Team Report

Research project Plant Protection Product Exposure and Parkinson's Disease: Spreading Awareness and Aiding in the Transition to Integrated Pest Management-Based Agriculture

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TRIPLE P
Plant Protection & Parkinson's

Triple P is a research group that was created as part of the research minor 'Translational Life Sciences' at the Graduate School of Life Sciences. Our aim with this project, as commissioned by TNO, is to find out how we can contribute to solving the problems that arise as an effect of the link between plant protection products and the development of Parkinson's Disease in Dutch farmers.

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1. Introduction of the problem

1.1 Scientific background of the problem

Parkinson's Disease (PD) is the second most common neurodegenerative disorder after Alzheimer's disease (De Lau et al., 2006), with approximately one percent of people above sixty years of age being diagnosed with PD. As of 2021, there are 50.000 PD patients in the Netherlands and this number is expected to increase to 80.000 patients by 2040 (Eimers et al., 2019). As PD currently is the fastest growing neurological disease in the world, this rise is expected to take place worldwide, with some researchers even referring to this increase as a pandemic (Dorsey et al., 2018). PD is a progressive brain disorder that is caused by the death of the dopaminergic neurons in a part of the brain called the substantia nigra. These neurons, besides being known for their function in feelings of reward and motivation, are very important for motor function. When these neurons die, dopamine levels in the brain decrease, which causes movements to become slow and abnormal and leads to symptoms like shaking, stiffness and difficulty with walking, balance, and coordination (Martinez-Martín et al., 2015). The loss of dopaminergic neurons is a slow process and only becomes noticeable in late stages of the disease; usually, PD symptoms start to show when around 80% of dopaminergic neurons have already been lost (Cheng et al., 2010). The loss of dopaminergic neurons is known to be caused by a combination of genetic and environmental factors. Current research suggests that genetic factors are only big contributors in a small proportion of PD cases and that in most cases environmental factors play a bigger role (De Lau et al., 2006). As the current health care costs for PD in the EU have already been estimated at 13.9 billion euros yearly (Gustavsson et al., 2011), these environmental exposures should be reduced to avoid paying even higher prices in the future, in terms of both money and quality of life.

What specific environmental factors contribute to PD is not entirely clear. There may be a long list of exposures, which largely still have to be identified by scientists. Yet, international research currently has found that one specific factor may belong on that list: many independent research articles suggest that exposure to pesticides, or Plant Protection Products (PPPs), is associated with an increased risk of developing PD. More specifically, Yan et al. (2018) suggests that exposure to PPPs for a duration of 5 and 10 years respectively is associated with a 5% and 11% increase in PD risk. A cohort study by Ascherio et al. (2006) even reported a 70% higher incidence of PD for individuals that were exposed to PPPs compared to individuals that were never exposed. Although some studies suggest an association, determining a causal relationship between PD and PPPs is extremely difficult, because farmers often use combinations of different kinds of PPPs and PPP use is not well-documented, which makes retracing farmers' PPP use difficult. Three meta-analyses examined the association between exposure to PPPs and the development of PD; Van Maele-Fabry et al. (2012) report a relative risk of 1.28 and Ahmed et al. (2017) and Priyadarshi et al. (2000) report odds ratios of 1.46 and 1.93. All three studies found high heterogeneity and inconsistency amongst the evaluated studies. Ahmed et al. (2017) do suggest that there is a significant association, but that the underlying mechanism and the effect of the duration of the exposure need to be investigated further. Currently, the strongest associations with PD are found for PPPs that are no longer in use. The most convincing data connecting PPPs to PD considers the substances rotenone and paraquat (Franco et al., 2010; Freire et al., 2012; Pouchieu et al., 2018), which are already banned in the European Union (EU). The AGRICAN cohort study in France reported an odds ratio of 1.31-1.79 specifically for rotenone, paraquat, diquat and several dithiocarbamate fungicides (Pouchieu et al., 2018). Pezzoli and Cereda (2013) even suggest that exposure to paraquat was associated with a twofold increase in risk of developing PD. Over the years, additional groups of PPPs have become more suspicious than others, like is the case for organochlorine insecticides (Elbaz et al., 2009; Freire et al., 2012). Freire et al. (2012) found that PPPs of the insecticide-groups chlorpyrifos and organochlorines could contribute to PD development in six studies (OR: 1.8-4.4).

Despite finding strong correlations, however, researchers almost never find *causal* correlations. Although associations are strong for some PPP groups, the link with PD for most PPPs in use today is still unclear, which is in part complicated by new PPPs entering the market continuously and by how the PPPs are used in practice. Although the scientific community shows reasons to worry about the high levels of PPP exposure that comes with mass production of food in the EU, and although PD has already been recognised as an occupational disease in France, little health-related measures have been taken in the Netherlands. Why is determining whether there are causal correlations between PD and specific types of PPPs so difficult, whilst strong associations exist? Why is the current evidence enough for some countries to take action, but not for the Netherlands? This research report will dissect this societal issue and what this means for farmers in practice, as commissioned by TNO, according to the Design Thinking Model, which consists of five phases: the discover & define (together referred to as the problem definition phase), develop & deliver (together referred to as the solution phase), and evolve phases (Linke, 2021). We here propose a concept website as a contributing solution to parts of this complex societal issue.

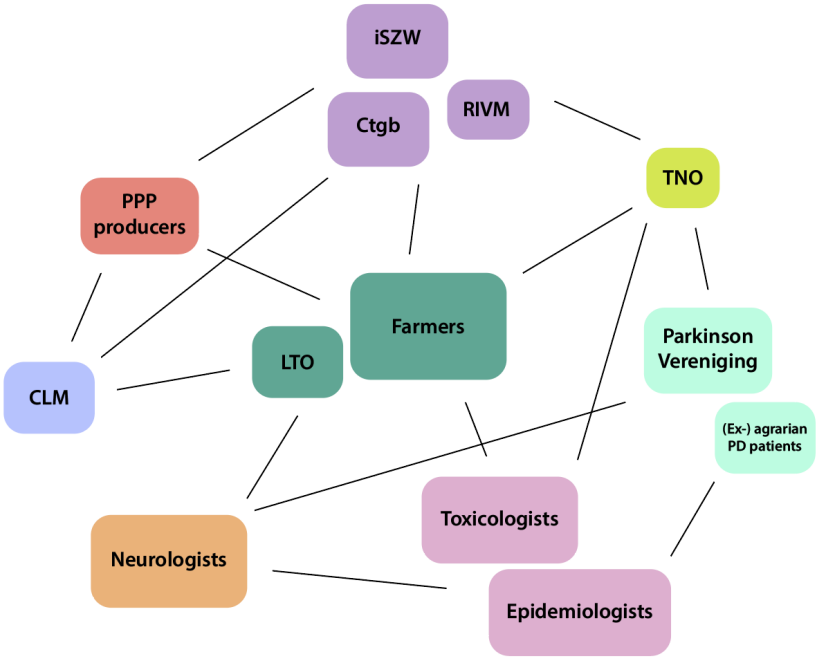

Figure 1: Stakeholder plot of the stakeholders that were interviewed to form the problem definition. Abbreviations: PPP: Plant Protection Product, CLM: independent research Centre for Agriculture and Environment, Ctgb: the Dutch College for the Admission of PPPs and Biocides, iSZW: inspection of the Ministry of Social Affairs and Employment, LTO: the Netherlands Agricultural and Horticultural Association, RIVM: Dutch National Institute for Public Health and the Environment, TNO: the Netherlands Organisation for Applied Scientific Research, PD: Parkinson's Disease.

1.2 The problem from stakeholder perspectives

To understand the apparent problem from different perspectives, we reached out and interviewed a large sample of stakeholders that are involved in this problem (see Figure 1), as well as performed literature research. Farmers and their trade association (the Netherlands Agricultural and Horticultural Association, LTO) were determined to be the main stakeholders, as the problem concerns the farmer's health as well as one of their most important tools (green). For regulation, admission of PPPs to the market, and inspection of regulatory compliance, governmental institutions were included (purple).

For a better look into the scientific progress and health care knowledge in this field, toxicologists, epidemiologists (pink) and neurologists (orange) were interviewed. Lastly, representatives and patient members of the Parkinson patient association (mint), PPP producers (red), agriculture advisory boards (blue) and our collaborating partner TNO (light green) were interviewed.

First, we discovered how the system of PPP market entry works. In the EU, PPPs that are available on the market are approved and consequently re-evaluated at intervals ranging from 5 to 15 years, depending on the identified risks associated with the PPP. When a PPP producer wants to bring a new product to the market, they must submit the necessary safety and environmental research (including acute neurotoxicity) to the governmental body of an EU Member State that oversees PPP use and evaluation (in the Netherlands, this is the 'College voor de Toelating van Gewasbeschermings-middelen en Biociden' or the Ctgb, which will hereafter be used as an example), as well as present the research results to all countries that the producer wants to sell his product in. The Ctgb will evaluate the submitted research using established thresholds and its assessment is peer reviewed by the European Food Safety Authority (EFSA), to then be either approved or rejected by the European Commission. This approval can be given on condition that strict safety use instructions are followed by preparation and application of the product, as well as regarding re-entry of a field on which the product was used recently. Upon talking to many farmers, and when reading several research reports, however, we found that these instructions are often not followed properly in practice, and safety seems to have a quite low priority when working with PPPs (Gezondheidsraad, 2020; TNO, 2019). Besides, the Gezondheidsraad (2020) has found that the current risk evaluation tests for PPP approval should improve, also specifically for evaluating risks for PD. The PPPs on the market can only be used by farmers and employees that have received an accredited spray licence. In obtaining this license, education about PPP use safety is mandatory, as well as repeating similar education for licence renewal every 5 years. However, very little information is provided within this education about the health risks of PPPs (TNO, 2019).

