foliar application and mainly organic fertilizer for soil application. However, it is unclear how the micronutrients along with other ingredients in the combination preparations with EM are sourced. Nonetheless, since they are not essential to the EM treatment, it is safe to assume that those inputs do not significantly reduce its resource efficiency.

Principle 2: Input Reduction

EM balance out the nutrient input required by increasing the use efficiency of other inputs. The problems mentioned by scientists (Nardi et al. 2016, Lamont et al. 2017, Raya-Hernández et al. 2020, Glaser et al. 2015, Fatunbi and Ncube 2009, Shin et al. 2017, Abdullah et al. 2011) regarding industrial agriculture are mainly related to methods of managing the agroecosystem through conventional inputs. And the dependency on external inputs should be minimized to reduce the vulnerability of farmers, which have no control over the input price and supply (Rasul and Thapa 2004). Regarding nutrient inputs, biostimulants like EM are expected to reduce the application of fertilizer (Colla et al. 2014, Abdullah et al. 2011). In practice, the reduction of synthetic fertilizer was only mentioned in one case although 5 respondents farm or partially farm conventionally. On the other hand, the potential for reducing plant protection treatments was directly or indirectly reported by 6 farmers. Mostly this was practiced in form of a gradual transition phase, while using existing equipment. In research (Abdullah et al. 2011), this was connected to improved biotic stress tolerance. Similarly, beneficial effects on the water management described in the literature (Yakhin et al. 2017) were specifically mentioned in one case and related to the plants' improved response to abiotic stress. Meanwhile, the efficiency of inputs like seeds and feed is improved, as well as contributing to practical input reduction. The potential of EM to protect against weeds elaborated in one paper (Javaid 2010) and by one of the respondents further reduces the need for agrochemicals or mechanical control methods.

The improvement of organic fertilization schemes, prepared using local labor, machinery and raw materials strengthens self-sufficiency and therefore food sovereignty, since this way the producers of food are less vulnerable to external markets. Further, the reduction of inputs and losses is expected to contribute to the profitability of this practice and is confirmed by the farmers. According to them, these saving together with the higher revenue due to the ability to produce exclusive crops of high quality early in the season cover the higher expenses. And constant if not increased yield ensures income security, while an increase potentially conserves land resources.

Due to the slow changes and the nature of long-term processes, the input cost including labor can be seen as upfront investments or advance payments. Especially, since the poor knowledge about EM requires a trial-and-error period. On the other hand, the work safety and storage are easier to manage, and in most cases, EM integrate well with the workflow and a necessary adaption of the business structure is exceptional. But overall, the workload and therefore labor input is increased. In literature this is related to the bulk quantities of organic fertilizer needed to meet the nutritional requirements of the crops, complicating the handling compared to mineral fertilizer (Jilani et al. 2007).

Additionally, due to the high pricing of biostimulants the combinability with other control inputs as done in practice by adding EM to pesticide treatments, is recognized by a study on biostimulants (Addabbo et al. 2019). Practitioners have also proven the potential implementation parallel to other farm developments. Further, the independence from geographical conditions (Egle et al. 2016) is limited in practice due to the close relation to climatic conditions, which are an important factor in the practical application of EM in combination with a catch crop.
The use of local microorganisms from healthy soils described by scientists (Olle 2019, Olle and Williams 2013, Abdullah et al. 2011) as an inexpensive alternative seems to have more limitations in practice than expected. Establishing an own EM production requires a lot of knowledge and experience according to the interviewees. Both researchers (Mayer et al. 2010) and practitioners, criticize the lack of accessible and affordable screening methods for self-produced EM solutions. Therefore, practitioners rather trust the products and recommendations given by producers based on the perceived expertise and guaranteed safety and efficiency of the EM product. Further, the initial investment costs, especially for the technical setup are a drawback for them. The economic efficiency of EM expected by the literature (Abdullah et al. 2011, Jaramillo-López et al. 2015) is reduced if practitioners have to rely on commercial EM inoculum. Further, it limits the accessibility of EM. Commercial EM products as external inputs are out of the farmers’ control in terms of price and supply. Nonetheless, regarding the nutrient source for the EM mostly local inputs are used. And investments are low since all farmers interviewed use their current machinery with small adjustments and involve existing labor in the task of EM treatment. The self-sufficiency could be strengthened by finding solutions for the technical limitations, especially regarding the own production of EM, which inter alia requires a testing scheme for evaluating the quality and effectiveness of EM solutions. Additionally, one interviewee demanded the provision of EM treatment in a solid form, maybe even as a slow-release product as well as an improvement of the time scale of building fertile soils with EM, which might further improve resource use efficiency.

5.1.2. Resilience

Farmers describe the integration and establishment of EM on the farm as a long-term process. However lasting effects can already be expected after short-term application, providing some stability of the positive effects over time and promoting sustainable intensification and resilience. Strengthening positive ecological interactions, partially by enhancing soil fertility and biological activity and by supporting functional and genetic diversity, to achieve vitality in plants and animals is another aspect of reducing the influence of external factors. The operational principle of resilience also includes increasing the production flexibility and range for financial independence and facilitated customer orientation. The resilience to external factors is especially important in light of more frequent extreme weather conditions in relation to climate change as well as the subsequent disruptions on supra-regional markets.

Principle 3: Soil Health

Bokashi**,** although produced exclusively anaerobe compared to the conditions at field application, shows similar effects (Xiaohou et al. 2008, Boechat et al. 2013) as EM applied within studies (Abdullah et al. 2011, Fatunbi and Ncube 2009, Górski et al. 2017, Mayer et al. 2010, Olle and Williams 2013) as well as in practice. Similar to research results for LAB (Caballero et al. 2020, Lamont et al. 2017), these effects include increased nutrient availability and use efficiency, and improved soil characteristics, mainly related to promoted soil life activity and decomposition. Besides the beneficial effects of soil application of EM, one farmer mentioned that they might degrade soil organic matter if not enough biomass is provided to sustain the EM, for example in the form of greenery. On the other hand, improved plant growth, especially of the root system, crop protection, and yield parameters were mentioned in implementations by farmers and researchers (Fatunbi and Ncube 2009, Abdullah et al. 2011, Górski et al. 2017, Olle and Williams 2013). As a preventive measure, EM's proactive support of the vitality of animals and plants makes them less deceptive and more resistant to pests and diseases as well as climatic stressors, including plant resistance to burns from pesticides and fertilizers. The latter might be related to EM's anti-oxidising effect documented in scientific reports (Mayer et al. 2010). Practitioners observed increased abiotic stress tolerance, seed germination, and beneficial alterations of the habitat described in association with LAB-produced organic acids in the literature (Lamont et al. 2017). The latter was related to the suppression of weeds. As the introduction of this paper and one respondent (8) brought up, synthetic agents alter biochemical cycles, which is harmful to soil fertility, increasing soil-borne diseases. The beneficial effects of EM are also reflected in the improved input efficiency observed. In addition, the promoted microbial decomposition of biomass from catch crops facilitates the timing and management. But since building soil fertility and altering habitats are long-term processes, they are limited by field rotation between farming businesses or rather production systems, like switching fields with neighbouring farms. On the other hand, this long-term process could provide ecosystem services elaborated in the section about principle 12, Land and natural resource governance.

Principle 4: Animal Health

The one recount of usage of EM in animal husbandry reports greatly improved animal health and welfare to the point where antibiotics and disinfection products could be replaced. Besides animal husbandry, EM are perceived as safe by farmers and researchers also for non-target species, assuming a selectivity of EM. Regarding LAB, the safety of the input is specifically mentioned in the literature (Lamont et al. 2017), again referring to SAR, preoccupation, and competition as the main methods as well as other non-toxic forms of suppressing undesirable microbial communities.

Principle 5: Biodiversity

The non-toxicity and reduced leaching due to increased input efficiency might reduce the negative externalities of farming on biodiversity. Further, by supporting yield security also in special, high-risk, and niche crops, EM might support diversification of the cultivation. On the other hand, practitioners report an alteration of the habitat, suppressing weeds, while scientists report decreased bacterial diversity under LAB application (Caballero et al. 2020). The exclusion of artificial synthesis or genetic engineering mentioned for EM in the literature (Abdullah et al. 2011) however seems to hold true for the products marketed for practical application, although one respondent confused the term.

