Smallholder pesticide use: Preventing health effects with the right information

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Preface

This thesis concludes my PhD project titled '*Smallholder pesticide use: Preventing health effects with the right information*' which was conducted at the Department for Environmental Chemistry (Uchem) at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) in Dübendorf, Switzerland, and at the Institute of Biogeochemistry and Pollutant Dynamics (IBP) at the Swiss Federal Institute of Science and Technology (ETH) in Zürich, Switzerland.

After attending the ecotoxicology lectures with Prof. Rik. Eggen during my Bachelor studies in Environmental Sciences, I conducted my Bachelor thesis in summer 2014 under his and Dr. Francis Burdons' supervision at Eawag on '*Investigating 'Bottom-Up' processes on microbial-mediated decomposition in wastewater affected streams*'. Thereafter I started my Master studies at ETH in a joint master program on 'Human Health, Nutrition and Environment'. In the lectures on health impact assessment I became acquainted with Dr. Mirko Winkler, a senior scientist from Swiss Tropical and Public Health Institute (Swiss TPH), who I then approached for a Master Thesis project.

The Master Thesis was embedded in a research project titled '*Comparative appraisal of pesticide use in tropical settings: exposure pathways, health effects and institutional determinants*', funded by the Swiss Network for International Studies and later renamed '*PESTROP Project*' with PESTROP for '*pesticide use in tropical settings*'. Dr. Mirko Winkler was the coordinator, with Prof. Karin Ingold and Dr. Christian Stamm as co-coordinators (Principal Members: Dr. Samuel Fuhrimann, Frederik Weiss, Prof. Ana María Mora, Prof. Charles Niwagaba; Associate Members: Prof. Jürg Utzinger, Prof. Guéladio Cissé, Prof. Rik Eggen, Prof. Erik Jørs, Aggrey Atuhaire, Prof. Martin Röösli, Prof. Leslie London, Prof. Aquiel Dalvie, Prof. Andrea Rother). During my Master thesis (May to November 2016), I was part of a data collection team studying human and environmental exposures to pesticides and associated health effects in the Zarcero region of Costa Rica. Prof. Ana María Mora from Universidad Nacional de Costa Rica and Dr. Samuel Fuhrimann from Swiss TPH were supervising the exposure assessment, while both Dr. Fuhrimann and I led a research team each. My Master Thesis was titled '*Pesticide Use and Acetylcholinesterase Level among Organic and Conventional Small-Scale Farmers in Costa Rica: A Cross-Sectional Stud*y' and was supervised by Dr. Mirko Winkler and Dr. Christian Stamm. The other data collection of the PESTROP Project in Costa Rica were handled by Ruth Wiedemann for institutional aspects and Frederik Weiss for pesticide residues in water. In their positions as supervisors of Fred Weiss's work, both Dr. Christian Stamm and Prof. Rik Eggen visited him in Costa Rica, thereby also examining the environmental and human exposure assessments. Following my return to Switzerland I was offered to start a PhD position, continuing the work I started in Costa Rica also in the second study site: Uganda.

In December 2016 I enrolled as a PhD student with Prof. Rik Eggen as main supervisor and Dr. Christian Stamm as direct supervisor at Uchem. Dr. Mirko Winkler remained co-supervisor from his position at the Swiss TPH. Throughout the first half year I developed my research plan, deviating from the original three-pronged PESTROP approach (health, environment, institutions) to study pest management also from a behavioral economics perspective, assessing trade-offs and externalities thereof. With neither of the supervisors having profound expertise in economics, we invited Prof. Isabel Günther from the ETH Center for Development Economics (NADEL) to join as co-supervisor.

In 2017 we conducted the second cross-sectional health assessment, this time in Uganda. The design was again supervised by Dr. Samuel Fuhrimann, while Dr. Andrea Farnham later assisted in analysis. Tiziana Manfioletti conducted her master thesis within the health assessment in Uganda on neurobehavioral aspects of pesticide health effects. In parallel Dr. Jennifer Inauen, a psychologist from Eawag, designed a pilot-study to assess behavioral practices among farmers in terms of health protection, which was conducted by Nikola Diemer. During her stay in Uganda, I assisted Nikola Diemer in her research where possible. This research was later picked up by Dr. Jonathan Lilje, also Eawag, conducting a full research on protective behavior among Ugandan smallholder farmers in 2018. Similar to the setup in Costa Rica, Ruth Wiedemann conducted research on institutional aspects, while Christelle Oltramare conducted the research on pesticide residues in water. The different study branches were conducted in close collaboration with partners from Uganda National Association of Community and Occupational Health (UNACOH) and their associates, most prominently Aggrey Atuhaire.

2018 was marked by analysis of all the collected data and article writing, as well as preparation for two restitution campaigns, one in each country. The Costa Rica restitution conducted in late 2018 consisted of a series of meetings with authorities from university and ministry of agriculture, as well as a series of farmer meetings, where the gained results were presented to the interested audience in their villages. In Uganda, the restitution took place in early 2019. Besides the farmer meetings and a press conference-like event where we presented our findings to national authorities from the ministry of agriculture, we also conducted a two-day workshop with stakeholders from local to national levels to see and validate the relevance of our findings.

From this workshop the last part of my research developed, the study on Agro-input dealers and their farmer advice, guided by inputs from Prof. Isabel Günther and Dr. Mirko Winkler. This research was conducted in the second half of 2019 together with Curdin Brugger, who wrote his Mater Thesis focusing mainly on the advice-giving part.

Throughout the PhD experience it was possible for me to take part in several cross-fertilizing projects, such as the participation in the ETH World Food System Center Summer School and the subsequent

Alumni Events, consulting the Doctoral Thesis Project by Martin Hansen from Aarhus University, as well as the whole spectrum of Eawag-related seminars and events.

This thesis provides an overview of the different steps of smallholder farmer pest management health risk behavior from pest occurrence, via agro-input dealer advice, to pesticide application and protection, and resulting policymaking challenges, summarizing findings from the different studies conducted as part of this PhD project. I am humbly hoping that this research provides ample insights for future researchers, policymakers and other stakeholders to assess the information-risk relations for smallholder pest management sufficiently.

Acknowledgements

First of all, I would like to take the opportunity to thank everyone who has supported, accompanied and motivated me during my doctoral thesis.

Foremost, I thank my doctoral advisors within Eawag, Rik Eggen and Christian Stamm, as well as Mirko Winkler and Isabel Günther from Swiss TPH and NADEL respectively. From the beginning, Rik gave me a lot of freedom, allowing me to also walk the 'wrong' paths, teaching me to focus. In crucial moments Rik found the right words and shared his view of the bigger picture. I am very grateful for the opportunity to conduct my PhD research with Rik's support. The work with Christian was similarly characterized by room given to explore my own ideas, advising on which paths to walk and which to avoid without mandating the direction. I especially valued his sudden appearances in the office door, briefly checking on the latest progress and sharing his wisdom where necessary, without imposing any of it. Meeting with Mirko was usually out of the ordinary, as either he or I would be out of our natural habitat, visiting each other in Basel or Dübendorf, or on a sunny beach in Costa Rica. I thank Mirko for sharing his enthusiasm and vigor for our projects and all the humans involved. It remains a mystery to me, how Mirko remains a sane empathic person while being available at any day or hour for a quick email response or phone call from any place around the globe. From Isabel I learned to keep back-checking my concepts with reality and not over-interpret on data. I thank her for sharing her vast experience in explorative social-science research in contexts different from Switzerland, as well as her introduction to many like-minded researchers working across boarders and cultures.

I thank everyone who was working directly with me during data collection, analyses and interpretation. Foremost I thank Samuel Fuhrimann for guiding me hands-on throughout the first years, while remaining a very close ally for the later research. I am glad to have walked by his side, and that he had not only an open ear, but also an open door in South Africa as well as the Netherlands. I thank Ruth Wiedemann for her clarity and persistence in our work together, as well as for being a friend along the PhD-rollercoaster. I thank them both for all the excitement and happy moments during and after our fieldwork. I was honored to assist in the Master Thesis of Tiziana Manfioletti and Curdin Brugger and am very proud of their work. I thank both of them for the enormous length they went during the exhausting and long days in Uganda as well as the analyses thereafter. I thank Nikola Diemer for introducing me into her research as well as the ever-entertaining exchanges we developed from there.

An enormous thank you goes to the research partners we had in both Costa Rica and Uganda. For Costa Rica, my thanks go to Ana María Mora, for making sound research the top priority, not allowing little slips of thought to develop into later avalanches. I am proud to have worked alongside her and getting the best of her expertise. I thank the data collection team, as well as our liaison to the local farmers: Andrés Campos and Ana RocÍo Ulloa, Carly Barker and Marcela Quirós Lépiz, Hannah Wey and Sophia

Colombari and Adrian Alfaro and Gabriel Rodriguez. I also thank Fernando Ramírez Muñoz as well as the researchers and students from the Central American Institute for Studies on Toxic Substances at Universidad Nacional for their support.

For Uganda, my deepest thanks and respect extend to Aggrey Atuhaire. I benefitted greatly from all the doors he was able to open, not only literally, but also all the doors in my mind that burst open through his empathic care about the research topic. For sharing her enthusiasm and pragmatic solutions I thank Sarah Fiona Kisakye. I thank Charles Niwagaba for all initial introductions, his uncomplicated way of solving our pressing issues and his inviting nature to be his guest. Here too I thank the data collection team, as well as our liaison to the local farmers: Tonny Mpanga and Simon Peter Bakkabulindi; Damalie Mukasa and Galiwango Kyoloobi; Annah Nyesigire, Gideon Kironde, Jonathan Mugweri, Julian Nandhego, Lydia Yariwo, Nuhuh Mutebi, Sarah Namirembe and Esther Mirembe; Alex Kazibwe, Annette Ococi, Christine Kanweri, Felex Muhumuza, Job Agaba, Joviah Gonza, Mercy Nsimamukama and Shaffi Mumbere. Furthermore I would like to thank Salim Kasamba for the cheerful cover illustrations.

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I felt very privileged to be part of the environmental chemistry group at Eawag (Uchem). Despite our apart research I found a very supportive working environment. Tales are told of countless coffee breaks, lunches, cakes and apéros, but also excursions, ski-days and of course our Christmas party. I want to thank all the current and former members of Uchem for the good team spirit and the friends I made during these four years. A special shout-out to Jakov Bolotin for the almost daily (post-)lunch banter, Werner Desiante for the Stammtisch and Aduccia Sciacovelli for her enthusiasm and care for me and the office-plants.

Working in the academic community, surrounded by researchers and scientists provided me with many learning opportunities beyond the scope of my research project. I would like to thank the teams and colleagues at Eawag FlyAware and the staff representation (PV), the ETH World Food System Center (WFSC) and WFSC Alumni, the ETH 4 Development (ETH4D) and the Swiss Network for International Studies (SNIS). I also thank the lecturers at ETH Zürich that guided me before and during my PhD studies, as well as all unnamed study participants, co-authors and reviewers from the many publications I was able to work on. Finally, I thank the PhD examiner Anke Huss and PhD defense chair Bernhard Wehrli for their engagement in making this dissertation a success.

I want to express my gratitude to my extended family for their support throughout all stages of my life, but especially the last five years. I thank my parents, step-parents and future parents-in-law for keeping their doors open and sharing their worldly wisdom. I thank my sister Sandra and her husband Luca for exemplifying how a healthy family life looks like while both parents pursue their doctoral degrees. Lastly, I am extremely thankful for the continuous encouragement, support and understanding provided by Géraldine. Your patience with my absences, long working days and weekends significantly contributed to my well-being and a vigorous PhD time. Thank you.

Evaluation Committee

Prof. Dr. Rik. I. L. Eggen

Rik Eggen is adjunct professor in environmental toxicology at ETH Zürich, Switzerland and deputy director at Eawag, Switzerland. His current projects are all of interdisciplinary nature, including environmental and environmental health, engineering and social sciences. In collaboration with stakeholders, research results get implemented in practice, result in new legislations and mitigation measures towards improving human and environmental health. Research projects run in developed and low and middle- income countries.

Prof. Dr. Isabel Günther

Isabel Günther is professor for development economics at ETH Zürich, Switzerland and is director of NADEL. Her main research interests are in empirical microeconomics with a particular focus on effectiveness of development aid, technologies and policies for poverty reduction, population economics and measurement of poverty and inequality. Research projects run primarily in sub-Saharan Africa.

Dr. Anke Huss

Anke Huss is assistant professor for environmental epidemiology at Utrecht University, Netherlands. She is involved in advanced methods of exposure assessment including modelling of diverse exposures (electromagnetic fields, pesticides, perceived exposures, noise and others) with a special focus on exposures displaying spatial distribution. She has evaluated these exposures regarding outcomes such as neurodegeneration and sleep quality using study designs such as case-control and cohort studies.

Dr. Christian Stamm

Christian Stamm is deputy head of the department environmental chemistry at Eawag, Switzerland and lecturer for agriculture and water quality at ETH Zürich, Switzerland. His research interests are interdisciplinary, on sustainable agriculture and water quality, ecological effects of micro pollutants in aquatic ecosystems and their transport from soils to water bodies at different spatial scales.

PD Dr. Mirko Winkler

Mirko Winkler is assistant professor and head of the health impact assessment research group at Swiss TPH, Basel, Switzerland. His main research interests are in the study of environmental exposures and societal factors contributing to adverse health conditions and wellbeing. His research focusses on large infrastructure development projects, urbanization and climate change, as well as chemical and microbial exposure in smallholder agriculture and sanitation safety planning.

Abstract

Pesticides are used globally in agriculture, and can have negative effects on human health and ecosystems, especially when not handled as intended. Still, an increasing number of smallholder farmers in low- and middle-income countries are using expensive pesticide products to increase their yield. Due to their low socio-economic status and educational level, smallholder farmers are particularly vulnerable to the negative impacts of yield losses, but also of those from pesticides. When confronted with pests, smallholder farmers develop a need for information and seek out appropriate sources. However, little is known about how smallholders go about this process, whether this process differs for organic and conventional pest management strategies and if farmers also focus on risks of pest management practices. Agro-input dealer are supposed to provide information on pesticide risks, but they often focus more on selling products than services. There is a knowledge gap in literature on how agro-input dealers give advice, what products they sell, whether they follow laws and recommendations on best practice, and whether their practices and shop organization prevent pesticide risk situations. This in turn leads to farmers not knowing about risks, or not considering them to be relevant. While farmers have been assessed regarding their pesticide knowledge, attitudes and practices, rarely these insights are compared across contexts, identifying differences and commonalities. This, together with a lack in pesticide training, results in farmers not always following good agricultural practices, thereby affecting their own health, their communities' and ecosystems. These issues are not resolved in disciplinary silos, but only through cross-sectoral and participatory research and interventions. This idea of a transdisciplinary, border-crossing research project named 'C*omparative appraisal of pesticide use in tropical settings: exposure pathways, health effects and institutional determinants'* laid the foundation for this dissertation.

The two study sites of the above research project were a market-oriented farming system in Zarcero County, Costa Rica and a subsistence-based farming system in Wakiso District, Uganda. In two cross-sectional surveys, this dissertation complemented a pesticide exposure and health assessment of farmers in both countries (Costa Rica in 2016, *n*=300 and Uganda in 2017, *n* =302), enrolling both farmers applying synthetic pesticides and such who follow other pest management practices. We found the majority of pesticides used in both case studies to be classified as highly hazardous by the World Health Organization. While a high awareness of negative health effects was identified, the use of personal protective equipment was rare, and hygiene and other safe use practices were not adopted by all farmers. Organic farmers were more likely to have been trained on safe pesticide use practices compared to users of synthetic pesticides. Pesticide use did not appear to drive household income.

In a qualitative study in parallel to the cross-sectional survey in Uganda, we investigated pest-management information behavior from the perspective of smallholder farmers. Using an

ethnographic approach, we conducted 46 semi-structured interviews and 15 on-farm observations in Wakiso District in 2017. The results indicated that farmers develop information needs when adopting new farming practices, or when presented with disruptive information (e.g. when new pests emerged), prompting farmers to seek information actively or be attentive to receiving information passively. Whether farmers used the new information depended on successful trial of the new pest management strategy, and on the credibility of the source. Furthermore, our results suggested that sources of information for conventional pesticides were well integrated into farmers' daily lives, whereas information on organic strategies was provided through external sources (e.g. NGOs), but was not available at all times.

To share the above results with the respective stakeholders in Uganda, we conducted a participatory workshop using the design thinking method. While assessing the knowledge gaps between academic and non-academic stakeholders, we found recommendations from non-academic stakeholders applying an inherently interdisciplinary and thus broader point of view, accounting for the roles of more different stakeholders in pesticide management, for example agro-input dealers and policy-makers. The non-academic knowledge was more fine-grained and detailed, exemplifying how a knowledge integration is essential to avoid a gap between what researchers investigate and what practitioners need.

Following new insights from this workshop, we conducted an agro-input dealer study in Central and Western Uganda in 2019. We selected a mixed methods approach, using structured questionnaires and observations to study their knowledge, attitude and practices on pesticides (n=402), shop organization (n=392) and sales interaction (n=236). Actual behavior of agro-input dealers when selling pesticides was revealed through mystery shopping with local farmers buying pesticides (n=94). The findings revealed that most dealers saw advising customers as a responsibility, while only around a quarter of mystery shoppers received unsolicited advice when buying pesticides. Observations of sales interactions showed that the focus of discussion was on product choice and price, neglecting aspects of safe use. Most shops were lacking safety equipment and a quarter of shops sold repackaged products. Agro-input dealer showed limited understanding of pesticide safety labels and active ingredients. Around half the agro-input dealers held a certificate of competency, while only a minority was able to provide a government-approved up-to-date license.

In conclusion, we found that the responsibility of why pesticides are not managed, handled and applied as intended is shared throughout actor levels. Crucial information does not reach the end-user, and where it does, the appropriate tools and equipment to follow the corresponding guidelines are missing. Meanwhile, a lack of awareness from farmers as well as conflicting interests prevent agro-input dealers from providing much needed advice. We recommend to make information on safe use,

as well as alternatives to pesticides more continuously available in farmers' daily lives, by leveraging the established information channels – the agro-input dealers and agricultural extension. Professionalization of both pesticide sellers and users allows to manage the negative effects of pesticides over the entire product life cycle, from purchase, via storage and application to residual and waste management. Bridging gaps and improving coordination and collaboration between stakeholders is crucial to align practice, research and policy in their quest for reaching a transition towards sustainable agriculture.

Zusammenfassung

Pestizide werden weltweit in der Landwirtschaft eingesetzt und können negative Auswirkungen auf die menschliche Gesundheit und die Ökosysteme haben, insbesondere, wenn sie nicht bestimmungsgemäss verwendet werden. Dennoch verwenden in Ländern mit niedrigem und mittlerem Einkommen immer mehr Kleinbauern teure Pestizidprodukte, um ihre Erträge zu steigern. Aufgrund ihres niedrigen sozioökonomischen Status und Bildungsniveaus sind Kleinbauern besonders anfällig für die negativen Auswirkungen von Ertragseinbussen, aber auch von solchen durch Pestizide. Wenn sie mit Schädlingen konfrontiert werden, entwickeln Kleinbauern ein Bedürfnis nach Informationen und suchen nach entsprechenden Quellen. Allerdings ist wenig darüber bekannt, wie Kleinbauern dabei vorgehen, ob sich dieser Prozess für ökologische und konventionelle Schädlingsbekämpfungsstrategien unterscheidet und ob die Bauern auch auf die Risiken der Schädlingsbekämpfungsmethoden achten. Händler von landwirtschaftlichen Betriebsmitteln (Agro-Input) sollten eigentlich über Pestizidrisiken informieren, konzentrieren sich aber oft mehr auf den Verkauf von Produkten als auf Dienstleistungen. In der Literatur besteht eine Wissenslücke darüber, wie Agro-Input-Händler beraten, welche Produkte sie verkaufen, ob sie sich an Gesetze und Empfehlungen zu besten Methoden halten und ob ihre Praktiken und ihre Ladenorganisation Risikosituationen mit Pestiziden verhindern. Dies wiederum führt dazu, dass die Landwirte nicht über Risiken Bescheid wissen oder sie als nicht relevant erachten. Obwohl Landwirte hinsichtlich ihres Wissens über Pestizide, ihrer Einstellungen und Praktiken untersucht wurden, werden diese Erkenntnisse nur selten kontextübergreifend verglichen, um Unterschiede und Gemeinsamkeiten zu identifizieren. Dies, zusammen mit einem Mangel an Pestizidschulungen, führt dazu, dass Kleinbauern nicht immer gute landwirtschaftliche Praxis anwenden und damit ihre eigene Gesundheit, die ihrer Gemeindemitglieder sowie die Ökosysteme beeinträchtigen. Diese Probleme lassen sich nicht in disziplinären Silos lösen, sondern nur durch sektorübergreifende und partizipative Forschung und Interventionen. Diese Idee eines transdisziplinären, grenzüberschreitenden Forschungsprojekts mit dem Namen '*vergleichenden Bewertung des Pestizideinsatzes in tropischen Gebieten: Expositionspfade, gesundheitliche Auswirkungen und institutionelle Faktoren'* legte den Grundstein für diese Dissertation.

Die beiden Studienstandorte des oben genannten Forschungsprojekts waren ein marktorientiertes landwirtschaftliches System in Zarcero County, Costa Rica und ein subsistenzorientiertes landwirtschaftliches System im Wakiso District, Uganda. In zwei Querschnittserhebungen vervollständigt diese Dissertation eine Bewertung der Pestizidexposition und Gesundheit von Landwirten in beiden Ländern (Costa Rica im Jahr 2016, *n*=300 und Uganda im Jahr 2017, *n*=302), wobei sowohl Landwirte, die synthetische Pestizide anwenden, erfasst wurden, als auch solche, die andere

Schädlingsbekämpfungsmethoden anwenden. Wir fanden heraus, dass die Mehrheit der in beiden Fallstudien verwendeten Pestizide von der Weltgesundheitsorganisation als hochgefährlich eingestuft wird. Während ein hohes Bewusstsein für negative gesundheitliche Auswirkungen festgestellt wurde, wurde persönliche Schutzausrüstung selten verwendet, und Hygiene und andere schützende Anwendungspraktiken wurden nicht von allen Landwirten übernommen. Im Vergleich zu den Anwendern synthetischer Pestizide war es wahrscheinlicher, dass Biobauern in der sicheren Anwendung von Pestiziden geschult waren. Der Einsatz von Pestiziden schien keinen Einfluss auf das Haushaltseinkommen zu haben.

In einer qualitativen Studie, die parallel zur Querschnittsbefragung der Kleinbauern in Uganda durchgeführt wurde, untersuchten wir das Informationsverhalten im Pflanzenschutz aus der Perspektive der Kleinbauern. Mit Hilfe eines ethnografischen Ansatzes führten wir im Jahr 2017, im Distrikt Wakiso, 46 halbstrukturierte Interviews und 15 Beobachtungen auf dem Betrieb durch. Die Ergebnisse zeigten, dass Landwirte Informationsbedürfnisse entwickeln, wenn sie neue landwirtschaftliche Praktiken einführen oder wenn sie mit störenden Informationen konfrontiert werden (z. B. wenn neue Schädlinge auftauchen), was die Landwirte dazu veranlasst, aktiv nach Informationen zu suchen oder aufmerksam zu sein und Informationen passiv zu empfangen. Ob die Landwirte die neuen Informationen nutzten, hing vom erfolgreichen Ausprobieren der neuen Schädlingsbekämpfungsstrategie und von der Glaubwürdigkeit der Quelle ab. Darüber hinaus deuteten unsere Ergebnisse darauf hin, dass die Informationsquellen für konventionelle Pestizide gut in den Alltag der Landwirte integriert waren, während Informationen über ökologische Strategien durch externe Quellen (z.B. NGOs) bereitgestellt wurden, aber nicht jederzeit verfügbar waren.

Um die oben genannten Ergebnisse mit den jeweiligen Anspruchsgruppen in Uganda zu teilen, führten wir einen partizipativen Workshop durch, der die Design Thinking Methode verwendete. Bei der Abschätzung der Wissenslücken zwischen akademischen und nichtakademischen Anspruchsgruppen stellten wir fest, dass die Empfehlungen von nichtakademischen Anspruchsgruppen eine inhärent interdisziplinäre und somit breitere Sichtweise anwenden, welche die Rollen von mehr verschiedenen Anspruchsgruppen im Pestizidmanagement berücksichtigt, z. B. Agro-Input-Händler und politische Entscheidungsträger. Das nichtakademische Wissen war eher feinkörnig und detailliert, was verdeutlicht, wie wichtig eine Wissensintegration ist, um eine Lücke zwischen dem, was Forscher erforschen und dem, was Praktiker brauchen, zu vermeiden.

Nach neuen Erkenntnissen aus diesem Workshop führten wir 2019 eine Agro-Input-Händler-Studie in Zentral- und West-Uganda durch. Wir wählten einen Ansatz mit gemischten Methoden, indem wir strukturierte Fragebögen und Beobachtungen nutzten, um das Wissen, die Einstellung und die Praktiken in Bezug auf Pestizide (n=402), die Ladenorganisation (n=392) und die Verkaufsinteraktion (*n*=236) zu untersuchen. Das tatsächliche Verhalten von Agro-Input-Händlern beim Verkauf von Pestiziden wurde durch Mystery Shopping mit lokalen Landwirten beim Kauf von Pestiziden (*n*=94) ermittelt. Die Ergebnisse zeigten, dass die meisten Händler die Beratung der Kunden als Aufgabe ansahen, während nur etwa ein Viertel der Mystery Shopper beim Kauf von Pflanzenschutzmitteln beraten wurde. Beobachtungen von Verkaufsinteraktionen zeigten, dass der Schwerpunkt der Gespräche auf der Produktauswahl und dem Preis lag und Aspekte der sicheren Anwendung vernachlässigt wurden. Den meisten Geschäften fehlte es an Sicherheitsausrüstung und ein Viertel der Geschäfte verkaufte umgepackte Produkte. Die Agro-Input-Händler zeigten ein begrenztes Verständnis für die Sicherheitskennzeichnung von Pestiziden sowie für Wirkstoffe. Etwa die Hälfte der Agro-Input-Händler besass einen Befähigungsnachweis, während nur eine Minderheit eine staatlich anerkannte, aktuelle Lizenz vorweisen konnte.

Zusammenfassend stellten wir fest, dass die Verantwortung dafür, warum Pestizide nicht wie vorgesehen verwaltet, bearbeitet und angewendet werden, über alle Akteursebenen hinweg verteilt ist. Entscheidende Informationen erreichen den Endverbraucher nicht, und wo dies dennoch der Fall ist, fehlen die entsprechenden Werkzeuge und Geräte, um die entsprechenden Richtlinien zu befolgen. Gleichzeitig verhindern mangelndes Bewusstsein der Landwirte sowie widersprüchliche Interessen, dass Agro-Input-Händler die dringend benötigte Beratung leisten. Wir empfehlen, Informationen über die sichere Anwendung und Alternativen zu Pestiziden im Alltag der Landwirte durch die Nutzung der etablierten Informationskanäle - der Agro-Input-Händler und der landwirtschaftlichen Beratung - kontinuierlich verfügbar zu machen. Die Professionalisierung von Pestizidverkäufern und -anwendern ermöglicht es, die negativen Auswirkungen von Pestiziden über den gesamten Lebenszyklus hinweg zu kontrollieren, vom Kauf über die Lagerung und Anwendung bis hin zur Entsorgung von Resten und Abfällen. Die Überbrückung von Lücken und die Verbesserung der Koordination und Zusammenarbeit zwischen den Akteuren ist entscheidend, um Praxis, Forschung und Politik in ihrem Bestreben, einen Übergang zu einer nachhaltigen Landwirtschaft zu erreichen, in Einklang zu bringen.

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Chapter 1

1 Introduction

This introductory chapter provides insights into global pesticide use among smallholder farmers, exposure situations and potential health effects. Furthermore it introduces the project framework and gives and overview of the works produced in relation to this dissertation.

From an ecological perspective, pests are just another link in a food chain, but from a human-oriented perspective, they are competing organisms, transmitting pathogens or otherwise affecting human health, comfort and welfare (Flint and Van den Bosch, 2012). Yield loss and the potential resulting famines are commonly feared when farmed crops suffer from pests and diseases (Camuffo and Enzi, 1991). Therefore, agriculture has a long tradition of protecting crops against pests, such as the use of Sulphur compounds against insects and mites in modern day Iraq, in 2500 BC (Dent and Binks, 2020). Substances used to kill or impact living organisms, even at low concentrations, are commonly known as pesticides (van den Berg et al., 2012). The global annual pesticide use is estimated to be 3.5 million tons of active ingredient for 2020, risen from around 1 million tons in 1990 (Zhang, 2018). They are used intensely in agriculture as well as for control of vector-borne disease, and their use is likely to continue growing (van den Berg et al., 2012; Zhang et al., 2011). Despite the vast advances in agricultural sciences over the last millennia, especially also since the green revolution in mid-20th century, pre-harvest losses due to pests still range from 25 to 80%, with an average of 35 to 40%, depending on the crop (Oerke, 2006).

Data from the Food and Agricultural Organization of the United Nations (FAO) suggests that low- and middle-income countries (LMICs) located in warm climate have the highest annual average application rates of pesticides. Seven countries display an extraordinarily high pesticide application rate of 19-25 kg active ingredient per hectare (kg/ha), namely Mauritius, Trinidad and Tobago, Costa Rica, Bahamas, Ecuador, Barbados and Saint Lucia. Other countries displaying high pesticide (8-15 kg/ha) use are Latin-American (Suriname, Guatemala, Belize, Colombia), Mediterranean (Israel, Malta, Palestine, Cyprus) or East Asian (China (mainland, Hong-Kong, Taiwan), Japan and South Korea), or the Netherlands and New Zealand. On the other hand, countries reporting very low pesticide use (0-0. 1 kg/ha), such as Uganda or Tanzania are primarily located in Sub-Saharan Africa (Figure 1).

Farmers in LMICs are often smallholders, meaning they farm on less than two hectares (Lowder et al., 2016). Smallholder farming is not only a major source of income in LMICs, but also an important source of food production (Boserup, 2017). The first and often only pest management strategy of smallholder farmers is the application of synthetic pesticides (Hayes and Hansen, 2017; Williamson et al., 2008). While the pesticide application rates in Sub-Saharan Africa appear to be relatively low, smallholders may nevertheless be highly exposed due to related circumstances: Not all LMICs are assessing pesticides for their suitability to the local context, for example tropical climates with different decay rates for active ingredients and metabolites (Weiss et al., 2016). Otherwise, pesticide regulations may be lacking or improperly implemented (Jepson et al., 2014; Schreinemachers et al., 2017), such as when regulatory agencies fail to phase out harmful pesticides or monitor their safe use (Lancet, 2017).

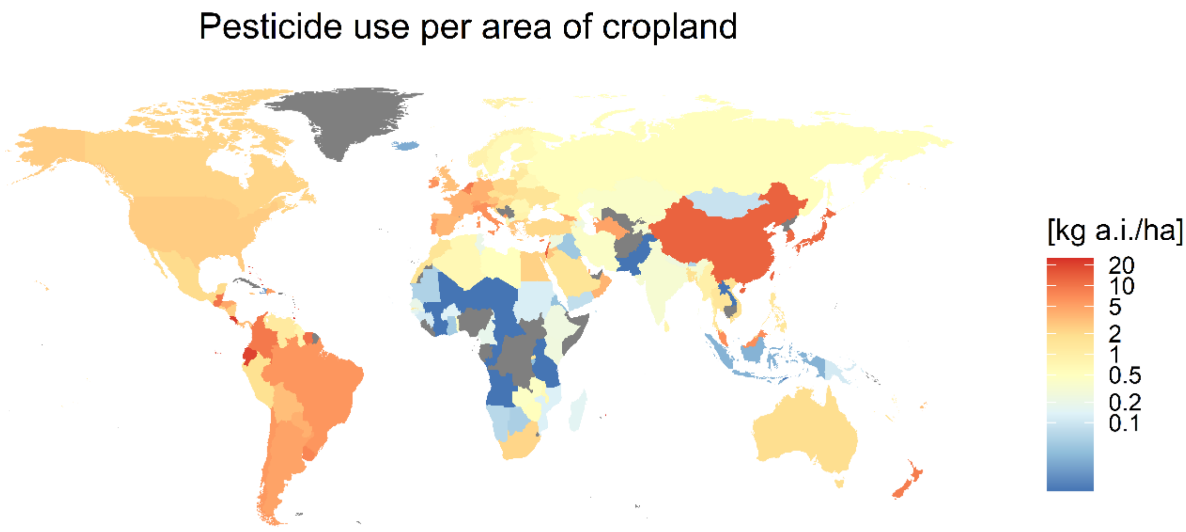

Figure 1: Kilogram active ingredient per hectare crop land. Five year average from 2014-2018. Own illustration with data from FAOSTAT (2020).