Upon talking to neurologists, toxicologists and epidemiologists, we found that it is still largely unclear how big the impact of PPPs is on the development of PD compared to other environmental factors, and that further research is required to ascertain the influence of PPPs on farmer health. Within epidemiology, mostly retrospective studies are performed, which rely on previous documentation of PPP use and the memory of (ex-)agrarian PD patients. This approach is inherently flawed, because documentation is often incomplete, mixes of different PPPs were used, and farmers often inaccurately remember the details about their past PPP use (recall bias). Another way of performing research is to follow farmers' PPP use over time. This ensures good documentation, but does not take away the complexity of the mixed use of PPPs. Therefore, epidemiologists can only find out general associations for groups of different kinds of PPPs, but not the effects of specific PPPs. (Neuro)toxicologists mainly use tests that are either *in vivo* animal models (which are the tests used for market approval of PPPs) or *in vitro* human models. These models, however, cannot reliably recreate a human exposure time span, and the exposure in these models is much more direct than in practice. Additionally, these models can only test acute (neuro)toxic effects of specific PPPs or mixes of PPPs. Research projects to develop tests for predicting long-term effects of PPPs (such as PD) are being developed (e.g. by the EFSA, using Adverse Outcome Pathways (AOPs)), but these are far from ready to use for market entry testing. This means that toxicologists cannot say anything about long-term effects of specific PPPs. Therefore, all researchers that we spoke are advocates for collaboration between epidemiology, toxicology and neuroscience, which is already being realised by several large research projects. When predictive long-term PD toxicology tests can be used in market approval testing, this would likely result in more PPP bans. This ultimately would be the best and most reliable way to ensure that the PPP system at large changes based on valid health claims. However, this can still take years, if not decades.

It is debatable whether the research results that we currently have are enough to justify taking action by the government. Important financially involved stakeholders are the producers and distributors of PPPs, who state that the biases that research faces today renders the results of research unreliable, and that better tests need to be developed. They really doubt that any causal results will be found, because PPPs already are subjected to a lot of strict testing. They point out that perhaps it is so hard to find causal links because there are none. The matter, however, is not that simple. The aforementioned current shortcomings of science have not allowed us to properly test for many (long-term) risks, causing us to neither be able to confirm or deny the presence of causal correlations. Because strong associative evidence has been found, however, there is reason to believe that causality could be found once the appropriate tests have been developed. The PD patient organisation (Parkinson Vereniging) does not want to wait for better admission tests to be developed, because according to them, enough associative evidence has been gathered to know that we are dealing with dangerous substances of which exposure levels must come down as soon as possible. Whilst waiting for sounder solutions, years of unnecessary exposure are allowed, likely increasing farmers' chances of developing PD. (Ex-)agrarian PD patients point out that it seems that, as long as PPP companies can choose to give the harmful effects of PPPs less priority and most farmers do not suffer health effects themselves, they rather would not think about it.

The inspection of the Dutch Ministry of Social Affairs and Employment (iSZW) states that there is not enough evidence to justify taking action for the Dutch situation. According to them, research from non-EU and even other EU countries (e.g. France, where PD is now recognised as an occupational disease) cannot simply be seen as indicative of the Dutch situation. They say that such research, however, should be discussed in society in a good way, as opposed to how the media often portray issues in agriculture. The Gezondheidsraad (2020) also claims that Dutch research, although corresponding with international research, is too weak to find reliable risk elevations for Dutch farmers. However, most of the governmental bodies that we interviewed point out that the EFSA is working on research of which the outcomes might bring change. Many of our stakeholders point out that whilst we wait for better evidence, the PPP safety instructions must be followed better, especially regarding personal protection. An article by TNO (2019) points out that the iSZW, whose function it is to check such safety aspects, has paid very little inspection visits to farmers in recent years and has not paid sufficient attention to safe PPP use in these inspections. This, according to the iSZW, was largely due to budget cuts, but they see improvements for the upcoming time. In the inspections that took place, however, approximately 10% of farming companies did not comply to harmful substance regulations (TNO, 2019). Yet, the iSZW points out that this number could be even higher, as many things cannot be checked unless the farmer is spraying with PPPs during the inspection or when he/she is 'caught in the act' of breaking a rule.

Farmers themselves stress that PPPs are very important tools for the production security of their crops, and with it, food security and the security of their income. The use of PPPs is so ingrained in the current worldwide agriculture system, that it is very hard to compete with other countries that have looser PPP regulations, especially when trying to produce crops with non-PPP plant protection methods. This side of the problem is hardly ever mentioned in the media, and farmers often think that PPPs get disproportionate negative attention when compared to other dangerous substances, like certain household items. The consequential societal pressure that the issue gets, then leads to 'unreasonable' regulations. They want to know what the facts surrounding PPPs are, without them being overshadowed by emotions. Many farmers point out that, although the Netherlands is making a lot of progression in plant protection innovation, new non-PPP methods oftentimes are more pricy, laborious or less efficient than using PPPs. According to some farmers and LTO, working on mass production scale will therefore never be able be 100% organic, and several other stakeholders hold that opinion too. Ironically, only larger farms will likely be able to afford using more non-PPP methods on the long term. Additionally, we found that farmers indeed are not presented with much more

knowledge about the health effects of specific PPPs than the skull icons and the safety instructions that come with purchased PPPs, which do not include health risk information (TNO, 2019). The iSZW has also expressed that farmers possess insufficient knowledge about the long-term risks of PPPs that are still on the market (TNO, 2019).

All in all, stakeholders seem to have many different and quite opposing opinions about this topic. This is something that stands out to us as problematic, because these polar perspectives have led many stakeholders, especially stakeholders that are financially dependent on PPP use (PPP-dependent, e.g. farmers and PPP producers) and stakeholders that are not (PPP-independent, e.g. PD patients, scientists etc.), to communicate badly or even to not communicate at all. We experienced this ourselves, as farmers pointed out that they did not want to participate in our interviews because they have had many bad experiences with scientists and the general public in the past. This communicative isolation is worrisome, as also pointed out by LTO, and prevents important scientific information from reaching farmers and vice versa.

1.3 Problem Definition

To summarise all aspects of the problem that we found, we created a 'problem tree' (Figure 2) that shows all main aspects of this complex societal problem. We identified two main aspects that form the core of the problem, which are visualised as the stem:

1) A lack of concrete, systematic and effective communication regarding PPP health risks and PPP alternatives between stakeholders, which results in isolation of stakeholder groups. This is especially evident between scientists and agrarians.

2) Reliable testing for causality of the link between PPPs and *long-term* health effects has not yet been achieved, resulting in insufficient representation of these long-term health effects, such as PD, in pesticide admission safety tests.

In addition to the problem tree, we summarised the stakeholder perspectives on some specific topics, as shown in Table 1. In this table, the differences in perspective and communication issues between PPP-dependent and PPP-independent stakeholders again become apparent. Many stakeholders even indicate themselves that communication is insufficient, and that more awareness and education are needed. Awareness in this case means awareness of PPP-independent people on agricultural practical insight and the need for PPPs, and education means providing PPP-dependent people with more scientific information about PPPs. Something else that stands out, however, is that many stakeholders think that most positive change can be achieved in the advancement of science and consequent improvement of admission tests.

However, research advancement and its translation to the admission system is a very long process and will likely not offer any relief of PPP exposure on the short term (Gezondheidsraad, 2020). Besides, researchers already are aware of the need for collaboration between different research fields and have started large research projects that are addressing this issue already, such as efforts taken by the EFSA and a new project in the Netherlands led by neurologist and PD expert Prof. Bas Bloem. Research continuously and naturally strives to innovate. The need for better communication, on the other hand, does not receive enough attention and effort, which hence is what we chose to work on in this project. In interviews, we discovered that farmers have a very fixed set of trusted sources for their information about plant protection, with the most prominent source being plant protection advisors. Because plant protection advice has been privatised in the Netherlands, the majority of these advisors is directly affiliated with PPP producers/distributors. As they can factor the costs of the advice into the price of the sold PPPs, the advice can be called 'free', giving a competitive disadvantage to independent advisors. The farmers we spoke with estimate that around 20% of the farmers receives independent

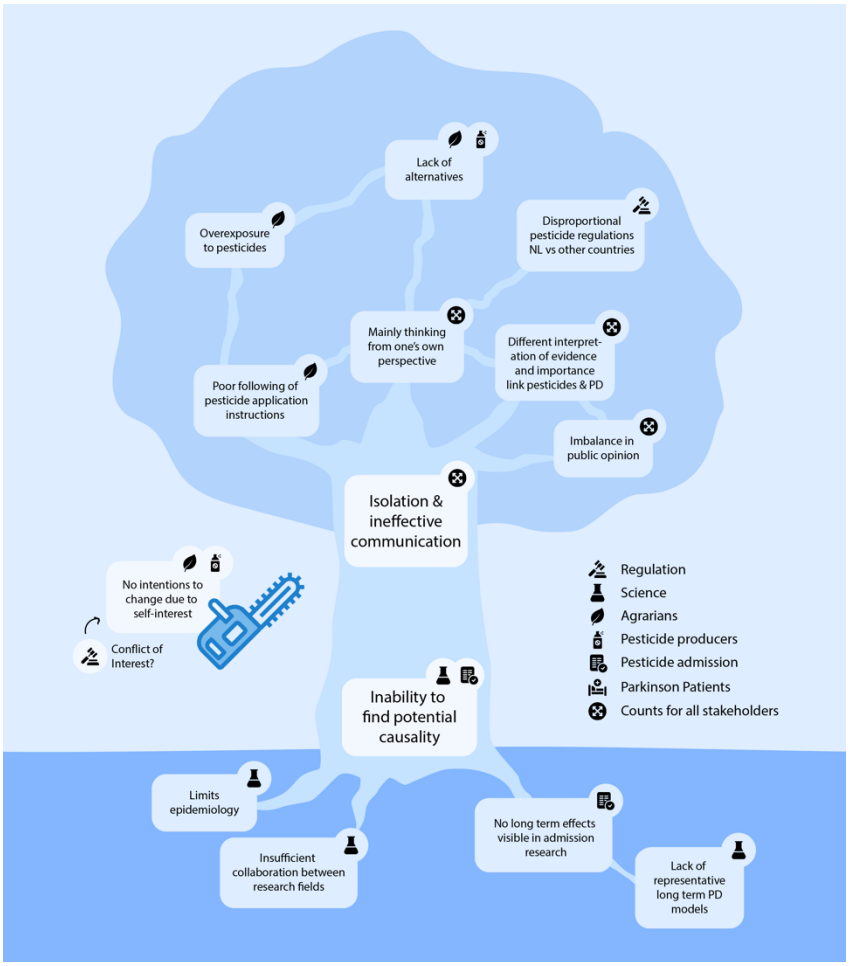

Figure 2: 'Problem tree' which summarises the complexity of the problem. The icons placed next to every bubble show that that specific aspect of the problem lies with a specific stakeholder. Science and its shortcomings are presented as the roots of the tree, because they have the most potency to change the whole system. The stem, which is a crucial segue to societal aspects of the problem (canopy), also contains the need for proper communication between stakeholders, amongst which communication of science with agrarians. PD: Parkinson's Disease.

