Reducing intentionally added microplastics in the Dutch Agricultural Innovation System

A contribution to mitigate plastic pollution?

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Abstract

The agricultural sector plays an important role in global food supply, but is also a major source of plastic pollution, for example via intentionally added microplastics (IAMPs) in fertilizers. A potential human health risk may exist as micro- and nanoplastics can be taken up by crops and eventually end up on our plate. Therefore, health risk experts have called to act based on the precautionary principle and reduce plastic use. Hence, more research regarding reduction of plastic by the agricultural sector is needed. This explorative study investigates the factors that influence the willingness to change of stakeholders in the Dutch Agricultural Innovation System (AIS) and what is needed to achieve an efficient reduction of IAMPs in the Dutch AIS. Following an extended version of the Theory of Planned Behavior (TPB), with the additional factors *awareness* and *risk perception*, the awareness and willingness to change of various stakeholder groups were tested. Because these factors differ extremely between and within stakeholder groups, a combination of policy instruments and reduction behavior of relevant stakeholders is required to realize an efficient reduction. Efficient policy methods should entail a mix of regulations and stimulating instruments, e.g. subsidies. An increase of willingness to change should be primarily accomplished in the most powerful stakeholder groups: Policy NL, Fertilizer producers, and Purchasers of output farmers. This can be achieved by acquiring more scientific evidence regarding health risks and a wide information distribution to all stakeholders, which can influence awareness and consequently willingness to change. Future research should focus on including more and diverse stakeholder representatives and include the Purchasers of output farmers stakeholder group.

Keywords: Theory of Planned Behavior (TPB), stakeholder analysis, micro- and nanoplastics, agriculture, fertilizer, awareness, willingness to change.

PLASTIC SOUP FOUNDATION

Radboud University

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Relevant abbreviations

IAMPs = Intentionally Added Microplastics

AIS = Agricultural Innovation System

TPB = Theory of Planned Behavior

SDGs = Sustainable Development Goals

CRFs = Controlled Release Formulations/Fertilizers

FAs = Fertilizer Additives

ECHA = European Chemicals Agency

EU = European Union

LNV = Ministry of Agriculture, Nature and Food Quality

NGOs = Non-Governmental Organizations

SABE regulation = Subsidy for sustainable agriculture; *in Dutch*: Subsidiemodule Agrarische Bedrijfsadvisering en Educatie regeling

Abbreviations used in the stakeholder overview can be found in Appendix C.

Executive summary

Background: The agricultural sector is not only immensely important as global food supplier, but also a major source of plastic pollution. Plastic is an inert material which can now be found all over the world, due to an increased use and waste mismanagement. The agricultural sector contributes worldwide to plastic pollution, largely via mulch, sludge, and the use of intentionally added microplastics (IAMPs), mostly fertilizers, in agricultural supplies. The small micro- and nanoplastics can end up in the environment or can be taken up by crops and distributed to the fruits and leaves. Significant human health risks have not been demonstrated yet, but clues regarding potential negative effects are shown and experts call to act based on the precautionary principle. Therefore, more research regarding a reduction of plastic is needed. This explorative study focused on agricultural supplies in the Netherlands. The exact emission of IAMPs by agricultural supplies in the Dutch agricultural sector is not known, although estimations and calculations were made in this study. In line with the precautionary principle and potential high emission numbers by the agricultural sector, a reduction of plastics by the agricultural sector was examined in this study. Factors that influence the willingness to change of stakeholders in the Dutch Agricultural Innovation System (AIS) were explored to investigate what is needed to achieve an efficient reduction of IAMPs in the Dutch AIS. **Objective and research questions:** The overall objective of this study is *To understand the dynamics towards a reduction of intentionally added microplastics (IAMPs) in the Dutch Agricultural Innovation System (AIS) by analyzing the factors that influence a change among stakeholders.* Subsequently, four research questions were formulated: 1) Who are the actors (stakeholders) involved in the use of IAMPs in the Dutch Agricultural Innovation System? 2) How is the awareness of the different stakeholder groups concerning the presence and the consequences of IAMPs in agricultural supplies? 3) What are the factors that influence the willingness to change towards the use of IAMPs in the Dutch Agricultural Innovation System and how do they differ between the stakeholders? 4) Under which conditions can a reduction of IAMPs use in the Dutch Agricultural Innovation System be efficiently realized? **Methodology:** This study used a stakeholder analysis and an extended version of the Theory of Planned Behavior (TPB) as theoretical framework to analyze the willingness to change/intention of the different stakeholders. Semi-structured interviews (n=15) were conducted with representatives of eight of the thirteen identified different stakeholder groups; i.e. Policy Netherlands (NL), Fertilizer producers, Fertilizer buyers, Farmers, Consumers, Sector organizations, Education, and Controlling institutions. The components that influence the willingness to change according to the theoretical framework are: attitude (which is influenced by risk perception and awareness), social norms, and perceived behavior control. Therefore, these factors were tested in various stakeholder groups. **Results:** Concerning the use of IAMPs, various stakeholders were involved in the Dutch AIS, and were categorized in thirteen stakeholder groups. These were: Policy NL/EU*, Fertilizer producers*, Fertilizer buyers*, Farmers*, Purchasers of output farmers, Consumers*, Sector organizations*, Advisors, Research, Nature organizations, Education*, Controlling institutions*, and Media. Groups indicated with an asterisk were included in this study. The level of awareness regarding the presence of IAMPs in agricultural supplies was *low* for Controlling institutions, Farmers, and Consumers, *middle* for Policy NL and Fertilizer buyers, and *high* for the Fertilizer producers. The level of awareness regarding the consequences of IAMPs in agricultural supplies was *middle* for Policy NL and Fertilizer buyers and *high* for Fertilizer producers. With regards to determining the willingness to change, the most remarkable differences were found in the attitude component within and between stakeholder groups, and this component was the key variable. The component attitude can be influenced by various factors, among which awareness and risk perception played a major role. To realize an efficient reduction of the use of IAMPs in the Dutch AIS, various factors and conditions should be improved. A combination of policy instruments and a change in behavior of the stakeholders is required. Therefore, higher levels of willingness to change of all stakeholders should be realized, with a specific focus on the most powerful stakeholder groups: Policy NL/EU, Fertilizer producers, and Purchasers of output farmers. More scientific evidence regarding potential human health risks or other consequences (e.g., soil quality) and independent distribution of this information will influence the awareness of the stakeholders and therefore attitude and eventually willingness to change. Due to market forces a reduction cannot easily be achieved by only behavioral changes of some stakeholders. Policy

instruments can tackle other additional factors that (apart from willingness to change) induce an IAMPs reduction, for example subsidies for farmers who use less or no fertilizer, or stimulation of development of alternatives without IAMPs. Furthermore, an EU-wide (or even global) uniform definition of microplastics should be established for consistent research and a reliable enforcement of upcoming restriction policies.
Discussion: This study is the first to investigate the awareness and willingness to change of different stakeholders in the Dutch AIS regarding using IAMPs in agricultural supplies. There are some different views between stakeholders on the Dutch emission numbers regarding IAMPs; therefore, further specification is needed to map the problem. The use of this extended version of the TPB was in general helpful as theoretical framework for this explorative study; however, to further understand the willingness to change for this specific topic an even more detailed, extensive version of the TPB should be used. The factor awareness should have a bigger role in that theoretical framework since this factor influences attitude in different ways. More scientific evidence is expected to influence awareness levels in a powerful way and therefore contribute to a change in behavior. However, during this study, it became clear that higher awareness levels of the potential consequences of IAMPs do not by definition result in a higher willingness to change and reduction behavior, as can be seen for the Fertilizer producers. Economic risks and other economic factors were also a key factor in reduction behavior. Additionally, the attitude of individuals regarding hazard and risk differed. To influence the willingness to change of different stakeholders, it is recommended to apply different approaches. Further research can elaborate on which approaches will be the most efficient for the different stakeholders. Due to the explorative nature of this study, not all interviewed stakeholder groups contained multiple representatives and not all relevant stakeholder groups were interviewed. It is recommended to include all stakeholder groups and more representatives in further research, which will increase the validity and reliability of the findings. Lastly, further research should specifically focus on the Purchasers of output farmers stakeholder group.

Preface

Dear reader,

The completion of this research project and thesis contributes to the accomplishment of my master Medical Biology, specialization in Science, Management & Innovation. The decision to go for a more social science direction has turned out to be a very interesting one. Performing this research project has taught me many new insights and experiences that can help me in future cases and places, for example my required interview and analytical skills. Due to my previous literature review thesis regarding the uptake of microplastics in the human gastro intestinal tract, my interest in and fascination for micro- and nanoplastics increased. Therefore, I contacted the Plastic Soup Foundation (PSF) for a possible collaboration research project and that worked out!

I would like to take this opportunity to thank Carlos Barzola Iza, supervisor of the Radboud University and the SMI specialization, for the constructive feedback and supervision during the research project. Especially the beginning of the project was a bit challenging when the whole research needed to be designed from scratch. I appreciated our hybrid way of communicating, despite the pandemic we also had some physical meetings. And of course the opportunity to borrow your voice recorder when the impossible incident happened and 2 hours of interviews were lost.. Fortunately this didn't happen again.

Additionally, I would like to thank Sophie Vonk, my supervisor at Plastic Soup Foundation. Although the social sciences were a new discipline for both of us, I would like to thank Sophie for discovering this new world together with me. I appreciate our meetings together, which were serious but also fun, and the extensive feedback. I really had a great and very interesting time in Amsterdam, once a week at the office of PSF, but also at several events like World Cleanup Day and The Plastic Health Summit. Also the team and RAS meetings were very interesting, I really got to know the organization and the various developments regarding (micro)plastics on scientific and political level. I would also like to thank the other colleagues at PSF, especially some from the RAS team who also reviewed parts of my thesis.

Furthermore, I would like to thank my peers, friends, and parents who helped me with brainstorming about difficult choices or approaches during the research and their support throughout the project.

Last but not least, I would like to thank all interviewees that participated in this study for the very interesting and nice conversations we had. I learned a lot and appreciated the flexibility of everyone. Some interviews could even be conducted physically, which I really enjoyed and resulted sometimes to some interesting adventures.

Hereby, I proudly present my graduation thesis called *Reducing intentionally added microplastics in the Dutch Agricultural Innovation System*. A great conclusion of this master and my time as a student, let's see what the future may bring.
Enjoy reading it!

Marina Bool

Nijmegen, 14th of December 2021

Introduction

Background, problem, and relevance

According to the Food and Agriculture Organization of the United Nations, the agricultural sector is immensely important in providing people with food [1]. However, the agricultural and horticultural sector is also a major source of plastic pollution [2]. The use of plastic has increased for the past fifty years and this inert material can now be found all over the world [3, 4], for example at an untouched alpine area [5]. Since this synthetic material is extremely persistent and can hardly be removed, it stays in the environment if not managed correctly [2].

The United Nations global Sustainable Development Goals (SDGs) aims to achieve peace and prosperity in 2030 for a sustainable planet and all its residents [6]. This research is in line with: SDG 2 regarding sustainable agriculture; SDG 3 for good health and well-being; SDG 12 with responsible consumption and production; SDG 14 by limiting plastic marine pollution, and SDG 15 a sustainable use of terrestrial ecosystems. Additionally, plastics contribute directly to climate change as well [7]; therefore, SDG 13, take action on climate change, is also addressed by this research. The contribution to the various SDGs demonstrates the relevance of this study on a global level.

Products used in the agricultural sector can contain plastics (like plastic mulch, sludge, and fertilizers) and due to the direct application of these products to the soil, a 100% dispersion of the product into the environment is created [2]. Therefore, the agricultural sector provides a large contribution to plastic pollution in our environment [2]. Plastics from this sector end up in the environment via ditches, channels, rivers and oceans, or the particles remain in the soil [8]. Subsequently, the small plastic particles from the products can be taken up by crops and transported to the leaves and fruits [9, 10], migrating into the food chain and potentially ending up on our plate and in our body. It has even been shown that humans consume the most plastic particles via ingestion of food and drinks [11]. Cox et al. have shown specific numbers regarding human consumption of microplastic particles and exposure, and they even mention their numbers are likely underestimates [12].

Although significant health risks are not demonstrated yet, potential health effects are mentioned by multiple experts [13-17], and include inflammation reactions, apoptosis, oxidative stress, and immune responses. Plastic particles can also contain toxic chemical additives and interact with chemicals around them, these toxic additives can later disintegrate from the plastic and infiltrate the (new) environment [16]. Furthermore, an interaction of plastic particles with human pathogens in the soil has been shown [18]. In addition, recent studies showed that shoot and root growth of wheat plants is negatively influenced by microplastics of ≤ 4 mm in the soil [19], which impacts plant growth and development. This likely also reduces the crop yield and can pose a risk to food scarcity. Altogether, this results in a concerning problem to society, regarding environment, food safety, and (human) health. This problem is not isolated to the Netherlands, but is present worldwide. Due to all (potential health) risks, experts encourage globally to act based on the precautionary principle [20, 21]. There is a broad discussion about the negative impact of (micro)plastic use, which calls for more research towards plastic reduction in the agricultural sector.

The focus in this research is solely on the use of agricultural supplies, specifically inorganic fertilizers, with intentionally added microplastics (IAMPs) in the Netherlands. These plastic particles have a size in the micro and probably also nano range. In the agricultural sector, IAMPs are used in specific fertilizers (controlled-release formulations (CRFs)), as anti-caking agent in fertilizer (as fertilizer additives (FAs)), plant protection products (e.g. seed coating), and as soil conditioner [2]. Compost, wherein unintentional plastics can be present, will not be included in this research. Also, sludge/biosolids and plastic mulch are neither part of this study. Sludge contains no intentionally added plastics and is also not used in the Dutch agriculture as fertilizer [22]. Additionally, a study in Germany showed 19% of plastic emission by the agricultural sector is caused by direct application of agricultural supplies, of which almost 70% corresponds with emission by fertilizers [23]. Furthermore, the largest part of IAMPs emission in the European agricultural sector is by CRFs and FAs [24]; therefore, this research focusses solely on fertilizers, and consequently CRFs and FAs. The IAMPs in CRFs and FAs are, or can eventually degrade into, plastic particles in the submicro and nano range. Only one study has managed to measure nanoplastics in soil, as

these are hard to detect and soil analysis do not correctly reflect the amount of small plastic particles in the environment [25, 26]. In addition to that, nanoplastics are probably taken up more easily than microplastics [2] and are hypothesized to pose a greater risk to the environment and human health.

The emission of IAMPs by agricultural supplies is only known on European level [24], not in the Netherlands specifically. As became clear from questions in the Dutch parliament, the Dutch minister of LNV (Ministry of Agriculture, Nature and Food Quality) is not familiar with the Dutch emission numbers by IAMPs and not aware of the magnitude of this problem [27]. The number of plastics in the Dutch soil from these sources could be high and consequently associated risks could be serious. Therefore, the magnitude of the problem in the Netherlands should be specified. Additionally, in line with the precautionary principle and potential high emission numbers by the agricultural sector, a reduction of plastic emission by the agricultural sector should be examined.

The Dutch agricultural sector can be seen as a value network of interacting actors, leading to using the 'Dutch Agricultural Innovation System (AIS)' to investigate the Dutch agricultural sector in this study. A reduction can be realized in various ways, for example by a change in behavior of relevant stakeholders and accompanying political measures. Despite the concerns regarding the negative effects of IAMPs in agricultural supplies, little is known regarding the factors influencing a behavioral change towards the reduction of microplastic use in the Dutch AIS. Therefore, it should be investigated which factors are important for the direct stakeholders and how they can attribute to a behavioral change that will contribute to a reduction of IAMPs. This research used an extension on the Theory of Planned Behavior [28] to determine the factors that influence the willingness to change of stakeholders in the Dutch AIS regarding a reduction of IAMPs and investigated which factors can contribute to an efficient reduction of IAMPs in the Dutch agricultural sector. In this way, this explorative study provides insight into the factors that influence stakeholders' willingness to change and need to be considered when formulating and implementing plastic reduction measures.

Research project

This explorative study sheds light on IAMPs use in the Dutch AIS and the factors that influence the willingness to change of the relevant stakeholders.

Research objectives

General objective: To understand the dynamics towards a reduction of intentionally added microplastics (IAMPs) in the Dutch Agricultural Innovation System (AIS) by analyzing the factors that influence a change among stakeholders.

- To identify the factors that influence the use of IAMPs in the Dutch AIS.
- To understand the stakeholders' awareness on the use of IAMPs in the Dutch AIS.
- To understand the willingness to change by the stakeholders towards the reduction of IAMPs in the Dutch AIS.

Research questions

RQ1. Who are the actors (stakeholders) involved in the use of IAMPs in the Dutch AIS?
RQ2. How is the awareness of the different stakeholder groups concerning the presence and the consequences of IAMPs in agricultural supplies?
RQ3. What are the factors that influence the willingness to change towards the use of IAMPs in the Dutch AIS and how do they differ between the stakeholders?
RQ4. Under which conditions can a reduction of IAMPs use in the Dutch AIS be efficiently realized?

To answer RQ1, RQ2, RQ3, and RQ4, this research followed a stakeholder analysis methodology. Qualitative Data was collected via semi-structured interviews by using a case study approach [29]. The case study for this research corresponded to the use and production of inorganic fertilizers in the Dutch AIS.

To answer RQ1, the stakeholder analysis started with the identification of the stakeholders in the Dutch AIS. This RQ led to an overview of all stakeholders involved in the use of IAMPs in the Dutch AIS.

To answer RQ2, a theoretical framework on stakeholder awareness towards IAMPs was proposed as a theoretical lens. RQ2 provided an overview regarding the awareness of the stakeholders concerning the presence and consequences of IAMPs in agricultural supplies.

To answer RQ3, a theoretical framework on stakeholders' willingness to change was proposed. This RQ showed the different factors that influence the willingness to change and how these factors will differ between the various stakeholders.

Finally, to answer RQ4 the answers from RQ1, RQ2, and RQ3 were integrated to understand the dynamics towards the reduction of IAMPs use in the Dutch AIS. RQ4 presented the factors that should be taken into account to achieve an efficient reduction of IAMPs in the Dutch AIS.

In conclusion, this thesis provides insight into the factors that influence the willingness to change of stakeholders in the Dutch AIS and need to be considered when formulating and implementing plastic reduction measures. Additionally, specific recommendations for the host organization are proposed.

Host organization

The Plastic Soup Foundation (PSF) is a Dutch, but fully international-oriented, non-profit, non-governmental organization that focusses solely on plastics. The current slogan of the organization states the following: 'No plastic in our water and in our bodies'. The PSF combats the growing plastic soup and keeps an eye on the potential health effects. Plastic pollution is internationally recognized as one of the world's worst environmental problems and a global growing danger. Plastic can degrade in smaller and smaller pieces, called micro- and nanoplastics, to which we are constantly exposed via air, water, and food. The PSF also operates by the precautionary principle. Although not all consequences of plastics in our body are known yet, the number of indications regarding potential harmful health effects and other negative effects is growing. Therefore, a general global reduction of plastic (waste) is needed [30].

Within the PSF I am based within the Research, Advocacy & Solutions unit, the RAS-unit. This unit tries to combat plastic pollution through a science-based approach. They concentrate on scientific studies, advocacy and how innovations can improve the situation.

This research project will be linked to a collaboration project between the RAS-unit and Wageningen University and Research (WUR) called *Plastic Food*. The collaboration project focusses on the use of plastics in Dutch agriculture and aims to put this increasing problem of micro- and nanoplastic pollution on the agenda. In the project samples of soil, water, and air will be taken in different parts of the Netherlands from farms that use compost, plastic mulch, or do not use plastics. All samples will be analyzed for the number of plastic particles, but also for polymer type and size. In this way the contribution of different agricultural supplies (compost and plastic mulch) on the plastic pollution will be made visible.

Outline

This explorative research first covers an extensive literature study to provide more information regarding plastics, inorganic fertilizers, plastic emission, and (current) rules and regulations on this topic. Subsequently, this information will be linked to the research and theoretical framework that discusses the factors that influence willingness to change. Additionally, the methodology of the research will be discussed, and how this will lead to answering the research questions. The results will be discussed in the order of the research questions, so first an overview of all stakeholders in the AIS will be presented. Subsequently, an overview of the awareness of the stakeholders on the presence and consequences of IAMPs in fertilizer will be demonstrated, followed by the factors that influence the willingness to change. Concluding, for RQ4 all acquired information will be combined and it will be discussed under which conditions, in line with the precautionary principle, reduction measures could be efficiently implemented. Eventually, limitations of this research and future suggestions will be formulated, followed by an overall conclusion of this research project and some recommendations for the host organization.

Literature and theoretical framework

Plastic

In general, plastics are a wide range of synthetic polymers produced from oil or gas [3, 31]. Due to recent innovations, various bio-based plastics are produced and developed [32]. The use and production of plastics has increased immensely over the past decades [3]. The most common types of plastics can be found in Table 1. Plastic ends up in the environment if not managed correctly. Macroplastics can degrade into smaller fragments, due to ultraviolet (UV) radiation and mechanical abrasion. Particles < 5 mm are generally called microplastics [33]. Nanoplastics are even smaller, i.e. particles ≤ 0.1 µm, so ≤ 100 nm [34]. Next to the breakdown of (macro)plastic in the environment to micro- and nanoplastics, micro- and nanoplastics are also intentionally produced and processed in products, for example in personal care products or cleaning products. Particles already manufactured at a microscopic size are called *primary* micro- and nanoplastics. Primary microplastics that are added intentionally to various products are called intentionally added microplastics (IAMPs). Particles derived from degradation by UV radiation and mechanical abrasion of macroplastics are called *secondary* micro- and nanoplastics [3, 35]. Plastic is an inert material, extremely resistant and microplastics can hardly be removed from the environment, posing plastic pollution as an environmental problem. It is often claimed bio-based plastics are pro-environmental, but these materials have to be evaluated critically [32].

In this research, the same definition for microplastics as the European Chemicals Agency (ECHA) proposes will be used: [microplastic means a material consisting of solid polymer-containing particles, to which additives or other substances may have been added, and where ≥ 1% w/w of particles have (i) all dimensions 0.1 µm ≤ x ≤ 5 mm, or (ii) for fibres, a length of 0.3 µm ≤ x ≤ 15 mm and length to diameter ratio of > 3.] [2]. As nanoplastics have a dimension < 0.1 µm [34, 36], these are not included in this study.

Primary plastics can be present in products used in agriculture, which have a 100% emission in the environment when applied [2]. This research will focus on CRFs and FAs, since these sources are the largest contributors in terms of annual plastic emissions by agricultural supplies with IAMPs. CRFs contribute for 12.500 tonnes per year and FAs 10.000 tonnes per year emission of polymeric material in the EU by the agricultural and horticultural sector. Together these sources contribute to 96% of the total emission of polymeric material by the European agricultural and horticultural sector (Figure 1) [24].