Besides systemic factors, smallholders are also challenged through various personal factors. Studies suggest lower education, lack of training, insufficient knowledge as well as the pursuit of high profits to be indicators for higher than recommended pesticide use (Abadi, 2018; Akter et al., 2018). Research from LMICs has highlighted that smallholder farmers are applying highly toxic pesticides with low use of personal protective equipment (Bondori et al., 2018; Negatu et al., 2016a) and inadequately dispose of pesticide residues and containers (Clausen et al., 2017). A survey on smallholder farmers found similar results across 26 countries, indicating that famers were aware of the need of PPE, but mostly did not use them, e.g. due to lack of availability (Matthews, 2008; Tomenson and Matthews, 2009).

Pesticides that are handled unintendedly can lead to exposure situations, thereby negatively affecting human health and ecosystems. Direct exposure of humans can take place for example during purchase, transport or storage of leaking containers, preparation for application, such as mixing of products, application itself, as well as after spraying when re-entering a previously sprayed field (MacFarlane et al., 2013; Suratman et al., 2015). Indirect exposure to humans on the other hand takes place through drift, contamination of food produce or water sources, as well as handling of materials in contact with pesticides, such as clothing (Deziel et al., 2015). Once exposed, the active ingredients affect systems or enzymes through a mode of action that is identical or very similar between humans and pests (Hayes and Hansen, 2017). The short half-live of most of the chemicals, as well as the limited availability of biomarkers of exposure and corresponding epidemiological data makes characterization of pesticide exposure in LMICs challenging (Carles et al., 2017; Ismail et al., 2017; Negatu et al., 2016b).

Concerns about the widespread use of these chemicals and the resulting negative impacts on ecosystems and human health have a long history (Azandjeme et al., 2013; Carson, 1962; Chakraborty et al., 2009; Tago et al., 2014). Pesticides have for example been linked to soil degradation, water contamination, pest resistance, biodiversity loss and loss of ecosystem functions, such as pollination of crops (Gallai et al., 2009; Reynolds et al., 2015; Sánchez-Bayo and Wyckhuys, 2019). For farmers, exposure to multiple hazardous pesticide active ingredients is the rule rather than the exception (Jepson et al., 2020). Studies have indicated, that as few as 5% of acute pesticide poisoning cases are recorded in national registries, meaning that the true burden of acute pesticide poisonings remains unknown (Corriols et al., 2008; Wesseling et al., 2005). Despite the fact that LMICs only use 20% of the pesticides produced internationally, it is estimated that up to 99% of deaths from acute pesticide poisonings occur there (Kesavachandran et al., 2009). Links to long term effects, such as increased risk for cancer or mental health impairments have also been established (de Rezende Chrisman et al., 2009; Stallones and Beseler, 2016).

To prevent these health effects, a series of barriers can be brought in place. The primary barrier is the application of agricultural practices that minimize the use of chemical pesticides. Integrated pest management (IPM) is the globally endorsed future paradigm for crop protection (Stenberg, 2017) and has been endorsed for decades. Figure 2 displays, how the different elements of IPM build upon each other, with chemical control being a means of last instead of first resort. IPM counteracts negative pesticide-related impacts by keeping interventions (including pesticide use) at economically justified levels, while minimizing risks to human health and ecosystems. The obstacles previously identified that keep smallholders from applying pesticides as intended, are also obstacles for IPM. Low levels of education and literacy, insufficient training and technical support, and a lack of favorable government policies prevent smallholders from adopting IPM practices in LMICs (Parsa et al., 2014). As an alternative to IPM, depending on the standard applied, organic practices completely exclude the use of synthetic agro-inputs such as fertilizers and pesticides (Lampkin et al., 2000). They do however require smallholders to make a paradigm shift (Jouzi et al., 2017).

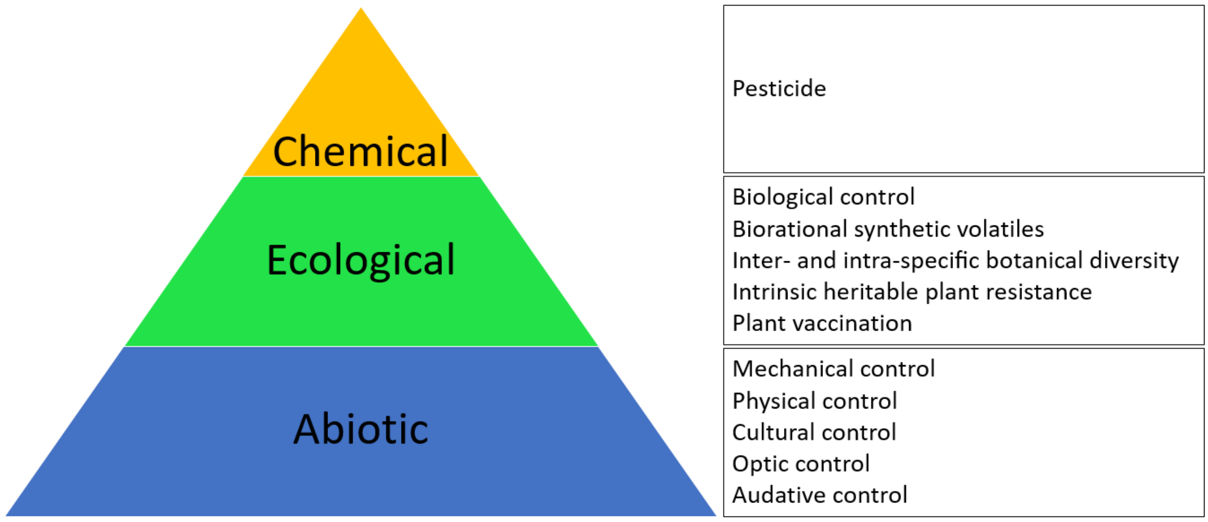

Figure 2: The Integrated Pest Management (IPM) pyramid showing the most important pest management elements, adapted from Stenberg (2017).

When farmers decide to use chemical pesticides despite the above mentioned alternatives, they need to understand the risks they are taking for themselves, their communities as well as the ecosystems they life in. Farmers need to obtain information regarding these risks to possibly change their default behavior to a more risk-conscious behavior (Ajzen, 1991; Weinstein and Sandman, 1992). Manufacturers use the pesticide container label as one of the major risk communication tools. It is intended to provide all relevant information on content and handling, as well as protection of human health and ecosystems (FAO and WHO, 2015). However, to be an effective risk communication tool, the pesticide label must match the content of the container, must be in a language familiar to the reader, the end-user must be literate as well as able to understand the phrasing on the label and lastly, the end-user must have the means to implement the instructions as well as the safety precautions (i.e. measuring instruments and Personal protective equipment (PPE)). With any of these elements missing, pesticide 'misuse' is inevitable (Rother, 2018). Different actors in the smallholder farmers' life must ensure the provision of these elements: The manufacturer provides the matching label in an accessible language, the retail sector provides these labelled products as well as the means to implement the instructions at an affordable price, while the educational and health system ensure the capacity of smallholders to read and understand the label. While import regulations and manufacturing standards can be enforced at specific bottlenecks along the value chain, the retailers are geographically dispersed much like farmers. Agro-input dealers have been identified as dominant source of agro-inputs to farmers (Kato and Greeley, 2016), and are therefore also perceived to be responsible to recommend on product choice, application and handling, as well as risk communication (Alam and Wolff, 2016). However, agro-input traders, like smallholders, face incentives to maximize profits over quality (Aga, 2018) and are lacking knowledgeable, and trained staff (Kwakye et al., 2019; Lekei et al., 2014; Stadlinger et al., 2013). Summarized, smallholders find themselves in a situation, where hazardous products are freely available on the market, while information, training, or protective equipment are scarce, thus the potential for effects of unintended use is high.

There is a lack of studies in LMICs assessing the effects of pesticide use on human health and ecosystems, and how these practices are influenced by the institutional context (Prüss-Ustün et al., 2011). This can lead to inconsistent or even conflicting actions being implemented, posing a problem to the improvement of the situation. The pesticide use in tropical settings (PESTROP) project aimed to deepen the understanding of the environmental health and regulatory dimensions of pesticide use in conventional and organic agriculture in LMICs (Winkler et al., 2019). Focusing on two case studies in a middle-income country (Costa Rica), as well as a low-income country (Uganda), the PESTROP Project explored the following five aspects of pesticide use:

i. Environmental aspects by sampling campaigns targeting streams draining the study area and drinking water wells

ii. Human health effects by a cross-sectional epidemiological survey in small-scale farmers practicing organic and conventional farming
iii. Exposure pathways by combining health and environmental effect data with questionnaire survey insights.
iv. Policy characteristics by an in-depth analysis of official documents and interviews with key representatives of public agencies, non-governmental organizations and farmer's associations.
v. Integrated assessments of the four work packages and translation of the study results to feed them back to the study participants and local stakeholders.

This dissertation is organized in six chapters; four single publications enveloped between this *first* introductory *chapter* and a conclusion at the end. The *second chapter* gives an insight into how organic and conventional smallholder farmers in the case study region in Uganda develop a need for information and seek out corresponding information providers. The *third chapter* displays how agro-input dealers from 35 districts in Uganda are setup as pesticide providers, and how they give advice to farmers. The *fourth chapter* presents results from the above mentioned cross-sectional epidemiological questionnaire survey (aspects ii and iii of the PESTROP project), exhibiting knowledge, attitude and practices of pesticide use in a comparative manner between the Costa Rica and Ugandan case study. The *fifth and last chapter before the conclusion* gives an insight into how the restitution activities from the integrated assessment above (aspect v) have informed local stakeholders in Uganda using the design thinking technique as a guiding line.

From the perspective of a smallholder farmer, the five chapters follow a timeline that begins with the farmer developing a need for information upon discovery of a new pest (*chapter 2*). In *chapter 3*, the farmer goes and buys a pesticide product from an agro-input dealer, potentially receiving advice. Followed by application and handling of the product, while displaying the characteristic hygiene and protective behaviors, which were recorded during the survey (*chapter 4*). Over the short or long term, the farmer may then develop a health effect, where after numerous accounts of such health effects, society starts engaging in uncovering the roots of the problem, and starts designing potential solutions in a participatory manner (*chapter 5*).

Table 1 displays the different publications I was directly involved with over the course of the dissertation (excluding conference abstracts), and to what dissertation chapter they are related to.

*Table 1: Publication overview excluding conference abstracts. * Chapter indicates to what chapter the respective publication is related. § Publication or manuscript in this dissertation.*

Chapter*	Authors	Title	Country	Year	Outlet	Role	Status
1, Introduction	Mirko S Winkler, Aggrey Atuhaire, Samuel Fuhrimann, Ana M Mora, Charles B Niwagaba, Christelle Oltramare, Fernando Ramírez, Clemens Ruepert, **Philipp Staudacher**, Frederik Weiss, Ruth Wiedemann, Rik IL Eggen, Karin Ingold, Christian Stamm	Environmental exposures, health effects and institutional determinants of pesticide use in two tropical settings (working paper))	Costa Rica, Uganda	2019	SNIS Website	Co-Author	Published
1, Introduction	Samuel Fuhrimann, Mirko S Winkler, **Philipp Staudacher**, Frederik T Weiss, Christian Stamm, Rik IL Eggen, Christian H Lindh, José A Menezes-Filho, Joseph M Baker, Fernando Ramírez-Muñoz, Randall Gutiérrez-Vargas, Ana M Mora	Exposure to Pesticides and Health Effects on Farm Owners and Workers From Conventional and Organic Agricultural Farms in Costa Rica: Protocol for a Cross-Sectional Study	Costa Rica	2019	JMIR Research Protocols	Co-Author	Published
1, Introduction	Christian Stamm, Samuel Fuhrimann, Jennifer Inauen, Christelle Oltramare, **Philipp Staudacher**, Frederik Weiss, Ruth Wiedemann, Aggrey Atuhaire, Ana M Mora, Charles B Niwagaba, Clemens Ruepert, Karin Ingold, Mirko S Winkler, Rik IL Eggen	Pesticide use in the tropics: how effective are pesticide risk reduction regimes? (working title)	Costa Rica, Uganda	-	-	Co-Author	Outline
2, Information Behavior §	Nikola Diemer, **Philipp Staudacher**, Aggrey Atuhaire, Samuel Fuhrimann, Jennifer Inauen	Smallholder farmers' information behavior differs for organic versus conventional pest management strategies: A qualitative study in Uganda	Uganda	2020	Journal of Cleaner Production	Shared First Author	Published
3, Agro-Input Dealer §	**Philipp Staudacher**, Curdin Brugger, Andrea Farnham, Ruth Mubeezi, Rik IL Eggen, Mirko S Winkler, Christian Stamm, Isabel Günther	"No side effect unless you drink it" – What agro-input dealers know and believe about pesticides and how they advise smallholders: A mystery shopping and KAP analysis (working title)	Uganda	-	Environmental Health	Shared First Author	Submitted
3, Agro-Input Dealer	Curdin Brugger	"No side effect unless you drink it." Analysing sale talks between agro-input dealers and farmers in Uganda	Uganda	2020	Master Thesis, Swiss TPH	Advisor and Internal Reviewer	Accepted
4, KAP §	**Philipp Staudacher**, Samuel Fuhrimann, Andrea Farnham, Ana M Mora, Aggrey Atuhaire, Charles Niwagaba, Christian Stamm , Rik IL Eggen, Mirko S Winkler	Comparative Analysis of Pesticide Use Determinants Among Smallholder Farmers From Costa Rica and Uganda	Costa Rica, Uganda	2020	Environmental Health Insights	First Author	Published

Chapter*	Authors	Title	Country	Year	Outlet	Role	Status
4, KAP	Ruth Wiedemann, Mirko S Winkler, Christian Stamm, **Philipp Staudacher**, Samuel Fuhrimann, Fernando Ramirez, Fredrik Weiss, Ana M Mora	Uso de plaguicidas en fincas hortícolas en Costa Rica: desafíos y oportunidades para la salud, el medio ambiente y las políticas	Costa Rica	2019	Policy Brief	Co-Author	Published
4, KAP	**Philipp Staudacher**, Mirko S Winkler, Christian Stamm, Ruth Wiedemann, Samuel Fuhrimann, Christelle Oltramare, Aggrey Atuhaire	Pesticide use in Smallholder Farms: Challenges and Opportunities for Health, Environment and Policy in Uganda	Uganda	2019	Policy Brief	Co-Author	Published
5, Stakeholder Workshop §	Ruth Wiedemann, Christian Stamm, **Philipp Staudacher**	How to promote smallholder farmers' safe pesticide management in Uganda? Confronting different types of knowledge with a design thinking workshop for stakeholders (working title)	Uganda	-	Environmental Science & Policy	Last Author	Submitted
No direct link to dissertation	Dominik Dietler, Andrea Leuenberger, Nefti-Eboni Bempong, Diarmid Campbell-Lendrum, Conradin Cramer, Rik IL Eggen, Séverine Erismann, Silvia Ferazzi, Antoine Flahault, Helen A Fletcher, Bernhard Fuhrer, Samuel Fuhrimann, Helena Greter, Anne Christine Heerdegen, Melissa Leach, Anna Leissing, Jonathan Lilje, Melissa A Penny, Helen Prytherch, **Philipp Staudacher**, Penelope Vounatsou, Frederik Weiss, Ruth Wiedemann, Mirko S Winkler, Xiao-Nong Zhou, Jürg Utzinger	Health in the 2030 Agenda for Sustainable Development: from framework to action, transforming challenges into opportunities	Global	2019	Journal of Global Health	Co-Author	Published
No direct link to dissertation	Andrea Farnham, Samuel Fuhrimann, **Philipp Staudacher**, Marcela Quirós-Lépiz, Carly Hyland, Mirko S Winkler, Ana M Mora	Long-term neurological and psychological distress symptoms among smallholder farmers in Costa Rica with a history of acute pesticide poisoning	Costa Rica	-	International Journal of Hygiene and Environment	Co-Author	Submitted
No direct link to dissertation	Samuel Fuhrimann, Andrea Farnham, **Philipp Staudacher**, Aggrey Atuhaire, Tiziana Manfioletti, Charles B Niwagaba, Sarah Namirembe, Jonathan Mugweri, Mirko S Winkler, Lutzen Portengen, Hans Kromhout, Ana M Mora	Exposure to multiple pesticides and neurobehavioral outcomes among smallholder farmers in Uganda	Uganda	-	Environment International	Co-Author	Published
No direct link to dissertation	Samuel Fuhrimann, **Philipp Staudacher**, Christian Lindh, Berna van Wendel de Joode, Ana M Mora, Mirko S Winkler, Hans Kromhout	Variability and predictors of weekly pesticide exposure in applicators from organic, sustainable and conventional smallholder farms in Costa Rica	Costa Rica	2019	Occupational and Environmental Medicine	Co-Author	Published

Chapter*	Authors	Title	Country	Year	Outlet	Role	Status
No direct link to dissertation	Samuel Fuhrimann, Iris van den Brenk, **Philipp Staudacher**, Ruth Mubeezi, Aggrey Atuhaire, Hans Kromhout	Increasing sleep problems after recent pesticide exposure: a cross-sectional study among smallholder farmers in Uganda	Uganda	-	Environment International	Co-Author	Draft
No direct link to dissertation	Martin Rune Hassan Hansen, Erik Jørs, Annelli Sandbæk, Daniel Sekabojja, John C Ssempebwa, Ruth Mubeezi, **Philipp Staudacher**, Samuel Fuhrimann, Alex Burdorf, Bo Martin Bibby, Vivi Schlünssen	Exposure to cholinesterase inhibiting insecticides and blood glucose level in a population of Ugandan smallholder farmers	Uganda	2020	Occupational and Environmental Medicine	Co-Author	Published
No direct link to dissertation	Martin Rune Hassan Hansen, Erik Jørs, Annelli Sandbæk, Daniel Sekabojja, John C Ssempebwa, Ruth Mubeezi, **Philipp Staudacher**, Samuel Fuhrimann, Torben Sigsgaard, Alex Burdorf, Bo Martin Bibby, Vivi Schlünssen	Organophosphate and carbamate insecticide exposure is related to lung function change among smallholder farmers in Uganda: A prospective study	Uganda	2021	Thorax	Co-Author	Published
No direct link to dissertation	Wajd Abbas Hassan Hansen, Vivi Schlünssen, Erik Jørs, Daniel Sekabojja, John Ssempebwa, Ruth Mubeezi, **Philipp Staudacher**, Samuel Fuhrimann, Martin Rune Hassan Hansen	The Vitalograph copd-6 mini-spirometer as more than a screening device: Validation of FEV1 in a healthy Ugandan population	Uganda	-	PLOS ONE	Co-Author	Submitted
No direct link to dissertation	Vanessa A Palzes, Sharon K Sagiv, Joseph M Baker, Daniel Rojas-Valverde, Randall Gutiérrez-Vargas, Mirko S Winkler, Samuel Fuhrimann, **Philipp Staudacher**, José A Menezes-Filho, Allan L Reiss, Brenda Eskenazi, Ana M Mora	Manganese exposure and working memory-related brain activity in smallholder farmworkers in Costa Rica: Results from a pilot study	Costa Rica	2019	Environmental Research	Co-Author	Published
No direct link to dissertation	**Philipp Staudacher,** Andrea Farnham, Mirko S. Winkler, Ana M. Mora, Samuel Fuhrimann	Acetylcholinesterase levels and pesticide use among smallholder farmers in in Zarcero, Costa Rica: A Cross-sectional study (working title)	Costa Rica	-	-	First Author	Outline
No direct link to dissertation	**Philipp Staudacher**, TBD	Acetylcholinesterase levels and pesticide use among smallholder farmers in in Wakiso, Uganda: A Cross-sectional study (working title)	Uganda	-	-	First Author	Data cleaned

Chapter*	Authors	Title	Country	Year	Outlet	Role	Status
No direct link to dissertation	Jonathan Lilje, **Philipp Staudacher,** Samuel Fuhrimann, Aggrey Atuhaire, Jennifer Inauen	Psycho-social factors explaining the use of personal protective equipment during pesticide application in smallholder farmers in tropical settings (working title)	Uganda	-	Health Education & Behavior	Co-Author	Draft
No direct link to dissertation	Chenjie Wan	Spatial distribution of environmental and public health research related to pesticide exposure in sub-Saharan Africa: a systematic review	Sub-Saharan Africa	2018	Term Paper, ETH Zürich	Internal Reviewer	Accepted
No direct link to dissertation	Tiziana Manfioletti	Pesticide Exposure and Neurobehavioral Performance in Small-Scale Farm Workers in Uganda	Uganda	2018	Master Thesis, ETH Zürich	Advisor and Internal Reviewer	Accepted
No direct link to dissertation	Ruth Wiedemann	What works, when and why? Linking policy and practice to enhance safe and sustainable pesticide use in Uganda	Uganda	2019	PhD Proposal, University of Bern	Advisor and Internal Reviewer	Accepted
No direct link to dissertation	Anaïs Galli	Assessing human and environmental health exposures in the Vietnamese Mekong Delta	Vietnam	2020	Master Thesis, Swiss TPH	Advisor and Internal Reviewer	Accepted
No direct link to dissertation	Francis J Burdon, Yaohui Bai, Marta Reyes, Manu Tamminen, **Philipp Staudacher**, Simon Mangold, Heinz Singer, Katja Räsänen, Adriano Joss, Scott D Tiegs, Jukka Jokela, Rik IL Eggen, Christian Stamm	Stream microbial communities and ecosystem functioning show complex responses to multiple stressors in wastewater	Switzerland	2020	Global Change Biology	Co-Author	Published
No direct link to dissertation	Ayat Ullah, Nasir Mahmood, Alam Zeb	Factors influencing farmers’ knowledge of pest management practices in the rainfed districts of Khyber Pakhtunkhwa (KP), Pakistan	Pakistan	-	Information Processing in Agriculture	Reviewer 1	Rejected

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Chapter 2

2 Smallholder Farmers' Information Behavior

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2.1 Abstract

Conventional pesticides are associated with numerous human and environmental health risks. Nevertheless, an increasing number of smallholder farmers in low- and middle-income countries are using conventional pesticides. Adopting safer pest management requires farmers to obtain new information. However, little is known how farmers develop an information need, seek, and use pest management related information, and whether this process differs for organic and conventional pest management strategies. In this qualitative study, we investigated pest-related information behavior in depth, from farmers’ own perspective. Using an ethnographic approach, we conducted 46 semi-structured interviews, 15 on-farm observations and 302 structured questionnaire interviews with farmers in Wakiso District, Uganda, in 2017. Our results indicated that farmers develop information needs when adopting new farming practices, or when presented with disruptive information (e.g. when new pests emerged). This prompted farmers to seek information actively, or they received passive information. Whether farmers used the new information depended on successful trial of the new pest management strategy, and on the credibility of the source. Most revealing, our results suggested important differences in information behavior between conventional and organic pest management strategies. Sources of information for conventional pesticides were well-integrated into farmers’ daily lives and comprised pesticide dealers and fellow farmers. Conversely, information on organic strategies was provided through external sources (e.g. NGOs), and was not available at times when farmers developed an information need. Our results imply that farmers are most likely receptive to organic pest management information at times when they develop an information need (e.g. when encountering a new pest). To promote safer pest management, information about organic and integrated pest management should be made continuously available in farmers’ lives. Furthermore, we recommend leveraging established information channels (e.g. dealers) among pesticide users to promote safer use practices.

Keywords: information behavior, information seeking, organic pest management, pesticide, smallholder farming, Uganda

2.2 Introduction

Smallholder farming is an important source of global food production and a major source of income in many low- and middle-income countries (LMICs) (Boserup, 2017). The majority of smallholder farmers apply conventional (i.e. synthetic) pesticides as their first and often only pest management tool (Hayes and Hansen, 2017). Low educational level, insufficient training, lack of knowledge and pursuit of high profits were reported to be indicators for higher than recommended pesticide use (Abadi, 2018; Akter et al., 2018). However, conventional pesticides are associated with numerous human and environmental health risks (Hayes and Hansen, 2017).

To avoid these adverse effects, a reduction of pesticide use, specifically switching to organic or integrated pest management (IPM) strategies, is advocated (Mie et al., 2017). Organic strategies include mechanical weeding, picking off insects from infested plants, or using natural pesticides (Lampkin et al., 2000). IPM includes cultural and ecological host plant resistance, mechanical, behavioral and biological methods, and the careful use of conventional pesticides (Pimentel and Peshin, 2014). Despite their advantages, organic and IPM strategies have not been widely adopted (Parsa et al., 2014). To make the switch from conventional to organic or IPM strategies, farmers must first make a paradigm shift (Jouzi et al., 2017). While behavior change is complex, many theories propose that obtaining information is the first step to change (Ajzen, 1991; Weinstein and Sandman, 1992). However, little is known about how smallholder farmers obtain pest management information.

2.2.1 A model of information behavior in agricultural systems

Two promising approaches to understanding farmers' information behavior are the sense making theory (Dervin, 1998), as applied in Munyua and Stilwell (2012), and the information behavior model created by Wilson (1999). An integrated, simplified theory of farmers' information behavior based on the two above-mentioned approaches is depicted in Figure 1. It is framed by the *initial situation*, which leads to an *information need*. The need for information can consequently lead to *information seeking* and, subsequently, to the decision to use (or not use) the encountered information. The *future farming practice* is the outcome of the information behavior. A farmer's decision to use the encountered information may be reflected in an adapted farming practice. On the other hand, if a farmer rejects the information, this may lead to further *information needs* and *information seeking* or simply the continuation of the current farming practice.

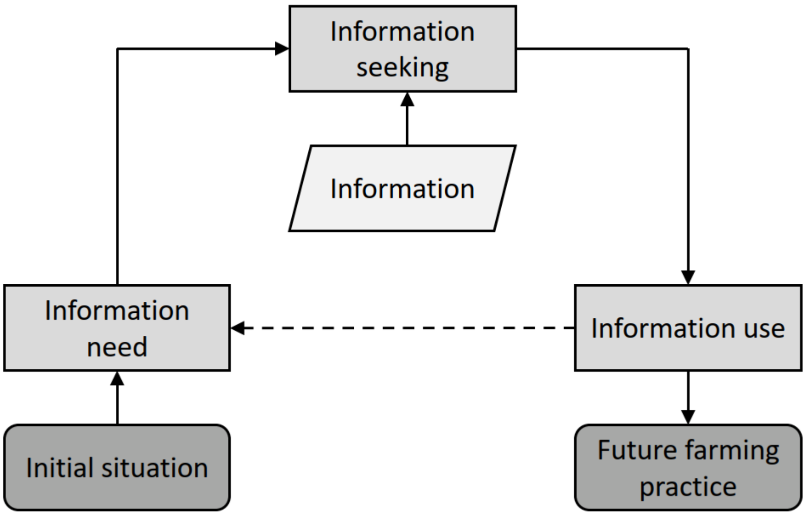

Figure 1: Schematic of farmers' information behavior following Wilsons' model of information behavior (Dervin, 1998; Wilson, 1999)

2.2.2 Information behavior in smallholder farming

In sub-Saharan Africa research has reported a large degree of variety in farmers' *information needs*, which mainly depend on individual activities, with pest and disease management always being extremely important (Byamugisha et al., 2008; Tandi Lwoga et al., 2011). Recent Ugandan studies have reported a lack of general knowledge on pest management strategies aside from pesticide use (Okonya and Kroschel, 2016), scant knowledge about the uses and risks of conventional pesticides (Oesterlund et al., 2014), and a relationship between low knowledge scores regarding pesticide hazards and the effectiveness of public health interventions, such as awareness campaigns (Muleme et al., 2017).

Further research has been concerned with *information seeking*, specifically the use of *information sources* in this process. In Turkey, Boz and Ozcatalbas (2010) differentiated between traditional (e.g., personal experience, family members, and neighbors) and modern *information sources* (e.g., government extension services, mass media, pesticide dealers). Pesticide dealers seemed to be the most frequently used *information source* of pest management information. Similarly, studies in Kenya found two parallel information systems, a local, indigenous one that included neighbors, other farmers, and family members, as well as an external, science-based, globally applied information system. While most farmers used both, only half of them were able to relate one to the other (Munyua and Stilwell, 2013).

Overall, smallholder farmers seem to prefer mouth-to-mouth information (Byamugisha, 2009; Elly and Epafra Silayo, 2013), e.g., that was obtained via interactions with neighbors, families, and community-based organizations (Rees et al., 2000). These *information sources* can also provide opportunities for observational learning (Foster and Rosenzweig, 1995).

Some farmers receive information from external sources, e.g., extension services, which can provide farmers with knowledge and new findings on agricultural topics. Munyua and Stilwell (2013) found this to be the most important *information source* for farmers in Kenya. However, research also shows that many farmers lack an awareness of extension services (Boz, 2002; Tandi Lwoga et al., 2011). They further cite their high cost in terms of time and money (Boahene et al., 1999), their poor response to *information needs* (Tandi Lwoga et al., 2011), and their lack of coverage (Muyanga and Jayne, 2006).

After acquiring information a farmer decides whether and how to use this information. Ugandan farmers reported that the quality of the information, which is sometimes inaccurate or insufficient, can hinder their use of such information, as can a lack of resources (Byamugisha, 2009). Additionally, incomplete knowledge can be a major hindrance to the adoption of new farming ideas (Foster and Rosenzweig, 1995), while better knowledge can reduce pesticide use (Feder et al., 2004).

Few studies have investigated whether farmers’ information behavior is related to specific pest management strategies. One study indicated the importance of access to information regarding the adoption of organic or IPM strategies (Tatlıdil et al., 2009).

In summary, previous research has provided important insights into certain aspects of farmers’ information behavior (e.g., the *information sources* used). However, a comprehensive understanding of farmers’ information behavior regarding pest management from farmers’ perspectives, and how this may differ between conventional and organic farmers remains lacking. In the present study, we aim to extend previous research on farmers’ information behavior with smallholder farmers in Uganda by i) providing an in-depth view on farmers’ subjective experiences related to pest management information behavior and ii) differentiate between farmers’ information behaviors regarding conventional and organic pest management strategies.

2.3 Methodology

An ethnographic approach was chosen, focusing on farmers’ subjective experiences of pest management. Ethnography is a form of observation where the researcher collects qualitative data from various sources, focusing on the cultural meaning of actions of the individuals involved (Griffin and Bengry-Howell, 2017). This approach is therefore appropriate to study subjective experiences as researchers do not superimpose their views, but rather elicit unforeseen perspectives. Using a grounded theory approach, we analyzed the data with the goal of gaining in-depth insights in farmers’ information behavior, and extending theory (see Figure 1) rather than testing it. (Glaser and Strauss, 1980). Grounded theory is a systematic, iterative approach of inductive reasoning, whereby a theory forms from the data (rather than being superimposed (Charmaz and Henwood, 2017). Additionally, quantitative data from a cross-sectional survey are used to corroborate some of the qualitative findings.

2.3.1 Setting and study area

This study was conducted in Central Uganda in the peri-urban district of Wakiso, in the three farming Sub-Counties of Mende, Masulita, and Gombe, from October to November 2017. Wakiso is the most densely populated district in Uganda, with two million inhabitants (UBOS, 2014). The main subsistence crops in the area are bananas, beans, cassava, groundnuts, maize and sweet potato. Additionally farmers grow cash crops such as coffee and tomato (UBOS, 2017). The wet tropical climate encourages rapid plant growth but also favors disease outbreaks. There is a wide network of private importers, distributors, and retailers of conventional pesticides across the country. This makes pesticides affordable and readily available to farmers within their community settings. This study was part of the pesticide use in tropical settings (PESTROP) Project, which aims to deepen understanding of the environmental, health (Fuhrimann et al., 2020; Palzes et al., 2019), and regulatory dimensions of pesticide use in conventional and organic agriculture in LMICs (Fuhrimann et al., 2019).

2.3.2 Data collection

All study materials and procedures were approved by the higher degrees, research, and ethics committee of the School of Public Health at Makerere University, Uganda (Protocol 522), and the Ethical Board of the Ethikkommission Nordwest- und Zentralschweiz in Switzerland (EKNZ-UBE 2016-00771). Written informed consent was obtained from all participants prior to participating in this study.

Ethnographic data were gathered through household visits (documented in the form of written observation protocols and field notes), and face-to-face interviews (using a semi-structured interview guide and an audio recording device). The 50 interviewed smallholder farmers were a sub-sample of a random sample of farmers of the PESTROP study. The criterion for inclusion was having taken a decision-making position regarding pest management on their farms (see Table 1, note that age ranges are provided to ensure the anonymity of participants). Subsequently, interviews where translated into English and transcribed using a consistent transcription scheme.

To further corroborate some of the qualitative findings, quantitative data from the PESTROP study (n=302 randomly selected farmers) were analyzed to provide a quantification of the sources of information revealed in the present study (comprehensive results of this survey will be published elsewhere).