Stakeholder group	Changes to current system necessary?	Current knowledge sufficient to take action?	Biggest steps to take for solving the issue?	Extent/quality of communication and collaboration between parties	What to improve in communication?	Current level of science regarding this topic	What are points of improvement for science?
Pesticide producers	1	No	Admission	2	Awareness	3	Admission PD
Agrarians	2	No	Admission, Research	1	Awareness, Regulations	2	N/A
Admission	3	No	Admission, Education	3	Education	3	Admission PD
Regulation	3	No	Admission	3*	N/A	3	Admission PD, Causality
Researchers	3	Yes	Research, Education	2	Collaboration	3	Collaboration, Association
PD patients	4	Yes	Awareness, Alternative	2	Education, Awareness	4	Causality
Average/total	**2.666667**	**Yes 33%**	**Adm 67% Res 33% Edu 33%**	**2.16667**	**Aware 50%, Edu 33% Reg 17% Collab 17%**	**3**	**Adm 50% Cau/Ass 50% Collab 33%**

* = Uncertainty due to implicit answer in the interview

Table 1: Table which provides an overview of the perspectives that different interviewed stakeholders take on the problem. The individual stakeholders have been grouped based on similar perspectives and roles within the problem. Questions that have been answered with numbers show the perspective of the stakeholder group on a scale from 1 to 5, with 1 being 'not at all/very bad' and 5 being 'absolutely/very good'. The stakeholder groups are not ordered in any significant way. PD: Parkinson's Disease.

advice, which means that most farmers work with commercial advisors. We discovered that most advisors, regardless of their affiliations, rarely cover the health effects of PPPs. Additionally, financial motives of commercial advisors cause their advice to be inherently biased and focused on PPP use, as opposed to also including non-PPP methods to lower PPP exposure (as also mentioned by the Planbureau voor de Leefomgeving (2019)). This is in contrast with goals of PPP use reduction that were set in 1991 by the EU (European Court of Auditors, 2020) and the recent goals of the Dutch government to reduce PPP use further by 2030 for environmental reasons (Rijksoverheid, 2019; 2020) and for the health of farmers and countryside residents (Gezondheidsraad, 2020). A method that has been suggested to help lower PPP use whilst not completely overturning the current plant protection system is Integrated Pest Management (IPM). This is a plant protection strategy that strives to reduce PPP use by mainly using alternative non-PPP plant protection methods and which only resorts to PPP use when absolutely necessary (Rijksoverheid, 2019; 2020) (see Infobox 1 for more information). Such alternative methods are continuously being developed and tested by Wageningen University and Research (WUR), like in the 'Kennisimpuls Groene Gewasbescherming' research project, and by specialised companies.

We believe that lowering PPP use would be the best way to protect farmers' health because of the associations found and the aforementioned inability to test for long-term health effects in admission. Additionally, the long-term regular exposure of most farmers to PPPs increases the chance of such health effects occurring. The Ctgb points out that the health risks are defined by the hazard (harmfulness) of a substance multiplied by the exposure to this substance. For extra safety, the Ctgb already includes a ten times multiplier for determining the safety threshold in both intra- and interspecies testing for the approval of the active ingredients of PPPs. However, because PD only becomes apparent over a long period of time, long-term regular exposure to these PPPs can still lead to toxic damage build-up over time, as a neurologist points out. For this reason, a small diminishment of exposure can make a large difference in the long run. Like the government, we believe that IPM could be an effective way to reduce PPP exposure and its suggested negative health effects. We conclude, however, that at least a subset of farmers is still unaware of the government's goals and that only a few branches of agriculture have now really started using IPM strategies. Most farmers stress that they already strive to reduce the amount of PPPs they use by optimising target-specific application. This, however, should not be confused with IPM, as these farmers still predominantly use PPPs for their plant protection. This is an example of the observation that most farmers are not up to date with knowledge about IPM and its innovation, which was also made by Bakker (2021).

Based on the aforementioned analysis, we have defined the problem that we will address in this project as follows:

"Dutch agrarians are not sufficiently aware of the possible Parkinson's Disease risks tied to Plant Protection Product (PPP) use and suitable non-PPP alternatives."

Figure 3 provides a summary of our problem analysis and points out the need for better information flow, as shown in red.

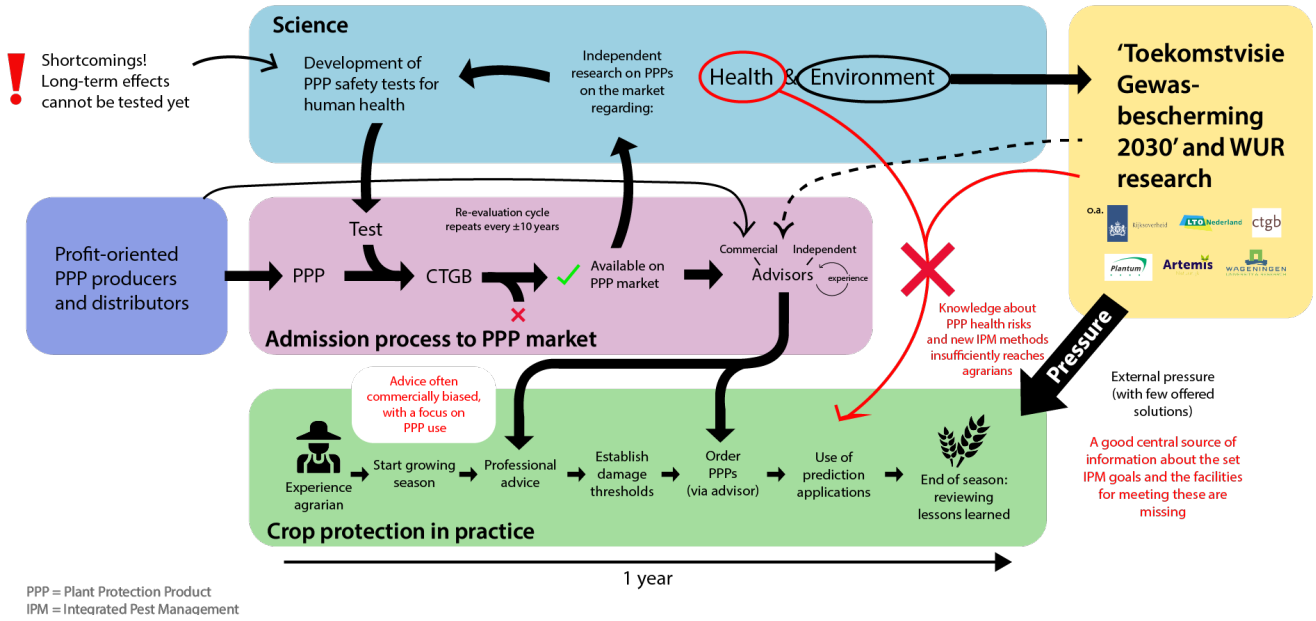

Figure 3: Overview of our analysis of the Dutch plant protection system and the problems we identify in it. Farmers seem to be isolated from scientific knowledge regarding PPPs by the admission process of PPPs to the market. PPP producers and distributors use safety tests that were developed by science to apply their products to the Ctgb for market (re-)entry, although these do not sufficiently cover long-term health effects yet. After revision of the submitted research, the Ctgb, EFSA and European Commission then either reject or approve the PPP for market (re-)entry. Advisors, which can be independent but are mostly affiliated with PPP producers/distributors, can then use the PPPs on the market in their plant protection advice for farmers, which is a farmer's main source of plant protection information. The scientific knowledge about the PPPs, however, is not communicated to the farmers in this advice and 'strands' at the Ctgb. Farmers are thus presented with incomplete and oftentimes biased advice which is focused on PPP use. Simultaneously, scientific findings have fuelled governmental goals that focus on the use of alternative non-PPP plant protection to reduce negative PPP effects on health and the environment. These goals and information about new alternative methods are also underrepresented in current professional advice. Therefore, a good objective central source of information about plant protection, including the health effects of PPPs and new alternative strategies, is missing. These problems are indicated in red.

2. Concept of the proposed solution and added value

2.1 Core elements of the solution

To address the insufficient awareness of PD risks tied to PPP use and of suitable alternatives for PPPs, the solution that is needed should bridge the communication gap between agrarians and scientific knowledge about PPP health risks, as well as the gap between agrarians and IPM expertise. Therefore, our solution will focus on agrarians to be the end user.

To bridge these gaps, our solution should contain a few core elements, as shown in Figure 4. The solution, indicated with a question mark, strives to do two things, which are depicted by arrows:

1) It brings scientific knowledge to the farmers and establishes a stable flow of information about PPP health risks.
2) It transfers helpful up-to-date knowledge to farmers about the IPM strategies that are available to them or that are being developed.

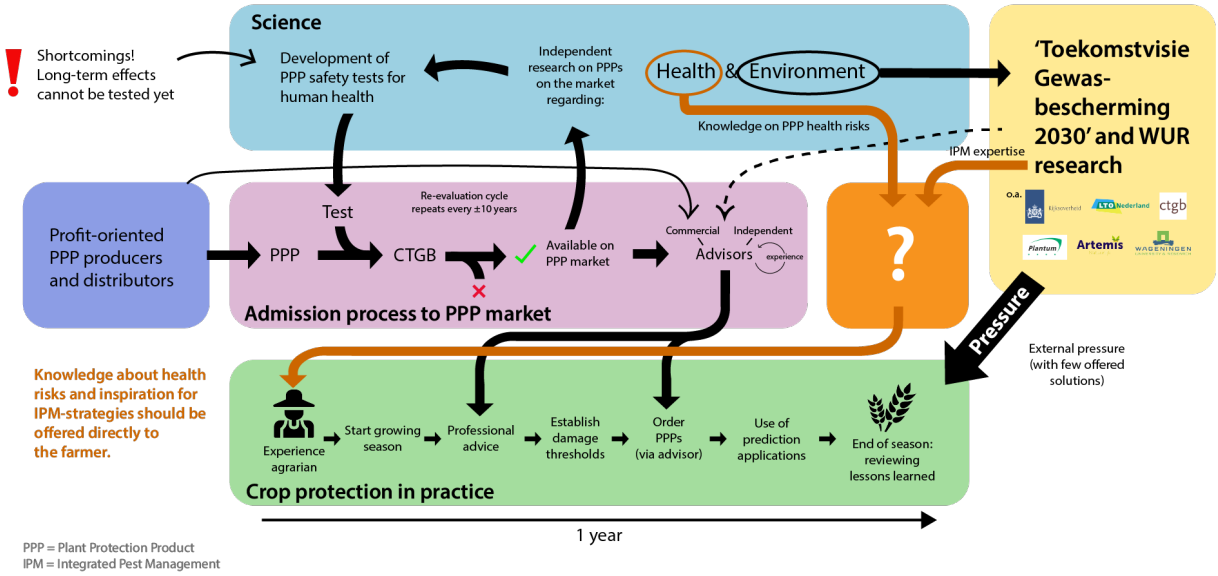

Figure 4: Core elements of the solution and added value to the existing system. The proposed solution (depicted in orange) aims to solve the identified problems (as depicted in red in Figure 3).