Principle 6: Synergy

Contrary to managing the agroecosystem with the main aim of control, agroecological inputs aim at minimizing the control necessary through enhancing positive ecological interaction creating a more self-sustaining farming system. In particular, one respondent repeatedly mentioned the synergy between soil health and plant health (4.32). So, improving poor soil structure with EM aims to prevent root- and soil-borne diseases in practice as described in the literature (Shin et al. 2017). This is additionally related to improved crop quality mentioned for biostimulants and EM increasing the yield in scientific reports (Olle and Williams 2013, Abdullah et al. 2011, Górski et al. 2017, Pandit et al. 2020). Either or both could be observed by most practitioners. According to the literature (Nardi et al. 2016) the beneficial effects are independent of the biostimulants' nutritious value, including EM. However, as was observed also in practice, the pairing with a nutrient source is recommended. So, many uncertainties are related to the provision of a nutrient source and its characteristics, including its quality. Meanwhile, the simultaneity of the effects originating from the application of organic material and those arising from the EM application as well as the synergy between those two are recognized in studies (Jaramillo-López et al. 2015, Boechat et al. 2013). Further, researchers (Nardi et al. 2016, Fatunbi and Ncube 2009, Andreev et al. 2016) report that biostimulants promote microbial activity, regarding EM this could be an inherent or external process. That EM benefit the timing of organic fertilization is recognized by the literature (Abdullah et al. 2011, Boechat et al. 2013) as introduced in the beginning and mentioned by the interviewees. And it is related to the aforementioned timing of organic fertilization by speeding up the decomposition process by consuming and making the contained nutrients available to the plants but also to other beneficial microorganisms. The resulting organic acids are also contained in the prepared mixtures applied in combination in farming. While soil characteristics, abiotic and biotic stress resistance are additionally positively influenced. The latter benefits from the natural competitive and antagonistic activities of EM described by scientists (Olle and Williams 2013, Fatunbi and Ncube 2009, Sales et al. 2020) and practitioners. As a preventative measure, the preoccupation, their establishment prior to stressors is important in EM's ability to outcompete unfavorable microorganisms. Further, the benefits of proactive induction of SAR including the effect on plant morphology and phenology are recognized by the literature (Yakhin et al. 2017, Lamont et al. 2017) and indirectly described by the farmers. Biostimulatory effects on plant morphology mentioned in the literature are observable in practice as higher weight measured under EM treatment for the same volume of produce without EM application. Similarly, biostimulation of plant phenology might be the cause of shriveling prevention due to sunburn. Literature (Lamont et al. 2017) particularly mentions LAB adjusting the osmotic potential of cells and decreasing the vulnerability to mechanical damage. Further, extensive development of the root apparatus is observed by researchers (Colla et al. 2014, Górski et al. 2017, Formowitz et al. 2005, Dou et al. 2012, Li et al. 2016) as well as practitioners. The resulting stimulation of growth is also reported for EM in particular by both groups.

The variety of beneficial effects supports ecological intensification and provides a diversity of ecosystem services. To strengthen these natural functionalities of the agroecosystem the EM application needs to adjust to the local conditions, including general environmental variations, plant and soil community as well as initial soil characteristics. In combination with the differences between mixtures, methods of application, and other management practices, the comparability of cases is limited. Additionally, there is a diversity of unpredictable influences factors like biotic stressors and short-term climatic limitations. Meanwhile, the lack of information contributes to the uncertainty related to the variations with the crop type, variety, state, and growth stage. These complex interactions observed in studies (Nardi et al. 2016, Brown and Saa 2015) and by the interviewees impede advanced planning and require work flexibility.

Principle 7: Economic Diversification

Since EM are an alternative to conventional inputs, these remain an option to prevent a total loss of the stock or harvest and animal suffering when EM treatments fail. So, EM is one of the tools in the toolbox enhancing the flexibility of production according to the farmers' reports. Further, the variety of EM products and their versatility enable the farmers to adopt the method according to their aim of application and local conditions with the consumers in mind as recounted by the respondents. A broader spectrum of customer demands can potentially be satisfied due to the extended product range due to the enabled cultivation of special, high-risk, and niche crops and diversified marketing due to being able to advertise products as free of protection agents, including antibiotics and pesticides, in some cases. This might explain the high demand observed by some producers. In addition to the higher returns from these crops, improved quality, seasonality and yields support the financial independence of farmers according to the interviewees. However, if EM do not originate from their own production, but are purchased, input dependency is created. On the other hand, EM often replace other external inputs or increase their efficiency, while also improving natural processes like green manure production and plants' response to stress. Simultaneously, ecosystem services are provided, for which practitioners could maybe demand compensation in the future, diversifying the farm's sources of income.

5.1.3. Social Equity and Responsibility

The third operational principle includes the communication and exchange between the stakeholders of the food production system. With a focus on co-determination, considering local customs, the aim is to support equity and food security. By encouraging self-determination and governance of farmers and communities, their livelihoods, authority and responsibility in terms of local resources are strengthened.

Principle 8: Co-creation of Knowledge

Contacts with EM producing and selling industries plays a major role in information acquisition. As reported by the farmers, producers greatly value farmers' experiences and involve some of them in decision-making, supporting co-creation. At the same time, advisory services are provided to the farmers, for example in one case in the form of establishing valuable farmer-to-farmer contact. While the lack of independent consulting might additionally motivate the establishment of horizontal knowledge sharing, the lack of organization, role models and exchange with academic institutions impedes local and scientific innovation. Currently, peer contact is very important due to the limited availability of information and the success of the treatment being based on experience and knowledge-intensive monitoring and management. Especially, since the assessment is mainly based on sensory perception, which is difficult knowledge to document and transfer. In addition, the changes in the habitat happen over a longer period of time. Measurements and comparisons are rare and complicated by the complexity of natural systems, the individuality of cases and overlap with other farm developments in practical implementations. The importance of local knowledge to adapt the EM treatment to the specific conditions and the increased reliance and support of natural functionalities are mentioned in papers (Nardi et al. 2016, Andreev et al. 2016, Mayer et al. 2010) and by practitioners. This explains the practitioners focus on their own satisfaction with the EM treatment, sometimes reflected in yield and profit. It also plays into the agroecological principle of farmers being the real innovators, which instead of just adopting practices developed outside of the practitioner community, adapt technologies to their conditions based on local knowledge (Tittonel 2014). Practice recognizes that the involvement of local groups, including the non-farm community and their commitment can facilitate the adaption of the EM treatment. But the interviews show that there are successful cases of “lone fighters” due to their sense of responsibility in this field as well. However, like prejudiced experiments by Jaramillo-López et al. (2015), the adaption of EM technologies is doomed to failure if there is a lack of local community involvement and commitment. On the other hand, farmers mention lobbies that are uninterested in innovations that support their self-sufficiency. Additionally, the shift of investments towards low-risk, low-return activities due to the increased uncertainties related to climate change (Lipper et al. 2014), impedes effective farm innovations. In practice, EM seems to encourage farm development beyond shifting towards high-risk, high-return crops. On the other hand, not all respondents are motivated to engage in an agricultural turnaround or reformation, so this could also be unrelated to EM.

Principle 9: Social Values and Diets

Conviction plays a major role, and most farmers see EM as part of their philosophy of supporting natural mechanisms, preserving resources, and relying on renewables as necessary to develop and improve the farming system. Independence and eliminating the reliance on external inputs, especially agrochemicals facing restrictions are also important to them. In some cases, EM are described as the means to implement organic or regenerative farming. On the other hand, due to the versatility of EM, the treatment can easily be adapted to customer preferences, like aesthetics as a practical example. Further, local customs and dietary preferences can be considered and diversified by the supported cultivation of special, high-risk, and niche crops, possibly explaining the high demand and positive consumer perception observed.

Since the application of EM does not require specific training but therefore physical presence, local labor is favored, contributing to higher equity. Practitioners confirm this, but the establishment of the treatment scheme needs a lot of knowledge. With the promotion of organic fertilization schemes, more local resources are used, reducing the outflow of money and therefore providing more benefits to local communities (Rasul and Thapa 2004). Further, the suppliers to the farmers of this interview study are local businesses although as previously mentioned the sourcing of the other inputs of the prepared EM mixtures is not disclosed.

Potentially, gender and social equity could be promoted by supporting developing countries in their access to phosphorus recycling (Weikard and Seihan 2009) since the access to sources of phosphorus is particularly limited for small-scale and female-managed farms. But since accessibility and affordability depends on how refined the EM treatment applied is, EM's ability to strengthen small-scale farms and transform the food system towards food sovereignty is more limited in practice than expected by the (Jaramillo-López et al. 2015). Additionally, the negative externalities associated with excess inorganic N have a stronger impact on women and children since they are often more exposed especially in developing countries (Farnworth et al. 2017) and EM application in animal husbandry particularly reduced these. Further, marginalized ethnic groups, producers on the poorer spectrum, and those not owning their land resources are most vulnerable to the increasing risks and market disruptions that come with climate change (Lipper et al. 2014). EM treatment was reported by farmers as a tool for pollution and climate change mitigation and adaptation. In addition, a small-scale farmer in this study claimed that the effects of EM treatment give them a competitive advantage due to earlier marketing and good quality of their produce, supporting equity.

Principle 10: Fairness

Industrial agriculture's dependency on fossil fuel and energy-intensively produced, finite mineral phosphorus fertilizer causes food prices to peak with price spikes in crude oil, putting pressure on household spending and increasing vulnerability as described by a farmer. Practitioners reported that they use EM to diversify their farming strategies to reduce their dependence on other farming inputs also in regard to the restrictions on pesticides mentioned in the introduction. Based on the literature (Hoeppner et al. 2015) EM treatment could potentially make farming less energy-intensive, but this was not particularly investigated in the interviews. Further, the promoted shift from mineral to organic fertilizer contributes to an increase in the requirement for labor, which creates employment opportunities and supports people's financial access to food. Fertilization schemes with bokashi being laborious was also mentioned by Mendoza et al. (2020) and related to the difficult handling of bulk quantities in organic fertilization (Jilani et al. 2007). The increased workload was mentioned by farmers as well. Further, easier management, especially in the light of work safety where pesticides are replaced, is recorded in the conversations, improving working conditions as hinted by researchers. Meanwhile, the timing of the decomposition of greenery is improved, synchronizing it with the plant nutrient need and reducing leaching as described by researchers, but also facilitating the sequence of work processes in practice. And while the higher input self-sufficiency contributes to higher economic stability regarding food prices, the localized benefits reduce the vulnerability to political agendas from other communities, increasing food security.