Table 1: Participant Characteristics

Participant number	Interview, farm visit	Approach to pest management	Sex	Age range	Age when started farming
1	I, V	both	m	20 - 39	NA
2	V	conventional	m	40 - 59	NA
3	I, V	conventional	m	40 - 59	NA
4	I, V	conventional	m	40 - 59	NA
5	I, V	conventional	m	60 - 75	NA
6	I, V	both	m	60 - 75	NA
7	V	conventional	m	40 - 59	NA
8	V	conventional	m	NA	NA
9	I, V	conventional	m	40 - 59	NA
10	I, V	both	m	40 - 59	NA
11	I, V	both	m	20 - 39	NA
12	I, V	both	m	40 - 59	NA
13	I, V	both	m	60 - 75	NA
14	V	both	m	60 - 75	NA
15	I, V	both	f	60 - 75	NA
16	I	both	m	40 - 59	0 - 9
17	I	conventional	m	40 - 59	0 - 9
18	I	conventional	m	20 - 39	10 -19
19	I	both	f	60 - 75	10 -19
20	I	both	m	60 - 75	0 - 9
21	I	both	m	40 - 59	30-39
22	I	both	m	40 - 59	10 -19
23	I	both	m	60 - 75	0 - 9
24	I	organic	f	60 - 75	10 -19
25	I	both	f	40 - 59	0 - 9
26	I	both	m	40 - 59	0 - 9
27	I	both	m	20 - 39	0 - 9
28	I	both	f	40 - 59	0 - 9
29	I	both	f	40 - 59	10 -19
30	I	organic	f	60 - 75	20 - 29
31	I	both	m	40 - 59	10 -19
32	I	conventional	m	40 - 59	10 -19
33	I	organic	f	60 - 75	10 -19
34	I	both	m	40 - 59	0 - 9
35	I	both	f	60 - 75	20 - 29
36	I	both	m	20 - 39	10 -19
37	I	both	m	20 - 39	10 -19
38	I	both	m	40 - 59	0 - 9
39	I	both	m	40 - 59	10 -19
40	I	conventional	m	40 - 59	20 - 29
41	I	both	m	40 - 59	10 -19
42	I	both	m	60 - 75	10 -19
43	I	both	m	40 - 59	0 - 9
44	I	conventional	m	20 - 39	20 - 29
45	I	both	m	20 - 39	0 - 9
46	I	organic	f	40 - 59	10 -19
47	I	both	f	20 - 39	10 -19
48	I	both	m	40 - 59	10 -19
49	I	both	m	20 - 39	20 - 25
50	I	both	f	40 - 59	40-49

Note: Interview (I) indicates an interview being conducted, farm visit (V) indicates a visit to their farm. The approach to pest management is summarized as conventional if there is use of synthetic pesticides, organic if there are alternative strategies applied such as manual weeding, natural pesticides or repellents, both indicates both strategies applied simultaneously. The age is an estimate by the interviewer. NA: Not available.

2.3.3 Data analysis

The first author, using two methodological approaches, analyzed the data, and the research team verified the coding through discussion. First, a qualitative content analysis (Mayring, 2014) of all the interview transcripts and observation protocols was performed to identify the pest management practices of the participating farmers. The entity of analysis was the pest management strategy (conventional vs. organic), and not the individual farmers, because most farmers used both pest management strategies.

Second, the interview transcripts were submitted to a deeper analysis using the grounded theory method, which includes three steps: open coding, axial coding, and selective coding. The analysis was performed using MAXQDA (VERBI Software, 2017).

In the first step of the grounded theory approach (open analysis), the first author created an extensive list of codes that were subsumed in various categories and thereafter further particularized by analyzing their specific properties and dimensions. In the second step (axial coding), these categories were put into context, (Strauss and Corbin, 1994) increasing understanding and developing a systemic perspective. Following the coding paradigm of (Strauss and Corbin, 1998) we then focused on three factors: *Conditions* under which a certain social phenomenon occurs, *actions and interactions* that take place with reference to the phenomenon of interest, and *consequences* that result from these actions. Thereby, relations between categories were discovered and developed. With this context in mind, we outlined and integrated the categories into the central categories of *information need, information seeking* and *information use,* according to the farmers' information behavior approach (Figure 1). In this process of selective coding the theoretical approach was refined by use of the theoretical memos developed during coding, figures visualizing relationships between concepts, and field notes produced throughout the process of analysis.

The results are presented next, providing direct quotations supporting or contradicting the coding solution as a means to verify their validity. Note that interpretations are separated from the results, but are presented in the same section as they form the core part of the findings in this kind of research.

2.4 Results and interpretation of findings

2.4.1 Sample description

In the qualitative sample (*n*=50), the majority (68%) of participants reported using both organic and conventional pest management strategies, while 12 and 4 only used conventional and organic strategies, respectively (Table 1). The organic strategies reportedly used by farmers were physical strategies (66%), homemade pesticides (36%), and repellents (4%).

The quantitative sample (*n*=296) consisted of 59% male and 41% female participants. The mean age was 48 years. In this survey, 52% self-identified as conventional farmers, 30% perceived themselves as organic farmers, and 19% conducted both practices in parallel.

2.4.2 Farmers' information behavior

The data showed two ways in which an *information need* could arise in a farmer. Depending on this, farmers chose an active approach in the form of *information seeking* (i.e., by asking for advice), a more passive approach, i.e., exposing themselves to information in an un-targeted way. After obtaining information about pest management strategies, the farmers dealt with the new information in one way or another (*information use*). In the following, we present the findings regarding how farmers developed an *information need*, sought, and used information.

2.4.2.1 Developing an information need

Two ways of developing an *information need* emerged from the interviews: i) starting a new farming practice and ii) receiving disruptive informational input. Related to the former, one participant explained, for example:

> *I was a businessman in timber business (…) but because this job was increasingly becoming hard (…) I got the idea of farming. (…) Now with getting to growing fruits, I had not known about the spraying detail because I was new. (3a)*

The second way to develop an *information need* according to the data was to receive disruptive informational input. This occurred when farmers faced a new farming challenge, such as a pest they had not encountered before, and seemed to motivate farmers to seek new information:

> *When this pest comes, we get up, and we ask, "What can we do?" This pest is finishing our crops, and it eats the whole maize garden if you do not do anything. (29a)*

2.4.2.2 Information Seeking

Information seeking is the behavior a farmer engages in to come into contact with information, which can include active *information seeking*, or the passive reception of information. It also refers to the various *information sources* a person uses.

2.4.2.2.1 Information sources

The qualitative results showed that information reached farmers through both internal (social network of family, friends, and the community) and external sources (dealers of agricultural products, extension workers, labels on pesticide packages, radio, and sensitization programs) (Figure 2). Farmers reported various non-governmental, commercial, and church-related sensitization programs as sources of information. Further, farmers reported personal experiences and observations during farming as a source of information. One farmer proudly recounted how he developed a pest management strategy by observing his plants.

> *About picking those pests, it was myself, after spraying, I used to go back where I had sprayed and started to look at the crop like that maize inside and I would find the pest still inside eating, now I would remove it and get a cup…or a cup…bottle and put it inside, you may pick up to about two cups full of these pests and then I bring them here and burn them and there I am sure that from each crop that I have removed it, the crop remains growing that I have killed the pest. (…) So that knowledge of picking those pests I got it myself so I did not get it from anyone or anyone teaching me and telling me that, "when you go to the garden, you pick those pests like this" No! It was my idea from my brain. (12a)*

The information he needed came from his own mind and can be described as an intuition to pick, collect, and burn the pests.

The results of the quantitative interviews support the qualitative findings (Table 2). The most important information source was the community (42%). Others named agribusiness (23%), extension services (17%), sensitization programs (16%), media (16%), and personal experiences (16%) as sources of advice on pest management.

Table 2: Sources of Advice for Pest Management by Major Self-Identified Pest Management Practice

Major Self-Identified Pest Management Practice	**Total**		**Organic**		**Both**		**Conventional**		***p*-value (χ2)**
	n	%	*n*	%	*n*	%	*n*	%	
Source of Advice for Pest Management	296	100	88	100	55	100	153	100	0.037
Community	126	42.6	30	34.1	20	36.4	76	49.7	> 0.001
Agribusiness	70	23.6	7	8.0	14	25.5	49	32.0	0.011
Extension	50	16.9	23	26.1	10	18.2	17	11.1	0.002
Sensitization	49	16.6	22	25.0	13	23.6	14	9.2	0.420
Media	48	16.2	12	13.6	12	21.8	24	15.7	0.360
Personal Experience	47	15.9	18	20.5	7	12.7	22	14.4	0.037

Note: The answer options for sources of advice were multiple choice. However, each participant had to self-identify for only one of the three options for pest management practice. Community entails family, friends, neighbors, and lead farmers. Agribusiness entails input dealers and buyer associations (five organic). Extension entails government bodies, research institutions, and veterinary doctors. Sensitization entails workshops provided by farming associations or international NGOs. Media entails radio, television, and newspapers.

2.4.2.2.2 Active information seeking

As shown in 2.4.2.1, farmers entered a state of *information need* by choice (e.g. when starting a new farming practice) or by necessity (e.g. when facing a new pest). This seemed to influence their motivation to engage in *information seeking*.

To overcome the challenge of dealing with a new pest, conventional pesticide users mentioned seeking information from dealers of agricultural products.

> *You ask the shop keeper that my maize has larvae, it is being eaten, it is not growing it is being destroyed so it's not growing so they can tell you that it is this type that can kill that pest. (…) That is where I first go to seek advice. (6b)*

This farmer's approach to solving a new farming challenge seemed to be a typical example of respondents' information behavior. He described a setting in which there was a clearly defined situation (his crop was affected by a specific pest) and an obviously desirable outcome (the removal of the pest). The kind of tool that would most likely achieve the goal of removing the pest (a conventional pesticide) was already defined. The farmer only needed one additional piece of information to choose a specific pesticide which he could obtain from a source (the pesticide dealer) that was close to his everyday environment.

2.4.2.2.3 Passive information exposure

Not all information transfers regarding pest management strategies were the result of a farmer actively searching for information. Information also passively circulated within the community. Some information was gleaned from observing the behavior of colleagues, as one farmer stated:

> *When you see your colleague has sprayed and the elephant grass has dried up you also then have to use it. (34a)*

Farmers also came together occasionally and exchanged ideas about pest management, without necessarily having a specific interest in the topic.

> *What we mostly talk about, most of the times a person speaks in relation of what he does because my colleague may ask me, "Ehh how are your tomatoes?" And I tell him 'my tomato has got such and such a problem.' Then he gives me some advice (…) Yes, those are the issue (49a)*

Our data indicated two other settings, in which information was provided in bundled form, including all the necessary steps and instructions to execute the method. First, information was transferred through socialization. Farmers growing up in a farming environment learned pest management strategies by watching their families:

> *Since I was born, I could see my father digging the weed. (25a)*

In doing so, they learned how to apply these strategies. A second setting for information exposure was sensitization programs. The programs provided detailed instructions about how to apply a certain strategy. This farmer, for example, learned how to prepare alternative pesticides in a sensitization program:

> *We were told in order to fight against those pests we have to use our local methods, for example like red pepper, tobacco, kawunyira (marigold) and also urine (…) also the ash if you mix all of these they somehow help. (22a)*

What is striking throughout the survey is that these programs were received in an almost entirely passive way. Respondents described organizations that came to the villages and brought trainings, rarely meeting the specific *information needs* that a farmer would have in a given situation.

2.4.2.3 Information use

After obtaining information (actively or passively), farmers decide whether to use it or not. Our interview data indicated that pest management practice were often first tested. If the results were positive, i.e. the crop was thriving and pest was gone, the farmer kept using the method:

> *When I see my crops with pests, when I consult from others, they tell me, "You go and buy such and such a pesticide, it will kill those pests." When I tried it and found that they die, I just went ahead to use them. (44a)*

If the strategy was ineffective, that farmer would look for an alternative. Additionally, some respondents addressed the issue of the reliability of specific information sources, which would affect their decisions to use the information contained in such sources. One farmer described his experiences with an unreliable information source:

Whenever I tried… you know this is a village so they made sure that whoever you went to you would actually see that they are wrongly advising you. That is why I took time to listen to the radio to at least get some knowledge from the radio. Then I also started like whenever I travelled (…) I would try and get some people that I consult. (3b)

2.4.3 Information behavior and differences in pest management strategies

The second research question addressed potential differences in farmers' information behavior regarding the use of conventional pesticides and organic pest management strategies. Our results indicated that information about conventional pesticides was highly present in farmers' daily lives. It was mentioned as a frequent topic of conversation in the community. Further, the knapsack sprayer, which is used to apply conventional pesticides, is visible all over these communities and functions as a symbol of conventional pesticide use. One respondent stated the following:

I always see people carrying knapsacks. (15a)

Agricultural dealers are a convenient way of gaining information, as the repeated purchasing of products necessitates frequent interactions with the dealer.

The person I would say I seek advice from is that person where I purchase the pesticides. (15b)

As such, the information behavior regarding conventional pesticides mostly occurred within the close proximity to the farmers, without them having to make any extra effort.

In terms of information sources, one striking difference between the two pest management strategies is that there were fewer information sources about organic strategies (Figure 2). Some information sources were specific to conventional pesticides (e.g., pesticide dealers), while others provided information on both strategies. Regarding conventional techniques, the community was the dominant source, while pesticide dealers were the second most important source. The most frequently stated information sources on organic techniques were sensitization programs (detailed above) and family. One characteristic of these information sources was that they were only present in the farming community at specific points in time. Sensitization programs did not remain in the communities but only happened periodically. Consequently, they may not be available when a farmer had an *information need*. Family members most commonly provided farmers with information when they were children, and more often among organic farmers than conventional.

These results were underlined by the findings from the quantitative survey (Table 2), in which community (49.4%) and agribusiness (31.8%) were found to be the two major sources of advice among farmers identifying as conventional. The community was also a major information source for farmers who identified as organic, though this was true to a significantly lesser extent as compared to conventional farmers (p<.022). The second most named information sources regarding organic pest management were extension services (25.0%) and sensitization programs (23.9%).

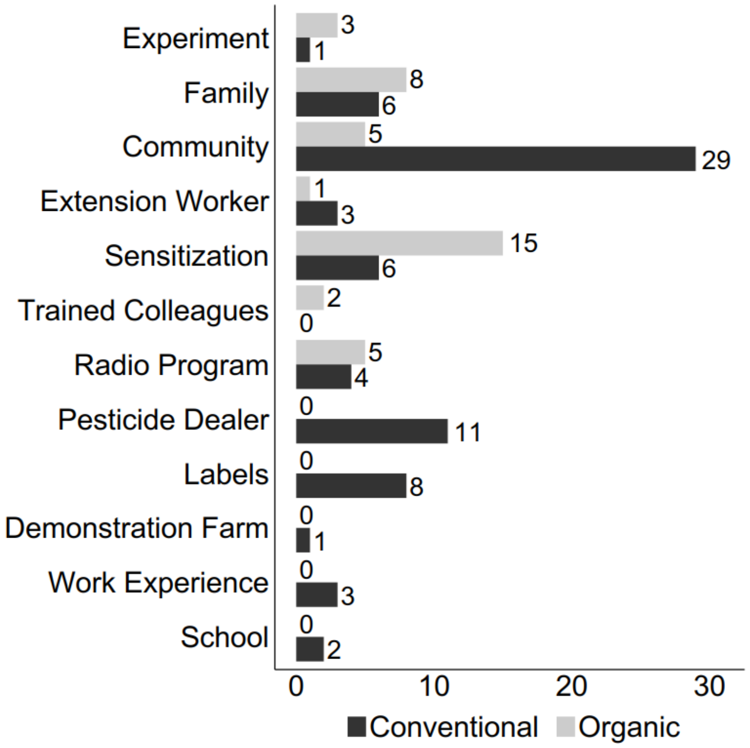

Figure 2: Farmers' information sources for various pest management strategies. Numbers are absolute because they represent individual, unsolicited statements (n=46).

2.5 Discussion

The results of this qualitative study provided novel insights into smallholder farmers' information behavior regarding organic and conventional pest management strategies from farmers' own perspective. Along the adapted model of information behavior (Dervin, 1998; Wilson, 1999), our results indicated that farmers developed *information needs* for pest management when starting a new farming practice (e.g. growing a new crop), or when receiving disruptive information (e.g. current practice has adverse effects). In response to this need, farmers actively seek information from sources within or external to their communities, or they are passively exposed to information. Finally, farmers use the new information by first testing new pest management strategies, depending on the credibility of the source.

2.5.1 Differences in information behavior for organic and conventional pest management strategies

Our results confirm earlier findings indicating that conventional pesticides are the dominant pest management strategy for smallholder farmers in LMICs (Williamson et al., 2008). Farmers who perceive an *information need* most commonly seek information within the domain of conventional pesticides (e.g., through their pesticide dealers) rather than venturing into new domains (e.g., organic strategies), which are often also unknown to the farmer. For conventional pesticide users, an *information need* for organic strategies only arises when the default pest management option is deemed invalid, e.g., due to a perceived downside, including perceived cost (Boahene et al., 1999) or health risks (Jørs et al., 2018). As such, the emergence of an *information need* can be seen as a "teachable moment" (McBride et al., 2003), i.e., a good opportunity to change current practices. Timing is therefore relevant to interventions among smallholder farmers.

Compared to conventional pesticides, information on organic pest management is not well-integrated into farmers' daily lives, except for the traditional non-chemical practices that farmers were exposed to by their parents as children. This may be attributed to the knowledge intensity and complexity involved in comprehending and applying modern organic farming practices. Feder and Slade (1984) state that if information provides an economic return, then farmers will actively engage in finding such information. This is in line with farmer statements indicating that Ugandan customers are not willing to pay for the added value of organic production.

Providers of information on organic pest management are few, and often only appear at specific times (e.g. sensitization programs). This limits the availability of information on organic pest management at times of need, and hence, their popularity among farmers. This is in line with the findings of Brown et al. (2018), who found that information sources on conservation agriculture are perceived to be inaccessible and/or to be of limited quality. Our results indicate a gap between the information channels providers prefer to use and those favored by information recipients. Our study also found that providers of information fail to incorporate new technologies that harmonize traditional and modern organic pest management practices. Both results corroborate previous research in Tanzania (Elly and Epafra Silayo, 2013; Msoffe and Ngulube, 2016).

Compared to conventional pesticide users, farmers using organic strategies have a limited network of community peers to rely on for information. A lack of exchange regarding organic strategies may hinder the spread of such practices. This is in line with the findings of Parsa et al. (2014) in that representatives from LMICs defined a lack of collective action within a farming community as the primary obstacle to IPM adoption.

2.5.2 Implications for practice

The results of our study have four important implications regarding how to successfully convey information about safer and more sustainable pest management strategies to smallholder farmers. First, to promote the use of organic or IPM strategies, our study suggests making information on organic pest management more continuously available in farmers' lives so that farmers can access it when they develop an *information need*. Similarly to pesticide dealers providing information about conventional pesticides, a knowledge broker for alternative pest management could be established within these communities, either in person (e.g. intermediaries (Stefano et al., 2005)) or as part of a platform. Where extension services are available, the awareness thereof should be promoted because farmers who rely on them adopt new techniques earlier than farmers who rely on other information sources (Boz, 2002). Alternatively, social learning can be encouraged, e.g., through introducing role models.

Second, with sensitization being the main channel of information transaction for organic strategies, a general increase in awareness can be attained within a farming community if a critical group size of sensitized farmers is reached. We therefore recommend local, densely focused information dissemination to enhance knowledge about organic pest management in specific communities, as opposed to a geographically widespread campaign among single individuals. Although our findings provide few insights into the content of such campaigns, a shared understanding of social and moral concerns between providers and recipients of information may increase organic farming practices (Mzoughi, 2011).

Third, we recommend utilizing teachable moments in farmers' lives (e.g., when adopting new crops). In these moments, farmers' *information needs* are strong, and they are open to information about alternative pest management strategies.

Lastly, we found that the farmers' most common and trusted information sources regarding pesticides were other farmers within their community, as well as pesticide dealers. These channels can be leveraged to promote previously neglected safe-use practices, such as proper application techniques, container disposal, and the use of personal protective equipment (Alam and Wolff, 2016).

2.5.3 Strengths and Limitations

This study is the first to provide comparative in-depth information about smallholder farmers' information behavior regarding different pest management strategies by applying grounded theory. The qualitative approach revealed novel insights into the complex characteristics of farmers' information behavior and information environments. Future quantitative and experimental research can now provide causal conclusions regarding the information behavioral processes revealed in our study by testing whether they hold for the population of smallholder farmers in LMICs and, potentially, additional farmer populations.

A further strength of this study is the focus on the farmers' perspective (Msoffe and Ngulube, 2016). The question of interest in our study was how farmers naturally acquired information. This emphasizes farmers as actors embedded in the circumstances of their daily lives. Ultimately, it is the farmer who choses and uses information and information sources. Therefore, their perspective is important and will be useful in designing interventions to promote organic or integrated farming.

This study also has some limitations. Foremost, the qualitative approach does not allow conclusions about the generalizability of these findings. The unique strength of this approach lies in providing in-depth insights into farmers' experiences that help build a theory of farmers' information behavior that can later be tested in quantitative surveys, and intervention studies. Further, the results of our study focused on how information is acquired and, to a lesser extent, which information is transferred between the provider and the recipient, or how it is used. While this study therefore has important implications which communication channels should be used to convey information to farmers, we can provide limited information about which information might best motivate farmers to change their behaviors. The behavior-change literature indicates that many motivations may be at play, including risk perceptions, attitudes, social norms, ability, and self-regulation (Mosler, 2012), which have been studied elsewhere (Meijer et al., 2015; Williamson et al., 2003). Lastly, we did not stratify our sample between motives for growing a certain crop, which could give further insights into pest management strategies applied.

2.6 Conclusions

Our study provided novel insight into smallholder farmers' information behavior related to conventional and organic pest management strategies. We found disparate information environments for conventional versus organic pest management strategies in terms of information sources and their availability in place and time. Our results suggest that providing information on organic pest management strategies in moments when farmers develop an *information need* may be crucial entry points for providing information on organic pest management strategies. Future studies can test the generalizability of this theory of information behavior, and use this information to promote the adoption of organic pest management strategies. This may ultimately help reduce adverse effects of pest management in low- and middle-income countries.

2.7 Acknowledgements

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Chapter 3

3 Agro-Input Dealers and Pesticide Sales

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3.1 Abstract

Background: Pesticides can have negative effects on human and environmental health, especially when not handled as intended. In many countries, agro-input dealers sell pesticides to smallholder farmers and are supposed to provide recommendations on application and handling. This study investigates the role of agro-input dealers transmitting safety information from chemical manufacturers to smallholder farmers, assesses the safety of their shops, what products they sell, and how agro-input dealers abide laws and recommendations on best practices for preventing pesticide risk situations.

Methods: Applying a mixed-methods approach, we studied agro-input dealers in Central and Western Uganda. Structured questionnaires were applied to understand agro-input dealers' knowledge, attitude and practices on pesticides (n=402). Shop layout (n=392) and sales interaction (n=236) were assessed through observations. Actual behavior of agro-input dealers when selling pesticides was revealed through mystery shopping with local farmers buying pesticides (n=94).

Results: While 97.0% of agro-input dealers considered advising customers as their responsibility, only 26.6% of mystery shoppers received any advice from agro-input dealers when buying pesticides. 53.2% of products purchased were officially recommended. Sales interactions focused mainly on product choice and price. Agro-input dealers showed limited understanding of labels and active ingredients. Moreover, 25.0% of shops were selling repackaged products, while 10.5% sold unmarked or unlabeled products. 90.1% of shops were lacking safety equipment. Pesticides of World Health Organization toxicity class I and II were sold most frequently. Awareness of health effects seemed to be high, while agro-input dealers showed incomplete hygiene practices and were lacking infrastructure. One reason for these findings might be, that only 55.7% of agro-input dealers held a certificate of competency on safe handling of pesticides and even fewer (5.7%) were able to provide a government-approved up-to-date license.

Conclusion: The combination of interviews, mystery shopping and observations proved to be useful, allowing to compare stated with actual behavior. While agro-input dealers want to sell pesticides and provide the corresponding risk advice, their customers might neither get the appropriate product nor sufficient advice on proper handling. In light of the expected increase in pesticide use, affordable, accessible and repeated pesticide training and shop inspections are indispensable.

Keywords: Attitude, Counterfeit, Highly-hazardous, Knowledge, Pesticide, Practices, Registration, Retail, Risk communication, Smallholder

3.2 Background

Pesticides can have negative effects on human and environmental health, especially when not handled as intended. Smallholder pesticide use is increasing in low- and middle-income countries, often practiced without personal protective equipment (PPE) (Oesterlund et al., 2014; Okonya and Kroschel, 2015; Staudacher et al., 2020). Pesticide exposure can lead to acute symptoms like headache and respiratory distress, or chronic health effects, such as increased risk for cancer and mental health impairment (Stallones and Beseler, 2016; Thundiyil et al., 2008). Examples of environmental effects include weakened honey bee immune systems, eggshell thinning in birds, and damage to reproductive systems among amphibians and mammals (Weiss et al., 2016).

The private retail sector, including agro-input dealers, is often the dominant source of pesticides for farmers in low- and middle-income countries (Kato and Greeley, 2016). Studies show that smallholders also consider agro-input dealers as a major source of information for pest management (Diemer et al., 2020; Okonya and Kroschel, 2015). Pesticide manufacturers on the other hand do not have direct contact with agro-input dealers and farmers, and thus use written formats, for example product labels, to inform their customers (FAO and WHO, 2015). The label on a pesticide container is intended to provide all relevant information on content and handling, as well as protective measures to be taken for the environment and human health (MAAIF and UNACOH, 2019). Agro-input dealers are crucial in providing farmers access to products with sufficient labelling, translating and transmitting the necessary information (to often illiterate farmers) and providing access to recommended tools and protective equipment where necessary (Rother, 2018).

Despite agro-input dealers' essential role in protecting humans and the environment from harmful use of pesticides, only few studies have investigated their knowledge, the safety of their shops, and the advice they give to their customers, transmitting safety recommendations from the chemical manufacturers to the users. Some studies from low- and middle-income countries suggest that agro-input dealers are not interested in providing proper advice, as this might reduce product sales (Aga, 2018; Chinsinga, 2011). Other studies found that agro-input dealers are not properly trained (Kwakye et al., 2019; Lekei et al., 2014) and base their advice on knowledge gained through personal experience, brand ambassadors, and level of commission (Devi et al., 2017; Mengistie et al., 2016). On the other hand, many studies suggest that farmers take the advice from agro-input dealers seriously and adopt the suggested practices (Alam and Wolff, 2016; Rutsaert and Donovan, 2020; Soares and Porto, 2009). The role of agro-input dealers in pesticide risk advice is underlined by the fact that farmers often prefer them as a source of information over alternatives such as extension services (Robinson et al., 2007) due to closer proximity and higher accessibility (Kwakye et al., 2019). Unfortunately, regularly the licensed shop owners are absent from their agro-input shops, employing untrained staff instead, thus making proper customer advice difficult (Lekei et al., 2014; Stadlinger et al., 2013).

Despite the abundance of agro-input shops selling potentially harmful chemicals, little is known about the safety of the shops, the knowledge of the agro-input dealers and the advice given to farmers. To fill this gap we conducted a study among agro-input dealers in Uganda. Previous studies have investigated farmers' pesticide use and related risks as well as information behavior in Uganda, identifying agro-input dealers as the primary provider of pesticides and an information source for smallholders on risk factors for safe pesticide use (Diemer et al., 2020; Okonya and Kroschel, 2015; Staudacher et al., 2020; Wiedemann et al., submitted). This study investigated what pesticides agro-input dealers sold, what safety advice they gave to farmers, what they knew about pesticides and believed about the risks, and how they are abiding by the laws, recommended guidelines, and best practices to prevent pesticide risk situations in their own shops.

3.3 Methods

To compare stated with actual behavior of agro-input dealers this study combined three different data collection modules: i) mystery shopping (MYS) to observe agro-input dealers providing pesticide risk and safety advice to farmers through trained undercover observers; ii) knowledge, attitude and practice (KAP) interviews on safe pesticide use and handling with sales staff working in agro-input dealers shops, and iii) observations of shop premises and sales interactions**.** The KAP interview as well as sales and shop observations were conducted with the complete sample, while only a sub-sample of 25% was selected for a mystery shopping *before* the KAP interview (Figure 1**Error! Reference source not found.**). KAP interviews were conducted with the same person who sold the pesticide during the mystery shopping.

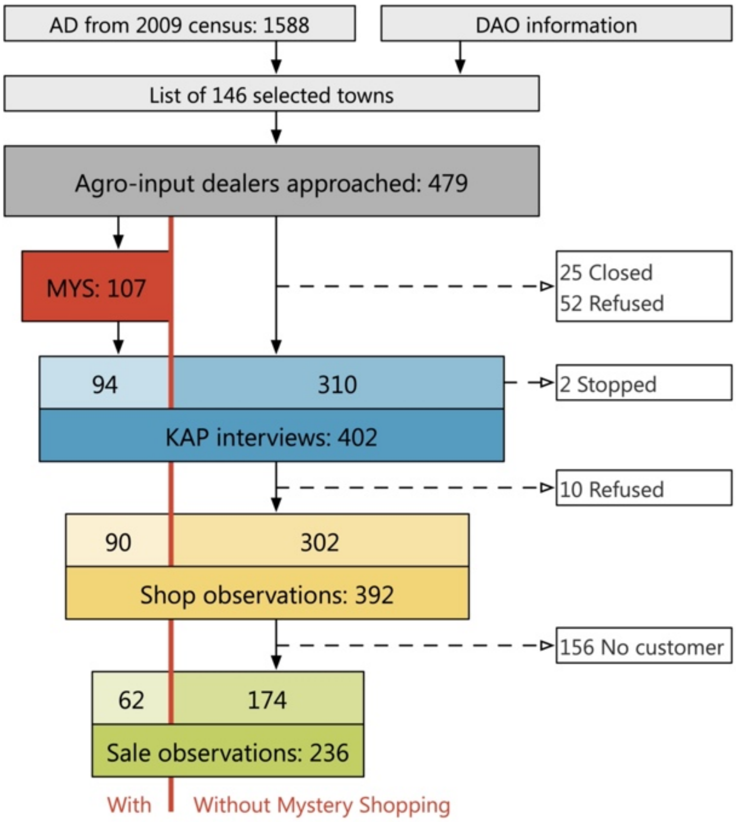

Figure 1: Distribution of study participants (own illustration, adapted from CONSORT flowchart (Schulz et al., 2010)).
AD: agro-input dealer; DAO: district agricultural officer.
Reading explanation: Of the 479 agro-input dealers approached, 25 Shops were closed and 50 agro-input dealers refused to take part in the study, resulting in 404 KAP interviews (310 + 94) that were started. 402 of the interviews were finished and used for analysis. From 107 MYS conducted, ten MYS had to be excluded from analysis because the agro-input dealers refused to take part in the KAP survey. Additionally, three MYS could not be included in the analysis because the KAP survey was conducted with a different staff member than the MYS. 10 agro-input dealers refused the shop observation thus 392 shop observations were conducted. At 236 shops a sale observation took place because 156 agro-input dealers did not have any customers during the time the researchers were at their store or they did not give consent. In one case, only a sale observation but no shop observation was conducted.

3.3.1 Study setting Uganda

In order to be allowed to sell pesticides, agro-input dealers in Uganda are required to complete eleven years of school (ordinary secondary school, Senior Four certificate), complete a certification of competency on safe handling of pesticide (CCSP), and register their business with several Ugandan authorities (USAID et al., 2016). The curriculum of the two-week long training course for the certification of competency on safe handling of pesticide contains the relevant information a pesticide dealer should know about. Pest identification and pest control measures (e.g. cultural control, integrated pest management) are as much part of the program as regulations, application practices, and equipment (Kyamanywa et al., 2007). In 2009, a census in Uganda of 2064 agro-input dealers found that only a minority had not completed mandatory school (12%), while less than half (45%) reported undergoing training for a certification of competency on safe handling of pesticide. Still, 31% reported an academic specialization in the field of agriculture. The majority reported a trading license (85%), while only 27% were registered with the Ministry of Agriculture, Animal Industry and Fisheries (AT Uganda Ltd, 2009).

3.3.2 Sample

The study was conducted in 35 districts and 146 towns in the central and western region of Uganda in October and November 2019 (Figure 2). To ensure a representative sample, districts with high and low agro-input dealer density (estimated number of agro-input dealers per agricultural household from the corresponding official national agricultural census (UBOS, 2010)), and with high and low number of registered agro-input dealers (share of self-reported registered agro-input dealers according to the first and only national agro-input dealer census (AT Uganda Ltd, 2009)) were selected. Because of logistical considerations only districts with a majority of the population speaking Luganda or Runyankore were included. To ensure at least one open agro-input shop per town was present, the focus was placed on larger towns. In each town agro-input dealers were selected by a predefined process using coin toss to maximize random selection.