In this second element, we have found a good connection with the recently published governmental report 'Toekomstvisie gewasbescherming 2030' (Rijksoverheid, 2019; 2020), which describes why the current PPP-dominated plant protection strategy of most Dutch farmers is no longer tenable both from economic and environmental perspectives. WUR IPM experts explain that the use of PPPs often disturbs the biodiversity and soil quality of the land, which, when healthy, would have offered the crops some natural protection against pests. This creates more need for artificial protection and thus generates a vicious cycle of PPP use. However, because pests increasingly become resistant to PPPs, PPPs will no longer work in the long-term and thus are not sustainable in a financial sense either. Additionally, the availability of PPPs is shrinking due to increasing bans by the EU as admission research improves and identifies more environmental and health risks. As stated in the report, the government therefore wants to achieve a nation-wide transition towards the IPM method, which uses less PPPs. Although we come from the perspective of farmer health, lowering PPP use by transitioning to IPM also serves our goal, because it lowers PPP exposure, effectively lowering the health risks. Because sufficient knowledge about IPM is required on behalf of the farmer to make its use successful (Planbureau voor de leefomgeving, 2019) and because most farmers do not seem to have this knowledge (Bakker, 2021), we want to include the IPM-aspect in our solution.

Based on our findings in the problem analysis, we believe that there is a need for an openly accessible independent central source of knowledge about PPP health risk information and IPM strategies, which is a conclusion that is supported by several independent Dutch (governmental) advisory bodies that have investigated the matter of plant protection (Gezondheidsraad, 2020; RIVM, 2011; Planbureau voor de Leefomgeving, 2019). Additionally, even LTO and other farmer organisations themselves have expressed this need (Gezondheidsraad, 2014). Therefore, our solution should function as such an accessible central information platform, where complicated information about its two core elements is presented to farmers in an understandable and farmer-tailored way.

2.2 Stakeholder input and development of the concept

We consulted literature and performed interviews with various stakeholders that we deemed helpful for input on both the core elements of our solution and its further development (Figure 6). We reached out to farmers and their branch organisations, as both core elements of our solution are meant to serve these parties. Additionally, we contacted regulating governmental bodies and health scientists, to discuss the risk aspect of our solution specifically. For the IPM aspect of our solution, we talked to PPP producers, organic plant protection companies, IPM experts and regulating governmental bodies. For the approach, optimal effectivity and the design of the solution, we talked to a behavioural scientist. During our interviews, we discussed the viability of the core of our idea, as well as the best ways to implement our solution. Over time, our solution concept became more refined as new information and advice from stakeholders, as well as new insights were acquired. Considering the dynamic nature of this process, stakeholder input and feedback were integrated in the following description of our process of shaping our solution.

Infobox 1: Integrated Pest Management (IPM)

The IPM plant protection method strives to be as independent of traditional PPP use as possible, whilst keeping crops healthy and pest-free. This is done by shifting the focus onto what pest protection is already offered by nature and strengthening these systems, before using any artificial pest protection. This can be done by working with pest-resistant plant species and by creating resilient crop cultivation systems that are focused on preventing, monitoring and learning from pests. As described by the European Parliament in 2009, IPM plant protection follows a cycle of 8 steps, which are depicted in Figure 5.

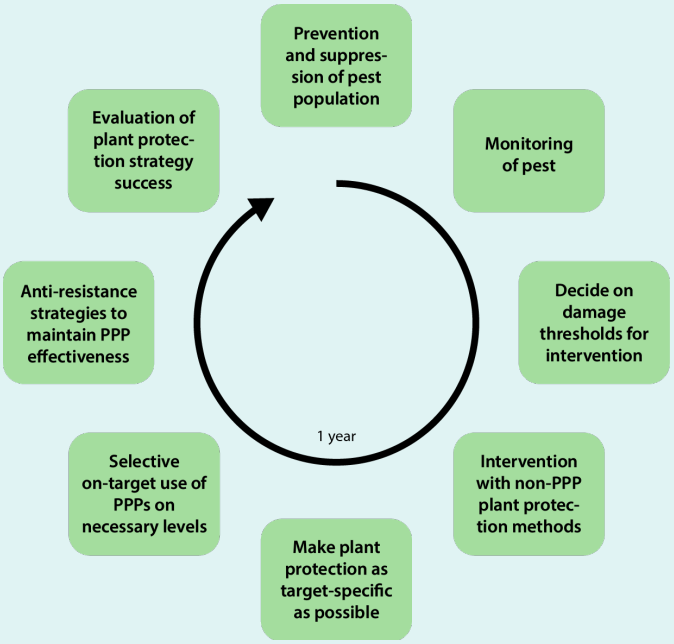

Figure 5: The eight steps in the cycle of Integrated Pest Management that take place in one growth season (European Parliament and Council, 2009).

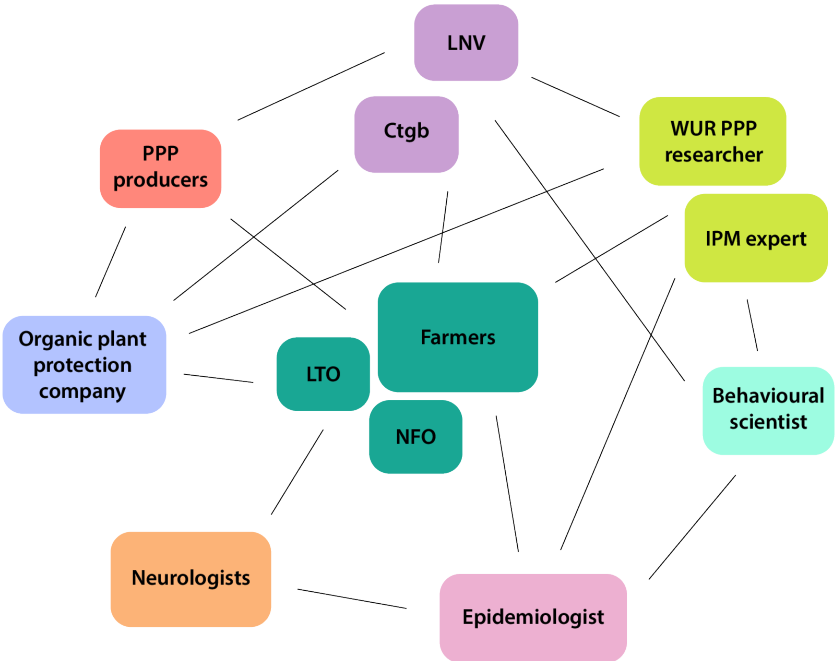

Figure 6: Stakeholder plot of the stakeholders that were interviewed for feedback and collaboration in the solution phase (Develop and Deliver phases) and evolve phase of the project. Abbreviations: PPP: Plant Protection Product, Ctgb: the Dutch College for the Admission of PPPs and Biocides, LNV: the Dutch Ministry of Agriculture, Nature and Food Quality, LTO: the Netherlands Agricultural and Horticultural Association, NFO: Dutch Fruit Farming Organisation, WUR: Wageningen University and Research, IPM: Integrated Pest management.

2.2.1 Platform

Because of the complexity of the field of plant protection methods, the number of involved parties and the continuing developments in this field, having a central platform for the information of our solution is essential. It will avoid creating confusion and provides clarity about the conveyed information. Our main goal is to bring the information to the farmers directly and, thus, it should be tailored to them specifically. As PPP and IPM companies as well as farmers pointed out to us, plant protection is not the farmers' sole activity and should not cost too much effort. Therefore, the source of the information should be easily accessible, ideally at any time. Because of the combination of these desired aspects, we chose for a website as our platform. That way, no commitment from the farmer is required, like would be the case for example with downloading a phone application. The behavioural scientist pointed out that such little commitments can be perceived as annoying and create an effort threshold for people to cross. Additionally, utilisation of the website would not result in any extra tasks for the farmer. It will be a 'no-strings-attached' way of gathering knowledge for free, and farmers will have the time to browse online and learn more about plant protection at any time, e.g. in the less busy winter months.

2.2.2 How the website communicates health risks

The goal of the first part of the website, regarding PPP use and PD risks, is to allow agrarians to make a well-informed decision about their plant protection and PPP use, with health taken into account. We believe that farmers are entitled to better knowledge about the possible risks tied to the products they work with. The main downside about informing farmers about the risks of PPPs, as expressed by WUR scientists and the Ctgb, is the risk of spreading excessive fear. To avoid doing so, the farmer will not only be informed of known risks, but also on the extensive safety testing that PPPs are already subjected to, and the information will be stated in an unbiased and composed manner. We want, however, to include the limitations of these safety measures as well, to provide both sides of the situation and make sure the farmer is aware of the big picture.

Another big point the website will convey is the associations found between PPPs and PD in general, both from the past and the present. It will provide context for the farmer as to why there are concerns about the relation and will clearly explain the full story even to those that are new to this information. Some of the stakeholders we spoke to, like PPP producers and a handful of farmers, do not think there is enough reason to believe there is an actual connection. This is contrasted by a lot of other stakeholders we spoke to, including, but not limited to scientists from the WUR. To make sure that the information on this topic is accurate, it will just point out what evidence has been found and will not draw any conclusions based on assumptions. This will apply to all the health risk information on the website.