Table 1: Overview of most common types of plastics.

Plastic type	Abbreviation	Example product	Chemical formula
Polyethylene terephthalate	PET	Drinking water bottles	$[(CO)C_6H_4(CO_2CH_2CH_2O)]n$
High density polyethylene	HDPE	Shampoo bottles	$[CH_2–CH_2]n$
Low density polyethylene	LDPE	Sandwich bags	$[CH_2–CH_2]n$
Polyvinyl chloride	PVC	Pipe	$[CH_2–CHCl]n$
Polypropylene	PP	Cream containers	$[CH_2{=}CHCH_3]n$
Polystyrene	PS	Cutleries	$[CH_2{=}CHC_6H_5]n$
Polycarbonate	PC	Digital Versatile Disc (DVD)	$[(OC_6H_4)_2C(CH_3)_2CO]n$

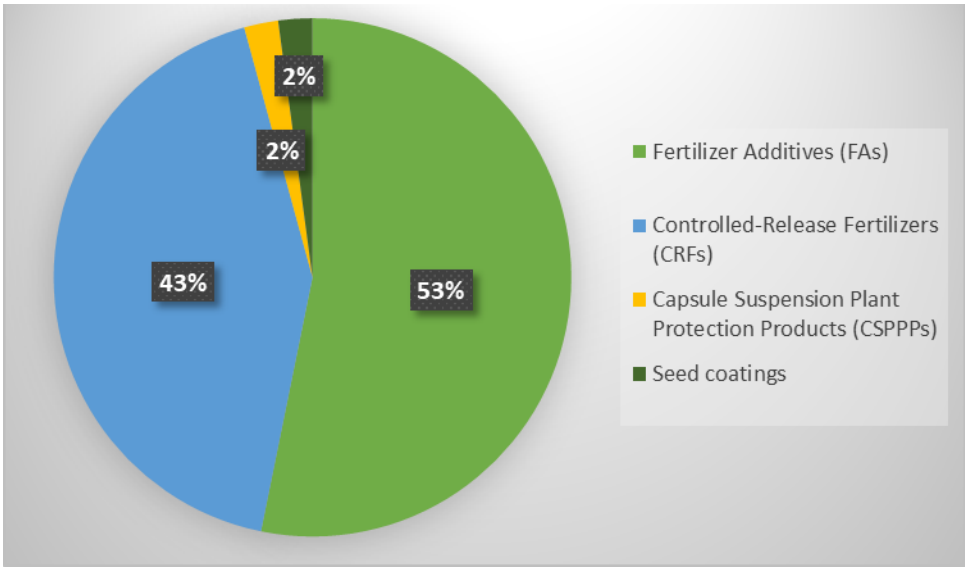

Figure 1: Estimated annual tonnage emission of polymeric material by agricultural supplies with IAMPs in the agricultural and horticultural sector in the EU (figure adapted from ECHA [24]).

Fertilizer

As the minerals a plant need for growth and development are not always present in the direct environment, extra nutrients can be added via organic/natural fertilizer (like manure or compost) or inorganic fertilizer (also called artificial, synthetic, or chemical fertilizer), this research will focus on the latter. Fertilizers are used to enrich the soil and promote plant growth, contributing to the improvement of crop yield. The macronutrients nitrogen (N), phosphorus (P), and potassium (K), often called NPK, are mainly used in fertilizers to provide plants with an extra nutrient boost. Fertilizers can be straight with only one nutrient, or heterogenous with multi-nutrients, like NPK. The most common used fertilizer is fertilizer with urea. However, there is a limitation to the conventional inorganic fertilizers: nutrients and energy could get lost. Due to inefficient uptake, the nutrients can leak into the environment, which can lead to concentration variations and potential toxicity for the plants. This results in the need for periodic dosing, which can be achieved by gradually released nutrients.

Controlled Release Fertilizers

Controlled Release Fertilizers (CRF) are fertilizers that gradually release their nutrients which is beneficial for the plant, since it will not get an overdose of the provided nutrients. CRF matches the growing need of the plant and releases only when the plant requires the nutrients. The gradually release rates are caused by the presence of a coating material surrounding the fertilizer. CRF is quite similar to Slow Release Fertilizer (SRF), although SRF does not depend on coating, but for example on long-chain molecules and delayed biodegradability [37]. The CRF release rates can vary per crop, per environment, and per period. This has led to the development of a wide variety in types CRFs. Strict criteria for release rates have been developed, but also for impact on the environment and sustainability. There are different ways to achieve the controlled-release function, e.g. by encapsulation, physical barrier, or chemical attachment [24].

The mechanism of release is by controlled diffusion [38]. The coating becomes moisturized, and vapor diffuses to the core through pores in the coating. The nutrients will dissolve, and an osmotic pressure is generated, which creates a continuous release of the nutrients. The function of the CRF can also be influenced by temperature, pH, ionic strength, granule radius, and coating thickness [39].

CRF has advantages, since it will save energy, time, and labor, due to single application. It results in higher plant quality and reduced toxicity for plants, increased nutrient efficiency, and less nutrient fixation [38, 39]. There are also some negative aspects of CRFs, for example the high material costs, which prevents broad-scale use of CRFs. Another negative aspect is the impact on the terrestrial environment like acidification of the soil [40]. Additionally, CRF users want the release of the nutrients to be as gradually as possible, but in the end the tailing effect comes into force, implying a too slow release at the last third or

quarter of the release period [41]. Moreover, they are difficult to coat, since P containing fertilizers consist often of irregular formed particles[42]. Therefore, not many controlled release P fertilizers are on the market yet.

Lastly, and most importantly for this study, the coating itself can form a problem. There are different types of coatings, for example based on inorganic materials, synthetic polymers, natural polymers or other organic materials, or mixes between various materials. The synthetic coating is hard to degrade and will stay in the environment. Since the synthetic polymeric materials are intentionally added to agricultural products, we can speak of primary microplastics. Especially if the release period is quite long, for example 6-12 months, it is necessary to use a coating material that will not degrade fast. Examples of synthetic polymer based coating materials are: polystyrene, polyethylene, polyurethane, polyether sulfone, polyolefins [43]. However, also biopolymers or biodegradable synthetic polymers can be used. This study focusses on synthetic polymers that will not degrade fast and stay in the environment, and can degrade into smaller micro- and nanoplastics.

Fertilizer Additives

Conditioning agents can be added to fertilizers to make sure the granules are preserved and to maintain a uniform application. Such fertilizer additives (FA) can be anti-caking agents, granulation and prilling aids, anti-dust agents, micronutrient binders, de-foaming aids, and coloring agents [24] (Table 2), or a combination of multiple additives.

Table 2: Overview of different fertilizer additives (FA) and their function and mechanism.

Fertilizer additives (FA)	Function	Mechanism
Anti-caking agents	Prevention of clumping of the fertilizer granules.	Coating of the fertilizer granule. In e.g. ammonium nitrate fertilizers this coating can contain e.g. octadecylamine, hexadecylamine, stearic acid [44]. Type of coating depends on type of fertilizer. The anti-caking agents are mostly based on polyolefin waxes and polyethylene based additives [38].
Granulation and prilling aids	Agents that help in the formation of granules and prills. They increase the bonding and strength of the products.	Type of aid molecule depends on type of fertilizer.
Anti-dust agents	Control dust formation during fabrication, storage, transport.	Coating surrounding the fertilizer granules which controls dust formation.
Micronutrient binder	Additionally to NPK also micronutrients could be necessary. Due to differences in size, shape, volume e.g. blending of the micronutrients with the fertilizer is not advantageous.	A micronutrient binding coating is applied to the fertilizer granule and the micronutrient powder is attached to the outside of the granule.
De-foaming aids	Controlling the foaming which occurs during the production of the fertilizer.	The defoamers remove the unwanted gases and create a better output.
Coloring agents	Staining of the fertilizer, in this way the treated fertilizers can be separated from the non-treated. Also used to improve the marketability of the fertilizer, a specific brand can use a specific color.	Dyes or pigments that color/stain the fertilizer granule.

Most additives also have multiple functions, e.g. a granulation aid agent that also has anti-caking or anti-dust functions or anti-caking agents with a coloring function. Most of these additives can also contain (synthetic) polymers. The FAs in Figure 1 consist of only anti-caking agents, since information and data of other additives is not known [24].

A distinction can be made between water-insoluble additives and water-soluble powder fertilizer additives [24]. Water-insoluble additives are added to multi-nutrient fertilizers, whereas water-soluble powders avoid the caking of nutrient salts. In contrast to what the name suggests, water-soluble powders are not completely water-soluble, resulting in the remainder and contribution of microplastics to plastic emission. These water-soluble powders are not called microplastics according to the ECHA definition of microplastics, so this study does not consider them as microplastics. Some parties do not agree with the ECHA definition for that reason, this will be elaborated on in a later paragraph.

Plastics in the soil

When eventually the agricultural supplies are used and fertilizer has been applied to the soil, the nutrients will be used by the crop or will be rinsed away. The CRF-coating will fragment and the plastic particles, also from the FAs, will remain in the soil [38]. They can even be transported to groundwater [45].

The probably first scientific opinion piece on increasing amounts of microplastics in the terrestrial soil discusses the use of sludge in agriculture as an important source of microplastic pollution [46]. As one of the firsts it discusses the risks and potential negative impacts of microplastic pollution by the agricultural sector and calls for prioritization of the topic. One of its conclusions is that raising awareness among farmers is needed [46]. Awareness of the problem has increased over the last few years, because more negative effects are known at the moment.

In the soil plastic particles can undergo alterations and interactions that can lead to fragmentation/degradation [8], resulting in smaller and smaller particles. Microplastics in the soil interact with biota in terrestrial soil and the physical, chemical characteristics, and toxicity of nanoplastics can also influence the soil ecosystem [47].

It has been shown that acidic and basic pH levels do more harm to plastic materials than neutral pH levels do [48], resulting in faster aging of the plastics. Therefore, one could say that soil acidification, which can be accelerated by the use of nitrogen fertilizers [49], causes the pH in the soil to be lower, resulting in a faster degradation of the plastic particles..

The plastic particles can also be affected by UV radiation, which contributes to the fragmentation process. Also the biota in the soil interacts with the different plastics, changes in the bacterial community have been shown after addition of aged microplastics. A decrease of soil microbial enzyme activity was shown when the soil was contaminated with polypropylene or polystyrene [50]. If these plastic particles were more aged the enzyme activity was even lower.

Additionally, an even more worrisome effect of plastics in the soil is the uptake of plastic particles by the crops [10].

Environmental and human health effects

The presence of micro- and nanoplastics in plants, their fruits and vegetables has been demonstrated [9]. Plants can take up nanoplastics from their direct environment and transport the particles eventually to their leaves and fruits [10]. When these components of the plants are being consumed, plastics can end up in the consumer. Although direct health consequences have not been demonstrated yet, plastic is an inert material that is extremely persistent. Most of the plastic particles will be excreted, but the smaller particles can be taken up by organs or wander through the body. Theoretically it is suggested that uptake increases with decreasing particle size [2], implying nanoplastics are more easily taken up than microplastics. Potential health effects are mentioned by multiple experts [13-15]. Plastic particles can contain toxic chemical additives and interact with chemicals around them, these toxic particles can later leach from the plastic and infiltrate the (new) environment [16]. Next to that, recent studies also showed reduced growth and development of plants due to plastics [19], which could result in reduced yield and potential food scarcity. Also, oxidative stress was increased in wheat seedlings, which probably resulted in reduced root growth. A correlation between environmental factors and a fastened degradation of the plastics was proposed, causing the leaching of toxic compounds in the environment. Also, the well-known chemical bisphenol A (BPA) can induce multiple adverse human health effects, like carcinogenesis or endocrine disruptions [51, 52]. Presence of BPA in the soil can also induce negative consequences on e.g. root development [53]. Furthermore, another study showed an interaction of microplastics and human pathogens in the soil, where the microplastics could function as vector for the pathogenic fungi [18]. Due to

all potential health risks, a precautionary principle is encouraged by various experts and small steps are already implemented throughout the world [21]. Next to that, more research concerning the health risks and better detection methods to analyze the small plastics is a growing demand [54].

Recently, several research projects have started to further investigate micro- and nanoplastics in (agricultural) soil. One of these is a research that has recently started investigating the spread of microplastics in the terrestrial soil, called the European MIcroplasticS in Soil and grOUndwateR: sources, transfer, metrology and Impact (MISSOURI) project. This project aims to 'characterize the presence and fate of microplastics in terrestrial ecosystems (soil and groundwater)' [55]. An additional project on EU level, called MIcro- and Nano-plastics in AGRIcultural Soils (MINAGRIS) has started in fall 2021 [56]. This project is part of European Union's Horizon 2020 (the EU Research and Innovation program) and will provide recommendations for sustainable use of plastic in agriculture in Europe, to ensure safe and economically viable food systems. These two projects show research which is at the moment performed regarding (consequences of) microplastics in (agricultural) soil. This again demonstrates the relevance of this topic and will hopefully soon add new scientific evidence regarding this topic.

Regulations and procedures

Different regulations regarding this topic are already set or are currently on their way, mostly on European level. However, countries can decide to be stricter on national level if this is allowed by the European Union (EU). Additionally, different implementation strategies could be performed per country, for example regarding the communication of the new regulation.

Recently, the EU has set the European Green Deal, a program that aims to reduce climate change and aims that Europe is climate neutral in 2050. The European Green Deal is funded by the European Union's Horizon 2020.

Farm to Fork strategy

The Farm to Fork Strategy is part of the European Green Deal [57]. The aim is to achieve a more sustainable, healthy food chain. Included in the strategy is also a minimal 20% reduction of the use of fertilizers by 2030. Although this reduction desire is not aimed at an IAMPs reduction, a 20% fertilizer reduction will also lead to a reduction of IAMPs in the agricultural sector.

Registration, Evaluation, Authorization, and restriction of Chemicals

Registration, Evaluation, Authorization, and restriction of Chemicals (REACH) is a regulation by the EU [58]. The regulation entered into force in 2007 and its main purpose is to improve the protection of human health and environment. It applies to all chemical substances, so a broad variety of companies in the EU has to comply to this regulation by presenting the risk management. Synthetic polymers are mostly excluded from registration, although monomers should be registered [59]. Recently a proposal was published by the European Commission to include synthetic polymers in REACH [60]. However, according to the International Panel on Chemical Pollution, this proposal covers only 6% of all polymers on the European market [61]. Therefore, the REACH regulation is not extremely relevant for this study; however, lobbies are going on to include more synthetic polymers.

EU Fertilizing Product Regulation

The new EU Fertilizing Product Regulation (FPR) [62] is an adaption to a previous regulation regarding Fertilizing products and will go into force in July 2026. This regulation will require the standard labelling for all fertilizing products with a Conformité Européenne (CE) mark, which indicates it can be sold EU-wide, and prescribes strict regulations for labelling, safety, and quality. This regulation will then harmonize all rules for CE fertilizers and will focus more on both the input and output of the production of the products. It also requires standard production procedures with different products categories. This will result in more transparent ingredient lists of fertilizers. Next to that, in article 42 the specific degradation criteria for polymers are discussed, although the exact criteria still need to be formulated, ultimately July 2022. This means that from July 2026 the polymers in fertilizers (also CRF and FAs) have to comply to this degradation criteria. These criteria can include a certain time period after which the particles should be undetectable in the soil. Therefore, this new EU FPR might contribute to less plastic pollution by fertilizers, because the

plastic particles will remain in the soil for a shorter period of time. However, it is not known yet if the degradation products can potentially form an additional problem.

ECHA proposal for restriction on IAMPs

In the beginning of 2018, the European Commission (EC) asked for a strategy concerning plastics and circularity. Some reports, recommendations, and actions on microplastics were published. Eventually in January 2019, the ECHA restriction proposal concerning IAMPs was published [2]. The synthetic polymers that are not covered by the REACH regulation are addressed by this proposal. In this proposal a restriction on the use of IAMPs in different sectors is proposed, including the agricultural sector. It is expected that, due to growing awareness, there will be a downward trend of use of IAMPs. However, also an increase in the use of IAMPs is predicted, as long as there is no agreement on this proposal and due to biodegradable alternatives. This will probable even each other out; therefore, leading to no net changes in the levels of IAMPs by 2041 (ECHA proposal, page 70). The European Commission planned to make a decision on this proposal late 2021. However, the voting regarding the ECHA restriction proposal has been (likely) postponed with a year [63]. It is not sure why, but this shows action is taken regarding the topic, potentially also influencing the lobbying processes. Therefore, in contrast to the EU FPR, which will go into force in July 2026, the ECHA restriction proposal has not been agreed on yet.

Then, in 2020, in response to this restriction proposal, also a stakeholder analysis on European level was performed [64]. This analysis concerned 205 stakeholders, throughout Europe and from different sectors, additionally, no interviews were conducted. The stakeholder analysis that will be performed in this research will cover only the Netherlands and its agricultural sector and will use semi-structured interviews. However, defining stakeholders in this research is based on the bigger, quantitative stakeholder analysis study on European level.

In response to the ECHA proposal, a position paper was written by several non-governmental organizations (NGOs) called *The road to an effective EU restriction of intentionally-added microplastics* [65]. ECHA states biodegradable polymers do not fall under the restriction [2], so a transition to these biodegradable polymers might be a solution for companies to meet the requirements in this proposal. The NGOs of the position paper mainly urge that the proposed exceptions should be limited. They disagree with the exception of water-soluble microplastics, since these can also cause environmental problems, because most of them are not completely water soluble. The NGOs also disagree with the minimum size limit of 100 nm, since plastic particles < 100 nm, nanoplastics, can induce even worse negative effects. However, nanoplastics are hardly to detect in field samples, especially the smaller nanoplastics [25, 26]. Additionally, they state 'no real biodegradable polymers are found yet'; therefore, they argue that exemption should not be honored. ECHA mentions in the proposal that 'if biodegradability is not a good alternative, then the proposed restriction is doubtable, since the agricultural sector benefits hugely from the non-degradability of the products.' [2]. The availability of alternatives might have an impact on the factors that influence the willingness to change of the stakeholders. Alternatives for CRF coating materials could be materials like chitosan, cellulose, rosin, waxes, starch etc. [43]; however, reformulated CRF products have to be further developed. For FAs some stakeholders say there are no suitable additives yet, although one manufacturer stated in the ECHA proposal that there is an alternative for anti-caking agents, based on hydrophobic silica [24]. In response to the announced delay of the restriction, the NGOs wrote an report in which they stress a delay should be prevented since emission levels keep on rising [66].

The focus in this research is solely on agricultural supplies with IAMPs used in the Dutch AIS.

The Netherlands

The urgency of the topic is shown by the fact that in the Dutch House of Representatives on February 5 2019 questions were asked by members Bromet and Kröger concerning the ECHA proposal [27]. They asked which agricultural supplies contain IAMPs and on which scale they are used in the Netherlands. Minister Schouten (from the Ministry of Agriculture, Nature, and Food quality) mentioned "unfortunately no concrete data was available". In the next paragraph of this study some Dutch specific emission numbers will be calculated. Another question by Bromet and Kröger concerned the potential future regulations and short-term implementation. Schouten stated that when the regulations were definite and approved, the Netherlands of course would adopt those.

Emission numbers

In the ECHA proposal emission numbers of plastic by agricultural supplies with IAMPs are mentioned; however, these numbers account for the European level. The agricultural products ECHA mentions are fertilizers (CRFs), fertilizer additives (e.g. anti-caking agents), plant protection products (e.g. seed coating), and soil conditioners [2]. This research focusses on fertilizers and fertilizer additives.

Within the EU there are differences in the agricultural sector between countries, so the emission numbers of plastics by Dutch agriculture will deviate from the EU numbers. By using the same calculation as ECHA has used for the EU numbers, the emission numbers for Dutch plastic pollution by IAMPs in CRF and FA could be estimated (Table 3). The estimation details can be found in Appendix A. The annual emission (last column Table 3) is a wide range due to the fluctuating polymer percentage of 1 – 12% in products.

*Table 3: Dutch plastic emission numbers for Controlled Release Fertilizer (CRF) and Fertilizer Additives (FA) in tonnes per year in the agricultural sector. * Percentage of use for water soluble FA is not known specifically, but it is less than the percentage for water insoluble FA.*

Dutch plastic emission numbers	Subcategory	Annual emission (tonnes / year)
Controlled Release Fertilizer (CRF)	Encapsulated	21.3 - 255.6
Fertilizer Additives (FA)	Water-insoluble	70.29 - 421.74
	Water-soluble	< 70.29 - 421.74*

The use of CRF in the Netherlands is probably higher than the 1% used in the calculations according to one of the ECHA members [67], which could potentially imply the Dutch emission numbers are higher. Also, the numbers for other subcategories of CRF, i.e. physical barrier or chemical attachment, are not known. Therefore, these specific Dutch numbers help in visualizing the magnitude of the problem of IAMPs on plastic pollution in the Netherlands; however, still a big part remains unknown and should be further investigated.

The Dutch Agricultural Innovation System (AIS)

The different actors that play an important role in the Dutch agricultural sector form the Agricultural Innovation System (AIS). This system shows the value network of the different actors and the corresponding interactions. The stakeholder groups that will be interviewed are: Farmers, Fertilizer producers, Fertilizer buyers, Consumers, Education, Controlling institutions, and Policy NL. Therefore, a short explanation regarding their role in the AIS will be provided.

Farmers

In the Netherlands there are different types of farmers. As a farmer you can focus on one specific specialism, for example cattle breeding, agriculture, or horticulture. Most cattle breeders also cultivate corn for example, and they can use this as food for their cattle. There are also some multifunctional farms in the Netherlands, which combine for example their agricultural farm with a care institution on their land. Most cattle breeders will use the manure of their own cattle on their land, so they do not use any or little fertilizer. However, in agriculture and horticulture fertilizers are being used frequently. Every farmer works differently, for example due to traditions in the company, which can potentially influence the type of fertilizer that is used. It depends also per crop how much fertilizer is used [68], for example the average fertilizer usage for consumption potatoes is much higher than for corn. Therefore, this study only looks at agricultural entrepreneurs. Due to the fact that organic farmers do not use synthetic fertilizers, this research will only look at non-organic farmers.

Fertilizer producers

The companies that produce fertilizer products with or without IAMPs are the Fertilizer producers. A few companies are based in the Netherlands, although it is a global market.

Fertilizer buyers

In the Netherlands there are five big wholesale companies that buy most fertilizer from the producers. They will trade the products and eventually farmers order the fertilizers they use at various supply organizations. Both wholesale companies and supply organizations fall in the Fertilizer buyers stakeholder group.