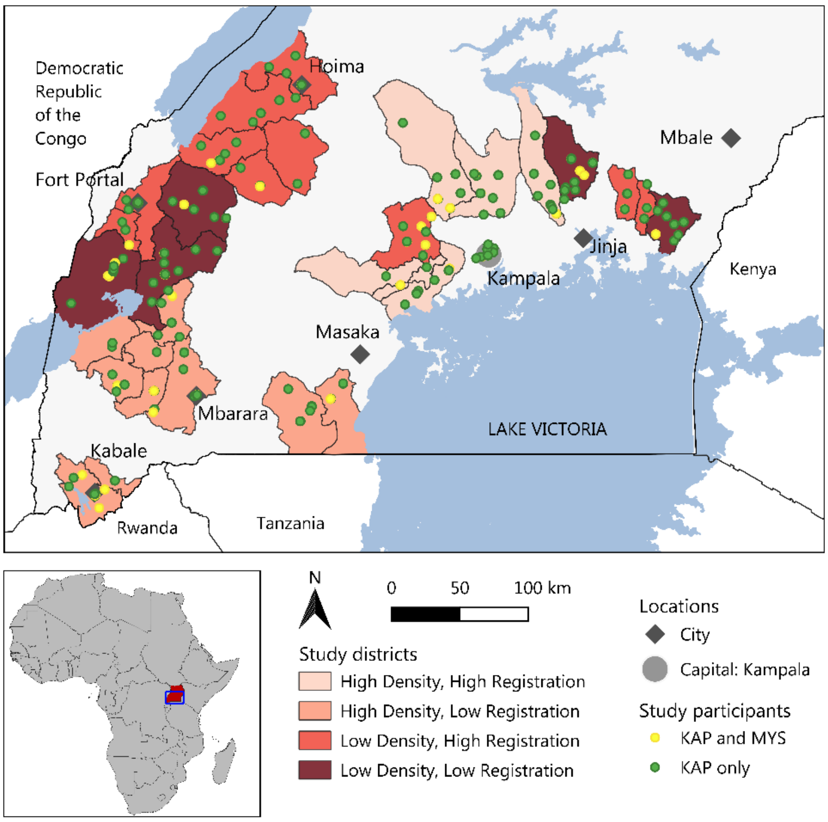

Figure 2: Map of Uganda showing the 35 selected districts and corresponding study sites.
A green point indicates that an agro-input dealer shop was identified and a KAP interview conducted. A yellow point indicates, that a KAP took place with a MYS in the same shop beforehand.

The agro-input dealer census from 2009 identified 1588 agro-input dealers in the central and western region of Uganda (AT Uganda Ltd, 2009). Across the 35 districts and 146 towns we approached 479 agro-input dealers to reach the target sample size of 400 agro-input dealers, representing approximately 25% of the 2009 agro-input dealer population. The KAP interviews and shop observations were conducted in 146 towns (median: 7 per district), whereas the additional mystery shopping was conducted in 65 towns (median: 3 per district) (Figure 1**Error! Reference source not found.**). To ensure that the final sample was representative of the cultural and climatic context of central and western Uganda, we practiced stratified sampling for important agro-input dealer characteristics, such as registration status and rural vs. urban settings.

3.3.3 Data collection

Mystery shopping is a form of covert participatory observation to gain a better understanding of the interaction between a seller and a customer (Wilson, 1998). A mystery shopper who is trained by the researcher enters a store and acts as a typical customer in need of a product or service. After acquiring the product or service, the mystery shopper is interviewed by a researcher, through which important information on the services in the respective store is gained (Devi et al., 2017; Hetzel et al., 2008). Outside of market research and customer service evaluation, mystery shopping is not widely used yet. A few studies have successfully applied mystery shopping in public health settings in Europe (Glasier et al., 2010; Lakhdar et al., 2020) and Africa: The studies in Kenya (Tavrow et al., 2003) and Tanzania (Chalker et al., 2015; Hetzel et al., 2008) investigated the drugs sold and advice provided by drug retailers when presented with symptoms by a mystery shopper.

For the mystery shopping technique to produce valid and reliable data it is important that the mystery shopper appears to be a plausible regular customer and that all mystery shoppers follow the same protocol. In this study, we recruited local farmers and systematically trained them to describe the case problem with the same four sentences. The case problem used was the fall armyworm affecting the farmer's maize. The fall armyworm was first noted in Africa in 2014 and has become a devastating pest in sub-Saharan Africa, including Uganda (Bateman et al., 2018; Tambo et al., 2020). In the case where farmers were not given any advice before they had paid for the pesticide, they were instructed to ask three specific questions on health risks and protection. After completion of the mystery shopping the farmers were debriefed about their shopping experience and interaction with the agro-input dealers, using a standardized structured questionnaire in ODK (Open Data Kit) (Hartung et al., 2010).

KAP interviews are a well-established method to collect a large amount of quantitative data from study participants on self-reported knowledge, attitude and practices related to a specific field (Gumucio et al., 2011). In this study, KAP interviews were conducted with a standardized structured questionnaire in Luganda, Runyankore or English. The KAP survey covered knowledge, attitude and practices on their profession as agro-input dealers, handling and protection of pesticides, effects of pesticides on human and environmental health, alternatives to pesticide use, and general agricultural aspects. In addition, the interviews included questions on socio-demographics, education, training, sales experience, shop organization, and personal health.

In parallel with the KAP survey, each interviewer also conducted two observations per interviewee: i) the dealer's sale interaction with a customer; ii) the shop premises regarding compliance with official safety recommendations (FAO, 1988; USAID et al., 2016). Both the sale interaction and the shop premises were studied through a non-participatory, structured and overt observation. Refusal to take part in one or both observations did not exclude the dealer from the study.

The research team was thoroughly trained for 10 days and conducted a pilot study in one district, Wakiso. The questionnaires were translated from English to Luganda and Runyankore by professional translators and refined after the pilot. Ethical clearance was obtained in Uganda and Switzerland (see declarations).

3.3.4 Data and analysis

Descriptive statistics were estimated for all variables using R version 4.0.2 (R Core Team, 2020). To assess whether the subsamples mystery shopping and sale observation were drawn from the same distribution as KAP, we conducted a two-sample Kolmogorov–Smirnov test for each numerical variable, while for categorical variables we applied the chi-square test to test whether subsets differed. All prices were calculated from Ugandan Shilling to United States Dollar ($), using the conversion rate of October 2019 at 1:3700.

The agro-input dealer shop observations were based on guidelines by both the Ministry of Agriculture, Animal Industry and Fisheries and the Food and Agriculture Organization of the United Nations (FAO, 1988; USAID et al., 2016). The failure to adhere to these recommendations was categorized into three increasing categories of seriousness, following the work of Akhabuhaya (2005): somewhat serious, serious and very serious. These categories were selected to reflect the risk for acute intoxication through oral or dermal exposure (very serious), chronic intoxication through inhalation, or dermal exposure (serious), or otherwise not following the guidelines (somewhat serious).

When comparing different pesticide products, their active ingredients, and their toxicity we use the toxicity classes recommended by the World Health Organization (WHO) (WHO, 2020). The WHO classifies pesticides based on acute oral and dermal toxicity of the AI, defining five classes based on different LD_{50}: Ia – extremely hazardous, Ib – highly hazardous, II – moderately hazardous, III – slightly hazardous, and U – unlikely to present acute hazard (formerly class IV – Less hazardous) (Supplementary Table ST 1).

During the agro-input dealers' knowledge assessment, the first set of questions was referring to a typical safety label, which are normally placed on the bottom end of a pesticide container. The colored part, the two areas with similar symbols, as well as the individual symbols have different meanings and are supposed to be read (and understood) from left to right (Figure 3).

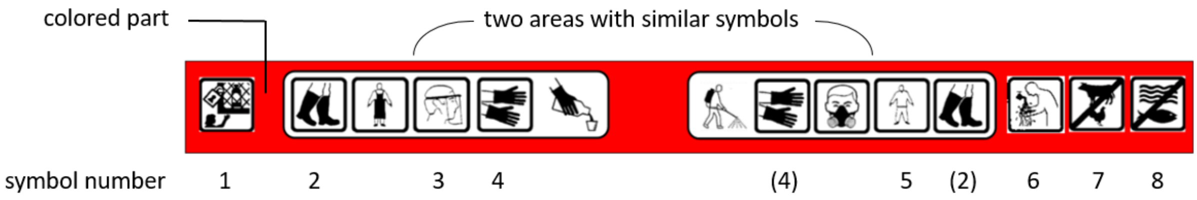

Figure 3: Example label used for knowledge test.
The image was provided without the text and numbers, see also Supplementary Table ST 2. Image adapted from FAO and WHO (2015)

For the attitude assessment, we adapted a battery of statements originally designed for smallholder vegetable farmers in Southeast Asia (Schreinemachers et al., 2017). The statements were determined to be disputed, when the absolute difference between 50 and the share of answers stating 'true' or 'yes' was smaller than 20 (Example: 10% Yes, not disputed: |50-10| > 20; 35% Yes, disputed: |50-35|<20).

The dataset, as well as the instruction materials and questionnaires from the collection are accessible openly under opendata.eawag.ch.

3.4 Results

3.4.1 Pesticide dealers

Of the 479 agro-input dealers approached, we sampled 107 shops for a mystery shopping, 402 for knowledge, attitude and practice interviews, 392 for shop observations, and 236 for sale observations (Figure 1). The 402 interviewed agro-input dealers were close to thirty years old (28.5 years), with a majority of women (60.7%). Roughly half of them were shop owners (53.0%), and half of them employees (47.0%) with a median employment in agro-input dealers shops of three years equaling also the median experience in selling pesticides. Agro-input dealers in Uganda worked on average twelve hours per day, seven days a week, and earning $54.1 per month (Table 1). The majority of agro-input dealers (83.3%) had completed mandatory school (seven years primary and four years secondary) or more. Of all agro-input dealers, 29.3% had a higher education in agriculture, veterinary, pharmacy or medicine, whereas 19.7% were trained in business, administration, accounting, etc. (Supplementary Table ST 3).

The majority of agro-input dealers (76.1%) were responsible for everything in the shop, while the others were mainly responsible for conducting sales (23.9%) and giving advice (20.9%) (Table 1). Only 55.7% of the interviewed agro-input dealers held a certification of competency on safe handling of pesticide, a requirement to sell pesticides in Uganda. But more than 90.3% had received instructions on pesticide application and 77.9% had received any other general training on pesticides (Table 1). The content of the general pesticide training were primarily safe use and handling of chemicals (86.9%) (Supplementary Table ST 4) and were provided by either the Uganda National Agro-Input Dealers' Association (UNADA), the shop owner, a government agency, or schools and university, while agricultural extension services and pesticide manufacturers played a less important role. On the other hand, less than half of agro-input dealers had ever received training on alternatives to synthetic pesticides, while 38.1% of those agro-input dealers who had, received it in school or university (Supplementary Table ST 5). The sample does not show indications of imbalances between the main sample for KAP and the subsamples for sales observations and mystery shopping.

Table 1: Sample description for agro-input dealers, their education and training.

Agro-input dealers	**Unit**	**KAP[a]**	**OBS[a]**	**MYS[a]**
Number of participants	n	402	236	94
Female (vs male)	%	60.7	61.0	62.8
Age (median[b])	years	28.5 (6.7)	29 (7.4)	29 (7.4)
Employees (vs owners)	%	47.0	44.5	43.6
Employment in this shop (median[b])	years	3 (3.0)	3 (3.0)	3 (3.0)
Working hours per day (median[b])	n	12 (1.5)	12 (1.5)	12 (1.5)
Working days per week (median[b])	n	7 (0)	7 (0)	6 (0.7)
Monthly income from shop (median[b])	$	54.1 (40.1)	54.1 (40.1)	54.1 (40.1)
Responsibilities around pesticides in the shop (multiple choice)				
Responsible for everything (see below)	%	76.1	74.2	75.5
Conducting sales	%	23.9	25.90	24.5
Giving advice	%	20.9	23.3	19.1
Handling pesticides	%	18.7	20.8	17.0
Bookkeeping	%	18.4	21.2	17.0
Cleaning	%	17.7	19.9	14.9
(Re)packaging	%	6.97	7.6	8.5

Education and Training of agro-input dealers	**Unit**	**KAP(a)**	**OBS(a)**	**MYS(a)**
General Education (median[b])	years	13 (3.0)	13 (3.0)	13 (3.0)
Experience selling pesticides (median[b])	years	3 (3.0)	4 (3.0)	4 (3.0)
Interviewee has a CCSP[c]	%	55.7	64.8***	61.7
Ever received any training ...				
... on pesticides in general	%	77.9	74.6	76.6
... in alternatives to pesticides	%	43.8	46.2	45.7
... in pesticide application	%	90.3	90.7	88.3

*Note: No significant differences were found with one exception: CCSP is different between KAP and OBS: ***Significant difference at p<0.001*
[a]The samples are abbreviated with KAP for the full sample of interviewees, MYS for those participating in mystery shopping and OBS for those participating in the sales observation
[b]Median with median absolute deviation in parentheses
[c]CCSP: Certification of competency on safe handling of pesticide

3.4.2 Pesticide shops

The majority of agro-input shops (82.3%) reported at least one employee with a certification of competency on safe handling of pesticide (Table 2) and has in the past at least once been inspected (81.1%), mostly to check for counterfeits or other unauthorized products (36.8%), or license approval or renewal (30.6%). A shop license, issued by the Ministry of Agriculture, Animal Industry and Fisheries is mandatory to sell pesticides in Uganda. However, only 5.7% of shops could provide an up-to-date license, while 41.5% stated they have no license (Supplementary Table ST 6). Each shop has a median estimate of 20 customers per day, half of which buy pesticides for a median price of $4.1. The customers are primarily smallholder farmers (90%), male (70%) with a median farm size of one acre (Table 2).

Table 2: Sample description for shops and customers

Shop organization and customer relations	Unit	KAP[a]	OBS[a]	MYS[a]
At least one person with CCSP[c] working in shop	%	82.3	88.6***	87.2
Number of employees per shop (median[b])	n	2 (1.5)	2 (1.5)	2 (1.5)
Sole ownership (vs partnerships or cooperatives)	%	87.8	89.0	87.2
Owner regularly interacting with customers	%	88.8	92.4*	92.6
At least one shop employee visiting farmer fields	%	68.7	69.9	63.8
Estimated shop size (median[b])	m2	9 (7.4)	9 (7.4)	9 (7.4)
Shop age (median[b])	years	4 (2.97)	4 (2.97)	4 (2.97)
Open days per week (median[b])	n	7 (0)	7 (0)	6.5 (0.7)
Customers per day (median) [b]	n	20 (14.8)	20 (14.8)	20 (14.8)
Number of pesticide transactions per day (median[b])	n	10 (7.4)	10 (7.4)	10 (7.4)
Spending on pesticides per transaction (median[b])	$	4.1 (4.0)	4.1 (4.0)	4.1 (4.0)
Number of customers per season (median[b])	n	1680 (1068)	1920 (1423)	1680 (1328)
Number of competitors in parish (median[b])	n	5 (4.5)	6 (4.5)	7 (5.9)
Share of non-smallholder customers (median[b])	%	10 (14.8)	15 (19.3)	10 (14.8)
Share of female customers (median[b])	%	30 (14.8)	30 (14.8)	30 (14.8)
Customer farm size (median[b])	acre	1 (0.7)	1 (0.7)	1 (0.7)
Customers with smartphone (median share[b])	%	20 (22.2)	20 (22.2)	25 (22.2)

*Note: No significant differences were found with two exceptions: CCSP is different between KAP and OBS: ***Significant difference at p<0.001 and owner interaction for OBS *Significant difference at p<0.05*
[a]The samples are abbreviated with KAP for the full sample of interviewees, MYS for those participating in mystery shopping and OBS for those participating in the sales observation
[b]Median with median absolute deviation in parentheses
[c]CCSP: Certification of competency on safe handling of pesticide

The shop observation revealed that 100% of shops showed *somewhat serious*, 98% of shops *serious*, and 36% *very serious* deviations from the shop setup recommended by both the Ministry of Agriculture, Animal Industry and Fisheries and Food and the Agriculture Organization of the United Nations (FAO, 1988; USAID et al., 2016). *Very serious* deviations were found in a quarter of shops repackaging pesticide containers (25.0%) and a tenth of shops having unmarked/unlabeled pesticide containers (10.5%). The *serious* deviations were lack of safety equipment (90.1%), such as PPE, water, soap, or materials for spill-cleanup such as brooms. Also prominent were obstructed fire exits (41.6%), insufficient ventilation (31.1%), and small shop sizes (41.1%). Moreover, *somewhat serious* deviations like the absence of safety displays (99.7%), missing firefighting equipment (93.4%), absence of documents (85.7%), or lacking floor drainage (78.8%) were frequently observed (Supplementary Table ST 7).

Agro-input dealers were commonly not using PPE when handling pesticides in the shop. The most accessible PPE (to more than 69%) were also the most used (by more than 30% of those who had access): Masks without carbon filter, long sleeved shirts, gloves, long pants, and rubber boots (Supplementary Figure SF 1). The reasons agro-input dealers gave why they weren't using PPE were lacking availability (43.3%), high price (33.1%), lack of comfort (32.1%), and the belief that they weren't needed (25.9%).

Proper hygiene practices are also relevant to minimize risks. Nevertheless 55.5% of agro-input dealers reported drinking beverages and 43.0% eating food in the shop. The majority (92.0%) claimed to wash their hands immediately after pesticide handling and 95.0% change their clothes after a day involving pesticide handling (Supplementary Table ST 8).

Handling of pesticides and residues can be a source of risk: A third of agro-input dealers had ever opened sealed containers to sell smaller quantities in different containers (repackaging) and a quarter were currently doing it. Those who stopped, did so because of health effects (53.8%) and illegality (28.2%). The most commonly repackaged active ingredients were mancozeb (54.0%) and glyphosate (25.0%). Agro-input dealers commonly did not dispose of returned pesticide containers at all (45.0%). Those who did, mostly burnt them (35.3%) or brought them to municipal disposal sites or other trash (11.7%) (Supplementary Table ST 9).

3.4.3 Pesticides on sale

Pesticides are the most often sold product of agro-input dealers (88.6%) and the most profitable (80.5%) (Supplementary Table ST 10). Specifically, most sold products are herbicides (47.3%), insecticides (33.3%), and fungicides (8.0%), while most profitable products are herbicides (50.7%), insecticides (22.9%), and fungicides (6.7%). Besides pesticides, most shops also sell fertilizers (92.3%), seeds (85.6%), and spray pumps (65.4%). The most commonly sold PPE in shops are gumboots (35.6%), followed by masks without carbon filter (31.6%), gloves (27.6%), masks with carbon filter (17.4%), and glasses (11.7%) (Supplementary Table ST 11).

A look at the WHO toxicity class of the 15 bestselling pesticide brands according to the KAP interviews reveals that 26.5% of active ingredients were of class Ib and 47.6% of class II, so moderately to highly toxic. The only active ingredient of class III and U were the herbicide glyphosate and the fungicide mancozeb respectively. Shop observations revealed that the most common WHO toxicity class in shops was III (41.1%) (Supplementary Figure SF 2). Labels on pesticides in the shop are mostly available in English (91.2%). Only 19.8% of labels are available in a local language.

The 94 mystery shoppers purchased 25 different pesticide brands against the fall armyworm, consisting of eleven different active ingredient combinations. While only four of the brands were approved by Ministry of Agriculture, Animal Industry and Fisheries for use against fall armyworm (Supplementary Figure SF 3), they made up 53% of purchases (Supplementary Table ST 12). Of the products purchased 13% were WHO toxicity class Ib and 68% were class II (Figure 4). The purchased products significantly differed in prices for class II (n=64, mean = $1.44) versus class Ib (n=11, $1.69) and class U (n=3, $1.85), while class III cost $1.56 (n=16).

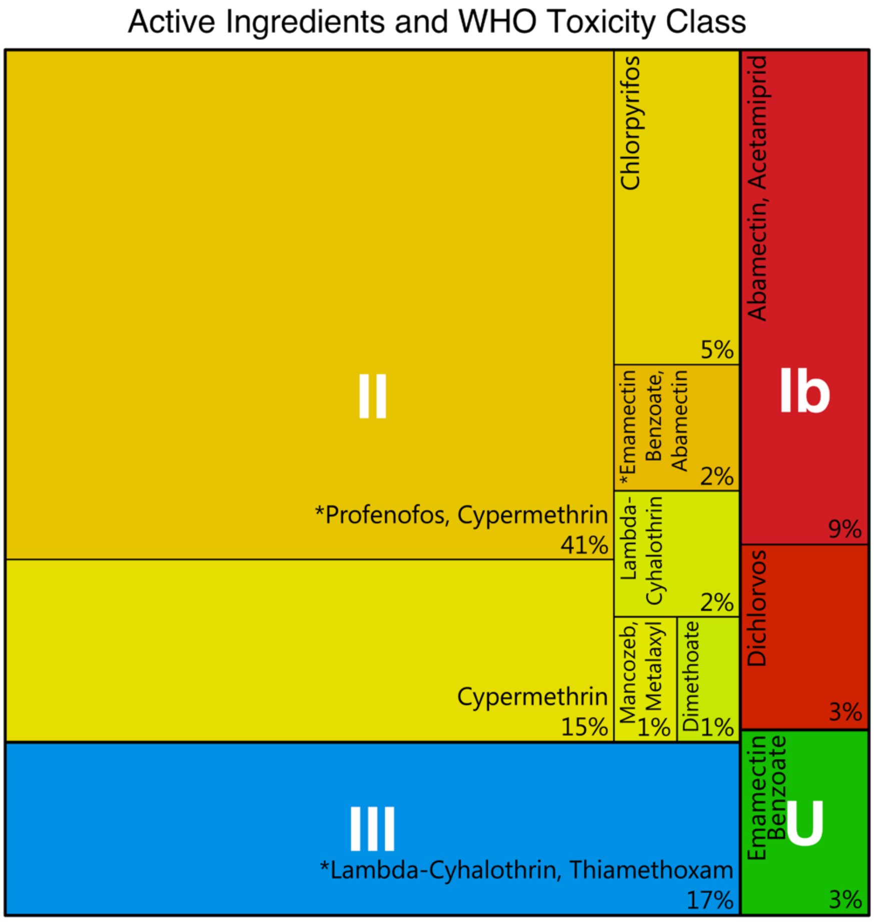

Figure 4: Active ingredients of purchased pesticides during mystery shopping and their WHO toxicity class.
** = Active ingredient is on the list of approved pesticides against the fall army worm from the Ministry of Agriculture, Animal Industry and Fisheries.*

3.4.4 Dealer advice

The first column of Figure 5 displays that agro-input dealers reported to commonly give advice on specific topics ranging from product choice and application and handling (both 97%) to label explanations (58%). The second column displays the share of agro-input dealers mentioning that 50% or more of farmers ask for advice on these topics. 65% of agro-input dealers claim their customers often ask for advice on product choice and 68% for application and handling of pesticides. Sale observations (third column) revealed that product choice was indeed a topic in 86% of interactions and mostly initiated by the farmer, whereas dealers initiated the topics price (a topic in 75% of interactions) and application and handling (28%). All other topics (such as use of PPE, adequate storage and disposal of pesticides, or health effects of pesticides) were rarely observed despite agro-input dealers stating to give that type of advice regularly (Figure 5, Column 1).

Last, the participatory observation during mystery shopping revealed that only twenty-seven shoppers (29%) were given any advice without asking for it and the topics were mainly application and handling (24%), followed by PPE (9%) and health effects (7%) (fourth column). No advice was given on safe storage or disposal of pesticides, nor about the impact on the environment. Product choice was discussed in all mystery shopping, as the farmers were instructed to describe the problem but not ask for a specific product. The content of such a product choice discussion as well as discussions about the price were not further investigated.

After their pesticide purchase the majority of the 94 mystery shoppers asked probing questions. Of the agro-input dealers who were asked the question "Is it dangerous for my health?", the majority (79%) replied it was dangerous. To the follow-up question "How should I protect myself?" agro-input dealers suggested primarily the use of PPE (64%). However, the following quotes illustrate the range of answers and advice mystery shoppers were given when purchasing pesticides. For example, one agro-input dealer (female, 34, with certificate) answered that there is *"No side effect unless you drink it".* Another agro-input dealer (female, 23, no certificate) advised *"After spraying you should also take some cold milk…"*. A third agro-input dealer (female, 37, no certificate) suggested to *"Look for other people to spray for you or just use it carefully"* as means of protection. Summarized, farmers and agro-input dealers both focus on product choice and application procedures during sale interaction.

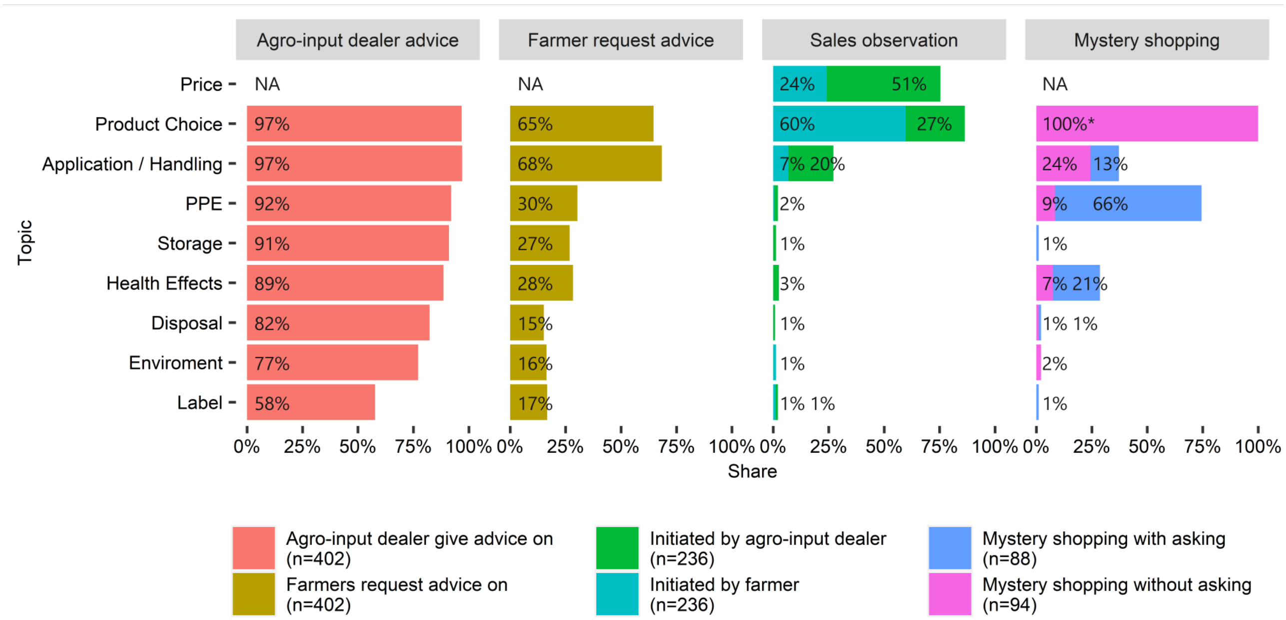

Figure 5: Comparison of mentioned topics in sale interaction by approach applied.
Price as a topic was only investigated in sales observations. PPE: personal protective equipment.
Reading example for 2nd column: 65% of agro-input dealers say that more than half their customers ask them to advise on product choice.
** 100% Product choice in mystery shopping, due to the fact, that every farmer also purchased a product.*
Original questions for each section accessible in Supplementary Table ST 13.

3.4.5 Dealer knowledge

The question that arises from this lack of safe shops, proper pesticide sales, and needed advice on protective behavior for farmers is whether a lack of knowledge or attitudes is constraining agro-input dealers. First, all agro-input dealers were asked to identify and explain specific parts of an example pesticide hazard label (Figure 3). Four out of five participants (79.9%) identified the colored label as indicating danger or hazards with 15.2% naming it according to WHO guidelines ‘extremely dangerous’, while the others indicated statements such as (highly) hazardous, dangerous, (very) toxic, or fatal. Two out of five agro-input dealers were able to identify all other possible colors of pesticide labels (Supplementary Table ST 1), while only one in eight agro-input dealers also correctly identified the corresponding meaning of these colors (Supplementary Table ST 14). Only 43.3% of agro-input dealers identify all symbols on Figure 3 correctly, while seven agro-input dealers (out of 402) identified none of the symbols. Wearing gloves was the symbol correctly identified by the most agro-input dealers (96.3%), while the least understood symbols were those related to the protection of other vulnerable life, such as children (36.6% wrong or no response), terrestrial (24.4%), or aquatic animals (22.1%) (Supplementary Figure SF 4).

Agro-input dealers were asked whether they understand what particular active ingredients are used for (Table 3). Seven of the fifteen active ingredients scored below 50%. Least correctly identified were three active ingredients of WHO toxicity class Ib or II: carbaryl, carbofuran, and diazinon. Similarly, when asked for their best selling products, agro-input dealers reported brands without being aware of the corresponding active ingredients (Supplementary Table ST 15 and Supplementary Table ST 16). Moreover, around two out of five agro-input dealers were unable to name at least one pesticide banned in Uganda (active ingredients or corresponding brand; e.g. paraquat, DDT or carbofuran). Summarized knowledge on active ingredients is comparably low.

Table 3: Identification of active ingredients vs. their use.

Use identification (%)	Correct	Incorrect	Use unknown	AI unknown
2,4-D	96.0	1.2	2.0	0.8
Mancozeb	87.6	7.7	3.7	1.0
Cypermethrin	82.8	1.5	10.7	5.0
Glyphosate	82.6	0.8	10.7	6.0
Paraquat	70.4	4.5	19.2	6.0
Dimethoate	69.7	3.2	17.9	9.2
Profenofos	63.2	2.2	23.6	11.0
Diazinon	57.0	11.7	21.6	9.7
Carbofuran	48.5	11.9	27.6	11.9
Dichlorvos	44.8	2.2	32.6	20.4
Permethrin	34.8	3.2	40.3	21.6
Chlorpyrifos	33.3	3.2	36.8	26.6
Deltamethrin	29.4	2.5	43.3	24.9
Λ-Cyhalothrin	26.6	1.0	38.6	33.8
Carbaryl	10.0	3.5	52.2	34.3

Note: The different columns denote correct (Yes) or incorrect (No) identification of the active ingredients' (AI) use, knowing the AI name, but not its' use (don't know) or stating the AI is unknown. The proportion (last column) indicates the ratio between correct (yes) and wrong (no) answers
The fifteen AI were selected as most commonly used AI in the study area (Staudacher et al., 2020).

3.4.6 Dealer attitudes and believes

In addition to the knowledge, agro-input dealers' beliefs and feelings with regard to pesticides were investigated (Table 4). The agro-input dealers were provided with 30 statements that they could agree on or not (they were specifically told that these questions do not have a right or wrong answer). Fifteen out of thirty statements were agreed upon by less than 10% or more than 90% of agro-input dealers and revolved around topics of health and environmental risks, general protection, and farm profits. Nine statements were agreed upon by more than 30%, but less than 70% of agro-input dealers and revolved around pest management strategies (e.g. organic), pesticide effectivity, and government oversight, but also safety aspects such as product labelling or product handling by customers.

Additionally, agro-input dealers were asked questions around their self-perception as source of information, as well as about their attitudes and believes with regard to the use of licenses, on counterfeits, pest resistance, and organic alternatives to synthetic pesticides. Almost all agro-input dealers (95.3%) perceived themselves to be a source of information to farmers, while just more than half (52.7%) of them thought that they were the best source of information for farmers in terms of safe pesticide use (Supplementary Figure SF 5). Almost nine out of ten agro-input dealers considered their shop license as relevant. It enabled them to do business according to regulation (50.8%), enabled tax payment (20.7%), occupational safety (19.9%), and was a quality assurance to the customer (19.9%). Also, almost all agro-input dealers (93.3%) believed counterfeits were a big problem in Uganda and most believed (71.6%) they could identify a counterfeit. Seven out of ten (69.2%) had ever been concerned that the products they buy and sell could be counterfeits and three quarters (75.9%) of those had this worry in the last twelve months. Pest resistance was perceived to be a problem by 87.3% of agro-input dealers. The preferred strategies to go about it were to better advise the farmer (33.8%) and recommending stronger pesticides (23.6%) (Supplementary Table ST 17). The majority (78.4%) of agro-input dealers was also aware of alternative approaches to chemical pest management, such as cultural, ecological, biological, and mechanical approaches (Supplementary Table ST 18). However, agro-input dealers stated that alternatives are perceived to be less effective, more time and labor consuming, while being cheaper, less skill-demanding, and with lower health risks. (Supplementary Figure SF 6). Most agro-input dealers stated to recommend synthetic pesticides over alternatives (68.7%), mainly due to their effectivity (90.5%) and economic benefits (92.5%). Those who recommended alternatives (31.3%), did so mainly to protect human health (80.0%) or the environment (78.1%) (Supplementary Table ST 19).

Table 4: Questions investigating attitude towards pesticides. Sorted most to least agreement.

Statement	**yes (vs. no) %**
Protective measures are necessary for pesticide use.	99.5
Pesticides contaminate water bodies.	97.8
You are worried about the toxicity of the chemicals to the people who use them or the people who eat the food.	97.3
You are worried about damaging the environment with toxic chemicals.	97.0
Pesticides can enter the body through the skin.	96.8
Pesticides can cause harm to the environment.	96.3
Using pesticides increases farm profits.	95.8
Pesticides affect livestock negatively.	94.3
You keep your pesticides inside the shop and out of reach of children and animals.	94.3
Pesticides have negative effects on the health of children.	93.3
When handling pesticides you are worried about getting cancer.	92.3
Pesticide use leads to soil degradation.	89.6
You are concerned about pesticide residues when buying vegetables from the market.	87.3
You think that the supply of agro-chemicals should be better controlled by the government.	86.1
Commercial production without pesticides is impossible.	78.6
Biopesticides are not as effective as chemical pesticides.	69.9
Organic agriculture is a good alternative to conventional agriculture.	69.7
You can determine whether a pesticide is dangerous or not by its smell.	53.5
Good pesticides are those that kill all insects immediately.	49.8
You think pesticide retailers are sufficiently monitored and supported by the government.	45.8
You think farmers apply the pesticides safely.	39.1
Mixing different pesticides makes the spraying more effective than using a single pesticide.	35.1
If there are many pests in the field then one should make the spraying mixture stronger.	34.6
You think colour codes on pesticides are not important.	30.6
Some pesticides have a pleasant smell.	26.4
Herbicides are not dangerous to humans.	23.4
Washing pesticide equipment in ponds or rivers does not affect the water quality.	9.7
Pesticides have a positive effect on beneficial species like bees or fish.	7.7
Empty pesticide containers can be reused for other purposes.	7.2
Drinking alcohol after spraying helps to eliminate side effects.	5.0

Original Text: "I would like to ask you some questions about your beliefs and feelings in relation to pesticides. When we say pesticides, we mean synthetic, chemical pesticides. There are no right or wrong answers in this section. We are interested in what comes to your mind immediately after hearing the statement. Please answer with either true or false only." And "I would now like to ask you again some questions about your beliefs and feelings in relation to pesticides. Please answer this time with either yes or no."