The main communication element about risks we envisioned to be offered on the website is informing the farmer about different substances used in PPPs and the known risks associated to them. When talking to scientists and the Ctgb, however, we discovered that it is hard to inform farmers about risks of specific PPPs, because of the limitations in testing and research that refrain science from being able to find causal relationships between specific PPPs and PD. There would simply be too many substances of which nothing is known, and this will make the website forego its purpose by not being able to give insights to the farmer as to which PPPs are likely to bear risk and which ones are not. However, as explained by our toxicologist stakeholder, PPPs within certain groups with a similar mode of action (hereafter referred to as PPP groups), based on their chemical structure, are more prone to affect health in the same manner. Because of this, research being done on a substance that is part of a PPP group can give an indication about the rest of this group as well. In this manner, substances within the same group of a substance that is banned in the past or that will be banned in the future can be flagged as having a higher risk to be unsafe. This also works the other way around, when research has good reason to believe that there is no association of a PPP from a specific group with PD development, than the other PPPs of this group have higher chances of being relatively safe. Epidemiologic research can also add to this by associations found in groups that have similar working mechanisms. Therefore, we decided that the information on the website will cover the toxicological and epidemiological research associations (or lack thereof) found between these PPP groups and PD development and will only go into specific substances when they are very controversial, like is the case for Mancozeb (Lucchini et al., 2009).

Articles on the latest scientific developments will be posted on this part of the site as well. The intention is to keep the news items short and to update the farmer about the science behind PPPs, PPPs bans and any changes that are made in the PPP admission testing procedure. One of the scientists we spoke to indicated that our website could be a good platform to communicate the found results of a big national study that is currently being set up to farmers. As pointed out to us by a stakeholder from the Ministry of Agriculture, Nature and Food Quality (LNV), science tends to not always translate

well into the real world. Thus, like mentioned before, the information will not draw any conclusions based on assumptions and will inform the farmers of the translational aspects, like is done in normal scientific articles.

The majority of our stakeholders stress that the information in this section of our website needs to be trustworthy. To ensure this, the text will be written by established scientists from different fields, consequently peer reviewed on accuracy and tailored to an agrarian audience by agricultural journalists.

To see how this part of the website affects the actual situation we revisit Figure 4, where now the question mark is replaced by our website (see Figure 7). The health risk part of the website will represent the arrow that connects PPP health research to the farmer. The website will provide information on PPP health risks in the following ways:

- Research and safety measures regarding PPP testing on PD and the limitations thereof.
- The current understanding that we have of the relation between PPPs and PD.
- PD associations of specific chemical PPP groups, including specific controversial substances.
- Farmer-tailored scientific news articles on recent scientific developments on PPPs and PD development.

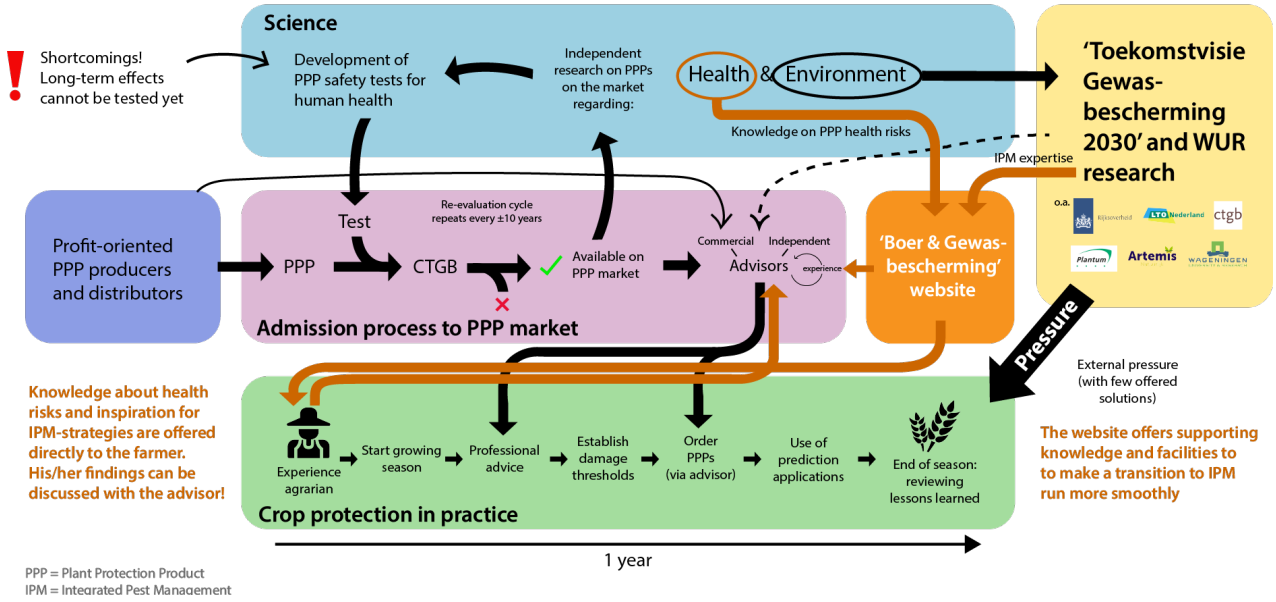

Figure 7: What our concept offers. When compared to Figure 4, the Boer- en gewasbescherming website includes all core elements, but even adds some specific benefits to this concept compared to the general solution displayed in Figure 4.

2.2.3 How the website communicates IPM information

The goal of the second part of the website, regarding IPM information, is to allow farmers to consider IPM as a plant protection method and provide them with the tools to explore what IPM methods they can implement to reduce their PPP use. The risk part of the website only provides agrarians with a problem. This problem creates a sense of urgency, which is something which is essential when you want to bring about change, as the behavioural scientist tells us. However, as farmers expressed in our interviews, there are enough sources providing them with problems, but there is not a lot of actual help provided to solve these problems, which again could fuel uncertainty and fear. The 'Toekomstvisie gewasbescherming 2030' plan (Rijksoverheid, 2019; 2020) describes clear concepts for how the set PPP reduction goals can be achieved, including good ideas for pilots, yet it lacks concrete ways on how to realise these concepts and help the farmer to reduce their PPP use. Our website wants to contribute to achieving these goals by giving the farmer a tool that allows them to explore IPM strategies. In this manner we do not only present the farmer with a problem, but also with a solution. This part of the website is split into two different parts: a part informing the farmer about IPM as a plant protection method in general and an 'IPM Explorer' that shows the farmer IPM methods applicable to their specific crops.

2.2.3.1 IPM information

The current knowledge on IPM is there, but it is mostly scattered and not easily accessible. This belief is supported by others, like WUR scientists. Interestingly, the need for structured IPM information was already expressed by farmer associations themselves, as the association for greenhouse farming (the Glastuinbouwvereniging) created a website called the 'IPM Tool', which acts as a basic information platform about IPM specifically designed for greenhouse farmers (Glastuinbouwvereniging Nederland & WUR, 2021).

On the IPM part of our website, farmers will be able to read about what IPM is in general and what steps it is comprised of (see Infobox 1). Moreover, the information will cover both the advantages and disadvantages of IPM. Topics that will be addressed include sustainability, health and financial aspects. This way, farmers' common misconceptions and knowledge gaps can be addressed, which perhaps previously stood in the way of farmers that already were interested in transitioning to IPM. Some of the farmers that we interviewed were not aware of the 'Toekomstvisie gewasbescherming 2030' report (Rijksoverheid, 2019; 2020) and the aim of a transition towards IPM it describes, which therefore also will be addressed by the website. Lastly, this website page will share success stories of farmers that already started using IPM methods to protect their crops. Such a 'testimonial', as endorsed by the behavioural scientist we spoke, will show farmers that it is achievable to protect your crops with IPM methods. This is especially powerful if the testimonial is relatable to the farmer, e.g. because the farmer portrayed comes from the same region or grows the same crop. The success stories will be written by an (agricultural) journalist (see Appendix 3) and the rest of the information of the website will be provided and written by IPM experts.

This aspect of the website is represented by the arrow from 'Toekomstvisie gewasbescherming 2030' and WUR research to the farmer in our overview (see Figure 7). Information on IPM will be provided in the following ways:

- General knowledge on IPM
- Advantages and disadvantages of IPM
- IPM information and PPP reduction goals as described in the 'Toekomstvisie gewas-bescherming 2030' report (Rijksoverheid, 2019; 2020)
- General success stories of farmers that work with IPM methods

2.2.3.2 Provision of IPM advice and inspiration

A very important part of the website will be the IPM advice given by the IPM Explorer. It will allow farmers to directly access an unbiased source of information that provides IPM methods that are applicable to them. This information can cater to farmers that have little IPM knowledge and want to explore what is possible. According to the behavioural scientist, making a first step look small allows for bigger steps to be taken more easily afterwards. The IPM Explorer aims to be such a small first step. It will also be applicable to farmers that want an IPM method for a specific pest, to replace a specific PPP or that just want to see if there are any innovations in IPM methods. At this moment, there is no publicly available place where IPM methods are documented. Creating such a platform would be a good development, according to a WUR scientist.

The IPM advice should be specifically tailored to the farmer in question. To realise this, the website includes an IPM Explorer. Because we want to make the information on our website as applicable as possible, this tool can be used for the specific pests that the farmer is facing. The tool will present the farmer with a series of questions to establish what advice they require. These multiple-choice questions will ask the farmer about what crop they cultivate, the quality of the soil, the location of their farm, the pest this specific crop is suffering from etc. Once the questions are answered, the tool will generate an IPM advice focused on their situation and suggests a list of IPM methods. These methods will be shown in the order of the IPM strategy (see Infobox 1). This order presents the methods that use the least PPP intervention at the top and the PPP methods last. The farmer can subsequently click on a specific method and see how this method should be implemented to get an idea of how this would work on their own crops.

To help the farmer to implement specific IPM methods, we will refer to companies with expertise on this method and the organisations that offer this specific method to be purchased on this page. This allows the farmer to purchase or seek out specialised organisations on his/her own. If any products have known health risks tied to them or fall under a PPP group that has been deemed risky, this will be reported on this page, as well as a redirection to the corresponding risk part of the website. In this manner, the farmer can judge the methods they want to use with the direct knowledge about known risks tied to them. Lastly, a success story of a farmer that has implemented this method will be displayed. As mentioned before by the behavioural scientist, this serves as a source of motivation and will give the farmer an insight on the feasibility. It will also give the farmer a sense of being part of a community that is making a transition to IPM as a whole, which is a powerful motivational tool. Both the overview of all possible IPM methods and specific methods can be saved onto a personal account which the farmer can create on the website. When information about these saved methods is updated, the farmer can subsequently be informed about these updates via email or notifications on the site. This is crucial, because IPM is a relatively new and continuously developing field and farmers have often told us that, once they have used a method for a while, they do not actively investigate new application methods on their own initiative. The farmer will also be asked if he/she wants to upload an IPM success story of their own, which could e.g. be a method that they have found on our website the year before. Thus, the website's IPM success stories could be self-sustainable in the long run.