Consumers
This group consumes the agricultural products (crops) provided by the AIS. Via purchasing, the products can end up with the consumers. This can take place directly or indirectly via supermarkets for example.
Education
Agricultural knowledge and skills regarding farming can be acquired via universities or applied universities. Most farmers went to such a school and this is where their basic knowledge originates.
Controlling institutions
The organizations that survey the existing rules and monitor for example food safety and potential health risks for the Controlling institutions stakeholder group.
Policy NL
Farmers must take various factors into account, for example regulations regarding manure and fertilizer use, transport, or license plate requirements. These are proposed and set by the government (stakeholder group Policy NL), often the Ministry of LNV. An example of such a regulation set by Policy NL is the 'Meststoffenwet', a law that regulates the use of manure and fertilizers. This law mentions for example norms for the use of phosphate, the use of nitrogen, and manure based on nitrogen content. Especially the norms for the use of nitrogen fertilizers can differ extremely between crop and type of soil. Often regulations are made on EU level by Policy EU, therefore Policy EU is also taken into account in the Policy NL stakeholder group.

Reduction of plastic pollution

The awareness concerning the plastic pollution problem is growing. Amongst citizens, in the United Kingdom and in the Netherlands [69], but also on European (policy) level. In line with the precautionary principle there is a growing need, for example in politics, for a reduction of plastic. Therefore, more research towards reduction of plastic is desirable. In this research the reduction of the use of IAMPs by agricultural supplies will be studied.

To reduce plastic pollution a global interdisciplinary approach is required [70]. Reducing (micro)plastic pollution can be achieved by different methods, which can be divided into three categories: containment, separation, and mitigation [71]. Containment regards plastic disposal, which is nowadays mostly focused on recycling and landfilling. More research is required to improve this method, and current evidence suggests this is not a likely solution against microplastic pollution because of the microplastic leakages via landfill runoff. Separation is the prevention of microplastics entering the environment, for example via wastewater treatment plants. For separation plastic-degrading enzymes may be promising; however, still more research and investment is needed before these can be practically applied [71]. This might be promising on the long term, but on the short term an alternative is required. A focus on the prevention of further emissions (mitigation) is essential because once microplastics have found their way to the environment, they are difficult to remove. Mitigation can for example be realized by restricting the use of plastics in fertilizers. A recent study formulated ten recommendations to mitigate plastic pollution, for example regulation of production, eco-design, reducing the use of plastic, and use of bio-based or biodegradable plastics [70]. A reduction of the production and use of IAMPs in the Dutch AIS could be a first step, and can be achieved by using no synthetic polymers in agricultural supplies anymore and/or a focus on alternative materials [72]. Redesigned products can be innovated into alternatives, for example fertilizers using biodegradable polymers. A reduction in the use and production of IAMPs can be realized in various ways, for example by a change in behavior of relevant stakeholders and/or accompanying political measures. Admired (behavioral) changes, like a reduction of IAMPs, can be pushed through by regulations or laws, creating a tension generating force [73]. However, this might lead to a lot of tension instead of the most efficient implementation and attitude towards future adaptions. Other studies show it is important to focus on both push and pull factors to create advantageous conditions for eco-innovation [74]. Stakeholders can eco-innovate in different directions, creating for example different products. An example of a pull factor can be subsidies, a push factor can be regulations. Additionally, environmental regulations can stimulate eco-innovations [75]. Just restricting the use of IAMPs is hard due to definition discrepancies and the unknown effects of biodegradable alternatives. Though mitigation by the reduction of the use and

production of agricultural supplies with IAMPs will not entirely solve the plastic pollution problem, it will contribute to a decrease of microplastic emission to the environment.

It should be investigated which factors are important for the direct stakeholders to function as pull factors and can attribute to a behavioral change that will contribute to a reduction of IAMPs in the Dutch AIS. Therefore, this research will investigate the willingness to change of various stakeholders in the Dutch AIS.

Behavioral change

According to Ajzen's Theory of Planned Behavior (TPB), intention (willingness to change) is the most important factor in performing a certain behavior [28]. This theory is widely used for analyzing intentions and specific behaviors. According to this theory, intention is influenced by attitude, social pressure (subjective part), and the ability to perform the specific behavior (perceived behavioral control). Various publications describe the intention towards pro-environmental behavior. Price et al. shows the first general theories regarding pro-environmental behavior and agriculture [76]. They show agricultural changes are mainly influenced by individual motivations and they provide a theoretical framework to understand the environmental behavior of farmers. They make use of a combination of the Value Beliefs Norms model [77] and the Theory of Planned Behavior [28]. In the Value Beliefs Norms model trust also plays a major role and it is shown that trust in agronomical advice can also predict pro-environmental behavior. The integration of both theories leads to the use of four independent variables in their study, namely Environmental & behavioral context, Environmental values & beliefs, Behavioral control beliefs, and Behavioral & Social norms. Stating pro-environmental behavior is influenced by context, values, beliefs, and norms. Another study demonstrates that locus of control [78] also plays an important role. Locus of control is the extent to which people think they have control over their life. People with an internal locus of control will probably show pro-environmental behavior sooner [76]. Pannell shows that it is also important to consider the public and private benefits before proposing any policy mechanism for a change in land-use [79]. According to the Theory of Interpersonal Behavior, the non-cognitive determinants of behavior, like emotion and habit, are also considered important and should not be overlooked [80]. Also age can have a certain influence [81]. Although many factors can influence a change towards pro-environmental behavior, this study will only use the TPB, which will be elucidated in the next paragraph.

Theoretical framework

To find out how the use of IAMPs-containing fertilizers can be reduced, the willingness to change/intention of the actors in the Dutch Agricultural Innovation System (AIS) should be analyzed. The AIS provides a theoretical lens.

This research will make use of Ajzen's Theory of Planned Behavior (TPB) [28] as theoretical framing. According to TPB, intention (willingness to change) is the most important factor in performing a certain behavior. Intention is influenced by three components, i.e. attitude, social norms, and perceived behavioral control; therefore, these factors will be investigated in this research. The weight of those different aspects, the relative importance, can depend on the desired behavior. According to Klöckner, not one original behavioral change theory is perfect to predict environmental behavior [82]; therefore, a small extension to the TPB is made. As, the component attitude can be influenced by e.g. the factors awareness and risk perception, these factors will be added to the TPB model (Figure 2). TPB does not explain behavior that concerns a more interdisciplinary complex topic, but applies more to really specific behavior. Nevertheless, for this explorative study this theory will be used. Per stakeholder group different specific factors can be key variables in determining willingness to change.

To eventually understand the willingness to change of the various stakeholder groups the next components and factors will be integrated. In this way it can be predicted which factors are most important in the Dutch AIS to reduce IAMPs use and influence the intention of the stakeholders.

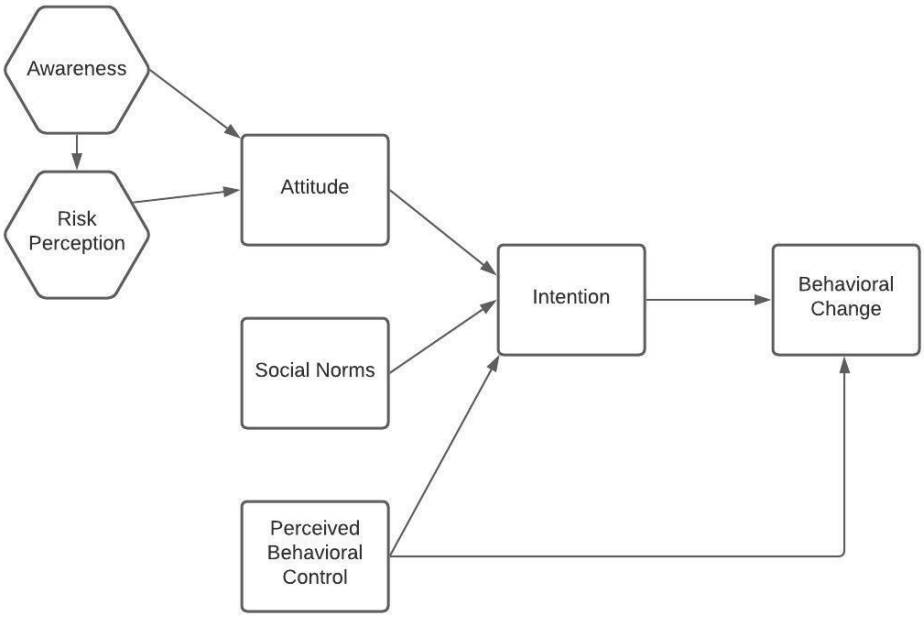

Figure 2: Extended Theory of Planned Behavior.

Awareness and attitude

In general, awareness regarding a certain topic corresponds to having the ability to make the knowledge explicit. The definition of awareness that will be used in this study is explained in the Methodology, RQ2. It has been shown that awareness can influence behavior [83], therefore the awareness of the stakeholders will be analyzed. Awareness can be influenced by knowledge and will influence the component attitude. Attitude can be influenced by various factors, including habits/traditions, awareness, and demographic factors. Therefore, these factors will be tested. More environmental knowledge will induce a higher level of awareness; however, it does not lead directly to pro-environmental behavior [84], but it does indirectly [85]. According to Ham et al. environmental awareness goes hand in hand with environmental responsibility [86]. If farmers become aware of negative consequences, they do have a more positive attitude towards pro-environmental behavior [87]. Additionally, Martin et al. shows that nature connectedness is also correlated with pro-environmental behavior [88]. Therefore, it is expected that the farmers might perform pro-environmental behavior and might be more willing to change. It is shown that aversion to risk and debt often goes hand in hand with unwillingness to change and adoption of innovation in certain types of farmers [89]. Therefore, the risk perception will also be examined.

Risk perception

Nguyen et al. have recently studied the intention of Vietnamese coffee farmers to adopt more sustainable practices [90]. Additionally, another recent study about farmer's intention was performed in Iran [91], where the intention to safe use of chemical fertilizers was investigated. Both studies used an extension to the TPB with the factor risk as theoretical framing. The Comprehensive Model of Environmental Psychology also states that awareness about consequences plays an important role in pro-environmental behavior [81].

In order to study risk perception, it is important to make a clear distinction between hazard and risk, since communication problems can arise from a misperception between the two concepts [92]. Hazard in this case is defined as the potential of harm to (human) health or environment. Risk also encounters the likelihood of exposure and the level of damage. In this study, the distinction between the two terms will not be made by the interviewees, but only by the researcher while interpreting the findings. Some overlap in awareness of the consequences and risk perception can occur, but the latter can also cover economic risks, for example risk for a lower yield.

Social norms

To study the subjective part, questions can be asked on how people close to the interviewees thought about a specific topic and certain behavior of the interviewees. As was mentioned by Nguyen et al. social trust can also influence behavior [90]. Additionally, general social norms will be gathered.

Perceived behavioral control

This factor regards the ability to perform the specific behavior. To check the perceived behavior control the participants can estimate their likelihood of the behavioral change. In this study, this factor will be covered by learning more about the use of fertilizers and which factors influence the use of and choice for certain fertilizers and how this influences their ability to perform the behavior.

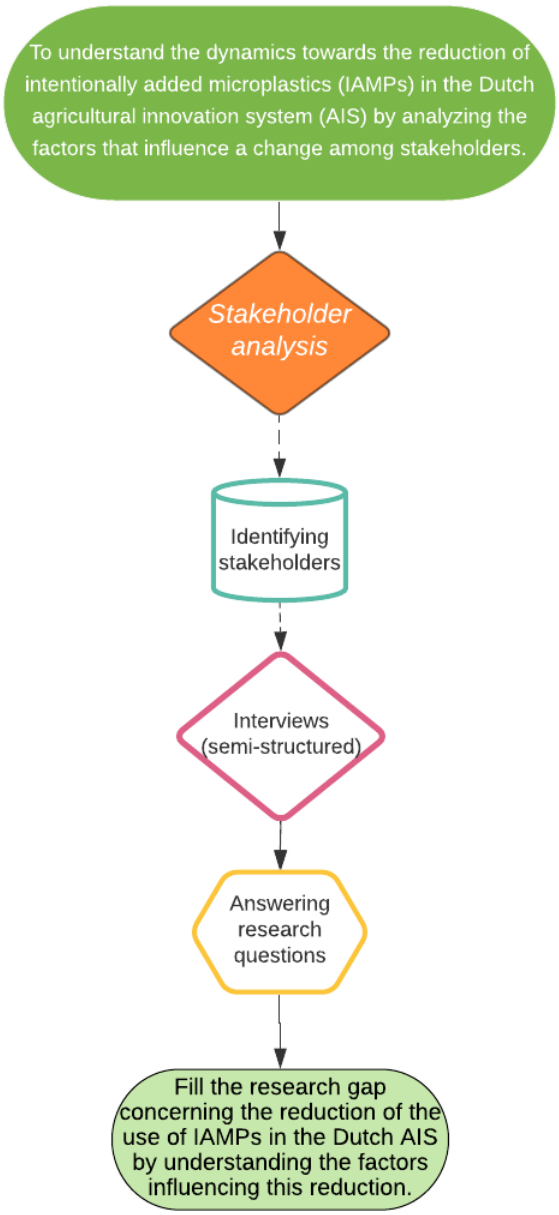

Figure 3: Research approach Marina Bool.

Research methodology

Overall research structure

In order to study *the dynamics towards the reduction of intentionally added microplastics (IAMPs) in the Dutch Agricultural Innovation System (AIS) by analyzing the factors that influence a change among stakeholders*, this research will be using a case study approach, following an interpretative perspective [29]. The stakeholder analysis consists of two parts (see Figure 3):

- Identifying and mapping stakeholders
- Interviews

The stakeholders of the AIS, specified on fertilizer use, were interviewed to study the factors that influence the willingness to change of the different stakeholders. This information was systematically collected and mapped according to the theoretical framework.

Afterwards, all obtained information was combined and conclusions were drawn. The final result consisted of insight into the factors that need to be considered when formulating and implementing plastic reduction measures.

Methodology

This research is based on a document analysis and fifteen semi-structured interviews [93] with various stakeholders in the Dutch Agricultural Innovation System (AIS). Although all stakeholders that act in the Dutch AIS followed eventually from the interviews, the stakeholder groups that were interviewed were: Farmers, Fertilizer producers, Fertilizer buyers, Consumers, Sector organizations, Education, Controlling institutions, and Policy NL. This selection was based on document analysis and test interviews, to find out which groups are relevant in the Dutch AIS, specifically focused on fertilizer use.

Document analysis

In order to start the interviews, well informed various documents were used in the document analysis through academic search on intentionally added microplastics, nanoplastics, agriculture, fertilizers, fertilizer additives, the Netherlands, but also rules and regulations regarding fertilizer use and production. Next to that, also multiple (upcoming) regulations, restrictions, and acts were consulted on Dutch but mostly EU level. Additionally, policy documents, newspapers and news articles, and various journal articles were used, and the different stakeholder analysis study in response to the ECHA restriction proposal [64].

Semi-structured interviews

Nine of the interviews were conducted online via video calling (Zoom Video Communications, Microsoft Teams, or Google Meet), two via phone calling, and four took place physically (Table 4). All were recorded and lasted between 60 and 90 minutes. Following conduction, the interviews were transcribed literally and anonymized afterwards. Transcripts are available on request.

The questions during the interviews differed slightly depending on the perceived position of the stakeholder in the network. In general, the same questions were asked during the interviews. Some interviewees wanted to receive the questions beforehand, which were accordingly provided in a general descriptive way.

*Table 4: Overview conducted interviews research Marina Bool. * this interviewee is also considered as representative of the Fertilizer buyers stakeholder group.*

Stakeholder group	Description	Data interview	How conducted
Policy NL	LNV representative (focused on manure and fertilizers)	24-09-2021	Videocall
	LNV representative (focused on nature inclusive agriculture)	11-10-2021	Videocall
Controlling institutions	Representative of food and consumer products control	28-09-2021	Videocall
Fertilizer producers	Fertilizer producer	16-09-2021	Physical
	Fertilizer producer and distributer *	4-10-2021	Physical
	Producers representative	12-11-2021	Videocall
Fertilizer buyers	Wholesale representative	20-09-2021	Videocall
Farmers	Individual farmer	7-10-2021	Physical + phone call
	Individual farmer	14-10-2021	Phone call
	Individual farmer	15-10-2021	Phone call
	Individual farmer	16-10-2021	Physical
Consumers	Consumer organization representative	15-10-2021	Videocall
Sector organizations	Agricultural chain representative	20-09-2021	Videocall
	Farmers representative	12-10-2021; 13-10-2021	Videocall
Education	Applied university representative	23-09-2021	Videocall

Analysis

The analysis of the transcribed interviews took place via Atlas.ti 9 Windows. 54 codes were used, of which an overview can be found in Appendix B. With the extended version of the TPB by Ajzen [28] as theoretical framework, the willingness to change (intention) of the various stakeholders was studied. In order to investigate a reduction, first the awareness of various stakeholder groups was studied. Additionally, the willingness to change of various stakeholder groups was studied and eventually all findings were integrated to answer the fourth research question: what is needed to achieve an efficient reduction of IAMPs in the Dutch AIS.

RQ1

To answer RQ1, a stakeholder analysis [94] was performed. All relevant actors mentioned in the interviews were coded with 'stakeholder', to provide an overview of all actors that are involved in the Dutch AIS. All relevant stakeholders were listed and different stakeholder groups were created and described. To understand the role of the stakeholders in the AIS, additional subcodes concerning the AIS were applied, like factors that influence their role in the system and more details on their contacts and interactions in the system. Also, more details concerning the farms, for example the type of farm and the agricultural products were added. This information was used by creating a visual representation of the AIS network. Subsequently the stakeholder groups were categorized using a power-interest grid (Figure 4) as described by Thompson [95] to indicate all relevant stakeholder groups. This was constructed based on the perception of the interviewees.

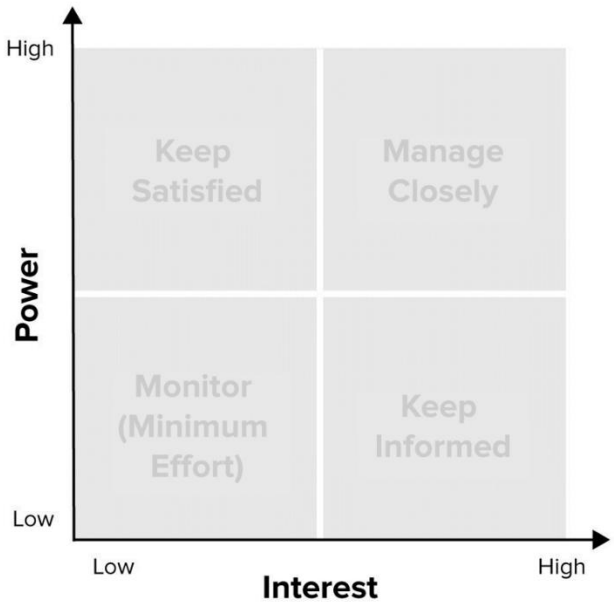

Figure 4: Power interest grid by Thompson [95].

RQ2

To answer RQ2, it was necessary to differentiate between the awareness concerning the *presence* and *consequences* of IAMPs in agricultural supplies. The awareness was coded per stakeholder group to differentiate easily between the different stakeholder groups. A stakeholder will be assessed *aware* if the individual is familiar with the presence of IAMPs in agricultural supplies and if the stakeholder could actively mention consequences of microplastics in the soil/fertilizer.

To answer the first part of RQ2 regarding awareness of the *presence* of IAMPs in agricultural supplies, first the knowledge about CRFs and the accompanying mechanism was tested. Subsequently, the awareness on the presence of microplastics in agricultural supplies was examined per stakeholder. The level of awareness was subsequently labelled with Low, Middle, or High (Table 5).

To answer the second part of RQ2 about the awareness of the *consequences* of IAMPs in agricultural supplies, a focus on the stakeholders that were aware of the presence of microplastics in agricultural supplies was applied and only their awareness was tested. The level of awareness was subsequently labelled with Low, Middle, or High (Table 5).

Table 5: Awareness labels.

Level of awareness	Description
Low	If none of the interviewees within that stakeholder group showed recognition or knowledge concerning the presence or consequences of microplastics in agricultural supplies.
Middle	If some/one of the interviewees within that stakeholder group showed recognition or knowledge concerning the presence or consequences of microplastics in agricultural supplies.
High	If all of the interviewees within that stakeholder group showed recognition or knowledge concerning the presence or consequences of microplastics in agricultural supplies.

RQ3

To answer RQ3, first more information considering the use of fertilizers by farmers had to be determined. All information regarding the use of fertilizers was coded. Because this was almost solely applicable to the farmer group, this code was not applied per stakeholder group. The aim of this code was to show where and how the use of fertilizers was executed. Also, factors that influence the use of fertilizers were indicated, and additionally how the use was influenced. This led to more insights in the use of fertilizers.

According to the theoretical framework attitude (influenced by awareness and risk perception), social norms, and perceived behavior control influence one's intention/willingness to change. Therefore, these codes were used for answering this question.

Since not all stakeholders were aware of the potential presence and because of that also the consequences of IAMPs in agricultural supplies, the stakeholders were at a certain moment during the interviews informed about a study that stated that crop roots could take up nano sized plastic particles [10]. This was done to measure their risk perception. The reaction after mentioning the presence of microplastics in fertilizer and potential uptake was used for answering RQ3, since the awareness of the consequences was influenced by providing this information. The reactions of the interviewees were examined. Additional questions were asked to measure one's risk perception, which was subsequently coded.

A code group Economic factors was created to provide an overview of all economic factors that were mentioned. Specific subcodes were created during the analysis. These factors potentially influence the factor perceived behavior control. The code group Willingness to change was created specifically for the direct factors that influence the willingness to change. These will most likely cover the answers to the direct questions concerning willingness to change. More indirect questions and answers will be considered within different code groups. To answer eventually RQ3 all factors that influence the willingness to change will be combined and compared between the different stakeholders. An overview of all used codes can be found in Appendix B.

RQ4

To answer RQ4 all required information and findings from previous questions were combined. Next to that, all factors that influence reduction were added in the analysis. This provided an overview on the different perspectives regarding a reduction and the factors influencing reduction. Also one's view on the necessity of reduction was coded, which is linked with one's risk perception. Potential (specific) actions already taken/or planned in the near future on reduction were coded separately. When all findings are combined, specific conditions were formulated under which reduction measures could be implemented efficiently.

Research quality

The stakeholder analysis is used to secure validity and reliability. Different actors per group were interviewed to contrast the information and the theoretical lens is used to understand the awareness and the different factors contributing to willingness to change.

Furthermore, as the topic is quite broad and can cover several levels (e.g. European, national, global), a systematic approached was used to keep the scope of the study not too broad and frame it

clearly. The focus of this research project was solely on *intentionally added* microplastics in *agricultural supplies* in the *Netherlands*.

It was important to address this research objectively and not exclusively from the perspective of e.g. the Plastic Soup Foundation or plastic industry/branch. To stay critical during the literature study a broad variety of sources were consulted, e.g. not only use the position paper of the NGOs. During the interviews it was also important to operate via an ontological view, to stay objective and not form an opinion before and during the interviews.