Interestingly, almost all agro-input dealers believed that pesticides could affect their own health (98.8%). Most agro-input dealers assumed the short term effects to be *little* (39.9%), whereas the long-term effects were considered to be mostly *large* (54.7%) or *fatal* (28.1%) (Figure 6). This was reflected in the terms agro-input dealers used for pesticide products when speaking with customers in their native language. The majority said they use the word for medicine (59.5%), followed by the word pesticide (30.1%) and lastly poison/toxin (9.5%).

short term \ long term (%)	No effects	Little effects	Some effects	Large effects	Fatal effects	Don't know	Total
No effects	2.3	1.3	1.3	4.3	2.0	0.5	11.6
Little effects	0	2.3	1.8	28.0	7.3	0.8	40.1
Some effects	0.3	1.3	2.0	15.9	11.3	0.3	31.0
Large effects	0	1.0	0	6.5	5.5	0	13.1
Fatal effects	0	0	0.5	0.5	2.0	0.3	3.3
Don't know	0	0	0.3	0.3	0.3	0.3	1.0
Total	2.5	5.8	5.8	55.4	28.5	2.0	100

Figure 6: Assumed overall impact of pesticide handling and/or exposure on own short- and long-term health.

Worryingly, more than two thirds (69.7%) of agro-input dealers had ever experienced health-related effects within 24 hours after pesticide handling. The three most-recalled self-experienced symptoms were headache (29.1%), respiratory difficulties (23.6%), and skin irritation (22.4%). When asked about all possible symptoms of pesticide poisoning the most recalled were skin irritation (57.2%), headache (44.0%), itchy eyes (37.3%), and vomiting (33.3%) (Supplementary Table ST 20). Close to half of all agro-input dealers (44.8%) recalled all four pesticide entry sites into the body (oral, dermal, inhalation, and ocular), whereas more than a quarter (28.9%) believed ears to be sites of entry (Supplementary Table ST 21). Being aware of all possible entry sites is important as it can affect the PPE the agro-input dealer might recommend.

3.4.7 Dealer outlook

The majority of agro-input dealers saw pesticide sales raise over the past five years (86.8%) and expect a further increase over the next five years (91.0%). The main explanations provided was an increase in farmers (31.1%) (Supplementary Table ST 22, Supplementary Table ST 23). Agro-input dealers were also asked for their perspectives on possible future changes in the pesticide sector and all suggestions were agreed or strongly agreed upon by more than 80% of agro-input dealers (Supplementary Figure SF 7). The highest agreement was reached for reduced PPE pricing and an agro-input dealer certification of good practice. Furthermore, training needs to be decentralized and more affordable, as we all as repeated even for established dealers. Organic farming demonstrations plots, inputs suitable for organic farming as well as a governmental strategy on organic farming are also wished for.

Least popular was a restriction and penalization of agro-input dealers which are not complying with regulations. Three in five (60.7%) agro-input dealers have a smartphone, while they estimate that on average only 24.6% of their customers have one. Two out of five agro-input dealers (40.3%) are subscribed to a text-message based service to receive regular messages with business-related information (Supplementary Table ST 24).

3.5 Discussion

This study applied three different approaches to illustrate agro-input shop conditions and products available, agro-input dealers' pesticide advice for smallholder famers, and agro-input dealers' knowledge, attitude and practices in terms of pesticides and the related risks to human and environmental health. The findings display a gap in customer advice between stated and observed behavior, suggesting important opportunities for dealer professionalization and improvement of risk communication towards smallholder farmers.

The findings demonstrate that 97% of agro-input dealers perceive it as their responsibility to advise farmers, which is an increase of 13% from the results presented in the 2009 census (AT Uganda Ltd, 2009). While the majority of agro-input dealers claims to advise farmers also on health and environmental effects, storage, disposal, PPE, and labels, observation of sales interactions revealed that with rare exception product choice, price, and application practices are the only topics discussed. Farmers are not asking for topics beyond these and agro-input dealers hence do not impose further information they might have on the farmer. Mystery shopping has shown that when asked, agro-input dealers can also advise smallholders on health topics, but without necessarily providing best practice answers. Although we know, that existing awareness does not always translate into action (Oesterlund et al., 2014; Okonya and Kroschel, 2015; Staudacher et al., 2020), it is still essential that farmers are informed about health and environmental risks as well as their prevention. While regulators and the WHO consider the label as one of the main tools to share risk, safety, and health information, the evaluation in this study of agro-input dealers' advice has shown that label explanation is rare. Previous research showed that label information does not reach farmers when they are unaware of its importance. If agro-input dealers were explaining the label more frequently, they could help farmers overcome hurdles in literacy, language, and access to labels (Rother, 2018).

An explanation for the absence of risk-advice giving practices could be the domination of the pesticide-value chain by immediate profit motives, which has been suggested for Ethiopia (Mengistie et al., 2016). The combination of a knowledge monopoly in the last mile (Minten et al., 2013) and the absence of a competitive advantage for environmental and health advice places the smallholder farmer in a vulnerable position, with no other access to this information. This effect is amplified in low productivity areas, where the farmers are also underserved in health care, where an untreated pesticide poisoning could result in larger health effects, such as permanent neurological damage or reproductive effects (Wesseling et al., 1997).

A second possible explanation for the gap between perceived responsibility and advice given is the lack of appropriate training. The findings have shown, that while the majority of agro-input dealers fulfill the criteria for general education, specialized training, provided through the certification of competency on safe handling of pesticide, was only attained by about half the interviewed agro-input dealers (55.7%). This is in line with previous studies from low- and middle income countries claiming agro-input dealers missing education and training, therefore giving smallholders access to hazardous chemicals without appropriate stewardship (Kwakye et al., 2019; Lekei et al., 2014). The certification courses takes place centralized at Makerere University in the capital Kampala. Travelling there and staying in town is expensive and not always affordable for everyone. After certification, agro-input dealer also have to undergo a long and expensive process to register their businesses. Together, this may be too expensive for new businesses, crippling them, before they have established viability.

Most agro-input dealers agree that the trainings need to be decentralized and more affordable. A subsidized collaboration with pesticide suppliers as well as specialists for environment and health could tour different cities, thereby eliminating agro-input dealers' need to travel far from their business, while ensuring they hear not only about economic benefits, but also the risks coming with pesticide use. The present study indicates that knowledge retention is not yet ideal, suggesting repetition courses as useful tool to avoid knowledge loss over time. Furthermore, two studies from Nepal have shown, that agro-input dealer training significantly increased their knowledge on pesticide hazards and reduced sales of unregistered pesticides (Vaidya et al., 2017), but agro-input dealers lacked the incentives to adopt other necessary safety measures in pesticide handling, thus missing the opportunity to be a role-model to their customers (Bhandari et al., 2018).

Likewise, this study showed that not all agro-input dealers are a good example for farmers when it comes to personal protection and hygiene in the light of pesticide handling. Precautionary practices, such as avoiding eating and drinking, regular handwashing, and the use of PPE are not trivial if a shop is open 12 hours per day, every day of the week, while tap water is lacking and PPE inaccessible. Furthermore, even where the conditions are ideal, these practices can be uncomfortable or agro-input dealers can believe they are not needed. This lack of precautionary practices also of agro-dealers stands in contrast to the vast majority of agro-input dealers (98.8%) believing that pesticides can affect their health. This in turn can stem from own experiences, such as self-reported symptoms of intoxication or their experience with farmers having pesticide poisonings or even the use for self-harm. Nevertheless, when asked to categorize health effects into short and long term, it becomes evident that the downsides of pesticide use are mentally postponed into a distant future, where they are all the more harmful and more costly (Sheahan et al., 2017). This is in line with the concept of discounting, where the benefits of today are valued higher than the losses of the future (Torgerson and Raftery, 1999). When targeting agro-input dealers for a behavior change intervention, this context needs to be taken into account.

A third explanation, why risk-advice is missing, could be, that the curriculum for the certification of competency on safe handling of pesticide may be targeted only at what agro-input dealers should know and not at how agro-input dealers transfer their knowledge to the farmer. An approach to standardize the sale interaction between smallholder farmers and agro-input dealers would be to train them similar to pharmacists (Mesquita et al., 2010), always explicitly asking the customer whether they need information on pesticide storage, container disposal, PPE, and the like. Logistically, the number of customers per shop indicates that training agro-input dealers in risk communication would leverage more than one thousand farmers per season. An alternative lever would be the use of free smartphone applications advising on pest management practices and related safety measures. In this survey, 61% of agro-input dealers and around 25% of their customers already have a smartphone. A study researching the effects of text message services on the behavior of their subscribers (40% of agro-input dealers in this survey) could provide insights into how to shift agro-input dealers towards new business models based on services instead of or additional to product sales.

Service provision could also resolve the threat agro-input dealers see in pest management practices involving lower or no amounts of pesticide. Pesticides are currently the best-selling and most profitable products of almost all agro-input dealers alike. This research reveals, that many agro-input dealers are ready to shift away from this, more towards guiding farmers on different pest management practices, including organic. Attitudes revealed that those agro-input dealers who recommended alternatives to synthetic products (31.3%) did so to protect human and environmental health. While agro-input dealers perceive these alternatives to be more time consuming and labor intense they are also deemed cheaper and less skill-demanding. This is also supported by the majority of agro-input dealers agreeing that Uganda needs a national strategy on organic farming as well as the need for more products suitable for organic farming.

Fourth, similar to the 2009 census, most agro-input shops have only been in business for a few years and the employees experience in selling pesticides was even shorter. Furthermore, 90% of the interviewed agro-input dealers saw an increase in pesticide sales over the last five years and expect a further increase for the next five. This could be a sign for a rapidly increasing market, emphasizing the need for proper guidance and training of agro-input dealers, as well as an aggravation of the current situation in the future. It also raises the question, whether the staff in these new shops possess adequate knowledge and experience to encourage farmers to reach out to them for advice.

The most sold products in the mystery shopping and according to agro-input dealers, are either WHO toxicity class Ib or II, indicating a moderate or high acute toxicity for adult humans. In our specific mystery shopping example, the list of recommended products against the fall armyworm included five of 13 products in toxicity class III and U. This indicates, that besides not advising customers on the risks, agro-input dealers also do not prioritize products of lower toxicity. In the mystery shopping, purchased products other than class II were somewhat more expensive. A possible explanation for higher prices for class III and U could be that these products are often more specific, thus less in-demand. Another explanation may be that agro-input dealers perceive broad-spectrum pesticides (which are most often also the cause of the higher toxicity) as more effective or are more experienced with them. When comparing the WHO toxicity classes found in previous research, there seems to be no change away from the products of class I and II (Oesterlund et al., 2014; Okonya and Kroschel, 2015; Staudacher et al., 2020), indicating an explicit choice by agro-input dealers to keep these products on the market. This means that a change is currently unlikely, indicating the need for actors higher up in the value-chain to place more emphasis on the risks of such pesticides.

Upstream pesticide value-chain-actors can use different mechanisms to steer farmers towards specific products. In Switzerland for example, a study has shown, that farmers advised by public extension were more likely to use preventive measures, while farmers advised by private extension were more likely to use synthetic insecticides (Wuepper et al., 2020). In our study, mystery shopping has revealed that not all agro-input dealers follow the recommendations of the Ministry of Agriculture, Animal Industry and Fisheries. It is however unclear what criteria the Ministry applied to select the recommended products and how they communicated this to the agro-input dealers. Similarly, most agro-input dealer shops were not registered with the Ministry or were never or only initially inspected. All shops show minor deviations from recommended practices, while a third of shops show very serious deviations (e.g. repackaged or unmarked containers, food on sale). Previously, governmental regulating bodies, as well as Uganda National Agro-Input Dealer Association have expressed the need for governmental inspection of their shops, to prevent and control such deviations in a timely manner (Winkler et al., 2019). Such inspections would follow environmental governance standards advocating for inclusion of those directly responsible for a problem in also governing it (Mueller et al., 2009).

3.5.1 Strengths and limitations

This study is the first among agro-input dealers in low- and middle-income countries using a mixed-methods approach to collect data on both stated and observed behavior of agro-input dealers to describe their pesticide sales and information behavior towards farmers as well as the knowledge, attitude, and pesticide handling practices in their shops. The combination of approaches allowed us to account for social desirability- and recall bias, leading to more accurate results. Moreover, our approach to take a random selection of agro-input dealers from a given sampling frame, allows us to extrapolate data to other agro-input dealers working under similar conditions under similar cultural, economic, and agricultural circumstances.

A possible bias may have been introduced through the data collection method and process, as the number of agro-input dealers visited over a brief period was high and the survey comparably long, which may have left agro-input dealers or interviewers tired and thus answering or collecting data wrongfully. However, neither inquiries with the interviewers nor the low number of incomplete interviews support this hypothesis. Furthermore, when comparing interview data to the observational findings, we need to be aware that the self-reported interview data represent an average perspective from the agro input-dealer, whereas the observation is a one-time situational assessment, therefore not accounting for intra-personal or temporal-variability.

For the mystery shopping it was critical that the investigated employees believed they were interacting with a real customer. Local farmers were recruited and systematically trained for their role as mystery shoppers. In order to have comparable mystery shopping data, the farmers always presented the same problem to the agro-input dealers. The self-reported data from mystery shoppers was systematically retrieved during the debriefing. While none of the data indicated in this direction, it is still possible, that recruiting different farmers for different observations may have introduced a large variance in the mystery shopping experience reporting.

While we did analyze if agro-input dealers gave advice on a certain topic, we did not systematically analyze the content of the advice given and whether it was correct. Moreover, the long-term outcome of whether there is a connection between the lack of advice and farmers' handling of pesticide, resulting in negative health and environmental impacts, was not assessed. Despite these limitations, we believe that due to the low number of studies on agro-input dealers' knowledge, attitude and practices our research remains highly insightful.

3.6 Conclusion

This research among 402 Ugandan agro-input dealers is the first to systematically collect data on both stated and observed behavior towards farmers. Combined with the collected information on agro-input dealers’ knowledge and agro-input dealers’ shops it provides useful and novel insights. Training, certification, registration, and licensing, a combination of efforts to ensure the health and safety of the agro-input dealers in their shops, their customers, their environment and communities are underway, but far from complete. With the rapid increase in pesticide use, it is imperative to make agro-input dealer training accessible and affordable and specifically targeted at providing an encompassing service to farmers. Shifting agro-input dealers’ business model away from product sales and more towards service provision could reduce conflicting incentives of selling many products as quickly as possible. Governmental and private actors should streamline the pesticide value chain to provide access to appropriate tools and information equitably, to avoid a worsening of the status quo in the future.

3.7 Declarations

3.7.1 Ethics approval and consent to participate

All study materials were approved by the Higher Degrees, Research and Ethics Committee (HDREC) of Makerere University in Uganda (HDREC 718). The Ethical Board of the Ethikkommission Nordwest- und Zentralschweiz in Switzerland (EKNZ-REQ-2019-00850) declared this research does not need approval.

Agro-input dealers, and where applicable their customers, consented to participate in the research for the KAP interview, the sale observation and the shop observation. Due to the nature of the method applied, agro-input dealers could not consent to the mystery shopping. When agro-input dealers were approached after the mystery shopping and did not consent to the KAP interview, or if they were not available for a KAP interview, we did not evaluate the data obtained during the mystery shopping. Farmers who pretended to be customers during the mystery shopping were thoroughly briefed and consented to their covert action before implementation.

3.7.2 Consent for publication

Not applicable.

3.7.3 Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

The datasets generated and/or analyzed during the current study are available in the Eawag research data institutional repository (ERIC): opendata.eawag.ch.

3.7.4 Competing interests

The authors declare that they have no competing interests.

3.7.5 Funding

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3.7.6 Authors' contributions

PS conceived the study and its design, coordinated data collection and analysis, analyzed and interpreted data and drafted the initial manuscript. CB prepared data collection tools, oversaw the data collection, analyzed and interpreted data and contributed to the initial manuscript. AF provided technical input on study design and statistics. RM provided contextual insights and facilitated the ethical approval. IG, MSW, CS and RE provided input on study design, analysis and manuscript preparation. The authors read and approved the final manuscript.

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3.9 Supplementary Materials

Supplementary Table ST 1: WHO toxicity classes and hazard color band. Adapted from WHO (2020) and FAO and WHO (2015). LD_{50}: Lethal dose whereby 50% of the animals die

	WHO Toxicity Class	LD_{50} for rat (mg/kg body weight)	
Class*	**label**	**Oral**	**Dermal**
Ia	Extremely hazardous	< 5	< 50
Ib	Highly hazardous	5 – 50	50 – 200
II	Moderately hazardous	50 – 2000	200 – 2000
III	Slightly hazardous	> 2000	> 2000
IV / U	Unlikely to present acute hazard	> 5000	> 5000

Supplementary Table ST 2: Label explanation

Part of Label	Explanation
Symbol 1	Keep locked away and out of reach of children
Symbol 2	Wear rubber boots
Symbol between 2 and 3	Wear rubber apron
Symbol 3	Wear overalls
Symbol 4	Wear gloves
Symbol between 4 and (4) left	Handling of product
Symbol between 4 and (4) right	Application of product
Symbol between (4) and 5	Wear mask with carbon filter
Symbol 5	Dangerous/harmful to animals
Symbol 6	Dangerous/harmful to fish – do not contaminate lakes, rivers, ponds or streams
Symbol 7	Wear eye protection
Symbol 8	Wash after use
Reading from left to right	Order of actions to be conducted
Warning color red	WHO toxicity class Ia/Ib

Supplementary Table ST 3: Highest Qualification to be an agro-input dealer

Highest Qualification to be an agro-input dealer	Unit	KAP[a]	OBS[a]	MYS[a]
Degree AVPM[b]	%	5.2	5.9	6.4
Diploma in AVPM[b]	%	10.7	11.4	10.6
Certificate in AVPM[b]	%	13.4	13.1	11.7
Deg. /Dip. /Cert. in Business, Admin., Accounting, etc.	%	19.7	21.6	20.2
Advanced secondary (A Level) without additional training	%	9.7	10.2	12.8
Ordinary secondary (O Level) without additional training	%	24.6	22.5	27.7
Below O Level without additional training	%	16.7	15.3	10.6

Note: No significant differences were found.
[a]The samples are abbreviated with KAP for the full sample of interviewees, MYS for those participating in Mystery Shopping and OBS for those participating in the sales observation
[b]AVPM: Agriculture, Veterinary, Pharmacy or Medicine

Supplementary Table ST 4: Content of general pesticide training

Topic	%
Safe use and handling of chemicals (or pesticides)	86.9
(New) product knowledge	32.9
Crop protection (Pest and disease identification & product matching)	20.8
General agriculture	18.5
Business management	23.0
Don't know / No response	2.6

Supplementary Table ST 5: Training providers for general pesticide training as well as specific training on pesticide alternatives and pesticide application. MAAIF: Ministry of Agriculture, Animal Industry and Fisheries.

	General Training (%)		Alternatives (%)		Application (%)	
Base for share (number)	n=402	n=313	n=402	n=176	n=402	n=363
Ever attended a training on pesticides ...	77.9	100.0	43.8	100.0	90.3	100.0
Informal training from shop owner	16.4	21.1	5.2	11.9	20.4	22.6
MAAIF or other national government agency	16.7	21.4	6.0	13.6	20.1	22.3
Pesticide manufacturer, importer or supplier	4.5	5.8	2.0	4.5	8.0	8.8
Local government, such as agricultural extension	7.0	8.9	4.5	10.2	7.7	8.5
Schools or university	14.7	18.8	16.7	38.1	27.4	30.3
UNACOH (Uganda National Association for Community and Occupational Heath)	1.0	1.3	0.2	0.6	1.0	1.1
UNADA (Uganda National Agro Input Dealer Association)	18.4	23.6	7.7	17.6	21.1	23.4
Crop Life (Umbrella Pesticide Importer Association)	2.5	3.2	0.7	1.7	0.7	0.8
NOGAMU (National Organic Agricultural Movement of Uganda)	0.5	0.6	0.0	0.0	0.5	0.6
Media (radio / TV / newspaper)	3.2	4.2	2.7	6.3	2.7	3.0
Self-trained through product labels or supplier leaflets	3.0	3.8	2.7	6.3	8.0	8.8
NGO	2.0	2.6	1.2	2.8	1.2	1.4
Agribusiness	5.5	7.0	1.0	2.3	2.5	2.8
USAID / Feed the Future	2.2	2.9	0.2	0.6	1.5	1.7
Fellow Farmers / Cultural Practice	0.0	0.0	3.2	7.4	1.0	1.1
Other	0.2	0.3	0.0	0.0	0.0	0.0
Don't remember	5.5	7.0	2.5	5.7	2.7	3.0
No response	0.0	0.0	0.0	0.0	0.2	0.3

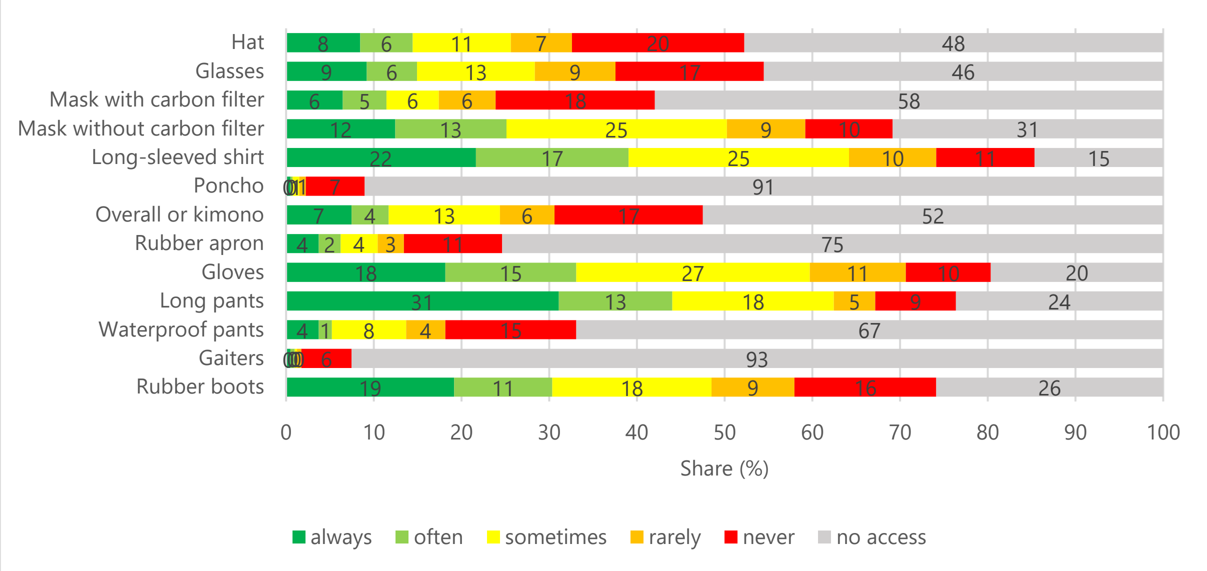
Supplementary Table ST 6: Inspection and License. MAAIF: Ministry of Agriculture, Animal Industry and Fisheries

Has your shop ever been inspected by an authority, and what for?	**%**
No inspection	16.2
initial license approval or license renewal	30.6
Quality control: Counterfeits, fake, unregistered, unauthorized, outdated products	36.8
inspection of the shop/setup	10.2
sensitization	3.0
other	0.5
Don't Know	1.0
No response	1.7
Is the shop licensed as pesticide distribution store with MAAIF	**%**
No	41.5
In progress	17.7
Yes without evidence	23.9
Yes with evidence: license not up-to-date	2.74
Yes with evidence: license up-to-date	5.72
Don't Know	7.96
No response	0.5

Supplementary Table ST 7: Categorization of deviations from recommended shop organization and setup.

Deviation	somewhat serious	serious	very serious
Documents	**85.7%**		
Display of CCSP	58.4% No		
Display of business license	71.7% No		
Product records	38% No		
Shop organization	**20.2%**	**25.5%**	**7.7%**
Clean and orderly shop	20.2% No		
Food on sale in shop			6.6% Yes
Animal feed on sale in shop			1.3% Yes
Neighboring shops selling food or animal feed		25.5% Yes	
Containers	**90.3%**		**30.6%**
(Restricted) pesticides under lock	90.3% No		
Unmarked/unlabeled containers			10.5% Yes
Repackaged containers			25% Yes
Leaking containers			6.1% Yes
Displays	**99.7%**		
Displaying general health and safety information	87.2% No		
Displaying warnings on pesticides	94.9% No		
Displaying prohibition of smoking, eating and drinking	93.4% No		
Displaying prohibition of underage pesticide sales	99% No		
Infrastructure	**99.7%**	**89.8%**	**2.8%**
Shop size > 9m2		41.1% No	
Shelves for pesticide storage	25.5% > 2.5m	3.6% No	
Palettes for pesticide storage	6.1% > 1.3m	41.6% No	
Pesticide exposure to sunlight, water or moisture		7.7% Yes	
Pesticides stored separately from other commodities	20.9% No		
Shop walls from washable materials	23.2% No		
Shop floor from washable materials	18.4% No		
Shop floor drainage	78.8% No		
Sufficient lighting	6.1% No		
Sufficient ventilation		31.1% No	
Sufficient water supply		43.4% No	
Electric wires in wall tubes	42.9% No		
Fire Fighting equipment	93.4% No		
Unobstructed fire exit		41.6% No	
Lockable doors			2.8% No
Safety Equipment*		**90.1%**	
No PPE visible		61.2% Yes	
Nothing to wash eyes or remove toxic materials visible		41% Yes	
Soap and water (tap/bucket) visible		75.5% No	
No materials for cleanup or disposal visible		41.8% Yes	
Broom visible		43.4% No	
Total	**100%**	**98%**	**36%**

**Safety Equipment is categorized based on subsets of questions given in Supplementary Table ST 25*
CCSP: Certification of competency on safe handling of pesticide



Supplementary Figure SF 1: PPE access and use for agro-input dealers when handling pesticides.

Supplementary Table ST 8 Hygiene practices

How long after you handled pesticides do you take a bath?	**%**
Immediately after	22.64
A few hours later	9.45
Many hours later	64.43
The next day or later	1.24
Not applicable	0.75
No response	1.49

How long after you handled pesticides do you change your clothes?	**%**
Immediately after	16.92
A few hours later	14.68
Many hours later	63.43
The next day or later	2.24
Not applicable	1.49
No response	1.24

Who washes the clothes you wore during pesticide handling?	**%**
Me	66.67
A family member	23.38
Maintenance aid or washerwoman of the shop	7.46
They aren't washed	0
No response / Don't know / etc.	2.49

A minority (8.5%) had refillable containers in stock, but nineteen out of twenty (94.8%) of agro-input dealers said none of the farmers ever returned containers to them.

Supplementary Table ST 9: Container handling practices and disposal

Why have you stopped repackaging or mixing pesticides in your shop?	%
health effects	33.33
personal health effects	20.51
it's illegal	28.21
packaging changed	7.69
Other	5.13
No response	5.13
How are you disposing of empty pesticide containers?	**%**
I don't dispose of any empty containers	45.0
Municipal disposal site / waste / trash	11.7
Burning	36.3
Burying	5.5
Recycling to manufacturer	2.2
Reused for pesticide refill	0.7
Reused for other purposes	2.0
Other	0.5
Don't know	0.5
No response	0.5
How are you disposing of waste pesticides?	**%**
There are no waste pesticides	33.1
Municipal disposal site / Waste / Trash	19.7
Burning	12.9
Burying	8.7
Recycling to manufacturer	24.1
They are sold to customers	1.0
Apply in own garden	4.5
Other	1.0
Don't know	0.7
No response	0.5

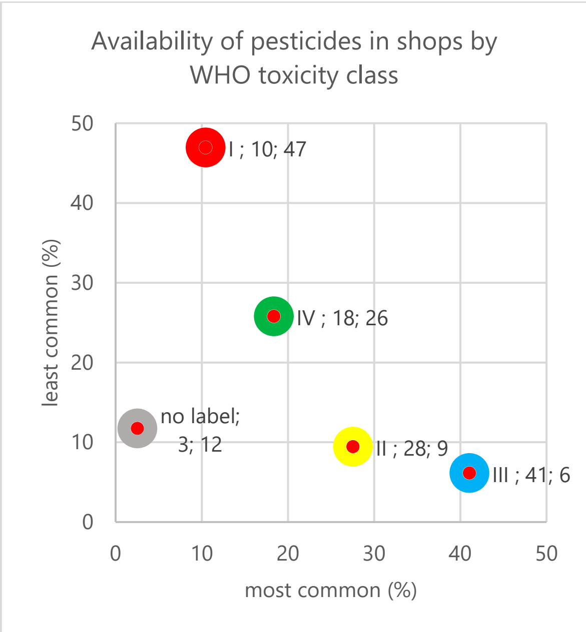
Note: Waste pesticides are pesticides that have expired or are excess pesticides and need to be disposed of.