Because of the complexity and intricacies of plant protection, the information that the IPM Explorer offers will, although feasible for some farmers, generally not be enough to allow the farmer to implement the method fully. Therefore, we want to stimulate the farmers to discuss what they learned about IPM with their advisor, e.g. how to implement the method and if it suits the farmer's crops. It is not our goal to replace the traditional advice, but to provide an additional independent source of knowledge that stimulates farmers to make the final plant protection advice more of a well-informed collaborative effort. PPP companies and advisors tell us that this can also be done without a website, and therefore do not see the added value of our advice. We, however, highly doubt if this sufficiently happens, as currently advisors are mostly in charge of what is discussed in the advice. In the past, pest

control advice was provided by the government. Since the nineties, it was privatised (Poppe et al. 2009), which has resulted in skewed advice that tends to prioritise products that the affiliated company sells, oftentimes PPPs. Farmers cannot discuss things that they do not know about, and our website forms a good independent source of all the other options that exist, which allows for more focus on IPM in the advice. Our website will therefore offer the opportunity to level out the playing field between PPP and IPM methods represented in the advice a bit more.

The biggest challenge for generating the IPM advice is the construction of the database that will contain the information on which the IPM Explorer's suggestions are based. According to a stakeholder from the Ministry of LNV, there have been ideas about a similar database before, although they were never realised. We speculate that possible reasons for this could be that nobody felt responsible to do so or there was no urgency behind it. We believe that the need for such a central point where the current information comes together *has* become an urgency. Bakker (2021) addresses that many farmers want to make a change to reduce their PPP use where possible, but do not have sufficient information on how to do this. On top of this, the recent announcement of the 'Toekomstvisie gewasbescherming 2030' plans (Rijksoverheid, 2019; 2020) make this the moment to start creating such a database. The Dutch Fruit Growers Organisation (NFO) also tells us that a database would be a good place to gather the information from their current IPM methods and keep it accessible to the agrarians, as well as to report on innovations. As mentioned before, scientists from the WUR also stand behind the idea. Taken together, the urgency for such a database seems apparent. Unfortunately, we found that there are some obstacles in the way. Some of the IPM methods that are developed are being held confidential by companies, making our IPM database incomplete. Yet, if our IPM Explorer becomes widely used and there is no recording of confidential IPM methods, this might eventually result in the companies missing out on potential customers. Even without the confidential IPM methods, we believe that our database would be a major improvement to the current situation. A goal in the long run will be, of course, to make it as complete as possible. As complete as possible will sometimes, as mentioned by some stakeholders, still mean that some things are lacking, because not all pests on all crops can already be targeted with IPM methods. However, as IPM is constantly developing, the database will grow alongside it and becomes more effective as more methods are added.

To make sure the data of the IPM Explorer is accurate, IPM experts (e.g. from the WUR) will be responsible for gathering the information. On top of this, the database needs to be set up well to ensure a good foundation for a constantly growing database with many complexities. For this, TNO will be involved because of their experiences on setting up such databases (see Appendix 4).

The IPM Explorer adds to the information flow from 'Toekomstvisie gewasbescherming 2030' and WUR research to the farmer in Figure 7. In summary, the IPM Explorer contributes in the following way:

- Knowledge on specific IPM methods

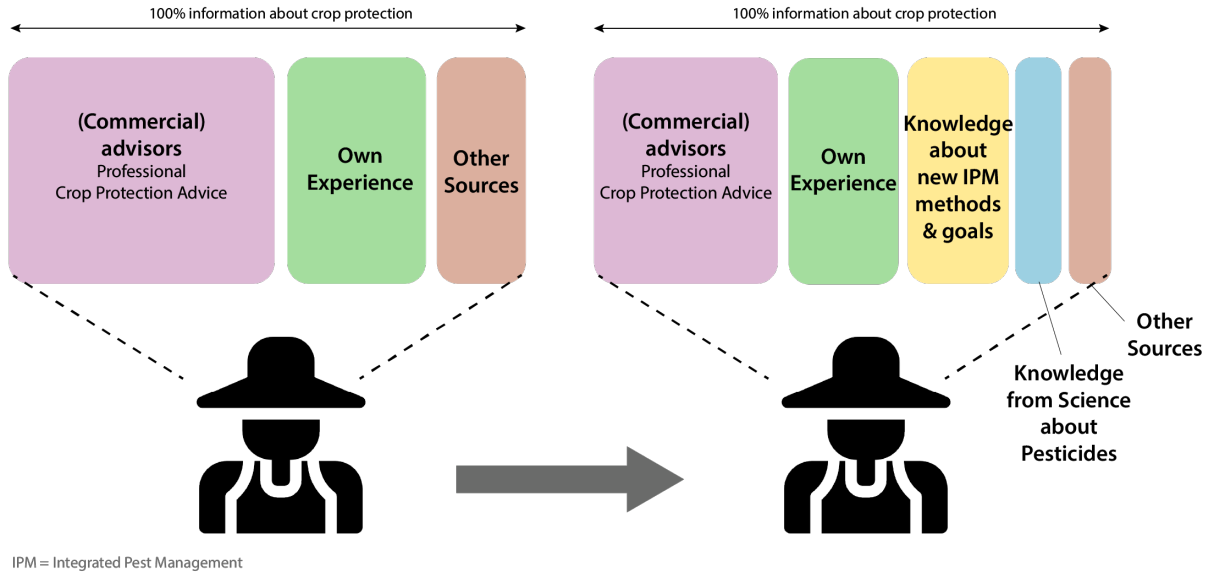

Figure 8: How does our concept change the provision of information about crop protection to agrarians?

The overall concept of our solution also adds some nice additional benefits, that are represented in Figure 7. Because the website allows farmers who have learned about PPP health effects and suitable IPM methods for their specific crops they can ask their advisors about these aspects too, which increases the likelihood that such elements will be considered in the final advice. Additionally, because the website is openly accessible, it could also be a valuable source of information to advisors directly. Lastly, farmers point out that autonomy is an aspect that is increasingly taken away by new regulations that are set every year. Because we offer an extra source of information, we can stimulate farmers to have some more input on the final plant protection advice and to take more autonomy in their PPP exposure and their approach to work towards the government's PPP reduction goals. Therefore, our concept as a whole adds the following benefits:

- Influence of farmers on the crop protection advice by asking advisors about health risks and specific IPM methods
- Source of information to advisors
- More farmer autonomy in determining PPP exposure and how to reach PPP reduction goals

Note that our website concept does not impact any of the existing flows of information and is something that adds to the current system. The result is a more complete set of information sources that is available for the farmer to consult before selecting their crop protection methods (see Figure 8). This directly addresses the problems we determined in our problem definition: "Dutch agrarians are not sufficiently aware of the possible Parkinson's Disease risks tied to Plant Protection Product (PPP) use and suitable non-PPP alternatives."

2.3 Feasibility of the solution

For our solution to be successful, it must be used by farmers. However, it seems like some farmers we spoke with do not feel any urgency to make a transition to IPM. Although this transition is encouraged in the 'Toekomstvisie gewasbescherming 2030' plan, concrete interpretations of these plans are not yet translated to the farmer. One point of feedback we received from an investment director was that, although farmers might want to make the transition towards IPM, they need financial support to be able to make the transition. A just point was that the information provided on our website would not be of added value if farmers do not have the financial means to do something with the information we provide. This was also emphasised by a professor from the WUR and by stakeholders that work for PPP companies. One employee of a large PPP company explained to us that PPP producers are already switching towards producing more organic products, but these products simply sell less because they are more expensive, less reliable, and less easy to use than conventional pesticides. However, as another expert from the WUR pointed out, it is impossible to continue working with PPPs like farmers are now in a few decades. The decreasing number of PPPs on the market as a result of bans and increasingly PPP resistant pests will eventually force farmers to make a transition towards more sustainable plant protection methods. Besides, it will take time for farmers to implement such a transition, so the sooner they start the better. To aid this transition, the government has made available 12 million euros within the first three years to start this transition (Tweede Kamer, 2020), so some financial support can be expected. Farmers now can apply for a €1.500 voucher for getting IPM advice until 2023 (Rijksdienst voor Ondernemend Nederland, 2021). Therefore, we argue that sufficient financial means will be available to farmers to make the changes that we promote on our website, and the information we provide will be of added value to the increasing number of farmers that become aware of the fact that they should change their plant protection practices. The website will also inform farmers of the urgency, when they were not yet aware of this.

Our concept is ambitious and needs the financial and intellectual support of agricultural organisations. We think that our concept would especially be well-suited to be adopted by LTO, as this is the biggest agrarian trade association. Having LTO on board will promote the use of our website and allow adoption from farmers. Besides, we think that our concept connects well to the responsibilities of LTO within the 'Toekomstvisie gewasbescherming 2030' (Rijksoverheid, 2019; 2020), for which they will receive funds. LTO has several responsibilities within the 2030 plan to which we think our idea can contribute; Firstly, LTO is starting up pilot projects in the agrarian sector to test preventive PPP measures in practice (Rijksoverheid, 2019; 2020). In our opinion, our concept could function as such a pilot project or could be linked to one of the existing pilot projects if they match well. Secondly, LTO has taken the initiative to ensure that information provided to PPP users by employers is adequate. This includes information about possible health risks that are associated to PPPs, as well as information about personal protection measures and how to use these correctly. LTO also wants to promote access to information about health risks and protection measures that is collected by the Ctgb (Rijksoverheid, 2019; 2020). Currently, this information is not easily accessible for farmers. This task of LTO fits perfectly to our concept, as our main aim is to make health and IPM information accessible. Finally, LTO will develop an instrument for agricultural entrepreneurs that provides insight into different methods that could help in creating more resilient crops (Rijksoverheid, 2019; 2020). Advisors, agrarians and other professionals will cooperate proactively in this task by sharing their experiences. This also relates to the success stories on our website. If LTO would not be interested in adopting our concept, we will reach out to different smaller stakeholders. For example, the Parkinson Vereniging, the WUR, the ministry of LNV and different smaller farmer organisations could also be interested in our concept.

Lastly, because the Dutch agriculture system is very broad and includes numerous sectors with various cultivations, we want to start small to get a proof of concept and promote the feasibility of our concept. Therefore, we decided that we want to do a pilot that focuses on only one cultivation type.