The research could be quite controversial for example for the producers/suppliers. This group might not want to cooperate in research that could eventually contribute to tighter regulations and therefore limitations for their productions. Next to that, also farmers might not want to cooperate. Plastic-free alternatives could be more expensive or less functional and therefore potentially not beneficial for them.

Additionally, in order to ensure quality, it was best to approach the stakeholders via Radboud University, since stakeholders could be potentially biased when hearing 'Plastic Soup Foundation'.

Findings

RQ1

Who are the actors (stakeholders) involved in the use of IAMPs in the Dutch AIS?

An overview of the stakeholders in the Dutch AIS was provided (Appendix C). A visual representation of the AIS network was created (Figure 5) to show the relations between the different stakeholder groups and the position of the different stakeholder groups within the AIS. Subsequently, a power-interest grid was constructed (Figure 6) as described by Thompson [95], to provide an overview of the stakeholder groups and their relative interests and power.

The different stakeholder groups regarding the use of intentionally added microplastics (IAMPs) in fertilizers in the AIS are:

- **Policy NL/EU**: Governmental and non-governmental organizations that play a major role in policy making or lobbying in the Netherlands and/or EU. During the interviews a global policy organization was rarely mentioned; therefore, those were also categorized into this group. This group scores high on the power-axis, since they make the rules and regulations. They have high interests since regulations are on their way.
- **Fertilizer producers**: Companies that produce fertilizers and/or organic manure. The organization that represents the fertilizer producers was also categorized in this stakeholder group, since the views, knowledge, and opinions were mostly similar to the fertilizer producers. This group also has high power, as they provide the fertilizer products and make the decision to use IAMPs for their products. They have to act conform the rules and regulations from Policy NL/EU, so they are placed a bit lower on the power scale (Figure 6). They have high interests in the use of IAMPs since this influences the products they produce.
- **Fertilizer buyers**: The companies/organizations that buy fertilizing products from the producers or from the wholesale organizations within this stakeholder group. This group provides (eventually) fertilizer for the individual farmers. Therefore, their interests are high, although they also provide other products and are not completely dependent on fertilizers. Their power is not that high, since they are dependent on the wholesale and the producers, although they can decide to buy somewhere else.
- **Farmers**: Individual agricultural entrepreneurs. This group consists of individuals and has not that much power. Although, when on the same page, they could have higher power, but as appeared during the interviews this is not a likely situation. Their interests are high, since almost every farmer uses fertilizer.

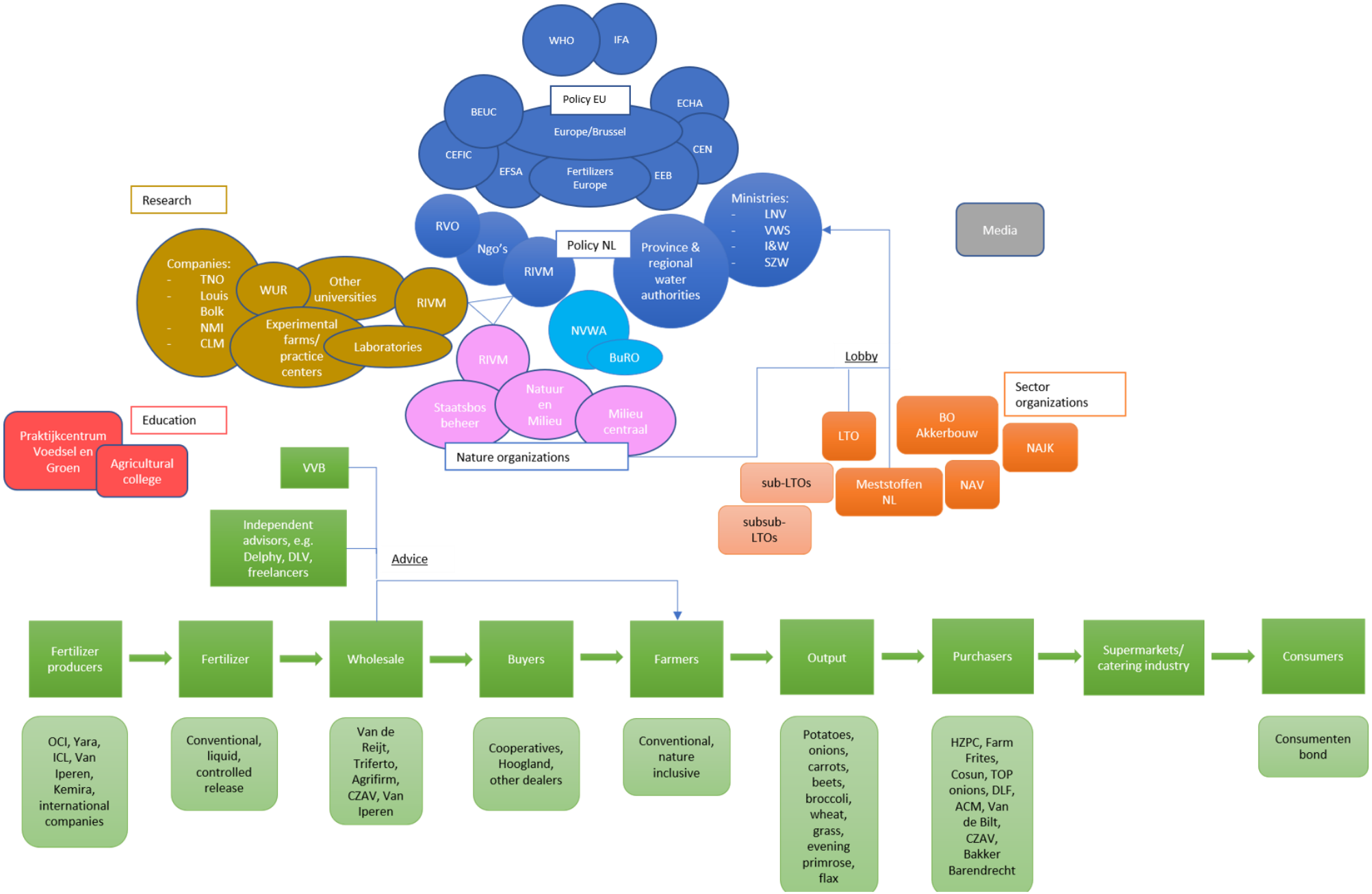

Figure 5: Overview of the stakeholders in the Dutch Agricultural Innovation System (AIS). In green the chain from fertilizer producers to farmers to crops (output) to consumers, in the light green boxes underneath the chain examples per step can be found. In blue the different policy stakeholders, in light blue the controlling institutions, in gold the research organizations, in pink the nature organizations, in orange the sector organizations, in grey the media, and in red the education stakeholder group can be found. Abbreviations or explanations are stated in Appendix C.

- **Purchasers of output farmers**: Companies/organizations that buy the farmer's output, e.g. output processors or supermarkets. This group has high power, they decide where they want to buy their products. If they think one's output is too expensive they will find another supplier. Their interests are low since consumers and customers will at the moment buy their products regardless of presence of IAMPs in these products.
- **Consumers**: The group of individuals that buys and consumes eventually the output of the farmers. This group is broad and diverse, consisting of all individual inhabitants in the Netherlands that buy and consume the crops and products produced by the farmers. Their power could be potentially high, when all on the same page and organized. Their interests in the use of IAMPs in the AIS is low, mostly due to a lack of knowledge.
- **Sector organizations**: Organizations that represent the agricultural sector, primarily in policy processes. This group is the linkage between the agricultural sector and Policy NL/EU. Some organizations within this stakeholder group have high power and try to influence policies and decisions in the Policy NL/EU stakeholder group. Most of them do have high interests since the majority of the farmers they represent are dependent on fertilizer.
- **Advisors**: Organizations that provide advice within the AIS for other stakeholder groups. This group consists of commercial and independent organizations that influence the farmers and their use of fertilizers, resulting in a high power. The interests are also high since they advise about e.g. fertilizer use and products.
- **Research**: Organizations that perform research, optional at the request of other stakeholder groups. This group consists of organizations that are assigned to perform certain research by other stakeholder groups and organizations (like universities) that also perform their own research. The interests of the latter are probably much higher than the organizations that are instructed. The power is not that high, although the knowledge/findings they provide can have high power when communicated via media.
- **Nature organizations**: Organizations that represent nature and environmental topics. This group would have high interests in the use of IAMPs, if they have more knowledge on the subject. Their power is also not that high, since most organizations are small. They also try to influence policies and rules, but have less power compared to the sector organizations.
- **Education**: This stakeholder group provides agricultural knowledge via education institutes. This group has high power since it educates all future farmers. Their goal is to educate on a broad level and teach about general topics that are required in the AIS. Therefore, their interests in the use of IAMPs are not that big.
- **Controlling institutions**: Organizations that monitor the quality and/or safety of various products and/or processes. These institutions do have high power, since they are executing the rules made by Policy NL/EU. Their interests are lower since they are mostly an executing organization, although for example BuRO is part of the NVWA and keeps an eye on health risks. However, due to a lack of knowledge their current interests are also low.
- **Media**: Organizations that distribute knowledge throughout society (and reach the consumers and therefore also all other stakeholder groups). This is also a powerful stakeholder, since it can influence society and its consumers by communication. They have less interests, as long as there is new to be covered.

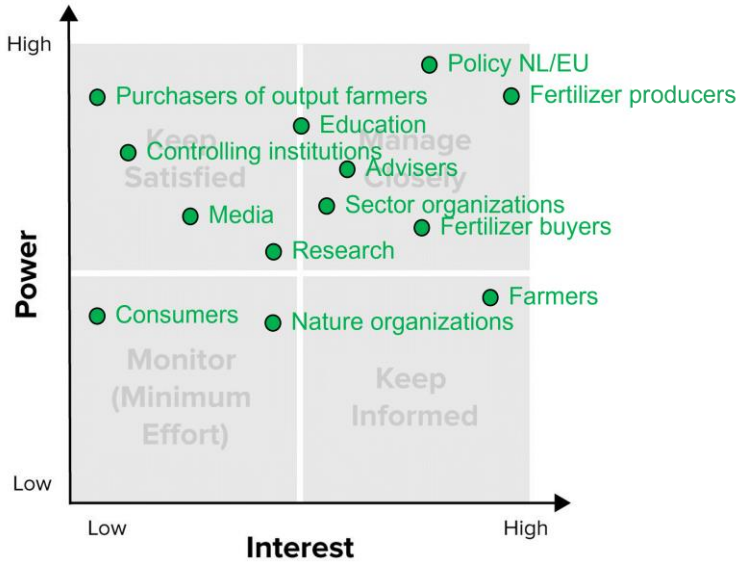

Figure 6: Power-interest grid of all stakeholder groups concerning the use of intentionally added microplastics (IAMPs) in fertilizers in the Dutch Agricultural Innovation System (AIS).

RQ2

How is the awareness of the different stakeholder groups concerning the presence and the consequences of IAMPs in agricultural supplies?

Interviews were conducted with stakeholder groups *Policy NL, Controlling institutions, Fertilizer producers, Fertilizer buyers, Farmers, Consumers, Sector organizations,* and *Education* (Table 4) and the the awareness of these stakeholder groups was tested.

Awareness regarding the presence of IAMPs in agricultural supplies

First, the knowledge and awareness CRFs and the accompanying mechanism was examined per stakeholder group (second column Table 7). Subsequently, the awareness considering the *presence* of IAMPs in agricultural supplies and mostly in fertilizers (CRF and additives) was presented (third column Table 7). In the last column a conclusion on the level of awareness concerning the presence of IAMPs in agricultural supplies per stakeholder group was stated and labeled with Low, Middle, or High awareness, according to Table 5 in the Methodology.

Table 7: Overview of the awareness of different stakeholder groups of the Dutch Agricultural Innovation System considering the presence of microplastics in fertilizers.

Stakeholder group	Existence controlled release fertilizers (CRFs) + mechanism	Awareness: Presence IAMPs in agricultural supplies	Conclusion + Level of awareness
Policy NL	Both representatives of the ministry of LNV have stated to be familiar with gradually release fertilizer products. Although they were not familiar with the exact mechanism, one of them knew there is a coating.	*"The coating is often made of plastic, or at least a polymer, which degrades very slowly, therefore staying very long in the soil." LNV representative, 24-09-2021* One of the LNV representatives did know microplastics could be present in the coating and provided some details. The other representative was familiar with the fertilizer products but did not give a clear answer/reaction on the fact that microplastics could be present. The NVWA/BuRO recently released a report considering the risks of non-consuming products	**Awareness**: Differs within LNV, some in LNV know about microplastics in fertilizers, but it is not on the agenda. **Middle**

		where they also mentioned microplastics. However, LNV is not involved in this topic yet.	
Controlling institutions	The representative of food and consumer products control is not familiar with this type of controlled release fertilizers.	*"Cosmetics are a well-known source." Representative of food and consumer products control, 28-09-2021* The representative is familiar with the presence of microplastics in products, but not within fertilizers. The representative stated consumers probably think about it as a topic far away.	**Awareness**: One of the controlling institutions is not familiar with microplastics in fertilizers. **Low**
Fertilizer producers	*"The CRF products we are producing here, are for a real specific market, that's a small part." "We produce 3 types of CRF that work via different mechanisms." Fertilizer producer, 16-09-2021* The producers are producing the fertilizers themselves; therefore, they are aware of the mechanism and the process, and are also familiar with the substances. Although both companies sell the specific fertilizers, they do not have their main focus on the same products.	*"[X] has a sulphur layer with a very thin polymer layer." "The anti-caking agents we use are without synthetic polymers." Fertilizer producer, 16-09-2021* Polymers can be present in the coating of CRF, not the anti-caking additives used according to one of the representatives. It was mentioned that not all polymers are synthetic polymers by definition, which suggests that not all the products of the representatives contain microplastics. *"We are alert on those microplastics in the coatings." "Microplastics could be present in additives, but I'm not sure. We as distributer don't have to deal with that a lot." Fertilizer producer and distributer, 4-10-2021* The other representative (that is also distributer) mentioned the microplastics that are present in the coating. Although, the representative was not sure about the presence of microplastics in additives.	**Awareness**: Fertilizers with microplastics are produced by these producers. Although, for the additives there are some discrepancies. **High**
Fertilizer buyers	The CRF products are sold by both Fertilizer buyer companies and therefore both representatives are familiar with CRF.	One of the representatives said polymers were used for coating for CRF and the additives coating. *"But primarily, yes, synthetic, that do degrade in the soil, otherwise they would not be permitted according to the fertilizing regulations." Wholesale representative, 20-09-2021* There are also other coating materials for CRF than just synthetic polymers, but the ones primarily used are the synthetic ones. The other representative (that is also producer) mentioned the microplastics that are present in the coating. Although, the representative was not sure about the presence of microplastics in additives.	**Awareness**: It was known synthetic polymers can be used, but less details compared to the producers were mentioned. **Middle**
Farmers	All four individual farmers did know that CRF exists or other gradual release fertilizers. Not all farmers knew CRF	*"Synthetic polymers? Hm interesting." Farmer, 7-10-2021 "No I did not know that, but I'm not surprised." Farmer, 14-10-2021 "I knew they were in the soil, but not that this came via fertilizers. I didn't know that, that's new for me."*	**Awareness**: None of the farmers knew about the microplastics

	contains a coating, and none knew the exact mechanism. *"I'm in doubt if a farmer really knows what he's using and what's in it. Often they say my advisor advised me this." Applied university representative, 23-09-2021* Representatives of LNV, sector organizations and education also thought farmers would not know about this mechanism and potential plastics. They stated farmers never mention it during gatherings.	*"If it's new for me, than other farmers will not know it either." Farmer, 7-10-2021 "Hey, I didn't know that either, no." "Yes, it doesn't ring a bell for me, or I did not hear about it before. Until you just brought it up, interesting." Farmer, 16-10-2021* Indeed the individual farmers indicated they are not familiar with synthetic polymers in fertilizer or in the coating. Two of them think this is interesting. *"No no, I know there are excipients present in fertilizer, but what's exactly in it, I don't know." Farmer, 15-10-2021* One farmer was familiar with excipients, but not familiar with the synthetic polymers.	in fertilizers. **Low**
Consumers	The representative was not immediately familiar with CRF, after further explanation it was recognized as fertilizer for houseplants.	*"But I wasn't aware what those were made of, or that it released microplastics." "We are aware that microplastics might be present in other products than food, we see microplastics as a growing problem." Consumer organization representative, 15-10-2021* According to the representative it is known that microplastics might be present in toothpaste and cosmetics, but not in fertilizers. Consumers do think microplastics are an important topic, but awareness of consumers is low. Consumers indicated that they worry about microplastics and are not aware that these fertilizers might contain microplastics or what they are made of.	**Awareness**: Consumers know little about microplastics in general, and nothing about microplastics in fertilizers. **Low**
Sector organizations	Both representatives were not familiar with CRF fertilizers. One did hear about it, but they never discussed it within the association. *"I am familiar with coatings from my schooling." Farmers representative, 12-10-2021* The other representative was also not familiar with CRF, although the representative was familiar with coatings.	*"I mean, of course we know what microplastics are, but where they come from is sometimes for us of course also a mystery." Agricultural chain representative, 20-09-2021* *"Look, I understand that it's produced like this, but I'm not familiar with that." Farmers representative, 12-10-2021* Both representatives had never heard about microplastics in such a coating. *"You can conclude that my awareness is zero on this topic." Agricultural chain representative, 20-09-2021*	**Awareness**: Sector organizations do not come across this topic, depending on who in the sector they represent. They are not really familiar with CRF and not familiar with the presence of microplastics in fertilizers. **Low**

Education	*"There are specific courses where fertilization is discussed, focused on the specific sectors of course." Applied university representative, 23-09-2021* According to the representative controlled release and coated fertilizers are addressed in specific courses in the curriculum; however, not in the courses the representative provided. In general, it can be suggested that students and potential future farmers are taught about these kind of fertilizers.	It became not clear if the presence of microplastics/synthetic polymers is discussed during the specific courses. The representative (teacher of environmental sciences) did not show a recognizing reaction concerning the presence of microplastics in fertilizers during the interview.	**Awareness**: Unknown because no teacher from the specific courses was interviewed. **Not known**

In conclusion, the awareness concerning the presence of microplastics in agricultural supplies differs between the stakeholder groups (Table 8). The producers and sellers of the fertilizers show high awareness levels, but the users (the farmers) of fertilizer are not aware at all. Also the Sector organizations that represent the farmers, the Controlling institutions, and the Consumers were not aware. Within stakeholder group Policy NL there were some differences between one's awareness, depending on the specific department/institution within that stakeholder group.

Awareness regarding the consequences of IAMPs in agricultural supplies

Subsequently, the awareness considering the *consequences* of IAMPs in agricultural supplies was examined. Not all stakeholders were aware of the potential presence of IAMPs in agricultural supplies, the awareness considering the consequences of IAMPs in fertilizer was only examined of those that showed middle or high awareness regarding the presence of microplastics. These were Policy NL, Fertilizer producers, and Fertilizer buyers.

Policy NL

'Yes, this coating is made of plastic, or at least a polymer, which degrades very slowly and therefore stays a long time in the soil. And of course concerning plastic pollution, you want to prevent that these kind of products enter the environment.' LNV representative, 24-09-2021

Again some differences between the LNV representatives regarding the awareness can be observed, one of the representatives of LNV shows high awareness regarding the consequences specific for IAMPs in fertilizer. The representative stated that if plastics will degrade well, they degrade into CO_2 and H_2O, which will not form a problem. However, he was also aware that, before the plastics degrade into those two elements, the plastics would first degrade into microplastics, which might form a problem. Because not much is known about the consequences of those plastics in the soil and how dangerous they can be yet, a problem could arise. At the moment, the European Chemicals Agency (ECHA) is working on a proposal about microplastics in different products and the risks and exposure. The agricultural sector and the European Committee for standardization (Comité Européen de Normalisation; CEN) are working on measuring the degradability, because according to one of the representatives of LNV the degradable products are the future. According to the same representatives, there are no signs at the moment from environmental organizations that degradable products will result in a problem.

'You can image at some point that products are that small that they won't form a problem for humans, for animals, for micro-organisms that might take up these products. Because there could be risks, causing

blockages for example because those products are not degradable or carcinogenic. However, until now I didn't, we didn't hear any signals something is happening.' LNV representative, 24-09-2021

The other representative was not aware of the presence of microplastics in fertilizer; however, did show some knowledge about microplastics in the soil and fragmentation processes. Both representatives mention that still a lot about the consequences, for example for human health, is not known yet.

Level of awareness: **Middle**.

Fertilizer producers

The level of awareness regarding the presence of microplastics in agricultural supplies is high for the producers. Both producers indicated they keep an eye/are alert on the effects of the microplastics in the coating and according to one of them they do have the right intention. One of the producers stated no negative consequences are known yet. That same producer also mentioned that this source of microplastic pollution is a really small part, although the representative understood that all small steps can help and we have to start somewhere. They also collaborate in a study to provide more knowledge regarding these effects, which might contribute to a higher general awareness in society. Both representatives of the fertilizer producers stated they would like to improve their products and to minimize the duration of the synthetic polymers in the soil.

'Up until now there are not that many effects known, synthetic polymers are an inert product. We're not familiar with any negative consequences. But we do keep an eye on the consequences, that's why we collaborate in a research study. This collaboration was initiated by us, we want to know what the impact is on the soil and environment for example.' Fertilizer producer, 16-09-2021

The other representative of the fertilizer producers was familiar with the study concerning uptake possibilities. However, the representative emphasized more research is needed. The representative of the producers had no idea the microplastics from additives for example can also end up in our food, and also stated that this source of microplastics was very small compared to car tires for example.

Level of awareness: **High**.

Fertilizer buyers

'The degrading products will be degraded within half a year.' 'The smaller particles, the degraded particles, they will be converted by the microbiology in the soil to such particles that won't be traceable in the soil. It will be processed by the microbiology.' Wholesale representative, 20-09-2021

One of the representatives said they are alert on the microplastics in the coatings. They keep track of whether it is a problem or could form a future problem. The other representative of the fertilizer buyers showed a high level of awareness of the consequences. The representative mentioned that the synthetic polymers have way less influence on the soil, compared to the slow release fertilizers that use acid, just small effects surrounding the granule. The slow release fertilizers with acid will only affect the micro-organisms, macro-organisms will not be bothered. The acid will cause the micro-organisms to be inactive till the acid wears off. The fertilizers with synthetic polymers will have even less influence on the soil, the degradation of the polymers results in nutrient release. The degradation products will end up in the soil, but will be gone within half a year. They will be processed by the microbiology and degraded in such small particles that cannot be found in the soil anymore.

Level of awareness: **Middle**.