According to the interviewees, EM treatment can lead to an extension of the season by speeding up growth and delaying infestation. The latter in addition to reduced vulnerability to abiotic stress decreases the occurrence of losses and improves input use efficiency, backed up by literature on EM and the related biostimulants (Olle and Williams 2013, Abdullah et al. 2011, Górski et al. 2017, Colla et al. 2014). Some of these studies reported biostimulation of photosynthetic and senescence processes as well as on phytohormonal pathways, which might be the reason for the observed early sprouting in practice. The beneficial effects on risk-resilience increase income security as reported by farmers, potentially increasing food security. Additionally, farmers agreed that a higher price for their produce can be demanded due to the improved quality, earlier harvest, and marketing of produce as pesticide-free. In combination with the positive consumer perception towards EM, a small-scale producer sees the competitive advantage as particularly important. Theoretically, these aspects also create health benefits for the population in terms of food utilization and safety. Further, improved marketability and shelf-life observed in practice could increase compliance with standards and reduce food waste, increasing its availability. Food security is additionally promoted due to the stable if not increased yields reported under EM treatment. But no farmer mentioned any benefits from prediction accuracy other than ease of mind, but also none of them explicitly mentioned involvement with contracts or price futures. Overall, higher net revenues regardless of the higher production costs are generated as expected by the literature (Pandit et al. 2020, Jilani et al. 2007), potentially making organic farming systems more competitive with intensive agricultural systems.

Regarding the EM solution, limitations to its accessibility mentioned in the previous principle and associated costs, the market entry seems to not be very limited, so if more companies enter the market the price and supply would develop beneficially for the farmers. Further, one of the respondents even aims at establishing a local association-organized EM production. However, three respondents highlighted that not all actors engaged in the food system have the same influence to change the system, referring to lobbying and a perceived lack of interest in farmers' self-sufficiency by the industry. While according to one of them, foreign producers are favored due to the lack of cross-country standards and transparency, leading to unfair competition. And beneficial effects on environmental externalities related to EM are currently not translated into economic benefits for farmers.

Principle 11: Connectivity

One of the farmers has the opinion that an agricultural turnaround with increased visibility of farms, cooperatives, consumer participation, and Corporate Social Responsibility is impossible under the current conventional agricultural system. By supporting regenerative farming practices, EM application indirectly contributes to a potential system change according to the interviewee. Further, EM treatments are perceived positively based on the farmers' statements about conversations with customers but also by the local community, for example, due to the reduction of odor nuisance. It is important to involve the non-farm community in conversations about EM to avoid unreasonable consumer concerns and misconceptions by the public as has been the case for phosphate recycling from sewage in the past (Edholm Widén 2019). Regarding the costs of farming with EM, direct marketing with a good consumer contact is additionally favorable in terms of cost allocation, as proven by a respondent.

Principle 12: Land and Natural Resource Governance

No effects on property, ownership, or right of use could be associated with EM, but it can be a useful tool to farmers as managers and guardians of natural and genetic resources as touched upon previously. Because a great share of GHG originates from agricultural activities and farming is also greatly affected by climate change, there is a great interest in reducing emissions in this sector. Especially, since mitigation strategies to GHG emissions can come with a multitude of benefits from e.g. reduced eutrophication and acidification, including wildlife conservation, and improved human and soil health. Latter potentially feeds back into increased income and resilience of rural livelihoods (Lipper et al. 2014). The multitude of positive effects is reflected by the EM treatment which doubles as a mitigation and adaptation strategy in terms of climate change, by increasing the use efficiency of inputs and the crop's tolerance to abiotic stress as reported by researchers (Lamont et al. 2017) and farmers. Practitioners confirm EM’s contribution to the management of the additional stress maintains the productivity at low input. Therefore, it combats the lower yield and increased crop failure expected due to the increased frequency of extreme weather events, rising sea levels, increased soil salinization, changes in average temperature, pests, diseases and nutritional quality of some food (Lipper et al. 2014). Meanwhile, drought and issues in water management related to climate change came up during the interviews, limiting the EM’s ability to ameliorate green manure and improve the timing of its decomposition with other work processes.

EM-induced input efficiency conserves resources otherwise used for the production of these inputs, while reduced losses limit pollution, like NO_x emissions. This plus the practical replacement of pesticides probably conserves the quality of natural resources. Further, improved soil health, as observed under EM treatment, is additionally an important factor in the provision of the ecosystem service of water purification and carbon sequestration. Directly and indirectly, this could improve human and environmental health as well as food security and safety in addition to the detoxification of heavy metals through EM (Abdullah et al. 2011). On the other hand, EM’s contribution to soil amelioration could potentially put marginal lands back into agricultural production. Maintaining productivity promotes food security, while probably the pressure on protected areas is reduced, preventing the disruption of natural habitats and conserving biodiversity and land resources. Generally speaking, the respondents seem to be convinced that EM create an overall healthier environment.

Principle 13: Participation

The overall perception of the farmers can be summarized by three statements, calling for more understanding and support of farmers by policymakers, society, academic institutions, and official associations, and the sharing of responsibilities solely carried by farmers. Knowledge and skills in the development of the EM application are required. Further, the importance of the removal of barriers mentioned regarding legislative issues in the literature (Addabbo et al. 2019) also applies to certification issues regarding organic bokashi production in practice. The support of organic fertilization schemes facilitates the shift from external nutrient sources to on-farm generated fertilization. The resulting decentralization empowers local communities and creates community responsibility in terms of environmental protection, which requires legitimate institutions and rules (Jaramillo-López et al. 2015). Although the non-farming local community is not as immersed in the practice as expected by Jaramillo-López et al. (2015), involvement seems to be fostered anyways although the role of EM in this context is unclear.

5.2. Critical Discussion of the Research Methodology

By valuing practical experiences as well as scientific literature, a broad spectrum of knowledge is considered in this interdisciplinary study, providing a deeper understanding of the complex relationships and processes. All dimensions of sustainability of the farming system were considered. But to achieve a true whole-systems approach, the system-thinking should involve all stakeholders. So, increasing the level of participation by including more actors and action-oriented strategies would elevate the agroecological methodology of the paper. These actions should confront existing "economic and political power structures of the current industrial food system with alternative social structures and policy action" (Gliessmann 2018, p. 599), which was not achievable in the course of this study.

As has been established, agroecology is the practice of farming with the local conditions, including climate, soil characteristics, and plant and microorganism community, which also influence the EM. And since IPA is focused on the uniqueness of the individual accounts, the locality of the agroecological approach is represented. Further, the PRA follows the agroecological principles, since more sustainable outcomes are expected from this kind of process due to empowerment and capacity-building (Hoffny-Collins 2018b). But in this case, PRA is practiced with high outsider control, since the interest group participates solely through information-giving (Hoffny-Collins 2018b), which limits these effects. Therefore, PRA cannot build rapport and the reliability and validity of the information may be questionable. Further, no generalizations can be made for the whole interest group (Hoffny-Collins 2018b). On the other hand, this again relates to the site-specificity of the IPA and agroecology. And according to Brocki and Wearden (2006), the IPA does not aim to be representative but instead generates in-depth knowledge of a small group. So, while there are no general concepts applicable to all cases, the accentuation of nuances facilitates the identification of findings relevant to specific conditions, which makes this paper more appealing to practitioners.

Although prioritizing arable farms in contacting respondents, mostly horticultural production is represented in the study, while arable farming is still underrepresented.

Since there is a lack of official networks for farmers applying EM, the snowball sampling method did not work out. On the other hand, when contacting farmers through social media, it is possible to see what other organizations and groups they are associated with, which might bias the researcher in regard to which farmers are prioritized in the requests for an interview. Further, as visible in Figure 1, social media might be an easier method for identifying farmers that apply EM, but it requires more time since most of them did not respond or they responded more than 6 weeks after the reminder was sent. And despite trying to arrange interviews outside the peak season, due to unusual climatic conditions during the particular year, the interviews partially overlapped with a busy farming period restraining the availability of farmers. But at the same time, this gave the opportunity to discuss the influence of EM on these extreme climatic conditions, as well as which influence the conditions have on the application process of EM as the arid season becomes longer with more frequent event of drought in Germany.