In Figure 9, our business model canvas is presented. With regards to financial aspects, our website should be seen as an investment for the long-term. It will be relatively expensive to develop, especially because the developers of this website need to create an IPM database, merge this database with the existing PPP knowledge of the Ctgb (which is available in their online database: Ctgb, 2021) and link this final database to the IPM Explorer. However, after the website is launched, yearly costs will be relatively low. The only yearly expenses will be to maintain and update the website, implement desired improvements and promote the website. Promotion can be done according to the wishes and budget of the stakeholder that is willing to adopt our concept. One farmer recommended us to use social media, trade magazines and websites of LTO and the Rijksoverheid to get farmers acquainted with the website. As the yearly expenses will be relatively low, we estimate that, if one stakeholder party or a collaboration between several stakeholders understand the need for our concept and are willing to invest the money to develop our website, our solution is very feasible.

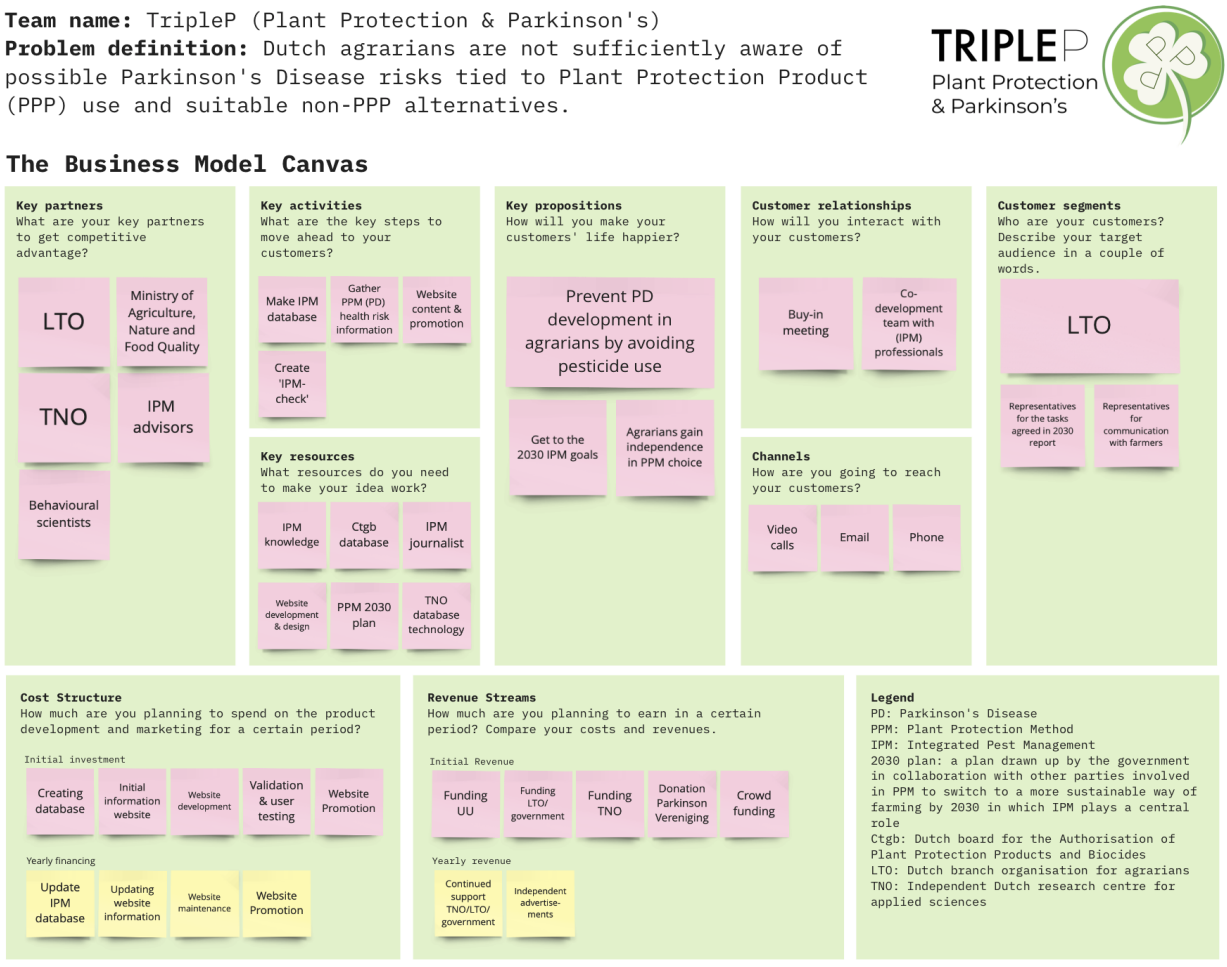

Figure 9: The business model canvas of the concept.

3. **Evolvement of our concept**

The evolve phase of this project was a very dynamic phase, which was when we thought about how exactly the website should look and about the future of our concept after our profile has finished. As mentioned above we are convinced that our concept would fit perfectly to the responsibilities of LTO. However, due to their busy schedule we were not able to properly pitch our concept to them within the time of our project. One farmer also explained to us that the majority of LTO members are dairy farmers who do not work with PPPs and would therefore not be interested in our concept. As mentioned in the section above, we decided to start our project with a pilot focusing on only one cultivation type. After doing research and having conversations with stakeholders such as LNV and IPM experts from WUR, we discovered that fruit farming, bulb growing and open-field farming would be the most suitable cultivation types for our pilot, because these are currently most suitable for IPM and have room to grow in IPM use. Therefore, we decided to shift our focus and consequently reached out to the Dutch Fruit Growers Organisation (NFO). After our meeting with the NFO, we decided to aim our pilot to fruit farmers, as this would make our concept more appealing for the NFO to adopt. Besides, our idea could connect to a pilot project that NFO is already starting. Some of the end products that we finished during this evolve phase can be applied to any cultivation type and do not only function for the pilot. Other end products were specifically tailored to a fruit farming pilot, including a mock-up of our website. All end products of this project, as well as more stakeholder feedback, are described below.

3.1 The mock-up website

The main product of our capstone project is the mock-up website that we have made in order to show stakeholders the concept that we have in mind for the website. The mock-up is catered to Dutch farmers and therefore made in Dutch. For this report, we have translated some things into English. The mock-up domain is https://www.boerengewasbescherming.com and the title of the website is ‘farmer and crop protection’. We chose this name because the goal of the website is to raise awareness and aid a transition towards IPM to both protect the farmer’s health and the crops they cultivate. Images of the mock-up website are presented as supplementary figures in Appendix 2. Please note that some details described in the solution have not been implemented yet.

Before entering the homepage of the website, you will be greeted by a disclaimer (supplementary figure 1) that informs you about the fact that the site is a mock-up website and that advice on PPP safety should be sought at the Ctgb, a professional advisor or from a governmental source. Before using the homepage, you can choose to accept or reject cookies and view the privacy policy which directs you to a separate page (supplementary figure 2).

The homepage of the website (supplementary figure 3) includes three columns (all accessible by clicking on them), which comprise the three main components of the website. The left column states ‘PPPs and health’, the middle column ‘everything about IPM’ and the right column says ‘IPM explorer’. These cover the risk part, general IPM information and IPM advice part of the intended website solution respectively. When scrolling down to our TripleP logo, some information about our organisation and a part where possible reviews of our site would be placed are shown. The website is provided with a menu at the top of every page, which allows navigation through the website from anywhere on the site, an account button and some general information about the site and contact options at the bottom. The account button allows you to make an account and, when made, it shows personal account details (supplementary figure 4) including saved IPM methods and articles.

The ‘PPPs and health’ part of the website (supplementary figure 5) is divided into three columns as well. The left column goes into ‘general information risks’ that contains a paragraph about the admission and it’s limitations and a paragraph about the general link between PPPs and PD. In the middle column ‘PPP groups and risks’ are covered of which three examples are named, which are all clickable for a more in-depth page (supplementary figure 6) on the PPP group stating general info, specific controversial substances and articles on these group of pesticides. The right column of the ‘PPPs and health’ page shows ‘what is going on in science’ covering two articles. One of these articles reports on worries of the Ctgb about PPPs and PD and the other presents a French study on PPPs and PD.

The ‘everything about IPM’ part of the website (supplementary figure 7) is again divided into three columns. The left column goes into a description of what IPM is. The middle column goes into the advantages and disadvantages of applying IPM and touches upon sustainability, health, financial aspects and the ‘Toekomstvisie gewasbescherming 2030’ plan. The right column covers success stories and contains a story of a fruit farmer successfully using an IPM technique to get rid of fruit moths.

The IPM Explorer part of the website (supplementary figure 8) shows how to use the IPM Explorer and contains a big button for starting it. The Explorer will ask you three questions, asking for the sort of crop you want to know more about (supplementary figure 9), region of your farm (supplementary figure 10) and type of pest that the selected crop is suffering from (supplementary figure 11). Every question gives you four options, but they all have the same result (the result would be correct when all multiple-choice answers with an asterisk are chosen). The result is a page called ‘IPM explorer result’ (supplementary figure 12) that starts with an instructional text on how to interpret the results shown beneath and a button to save this specific IPM methods for this specific pest to your account (non-functional). Below, the result is shown for the IPM methods on the Suzuki fruit fly in cherries. These IPM methods are ordered from monitoring, prevention and suppressing the population to non-chemical methods, followed by selective and sparing use of chemical PPPs. The method ‘nets and insect gauze’ can be clicked, and the following page (Supplementary figure 13) informs you about the implementation of the method, where to find (more information about) the method, possible health risks and success stories. The method can also be saved on the account (which is non-functional in this mock-up).

3.2 Advice letter

Currently, the NFO is reviewing our concept. Because we want to provide a complete package to NFO or other prospective partners that could be interested in our idea, we decided to write an advice letter can be sent to these prospective partners. In this letter, we briefly explain what problems we have identified throughout this project and what we think should be done. Here, we also present our concept as a solution to the problems. We will send this letter to NFO, LTO and other stakeholders that could possibly be interested, such as the open-field farming organisation and the greenhouse farming organisation. The advice letter is presented in Appendix 1.

3.3 Plans of action for content website

For the final website, we have written two plans of action for the content of the website, because these will make our concept more concrete and will help its realisation. Firstly, we have written a plan of action to collect IPM success stories for the final website (see Appendix 3). We envision the final website to include more success stories about IPM in general and at least one success story for each IPM method that is presented on the website. The Gezondheidsraad (2020) has expressed the need

for more knowledge transfer between agrarians, and the success stories on our website could be a means to fulfil that need, especially when success stories (consensually) includes the email of the farmer for others to contact in case they want to know more. Secondly, we have written a plan of action to develop the IPM database behind the IPM Explorer. This makes our plans for the database less abstract and provides insight in the feasibility of our database concept. This plan of action is presented in Appendix 4.