In general, it can be concluded that those who show awareness regarding the presence of IAMPs in agricultural supplies are also aware of the corresponding (potential) consequences (Table 8). The level of awareness regarding these consequences does again differ between and within the different stakeholder groups.

Table 8: Overview of the levels of awareness regarding the presence and consequences of IAMPs in agricultural supplies per interviewed stakeholder group.

Awareness of IAMPs in agricultural supplies	**Stakeholder group**	**Level of awareness**
Presence	Policy NL	Middle
	Controlling institutions	Low
	Fertilizer producers	High
	Fertilizer buyers	Middle
	Farmers	Low
	Consumers	Low
	Sector organizations	Low
	Education	Not known
Consequences	Policy NL	Middle
	Fertilizer producers	High
	Fertilizer buyers	Middle

RQ3

What are the factors that influence the willingness to change towards the use of IAMPs in the Dutch AIS and how do they differ between the stakeholders?

According to the TPB by Ajzen et al. [28] (Figure 2) willingness to change (intention) is influenced by attitude, social norms, and perceived behavior control. The factors that influence the willingness to change of the stakeholders will be analyzed following these three factors. Afterwards, the main differences between the stakeholder will be discussed.

Attitude

Attitude is influenced by various factors. Habits, traditions, and demographic factors influence this component, and in this study the factors awareness and risk perception are added. As observed at RQ2 the awareness regarding the presence and consequences of IAMPs in fertilizers differs between and within stakeholder groups. Due to the different factors and huge differences regarding these factors between the stakeholder groups, the attitude component will be analyzed per stakeholder group. At the end a small conclusion regarding the attitude of that stakeholder group will be provided.

Farmers

Much data was gathered regarding this stakeholder group, therefore smaller headings were applied to distinguish between the different components that contribute to farmers' attitude. The fact that the farmers are the direct users of the fertilizing products and are therefore heavily involved, has resulted in long and in-depth interviews and much data.

Beliefs/posture

'Farmers have a good intention'. Fertilizer producer and distributer, 04-10-2021

According to one of the interviewees farmers have a good intention; however, the focus of this intention differs somewhat between farmers. Among farmers there is a difference between those who look critically at the use of fertilizers and those who use fertilizer often and therefore also often use crop protection products. The latter group consists of mostly conventional farmers, that did not show much commitment when talking about reducing fertilizer use.

The more nature inclusive farmers showed a focus on the soil and the soil biology. They were aware of the products they used and the procedures they performed in the context of their soil. They showed a critical attitude against fertilizers and other chemicals and tried to reduce the use of those products by using for example natural enemies. They try to improve their way of farming step by step. When talking during the interview about his equipment one of the farmers deliberately called it his 'poison syringe', which shows his critical/negative attitude against the use of chemicals, although he did still use chemicals on small scale. The more conventional farmers also showed a quite negative attitude against organic farming, and stated that the quality of those products was overrated by consumers.

'We have to do anything to promote the biology in the soil.' 'I think we're sickening our plants by using fertilizers.' Farmer, 07-10-2021

'I look critically at fertilizers. I think it's favorable to use less fertilizers.' Farmer, 14-10-2021

According to the more nature inclusive farmers, this has to do with a critical look and attitude in general. It has something to do with interests, development, and observations. To be critical at what is told and what is taught, one has to think for itself, not just accept everything that is taught. If someone actively asks and looks for certain issues they will find out about some details and benefit from it. Therefore, a critical look at the world influences attitude.

'For me the quality of the crops we produce comes first, the presence or absence of plastics comes later.' Farmer, 14-10-2021

That plastics in general are not favorable in fertilizers and in the soil was for all farmers applicable. In general, the soil is extremely important for farmers, since they are dependent on it for their yield. Farmers want to keep their soil as healthy as possible and in good condition. However, one of them said they would keep using the products as long as they were allowed to be used (see Farmers risk perception). In contrast, one farmer emailed me later to obtain more information, as he was worried and perplexed by what he was told.

'You'll never bring farmers into line with one another.' Farmer, 16-10-2021

Agricultural entrepreneurs all have their own enterprise, therefore they behave individually. There are always farmers who want to join a certain movement, and some that do not. These individual differences became clear during the interviews, although only four farmers were interviewed. This demonstrates the diverse attitudes of the farmers regarding the use of fertilizers (with IAMPs).

'It's the level of knowledge of the farmers, but it's also the knowledge at the ministry, the policies are pointing in the wrong direction.' Farmer, 07-10-2021.

There is already quite some hassle and various regulations around farmers, this has led to a bit of a grumpy attitude of the farmers. Every year regulations are changing for the farmers. Therefore, they will not be applauding if the products they are used to have to change. They will experience this as an extra rule.

'Due to all regulations I comprehend they [the farmers] occasionally think: Oh no, what's wrong this time?' Agricultural chain representative, 20-09-2021

According to one of the farmers for him it feels like the environmental organizations are continuously trying to restrict the farmers even more. He also stated that other regional organizations try to limit the farmers or their areas.

´Also the province wants to construct more nature areas, so we also have to counteract that. To prevent our whole province becomes nature.´ Farmer, 15-10-2021

Habits and trust

Farmers are used to operate in a certain way or with certain products. They trust that approach and know it will work, it is proven effective. If new innovations arrive or new utilities are encouraged, farmers will be reluctant. There is a kind of insecurity or fear that things might fail. If you are used to practicing in a certain way, then you will not switch over a night. First you want to see what it can bring, you might want to start with a small step before you switch completely. Therefore, farmers want to preserve the products they are used to and trust.

'Farmers are frightened to stop fertilizing their soil, to stop adding fertilizers. Because then something happens that you're not used to, and it might fail.' LNV representative, 11-10-2021

Every agricultural entrepreneur runs a farm in its own way, and this can be done in various different ways. Also at a family business, within different generations things can be done in diverse ways. Although farmers like to stick to their original plan, eventually changes will be made over time. This depends if you are in the forefront or rearguard. The basis of running a farm will be the same, there will be no huge differences between different farms in different regions. Although, according to one of the farmers, there can be differences in farming based on the financing burden.

'Times have times [a saying in Friesland]'. Farmer, 07-10-2021

Knowledge and awareness

As observed at RQ2, the level of awareness of the farmers considering the presence of IAMPs in fertilizing products was low.

One of the LNV representatives thinks that farmers will change to alternative products for sure, if it is proven that the products the farmers use will be a risk for the crops/soil or the crops can take up those products and humans can consume them. More scientific evidence and wide distribution of that knowledge will influence their awareness and their attitude and willingness to change.

Additionally, a critical look and attitude of farmers will also lead to a pro-active attitude in search for more knowledge and information which will influence the awareness. Besides, all interviewed farmers stated that farmers mostly obtain their knowledge regarding fertilizing, sowing, different products etc. via the cooperatives or companies they buy their agricultural supplies, like fertilizer.

'We have come to the point where the location where you acquire your knowledge, is the same point as where you buy your supplies.' Farmer, 07-10-2021

Farmers have to understand that this knowledge is a bit biased, because these companies want to sell their products to you. If they will advise you to stop using fertilizers they will lose a customer, so they probably will not do that. Therefore, the farmers have to stay critical on the advice they receive. One of the farmers also mentions that more knowledge and information is present at these selling companies, but they choose to keep it to themselves.

According to one of the LNV representatives there is nowadays a growing number of independent advisors, meaning not via a commercial company. Via the SABE regulation (subsidies to learn about sustainable agriculture) farmers can receive subsidies to consult these independent advisors. However, to find out about these regulations farmers have to look for it pro-actively, since it is not promoted widely and actively.

Additionally, farmers are not really concerned with the different regulations regarding a restriction of the production of agricultural supplies, as long as there are enough products they can use and choose from.

Risk perception

One of the farmers mentioned that the chemicals they add to some agricultural supplies consist of a much higher dose than what is used for e.g. storing potatoes, therefore you should not want to use them. Also another farmer mentioned that the salts and chloride that are added to for example Kali 60 (widely used fertilizer) have a more destroyable effect compared to an addition for the crop, he said it is really bad for the soil organisms. He said you are also cleaning your toilet with chloride.

'As long as it's allowed we shall use it. It has been approved, it has been checked and released for use. We will use what we're allowed to use.' Farmer, 15-10-2021

Farmers agree it is necessary to investigate the potential (health) effects of microplastics in fertilizers and that their presence in the products is not desirable. If fertilizers contain dangerous or alarming elements these components have to be removed, or farmers will probably start using different products. However, as long as it is allowed, one of them stated he will not stop using the products.

'Eventually, these microplastics, they will be taken up by the plant itself. Bon Appetit!' Farmer, 07-10-2021

Although all farmers showed low awareness regarding the presence of microplastics in fertilizers, one of them was aware with the consequences of microplastics in the soil and stated they will be taken up by the crops. He said it is not desirable if such a coating with synthetic polymers would degrade into smaller particles. After mentioning that there is a study that showed that plant roots could take up nanoplastic particles most farmers reacted surprised and were worried regarding the consequences.

'Oh, I didn't know that, no. That would be a bad case, because that would mean that it can end up in the potato. And that would mean we could consume it ourselves.' Farmer, 16-10-2021

Another farmer had heard about microplastics via tv and other media and knew they were carcinogenic and they were already present in the human body in huge amounts (which does not correspond with today's knowledge however). He was wondering how much we as human beings could handle. The same farmer mentioned also that bacteria and fungi can degrade several elements, so potentially also these plastics. As long as you have the right ones and they need some time. He was convinced the micro-organisms in the soil were able to do something with it, but he had no idea if that would result in a positive or negative effect. He also did mention that the real problem for the environment would be plastic, not all the levels of nitrogen everybody is worrying about all the time. Another farmed mentioned that back in the

days no one talked about this, the techniques were not that far yet, and right now it is like the whole world is being polluted.

'You will get ill if you don't receive good quality food. But there's no quality control for our nutrition.' Farmer, 14-10-2021

Concerning the big worldwide fertilizer use and maximizing the yields, one of the farmers said it is probably not the best for our health. Another one stated that by optimizing the quality of the crops you will already prevent many illnesses we have today. He said there is no controlling institution for the quality of our food, there should be one that demands certain elements should be present in the products, like magnesium, iron, calcium etc. Next to that, he said that this might also have an effect on your next generation, good quality nutrition corresponds with children that study better.

'We are the growers, we are being at risk.' Farmer, 14-10-2021

The power in this system lays with the big companies and the supermarkets. They set the price for a certain product, if farmers do not want to sell their products for that price, supermarkets will easily find another farmer that will. The farmers are at risk, for example regarding the flexible prices for onions. Today you might get 10 cents per onion, but tomorrow it can be 8, or 12 cents. That is the market force, we are in a capitalistic system. The prices of fertilizers are also rising, mostly due to rising gas prices. The process of producing fertilizer granules is also not really effective and costs a lot of energy.

'A lot of work, a lot of weeds, low yield and the consumers don't want to pay for it.' Farmer 16-10-2021

The switch to farming without fertilizers also poses more economic risks. First, you have to invest in your soil, you have to make costs, that will not be paid back. Next to that, your yield will be lower. However, if you are organically certified, you will also receive more payments for your output. One of the farmers stated shutting down the use of fertilizer might be desirable, but it is not realistic if you want to feed the whole world. Although, this farmer later got back to this and said it would be possible to solely farm organic on a global level and referred to a WHO report [96]. Also alternatives for fertilizers might be way more expensive than conventional fertilizers and that price needs to be paid by the farmers, they will not be able to set off the extra costs, due to the system.

'The soil here is extremely valuable for farming, the clay adsorbs the water, this is healthy for the plants. Therefore our yield is quite high here.' Farmer, 16-10-2021

Farmers are concerned about their soil, which is their capital, they have to be careful with it. Therefore, they do not want to pollute it with plastics. A higher quality soil will result in a higher yield. Three out of four interviewed farmers said it would be bad and worrisome if plastics would end up in their soil, they worried about the consequences for the organisms in the soil (and perhaps also about the consequences of their yield). However, the fourth farmer was less skeptical, see quote.

'When it might be the case there are microplastics present, we won't just not use it anymore. No that's not how we [farmers] work.' Farmer, 15-10-2021

It was a bit remarkable that this farmer said 'no that is not how we (farmers) work', because he was the only one of the four with this opinion.

In conclusion, the attitude of farmers can differ extremely per individual. For example between conventional and nature inclusive farmers there are big differences, mostly due to a critical attitude in general and regarding the chemicals used in many products. However, there are also some similarities in the attitude of farmers, for example that they trust the products and procedures they are used to and are therefore a bit reluctant to changes or new products. Additionally, due to various regulations that are already implemented for the agricultural sector and the feeling that various organizations try to restrict them, the attitude of the farmers was not that positive regarding the politics in Den Haag and potential new rules. Also, all farmers were quite concerned with their soil quality and additionally the risk perception regarding the consequences for the environment and the organisms of most farmers was high. Especially when the farmers were informed about the potential uptake of microplastics by the crops, most were concerned with the potential health effects. It is shown that nature-inclusive farmers showed the most awareness concerning the consequences for environment and organisms. The other farmers´ risk perception was mainly regarding the economic risks that might arise due to less fertilizer use, mostly about

a smaller yield and a consequently lower income. It became clear that economic risk was for all farmers an important factor.

Policy NL

Both representatives of LNV (ministry of Agriculture, Nature, and Food Quality), stated it was important to look at the topic of IAMPs in fertilizers and additives and to further investigate the consequences. According to one of the representatives, policy institutions can be a bit stuck in the known processes; therefore, it is possible to develop some blindness for new possibilities and innovations which influences their attitude. One of the representatives was a bit reluctant on the upcoming ECHA restriction proposal, since it treats the IAMPs in CRFs and additives the same way, but they might not cause the same problem. Although, this representative also stated it would be best to just not use products that might cause a problem, and to just use products that will degrade for sure.

'If you will state now for example that it won't be allowed to use fertilizer anymore, you will generate a lot of resistance, I don't think that would be a very wise thing to do.' LNV representative, 11-10-2021

According to one of the representatives the future of the agricultural sector would be in the direction of precision agriculture and more about the quality of the products. However, it will not be wise to just implement policies that will not allow the use of fertilizer anymore. In order to use less fertilizers it is important to build up (new) knowledge and widely distribute it.

'Microplastics are whatsoever a problem for soil quality of course. Compost can also contain plastics for example, but those are no microplastics yet. But at a certain moment these plastic particles will also become microplastics, but that's a different route than what you're talking about. So it would be a problem if that would be the case, but how big will that problem be?' LNV representative, 11-10-2021

It is remarkable that one of the representatives stated that microplastics are not on the agenda of LNV and the other said microplastics are definitely on the agenda of LNV. This shows the organization is broad and the focus on various topics can differ between the different departments.

'Microplastics do not fit in nature inclusive agriculture.' LNV representative, 11-10-2021

There is a difference between the two representatives of LNV regarding their attitude. One of the representatives focused on nature inclusive agriculture within LNV and had a positive attitude to change to a system without fertilizers, but not to a system that used fertilizers without plastics. A system with fertilizers without plastics would still use fertilizer and therefore would not be nature inclusive. You do not want to optimize a system (with fertilizers) that potentially has no future. However, the attitude of the representative was still negative against microplastics.

Therefore, within LNV the attitudes can differ, potentially due to the size of the organization and the different topics and departments. For example the more nature inclusive path would result in a more negative attitude to fertilizers in general. Although, the two representatives both did state that it is necessary to investigate the consequences of microplastics in the agricultural supplies and the soil. The knowledge and therefore the awareness concerning the consequences differed between the two representatives (see RQ2), but they both showed a high risk perception regarding the potential effects.

Consumers

Most consumers probably will agree with the social norm that plastics in food are not desirable. Also according to the panel of the Consumentenbond regarding microplastics, with more than 11.000 respondents [97], consumers are not in favor of the addition of microplastics to various products. For this specific topic (microplastics in fertilizers) the awareness of consumers was low, which will influence their attitude.

'We see society desires that we use less chemicals, and less synthetic fertilizers. So that's what we are trying.' Fertilizer producer and distributer, 04-10-2021

According to one of the interviewees society desires nowadays a reduction of the use of chemicals, and therefore less synthetic fertilizers. This shows the attitude of consumers is quite negative against the use of microplastics and other chemicals.

In general, the Albert Heijn is located in urban areas. People who live in big cities like to go to the Albert Heijn, because Albert Heijn is reliable. According to one of the interviewees, people often miss a connection with the agriculture, they do not know any farmers and the agriculture feels a bit further away.

People who live and are close to farmers have more feeling with agriculture, which influences their attitude regarding farmers; therefore, they will buy more often at local farmers. Also people who do not live close to local farmer shops might not have an easy alternative for buying at a large supermarket.

'Consumers will not make a problem out of it and undertake action if the awareness stays this low or if only we tell them.' Consumer organization representative, 15-10-2021

The attitude of consumers is mostly influenced by unawareness caused by a lack of knowledge concerning IAMPs in fertilizers. According to the consumer organization it would be helpful if more scientific/ health related information was available in order to raise awareness amongst consumers and they could provide a comparison between different products for example.

After mentioning that there is a study that showed that plant roots could take up nanoplastic particles the consumer organization reacted worried regarding the consequences. They also mentioned it would be better to prohibit the addition of microplastics soon, especially if the products can also be produced without the microplastics. Why wait with putting it to a halt, if you already know it can have bad effects and that it will be prohibited in the future? They would like to have firm promises from the producers like 'we will stop using them from tomorrow on'. They also stated that the producers should do their best to at least not make the situation worse regarding the plastic pollution problem.

'Yes, that's worrisome.' Consumer organization representative, 15-10-2021

In conclusion, the attitude of consumers against microplastics is quite negative, although specifically for IAMPs in fertilizers most of them are unaware. In general, society wants to get rid of the use of chemicals. Additionally, demographic factors play an important role in the attitude of consumers, because consumers that live more urban tend to lose the connection with the agricultural sector. More awareness of IAMPs in fertilizers might result in a different/changed attitude of consumers.

Fertilizer producers

'We really do have the right intention to improve things together.' Fertilizer producer and distributer, 04-10-2021

One of the representatives stated he always buys his potatoes at a local farm, although he has to pay more than in a supermarket. He does this because he knows how hard farmers have to work. This shows the representative is (a bit) engaged with the rest of the agricultural chain and influences perhaps the attitude regarding changes in the AIS.

One of the producing companies also stated that they are aware on the reactions of society, if these reactions do not match with their actions, they will try to change their message to show society what they are doing. The production process of fertilizers also costs a lot of energy, especially nitrogen fertilizers require a lot of gas and water. This makes it questionable if we want this in today's world (also social norm), which is fine if we do not want that, but what will be the alternative?

'But, yes this is something we are alert on, those microplastics that are in the coating, is that a problem or will it become a problem.' Fertilizer producer and distributer, 04-10-2021

According to one of the LNV representatives the producing companies do want to keep on producing and selling their products. However, one of the producers also said that if their products are causing any problems they of course have to do something about it. If certain products induce some illnesses it is legitimate to restrict them.

As demonstrated at RQ2, the fertilizer producers have a high level of awareness regarding the presence and consequences of IAMPs in fertilizers. In general, the attitude of the fertilizer producers was quite positive against changes in the system, for example if things have to change due to negative consequences for human health. Although, they also implied to look at the bigger picture of plastic pollution, and that no negative consequences were shown yet. This suggests their attitude is influenced by upcoming results from studies and they are not enthusiastic to change already before more information is provided.

Fertilizer buyers

Also the fertilizer buyers will not be applauding if products they are familiar with have to change. Additionally, the introduction of more independent advisors might also influence their attitude against

Policy NL in general, because this might influence their selling numbers. The attitude against Policy NL is also influenced by the gap between theory and practice that has been mentioned in some interviews.

'I do think the health of humans and animals is very important, but sometimes decisions are made without foundation, I have difficulties with that.' Wholesale representative, 20-09-2021

After mentioning that there is a study that showed that plant roots could take up nanoplastic particles one of the representatives asked questions regarding the consequences and also mentioned his expectations on what would happen next.

'The question is what happens after uptake by the roots? What happens inside the plant? I expect it will stay in the root parts of the plant, I don't expect it will be transported all the way to the top and end up in the fruit.' Wholesale representative, 20-09-2021

In addition to this risk perception, the same representative also mentioned that the synthetic polymers have way less influence on the soil, compared to the slow release fertilizers that use acid. However, this representative expresses knowledge that is not in line with literature, see RQ2 regarding awareness of the consequences, which influences the awareness and the attitude of the wholesale representative. Additionally, one of the representatives stated that if there are health risks, they have to be minimized. However, to already restrict this at the first sign of a potential risk is not needed. Then he would like to first see more evidence. If products would be restricted they would also see this as an extra challenge, to still help agricultural entrepreneurs getting the same yield.

In conclusion, the fertilizer buyers stakeholder group showed in general a bit skeptical attitude regarding upcoming policies and regulations. Although they showed high risk perception regarding potential health effects, it became clear that first more evidence needs to be provided before they would show a positive attitude for change.

Sector organizations

According to one of the LNV representatives the sector organizations will not be really enthusiastic if more rules would be applied for the agricultural sector. This can be partly explained by a negative attitude concerning the gap between theory and practice, since it is experienced that policy makers sometimes have no idea how things really work in practice. However, one of the sector organizations also stated that people always think that if products have to disappear it will lead to a disaster, but later it will turn out that we can easily work without those products or use a different solution. Within the sector people try to do more with less already for a long time, for example how to use less manure or fertilizer and still get a high yield.

After mentioning that there is a study that showed that plant roots could take up nanoplastic particles the representatives asked questions regarding the consequences. One of the representatives also showed a concerned reaction as citizen/consumer. This representative was worried about the direct and indirect consequences and asked questions. This showed they care about the consequences and therefore show a high risk perception.

"Yes, my only question is, what happens if these products degrade? As a citizen/consumer I would say: Oops, is that what we want? Until which level will this be degraded?" Farmers representative, 12-10-2021

Additionally, one of the sector organizations mentioned they will not be starting any investigations by themselves, but they would keep an eye on upcoming studies regarding the consequences.

In general, the attitude of the sector organizations shows some similarities with other stakeholder groups. If things are indeed bad for human health they have to change, but they will not take the lead in investigating this. Next to that, more rules and regulations in the agricultural sector will not be appreciated that much.

Controlling institutions

The attitude of the representative of the controlling institutions was quite negative against the use of microplastics in general. The representative showed high risk perception regarding the consequences after providing more information on the potential uptake of microplastics by the crops.

'That might result in a possible food safety problem. How will this end up in the final food products. If it's the root of a crop that's not consumed, then the problem is there. But if it ends up in the edible part of the plant, yes, then we have to find out what will happen? What will be the health effects?' Representative of food and consumer products control, 28-09-2021

In general, the attitude was in line with the precautionary principle, as the representative stated it would be wise to not use products that might have a negative health impact.