Supplementary Table ST 10: Stocked products, their availability, bestsellers, profitability and future offerings

Products (n=402, %)	available	most sold	most profitable	offered in the future
Herbicides (synthetic)	97.5	47.3	50.7	4.2
Insecticides (synthetic)	95.3	33.3	22.9	4.0
Fungicides (synthetic)	87.3	8.0	6.7	1.5
Rodenticides	30.3	0.2	0.2	0.0
Nematicides	14.2	0.7	0.5	0.7
Acaricides	4.5	0.0	0.0	0.2
Organic pesticides	10.4	1.5	0.5	1.0
Insect pheromones	4.0	0.2	0.0	0.2
Veterinary products besides acaricides	2.5	0.2	0.2	0.2
Fertilizer	92.3	2.5	6.0	2.7
Seeds	85.6	2.0	5.7	4.7
Spray Pump	65.4	0.0	0.7	2.0
Farm Tools and Equipment	42.5	0.2	0.2	11.7
PPE	48.8	0.2	0.5	13.4
Processing and Packaging Equipment	3.2	0.0	0.0	0.5
Animal Feed	1.2	0.2	0.0	0.7
Food	0.7	0.0	0.0	0.0
Hygiene articles	0.2	0.0	0.0	0.5
Human medicine	0.2	0.0	0.0	0.0
Spray Pump spares	3.7	0.0	0.0	0.0
Other	2.2	0.7	0.2	0.7
Don't Know	0.5	0.2	2.0	33.3
No response	1.5	2.2	2.7	17.4

Supplementary Table ST 11: PPE available for sale

	Share of shops (%)	Share of shops offering PPE (%)
Base for share (number)	n=402	n=196
Cap	1.2	2.6
Glasses	11.7	24.0
Mask with carbon filter	17.4	35.7
Mask without carbon filter	31.6	64.8
Long sleeved shirt	0.5	1.0
Poncho	0.0	0.0
Overall or kimono	3.0	6.1
Rubber apron	0.2	0.5
Gloves	27.6	56.6
Long pants	0.2	0.5
Waterproof pants	0.5	1.0
Gaiters	0.2	0.5
Gumboots	35.6	73.0
Other	0.2	0.5



Supplementary Figure SF 2: Availability of pesticides in shops by WHO toxicity class

Approved pesticides available for controlling the fall armyworm in Uganda

Trade Name	Active Ingredient (AI)	Mode of action	WHO Classification	Rate of Application	
				15 L Knapsack	20 L Knapsack
AMDOCS	Emamectin, abamectin	IRAC 6	II	25 - 30 mls	30 – 50 mls
ROCKET	Profenofos Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
AGRO-CYPRO	Profenofos, Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
SUPA PROFENOFOS	Profenofos Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
HITCELL	Profenofos Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
PROFECRON	Profenofos Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
SOCKET PLUS	Profenofos Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
CYPERCAL	Profenofos Cypermethrin	IRAC 1B + IRAC 3A	II	15 - 40 mls	20 - 50 mls
STRIKER	Lambda Cyahalothrin thiomethoxam	IRAC 3A + IRAC 4A	III	15 - 20 mls	20 - 25 mls
ENGEO	Lambda Cyahalothrin thiomethoxam	IRAC 3A + IRAC 4A	III	15 - 20 mls	20 - 30 mls
CHLOBENZO	Emamectin benzoate	IRAC 6	IV	4 tea spoon (6 g/tea spoon)	5 tea spoons
PROVE (EC)	Emamectin benzoate	IRAC 6	IV	6 – 9 mls	8 - 12 mls
DYNAMO (WG)	Emamectin benzoate	IRAC 6	IV		

NARO

AGRA Growing Africa's Agriculture

World Health Organisation Classification and color band

IA, IB	Extremely hazardous, Highly hazardous
II	Moderately hazardous
III	Slightly hazardous
IV	Unlikely to cause acute effect in normal use

MAAIF Ministry of Agriculture Animal Industry and Fisheries

Supplementary Figure SF 3: Approved pesticides available for controlling the fall armyworm in Uganda

Supplementary Table ST 12: Suggested and purchased products during MYS

Pesticide Brand	Suggested		Purchased		WHO Toxicity Class	Approved for FAW
	Freq.	Share	Freq.	Share		
ROCKET	35	27.34%	24	25.53%	II	Yes
STRIKER	21	16.41%	16	17.02%	III	Yes
Dudu Acelamectin	11	8.59%	8	8.51%	Ib	No
PROFECRON	9	7.03%	8	8.51%	II	Yes
DUDU-FENOS	10	7.81%	7	7.45%	II	No
Alpha Killer	5	3.91%	4	4.26%	II	No
Dudu Cyper 5% EC	5	3.91%	3	3.19%	II	No
Eminent 5 WDG	3	2.34%	3	3.19%	IV	No
DD Force	3	2.34%	2	2.13%	Ib	No
AMDOCS	2	1.56%	2	2.13%	II	Yes
Cyper Lacer	2	1.56%	2	2.13%	II	No
Cypershi 5% EC	2	1.56%	2	2.13%	II	No
Ascoris 48EC	2	1.56%	1	1.06%	II	No
Kuu Cyper	2	1.56%	1	1.06%	II	No
Lava	2	1.56%	1	1.06%	Ib	No
Ant-Killer	1	0.78%	1	1.06%	II	No
Chorpy 480 EC	1	0.78%	1	1.06%	II	No
Cyper Force	1	0.78%	1	1.06%	II	No
Lara Force	1	0.78%	1	1.06%	II	No
M-D FOS 48% EC	1	0.78%	1	1.06%	II	No
Metalamanco 72 WP	1	0.78%	1	1.06%	II	No
Supacyper	1	0.78%	1	1.06%	II	No
Tafgor 40 EC	1	0.78%	1	1.06%	II	No
TROBAN 48EC	1	0.78%	1	1.06%	II	No
Umeme	1	0.78%	1	1.06%	II	No
SOCKET PLUS	1	0.78%	0	0.00%	II	Yes
Cyclone	1	0.78%	0	0.00%	II	No
Extreme	1	0.78%	0	0.00%		No
SUPA PROFENOFOS	1	0.78%	0	0.00%	II	Yes

FAW: Fall army worm

Supplementary Table ST 13: Original questions to Figure 5

Column	Original Question
First	“We are now coming to a section where we talk about *what you say* when selling pesticides. Please answer with yes or no. Do you generally offer *any* pest and disease advice to farmers? Do you give suggestions about *which chemicals to buy* when farmers buy pesticides? Do you give any advice regarding *handling and application* of the product? Do you *explain the label* of the product? Do you mention the possibility of *health effects*? Do you give advice on *personal protective equipment*? Do you mention the possibility of *environmental effects*? Do you give advice on *storage* of the pesticide? Do you give advice on *container disposal*?”
Second	“We are now coming to a section where we would like to know how many of your customers ask for a *specific kind* of advice. How many of the farmers ask you for advice regarding product choice, application procedure, information on the label, health effects, PPE, environmental effects, storage of pesticide, container disposal” Answer options: None (0%), Some (25%), Half of them (50%), Most of them (75%), All of them (100%), Don't know. Displayed here: Sum of answers for 50% or more.
Third	“Which topics were discussed during the sales procedure *overall*?” followed by “Who *initiated* the conversation regarding each of the following topics
Fourth	”Did the agro-input dealer give you advice WITHOUT you asking?” If yes: “On what topics did you receive advice?” Probing questions: “How should I protect myself?” and “Is there any other advice you have relate to the product?”

Supplementary Table ST 14: Label colors and areas

Reason for coloring	**%**
Correct answer: Hazard color band	64.2
Wrong Answer: any answer not indicating hazard, risk, toxicity, etc.	14.4
Don't know	20.9
No response	0.5
What color do you see?	%
Red	97.8
Any other color	0.5
Don't know	1.7
What is the specific meaning of this color?	%
Wrong answers	2.7
General expression such as 'hazardous' or 'dangerous'	46.0
Extremely hazardous	15.2
Highly hazardous	4.0
Very Toxic	6.2
Toxic	7.5
Fatal	1.0
Don't know	16.7
No response	0.8
What other colors could the label have?	%
Red	23.63
Yellow	47.76
Blue	40.3
Green	40.05
Other color	10.2
Don't know	29.35
No response	1.24
What do the other colors indicate?	%
Wrong answers	15.92
Yellow - Moderately hazardous, harmful, toxic	16.92
Blue - Slightly hazardous, caution, (may be) harmful	12.94
Green - Unlikely to present acute hazard in normal use, not classified	12.69
Don't know	62.44
No response	3.98
Please explain the difference between the two areas with similar symbols	%
Wrong answers	19.4
Correct Answer: left side: 'Necessary PPE for *handling* the product', right side 'Necessary PPE for *applying* the product'	19.4
Partially correct answer: 'Necessary PPE for the product'	14.4
Partially correct: left side: 'Necessary PPE for *handling* the product'	4.5
Partially correct: right side: 'Necessary PPE for *applying* the product'	2.0
Don't know	38.1
No response	2.2

Supplementary Figure SF 4: Hazard symbol identification

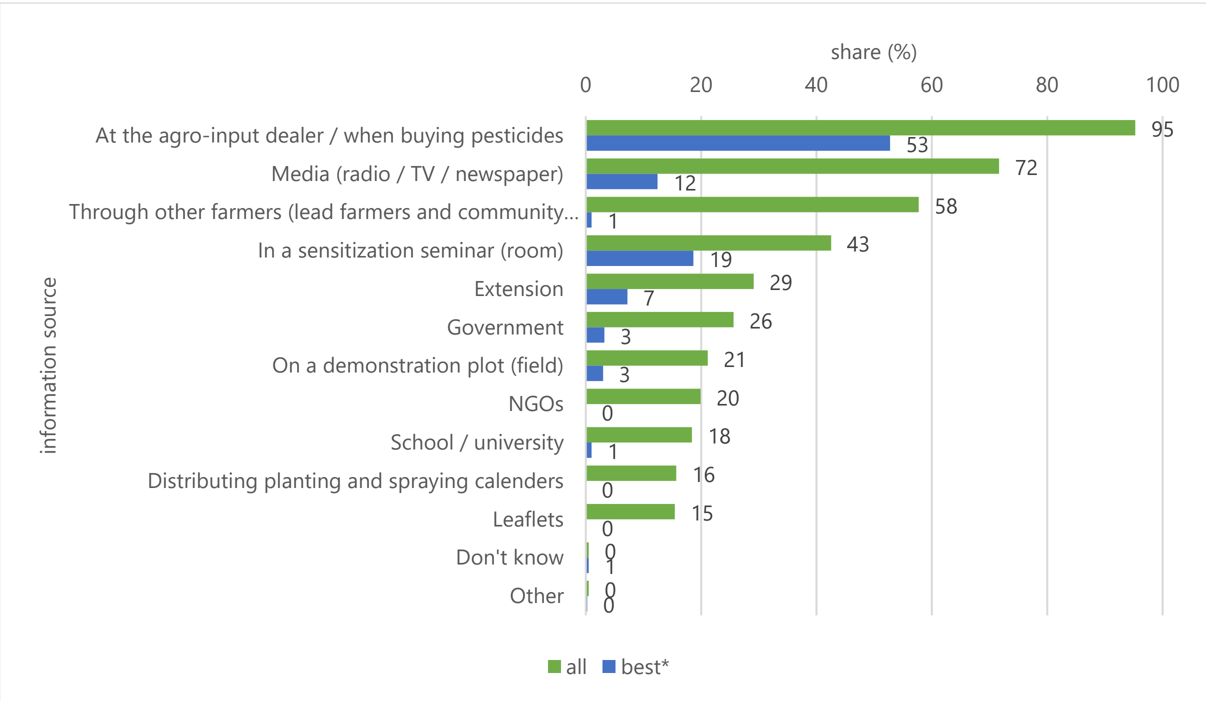
Supplementary Table ST 15: Brands mentioned as best, second or third selling product.

Brand name	n	%	Corresponding active ingredient	Group*	WHO Class
2,4-D	30	7.5	2,4- (Dimethyl) amine 720g/l	H	II
Ametryne	8	2.0	Ametryn 500g/l	H	II
Force Up	16	4.0	Glyphosate 480g/l	H	III
Weedmaster	159	39.6	Glyphosate 500g/l	H	III
Cyperlacer	52	12.9	Cypermethrin 50g/l	I	II
Dudu Acelamectin	202	50.2	Abamectin 1.8% + Acetamiprid 3%	I	Ib/II
Dudu Cyper	74	18.4	Cypermethrin 50g/l	I	II
Dudu Fenos	17	4.2	Profenofos 400g/l + Cypermethrin 40g/l	I	II/II
Lava	61	15.2	Dichlorvos 1000g/l	I	Ib
Profecron	14	3.5	Profenofos 400g/l + Cypermethrin 40g/l	I	II/II
Rocket	187	46.5	Profenofos 400g/l + Cypermethrin 40g/l	I	II/II
Striker	24	6.0	Lambdacyhalothrin 106g/l + Thiomethoxam 141g/l	I	II/II
Tafgor	56	13.9	Dimethoate 400g/l	I	II
Dithane	15	3.7	Mancozeb 800g/kg	F	U
Fangocil	13	3.2	Mancozeb 640g/kg + Metalaxyl 80g/kg	F	U/II
Indofil	66	16.4	Mancozeb 800g/kg	F	U
Other	177	44.0	-	-	-
Don't remember	0	0.0	-	-	-
Don't Know	9	2.2	-	-	-
No response	19	4.7	-	-	-

**Group corresponds to the chemical groups H for herbicide, I for insecticide and F for fungicide.*

Supplementary Table ST 16: Corresponding active ingredients to best, second or third selling product

Active ingredient	WHO Class	n	%
2,4-Dichlorophenoxyacetic acid	II	10	0.8
Abamectin	Ib	15	1.2
Abamectin + Acetamiprid	Ib/II	49	4.1
Acetamiprid	II	3	0.2
Cypermethrin	II	108	9.0
Cypermethrin + Profenofos	II/II	95	7.9
Dichlorvos	Ib	37	3.1
Dimethoate	II	46	3.8
Glyphosate	III	121	10.0
Lambda cyhalothrin	II	5	0.4
Lambda cyhalothrin + Thiamethoxam	II/II	5	0.4
Mancozeb	U	47	3.9
Profenofos	II	20	1.7
Thiamethoxam	II	1	0.1
Other	-	24	2.0
Don't remember	-	38	3.2
Don't Know	-	555	46.1
No response	-	26	2.2
Total		1205	100



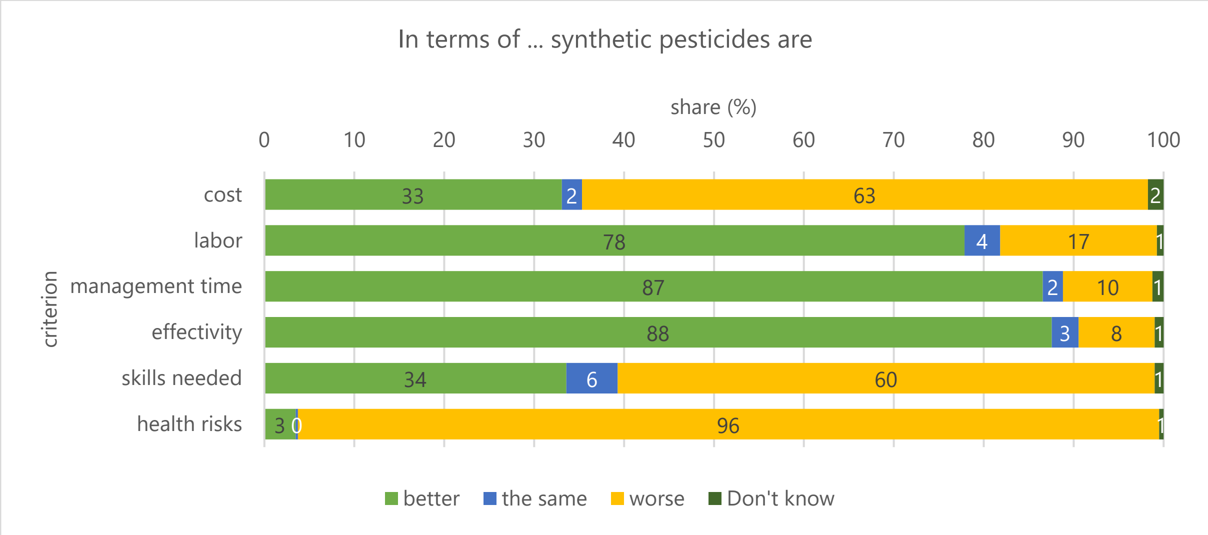
Supplementary Figure SF 5: Information sources of farmers according to agro-input dealers; best indicating: "the best way to inform farmers about safe pesticide use". All options were read out.*

Supplementary Table ST 17: Agro-input dealers' attitudes regarding license, counterfeits and management of pest resistance

Do you consider the license relevant? (%Yes)	**88.1**
Why?	%
Enables business according to regulation	50.8
Enables tax payment	20.7
Quality assurance to the customer	19.9
Enables occupational safety	19.9
Enables Business Promotion	5.0
Other	1.7
Don't Know	5.7
No response	4.2
119) What are the biggest problems with counterfeits?	%
They are less or not effective	73.9%
They negatively impact the farmer's business	55.5%
They negatively impact the agro-dealer's business	45.3%
They negatively impact human health	14.4%
They negatively impact on the environment	10.4%
Other	1.6%
Don't know	0.5%
No response	0.3%
121) What do you do in your business to prevent and manage pest resistance?	%
Better advising the farmer	33.8%
Recommending stronger pesticides to the farmers	23.6%
Better consulting with the supplier	19.9%
Buying more specific (targeted) pesticides from suppliers	14.9%
Buying different pesticides from the suppliers (pesticide rotation)	13.4%
Recommending different pesticides to the farmers (pesticide rotation)	11.9%
Recommending more specific (targeted) pesticides to the farmers	11.4%
Buying stronger pesticides from the suppliers	9.0%
Other	1.7%
Don't know	0.7%

Supplementary Table ST 18: Alternatives to synthetic pesticides and their limitations

	%
Agro-input dealers aware of alternatives to synthetic pesticide pest management	**78.4**
Alternative options	**%**
Cultural/ ecological (sanitation, tillage, crop spacing, crop rotation, push-pull)	58.9
Chemical (biopesticides / natural pesticides / organic pesticides)	36.3
Biological (release/promotion of natural enemies)	27.1
Mechanical (hand picking of insects or weeds, protective covers like insect nets)	25.2
Host plant resistance (crop variety less vulnerable to pest attack)	6.7
Behavioral (pheromone/hormone traps)	5.7
Other	0.6
Limitations to alternative options	**%**
Less effective against pests	53.8
Time consuming / Labor intensive	47.8
More expensive	14.3
Knowledge and skill demanding	12.1
Materials not readily available	11.1
Difficult to mix	6.4
Can't be easily used on large scale	5.7
Smell from materials	1.9
Mainly preventative than curative	1.3
Some irritate eyes and skin	1.3
Other	4.5
Don't know	4.5
No response	1.6



Supplementary Figure SF 6: Comparison of synthetic pesticides with alternatives to them

Supplementary Table ST 19: Recommendations and corresponding reasons

	n	Yes (%)	No (%)
Recommending pesticide use over alternative strategies	402	68.7	31.3
Reasons for recommendation			
Synthetic pesticides are more effective and work faster	200	90.5	9.5
For economic reasons (time, money)	112	92.9	7.1
To protect the human health	100	20.0	80.0
To protect the environment (e.g., sustainability)	73	21.9	78.1
Because it is more practical and easy	51	96.1	3.9
Source of income	10	100.0	0.0
Alternatives not known/available	9	88.9	11.1
Higher Yield	7	100.0	0.0
For cultural or traditional reasons	4	50.0	50.0
Other	4	75.0	25.0
Don't know	2	50.0	50.0

Supplementary Table ST 20: Symptoms of pesticide poisoning recalled (known) or experienced.

	Experienced (%)	Known (%)	Ratio
Skin irritation	22.4	57.2	0.39
Headache	29.1	44.0	0.66
Itchy eyes	11.4	37.3	0.31
Vomiting	5.7	33.3	0.17
Respiratory difficulties	23.6	29.1	0.81
Abdominal pain	7.5	25.1	0.30
Dizziness	11.2	19.9	0.56
Nausea	11.7	19.2	0.61
Other	4.7	17.2	0.28
Muscular weakness	6.0	9.2	0.65
Chest pain	5.0	7.5	0.67
Extreme tiredness	5.5	6.7	0.81
Blurred vision	2.2	4.2	0.53
Dry mouth	2.0	3.0	0.67
Back pain	2.0	3.0	0.67
Salivation	0.7	2.7	0.27
Loss of appetite	2.2	2.7	0.82
Excessive sweating	2.0	2.5	0.80
Trembling hands	1.2	1.7	0.71
Lack of coordination	0.7	1.2	0.60
Speech difficulty	0.2	1.0	0.25

Supplementary Table ST 21: Through which body parts do you think pesticides can enter us?

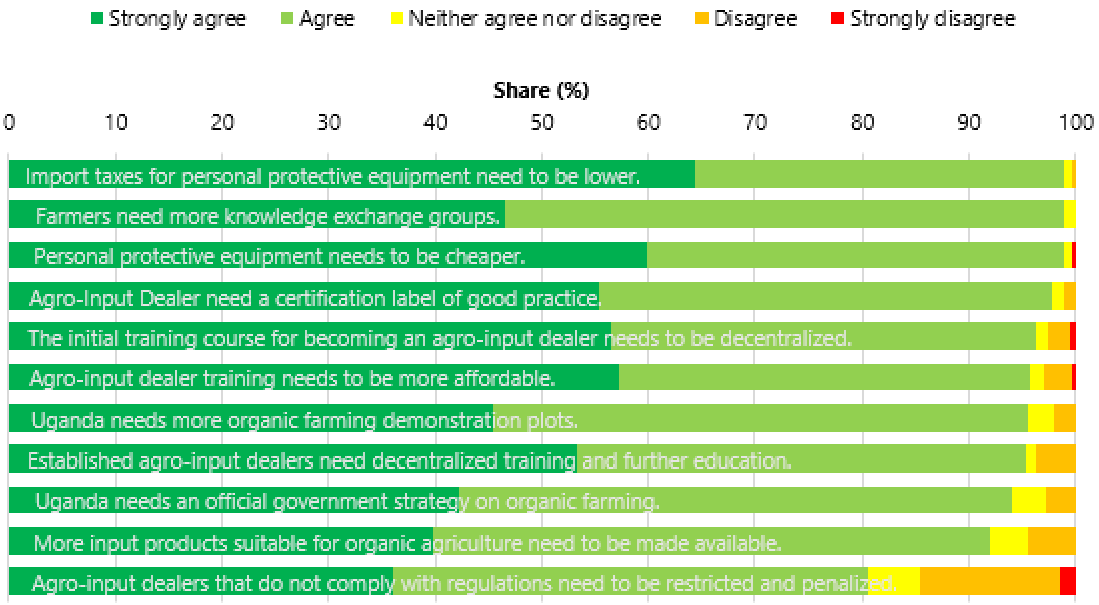
body party entry site	%
Nose (inhalation)	92.5
Skin (dermal)	88.3
Mouth (ingestion)	78.4
Eyes (mucous membranes)	60.4
Ears	28.9
Other	1.5
Don't know	0.5
None	0.2

Supplementary Table ST 22: Pesticide trends over the past and future five years within community

	Increasing	Constant	Decreasing	Don't know
past	91.0	2.5	3.0	3.5
future	86.8	1.5	5.2	6.5

Supplementary Table ST 23: Reasons for pesticide trends

Can you give a reason for this trend?	
Number of farmers increased/decreased	31.1
Pesticides are required to obtain good/any harvest at all	22.1
Abundance of pest organisms increased/decreased	14.9
Pesticides reduce labor	8.0
Pesticides are effective	3.7
Other	3.2
Organic farming increases/decreases	2.5
Pesticides are advertised/farmers are a	2.0
Pesticides increase yield	1.7
Agriculture modernizes	1.7
Farmers are sensitized about negative e	1.7
Don't Know	1.7
Pesticides are cheaper	1.5
Weather / Climate Change	1.2
soils aren't fertile	1.0
Farms are bigger	0.8
Counterfeits increase	0.5
No response	0.5



Supplementary Figure SF 7: Attitudes regarding future possible change in the pesticide sector in Uganda.

Supplementary Table ST 24: What companies are you subscribed to receive regular messages with business-related information on your mobile phone?

Bukoola Chemicals Industries Ltd	**35.8%**
Wefarm	22.8%
various verified Agrodealers	21.6%
East African Seed (U) Ltd	14.2%
Daps Distribution Co.Ltd	11.1%
various unverified Agrodealers	11.1%
Jubilee Insurance Company of Uganda Ltd	9.9%
NGOs and Government	6.8%
No response / Don't remember / Don't know / Unrelated answers	7.4%

Supplementary Table ST 25: Detailed safety equipment layout

Is there any safety equipment available for staff?	%
nothing available (not visible)	61.2
hat	3.1
goggles or face shields for eye and face protection	4.6
specific or all-purpose gas masks	9.4
respirators	9.4
long-sleeved, buttoned coat or suit completely covering the worker	11.2
gloves (water-proof and impervious)	18.1
boots	15.6

Which of the following facilities are available in the shop to wash eyes or remove toxic materials from the skin?	%
nothing available (not visible)	41.1
facilities for washing eyes such as fixed or portable eye-wash fountains.	0.5
adequate emergency water supply for washing off corrosive or toxic materials getting on the skin	0.5
Water Bucket	42.6
Soap / detergent	29.9
Tap Water outside shop	15.6
Tap Water inside shop	8.7

Which of the following materials are available to cleanup and decontaminate spills?	%
nothing available (not visible)	41.8
broom	56.6
inert absorbent material such as sand, soil or sawdust	1.3
disposable container	2.3
hydrated lime or soda ash	0.3
clay or similar material for absorbing scrubbing liquid	1.8

3.9.1 References

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Chapter 4

4 Smallholder Farmers’ Pesticide Knowledge, Attitude and Practices

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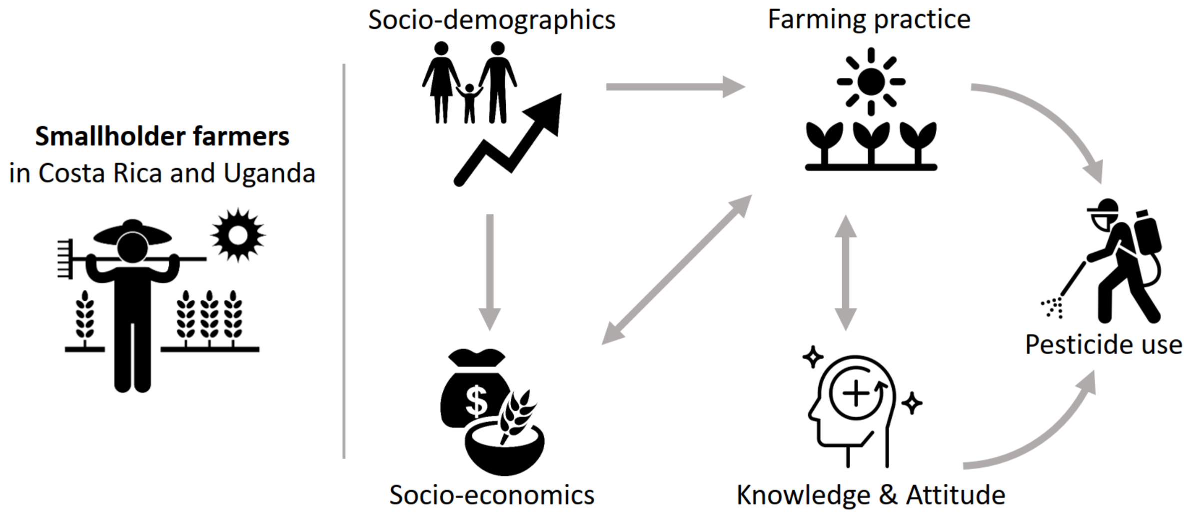
4.1 Abstract

Pesticides are used globally in agriculture and pose a threat to the health of farmers, communities, and the environment. Smallholder farmers in low- and middle-income countries have generally a low socio-economic status and educational level. Consequently, they are particularly vulnerable to negative impacts of pesticides on their health, yields, or land. In a Knowledge, Attitude, and Practices study, we compared the pest management practices between a market-oriented farming system in Zarcero County, Costa Rica, and a subsistence-based farming system in Wakiso District, Uganda. We conducted a cross-sectional survey among smallholder farmers from Costa Rica (*n*=300) in 2016 and from Uganda (*n*=302) in 2017. We enrolled conventional and organic farmers, but also farmers with mixed practices and non-applicators of any pest management strategy. We found that the majority of pesticides used in both case studies are classified as highly hazardous by the World Health Organization. While more than 90% of smallholder farmers from both countries were aware of the negative health effects of pesticide exposure, less than 11% in Costa Rica and less than 2% in Uganda reported using personal protective equipment every time they handled or applied pesticides. Hygiene and other safe use practices were not adopted by all farmers (<61%), especially among farmers applying more hazardous pesticides. Conventional farmers from Costa Rica (14%) and Uganda (19%) reported disposing pesticide residuals into rivers. Using a logistic regression we found that organic farmers were more likely to having been trained on safe pesticide use practices. Using a robust regression, we observed that smallholder household income was primarily driven by education and not directly by the use of synthetic pesticides. Our results suggest that negative effects of pesticides can be managed over the whole life cycle, from purchase, via storage and application to residual and waste management by fostering professionalization of farmers. We advise future safe use and handling interventions to consider the pesticide use-related socioeconomic and demographic findings highlighted in this paper.

Keywords: Agriculture, highly-hazardous, pesticides, KAP, knowledge, attitude, practices, smallholder, farmer

4.2 Graphical Abstract



4.3 Introduction

Pesticides are important for crop production worldwide and their use increases together with economic growth (Schreinemachers and Tipraqsa, 2012). Among smallholder farms (farms with less than 2 ha) (Lowder et al., 2016), pesticides are the dominant form of pest management (Williamson et al., 2008). These chemicals can have a negative impact on the environment (Köhler and Triebskorn, 2013; Lewis et al., 2016) and human health (Kim et al., 2017; Tago et al., 2014), particularly in low- and middle-income countries (LMICs) (Mew et al., 2017; Praneetvataku et al., 2013) and when used unintentionally (Rother, 2018). LMICs often lack pesticide use regulations or implementation thereof, and have limited resources available to deal with the environmental and health consequences of pesticide use, such as access to a functioning health system or monitoring of water quality in open water bodies (Weiss et al., 2016).

The negative impact of pesticide use is affected, among other factors, by user knowledge and behaviors (Bondori et al., 2018). Knowledge, Attitude, and Practice (KAP) surveys are used to describe situations within given contexts, in cross-sectional studies, and are commonly applied to compare changes over time (Kaliyaperumal, 2004). KAP studies from LMICs have highlighted the extensive use of highly toxic pesticides coupled with low use of personal protective equipment (PPE) (Polidoro et al., 2008), little awareness of exposure routes (Barraza et al., 2011), occurrence of acute pesticide poisonings confirmed with biomarkers of effect (e.g., acetylcholinesterase) (Cuenca et al., 2019), inadequate disposal of pesticide residues and containers (Clausen et al., 2017), and perception of pesticides as a simple solution (Ochago, 2018). Furthermore, a KAP study that compared pesticide use and related health effects in more than 8500 smallholder farmers across 26 countries found that the majority of farmers were aware of the need for PPE, but often did not use them (e.g., due to lack of availability) (Matthews, 2008; Tomenson and Matthews, 2009). The same authors determined that there was a need for better disposal of used pesticide containers in most countries (Matthews, 2008). In order to design effective mitigation strategies to the identified environmental and health effects associated with pesticide use, a thorough understanding of associated KAP in different cultural and socio-economic contexts is warranted (Launiala, 2009).

To that end, we designed an exploratory KAP study investigating pesticide use of smallholder farmers in contrasting cultural and economic situations. The study aimed at identifying commonalities and differences in pesticide use practices between market-oriented farms in Costa Rica and subsistence farming in Uganda. Costa Rica is an upper middle-income country with one of the highest rates of pesticide active ingredients applied (51.1 kg per hectare (kg/ha), whereas Uganda is a low-income country with one of the lowest application rates (0.01 kg/ha) (FAOSTAT, 2020). Both study sites are located in tropical countries where farmers apply/handle similar pesticides with similar tools, while differing considerably in school life expectancy and gross domestic product per capita (CIA, 2020). To describe how access to resources and education influence safe pesticide use, we investigate the following five guiding research questions (Figure 1): *First*, how are socio-demographic characteristics associated with farming practices? *Second*, how are socio-demographic factors and farming practices associated with socio-economic factors? *Third*, how are farming practices associated with knowledge and attitude of safe pesticide use? *Fourth*, how are farming practices as well as knowledge and attitude associated with pesticide use practices? And *fifth*, how hazardous and which are the pesticides used?

The ensemble of research questions forms an important piece of evidence of the pesticide use in tropical settings (PESTROP) project, which aimed to deepen the understanding of the environmental, health, and regulatory dimensions of agricultural pesticide use in tropical smallholder farming settings (Winkler et al., 2019). The overarching project design and specific study components of the PESTROP project have been described elsewhere (Baker et al., 2017; Fuhrimann et al., 2020; Fuhrimann et al., 2019; Palzes et al., 2019).

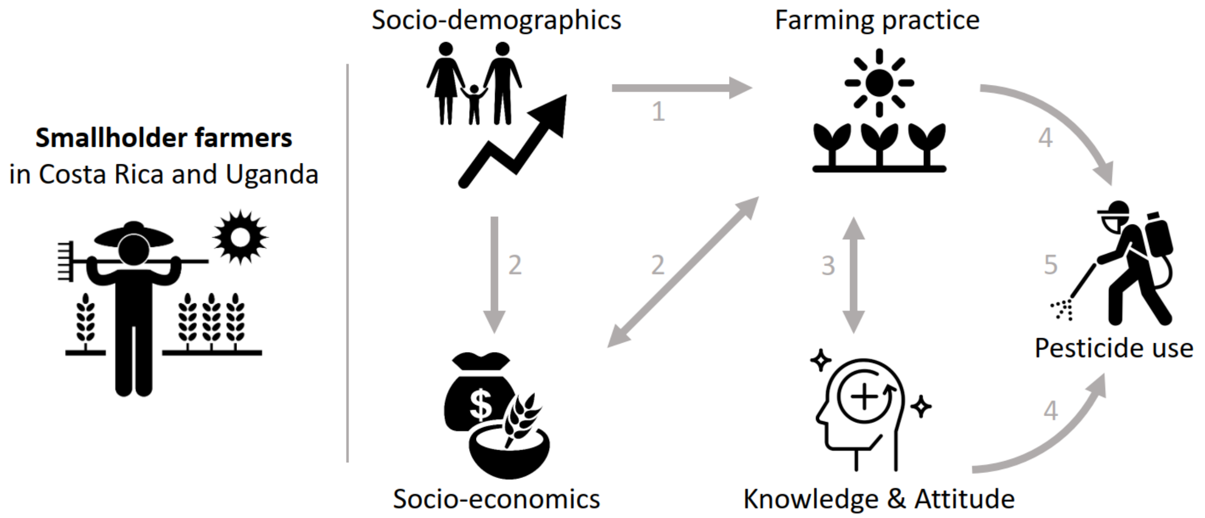


Figure 1: The framework links aspects of smallholder farmers' livelihood around pesticide use. The numbers indicate the research questions. The framework is derived from our own thought process.

4.4 Methods

4.4.1 Study areas and populations

This study included two different settings and study populations (Winkler et al., 2019) (i) the Tapezco river catchment area in Zarcero County, Costa Rica, which comprises commercial organic, sustainable (i.e., mixture of organic and conventional farming practices), and conventional (i.e., extensive use of synthetic pesticides) small-scale horticultural farms (Fuhrimann et al., 2019), (ii) the Mayanja river catchment area in Wakiso District, Uganda, which comprises subsistence-based horticultural farms whose practices range from no pest control to conventional farming (Diemer et al., 2020).

While the general study area characteristics were based on the intended comparison of contrasting cultural and socio-economic conditions for smallholder farming, the specific study locations were chosen such as to build on established contacts by the local partners to the respective farming communities. This ensured trust into the project team.