3.4 Feedback from agrarians

We have gathered the feedback of three different farmers on our concept during this project. Despite sending out emails to numerous agrarians, we were only able to speak with this limited amount, because this was during their busiest time of year. The farmers that were able to make time also indicated themselves that they were not 'the average farmer', because they were progressive and proactively looking up information about their plant protection. One of them was even a customer of independent advisor company Delphy. This did not give us the full overview of farmer opinions that we were looking for, which could also be due to many farmers not wanting to talk to us, as indicated in the problem analysis. To get more feedback, we wanted to send out a survey to reach more farmers to get a more representative opinion of the average farmer on our concept. Unfortunately, due to time constraints, we were not able to send out the survey, but advice this to be done in the future of this project.

Unfortunately, the farmers we spoke to were not very fond of our idea. One point of feedback was that the information about IPM and the IPM check would not be of added value for agrarians, because the number of possible crop protection methods that they can use is already very limited. For most crops, the amount of effective IPM methods is still very limited, which gives the farmer only a few options to choose from. Oftentimes, even when using IPM methods, PPPs will still have to be used to a certain extent to protect the crops, even if they can be potentially harmful for the farmer. Therefore, the agrarians argued that informing them about possible health risks would not be helpful as long as there are very few alternatives that are just as effective as the PPPs. However, one of the farmers was quite interested in the health information on the website, pointing out that he would like to know more, but would not know where to find this information currently. The agrarians agreed that having one central point of information would be good, but they question whether they will actually make use of this website. The majority of farmers we spoke to express their doubts about the possible link between PPPs and PD, which makes them more sceptical about the information on the health risks that is presented on the website.

Although the agrarians we spoke to were not that enthusiastic, we still want to pursue our idea. We know that farmers receive a lot of pressure to change their practices, not only regarding PPPs, but also regarding other aspects of their work. Change is often met with resistance, as new things come with uncertainty, and because the urgency is oftentimes not recognised. Besides, although farmers have to make changes, they only receive limited tools that aid them in such transitions and will trust offered help from sources they are familiar with the most. This could be one of the reasons that they were less open to our ideas. We argue that our concept could be a useful tool in the transition to IPM and using less chemical PPPs, but it needs to come from such a familiar source. This is why we want an agricultural organisation to adopt our idea.

3.5 Budget plan

In Appendix 5, our budget plan is presented. This budget plan is tailored to the fruit farming pilot. The budget plan is divided between initial costs and yearly costs. The initial costs include everything that is necessary to set up the website. Launching the mock-up website including the domain name is done using the website builder Wix, which costs €90,75 for one year, and an additional €11,97 was paid to ensure privacy of the domain owner. Furthermore, we bought a license for Shutterstock for five pictures, which cost €47,19. We estimated that building the official website would cost around €20.000, as we found that building websites costs between € 5.000 and € 30.000. Our estimated costs are at the higher end of this spectrum, because we expect this to expensive. For the section of the website about health risks we want to hire one epidemiologist and one toxicologist. We expect these two health experts to be finished writing the content for the website within a month. For the general information about IPM and the IPM database, we want to hire an IPM expert, for example from WUR. We expect the expert to be finished with writing the general IPM information for the website within one month and an additional two months for gathering the information for the IPM database. We included salaries for one or two months in the budget plan. All salaries that are included are estimations that are based on average yearly salaries that we found for each occupation. For the success stories that we want to include in the general section about IPM and in the IPM explorer, we want to use unpaid internships, for example for journalism students. Therefore, the success stories are not accounted for in the budget plan. The yearly costs in the budget plan include maintaining and promoting the website. In this section we also included one month salary for the IPM expert, because we need to keep the IPM Explorer updated with new IPM methods. The promotion costs that are included are an estimation and depend on the budget of the stakeholder that will adopt the website.

4. Results, outcome and future of the project

With the aforementioned end products, we aim to provide a full 'tester' package of our concept and how we think it could be achieved. Because of reasons mentioned before, we would like to hand over this concept to partners such as farmer organisations (e.g. LTO, NFO, or the Glastuinbouwvereniging), the WUR, scientists and the Parkinson Association for further development and customisation. To contact these parties at the end of our project, the advice letter is sent, along with the mock-up and Figures 3 and 7. The extensive problem analysis that was performed as part of this project is an inclusive overview of the current state of this issue in the Netherlands and could be very insightful to our other stakeholders as well, which is why this report will be shared with them.

When our pilot in fruit farming proves to be successful, our website and the database can later be extended to include other types of cultivations or even agriculture as a whole. Additionally, we could also expand the health aspects that our website reports on to stretch further than PD. Furthermore, we think that our website could function as a two-way street between science and agrarians. As we create a curated database with the available IPM methods, we will easily be able to identify which crops cannot yet be protected from certain pests with IPM. This will function as a good indicator for WUR scientists and companies to direct their research to certain needs for IPM innovation. Additionally, when the website is well established, a function can be added for collecting data on which IPM methods and PPPs are currently being used by farmers most. For this, permission of the farmers will be asked before saving this information. Currently, this information is not available, although it is deemed necessary to get a better understanding of the extend of IPM implementation in the Netherlands. This is a necessity that is recognised in the 'Toekomstvisie gewasbescherming 2030' (Rijksoverheid, 2019; 2020).

5. **Methods and Materials**

The data in this research project was collected in several ways. Firstly, broad literature research was conducted to create an overview of the scientific evidence on this topic. In order to investigate how this scientific evidence currently is translated to society and how it is received, interviews with important stakeholders in the problem were conducted, as well as some surveys. These interviews and surveys were also used to guide our project into the direction where we identified the most crucial problem that is still feasible for us to find a solution for and to generate a preliminary concept for that solution. Further interviews were conducted with stakeholders that were specifically contacted for giving feedback. This feedback was used to adapt our concept and make it as practically applicable for farmers as possible. Finally, certain email contact and an interview were established with important prospective agricultural partners for the project, such as LTO and NFO, to discuss the future of the project and their willingness to adopt it.

We have ensured to include sufficient stakeholders from different perspectives (n=24), but were not always able to reach all of the prospected interviewees due to their busy schedules or unfortunate timing. The interviews were prepared carefully and were audio recorded when consent was given. These recordings were only used for internal information processing and were removed after the project finished. Summaries of the interviews were sent to the interviewees for proofreading before they were included in this report. Interviewees that wish to remain anonymous have not been named in any documentation. Please note that the interviews also reflect the opinions and knowledge of the stakeholders and are not always factually correct.

For the creation of the mock-up website, we used the website creation platform Wix, because it would offer us a presentable and customisable website that meets our requirements without the need for coding. A subscription of one year was bought, including a domain name, which allows the mock-up website to be online for one year. Privacy for the domain name was also arranged for 1 year. The website uses cookies, and a pop-up allows visitors to view the privacy policy and to accept or reject the cookies (privacy policy was arranged by privacypolicyvoorbeeld.nl). Accounts can be created on the mock-up website, which will make the email address and country of origin of a user visible to us. As this element only serves as a preview, this information will not be used or shared in any way. Because the website is a mock-up and is not fully functional and contains incomplete information, viewers will get a pop-up with a disclaimer. The images on the website were either purchased from Shutterstock or come with an explicit source. Some of the example text is ‘lorem ipsum’ text, because the content was not needed to convey the intention of our solution.

The documentation of this project all took place within Microsoft Teams and was only accessible to a select group of students and staff members of the Graduate School of Life Sciences, Utrecht University. Video meetings took place in Microsoft Teams, Zoom and WebEx.

6. **Abbreviations and glossary**

Term or abbreviation	Definition
Agrarian	Agricultural entrepreneur. Is used interchangeably with the word farmer in this report.
AOP(s)	Adverse Outcome Pathway(s). Model used in toxicology that identifies the different cellular or molecular events in the sequential pathways in which exposure to a substance create a toxic effect.
CLM	'Centrum voor Landbouw en Milieu'. Independent Dutch research and advisory centre for Agricultural and Environmental research
CTGB	'College voor de Toelating van Gewasbeschermingsmiddelen en Biociden'. The Dutch governmental body that is in charge of admission of PPPs and biocides in close collaboration with the EFSA on a European level.
EFSA	European Food Safety Authority. Organisational body of the EU that has the final say for approval of PPPs and biocides in the EU.
EU	European Union
Farmer	Agricultural entrepreneur. Is used interchangeably with the word agrarian in this report.
IPM	Integrated Pest Management. 'Geïntegreerde gewasbescherming' in Dutch. A style of plant protection that strives to use as little PPP use as possible by shifting focus to strengthening natural protection mechanisms.
iSZW	'inspectie van het ministerie van Sociale Zaken en Werkgelegenheid'. Inspection body of the Dutch Ministry of Social Affairs and Employment.
LNV	'Ministerie van Landbouw, Natuur en Voedselkwaliteit'. The Dutch Ministry of Agriculture, Nature and Food Quality.
LTO	'Nederlandse Land- en Tuinbouw Organisatie'. The Dutch Agricultural Trade Association.
NFO	'Nederlandse Fruittelers Organisatie'. The Dutch Fruit Farmer Organisation.
Non-PPP method/alternative	A plant protection method that does not involve PPPs in any way, and instead relies on physical or natural principles to protect plants from pests.
PD	Parkinson's Disease
PPP(s)	Plant Protection Product(s), which is a term that refers to pesticides of both a natural or chemical nature.
PPP groups	Groups of PPPs that have a similar mode of action, e.g. because of similar chemical structures of the active ingredients.
RIVM	'Rijksinstituut voor Volksgezondheid en Milieu'. The Dutch National Institute for Public Health and the Environment.
TNO	'Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek'. The Netherlands Organisation for Applied Scientific Research.
TripleP	The name that we have given our research group. It stands for 'Plant Protection & Parkinson's'.
(Uitvoeringsprogramma) Toekomstvisie gewasbescherming 2030	Document created by the ministry of LNV in collaboration with many agricultural stakeholders, that states goals to bring down PPP use enough to reduce PPP emissions to almost zero by 2030. The government wants to achieve this by facilitating a nation-wide transition to IPM-based agriculture.
WUR	Wageningen University and Research

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