Education

This stakeholder group did not provide much input to test the willingness to change. Although, it was mentioned that more research would be required to provide more information on this topic. Additionally, the balance between using fertilizers with plastics (CRFs) and for example the leaching of nutrients into the environment was addressed. According to the representative it is a trade-off of different risks.

Social norms

The socials norms did not differ that much between the different stakeholder groups. In general, everybody agreed or showed signs of agreement with the social norm that plastic in food is not desirable. Additionally, in various interviews it was addressed that everybody should be able to eat and it is a good aim to eliminate hunger in the world. However, not all stakeholder immediately made a link with this social norm. Next to that, everybody wants to be honest and transparent, not to hide secrets for society. This applies for the producing companies but also for honest and transparent communication, avoid complicated terms and make it understandable for everybody.

'Everybody agrees we need to do something about plastic pollution.' LNV representative, 24-09-2021

Another social norm, that might be applicable for just the farmers stakeholder group and other entrepreneurs, is the norm about making profit and therefore continue to exist as an (agricultural) entrepreneur.

'I'm mostly thinking about myself, that might by anti-social. No, it's not, everybody thinks about themselves. And yes, I also want to continue as agricultural entrepreneur, I want to grow and make a profit.' Farmer, 16-10-2021

Perceived behavior control

The factors that influence perceived behavior control also differ per stakeholder group, although these factors did not emerge frequently or in every interview. However, the fact that we are all part of a system and cannot change factors easily was emphasized often. Farmers mentioned that if they potentially wanted to change their way of production, due to the system they just could not change their production ways. They would focus more on cost prices. More in depth details on this system will be provided at RQ4.

The sector organization, that represents all farmers, can run into problems, because farmers can think differently on the use of fertilizer, as can be seen in different ideas between farmers from the cattle-breed faction and agricultural entrepreneurs. Due to the representation of all farmers, this organization cannot move immediately along with for example a reduction on the use of fertilizers.

'LTO finds itself torn between different sides, it is such a big organization.' LNV representative, 11-10-2021

For farmers there are also some factors that influence their ability to perform a certain behavior. The availability of good quality alternatives for example. Next to that, for a switch to a fertilizer free way of farming, the soil needs to change. This will take at least five years, before the yield goes up again and the same quality is back. To bridge this gap a farmer needs a financial buffer and some amount of time. Also, most farmers just act on an individual level and their opinions or their actions cannot easily make a change on a broader level. As mentioned by one of the farmers, you will never bring farmers into line with each other.

Also the consumer stakeholder group consists of individuals, which are hard to bring on the same page, although knowledge and awareness regarding potential harmful microplastics in crops could contribute to this.

Conclusion: differences between stakeholders

The different stakeholders have different positions in the AIS and therefore often have a different view and attitude. Additionally, differences in awareness and knowledge and other factors also result in differences in attitude, social norms, or perceived behavior control and consequently in different levels of willingness to change of the stakeholders.

It can be concluded that attitude is the key variable in explaining the differences in willingness to change between the stakeholder groups in this explorative study. This component differs hugely between

and within the different stakeholder groups. A general conclusion for the attitude of most stakeholder groups is that first more evidence needs to be provided before they agree the situation needs to change. This suggests there is not a positive attitude for change present for most stakeholder groups yet. Some representatives suggested to directly or indirectly act in line with the precautionary principle and to already take some action before more problems will be created. Although all stakeholders agreed that things need to change if negative (human) health consequences would be likely, the risk perception of all stakeholders was quite similar. Another remarkable factor that influences attitude was the aversion against Policy NL and (additional) rules and regulations, which was most remarkable at the Farmer stakeholder group. However, also other interviewees stated there are some differences between theory and practice. Additionally, the economic risk perception in the farmer stakeholder group played a major role in defining their attitude and consequently willingness to change.

The social norms component did not differ that much between the stakeholder groups, in general everybody agreed that plastic in our food is an undesirable situation and everybody needs to be fed in the world. For farmers and other entrepreneurs the social norm regarding making profit also became clear during their interviews.

Also the perceived behavior control component showed no huge differences. Individuals can be hard to mobilize and organize, and farmers and consumers will not easily be on the same page. Next to that, everybody is part of the system and changes cannot easily be made without for example financial consequences. If farmers really want to change, this will take time and money and this influences their perceived behavior control. For organizations that represent a certain broad group it sometimes can be hard to perform certain actions or have certain statements if the interests of the people they represent differ considerably.

RQ4

Under which conditions can a reduction of IAMPs use in the Dutch AIS be efficiently realized?

To achieve desired behavior/actions, in this case a reduction of IAMPs use in the Dutch AIS, the willingness to change of relevant stakeholders plays an important role [28]. Higher willingness to change levels of stakeholders will positively influence reduction behavior and reduction actions. As observed while answering RQ3, the willingness to change between the stakeholders differs substantially.

To answer RQ4, a distinction between various factors should be made. First, the factors influencing the willingness to change will be looked at. Subsequently, additional factors will be analyzed. Eventually a distinction between the different stakeholder groups will be made to prioritize between the stakeholder groups.

Influencing the willingness to change

As concluded in RQ3 the key variable in determining the willingness to change is the factor attitude. Therefore, to influence one's willingness to change it is best to look at how to influences one's attitude. This can be done in various ways, which will be discussed below.

Scientific evidence and research

Almost all stakeholders mentioned during the interviews that scientific evidence plays a key role for this topic. More studies regarding the effects of microplastics on the soil, the crops, and eventually human health need to be performed. If the outcomes will be considered seriously enough and this knowledge will be widely spread by for example media, this will influence the awareness of all stakeholders. However, four of the interviewed stakeholders argued it is already serious enough and we should act based on the precautionary principle. However, limited available information has so far led to low awareness levels within the Dutch AIS (see RQ2; Table 8).

Regarding microplastics research, there are still some technical challenges considering the measurements of micro- and nanoplastics. It is difficult to say something about the smallest particles and the accompanying effects, if you cannot measure them. The development of new detection methods is ongoing, more can be measured nowadays than some years ago. Therefore, the expectations are that better and more accurate detection methods will be developed in the future to measure the degradation products of plastics, but also to detect what happens during degradation.

'The party that pays also decides on the research. Many research studies on crop protection products or fertilizers are being paid by the larger parties.' LNV representative, 11-10-2021

Another factor that became clear during the interviews, is the importance of independency of research. Due to co-financing of research studies, farmers do not trust all outcomes of studies immediately. Next to that, one of the representatives of LNV mentioned that still a lot of research is focused on the standard topics, which might influence the focus of the study.

Information distribution

Another factor that influences knowledge and consequently awareness are the various ways of information distribution throughout the AIS. If more information concerning the consequences of IAMPs in agricultural supplies is available and widely distributed via media, the awareness of all stakeholders that will be reached with this information will increase.

As can be observed from Figure 5, the organizations within the AIS network have (direct) interactions with each other, resulting in information distribution by word of mouth. For example from farmers to subsub-LTOs (regional departments), via sub-LTOs to the national level of LTO and subsequently via lobbying at the ministry of LNV (Figure 5 and Appendix C). More internationally oriented organizations can also attend web lectures from the International Fertilizer Association (IFA).

Specific information regarding fertilizer use or new fertilizing products can also reach farmers in various ways. For example via trade magazines or news letters from sector organizations, or advice via their purchasers, cooperatives, or the business information association (VVB; *vereniging voor bedrijfsvoorlichting*). Although most farmers from the interviews were aware that the information from purchasers could be not completely neutral, it did not became clear if they also behaved differently. According to the farmers, information in trade magazines and newsletters can also be a bit biased, due to advertisements from relevant companies. Via the representative of LNV it was understood that independent advisors could be consulted. To consult such an independent advisor farmers could make use of the SABE regulation (subsidies to learn about sustainable agriculture). Also education organizations can organize courses or masterclasses, for example an applied university that organized those for their alumni. However, none of the other interviewees mentioned those masterclasses from education organizations or the SABE regulation.

'The information about fertilizers in those newsletters/advertisements is always positive, they don't write any critical reviews regarding fertilizers.' Farmer, 07-10-2021

According to three of the four interviewed farmers all information from the trade magazines and newsletters combined is a lot, and consequently are not read that well. Therefore, the most important sources for information for farmers are their colleagues (what is my neighbor doing?), predecessor in the company (how things used to be done), advisors (mostly via the agricultural suppliers), or via open days/evenings of experimental farms/practical centers. Additionally, you can look for knowledge pro-actively via searching on the internet or in books, or attending specific courses.

'Producers will show and promote their new products, but they won't address the effects for the environment into detail.' Applied university representative, 23-09-2021

Higher awareness levels of the different ways of information distribution throughout the AIS could result in a more critical attitude towards information that is provided. For example, farmers could become more aware about the possibility to consult independent advisors or they would develop a more critical attitude towards advice provided by companies.

Attitude

The differences between theory (policies) and practice were addressed in six of the conducted interviews. According to one of the farmers there are two worlds, one on paper and one in practice.

'Sometimes we notice that policies are set and developed, but distant, from behind a desk, without any sense for reality.' Wholesale representative, 20-09-2021

According to one of the representatives of the sector organizations, the average civil servant has no idea about the conditions in the field, they only look at a small part and have no idea about the total picture. That sector organization tried to improve it and to bring theory and practice together. Also other interviewees mentioned the gap between theory and practice. This could potentially be improved by

involving more individual farmers in policy decisions, but this is a common problem in larger systems (more about this topic in the discussion).

In conclusion, more awareness can be created by more knowledge, which can be acquired by doing more (independent) research. Additionally, more independent knowledge distribution can be acquired by investing in independent advisors for the farmers. Higher awareness of the presence and consequences of IAMPs in agricultural supplies will positively influence the attitude, accordingly the willingness to change of stakeholders, and subsequently reduction behavior. Therefore, higher awareness levels need to be achieved in the different stakeholder groups to induce a reduction of the use of IAMPs in the Dutch AIS. To bridge the gap between theory and practice, and the accompanying adverse attitude of some stakeholders, these two worlds needs to be brought together, potentially via more involvement of individual farmers in the policy making processes. Together these factors will contribute to a more positive attitude of the stakeholders towards a reduction of IAMPs in the Dutch AIS.

Additional factors

Influencing the attitude or willingness to change of the stakeholders will not be sufficient for a reduction to be set into motion. During the interviews it became clear that more factors come into play, which are listed below.

Development of alternatives

The development of products that do not contain IAMPs plays a major role in the reduction process. According to one of the farmers, the Netherlands are world leader in the field of agricultural innovations. The past 15-20 years, already a lot of innovations have been implemented, so this should be possible too. More and new products should be developed.

'Innovate or die.' Fertilizer producer, 16-09-2021

In response to the upcoming regulations, producers are already developing alternatives, using faster degradable or bio-degradable polymers. This can still be IAMPs but they have to degrade faster. However, this developing process is hard, since the standards the products have to meet are not set yet. This means until now producers are innovating, but they do not know the exact direction yet. According to the representative of education, the technologies to check the new developed products are a bit behind, they are not adapted yet to inspect the new products. The existence of these measurement methods is essential, otherwise the enforcement will be hard. Also some market developments are necessary to develop good alternatives.

'But, this should not go from bad to worse. The newly developed materials should not subsequently cause a new or different problem.' Representative of food and consumer products control, 28-09-2021

The developed alternatives will not be by definition an improvement, it has to be checked whether these new products will not eventually form a new or different problem. Additionally, the alternatives could be more expensive, which influences the willingness to buy of the farmers. If few differences in performance between current fertilizers and alternative fertilizers could be demonstrated, for example via the experimental farms/practice centers, farmers would be more likely to buy them. Furthermore, if the effects of the alternatives are even better than the other fertilizer, for example they induce more growth or more tubers will develop, the farmers will be interested. According to a representative of a the sector organization, it is important to keep the wide range of agricultural supplies, since farmers use various different products. This means also various different alternatives have to be developed. If certain products disappear, farmers will switch to different products, which is only possible if the range of different products remains wide.

'Also the natural alternatives are not always that degradable. Elements that occur in nature do not necessarily score better.' Producers representative, 12-11-2021

According to one of the farmers there are also other alternatives that can be used for fertilizing the soil, for example elements or waste that is produced during certain processes of processors. These materials are not expensive and could also be used as soil fertilizer. This same farmer also mentioned that it really depends under which prosecution the products are classified, for example if you call it pesticide or biostimulant you have to go through a whole different process.

One of the representatives of the producers mentioned that some users highly depend on their products, but have to switch to alternatives because of the EU FPR. If they will not succeed the users have to find another alternative or use conventional fertilizers, but they need some time to adapt to the new situation. One of the representatives of LNV also mentioned it is important to provide everybody with sufficient time for the transition and to not set a certain regulation too quickly.

Economic factors and the capitalistic system

One of the other factors that was also mentioned in every interview was money. It became clear that the price of alternatives or a potential lower yield would extremely influence the reduction behavior. Especially for farmers, which is mostly due to the capitalistic system we are in. Farmers use fertilizers to obtain a higher yield.

'If the government would make sure we will receive a higher price for our products, we might buy the more expensive fertilizing products.' Farmer, 16-10-2021

If agricultural supplies would become more expensive, the farmers have to pay more for their supplies. However, that will not influence their yield, so they will still get the same price for their products/output. This would mean they have to invest more, but will not get a higher income.

'If all farmers would be multimillionaire, we might succeed to not settle for a low price. Then we might enforce a higher price.' Farmer, 16-10-2021

It would be nice if we would get a higher price for our products, which might be realized on a national level, according to one of the farmers. But, most farmers take part in the global market, and the general view there is: optimize the production for the lowest price possible. In Europe there is one market, although there can be some regional differences. Globally, there are global trade politics which result in trade deals between countries. Individual farmers do not have the power to interrupt that system. If a farmer needs some money, the farmer will sell the products. You will not be able to bring them into line with one another and enforce a higher price for your products for example, unless, according to one of the farmers, all farmers would be multimillionaire and money would not play such an important role.

'Voluntary subsidies for farmers that reduce their use of fertilizer would definitely work.' Farmer, 14-10-2021

One of the solutions that might help would be a subsidy. According to one of the farmers this would definitely work, and this has worked before in the case of manure injection. Farmers are continuously balancing the pros and cons, they might go for the subsidy if this would financially benefit them.

If there's no profit to be made, nobody will change, the stimulus to change won't be big in that case. Actually, there's a system change necessary to get rid of it. LNV representative, 11-10-2021

Political factors

There is (logically) some overlap between the economic and political factors, for example regarding trade agreements and the economic system. In general, agricultural related policies have their origin in Brussels, and are applied all across Europe. The implementation of such regulations can differ a bit per country, but in general these are taken over completely. There are some differences between countries of course, which can result in different implementations. For example in the Netherlands, due to intensive farming behavior there is a structural manure surplus, which is not the case is some other European countries and therefore results in different fertilizing policies. We can also learn from other countries, how they cope with certain problems for example, therefore we should also monitor other countries.

'The Netherlands characterizes itself by an intensive way of farming, as well in livestock farming as in agriculture.' Producers representative, 12-11-2021

In general, according to the representatives of LNV the Dutch government is not really into being more strict than necessary. We are always a bit behind and do not take the lead. This in comparison with the view of other stakeholders within the AIS, as one of them said the Netherlands always want to be the most virtuous. The Netherlands cannot without explanation set stricter rules regarding certain products, since this forms a trade barrier and that is not allowed in the EU.

'Experience shows us policies will be made if the problem is already there.' LNV representative, 24-09-2021

Within the ministry of LNV the departments have different focusses. This ministry has only been in its current form since the beginning of the present cabinet. Some departments focus more on short term

actions, some more on the long term (see next paragraph concerning developments in the Dutch AIS). Recently, LNV has formulated a vision focused on a movement towards circular agriculture, called Kringloopvisie or Realisatieplan Visie LNV. Within European meetings the Dutch are always in favor of more sustainable destinations of European subsidies, for example the EU agricultural subsidies, for all farmers in the EU. Additionally, there are the 'green subsidies', for which a farmer is eligible for if they, for example, sow green manure for a certain amount of weeks.

'It's obligatory to take part in these green subsidies.' Farmer, 14-10-2021

It is quite remarkable that according to one of the farmers it is obligatory to participate in this green subsides, he mentioned these were not voluntary. Additionally, the farmers mentioned a different number of weeks the green manure had to be grown, which should be the same for all farmers. This might suggest the rules are not that strict or the farmers are not up to date with the existing rules.

'You can't set demands for matters you can't measure.' LNV representative, 24-09-2021

In order to make policy regarding the use of IAMPs in agricultural supplies, more knowledge and good definitions are needed. The controlling institutions need a legal standard, potentially on EU level, to enforce such policies. Next to that, there were, according to the producer representative, also some discussions if the fertilizer additives should be really considered as microplastics. This is in line with the statements from one of the LNV representatives that not all IAMP sources in agricultural supplies should be treated the same way beforehand. More research is needed on the degradation processes. One of the farmers stated that the governments controls anything, like the crop protection products and fertilizers, but not the food quality. This once again confirms the negative attitude of farmers against the government.

Some big organizations are also lobbying against or in favor of certain policies and influence certain processes or decisions. According to the LNV representatives the nature organizations are less involved in these processes compared to the larger sector organizations. This is also confirmed by various farmers that state the industry has a powerful lobby. One of the representatives of one of the sector organizations stated that this could be the next discussion, as was the case with the crop protection products, it should be ensured that this will not be an eternal continuation of more and more discussions.

'We really should tackle this problem on a global level, but that's never going to happen.' Farmer, 16-10-2021

The upcoming regulations regarding fertilizers are on European level. One of the farmers asks how this will influence countries outside of Europe and states it should actually be dealt with this on a global level.

According to one of the LNV representatives first a decent vision needs to be developed in collaboration with various sector organizations, farmers etc., to establish the direction of the Dutch AIS. Additionally, rules are needed, because in general it is known that the last ten percent will not embark with just policy, you have to make them join. So you need a combination of both a joined vision and some regulations. Subsequently, the house of representatives needs to agree as well. Furthermore, you need to distribute the knowledge and stimulate the stakeholders, because with only rules and regulations you will make some enemies.

'You'll never bring farmers into line with one another, unless on political grounds.' Farmer, 16-10-2021

Protests can occur if people do not agree with the policies, like the farmer-protest in Den Haag. One of the farmers did, at least for the first protest, agree with the action and thought it was a good statement to express the dissatisfaction. So in this case farmers can be on the same page, if they do not agree with the policy that applies to all of them.

Developments in the AIS

There are some developments in motion in the Dutch AIS. For example, terms like circular agriculture and precision agriculture came by in various interviews and were mentioned by different stakeholder groups, and these terms can also be found in the Kringloopvisie from LNV.

'There are still some gains to be made for us in the future. For example by not fertilizing our whole area, but to do this more precise.' Farmer, 16-10-2021

The intentions might differ between the stakeholder groups. For example for farmers, if they need less fertilizer that will result in less investments. For nature organizations this is mostly to farm more in a nature inclusive way. Some organizations are looking at fertilizer alternatives, which can be realized by, for

example, the separation of organic manure, so not the use of slurry, or even use human manure in the future. The fertilizer alternatives can also be fabricated by regained products. Also, the fertilizer producing companies are developing various projects and innovations to get more out of the organic flows of manure. They stated they do that because the market asks for it. According to one of the representatives of the fertilizer producers this also depends on the type of enterprise, if you are a listed company you have to keep your shareholders content. So innovations will only be the result of regulations. In family businesses this is different, they try to survive and therefore need to innovate.

'In the whole chain we're looking at the use of less manure and fertilizer, and to still get a high yield.' Agricultural chain representative, 20-09-2021

Also within the agricultural chain they are looking at minimizing the use of manure and fertilizers, which is one of the motives for precision agriculture. They also mention manure is actually wrapped fertilizer.

'If your soil is alright, the use of fertilizers is way less urgent.' Farmer, 14-10-2021

One of the farmers suggests to provide all farmers with lessons of botany and soil sciences. If farmers improve their soil quality, they can use less fertilizers.

Between the farmers there was some disagreement regarding the possibility to feed the whole world if a switch to a fertilizer-free system was made. Initially three farmers agreed on the fact that this would be definitely impossible, since the yield would be lower and therefore not enough products would be produced. However, after the interview one of the farmers reconsidered and mentioned a report from the WHO that had studied and described this would be possible [96]. Also one of the LNV representatives mentioned an example of a recent adopted motion regarding the phase out of crop protection products, which results in the whole agricultural sector being turned upside down, and protested about food security. But the representative stated that if we would continue like this and do not change anything in the AIS, we might also end up with food scarcity.

Focus on specific stakeholder groups

According to the power interest grid (Figure 6) some stakeholder groups have more power than others; therefore, if reduction behavior in certain stakeholder groups can be influenced this might contribute more efficiently to a reduction of IAMPs than if others would be influenced. The next paragraphs will discuss some important stakeholder groups.

If the stakeholder group Policy NL/EU decides to propose stricter rules regarding the use of IAMPs in the Dutch AIS, a reduction could be achieved. Therefore, the willingness to change of this stakeholder group also has some overlap with possible reduction policy measures. Influencing regulations on EU level might be a bit difficult, due to other factors that need to be considered and members that have to agree. However, on national level this might be more feasible. Although it might not be possible to implement stricter regulations than on EU level, the Netherlands can focus more on Dutch policies. For example, explore the possibility of a subsidy for farmers who will not use fertilizers at all, or specifically use fertilizers without IAMPs. Since developments in the AIS are also pointing in the direction of a more sustainable use of products and a focus on circular agriculture, this might fit in the future direction of agricultural policies.

The fertilizer producers are already innovating their products to meet the requirements of upcoming EU regulations. However, standards for the period the synthetic polymers will be allowed to stay in the soil are not developed yet. If the producers completely prevent the use of synthetic polymers in their products this would be even better. This way no microplastics would end up in the soil, not even for a short period. This would definitely contribute to reducing the use of IAMPs in the Dutch AIS.

The purchasers of the output of the farmers can also play a major role. During the analysis of the economic factors and the capitalistic system it became clear that the supermarkets determine the products they buy from farmers and determine the price. If they decide to look at the production processes of the crops and not only buy the cheapest products (which might be driven by the wish from consumers), they might influence the behavior of the farmers. If the farmers get more money for their products if they use less or no fertilizer at all, they might switch. Influencing the willingness to change of the purchasers of the output can clearly contribute in the reduction of the use of IAMPs in the Dutch AIS.

For consumers, more and broad distributed knowledge will also result in higher awareness levels. However, they are not the users of the agricultural supplies. Although, CRFs are also used in flower pots by

consumers, those are not connected to the food production chain. Consumers can contribute to a reduction of IAMPs in the AIS by, for example, choosing for products that are produced without IAMPs, this choice might eventually influence the choice of the Purchasers of the output farmers as mentioned above. To distinct between products with and without IAMPs a special hallmark could be developed, which will also contribute to an increase in awareness of Consumers. In conclusion, more awareness might result in more power of the Consumer stakeholder group.