The interview type did not seem to influence the duration of the conversation (see Table 1). The phone and video calls went mostly smoothly, but when there is no video, facial expressions and gestures cannot be taken into account at the stage of interpretation, non-verbal probing is not possible and the conversation participants might interrupt each other. Still, the mood could be conveyed via the tone of voice. Only in some cases, there were delays or bad audio quality, which made transcribing difficult, but the meaning did not get lost. However, these minor issues sometimes created a more relaxed atmosphere since you have to work out those struggles together. Otherwise, the flow of the interview depended very much on the mood or attitude of the respondent. Some farmers seemed a bit hectic probably because of a tight schedule coming with the beginning of the season. In cases where I was referred to members of the family business, who were slowly stepping down or in cases where farmers took time off during their leisure to answer the questions, it improved the interview flow. Also regarding the conversation flow, the interview could have profited more from sequential questions, moving from the descriptive to the analyzing and opinion-focused questions to encourage logical thought and richer information (Hoffny-Collins, 2018a). However, based on common understanding, the interviewee's reaction and the interviewers shared culture with the respondents, ambiguous questions could be avoided. But some questions might have still been too leading or assumption-laden. But since the interviewer transcribed each interview before conducting the next, those mistakes were reflected and the process and formulation of questions improved. Further, specification and clarification sometimes required closed questions. And although the interviewer wanted farmers to give their reports independent of others' experiences, in some questions during the interviews at a later time, examples from other interviews were used to elaborate on the question asked but also to bring up those issues that were not previously thought of but came up during earlier interviews. Listing examples during the questioning process intended to make very general questions easier to understand, especially in cases where a different dialect was spoken by the respondent. As mentioned in the methodology section, some words or concepts are not transferable between languages. So, some information might get lost through the translation from German into English. But since the analysis focuses on the meaning, it is not a major issue. Therefore and for more lucidity of the study, verbatim extracts were not included in the analytical process although Brocki and Wearden (2006) recommend it for traceability purposes, especially regarding the bias of the researcher. An additional obstacle regarding language is the researcher's experience of interviewing in English as part of a group of interviewers in contrast to being the single investigator in a German conversation. In addition to a lack of experience in social science studies, the scientist has practical work experience in animal husbandry but not in crop farming, so phased assertion was still needed as a probing technique despite the preceding literature review.

Only one of the respondents did not agree to an audio recording and transcription of the interview (interview 6). But as it was conducted after over half of the interviews had been collected and transcribed, the interviewer was familiar with the topic and could catch on to the main points based on similarities and differences. The participant of interview 8 requested some of the statements not to be included in the study. Additionally, a lot of the data from transcript 3 could not be used, because the respondent did not differentiate between compost tea and EM although the interviewer tried to actively steer the conversation towards EM. The same problem occurred with respondent 8, but in this case, there was no differentiation between EM and another non-EM plant protection agent which is certified for organic farming but is based on selected bacterial spores. Research results could also be distorted by the fact that most of the interviewed farmers applied EM in combination with additives like other biostimulants or non-biostimulatory biocontrol agents.

The interpretative analysis as described by Brocki and Wearden (2006, p. 88) is limited since "interpretations are thus bounded by participants' abilities to articulate their thoughts and experiences adequately and, it would follow, by the researcher's ability to reflect and analyze". Further, qualitative analysis, in general, is a personal process, which therefore can be influenced by the researcher´s theoretical preconditions (Smith et al. 1999), which are described in the Preface for this case. And although for example setting up themes based on pre-existing theory or understanding of the topic has been practiced before for IPA, Brocki and Wearden (2006) state, partially drawing on Smith et al. (1999), that knowing the literature can lead to associative interpretation fitting this previous theoretical perception. But the researcher confirmed that these themes and connections are also found within the transcripts. However, the previous stage was biased by the initial aim to explore bokashi as an agricultural practice, which might have led to the prioritization of studies on soil application especially those with a combined fermentative process. Meanwhile, papers on foliar applications of EM might not have received the same attention. Therefore, EM were mostly examined in the context of soil amendments replacing fertilizer and improving soil characteristics. Their ability to relieve biotic stress from pests and disease came into focus mainly as a result of applying EM with the aim to strengthen soil fertility and increase yields. Preventing losses due to pests and diseases or damages from pesticide spraying was not considered of major concern. Additionally, the degree of importance of restriction on pesticides for farming was underestimated and therefore the relevance of EM in plant protection.

6. Conclusion

Regarding the objectives we started off with, the issues identified in the practical implementation of EM in the farming system reflect the issues described in the literature in addition to the social and economic effects of EM identified. Since there are many interactions between the environmental and socioeconomic aspects, they are not presented separately.

In general, the biostimulatory effects of EM application described in the literature could generally be observed in practice. Similarly, the aim of the application and the expected effects can be realized by the farmers and are confirmed by the observations. Most of these are related to the restoring of natural cycles. But the desired value addition by recycling waste described in research was only practiced as amelioration of green manure and indirectly of animal manure by EM addition to the feed. Nonetheless, EM treatments promote the use of local, renewable resources by supporting organic fertilization by improving their performance including the timing of the decomposition. Therefore, EM facilitate management processes, also in terms of work safety and they partially increase the self-sufficiency of farmers, reducing their vulnerability and therefore promoting food security. Although the combination with a nutrient source is recommended, especially external inputs are reduced, mainly through improved use efficiency and reduced losses.

These effects are mainly related to the interactions and synergy between soil health and plant health. EM proactively stimulate processes of SAR, phenological and morphological changes. Applied preventatively they control pests and disease through preoccupation and competition and are therefore regarded as safe for non-target species. This has potential benefits for biodiversity alongside the promoted diversification of the cultivation by making otherwise susceptible crops more stress resistant and therefore more attractive for cultivation, and reduction of agrochemicals, as well as increased nutrient availability, while weed and bacterial communities in-field might become less diversified. But as an alternative to restrictions-facing plant protection and weed control treatments as well as other pesticides, EM further reduce the vulnerability of farmers. In addition, other beneficial effects on water management and inputs like seeds and feed occur.

The input use efficiency is partially increased due to the EM-induced abiotic and biotic stress tolerance, including burns from pesticides or fertilizer, or both. Meanwhile, the contribution of organic material to these positive effects and to the improvement of soil characteristics and the activation of soil life remains unclear. Overall, vital plants and animals result in stable health, yield, and improved quality. Therefore, the produce shows high marketability and long shelf-life, potentially reducing food waste. Further, marketing benefits from EM's ability to extend the season by delaying infestation or earlier harvest maturity, or both. In combination with the broader product range, including high-risk, special, and niche crops, a greater diversity of customer demands and preferences can be satisfied, supporting a healthy diet, food security, safety and sovereignty. Besides cultural identity, there is the necessity to adapt the practice to the local conditions and individual settings, which requires work flexibility. But this is supported by the versatility of EM treatments, like their combinability with other inputs and work processes, and by the variety of EM products. The resulting production flexibility also facilitates customer orientation. Due to the competitive advantage, higher returns can be achieved and balance out the input costs for the EM product and labor, especially since the income security is increased due to the yield stability. Potential compensations for ecosystem service provision could further economically diversify the farming business. On the other hand, the self-sufficiency in terms of the EM solution could be improved but is impeded by lobbying, upfront payments, technical and knowledge limitations.

As a knowledge-intensive and experience-based practice, it relies on a farmer-to-farmer exchange, especially due to the limited communication with academia and an infantile information base. But the EM treatment has the potential to support innovations previously limited by the uncertainties related to climate change, and encourage high-risk, high-return investments. On the other hand, the novelty of the subject benefits the conversation between practitioners and producers of EM products. But it also sparks the curiosity of customers promoting connectivity, which in addition to direct marketing is beneficial for cost allocation. Further, the relationship between farmers and the neighboring non-farming community is improved by the reduction of negative externalities due to the EM application. Moreover, EM's potential contribution to decentralization, by reducing the outflow of money and creating employment opportunities, could empower the local community. It is speculated that EM treatment could have positive effects on gender and social equity also on a global level, by protecting groups most vulnerable to negative farming externalities and supporting those most vulnerable to climate change including small-scale farmers, and by offering access to nutrient valorization from waste, though with limitations.

EM's role in increasing participation and Corporate Social Responsibility remains unclear, since the farmers reporting beneficial developments are also very active, so the effects might not be directly related to the EM treatment. Further, conviction and dedication play an important part in the successful implementation of EM. However, EM are seen as a support by these farmers, which strengthens their influence in the agricultural system. And exactly the sharing of responsibility and more understanding and support for farmers is demanded by the practitioners interviewed. But the representation of practitioners farming with EM is limited by the lack of organization, legislative hurdles, and unfair competition due to missing cross-country standards.

The EM treatment does not establish stewardship but highlights the importance of farmers in providing ecosystem services beyond serving as climate change adaptation and mitigation strategy. On the other hand, climate change can complicate the integration of EM into the farming system. Meanwhile, areas benefiting from the EM application are: environmental protection, resource conservation and human health including food security and safety. Although the establishment of EM is a long-term process their lasting effects initiated even after short-term application promote ecological and sustainable intensification and create environmental and economic risk-resilience, the EM treatment complies with the agroecological principles.

7. Recommendations

Other qualitative studies would benefit from the inclusion of an author with expertise in language to be able to include more verbatim extracts to increase the traceability of the researcher's bias. Further, involving different stakeholder groups like farm employees or producers of commercial EM solutions could uncover more social issues and environmental implications. Studies could further explore the effects associated with the application of EM as a foliar spray in the context of controlling pests and disease, especially regarding predictions on future invasions related to climate change. Also in the realm of climate change adaptation, EM’s effects on salt tolerance should be explored in practice. Additionally, extending the lens of EM application from the field to animal husbandry could not just benefit climate change mitigation but also improve animal health and welfare. Especially in the field of environmental economics, quantitative research, like a comprehensive cost-benefit analysis of the EM treatment and life cycle assessment of combination preparations with EM, would be complementary.