4.4.2 Study design and sample

An observational cross-sectional study design was applied. Two equal groups of organic (expected to not use synthetic pesticides) and conventional farmers (expected to use synthetic pesticides) were recruited, in order to ensure differences in KAP of pesticide use in both study settings. Organic farmers were recruited through snowball sampling from locally available farmer lists among NGOs. Conventional farmers were sampled randomly from clustered convenience samples. In Costa Rica, we used satellite imagery to locate arable plots and then visited the owners to determine their interest in participating in our study. In Uganda, we conducted an information event for village leaders, who then provided us with a list of interested farmers. In both countries, we enrolled a subsample of those interested in participating in the study. Participants were eligible if they were aged ≥ 18 years and worked within the study areas. We aimed for a total sample of 300 farmers per country to detect a significant effect difference between two groups of 25 clusters (i.e., 25 conventional and 25 organic farms with an average of 6 farmers each) (Fuhrimann et al., 2019). During recruitment, we extended the possible clusters beyond organic and conventional farms to also include mixed farms (applying synthetic pesticides, but with evidence for the use of alternative pest management practices) and participants who were involved on farms, but not directly in pest management (henceforth called non-applicators, e.g., land owners) (Table 1).

Table 1: Term definitions as defined in this manuscript. Farmer-groups differ in self-conception by setting.

Variable	Category	Definition	
		Use of synthetic pesticides	*Use of alternative pest management practices*
Farming practice	Conventional	Yes	No
	Organic	No	Yes
	Mixed	Yes	Yes
	Non-applicator	No	No
Farmer-groups by setting	Farm owner (Costa Rica)	Person who owns the farm, or the land or parts of it and, thus, is involved in sales and/or profits of the business.	
	Farm worker (Costa Rica)	Employee on the farm.	
	Crop farmer (Uganda)	Focusing on crops, as opposed to livestock, or exercising any other main non-farming profession.	

4.4.3 Data collection

Data collection was conducted between June and September 2016 in Costa Rica, and between September and November 2017 in Uganda. Over two weeks, field staff received training on tools, ethics, and research background. Additionally, we conducted a week-long pilot study in both settings. We administered a structured questionnaire to farmers using Open Data Kit (http://opendatakit.org). Details on data collected via questionnaire have been described elsewhere (Fuhrimann et al., 2019) and can be found in the supplementary materials. Briefly, we collected information on socio-demographic characteristics including age, sex, education, marital status, and country of origin. Questions on socio-economic and occupational characteristics included years working in agriculture and handling/spraying pesticides, monthly household income, current job position or main profession, number of work hours per week, pesticide active ingredients used at the farm, average number of hours handling/spraying pesticides per week, farm size, crops cultivated at the farm, and distance between farm and water source. The knowledge, attitude and practices section covered pesticide safety-relevant daily behaviors such as bathing/showering, changing of clothes, clothes washing, disposal of residual water and empty pesticide containers, PPE use, and health risk perception. In Costa Rica, we conducted interviews in Spanish at the farmers' workplace or home. In Uganda, we invited farmers to a rented office and interviewed them in Luganda or English. In order to account for variation in pesticide application, the results presented for 'last week's use' correspond to the average of application rates provided in two interviews that were conducted three to four-week apart.

4.4.4 Statistical analyses and conventions

The four categories of farming practices were used to compare pesticide KAP within and between the two settings. We used analysis of variance (ANOVA) tests to determine whether socio-demographic characteristics between farmer groups differed significantly from each other. Two-group differences were calculated using chi-square statistics for categorical variables and *t*-tests for continuous variables.

We used *robust* regression models (R robustbase package) to examine the relationship between logarithmic household income (outcome) and socio-demographic and farm characteristics (predictors). We fitted a logistic regression model to identify the predictors for having received training on pesticide use. The level of significance was assumed at 0.05. All analyses were carried out in STATA v 15.1 (StataCorp, 2017) and R version 3.5.0 (R Core Team, 2019). When referring to pesticide toxicity, we use both the 'World Health Organization (WHO) Recommended Classification of Pesticides by Hazard' (WHO, 2010) and the 'Pesticide Action Network (PAN) International List of Highly Hazardous Pesticides' (PAN International, 2019).

4.4.5 Ethical considerations

All study materials were approved by the human subjects committee of the Universidad Nacional in Costa Rica (UNA-CECUNA-ACUE-04-2016), the Higher Degrees, Research and Ethics Committee (HDREC) of Makerere University in Uganda (HDREC 522), and Ethical Board of the Ethikkommission Nordwest- und Zentralschweiz in Switzerland (EKNZ-UBE 2016-00771). At enrollment, each participant gave written informed consent.

4.5 Results

Each subsection of the results chapter is addressing one of the guiding research questions. After the presentation of country-specific findings the most prominent differences between the study sites are highlighted in a comparative paragraph at the end of each subsection.

4.5.1 Socio-demographic characteristics classified by farming practices

Farmers in Costa Rica (*n*=300) were 36.9 years old (SD 14.1) with 6.1 years of school (SD 2.8, Figure 2). They were mostly married (61.0%) and Costa Rican nationals (59%, Figure 3). We found several associations between socio-demographic characteristics and farming practices among Costa Rican farmers. There were fewer farm owners (vs. farm workers; 17.4%), more women (47.8%), and shorter work shifts (mean 42.7, SD 18.9 hours per week (h/wk)) among non-applicators than among all other farmer groups (i.e., organic, mixed, and conventional; 41.3%, 2.0%, and mean 55.8, SD 16.0 h/wk in all three groups; Figure 2 and Figure 3). We also found that Nicaraguan-born farmers had a lower educational level (mean 4.8, SD 3.0 years), worked more hours (mean 59.9, SD 15.0 h/wk) and were less likely to be a farm owner (4.9%) than Costa Rica-born farmers (mean 7.0, SD 2.4 years, mean 49.5, SD 17.2 h/wk, and 60.5% respectively).

Ugandan farmers (*n*=302) were 48.0 years old (SD 13.6) with 8.0 years of school (SD 3.8, Figure 2). They were mostly married (65.6%) and Ugandan nationals (99%, Figure 3). We observed: (i) differences in education between users (organic and mixed farmers, mean 9.14, SD 3.7 years) and non-users (non-applicators, conventional farmers, mean 7.2, SD 3.6 years) of alternative pest management strategies ($p < 0.001$; Figure 2), (ii) a larger proportion of singles and widows among organic farmers (32.5% and 25.0%) and non-applicators (25.0% and 35.7%), in contrast with a larger proportion of married among mixed (69.0%) and conventional farmers (74.4%; Figure 3), (iii) a relatively low number (60.0%) of organic farmers reporting to farm crops as their main occupation (Figure 3), and (iv) a correspondingly lower amount of working-hours per week on the farm for organics (mean 20.9, SD 10.6 h/wk) vs. conventional (mean 35.3, SD 16.9 h/wk; Figure 2). Furthermore, conventional male farmers worked on average 36.9 h/wk (SD 17.5), while their organic male counterparts only worked 16.7 h/wk (SD 10.0; $p<0.001$). A similar pattern was found for female farmers (conventional: 30.7 h/wk (SD 14.2), organic: 22.2 h/wk (SD 10.6, $p<0.004$).

Costa Rican farmers were younger and had completed fewer years of education than their Ugandan peers. In both countries most farmers were married, and there were fewer women than men working in pest management. Among Costa Rican participants, we had 41% Nicaragua-born (migratory) farmers; whereas only three participants in Uganda were of other nationalities.

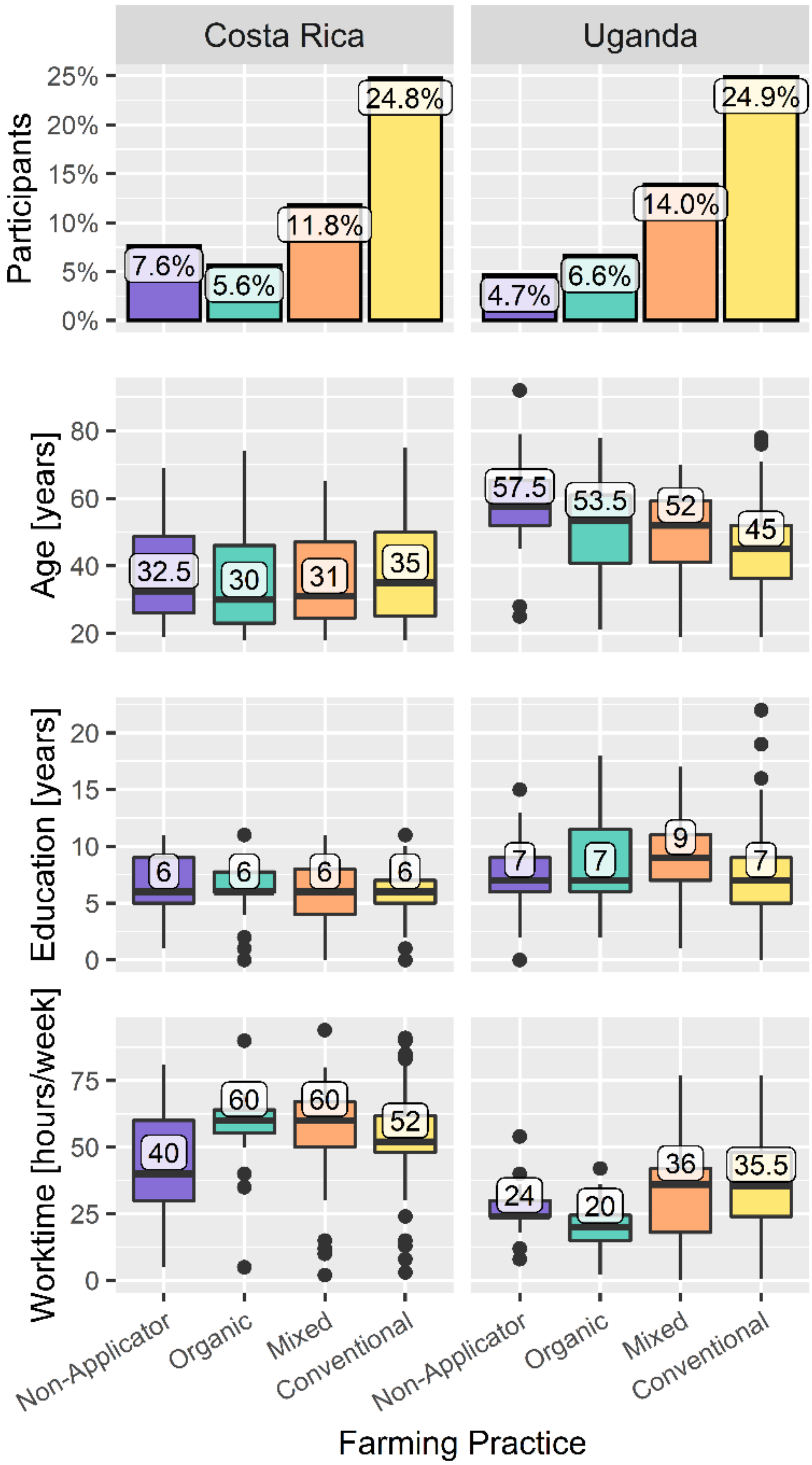


Figure 2: Socio-demographic characteristics per country and farmer classification. Working hours per week as average over the week before first and second visit.

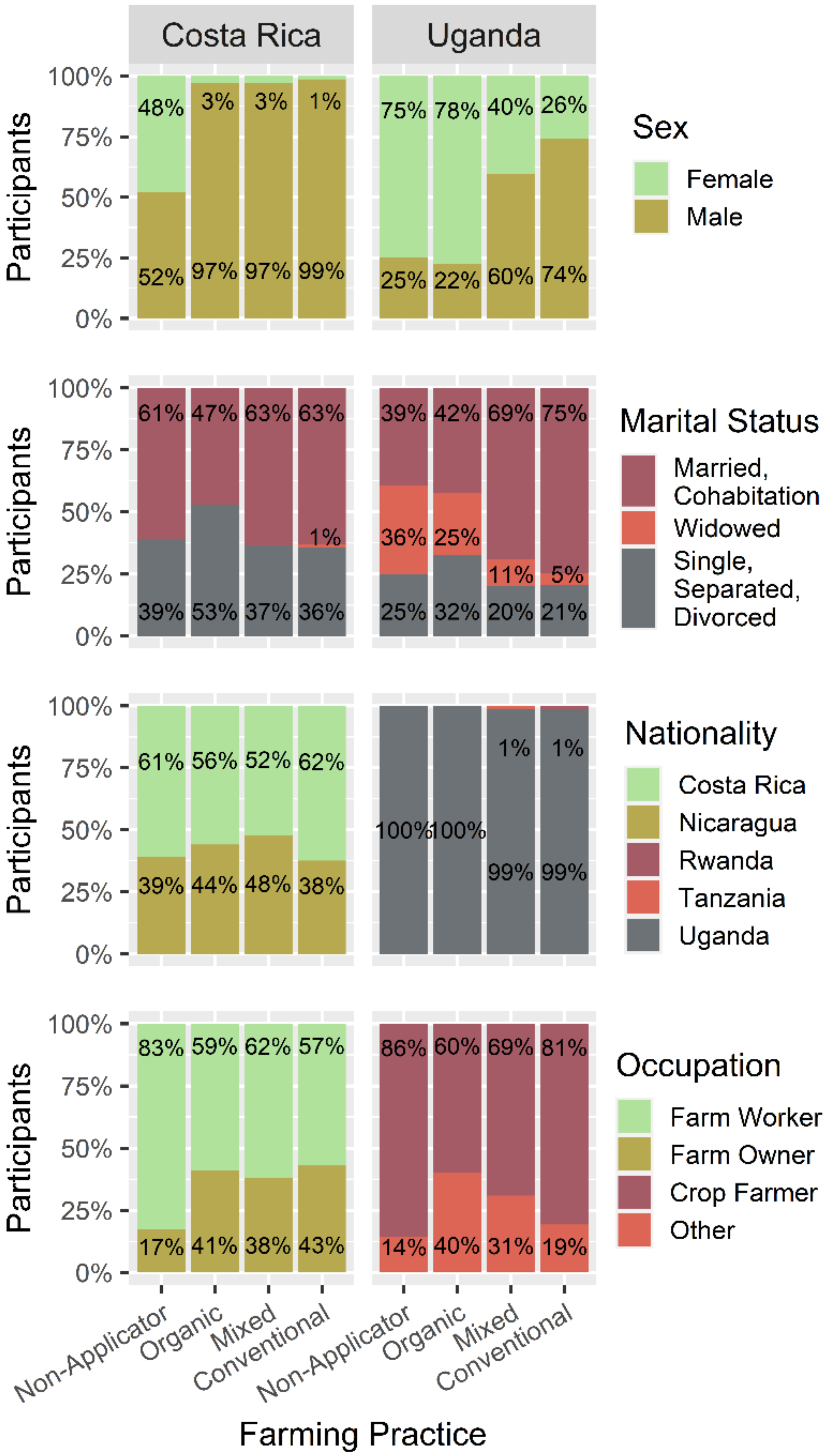


Figure 3: Socio-demographic characteristics per country and farmer classification. Nationality indicates nationality at birth, and occupation. Other indicates any profession besides crop farmer (see also Table 1).

4.5.2 Farm description and household income

In Costa Rica, the crops grown were considerably different between conventional and mixed farmers (i.e., potatoes, carrots, and coriander) and organic farmers (i.e., tomatoes, bell peppers, and lettuce, Supplementary Figure SF1). Being more educated and working longer shifts were associated with a higher household income, whereas being single, separated, or divorced was associated with a lower household income (Figure 4). Conventional and mixed farms were closer to rivers compared to their organic and non-applying counterparts (Figure 5).

In Uganda, the four most abundant crops (i.e., beans, maize, (sweet) potato, bananas) were the same across all farming practices, albeit in different order. Bananas were most popular among mixed farmers (53.6%) compared to all other farmer groups (i.e., organic, mixed, and conventional; 27.5%; Supplementary Figure SF1). Non-applicators had more years working in agriculture and handling/applying pesticides than farmers from other groups (Figure 5). Being more educated, not being a crop farmer as a main occupation, and using mixed farming practices were associated with a higher household income (Figure 4). Being male was also associated with a higher household income. Men received 112.7% more income compared to women ($p<0.001$).

Studying the determinants of household income, we found associations with farming practice, farm size, education, occupation, working hours and civil status in either or both countries, with effect sizes being larger in Uganda than those in Costa Rica (Figure 4). In both study settings, mixed farms were the largest in size, while organic farms were the smallest and the furthest from water sources (Figure 5).

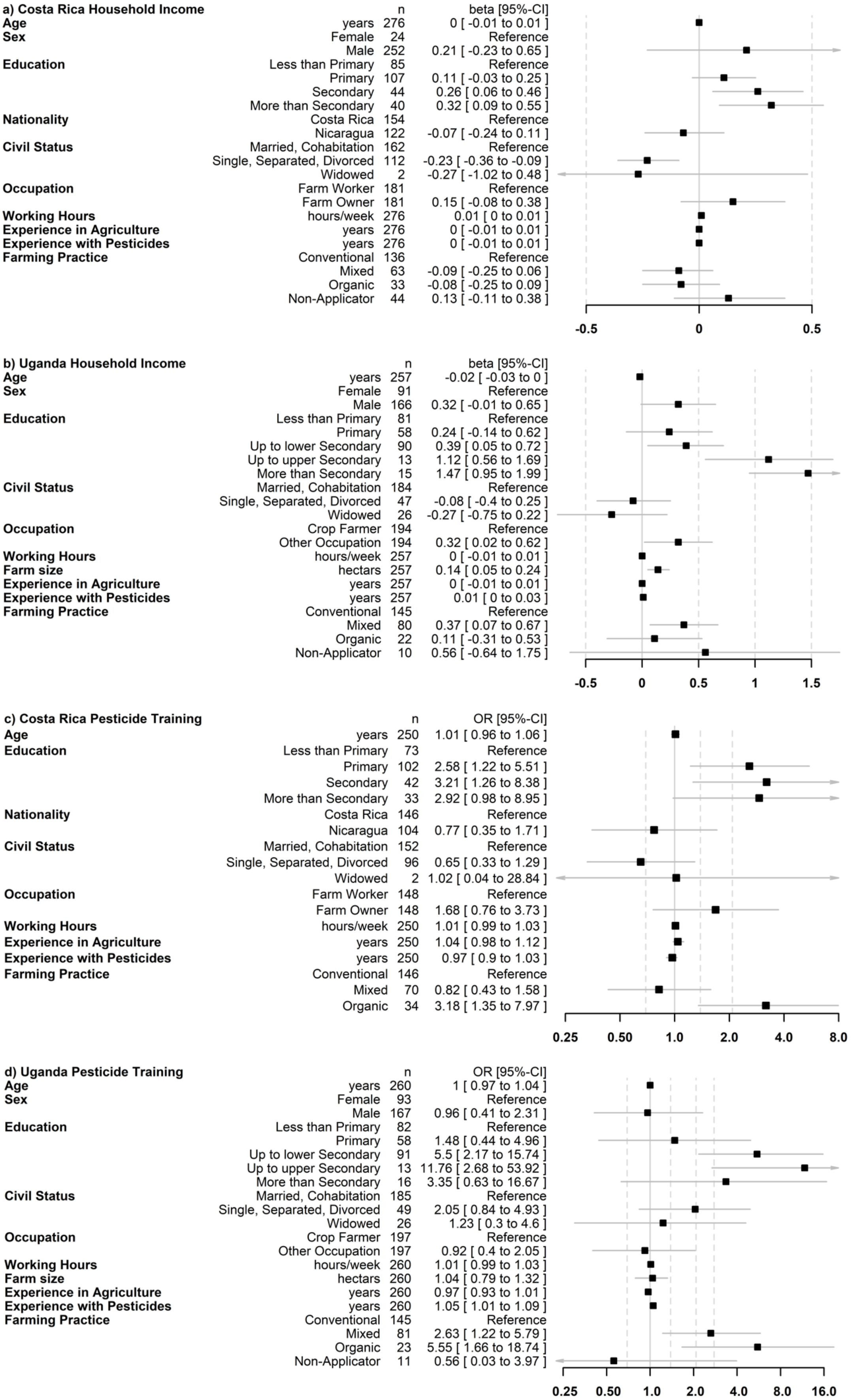


Figure 4, a) and b): Forest plot with coefficients for multivariate robust regression of logarithmic household income and its predictors. c) and d) Forest plot with Odds Ratio for multivariate logistic regression of received pesticide training and its predictors. Univariate results can be found in Supplementary Figure SF2.

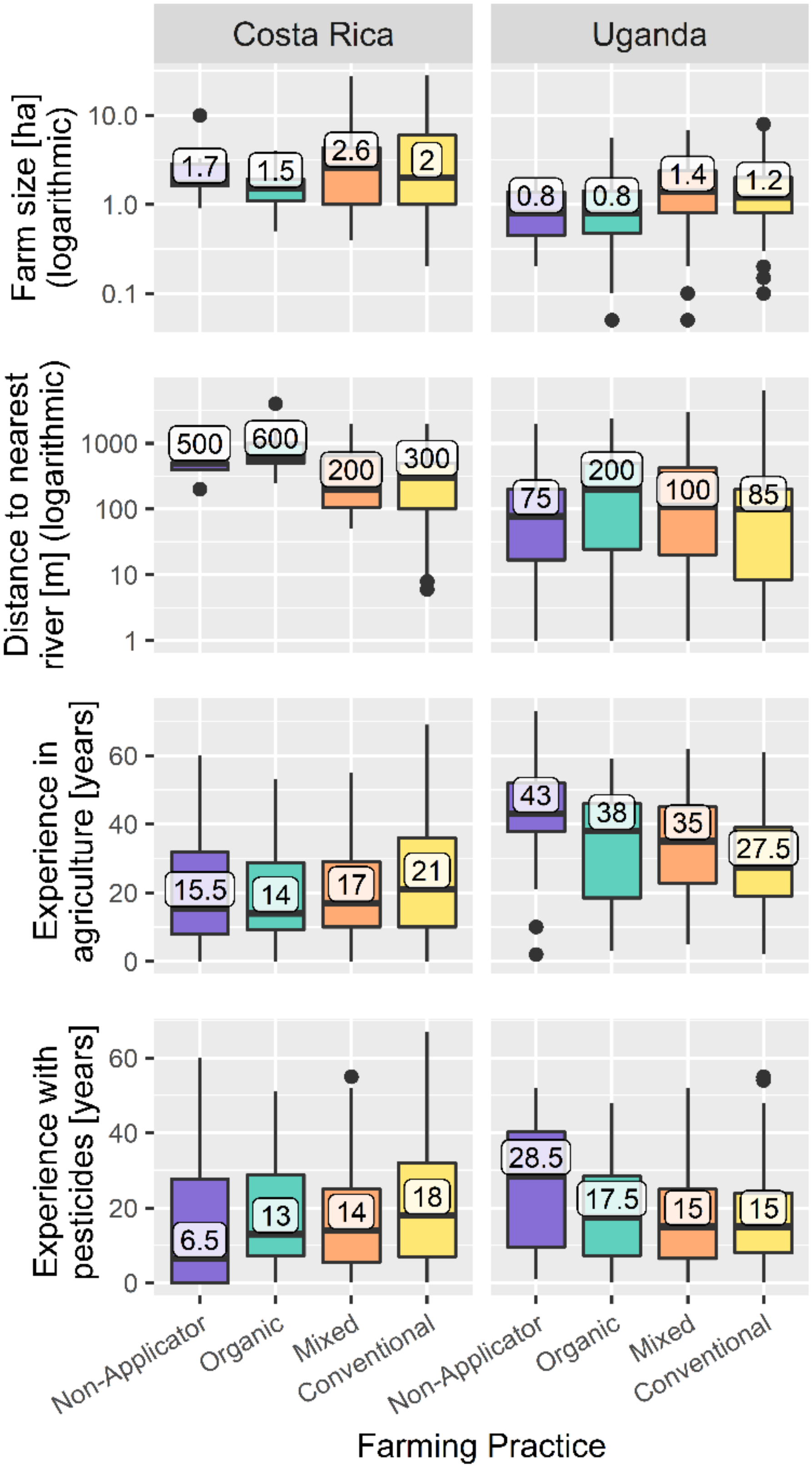


Figure 5: Socio-economic factors of individual farmers and their farms by country and farming practice.

4.5.3 Determinants of pesticide use training

In Costa Rica, 48% of study participants had received pesticide use training from governmental institutions, agribusiness, and/or farm owners. More organic farmers (67.7%) and farm owners

(66.7%), than conventional and mixed farmers (48.4% and 40.9%), or farm workers (35.6%) had received such a training. In the multivariate logistic regression model, the main predictors of whether a farmer had ever received pesticide training were being an organic farmer and being more educated (Figure 4).

In Uganda, only 22.9% of study participants had received training on pesticide use practices. Providers were primarily either Uganda National Association for Community and Occupational Health (28.0%) or other nongovernmental organizations (62.9%). In the regression model, the best predictors were the application of alternative pest management practices, being more educated, and having more years of experience handling/applying pesticides (Figure 4).

In both countries, the use of alternative pest management practices and having completed a secondary education were associated with having received training in safe pesticide use (Figure 4).

4.5.4 Health, hygiene, protection, and disposal of pesticides

In both countries, most farmers acknowledged that pesticides could affect their health (CR 97.7%; UG 90.4%) and identified dermal, inhalation, and ingestion as the main routes of pesticide exposure to the body (Figure 6a). In Uganda, in addition to the given options, a considerable number of participants (10.9%) explicitly stated "ears" as additional entry path. Notably, in Uganda, conventional and mixed farmers were significantly more aware of risks through inhalation (p=0.007) and dermal exposure (p<0.001) than organic farmers and non-applicators.

In both countries, rubber boots, long pants, long-sleeved shirts, and hats were widely available and also worn by the farmers. There was, however, a clear between-country difference in access and use of more specific PPE. In Costa Rica, some farmers had access to masks with (32.4%) and without carbon filter (44.1%), glasses (39.3%), gloves (47.8%), rubber aprons (32.4%), and water proof pants (80.2%), but not all of them used them (e.g., only 8.5% and 10.9% reported using masks with carbon filter or glasses always or often when applying pesticides, respectively; Figure 6b). In Uganda, farmers' access to PPE was much more limited (e.g., only 2.7% and 4.3% had access to masks with carbon filter and glasses, respectively (Figure 6b)).

In Costa Rica, none of the organic farmers reported bathing/showering immediately after applying homemade pesticides (i.e., an alternative pest management practice) or the day after, but overall more organic farmers report bathing/showering or changing clothes within a few hours after applying homemade pesticides (68.2% and 72.2%), compared to mixed (both 41.2%) and conventional farmers applying synthetic pesticides (55.6% and 54.9%). In Uganda, most organic farmers reported bathing immediately after applying homemade pesticides (62.1%) rather than many hours later (27.6%, p<0.001), whereas conventional farmers reported bathing many hours later (45.0%) rather than immediately (30.2%, *p*<0.001) after applying synthetic pesticides. More organic farmers (79.3%) reported washing their own clothes compared to mixed (59.0%) and conventional farmers (48.3%, *p*<0.001) (Figure 7).

In both countries, across all farming practices, water used for cleaning pesticide application equipment was mainly disposed in the drain (CR 54.7%), directly in the garden (UG: 46.7%), or elsewhere on the farm directly onto soil (CR: 30.2%; UG: 37.5%) (Figure 8). Conventional farmers from both countries also reported disposing this residual water into rivers (CR: 11.3%; UG: 19.0%). In Costa Rica, a notable disposal route was the biobed (12.3%).

Empty pesticide containers were either recycled (CR: 77.4%; UG: 32.0%), buried (UG: 42.5%), or burnt (CR: 22.6%; Figure 8). In Costa Rica, organic farmers did not burn any containers, but disposed all non-recycled containers in the garbage/landfill (28.6%). In Uganda, some conventional (13.4%) and mixed farmers (12.0%) left containers behind in their fields (Figure 8).

While being aware of health risks, farmers in both countries expressed low personal protective behaviors. Furthermore, pesticide residues and empty containers were disposed of into the environment.

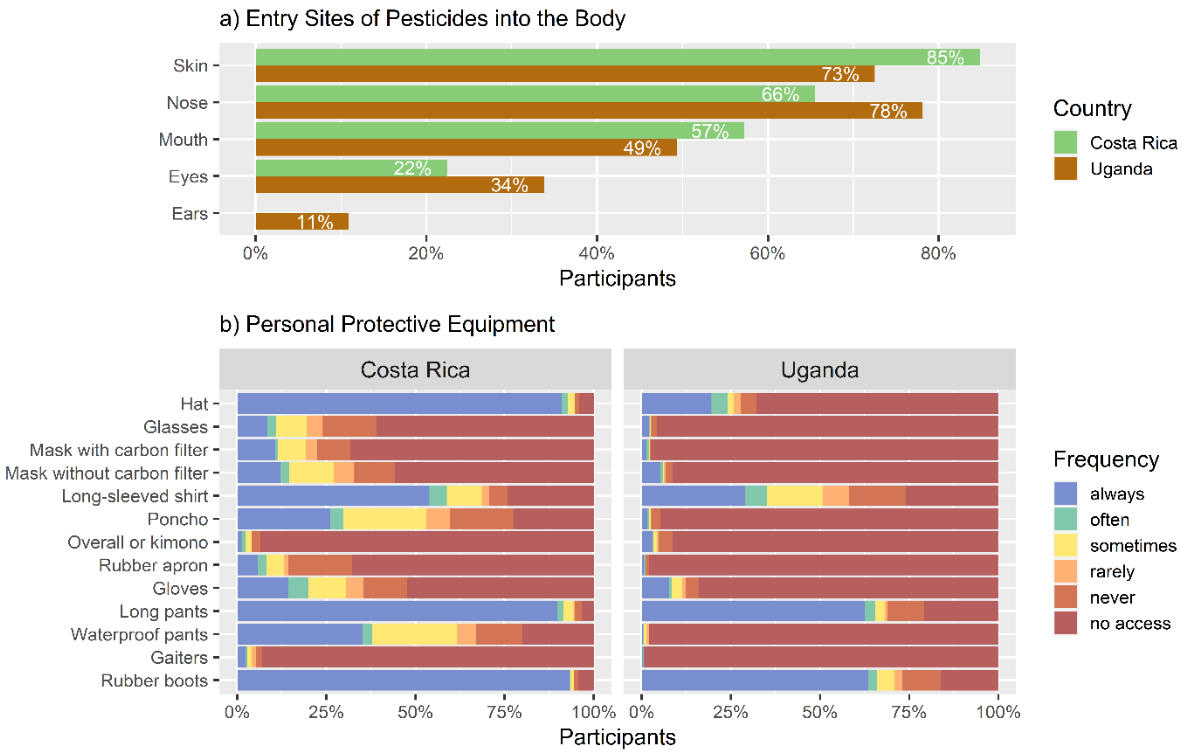


Figure 6: a) Pesticide entry sites into the body. Ears was not an answer option but explicitly mentioned in Uganda by 10.9% of participants. b) Access and use of PPE

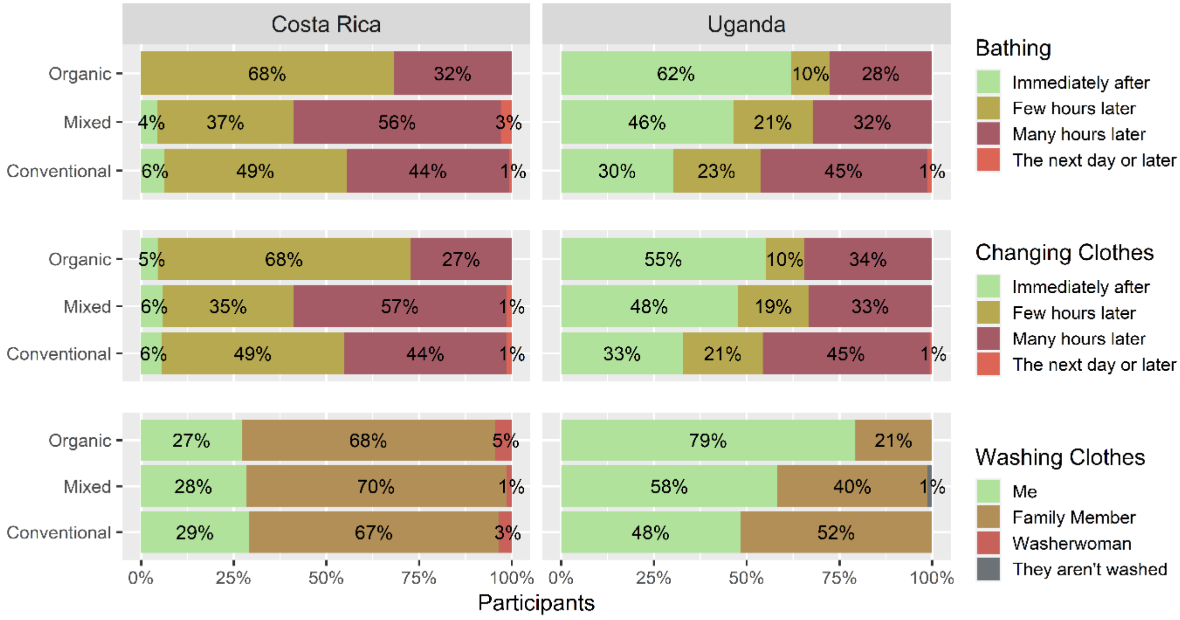


Figure 7: Hygiene practices in relation to pesticide application: Bathing and changing clothes after pesticide application and handling, responsible person washing clothes used during pesticide application and handling.