It became clear in all interviews that more and clear evidence regarding the consequences of IAMPs in agricultural supplies should be provided. Therefore, another important stakeholder group is Research. As this stakeholder group does not have a direct effect on the use of IAMPs in the Dutch AIS, improving the willingness to change of the stakeholder group Research will not contribute directly to a reduction of IAMPs. At the moment, studies are performed to gain more evidence on the effects of microplastics and their pathways and consequences in the human body [98].

Although farmers are individually oriented and do not have high power, they might obtain high power if organized and on the same page. This can be accomplished by higher awareness and knowledge, which will influence their willingness to change. Specifically more knowledge on the consequences of microplastics on the soil will contribute to this, since the soil is the most important factor and capital for an agricultural entrepreneur. As this is mostly dependent on research and scientific evidence, their focus should also be on consequences directly on the soil. Nevertheless, if farmers would like to change they still need enough money, time, and knowledge.

In general, the education stakeholder group wants to teach broad, essential knowledge for the agricultural sector. They do provide courses which present information regarding manure and fertilizers. During these courses accompanying risks and consequences of specific fertilizers could be addressed, which contributes to increasing levels of awareness. Although, it did not became clear if this was the case. Education has high power, because this stakeholder group can influence all agricultural entrepreneurs and other stakeholders.

The media has an important role, if scientific evidence will be provided and potential health risks will be known, the media can have a catalyzing role and contribute to the increase of awareness for all stakeholder groups.

To efficiently realize a reduction in the use of IAMPs in the Dutch AIS, a prioritization between the different stakeholder groups has to be made. A specific focus should be established on improving the willingness to change of the following stakeholder groups: Policy NL, Fertilizer producers, and the Purchasers of output farmers. A change in the behavior of these stakeholder groups might have the biggest consequences for a reduction of the use of IAMPs in the Dutch AIS and will therefore contribute to an efficient realization of a reduction of IAMPs in the Dutch AIS.

Discussion

Based on the literature review proposed in this research, this study is the first to investigate the awareness and willingness to change among different stakeholders in the Dutch AIS regarding the use of IAMPs in agricultural supplies. In order to dive into the use of IAMPs in the Dutch AIS, this study first demonstrated some Dutch emission numbers of IAMPs by agricultural supplies. These were calculated in line with the calculations for EU level by ECHA [24]; however, different sources have a different view regarding the specific Dutch level. Some state that the use of CRFs might be higher in the Netherlands in comparison with Europe, others state that the Dutch numbers are lower (as said by the Producer representative). Additionally, still a lot regarding other additives and other types of CRFs is unknown. Therefore, these numbers need to be further specified by in-depth research to provide a complete view of the Dutch contribution of plastic pollution by IAMPs in agricultural supplies. Furthermore, all stakeholders in the Dutch AIS involved with the use of IAMPs were displayed. Together these findings have provided a setup for the research objective which is in line with the precautionary principle: to investigate the dynamics towards a reduction of IAMPs in the Dutch AIS.

Theoretical framework

This study used an extended version of the TPB by Ajzen [28], with the additional factors risk perception and awareness that influence the component attitude (Figure 2).

The added factor risk perception influenced the attitude of stakeholders in different ways, since there were quite some differences regarding this factor between stakeholders. An example is the economic risk that especially popped up for farmers. One of the common criticisms on the TPB is the lack of incorporation of contextual variables, relevant examples like financial constraints, lifestyles, or economic costs. Financial aspects can act as barrier in adopting environmental behavior [99]. It can been argued if economic factors can influence the intention of an individual to perform a certain behavior. In this study it was proposed that financial aspects can influence attitude directly and indirectly via the risk perception factor, but also perceived behavior control can be influenced by economic factors. However, economic factors can also be categorized as additional factors and will be further discussed in the next passage. An additional element of differences in risk perception is the difference between hazard and risk [92]. In this study both concepts were be incorporated, as will also be discussed in the next paragraph.

The factor awareness is potentially more complicated and less straight forward than suggested by the simple extension of the TPB. Awareness is influenced by knowledge and influences the component attitude. However, the component attitude can also influence the awareness of an individual [100]. Ahmed et al. showed that the (indirect) effect of awareness depends on the level of awareness, for example in groups with high awareness the factor attitude influences intention more strongly than the social norms. In groups with lower awareness, the social norms play a bigger role in determining intention. Additionally, another study showed environmental awareness did not significantly affect the intention of for example single-use plastic reduction behavior [101]. Therefore, awareness can positively influence the relationship between other variables, but does not influence (indirectly) intention by definition.

Furthermore, the TPB is mostly focused on individual behavioral changes, but in this study the change of behavior of certain (stakeholder) groups is studied. However, the behavior of a group is of course also influenced by behavior of individuals and it is demonstrated that agricultural changes are mainly influenced by individual motivations [76].

Findings

One of the key findings of this study are the differences in knowledge and consequently awareness regarding the presence and consequences of IAMPs in agricultural supplies between and within stakeholder groups. For example, Fertilizer producers showed high levels of awareness regarding the potential negative (health) consequences, yet this did not result in a higher willingness to change. One of the representatives of this stakeholder group was aware of the potential uptake of nanoplastics, but this did not result in a positive attitude towards a reduction of IAMPs. It was stated that more research is needed. This suggests just raising awareness regarding potential consequences is not sufficient to increase willingness to change, at least for this stakeholder (group). This is potentially stakeholder dependent, because most other stakeholders, e.g. some farmers, did show a change in attitude when confronted with potential consequences. This is in line with literature, which states farmers' attitude would change towards pro-environmental behavior if they become aware of negative consequences [87]. So, raising awareness about consequences has different effects on attitudes for different stakeholders. For some stakeholders a potential risk was not enough to positively influence their attitude and their willingness to change. This group desired more scientific evidence and more information regarding the risks. For others, some farmers, the hazard was sufficient to influence their willingness to change. One of the farmers asked for additional information and was even already undertaking reduction behavior.

The interviews showed that knowledge from stakeholders regarding microplastics and potential (health) effects did occasionally not match the scientific knowledge state-of-the-art. Therefore, stakeholders sometimes thought they were familiar with potential consequences, but some information they provided appeared to be not in line with scientific evidence. An example is the assumption that smaller particles do less harm than bigger ones, which is in contrast with literature that suggests smaller particles have a bigger impact [2]. This has influenced the awareness of the stakeholders, for example the awareness regarding consequences of Policy NL or the Purchasers of output farmers. Although both groups

met the definition for awareness that was set for this study (see the Methodology), the knowledge they provided was sometimes not in line with current scientific evidence. Therefore, the high awareness level for these two groups should potentially be adjusted to Middle.

It was expected that farmers would be more willing to change, since literature suggested that nature connectedness was correlated with pro-environmental behavior [88]. Although only four individual farmers were interviewed, there are clear signs that not all farmers were ready to perform pro-environmental behavior when confronted with the potential effects. The interviewed farmers showed that they care about their soil quality, since the soil is their capital and they agreed plastic in the soil would not be favorable. In addition to that, it has been shown that microplastics in the soil can adsorb pesticides [102] and increase the duration time of pesticides in the soil. This would also influence soil quality and consequently influence the attitude of farmers. Therefore, more knowledge regarding the indirect consequences of microplastics could also influence attitude and eventually willingness to change of farmers. Microplastics in the soil also influences the yield [19], which influences the attitude of farmers based on economic risks. The gap between theory and practice, mentioned by stakeholders, influences their attitude. This gap might be (partly) bridged by e.g. the involvement of individual farmers in policy making processes. According to the Value Beliefs Norms model, the factor trust plays an important role in determining intention, additionally trust can positively influence pro-environmental behavior [77]. The mentioned gap between theory and practice suggests trust in Policy NL is not that high for all stakeholders and might therefore also influence their willingness to change. Higher levels of awareness of stakeholders might also result in more support for political measures by Policy NL/EU.

The wish/need for more scientific evidence and clear information influences the use and the willingness to change is. At the moment, there are different research studies performed regarding the consequences of microplastics, which will contribute to more scientific information. For example the MOMENTUM project of ZonMw [98], which is a Dutch national wide project with multiple studies to investigate the human health consequences of microplastics. Recently, the preliminary results were published, and the negative (human) health effects were confirmed once again, but it is uncertain till what extend. Therefore, they extended the research and called to continue with these studies [103]. Additionally, European projects like MISSOURI [55] and MINAGRIS [56] have started and will specifically look at plastics in agriculture. Technical challenges, like the detection limit for nanoplastics or difficulties of measuring samples in certain matrices, are still present, although steps are made on a global level to resolve these challenges [25].

The (possibly) biased method of information distribution by the producing and selling companies to farmers, is in line with the need for more clear evidence. Via the SABE regulation, farmers could e.g. receive subsidy to conduct independent advisors. None of the farmers mentioned this regulation, which suggests this regulation is not generally known. When diving into this SABE regulation it became clear the application is at the moment closed for some components of the regulation, since the budget for these components is already entirely spend [104]. One of the closed components is the possibility to acquire independent advice. This suggests at least some farmers knew about this regulation and shows there is a need for independent advisors for farmers. That suggests there might be a willingness to change among farmers regarding independent advice in the direction of more sustainable farming.

The awareness of the stakeholders is highly dependent of knowledge and information and therefore it is important to understand how information is distributed within the AIS. Newly required knowledge should be distributed to all stakeholders in the AIS. Reaching farmers could take place via the SABE regulation; however, since not all farmers are familiar with that regulation, also various newsletters, journals etc. should be approached. In general, the media will play a key role in the distribution of this additional knowledge, to also reach all other stakeholder groups.

The role of the stakeholder groups that should be prioritized (i.e. Fertilizer producers, Policy NL, and the Purchasers of output farmers) is different within the AIS and they have different power. The Fertilizer producers are producing the products, they must follow regulations regarding the production set by Policy NL/EU. If this entire group would decide to stop using IAMPs in their products, a reduction can be realized quite easily. However, this group contains various different companies, some located in the

Netherlands, but also other countries (EU and globally). This is where the market forces come into play, which implicates all fertilizer producers have to change and stop using IAMPs for their products. Therefore, a change in behavior of only this stakeholder group in the Netherlands will not result in a reduction of IAMPs. Additionally, the willingness to change of this stakeholder group tested by this study was not high. For example, a health hazard by the use of IAMPs in their products was not enough to result in a positive attitude regarding reduction. This indicates it can be harder to eventually realize reduction behavior in this stakeholder group. The second important stakeholder group is the Policy NL group. If this group becomes more willing to change this might result in political measures. The Dutch policy can set stricter regulations regarding the use (and production) of IAMPs in the Dutch AIS. Also other policy instruments can be promoted, like subsidies for farmers that use no or less fertilizers. Because the Policy NL stakeholder group is large and contains different interests, the willingness to change differs extremely between individuals in this stakeholder group. The Purchasers of output farmers were not interviewed for this study, but it can be stated they have high power due to their role in the capitalistic system and market. The economic factors play a potentially major role in determining their behavior. If they decide to attach more value to a plastic-free/ plastic-low crop production process and less to purchasing the crops for the lowest price possible, they could play an important role in realizing a reduction of IAMPs in the Dutch AIS.

This research focused on the factors that influence willingness to change and how the behavior of relevant stakeholders could influence a reduction of IAMPs in the Dutch AIS. However, during the research more additional factors (apart from the factors influencing the willingness to change) that can also influence an efficient reduction came to light. These additional factors can potentially be tackled with political instruments.

There is an on-going discussion about the definition of microplastics. Multiple NGOs argue the definition ECHA proposes [65], which was also used in this study, is not covering the whole scope of microplastics. They argue to further restrict the definition and also add water-soluble polymers, nanoplastics and biodegradable microplastics, for example. They argue that the exemptions in the current proposal should be removed. Additionally, the question arose if the transition to biodegradable polymers will solve the problem [105]. This transition might result in a similar situation in the future where these adjusted materials may cause a problem. This is contrary to another discussion that was held within the producing sector, regarding synthetic polymers used in fertilizer additives should not even be handled as microplastics. However, this study has used the ECHA definition and considers the additives as a microplastic source. This shows once again there is a high demand for an uniform definition that is applied EU-wide, which can additionally be used by controlling institutions to enforce new regulations.

The developments of alternatives influences the reduction of use and production of IAMPs in the Dutch AIS. The discussion regarding the environmental effects of bio-based and biodegradable products is still going on [32]. Although a reduction in the use of fertilizers in general will also contribute to a reduction of IAMPs emission by fertilizers, it is advised to not immediately focus on a complete fertilizer reduction. This would be a huge step and not feasible in the near future. Thus, a focus on specific reduction of fertilizers with IAMPs is recommended.

Proposed factors that reduce IAMPs use and subsequent a reduction of microplastic pollution are in line with the ten recommendations for reduction, proposed by the Prata et al. study [70]. They formulated ten recommendations to mitigate plastic pollution, of which the regulation of production and the development of alternatives also popped up as reduction contributing factors.

As shown by the numerous requests for the SABE regulation, there is willingness to change, which has resulted in a first step regarding more sustainable farming. This shows that subsidies can stimulate in achieving certain behavior and potentially an upcoming reduction of IAMPs in the Dutch AIS. Of course, this is a complex process with various next steps.

The agricultural sector is one of the biggest plastic polluters, this also applies to IAMPs [2]. This research has shown some specific amounts of micro- (and nano)plastic pollution by agricultural supplies in the Netherlands. However, these are mostly estimations, some relevant information is not known or not public and there is some discrepancy regarding the exact numbers. These calculations need to be further specified to identify the exact emission numbers of IAMPs by agricultural supplies in the Netherlands. The

exact numbers might contribute to an increased willingness to change of the Policy NL/EU stakeholder group. Additionally, this research has shown that the awareness of the presence and consequences of IAMPs in the Dutch AIS is low and the willingness to change of the relevant stakeholders is consequently not that high. To efficiently reduce the use of IAMPs in the Dutch AIS, a combination of a change in behavior of the relevant stakeholders and the use of policy instruments (subsidies and/or restricting regulations) should be realized.

Limitations

This study has shed some light on the use of IAMPs within the Dutch AIS and the relations and interactions between the different stakeholder groups. This research was an explorative study and time constricted; therefore, not all stakeholder groups that were interviewed contained multiple representatives and not all relevant stakeholder groups were interviewed. For example, the stakeholder group Purchasers of farmers output, e.g. the supermarkets, was not interviewed. Still, it became clear during this study that this group has (market) power and influencing their willingness to change can have potential high effects. Therefore, it is recommended to include this stakeholder group in further research and to investigate how to specifically increase their willingness to change. Also, the other stakeholder groups should be further analyzed by approaching numerous representatives per group, since statements in this study are sometimes based on one or two individuals. This will increase the validity and reliability of this study. Additionally, the demographic factors of the respondents should be further investigated, for example the differences between rural and urban areas. As became clear during several interviews, this factor could be important in influencing attitude and willingness to change.

Due to its explorative nature, this study came across various topics and factors that play within the Dutch AIS, but future research should focus on certain topics for further exploration. For example; the details regarding the use of fertilizers, or the gap between theory and practice, or the accompanying negative attitude to policy.

Additionally, since the use of IAMPs is also on EU level or even global level, it would be interesting to look at other countries. The upcoming regulations will be enforced on EU level, but can be implemented slightly different per country. Although agricultural and fertilizing situations can be totally different between countries, the factors influencing willingness to change might have some overlap which can result in potential improvements on Dutch level.

This research is the first to study the awareness and willingness to changes of stakeholders in the Dutch AIS; therefore, this study has filled some research gaps, but has also highlighted various new gaps (theoretical and research). This research looked at the awareness and willingness to change of various stakeholder groups in the Dutch AIS, but it should be studied further how both of these concepts could be increased most efficiently for the different stakeholder groups to realize an efficient reduction. This research also enhances the understanding of policy makers upon the intention of stakeholders, which they can use in the implementation of regulations or campaigns. Although regulations regarding the use of IAMPs are on their way, these regulations might not solve all potential proposed problems. For example, the ongoing discussions about whether bioplastics/ biodegradable plastics are the solution, definitely demonstrate the urgency of this study. Therefore, with the upcoming regulations the plastic pollution problem is not improved yet.

Conclusion

The stakeholders in the Dutch AIS that are associated with IAMPs in one way or the other are: Policy NL/EU, Fertilizer producers, Fertilizer buyers, Farmers, Purchasers of output farmers, Consumers, Sector organizations, Advisors, Research, Nature organizations, Education, Controlling institutions, and Media.

The level of awareness regarding the presence of IAMPs in agricultural supplies differed significantly between stakeholders. In general, those who show awareness considering IAMPs in agricultural supplies are also committed to the corresponding consequences. In conclusion, the level of awareness regarding the presence of IAMPs in agricultural supplies was *low* for Controlling institutions, Farmers, and Consumers, *middle* for Policy NL and Fertilizer buyers and *high* for the Fertilizer producers.

The level of awareness regarding the consequences of IAMPs in agricultural supplies was *middle* for Policy NL and Fertilizer buyers and *high* for Fertilizer producers. Within stakeholder group Policy NL there were different levels of awareness, depending on the specific department/institution within that stakeholder group.

Attitude seemed to be the most variable factor within and between stakeholder groups and the key variable in determining the willingness to change of the stakeholders. Awareness and risk perception played a major role in determining attitude, as big differences exist in attitude on e.g. hazard versus risk.

To realize an efficient reduction of the use of IAMPs in the Dutch AIS, various factors and conditions should be improved. A combination of policy instruments and a change in behavior of the stakeholders is required. Therefore, higher levels of willingness to change of all stakeholders should be realized. For efficient reduction, Fertilizer producers, Policy NL/EU, and the Purchasers of output farmers were identified to be the most important and potentially most influential.

More scientific evidence and independent distribution of information might influence the awareness of the stakeholders and consequently attitude and eventually willingness to change. Not all technical challenges that delay scientific evidence will be solved in the near future, but improvements are in development. Other factors that influence a reduction of IAMPs in the Dutch AIS are the developments of alternatives. New products have to be developed and they should not cause another problem, for example negative implications for the environment or human health. Due to market forces, a reduction cannot easily be achieved by just behavioral changes of some stakeholders. Additionally, the capitalistic system acts on a global level, since products can be traded globally. Policy instruments can tackle other additional factors (apart from willingness to change) that influence a reduction, like subsidies for farmers that use less or no fertilizer, since this also worked in the case of manure injection. Furthermore, an EU-wide (or even global) uniform definition of microplastics should be established for consistent research and a reliable enforcement of upcoming restriction policies. Policies restricting the use of IAMPs can be developed. First, a central vision by LNV and the agricultural sector in combination with some regulations is required before these policies can be efficiently implemented.

The extended version of the TPB was helpful as theoretical framework for this explorative study. However, to dive even deeper in the willingness to change for this specific topic, a more detailed extended version of the TPB should be used. This ensures that, specific for this topic, the role of more and different factors in relation to the willingness to change could be further explored. Additionally, the factor awareness should be further implemented in the theory, since this factor does not only influence attitude in one way. The factor awareness can have more indirect effects and attitude can influence awareness. Lastly, this theory is mostly based on individual behavior and if one would also want to further investigate the role of economic factors a different theoretical framework should be chosen.

Recommendations for host organization

This research has been executed in collaboration with the Plastic Soup Foundation (PSF). With the outcomes of this explorative study some recommendations can be provided for the host organization. This NGO acts in line with the precautionary principle and would like to see a reduction in the use of IAMPs in the Dutch AIS. This research has contributed to mapping the current situation in the Netherlands and formulated recommendations/conditions that would improve a reduction of the use of IAMPs in the Dutch AIS. More specific emission numbers by the use of IAMPs in agricultural supplies for the Netherlands contribute to putting the agricultural sector on the agenda as a huge source of microplastic pollution. Additionally, with these further specified Dutch emission numbers, more pressure can be put on the European Committee and/or Dutch governmental lobbyists to demonstrate once again and fiercer that change is really needed. The PSF can lobby on Dutch policy level for strict regulations, but can also influence on EU level. Additionally, they could lobby for subsidies for agricultural entrepreneurs that use less or no fertilizer at all. Lastly, PSF can also press for more research regarding the use of IAMPs in agricultural supplies and contribute to the dissemination to a wide audience.

References

1. Nations, F.a.A.O.o.t.U. *Food and agriculture data*. 2021 [cited 2021 20-08]; Available from: http://www.fao.org/faostat/en/#home.
2. European Chemicals Agency, E., *ANNEX XV RESTRICTION REPORT, intentionally added microplastics*. 2019, European Chemicals Agency: Helsinki, Finland.
3. Boucher, J. and D. Friot, *Primary microplastics in the oceans: a global evaluation of sources*. 2017: Iucn Gland, Switzerland.
4. Lim, X., *Microplastics are everywhere - but are they harmful?* Nature, 2021. **593**(7857): p. 22-25.
5. Materić, D., et al., *Nanoplastics transport to the remote, high-altitude Alps.* Environmental Pollution, 2021. **288**: p. 117697.
6. Nations, U. *Sustainable Development Goals*. 2021 [cited 2021 15-11]; Available from: https://sdgs.un.org/.
7. Hamilton, L.A., et al., *Plastic & Climate: The Hidden Costs of a Plastic Planet.* Center for International Environmental Law (CIEL), 2019.
8. Ng, E.-L., et al., *An overview of microplastic and nanoplastic pollution in agroecosystems.* Science of The Total Environment, 2018. **627**: p. 1377-1388.
9. Oliveri Conti, G., et al., *Micro- and nano-plastics in edible fruit and vegetables. The first diet risks assessment for the general population.* Environmental Research, 2020. **187**: p. 109677.
10. Li, L., et al., *Effective uptake of submicrometre plastics by crop plants via a crack-entry mode.* Nature Sustainability, 2020. **3**.
11. Lehner, R., et al., *Emergence of nanoplastic in the environment and possible impact on human health.* Environmental science & technology, 2019. **53**(4): p. 1748-1765.
12. Cox, K.D., et al., *Human Consumption of Microplastics.* Environmental Science & Technology, 2019. **53**(12): p. 7068-7074.
13. Wright, S.L. and F.J. Kelly, *Plastic and Human Health: A Micro Issue?* Environmental Science & Technology, 2017. **51**(12): p. 6634-6647.
14. Rai, P.K., et al., *Environmental fate, ecotoxicity biomarkers, and potential health effects of micro- and nano-scale plastic contamination.* Journal of Hazardous Materials, 2021. **403**: p. 123910.
15. Prata, J.C., et al., *Environmental exposure to microplastics: An overview on possible human health effects.* Sci Total Environ, 2020. **702**: p. 134455.
16. Yee, M.S.-L., et al., *Impact of Microplastics and Nanoplastics on Human Health.* Nanomaterials, 2021. **11**(2): p. 496.
17. Chang, X., et al., *Potential health impact of environmental micro- and nanoplastics pollution.* J Appl Toxicol, 2020. **40**(1): p. 4-15.
18. Gkoutselis, G., et al., *Microplastics accumulate fungal pathogens in terrestrial ecosystems.* Scientific Reports, 2021. **11**(1): p. 13214.
19. Pflugmacher, S., et al., *Case Study Comparing Effects of Microplastic Derived from Bottle Caps Collected in Two Cities on Triticum aestivum (Wheat).* Environments, 2021. **8**(7): p. 64.
20. Atwoli, L., et al., *Call for emergency action to limit global temperature increases, restore biodiversity, and protect health.* The Lancet, 2021. **398**(10304): p. 939-941.
21. Meidl, R.A., *Plastics and the Precautionary Principle.* Baker Institute Report, 2019. **9**.
22. Eurostat. *Water statistics*. 2020 december 2020 [cited 2021 18-06]; Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics#Wastewater_treatment_and_disposal.
23. Bertling, J., T. Zimmermann, and L. Roedig, *Kunststoffe in der Umwelt: Emission in landwirtschaftlich genutzte Böden*. 2021.
24. European Chemicals Agency, E., *Annex to the Annex XV Restriction report, intentionally added microplastics.* 2019.
25. Cai, H., et al., *Analysis of environmental nanoplastics: Progress and challenges.* Chemical Engineering Journal, 2021. **410**: p. 128208.
26. Wahl, A., et al., *Nanoplastic occurrence in a soil amended with plastic debris.* Chemosphere, 2021. **262**: p. 127784.
27. *Aanhangsel van de Handelingen II, Nr. 2245*. 2018/2019.
28. Ajzen, I., *The theory of planned behavior.* Organizational Behavior and Human Decision Processes, 1991. **50**(2): p. 179-211.
29. Crowe, S., et al., *The case study approach.* BMC medical research methodology, 2011. **11**: p. 100-100.