Since EM application seems to be economically feasible, no compensation in form of subsidies is necessary, but developments and innovations should be supported to strengthen farmers’ self-sufficiency. The focus should be on finding solutions to the technical and knowledge limitations for the production of self-made EM preparations. This could be achieved by strengthening the communication between farmers and research institutions and aligning science with practice by involving farmers in decisions on research orientation. By designing projects in a more action-oriented way, issues like lobbying and the lack of farmer organization could additionally be addressed.

However, other sustainable agricultural practices should not be neglected. Especially, since some are easier to implement, like decreased fertilizer application in European regions of excessive usage, where no significant reductions in yields can be expected (Steffen et al. 2015). Future research should therefore also take into account the general effect of biomass on soil biodiversity, soil structure, and consequently soil-borne pests and disease by including a reference area with organic fertilizer without EM. The increased occurrence of earthworms, which are known to produce excreta containing biostimulants, could be related to that. Further, EM might serve as feed for the earthworms and if consumed might interact with the colon bacteria of the earthworms. Additionally, other microbial inoculants like the aerobically multiplied ones contained in compost tea could also be of interest in terms of beneficial interactions.

References

Abdullah, M. M. A. B., Ma'Radzi, A. H., Saleh, N. A. M., Kamal, A. Z., & Yaacob, N. D. (2011). Production of effective microorganism using halalbased sources: A review. *African Journal of Biotechnology*, *10*(81), 18649-18652. https://doi.org/10.5897/AJB11.2772

Amann, A., Zoboli, O., Krampe, J., Rechberger, H., Zessner, M., & Egle, L. (2018). Environmental impacts of phosphorus recovery from municipal wastewater. *Resources, Conservation and Recycling*, *130*, 127-139. https://doi.org/10.1016/j.resconrec.2017.11.002

Andreev, N., Ronteltap, M., Lens, P. N., Boincean, B., Bulat, L., & Zubcov, E. (2016). Lacto-fermented mix of faeces and bio-waste supplemented by biochar improves the growth and yield of corn (Zea mays L.). *Agriculture, Ecosystems & Environment*, *232*, 263-272. https://doi.org/10.1016/j.agee.2016.08.012

Ashley, K., Cordell, D., & Mavinic, D. (2011). A brief history of phosphorus: from the philosopher's stone to nutrient recovery and reuse. *Chemosphere*, *84*(6), 737-746. https://doi.org/10.1016/j.chemosphere.2011.03.001

Atafar, Z., Mesdaghinia, A., Nouri, J., Homaee, M., Yunesian, M., Ahmadimoghaddam, M., & Mahvi, A. H. (2010). Effect of fertilizer application on soil heavy metal concentration. *Environmental monitoring and assessment*, *160*(1), 83-89. https://doi.org/10.1007/s10661-008-0659-x

Baldotto, M. A., & Baldotto, L. E. B. (2016). Initial performance of corn in response to treatment of seeds with humic acids isolated from bokashi. *Revista Ceres*, *63*, 62-67. https://doi.org/10.1590/0034-737X201663010009

Blaszczak, A. G., Parker, C., Gates, D.E., Boston, C. L., Allen, A., Pabon, A., Nelson, M. L., Sweeney, M., Galbraith, D. W. & Wozniak, E. M. (2012). A105 Stimulatory Effects of Fermentation Metabolites on Plant Defense Response to Biotic Stress and Their Impact on Crop Production. In: New AG International (ed.) *Abstracts Book for Oral and Poster Presentations at: The 1st World Congress on the use of Biostimulants in Agriculture,* November 26-29 2012, Strasbourg, France, 123.

Boechat, C. L., Santos, J. A. G., & Accioly, A. M. D. A. (2013). Net mineralization nitrogen and soil chemical changes with application of organic wastes with 'Fermented bokashi compost'. *Acta Scientiarum. Agronomy*, *35*(2), 257-264. https://doi.org/10.4025/actasciagron.v35i2.15133

Brocki, J. M. & Wearden, A. J. (2006) A critical evaluation of the use of interpretative phenomenological analysis (IPA) in health psychology. *Psychology and Health, 21*(1), 87-108. https://doi.org/10.1080/14768320500230185

Brown, P., & Saa, S. (2015). Biostimulants in agriculture. *Frontiers in plant science*, *6*, 671. https://doi.org/10.3389/fpls.2015.00671

Caballero, P., Rodríguez-Morgado, B., Macías, S., Tejada, M., & Parrado, J. (2020). Obtaining plant and soil biostimulants by waste whey fermentation. *Waste and Biomass Valorization, 11*(7), 3281-3292. https://doi.org/10.1007/s12649-019-00660-7

Clark, M. & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environmental Research Letters, 12, 1-11. https://doi.org/10.1088/1748-9326/aa6cd5

Colla, G., Rouphael, Y., Canaguier, R., Svecova, E., & Cardarelli, M. (2014). Biostimulant action of a plant-derived protein hydrolysate produced through enzymatic hydrolysis. *Frontiers in Plant Science*, *5*, 448. https://doi.org/10.3389/fpls.2014.00448

Cordell, D., Drangert, J. O., & White, S. (2009). The story of phosphorus: global food security and food for thought. *Global environmental change, 19*(2), 292-305. https://doi.org/10.1016/j.gloenvcha.2008.10.009

D'Addabbo, T., Laquale, S., Perniola, M., & Candido, V. (2019). Biostimulants for plant growth promotion and sustainable management of phytoparasitic nematodes in vegetable crops. *Agronomy*, *9*(10), 616. https://doi.org/10.3390/agronomy9100616

Dou, L., Komatsuzaki, M., & Nakagawa, M. (2012). Effects of Biochar, Mokusakueki and Bokashi application on soil nutrients, yields and qualities of sweet potato. *International Research Journal of Agricultural Science and Soil Science*, *2*(8), 318-327. http://www.pyroligneousacid.com.au/wp-content/uploads/2015/04/effects-of-biochar-mokusakueki-and-bokashi-application-on-soil-nutrients-yields-and-qualities-of-sweet-potato.pdf [2021-09-01]

Du Jardin, P. (2015). Plant biostimulants: definition, concept, main categories and regulation. *Scientia Horticulturae*, *196*, 3-14. https://doi.org/10.1016/j.scienta.2015.09.021

EBIC (2021a). *Function defines biostimulant products*. https://biostimulants.eu/issue/function-defines-biostimulant-products/# [2021-09-01]

EBIC (2021b). *Plant biostimulants contribute to climate-smart agriculture*. https://biostimulants.eu/issue/plant-biostimulants-contribute-to-climate-smart-agriculture/ [2021-09-01]

Edholm Widén, J. (2019). *The preconditions for increasing phosphorus recycling from sewage systems in Sweden – A study of factors influencing Swedish farmers' willingness to use phosphorus fertilizers produced from sewage sludge*. (EX0789). Swedish University of Agricultural Sciences Alnarp. Faculty of Landscape Architecture, Horticulture and Crop Production Science. Department of Biosystems and Technology. LM005 Agroecology - Master's programme. http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-s-500003 [2021-09-01]

Egle, L., Rechberger, H., Krampe, J., & Zessner, M. (2016). Phosphorus recovery from municipal wastewater: An integrated comparative technological, environmental and economic assessment of P recovery technologies. *Science of the Total Environment, 571*, 522-542. https://doi.org/10.1016/j.scitotenv.2016.07.019

Farnworth, C. R., Stirling, C., B. Sapkota, T., Jat, M. L., Misiko, M., & Attwood, S. (2017). Gender and inorganic nitrogen: what are the implications of moving towards a more balanced use of nitrogen fertilizer in the tropics?. *International Journal of Agricultural Sustainability*, *15*(2), 136-152. https://doi.org/10.1080/14735903.2017.1295343

Fatunbi, A. O., & Ncube, L. (2009). Activities of effective microorganism (EM) on the nutrient dynamics of different organic materials applied to soil. *American-Eurasian Journal of Agronomy*, *2*(1), 26-35. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.578.325&rep=rep1&type=pdf [2021-09-01]

Formowitz, B., Elango, F., Okumoto, S., Buerkert, A. & Müller, T. (2005). Wie wirken "effektive Mikroorganismen" auf EM-Bokashi in der Bananenproduktion (Musa ssp.)? [Is there an effect of 'effective microorganisms' on EM-Bokashi in banana (Musa ssp.) production?]. In: Heß, J und Rahmann, G (eds) *Ende der Nische, Beiträge zur 8. Wissenschaftstagung Ökologischer Landbau*, Kassel: kassel university press GmbH, 195-198. https://orgprints.org/id/eprint/3627/ [2021-09-01]

Francis, C., Lieblein, G., Gliessman, S., Breland, T. A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C. & Poincelot, R. (2003). Agroecology: The Ecology of Food Systems. *Journal of Sustainable Agriculture*, *22*(3), 99-118. https://doi.org/10.1300/J064v22n03_10

Gates, D. E., Parker, C., Boston, C.L., Allen, A., Pabon, A., Nelson, M. L., Blaszczak, A. G., Sweeney, M., Galbraith, D. W. & Wozniak, E.M. (2012). A078 (P019) Effects of Biostimulants Containing Fermentation Metabolites and Nutrients on Plant Response to Abiotic Stress. In: New AG International (ed.) *Abstracts Book for*

Oral and Poster Presentations at: The 1st World Congress on the use of Biostimulants in Agriculture, November 26-29 2012, Strasbourg, France, 96.

Glaser, B., Wiedner, K., Seelig, S., Schmidt, H. P., & Gerber, H. (2015). Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. *Agronomy for Sustainable Development*, *35*(2), 667-678. https://doi.org/10.1007/s13593-014-0251-4

Gliessman, S. R. (2018). Defining Agroecology. *Agroecology and Sustainable Food Systems, 42*(6), 599-600. https://doi.org/10.1080/21683565.2018.1432329

Gliessman, S. R. (2014). *Agroecology: the ecology of sustainable food systems*. 3rd Edition. Boca Raton: CRC Press, 15. https://doi.org/10.1201/b17881

Górski, R., Kleiber, T., & Sobieralski, K. (2017). The influence of effective microorganisms application on the chemical composition in lettuce grown under cover. *Ecological Chemistry and Engineering A*, *24*(1), 113-121. http://dx.doi.org/10.2428%2Fecea.2017.24(1)9

HLPE (2019). Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. *HLPE Report, 14*, 41. http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-14_EN.pdf [2021-09-01]

Hoeppner, J. W., Entz, M. H., McConkey, B. G., Zentner, R. P., & Nagy, C. N. (2006). Energy use and efficiency in two Canadian organic and conventional crop production systems. *Renewable Agriculture and Food Systems*, *21*(1), 60-67. https://doi.org/10.1079/RAF2005118

Hoffny-Collins, A. (2018a). Interviewing [Unpublished presentation] Swedish University of Agricultural Science, Alnarp. Faculty of Landscape Architecture, Horticulture and Crop Production Science. Department of People and Society.

Hoffny-Collins, A. (2018b). Participatory Approaches to Development, Research & Change Interventions [Unpublished presentation] Swedish University of Agricultural Science, Alnarp. Faculty of Landscape Architecture, Horticulture and Crop Production Science. Department of People and Society.

Jaramillo-López, P. F., Ramírez, M. I., & Pérez-Salicrup, D. R. (2015). Impacts of Bokashi on survival and growth rates of Pinus pseudostrobus in community reforestation projects. *Journal of Environmental Management*, *150*, 48-56. https://doi.org/10.1016/j.jenvman.2014.11.003

Javaid, A. (2010). Beneficial Microorganisms for Sustainable Agriculture. In: Lichtfouse E. (eds.) *Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming*. Sustainable Agriculture Reviews Vol. 4, Dordrecht: Springer, 347-369. https://doi.org/10.1007/978-90-481-8741-6_12

Jilani, G., Akram, A., Ali, R. M., Hafeez, F. Y., Shamsi, I. H., Chaudhry, A. N. & Chaudhry A. G. (2007). Enhancing crop growth, nutrients availability, economics and beneficial rhizosphere microflora through organic and biofertilizers. *Annals of Microbiology, 57*, 177–184. https://doi.org/10.1007/BF03175204

Jorgenson, A. K., & Kuykendall, K. A. (2008). Globalization, foreign investment dependence and agriculture production: Pesticide and fertilizer use in less-developed countries, 1990–2000. *Social Forces*, *87*(1), 529-560. https://doi.org/10.1353/sof.0.0064

Khaliq, A., Abbasi, M. K., & Hussain, T. (2006). Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan. *Bioresource technology*, *97*(8), 967-972. https://doi.org/10.1016/j.biortech.2005.05.002

Karimuna, L., Ansi, A., Marfi, W. E., & Samaruddin, L. (2020). 425 (012038) Yields of maize (Zea mays l.) and peanut (Arachis hypogaea l.) in intercropping system treated by bokashi plus fertilizer under early growth of teak plantation in Napabalano District, Muna Regency, Indonesia. In: IOP Conference Series - Earth and Environmental Science (ed.) *The 1st International Conference on Agriculture and Bioindustry 2019*, October 24–26 2019, Banda Aceh, Indonesia: IOP Publishing. 1-11. https://iopscience.iop.org/article/10.1088/1755-1315/425/1/012038 [2021-09-01]

Kühnen, V. & Goldbach, H.E. (2004). *Schwermetallbilanzen verschiedener Betriebstypen: Eintragswege, Flüsse, Minderungspotential*. (Schriftenreihe des Lehr- und Forschungsschwerpunktes USL Nr. 118). Bonn: Landwirtschaftliche Fakultät der Universität Bonn, 60-62. https://bonndoc.ulb.uni-bonn.de/xmlui/bitstream/handle/20.500.11811/1212/USL_Forschungsbericht_118.pdf?sequence=1 [2021-09-01]

Lamont, J. R., Wilkins, O., Bywater-Ekegärd, M., & Smith, D. L. (2017). From yogurt to yield: Potential applications of lactic acid bacteria in plant production. *Soil Biology and Biochemistry*, *111*, 1-9. https://doi.org/10.1016/j.soilbio.2017.03.015

Li, G., Xu, G., Shen, C., Tang, Y., Zhang, Y., & Ma, K. (2016). Contrasting elevational diversity patterns for soil bacteria between two ecosystems divided by the treeline. *Science China Life Sciences, 59*(11), 1177-1186. https://doi.org/10.1007/s11427-016-0072-6

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., Sen, T. P., Sessa, R., Shula, R., Tibu, A. & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature climate change*, *4*(12), 1068-1072. https://doi.org/10.1038/nclimate2437

Mayer, B. K., Baker, L. A., Boyer, T. H., Drechsel, P., Gifford, M., Hanjra, M. A., Parameswaran, P., Stoltzfus, J., Westerhoff, P., & Rittmann, B. E. (2016). Total value of phosphorus recovery. *Environmental science & technology*, 50(13), 6606-6620. https://doi.org/10.1021/acs.est.6b01239

Mayer, J., Scheid, S., Widmer, F., Fließbach, A., & Oberholzer, H. R. (2010). How effective are 'Effective microorganisms®(EM)'? Results from a field study in temperate climate. *Applied soil ecology*, *46*(2), 230-239. https://doi.org/10.1016/j.apsoil.2010.08.007

Mayer, J., Scheid, S., Widmer, F., Fließbach, A., & Oberholzer, H. (2007). Wirkungen von ‚Effektiven Mikroorganismen EM' auf pflanzliche und bodenmikrobiologische Parameter im Feldversuch. *Zwischen Tradition und Globalisierung - 9. Wissenschaftstagung Ökologischer Landbau*, March 20 - 23 2007, Stuttgart, Deutschland. 9691. https://orgprints.org/id/eprint/9691/ [2021-09-01]

Mendoza, T. C., Furoc-Paelmo, R., Makahiya, H. A., & Mendoza, B. C. (2020). Strategies for scaling up the adoption of organic farming towards building climate change resilient communities. In: Venkatramanan, V., Shah, S., Prasad, R. (eds) *Global Climate Change and Environmental Policy*, Singapore: Springer, 125-146. https://doi.org/10.1007/978-981-13-9570-3_4

Molinos-Senante, M., Hernández-Sancho, F., Sala-Garrido, R., & Garrido-Baserba, M. (2011). Economic feasibility study for phosphorus recovery processes. *Ambio*, *40*(4), 408-416. https://doi.org/10.1007/s13280-010-0101-9

Nardi, S., Pizzeghello, D., Schiavon, M., & Ertani, A. (2016). Plant biostimulants: physiological responses induced by protein hydrolyzed-based products and humic substances in plant metabolism. *Scientia Agricola*, *73*(1), 18-23. https://doi.org/10.1590/0103-9016-2015-0006

Neuman, J. (2017). Soil organic matter maintenance in no-till and crop rotation management systems. *Reference Module in Earth Systems and Environmental Sciences.* https://doi.org/10.1016/B978-0-12-409548-9.10653-0

Nziguheba, G., & Smolders, E. (2008). Inputs of trace elements in agricultural soils via phosphate fertilizers in European countries. *Science of the total environment, 390*(1), 53-57. https://doi.org/10.1016/j.scitotenv.2007.09.031

Olle, M. (2019). The improvement of the quality, and nutrient content of leaf celery transplants by effective microorganisms. *Agraarteadus: Journal of Agricultural Science, 30*(1), 32-35. https://doi.org/10.15159/jas.19.01

Olle, M., & Williams, I. H. (2013). Effective microorganisms and their influence on vegetable production–a review. *The Journal of Horticultural Science and Biotechnology*, *88*(4), 380-386. https://doi.org/10.1080/14620316.2013.11512979

Pandit, N. R., Schmidt, H. P., Mulder, J., Hale, S. E., Husson, O., & Cornelissen, G. (2020). Nutrient effect of various composting methods with and without biochar on soil fertility and maize growth. *Archives of Agronomy and Soil Science, 66*(2), 250-265. https://doi.org/10.1080/03650340.2019.1610168

Rasul, G., & Thapa, G. B. (2004). Sustainability of ecological and conventional agricultural systems in Bangladesh: an assessment based on environmental, economic and social perspectives. *Agricultural systems*, *79*(3), 327-351. https://doi.org/10.1016/S0308-521X(03)00090-8