30. PlasticSoupFoundation. *No plastic in our water or our bodies!* 2021 [cited 2021 11-06]; Available from: https://www.plasticsoupfoundation.org/en/about-us/mission-and-vision/.
31. PlasticsEurope, A.o.p.m., *Plastics - The facts 2020.* 2020.
32. Ferreira-Filipe, D.A., et al., *Are Biobased Plastics Green Alternatives?—A Critical Review.* International Journal of Environmental Research and Public Health, 2021. **18**(15): p. 7729.
33. Frias, J. and R. Nash, *Microplastics: finding a consensus on the definition.* Marine pollution bulletin, 2019. **138**: p. 145-147.
34. da Costa, J.P., et al., *(Nano) plastics in the environment–sources, fates and effects.* Science of the Total Environment, 2016. **566**: p. 15-26.
35. Cole, M., et al., *Microplastics as contaminants in the marine environment: a review.* Marine pollution bulletin, 2011. **62**(12): p. 2588-2597.
36. Chain, E.P.o.C.i.t.F., *Presence of microplastics and nanoplastics in food, with particular focus on seafood.* Efsa Journal, 2016. **14**(6): p. e04501.
37. Shaviv, A., *Advances in controlled-release fertilizers.* 2001.
38. *Microplastics in fertilizers*, in *Fertilizers Europe*. 2018, ECHA stakeholder workshop.
39. Lawrencia, D., et al., *Controlled Release Fertilizers: A Review on Coating Materials and Mechanism of Release.* Plants, 2021. **10**(2): p. 238.
40. Trenkel, M.E., *Controlled-release and stabilized fertilizers in agriculture*. Vol. 11. 1997: Citeseer.
41. Shaviv, A., *Advances in controlled-release fertilizers.* Advances in Agronomy, 2001. **71**: p. 1-49.
42. Lu, H., et al., *Polyolefin Wax Modification Improved Characteristics of Nutrient Release from Biopolymer-Coated Phosphorus Fertilizers.* ACS Omega, 2019. **4**(23): p. 20402-20409.
43. Milani, P., et al., *Polymers and its applications in agriculture.* Polímeros, 2017. **27**: p. 256-266.
44. Tyc, A., et al., *Influence of Anti-Caking Agents on the Highly Effective Organic Coatings for Preventing the Caking of Ammonium Nitrate Fertilizers.* Coatings, 2020. **10**(11): p. 1093.
45. Kim, H. and J.-Y. Lee, *Emerging Concerns about Microplastic Pollution on Groundwater in South Korea.* Sustainability, 2020. **12**(13): p. 5275.
46. Nizzetto, L., M. Futter, and S. Langaas, *Are Agricultural Soils Dumps for Microplastics of Urban Origin?* Environmental Science & Technology, 2016. **50**(20): p. 10777-10779.
47. de Souza Machado, A.A., et al., *Microplastics as an emerging threat to terrestrial ecosystems.* Global Change Biology, 2018. **24**(4): p. 1405-1416.
48. Mortula, M.M., et al., *Leachability of microplastic from different plastic materials.* Journal of Environmental Management, 2021. **294**: p. 112995.
49. Hao, T., et al., *Impacts of nitrogen fertilizer type and application rate on soil acidification rate under a wheat-maize double cropping system.* Journal of Environmental Management, 2020. **270**: p. 110888.
50. Choi, H.-J., W.J. Ju, and J. An, *Impact of the Virgin and Aged Polystyrene and Polypropylene Microfibers on the Soil Enzyme Activity and the Microbial Community Structure.* Water, Air, & Soil Pollution, 2021. **232**(8): p. 322.
51. Ma, Y., et al., *The adverse health effects of bisphenol A and related toxicity mechanisms.* Environmental Research, 2019. **176**: p. 108575.
52. Galloway, T.S., *Micro- and Nano-plastics and Human Health*, in *Marine Anthropogenic Litter*, M. Bergmann, L. Gutow, and M. Klages, Editors. 2015, Springer International Publishing: Cham. p. 343-366.
53. Kim, D., J.I. Kwak, and Y.J. An, *Effects of bisphenol A in soil on growth, photosynthesis activity, and genistein levels in crop plants (Vigna radiata).* Chemosphere, 2018. **209**: p. 875-882.
54. Piehl, S., et al., *Identification and quantification of macro- and microplastics on an agricultural farmland.* Scientific Reports, 2018. **8**(1): p. 17950.
55. Ineris. *Microplastics: Ineris leads the European Missouri project*. 2020 [cited 2021 23-06]; Available from: https://www.ineris.fr/en/ineris/news/microplastics-ineris-leads-european-missouri-project.
56. MINAGRIS. *MIcro- and NAnoplastics in AGRIcultural Soils*. 2021 [cited 2021 23-11]; Available from: https://www.minagris.eu/.
57. EuropeanUnion, *Farm to Fork Strategy*, E.G. Deal, Editor. 2020.
58. (EC), E., *Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.* 2006.
59. CIRS, C.I.R.S. *Polymer and REACH Regulation*. 2012 [cited 2021 24-08]; Available from: https://www.cirs-reach.com/REACH/Polymer_REACH_CLP.html.

60. Directorate-General for Environment (European Commission), P.-B., Wood, *Scientific and technical support for the development of criteria to identify and group polymers for registration/evaluation under REACH and their impact assessment*. 2020.
61. International Panel on Chemical Pollution, I. *Statement on the Registration of Polymers under REACH and List of Signatures in Support*. 2021 [cited 2021 10-12]; Available from: https://www.ipcp.ch/activities/polymer-statment.
62. EuropeanParliament, *Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003*, E. Union, Editor. 2019.
63. Watch, C. *Possible delay signalled on EU microplastics restriction timetable*. 2021 [cited 2021 23-11]; Available from: https://chemicalwatch.com/366006/possible-delay-signalled-on-eu-microplastics-restriction-timetable.
64. Clausen, L.P.W., et al., *Stakeholder analysis with regard to a recent European restriction proposal on microplastics.* PLOS ONE, 2020. **15**(6): p. e0235062.
65. European Environmental Bureau, E., ClientEarth, Rethink Plastic, *Position paper: The road to an effective EU restriction of intentionally-added microplastics*, in *Phasing out the use of microplastics*. 2021.
66. EEB, C.E., *Analysis of intentionally-added microplastics' emissions to the environment up to 2030*. 2021.
67. Rheinberger, C., *ECHA proposal IAMPs: questions Fertilizers*, M. Bool, Editor. 2021, European Chemicals Agency.
68. Smit, B.J., J. , *Schets van de akkerbouw in Nederland: Structuur-, landschaps- en milieukenmerken die een relatie hebben tot biodiversiteit*. 2018, Wageningen Economic Research.
69. PlasticSoupFoundation. *What do people really know and want to know about plastic & health?* 2021 June 2021 [cited 2021 17-06]; Available from: https://www.plasticsoupfoundation.org/en/2021/06/using-big-data-to-explore-interest-in-plastic-and-human-health/.
70. Prata, J.C., et al., *Solutions and Integrated Strategies for the Control and Mitigation of Plastic and Microplastic Pollution.* Int J Environ Res Public Health, 2019. **16**(13).
71. Zurier, H.S. and J.M. Goddard, *Biodegradation of microplastics in food and agriculture.* Current Opinion in Food Science, 2021. **37**: p. 37-44.
72. Calero, M., et al., *Green strategies for microplastics reduction.* Current Opinion in Green and Sustainable Chemistry, 2021. **28**: p. 100442.
73. Smith, T.B., *The policy implementation process.* Policy Sciences, 1973. **4**(2): p. 197-209.
74. Arfaoui, N., *Eco-innovation and regulatory push/pull effect in the case of REACH regulation: empirical evidence based on survey data.* Applied Economics, 2018. **50**(14): p. 1536-1554.
75. van Leeuwen, G. and P. Mohnen, *Revisiting the Porter hypothesis: an empirical analysis of Green innovation for the Netherlands.* Economics of Innovation and New Technology, 2017. **26**(1-2): p. 63-77.
76. Price, J.C. and Z. Leviston, *Predicting pro-environmental agricultural practices: The social, psychological and contextual influences on land management.* Journal of Rural Studies, 2014. **34**: p. 65-78.
77. Stern, P.C., et al., *A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism.* Human Ecology Review, 1999. **6**(2): p. 81-97.
78. Rotter, J.B., *Generalized expectancies for internal versus external control of reinforcement.* Psychological monographs: General and applied, 1966. **80**(1): p. 1.
79. Pannell, D.J., *Public benefits, private benefits, and policy mechanism choice for land-use change for environmental benefits.* Land economics, 2008. **84**(2): p. 225-240.
80. Russell, S.V., et al., *Bringing habits and emotions into food waste behaviour.* Resources, Conservation and Recycling, 2017. **125**: p. 107-114.
81. Attiq, S., et al., *Drivers of food waste reduction behaviour in the household context.* Food Quality and Preference, 2021. **94**.
82. Klöckner, C.A., *A comprehensive model of the psychology of environmental behaviour—A meta-analysis.* Global environmental change, 2013. **23**(5): p. 1028-1038.
83. Handayani, W., et al., *Literature Review: Environmental Awareness and Pro-Environmental Behavior.* Nusantara Science and Technology Proceedings, 2021: p. 170-173.
84. Csutora, M., *One More Awareness Gap? The Behaviour–Impact Gap Problem.* Journal of Consumer Policy, 2012. **35**(1): p. 145-163.

85. Liu, P., M. Teng, and C. Han, *How does environmental knowledge translate into pro-environmental behaviors?: The mediating role of environmental attitudes and behavioral intentions.* Science of The Total Environment, 2020. **728**: p. 138126.
86. Ham, M., D. Mrčela, and M. Horvat, *Insights for measuring environmental awareness.* Ekonomski vjesnik: Review of Contemporary Entrepreneurship, Business, and Economic Issues, 2016. **29**(1): p. 159-176.
87. Yuantari, M.G., et al., *Knowledge, attitude, and practice of Indonesian farmers regarding the use of personal protective equipment against pesticide exposure.* Environmental monitoring and assessment, 2015. **187**(3): p. 1-7.
88. Martin, L., et al., *Nature contact, nature connectedness and associations with health, wellbeing and pro-environmental behaviours.* Journal of Environmental Psychology, 2020. **68**: p. 101389.
89. Mesiti, L. and F. Vanclay, *Specifying the farming styles in viticulture.* Australian Journal of Experimental Agriculture, 2006. **46**(4): p. 585-593.
90. Nguyen, N. and E.G. Drakou, *Farmers intention to adopt sustainable agriculture hinges on climate awareness: The case of Vietnamese coffee.* Journal of Cleaner Production, 2021. **303**: p. 126828.
91. Savari, M. and H. Gharechaee, *Application of the extended theory of planned behavior to predict Iranian farmers' intention for safe use of chemical fertilizers.* Journal of Cleaner Production, 2020. **263**: p. 121512.
92. Scheer, D., et al., *The Distinction Between Risk and Hazard: Understanding and Use in Stakeholder Communication.* Risk Analysis, 2014. **34**(7): p. 1270-1285.
93. Qu, S.Q. and J. Dumay, *The qualitative research interview.* Qualitative research in accounting & management, 2011.
94. Daniel, B. and B. Horsburgh, *Stakeholders Analysis as a Research Methodology: Implications for Development of a Distributed Community of Practice for Health Research and Innovation*. 2009.
95. Thompson, R., *Stakeholder analysis.* Mind Tools, 2011.
96. McIntyre, B., et al., *Agriculture at a Crossroads: The Global Report*. 2009.
97. Consumentenbond, *Resultaten panel Microplastics*. 2020.
98. ZonMw, *Microplastics and Human Health Consortium (MOMENTUM)*, J. Legler, Editor. 2021: Utrecht.
99. Gadenne, D., et al., *The influence of consumers' environmental beliefs and attitudes on energy saving behaviours.* Energy Policy, 2011. **39**(12): p. 7684-7694.
100. Ahmed, N., et al., *Purchase intention toward organic food among young consumers using theory of planned behavior: role of environmental concerns and environmental awareness.* Journal of Environmental Planning and Management, 2021. **64**(5): p. 796-822.
101. Van, L., et al., *Factors of single use plastic reduction behavioral intention.* Emerging Science Journal, 2021. **5**(3): p. 269-278.
102. Wang, T., et al., *Adsorption behavior and mechanism of five pesticides on microplastics from agricultural polyethylene films.* Chemosphere, 2020. **244**: p. 125491.
103. ZonMw, *Vervolgonderzoek gewenst naar gezondheidsrisico's microplastics*. 2021.
104. Rijksdienst voor Ondernemend Nederland, R. *Subsidie om te leren over duurzame landbouw (SABE)*. 2021 03-11-2021 [cited 2021 23-11]; Available from: https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/duurzaam-boeren/subsidie-leren-over-duurzame-landbouw.
105. Park, K. and R. Mrsny, *Are controlled release scientists doing enough for our environment?* Journal of Controlled Release, 2021. **332**: p. 620-622.

Appendix

A. Calculations emission numbers in the Netherlands

In table 1 the calculations for the Dutch emission numbers can be found. In column J and K via [calculation] can be found how the eventual numbers (column L) were calculated. For water-soluble FAs no exact numbers can be calculated, but it is known that the use is less than the water insoluble FAs, therefore < 0.66. Consequently, the range for emission of water-soluble FAs is < 70.29-421.74.

Table 1: Overview of calculations for Dutch emission number of polymeric material emitted by CRF and FA use in agriculture.

A	B	C	D	E	F	G	H	I	J	K	L
IAMP source	**Abbreviation**	**Subcategory**	**Nitrogen Fertilizer consumption in 2018**	**Phosphorus Fertilizer consumption in 2018**	**Total mineral fertilizer consumption**	**Percentage IAMP source use in agriculture**	**Min. polymer concentration**	**Max. polymer concentration**	**Min. emission polymeric material (tonnes/year) [F*G*H]**	**Max. emission polymeric material (tonnes / year) [F*G*I]**	**Dutch annual tonnage of polymeric material emitted by CRF and FA use in agriculture [range between J and K]**
Controlled Release Fertilizer	CRF	Encapsulated	207000	6000	213000	0,01	0,01	0,12	21,3	255,6	21.3 - 255.6 tonnes / year
		Physical barrier									Not known
		Chemical attachment									Not known
Fertilizer Additives	FA	Water insoluble	207000	6000	213000	0,66	0,0005	0,003	70,29	421,74	70.29 - 421.74
		Water soluble	207000	6000	213000		0,0001	0,005	0	0	

B. Overview all codes used during analysis

Table 2: An overview of all codes used in the analysis of this study.

Code group	**Code**	**Intention**
Agricultural Innovation System (AIS)	Agricultural Innovation System (AIS)	To provide an overview of all actors that are involved in the Dutch Agricultural Innovation System.
	AIS: Direct contacts	
	AIS: Factors in the system	
	AIS: organisation details	
	AIS: Role in the system	
	Stakeholders	
Awareness	Consequences: Branch organizations	To differentiate between the awareness of the consequences of microplastics in fertilizers of the different stakeholders.
	Consequences: Consumers	
	Consequences: Distribution/suppliers	
	Consequences: Education	
	Consequences: Farmers	
	Consequences: Policy	
	Consequences: Producers	
	Presence: Branch organizations	To differentiate between the awareness of the presence of microplastics in fertilizers of the different stakeholders.
	Presence: Consumers	
	Presence: Distribution/suppliers	
	Presence: Education	
	Presence: Farmers	
	Presence: Policy	
	Presence: Producers	
	Risk perception (ook voorzorgsprincipe)	To provide an overview of the risk perception of the stakeholders.
Economic factors	Economic factors	To provide an overview of all economic factors potentially influencing the use and production of IAMPs in fertilizer.
Knowledge and information	Education	To provide an overview of the educational factors.
	Knowledge	To provide an overview of the knowledge, also specifically for microplastics and fertilizer/manure.
	Knowledge: microplastics	
	Knowledge: organic	
	Knowledge: fertilizer/manure	
	Knowledge: soil	
	Information distribution	To show in which ways information is distributed.
	Rules and regulations: awareness/knowledge	To provide an overview of the knowledge concerning the different rules and regulations.
	Rules and regulations: ECHA	
	Rules and regulations: Meststoffenverordening	
Reduction	Actions towards reduction / innovation	To provide an overview of factors that influence reduction of fertilizers with IAMPs.
	Alternatives	
	Factors that influence reduction	
	View on necessity reduction	
	Scientific evidence	
	Technical challenge	
Social norms	Social norms	To provide an overview of the social norms.
Use/production of fertilizers	Factors that influence the use/production of fertilizers	To provide an overview of how the use/production of fertilizers was executed.
	How it influences the use	
	Use of fertilizer	

	Soil quality	
	Crop quality	
	Abiotic factors	
Willingness to change	Factors that influence willingness to change	To provide an overview of factors that influence willingness to change.
	Willingness to change: Branch organizations	To differentiate between the willingness to change of the different stakeholders.
	Willingness to change: Consumers	
	Willingness to change: Distribution/suppliers	
	Willingness to change: Education	
	Willingness to change: Farmers	
	Willingness to change: Policy	
	Willingness to change: Producers	
Political factors	Political factors	To provide an overview of the political factors in the AIS.

C. Stakeholders in the Dutch AIS

An overview of the stakeholders in the Dutch agricultural innovation system (AIS) can be found in Table 3. The different stakeholder groups are represented in the first column, whereas the separate stakeholders included in the respective stakeholder groups are represented in the second column. Relevant examples of individual stakeholders, when available, are described in the third column of table 3.

Table 3: Overview of the stakeholders concerning the use of intentionally added microplastics (IAMPs) in the Dutch agricultural innovation system (AIS).

Stakeholder group	**Stakeholders**	**Examples**
Policy NL and EU	Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency; RVO)	
	Ministries	LNV, VWS, I&W, SZW
	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment; RIVM)	
	Province + regional water authorities	
	Non-governmental organizations (NGOs)	
	European Union/Brussel	
	Fertilizers Europe (umbrella organization for fertilizer producers)	
	Comité Européen de Normalisation (CEN; European Committee for standardization)	
	European Chemical Industry Council (CEFIC)	
	European Environmental Bureau (EEB)	
	Bureau Européen des Unions de Consommateurs (European Consumer organization; BEUC)	
	European Food Safety Authority (EFSA)	
	World Health Organization (WHO)	

	International Fertilizer Association (IFA)	
Fertilizer producers	ICL	
	Van Iperen	
	Yara	
	OCI	
	Kemira	
	Suiker Unie Cosun	
	Avebe	
	International companies	
Fertilizer buyers	Van de Reijt	
	Triferto	
	Agrifirm	
	CZAV	
	Van Iperen	
	Cooperatives	
	Companies	Hoogland
	Other dealers	
Farmers	Conventional	
	Nature inclusive	
Purchasers of output farmers	Processors, crop specific	FarmFrites, Suiker Unie Cosun, TOP onions, ACM, DLF, Van de Bilt, CZAV
	Trading firm/collecting firm?	HZPC, Bakker Barendrecht
	Supermarkets	Albert Heijn, Jumbo, shareholders
	Catering industry	
Consumers	Consumers	
Sector organizations	BO Akkerbouw	
	Netherlands Agricultural and Horticultural Association (LTO)	Sub-LTOs (ZLTO, LTO Noord and LLTB) + subsub-LTOs (regional departments)
	Meststoffen Nederland	BELFertil (Belgium), UNIFA (France)
	Dutch agricultural union (NAV)	
	Dutch agricultural youth association (NAJK)	
	Organic farming organizations?	
Advisors	Product selling companies	Van Iperen, Agrifirm, ICL, cooperatives
	Independent advisors	Delphy, DLV, freelancers
	Business information association (VVB)	
	Education related advisors	Wageningen University, applied universities (HAS)
Research	Wageningen University & Research (WUR)	WUR, Wageningen Food Safety Research
	Other universities/applied universities	HAS, UU, UvA, technical universities
	Experimental farms/ practice centers	Vredepeel, SPNA Kollumerwaard,

	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment; RIVM)	
	Companies	Louis Bolk Institute, TNO, NMI, CLM
	Small projectgroup	Boeren meten Water (via ZLTO)
Nature organizations	Staatsbosbeheer	
	Natuur en Milieu	
	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment; RIVM)	
	Milieu Centraal	
	Organizations that care about plastics	
	Inspectie leefomgeving en transport	
Education	Agricultural college	MBO (secondary vocational education) or HBO (applied university)
	Praktijkcentrum Voedsel en Groen	
Controlling organs	Crop protection products	Board for the Authorisation of Plant Protection Products and Biocides (College voor de toelating van gewasbeschermingsmiddelen en biociden; CTBG)
	Netherlands Food and Consumer Product Safety Authority (NVWA)	
	Office for Risk Assessment & Research (BuRO)	
	Labor	Inspectie sociale zaken en werkgelegenheid
	Organic certification organizations	
	Environment	Inspectie leefomgeving en transport
	Advertisement	Dutch advertising Code Committee (Reclame Code Commissie; RCC)
Media	Tv, news etc.	