Raya-Hernández, A. I., Jaramillo-Lopez, P. F., Lopez-Carmona, D. A., Diaz, T., Carrera-Valtierra, J. A., & Larsen, J. (2020). Field evidence for maize-mycorrhiza interactions in agroecosystems with low and high P soils under mineral and organic fertilization. *Applied Soil Ecology*, *149*(103511), 1-8. https://doi.org/10.1016/j.apsoil.2020.103511

Sahain, M. F., El-Motty, E. Z. A., El-Shiekh, M. H., & Hagagg, L. F. (2007). Effect of some biostimulant on growth and fruiting of Anna apple trees in newly reclaimed areas. *Research Journal of Agriculture and Biological Sciences*, *3*(5), 422-429. http://www.aensiweb.net/AENSIWEB/rjabs/rjabs/2007/422-429.pdf [2021-09-01]

Sales, B. K., Bryla, D. R., Trippe, K. M., Weiland, J. E., Scagel, C. F., Strik, B. C., & Sullivan, D. M. (2020). Amending sandy soil with biochar promotes plant growth and root colonization by mycorrhizal fungi in highbush blueberry. *HortScience*, *55*(3), 353-361. https://doi.org/10.21273/HORTSCI14542-19

Schröder, J.J., Cordell, D., Smit, A.L. & Rosemarin, A. (2010). *Sustainable use of phosphorus, EU tender ENV.B1/ETU/2009/0025*. (357). Wageningen: *Plant Research International, 357*. https://library.wur.nl/WebQuery/wurpubs/reports/404463 [2021-09-01]

Schulte, L. A., Niemi, J., Helmers, M. J., Liebman, M., Arbuckle, J. G., James, D. E., Kolka, R. K., O'Neal, M. E., Tomer, M. D., Tyndall, J. C., Asbjornsen, H., Drobney, P., Neal, J., Van Ryswyk, G. & Witte, C. (2017). Prairie strips improve biodiversity and the delivery of multiple ecosystem services from corn-soybean croplands. *Proceedings of the National Academy of Sciences*, *114*(42), 11247-11252. https://doi.org/10.1073/pnas.1620229114

Shin, K., van Diepen, G., Blok, W., & van Bruggen, A. H. (2017). Variability of Effective Micro-organisms (EM) in bokashi and soil and effects on soil-borne plant pathogens. *Crop Protection*, *99*, 168-176. https://doi.org/10.1016/j.cropro.2017.05.025

Smith, J. A., Jarman, M. & Osborn, M. (1999) Doing Interpretative Phenomenological Analysis. In: Murray, M. & Chamberlain, K. (eds.) *Qualitative health psychology: theories and minds*. Thousand Oaks: Sage Publications, 218-240.

https://uk.sagepub.com/en-gb/eur/qualitative-health-psychology/book206332#description [2021-09-01]

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science, 347*(6223), 736. https://doi.org/10.1126/science.1259855

Sutton, M. A., Oenema, O., Erisman, J. W., Leip, A., van Grinsven, H., & Winiwarter, W. (2011). Too much of a good thing. *Nature*, *472*, 159-161. https://doi.org/10.1038/472159a

Tasin, M. (2018). Introduction to Agroecology Basics [Unpublished presentation]. Swedish University of Agricultural Science, Alnarp. Faculty of Landscape Architecture, Horticulture and Crop Production Science. Department of Plant Protection Biology.

Tayibi, H., Choura, M., López, F. A., Alguacil, F. J. & López-Delgado, A. (2009). Environmental Impact and Management of Phosphogypsum. *Journal of Environmental Management, 90*(8), 2377–2386. https://doi.org/10.1016/j.jenvman.2009.03.007

Tittonell, P. (2014). Ecological intensification of agriculture—sustainable by nature. *Current Opinion in Environmental Sustainability, 8*, 53-61. https://doi.org/10.1016/j.cosust.2014.08.006

Velthof, G. L., Lesschen, J. P., Webb, J., Pietrzak, S., Miatkowski, Z., Pinto, M., Kros, J. & Oenema, O. (2014). The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2000-2008. *Science of the Total Environment, 468*, 1225-1233. https://doi.org/10.1016/j.scitotenv.2013.04.058

Vincent, Q., Auclerc, A., Beguiristain, T., & Leyval, C. (2018). Assessment of derelict soil quality: Abiotic, biotic and functional approaches. *Science of the Total Environment, 613*, 990-1002. https://doi.org/10.1016/j.scitotenv.2017.09.118

Weikard, H. P., & Seyhan, D. (2009). Distribution of phosphorus resources between rich and poor countries: the effect of recycling. *Ecological economics, 68*(6), 1749-1755. https://doi.org/10.1016/j.ecolecon.2008.11.006

Xiaohou, S., Min, T., Ping, J., & Weiling, C. (2008). Effect of EM Bokashi application on control of secondary soil salinization. *Water Science and Engineering*, *1*(4), 99-106. https://doi.org/10.3882/j.issn.1674-2370.2008.04.011

Yakhin, O. I., Lubyanov, A. A., Yakhin, I. A., & Brown, P. H. (2017). Biostimulants in plant science: a global perspective. *Frontiers in plant science*, *7*(2049), 1-32. https://doi.org/10.3389/fpls.2016.02049

Yamakura, T., & Sahunalu, P. (1990). Soil carbon/nitrogen ratio as a site quality index for some South-east Asian forests. *Journal of Tropical Ecology, 6*(3), 371-377. https://doi.org/10.1017/S0266467400004661

Zhang, J., Jiang, J., & Tian, G. (2016). The potential of fertilizer management for reducing nitrous oxide emissions in the cleaner production of bamboo in China. *Journal of Cleaner Production, 112*(4), 2536-2544. https://doi.org/10.1016/j.jclepro.2015.10.086

Acknowledgments

Many deserve recognition and appreciation for their support, which significantly contributed to my writing process for this thesis. Firstly, I would like to thank my supervisor Jean Yong for leading me into the study field of biostimulants with a lot of patience and sympathy. To the same extent, I am thankful to my co-supervisor Anna María Pálsdottír for giving me guidance on conducting social studies like interviews and analyzing qualitative data. Additional thanks to Georg Carlsson, my thesis course and study program coordinator, for his support. And thanks goes as well to Raj Chongtham for examining my work.

I would also like to thank my peers, because as Isaac Newton said, "If I have seen further it is by standing on the shoulders of Giants"[1]. Without their work, there would not be this comprehensive selection of papers in the literature review.

Finally, this thesis would not have been possible without the farmers taking the time out of their busy schedules to participate in the interviews. I am thankful for your openness and honesty, for sharing your passion and experiences with me, and for making me feel welcome. So, I am also grateful to Jürgen Bennighoven, Armin Meitzler, Michael Reber, Katharina Schödl-Hummel , Franz Steininger, Franz Tschiggerl and the other participants for helping me with their expertise on the practical usage of EM.

Tania Schwarzer, June 2022

[1] Newton, I. (1961). 420 Newton to Pepys. In: Turnbull, H. W. (ed) *The correspondence of Isaac Newton 1688-1694*. Vol. 3, London: Cambridge University Press, 420.

Appendix

Figure 1. Means of Contacting and Response Rate

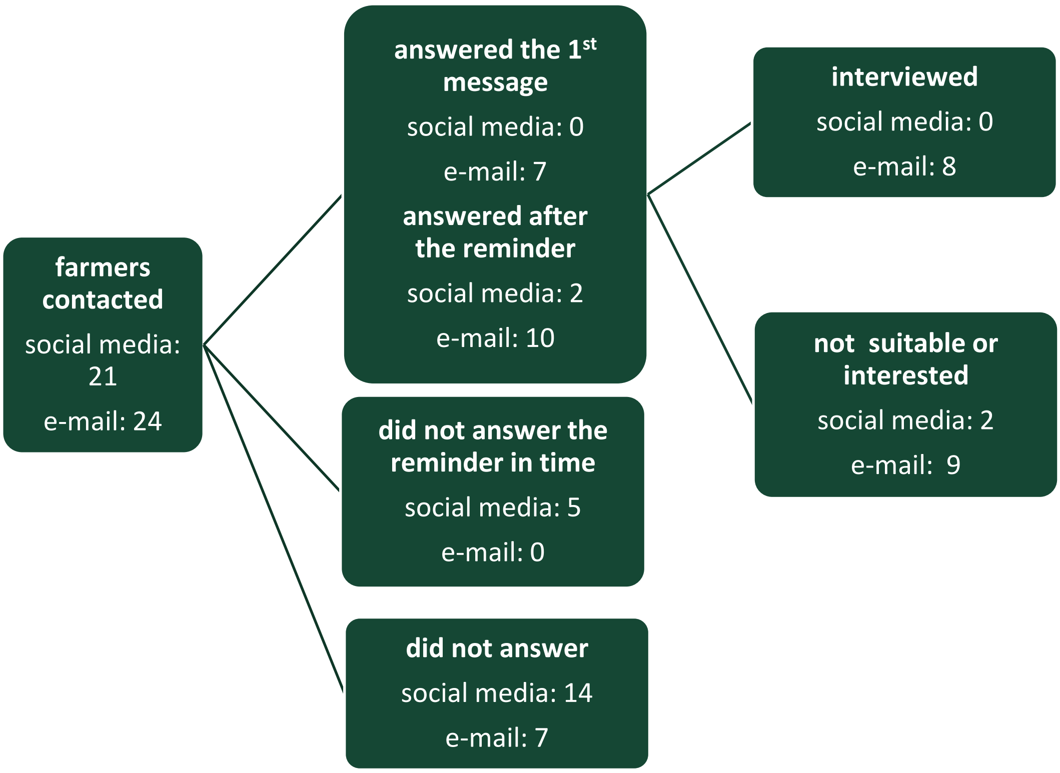

Table 1. Interview Duration and Type

Interview Code	Duration	Interview Type
Interview 1	29	Phone call
Interview 2	22	Video call
Interview 3	28	Video call
Interview 4	50	Phone call
Interview 5	43	Phone call
Interview 6	18	Phone call
Interview 7	52	Video call
Interview 8	43	Phone call

Table 2. Question Guide

Main Questions	Additional Questions
Can you briefly describe how you use EM in your farming business?	What form do you apply EM as? How do you determine the amount and timing of the application? How do you make sure the product/process is optimal for your conditions?
How do you obtain your EM?	How and why did you decide on that product? From which producer do you obtain your EM? What are your thoughts on the self-multiplication of EM?
What changes occurred since applying EM?	Which inputs or processes could you replace? How have EM changed your farm management? What advantages do you see in the application of EM (compared to other inputs)? How did your work change? Regarding workload? Regarding work safety? How has the cost structure changed? - How have the yields, crop quality, and season changed? - How have the losses due to diseases, pests, and climatic stress changed? - What investments are necessary?
What were the short-term effects? What changes occurred after long-term application?	How long have you been using EM? How has your application process changed since the beginning?
Why did you start using EM? What do you envision as a successful application of EM?	What expectations do you have regarding the application of EM? How do you measure success? What setbacks have you had? Could you elaborate on those? What importance do EM have for your farming business? What area of application is most important to you and why?
How do you communicate with other stakeholders?	How did you find out about EM? How is your usage of EM different from other farmers?
What is your vision for the future?	Where do you still see potential?
What else would you have liked to be asked?	What would your answer be?

Fact Sheet:

Assessment of the agroecological potential of biostimulatory effects originating from

Effective Microorganisms

in terms of environmental and socioeconomic aspects

In Germany and Austria there are farmers that use effective microorganisms (EM) to benefit their farming in multiple ways. Eight of these pioneers have been interviewed to assess if the biostimulatory effects described in literature can be achieved in practice and to collect information on potential socioeconomic effects.

Effective Microorganisms (EM) are a consortium of microorganisms, which positively influence the decomposition of organic matter and create a favourable environment for plants, promoting their health and growth by stimulating physiological processes, including the efficiency of photosynthetic and stress resistance pathways.

Biostimulants are "materials that contain one or more substances and/or microorganisms able to stimulate nutrient uptake and use efficiency by plants, increase plant tolerance to abiotic/biotic stress and improve crop quality when applied in small amounts" (Nardi et al. 2016)

Main findings:

- Due to the novelty of the practice, EM require:
    - experience, knowledge, monitoring, trials
    - farmer-to-farmer contact
    - inclusion of practitioners in EM product development
    - contact and support from academia and official associations, which is lacking
- Regarding application:
    - ready-made and stock solutions are preferred
    - timing depends on purpose, state and growth stage of the crop
    - favourably in susceptible, special, high-risk and niche crops and proactive, since EM preoccupy and compete for resources with other microorganisms
    - limited by input costs, increased labour, climatic conditions, and integration with other work processes and farming inputs, but facilitated by their non-toxicity
- Regarding their effects, EM:
    - positively interact with naturally occurring beneficial microorganisms inter alias stimulating the production of biostimulants
    - optimise/ reduce synthetic fertilizer application and make organic fertilizer competitive by improving the timing due to accelerated decomposition
    - strengthen the plant's resistance to extreme weather conditions, as well as pests and disease, causing savings on pesticides
- Resulting socioeconomic effects
    - diversification of cultivation
    - increased economic returns are possible due to reduced losses and improved input efficiency as well as increased yield, crop quality, earlier bloom, and non-toxicity
    - promoted use of local resources
    - EM draw the consumer's attention, and the application of EM often comes with an understanding of responsibility by the producers

Overall,

EM create a healthier environment. The practice of applying EM can function as a climate change adaptation strategy by increasing the plant's abiotic and biotic stress resistance as well as a mitigation strategy by reducing the emissions and pollution related to farming inputs. Further, the economic risk-resilience of farming businesses is strengthened due to the increased self-sufficiency. These effects reflect the agroecological principles and positively influence food security, safety and sovereignty.

Degree project by
Tania Schwarzer
Agroecology -Master's Programme
Alnarp 2022
Swedish University of
Agricultural Science

Faktenblatt:

Einschätzung des agrarökologischen Potenzials der Biostimulanzeffekte von

Effektive Mikroorganismen

in Bezug auf Umwelt und sozioökonomische Aspekte

Effektive Mikroorganismen (EM) sind ein Konsortium von Mikroorganismen, welche die Zersetzung organischer Stoffe positiv beeinflussen und ein günstiges Umfeld für Pflanzen schaffen, indem sie deren Gesundheit und Wachstum durch die Stimulierung physiologischer Prozesse fördern, einschließlich der Effizienz von Abläufen der Photosynthese und Stress-resistenz.

Biostimulanzien sind "Materialien, die einen oder mehrere Stoffe und/oder Mikroorganismen enthalten, die in der Lage sind, die Nährstoffaufnahme und -verwertung durch Pflanzen zu stimulieren, die Pflanzentoleranz gegenüber abiotischem/biotischem Stress zu erhöhen und die Pflanzenqualität zu verbessern, wenn sie in kleinen Mengen angewendet werden" (Nardi et al. 2016).

In Deutschland und Österreich gibt es Landwirte, die effektive Mikroorganismen (EM) einsetzen, um ihre Landwirtschaft auf vielfältige Weise zu verbessern. Acht dieser Pioniere wurden befragt, um zu beurteilen, ob die in der Literatur beschriebenen biostimulierenden Effekte in der Praxis erzielt werden können, und um Informationen über mögliche sozioökonomische Auswirkungen zu sammeln.

Wichtigste Ergebnisse:

- Aufgrund der Neuartigkeit der Praxis erfordern EM:
  - Erfahrung, Wissen, Monitoring, Versuche
  - Kontakt zwischen Landwirten
  - Einbeziehung von Praktikern in die EM-Produktentwicklung
  - Kontakte und Unterstützung durch die Wissenschaft und offizielle Verbände, die fehlen
- Bezüglich der Anwendung:
  - Fertig- und Stammlösungen werden bevorzugt
  - der Zeitpunkt hängt vom Zweck, Zustand und Wachstumsstadium der Kultur ab
  - vorteilhaft in anfälligen, Sonder-, Risiko- und Nischenkulturen
  - und proaktiv, da EM andere Mikroorganismen verdrängen, mit ihnen um Ressourcen konkurrieren
  - begrenzt durch Input-Kosten, erhöhten Arbeitsaufwand, klimatische Bedingungen und Integration mit anderen Arbeitsabläufen und landwirtschaftlichen Betriebsmitteln, aber begünstigt durch ihre Ungiftigkeit
- Was ihre Wirkungen betrifft, so wirken EM:
  - Interagieren positiv mit natürlich vorkommenden nützlichen Mikroorganismen und stimulieren unter anderem die Produktion von Biostimulanzien
  - optimieren/verringern den Einsatz synthetischer Düngemittel und machen organische Düngemittel wettbewerbsfähig, indem sie das Timing aufgrund der beschleunigten Zersetzung verbessern
  - stärken die Widerstandsfähigkeit der Pflanzen gegenüber extremen Witterungsbedingungen sowie Schädlingen und Krankheiten, was zu Einsparungen von Pestiziden führt
- Resultierende sozioökonomische Auswirkungen
  - Diversifizierung des Anbaus
  - Erhöhter Gewinn ist möglich aufgrund geringerer Verluste und verbesserter Effizienz der Betriebsmittel sowie höherer Erträge, besserer Pflanzenqualität, früherer Blüte und Ungiftigkeit
  - Förderung der Nutzung lokaler Ressourcen
  - EM lenken die Aufmerksamkeit der Verbraucher auf sich, und die Anwendung von EM geht oft mit einem Verantwortungsbewusstsein der Erzeuger einher

Insgesamt, schaffen EM eine gesündere Umwelt. Die Anwendung von EM kann als Anpassungsstrategie an den Klimawandel fungieren, indem sie die abiotische und biotische Stressresistenz der Pflanzen erhöht, sowie als Minderungsstrategie, indem sie die Emissionen und die Verschmutzung durch landwirtschaftliche Betriebsmittel reduziert. Darüber hinaus wird die Widerstandsfähigkeit landwirtschaftlicher Betriebe gegenüber wirtschaftlichen Risiken durch die erhöhte Selbstversorgung gestärkt. Diese Effekte spiegeln die agrarökologischen Grundsätze wider und wirken sich positiv auf die Ernährungssicherheit und -souveränität aus.

Abschlussarbeit von Tania Schwarzer

Agroecology -Master's Programme Alnarp 2022

Swedish University of Agricultural Science