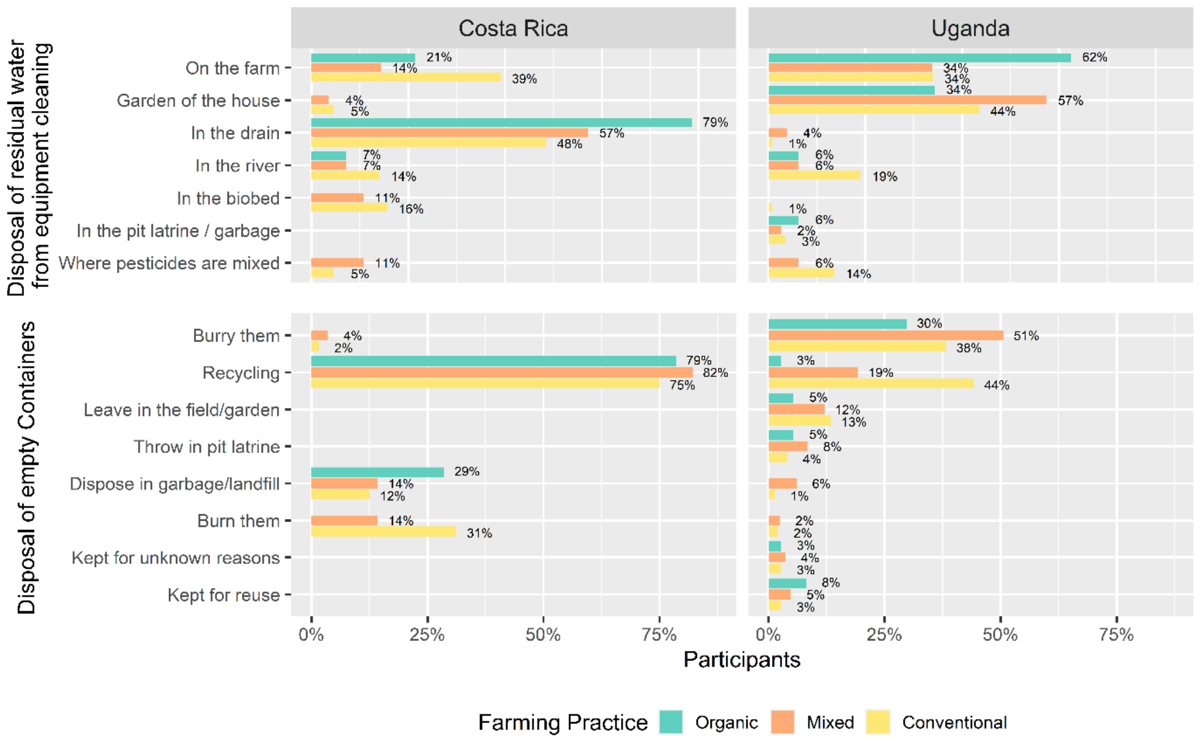


Figure 8: Disposal of residual water from pesticide application equipment cleaning and disposal of empty pesticide containers

4.5.5 Use of highly hazardous pesticides

In Costa Rica, the most commonly applied pesticide active ingredients during the twelve months prior to the study visit were the fungicide chlorothalonil, the herbicides paraquat and glyphosate, and the pyrethroid insecticide cypermethrin (Figure 9). About half of farmers reported using pesticides classified by WHO as Ia (extremely hazardous) and Ib (highly hazardous) during the twelve months prior to the study. Class II (moderately hazardous), III (slightly hazardous), and U (unlikely to present an acute hazard) pesticides were used by 69.7%, 58.3%, and 66.3% of farmers, respectively, in this same period. During the week prior to each study visit, the most commonly applied pesticides were chlorothalonil and cypermethrin. Together with mancozeb and propamocarb, they were also applied for longer periods of time (in h/wk) compared to other pesticides (Figure 10).

In Uganda, the most commonly applied pesticide active ingredients during the twelve months prior to the study visit were the herbicide glyphosate, the insecticide cypermethrin, and the fungicide mancozeb. Besides these three chemicals, profenofos, and 2,4-D, all other pesticides were used by less than 11% of participants (Figure 9). During the week prior to the each visit, the most frequently applied pesticides were mancozeb and cypermethrin, but the ones applied for the longest periods of time were the herbicides 2,4-D and glyphosate, and the insecticide lambda-cyhalothrin (Figure 10). Most of pesticide active ingredients used by Ugandan farmers were WHO class II.

In both countries, most conventional and mixed farmers used highly hazardous pesticides (HHP) (CR: 93.2% UG: 91.9%) and class I or II pesticides (CR: 91.8%, UG: 80.3%) over the twelve months prior to the study visit. The active ingredients applied in Costa Rica were more diverse and applied by more farmers on larger areas compared to Uganda. In both countries, the most widely used active ingredients involved a fungicide, an herbicide, and an insecticide. Six active ingredients were used in both countries (Figure 9), three of which also ranked among the top five used pesticides in the country: mancozeb, glyphosate, and cypermethrin. Paraquat and chlorpyrifos were widely used in Costa Rica but rarely in Uganda, whereas carbofuran was seldom used in either setting.

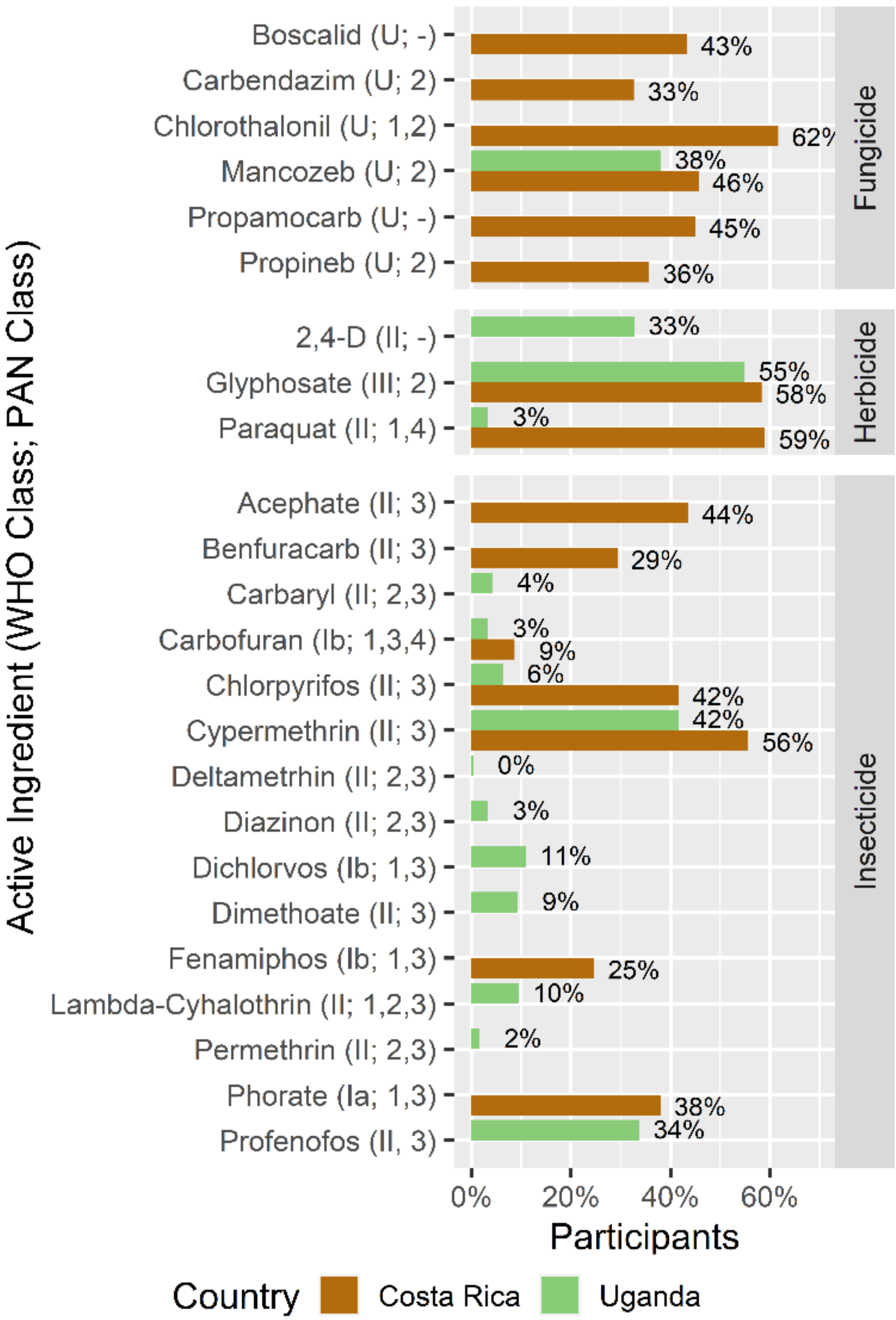


Figure 9: Proportion of participants using the listed active ingredients over the last 12 months. In parentheses first the World Health Organization recommended classification of pesticides by hazard (Ia, Extremely hazardous; Ib, Highly hazardous; II, Moderately hazardous; III, Slightly hazardous; U, unlikely to present acute hazard in normal use), followed by the Pesticide Action Network grouping for highly hazardous pesticides (1, acute toxicity; 2, long term effects; 3, environmental toxicity; 4, conventions).

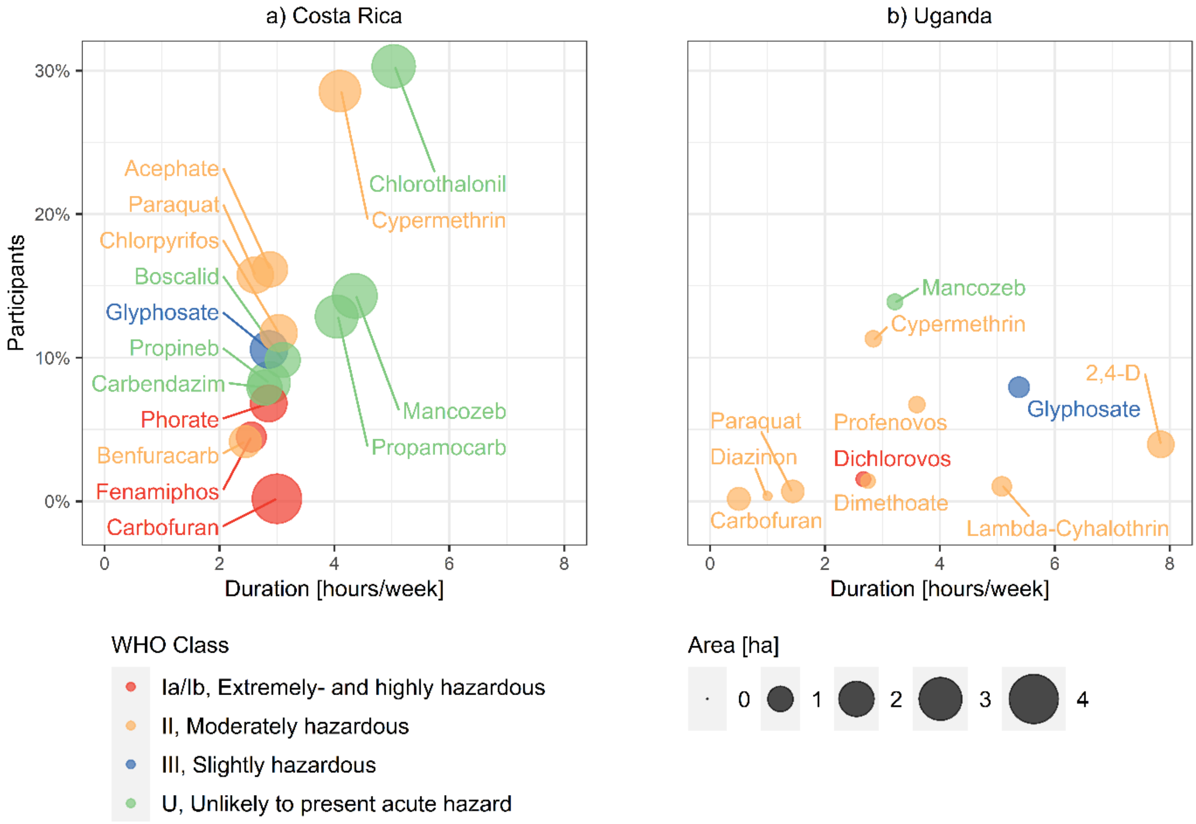


Figure 10: Y Axis: Share of participants applying the active ingredient; X Axis: Average exposure duration per active ingredient during the week prior to the two study visits; Bubble size: Average area of pesticides applied, in hectares; Color: WHO Toxicity classification.

4.6 Discussion

This study explores the commonalities and differences of the KAP of pesticide use among smallholder farmers between two tropical countries with unlike socio-economic and agronomic conditions. We found important similarities, but also substantial differences (Table 2). These descriptive findings form a basis to derive causal hypothesis regarding mechanisms explain the KAP of pesticide use.

Table 2: Differences and similarities between the study sites in Costa Rica and Uganda for each of the five research questions.

Topic	Costa Rica	Uganda
1) How are socio-demographic characteristics associated with farming practices?		
Participants were/had …	… younger, with fewer years of education, rarely women, and mostly married.	… older, with more years of education, about 2/5th women, and mostly married.
Migrant workers …	… made up 2/5th of participants, were less educated, worked longer shifts, and fewer were farm owners.	… were rare among participants.
Farming practices	Non-applicators worked shorter shifts, fewer were farm owners, and were comprised of equal proportions of men and women	Organic farmers were more educated, more likely to be women, single, and widowed, and 2/5th had a main occupation other than crop farmer
2) How are socio-demographic factors and farming practices associated with socio-economic factors?		
Household income was predicted by …	… more education, longer working hours, and civil status.	… more education, farm size, not being a crop farmer, and applying mixed farming practices.
Organic farms …	… were smallest in size and furthest from water.	
Major crops grown …	… differed between users and non-users of synthetic pesticides.	…were similar between practices.
3) How are farming practices associated with knowledge and attitude of safe pesticide use?		
Pesticide training …	… was common (1/2 of participants).	… was rare (1/5th of participants).
	… was associated with more education and being an organic farmer.	… was associated with more education, being an organic farmer, and more years using pesticides.
4) How are farming practices as well as knowledge and attitude associated with pesticide use practices?		
Health effects …	… and exposure routes were acknowledged and identified by most farmers.	
Regular PPE …	… was available and used.	
Specific PPE …	… was sometimes available but rarely used.	… was rarely available and used.
Hygiene behavior …	… was similar among all farmers.	Organic farmers had better hygiene behaviors and washed their clothes themselves.
Residual water …	… was disposed onto farm soil but also into rivers.	
Empty pesticide containers …	… were recycled or burnt.	... were recycled or buried. Some synthetic pesticide users left them behind in the field.
5) How hazardous are the resulting pesticide use practices?		
Toxicity	90% used highly hazardous pesticides (HHP) and 80% used WHO class I/II.	
Most commonly used pesticides	Chlorothalonil (fungicide), glyphosate and paraquat (herbicides), cypermethrin (insecticide).	Mancozeb (fungicide), glyphosate and 2,4-D (herbicides), cypermethrin and profenofos (insecticides).

4.6.1 Interventions need to address social inequalities

Differences in social characteristics between the two study populations were found for age and sex. When comparing median age above the participation limit of 18 years, we found that the Costa Rican participants were about 20% younger than the country median (32.5 years vs. approx. 41 years), whereas the Ugandan group was about 60% older than the country median (49.0 years vs. approx. 30 years) (UNSD, 2017). For Uganda, this age difference could be largely explained by three country-specific aspects: (i) our study site is close to the capital city Kampala, where young people flee from the countryside (Menashe-Oren and Stecklov, 2018), (ii) land ownership or capital is held by the older population (De Magalhães and Santaeulàlia-Llopis, 2018), and (iii) agriculture is perceived as backwards and not appealing by to the younger generation (Isgren, 2016). This difference could also be explained by the fact that the age distribution in our study population in Uganda followed the shape of a constrictive pyramid, whereas the national distribution for the same period followed the shape of an expansive pyramid (Heenan, 1965). Therefore, it is important to mention that all results described below have to be interpreted in the light of the demographic structure of our study populations.

Among Costa Rican farmers, we identified a minority of migrant farm workers with fewer years of education opposed by a majority of Costa Rican farm owners. The combination of lower education and limited access to and use of health services makes migrant farmworkers a vulnerable group (Bolaños et al., 2008; Cabieses et al., 2016). Thus, any interventions aiming to promote safer pesticide use practices should proactively involve vulnerable groups and address socio-cultural aspects (Coman et al., 2020; Rezaei et al., 2019).

Farmers in Uganda who applied alternative pest management practices had more years of education than those who did not. This is akin to a study from China, where farmers with more years of education applied more non-chemical pest management techniques (Wang et al., 2018). Given an already higher knowledge level, the switch to alternative pest management comes with a change in attitudes as opposed to even more knowledge (Muleme et al., 2017).

Pesticides are considered unsafe for the health of (future) pregnant women (London et al., 2002). Therefore, it is no surprise that women enrolled in this study were most common among non-applicators (both countries) and organic farmers (Uganda). These findings contrast with those reported by Ochago (2018) who found that women and elderly Ugandan smallholder coffee farmers did not consider the uptake of integrated pest management (IPM) practices attractive due to their increased labor requirements. Traditionally, both labor intensive work (i.e., carrying a knapsack sprayer) and commercial crop production have been considered men's tasks. Thus, it resonates that women would frequently avoid spraying synthetic pesticides in subsistence crops.

4.6.2 Pesticide use was not associated with farm household income

Reducing pesticide use is commonly seen to be a risk to income due to a possible loss in crop yield (Grovermann et al., 2017). However, our study showed that farming practices and thus use of synthetic pesticides was not the major driver of household income. Instead, the strongest predictor of household income was education, followed by occupations other than crop farming and longer work shifts, larger farms, and the application of mixed practices. More years of education leading to higher income is a well-known fact (Sparreboom and Staneva, 2014), but our study showed that other context-dependent factors played an important role in determining choice of farming practices and income from farming, which are discussed as follows: *First*, in Costa Rica, all farmers lived off their income from agricultural activities. In Uganda, on the other hand, one out of four participants had an occupation different than crop farmer. A common practice in Uganda is to have an occupation, such as teacher or hair dresser, and also have a garden at home, supplying the family with fresh vegetables (Amare and Shiferaw, 2017). Such subsistence farming can decrease overall household spending while at the same time increasing income by selling surplus (Guma et al., 2018). *Second*, differences in farm size and distance to water were linked with farming practices. In Uganda, market-oriented farmers (usually practicing pesticide intensive horticulture) tend to have larger plots (Opondo and Owuor, 2018) and farms near streams to be able to grow crops all year round. On the other hand, due to intense labor requirements and limited access to biological pesticides, organic farms tend to be relatively small. This is in agreement with our findings, where larger farms with mixed farming practices were associated with higher household income (i.e., opportunity to purchase bigger plots closer to water sources or expensive pesticides), whereas organic farms remain the furthest from water and smallest in size. With farmers of younger ages and more years of education, Ugandan agricultural systems will soon experience a shift from traditional (organic-by-default) self-subsistence farming practices to more market-oriented and sustainable practices (similar to Costa Rica) (Hall et al., 2017; Kamau et al., 2018). This process can further be supported by fostering full land ownership over mere occupancy rights (Deininger and Ali, 2008).

4.6.3 Farmers were likely to reduce pesticide use after pesticide training

In both countries, less than half of the study participants had received pesticide training. Along with education, organic pest management and years of pesticide use were identified as predictors for having received training in pesticide use. This finding may be explained by experienced pesticide users stopping or reducing pesticide use (i.e., becoming organic or mixed farmers) after having received specific training (i.e., including learning about the risks of pesticide use), as it has previously been observed in Uganda (Clausen et al., 2017). Alternatively trainers may have specifically targeted low- or non-users of pesticides to convince them to start using pesticides, provoking a lock-in, as seen in Cambodia by Flor et al. (2019).

In Costa Rica, organic and mixed farmers (using alternative pest management practices) were younger than conventional and non-applicators, whereas in Uganda conventional and mixed farmers (using synthetic pesticides) were younger than organic and non-applicators. These differences can be explained by the different perceptions of organic agriculture. In Costa Rica, organic and sustainable agriculture are considered progressive choices, set up for export (Galt, 2008; Schelhas, 1994), hence younger farmers tend to choose this option. In Uganda, organic and sustainable agriculture are perceived as old farming practices and are mainly promoted by foreign-funded NGOs (Isgren, 2016). Younger farmers are more likely to have access to information channels, such as smartphones and television (Diemer et al., 2020). Promoting alternative pest management strategies in these channels, classically dominated by marketing for synthetic pesticides (Menyha, 2010), could increase the share of organic and mixed farming in commercial agriculture.

4.6.4 Improvements on safe use are required

Most farmers in both countries reported that pesticides could have negative effects on health and correctly identified the two primary entry sites: skin (dermal) and nose (airways) (Damalas and Koutroubas, 2016). These findings contradict those from earlier studies conducted in Costa Rica (i.e., pesticide users were not aware of exposure routes and did not perceive spraying as hazardous) (Barraza et al., 2011) and Uganda (i.e., pesticide users had poor knowledge about pesticide toxicity) (Oesterlund et al., 2014).

Regular farmer's clothing (i.e., rubber boots, long pants, long-sleeved shirt, and hat) was available and in use in both countries, but access to specific PPE such as gloves and waterproof pants was higher in Costa Rica than in Uganda. Factors explaining this higher use of specific PPE may be higher income and larger farm size (Sapbamrer and Thammachai, 2020). PPE for airways and eyes (i.e., masks with carbon filters and glasses) were only used by a small fraction of farmers in both countries. These findings are consistent with those of previous studies (Atuhaire et al., 2016; Oesterlund et al., 2014; Polidoro et al., 2008; Yarpuz-Bozdogan, 2018). This is concerning because, even though PPE effectiveness under practical application is questioned (Garrigou et al., 2020; Machera et al., 2009), Cataño et al. (2008) showed that farmers using PPE while spraying were less likely to experience pesticide poisoning.

Residues from washing application equipment were disposed of in the surroundings of the farm. In both countries, more than ten percent of conventional farmers also reported pouring pesticide residues into nearby rivers, thereby directly affecting the aquatic environment, leading to loss of biological integrity (Stehle and Schulz, 2015). Indeed, pesticide pollution of the waterbodies was observed in both study areas, at particularly high concentration levels in Costa Rica (Weiss et al., in preparation; Winkler et al., 2019).

While a large proportion of empty pesticide containers in both countries are recycled, it remains unclear what recycled means in each case. Recycling can mean ‘bringing back empty containers to the dealership’, or it can also indicate ‘reusing the containers for other purposes’. Either way, analyses of used containers have shown that regular triple rinsing options are insufficient for decontamination of containers, implying that any kind of reuse or recycling in a low resource setting is inappropriate (Picuno et al., 2020). To reduce the environmental footprint of pesticide use, it is important to look beyond the application of the chemicals, and improve the residue and waste management conducted by the farmer, like equipment cleaning and container disposal, without forgetting to reduce the pesticides introduced into the environment through spraying, drift, and runoff (Munjanja et al., 2020).

4.6.5 Upstream pesticide restrictions are needed

Half of all study participants in Costa Rica used WHO class I pesticides, and in both countries more than 80% of applicators used class I or II pesticides. Of 24 active ingredients, only three are not listed as HHP (PAN International, 2019). These findings are consistent with those from previous studies in Costa Rica (Polidoro et al., 2008) and Uganda (Clausen et al., 2017; Oesterlund et al., 2014). Similar results were also observed in other low- (Mengistie et al., 2017; Toe et al., 2013; Vikkey et al., 2017) and middle-income countries (Bravo et al., 2011; Khan et al., 2015; Mengistie et al., 2017; Toe et al., 2013; Vikkey et al., 2017; Yap and Demayo, 2015). The use of HHP can lead to acute toxic or chronic health effects or pose a large threat to the environment. Both PAN and WHO recommend to reduce the use of HHP (PAN International, 2019; WHO, 2010).

The most commonly applied pesticides in both countries – mancozeb, glyphosate and cypermethrin – are non-selective pesticide (i.e., they also impact non-target organisms). The use of non-selective pesticides and HHP without adequate training and equipment can lead to short-term benefits and profits among smallholders, but excludes the long-term externalities to the health of the farmers, their communities and the consumers of their produce, as well as the expected negative impact on the environment, such as disruption of non-targeted organisms and thus the ecosystem at large (Hill et al., 2017). Training pesticide dealers such as gatekeepers and agricultural consultants could limit sales of dangerous chemicals (Weerasinghe et al., 2018) and increase sales of less dangerous ones. Sales restrictions and national bans on HHP have shown to be effective in reducing pesticide suicides (Gunnell et al., 2017), and are therefore promising to reduce lesser negative effects. Farmers could be required to demonstrate proficiency (i.e. certificate) in safe use and handling to buy such chemicals (Mengistie et al., 2017).

4.6.6 Strengths and limitations

Despite using quantitative data from a standardized questionnaire, this exploratory study is mainly descriptive. The KAP approach allowed us to study pesticide use under contrasting conditions, among two distinct groups of tropical smallholders. With the aforementioned descriptive findings, we learned to contrast findings from literature research, as well as our personal experiences and exchanges with stakeholders and either solidify or challenge our previous state of knowledge. The study also has some limitations: First, the cross-sectional study design limits our ability to infer causality. While we applied random sampling wherever possible, the samples we chose may not be representative of the populations at large, thus not allowing to draw conclusions for the studied populations at large. Nevertheless, we observed important associations between KAP and farming practices that could drive future research. Second, our findings from the KAP approach would be better supported if systematically combined with focus group discussions and individual interviews, drawing a comprehensive picture of the research topic (Muleme et al., 2017). Third, opposed to initially planned, we realized after piloting the questionnaire in the second study setting, that some of the questions need to be rephrased for the new context. We therefore suggest, that a future comparison of KAP between cultures needs to test questionnaires in both settings before data collection. Lastly, we grouped farmers according to their pest management strategy. However, farmers’ self-perception of what constitutes organic or conventional farming practices differs by culture (Bendjebbar, 2018). In addition, farmers can switch farming practices between seasons or plots. A binary approach classifying farmers as organic or conventional is therefore not optimal and can lead to exposure misclassification (Ohlander et al., 2020).

4.7 Conclusion

In this study we showed that KAP surveys are a suitable approach to compare the social characteristics of pesticide use across different socio-economic and agronomic settings in two tropical regions located in different world regions. In both Costa Rica and Uganda, the vast majority of synthetic pesticides applied are highly hazardous pesticides. The users of these synthetic pesticides are less trained in the use of them, compared to the farmers not using them, indicating the possibility of farmers stopping to use pesticides after learning about their use and effect in detail. Furthermore, protective behavior among smallholder farmers remains low and dissatisfactory for both human- and ecosystem-health.

Together these findings demand for context-specific, and target-group oriented training of farmers on pesticide use, while focusing on the farmers’ perception of perceived risk. Future research needs to study, how training programs can be inclusive of not only proper application practices and protection, but also agronomic measures (e.g., IPM), foster professionalization of farmers, and promote management of pesticide-related impacts beyond applicator health (e.g. run-off into community-streams, spray-drift, and consumer health). The large number of farmers with comparably low training suggests that preventive efforts could also be fruitful when working with other actors along the pesticide value chain. We therefore propose research into pesticide sales, specifically import policies and end-consumer sales, to prevent the spread of hazardous chemicals to unqualified buyers. By highlighting how pesticide use, farming practices, and social characteristics are connected, this paper contributes to improving safe use and handling of pesticides among smallholders.

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4.10 Supplementary Materials

Supplementary Table ST1: Variables and questions used in the survey. Stars (*) denote that the question or the answer is referring to the list of options in Supplementary Table ST2, indicating either repetition of the question for each item on the list, or the option to select any item from the list.

Variable name and question	Type	Unit / Categories
Socio-demographic characteristics		
Sex	Single choice	Female Male
Age: “How old are you?”	Integer	Years
Education, derived from: “What is the highest level of school you completed? Which specific year?”	Integer	Years
Marital status: “What is your current marital status?”	Single choice	Single Married Cohabitation Separated Divorced Widowed
Nationality: “What country were you born in?”	Single choice	Costa Rica Nicaragua Uganda Tanzania Rwanda
Socio-economic and occupational characteristics		
(Farming) practice	Derived from pesticide use and occupational variables	Non-Applicator Organic Mixed Conventional
Years of experience in agriculture, derived from age and “How old were you when you started working on agricultural farms?” and age	Integer	Years
Years of experience spraying/handling pesticides, derived from age and “At what age did you start mixing or applying synthetic pesticides?”	Integer	Years
Monthly household income: “On average how much money do you make in a month? Please include everyone who contributes to the income of the household: Household head, partner, children, relatives etc.”	Integer	Costa Rican Colon (CRC) / Ugandan Shilling (UGX)
Job position / main profession: “How do you consider your position in relation to that farm?” / “What is your main occupation?”	Single Choice	Costa Rica: Producer (Farm owner) Farm worker Uganda: Crop Farmer Other (aggregated from other options)
Worktime, derived from “On average, how many hours do you spend per working day in the field?” and “On average, on all the farms together, how many days do you work per week?”	Integer	Hours per week
Pesticide active ingredients used at the farm over the last twelve months, derived from “During the last twelve months, have you prepared or applied this pesticide* in your farms for crops, for your livestock, or against pests around your house or inside your house?”	Single choice	No Yes Don’t know
Pesticide active ingredients used at the farm over the last seven days, derived from “Have you prepared or applied this pesticide* in the last seven days?”	Single choice	No Yes Don’t know
For each active ingredient*: “How many hours have you applied this pesticide in the last seven days?”	Integer	Hours per week

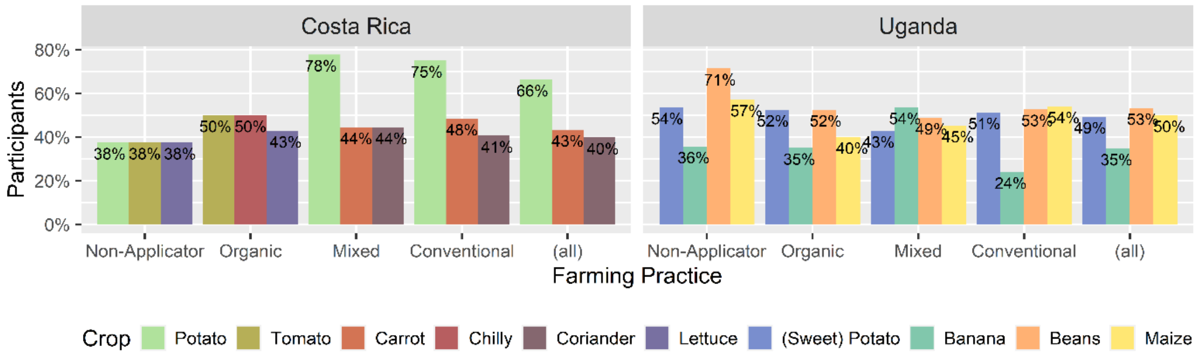
For each active ingredient*: "On how many acres have you used this pesticide in the last twelve months?"	Integer	Hectares (derived from acres)
Farm size: "In acres, how big is the total area you are cultivating crops on these farms?"	Integer	Hectares
Crops cultivated: "What are the three major crop you are currently growing?"	Multiple choice	List of country specific crops*
Distance between farm and water source: "How many meters is your farm away from a river or spring?"	Integer	Meters
Knowledge, attitude and practices		
Training in pesticide use "Have you ever been trained on how to apply pesticides?"	Single choice	No Yes Don't know
Training provider: "Who trained you?"	Text	-
Health risk awareness: "Do you believe that pesticides can affect your own health?"	Single choice	No Yes Don't know
Entry sites to the body: "Through which body parts do you think pesticides can enter us?"	Multiple choice	Skin Nose Mouth Eyes None Other (specify)
Bathing after handling/application of pesticides: "How long after you applied pesticides do you take a bath?"	Single choice	Immediately after Few hours later Many hours later The next day or later
Changing of clothes: "How long after you applied pesticides do you change your clothes?"	Single choice	Immediately after Few hours later Many hours later The next day or later
Clothes washing: "Who washes the clothes used in pesticide application?"	Single choice	Me Family Member Washerwoman They aren't washed
Disposal of residual water: "Where do you discharge the water after washing the pesticide application equipment?"	Multiple choice	On the farm Garden of the house In the drain In the river In the biobed In the pit latrine / in the garbage Where pesticides are mixed
Container disposal: "What do you do with empty pesticide containers or bags?"	Multiple choice	Burry them Recycling Leave in the field/garden Throw in pit latrine Dispose in garbage/landfill Burn them Kept for unknown reasons Kept for reuse
PPE* access: "Do you have access to this equipment?"	Single choice	No

		Yes Don't know
PPE* wearing "Do you wear this protective equipment when preparing or applying pesticides?"	Single choice	No Yes Don't know
PPE* frequency: "How often do you use this protective equipment when preparing or applying pesticides?"	Single choice	Always (100%) Often (75%) Sometimes (50%) Rarely (25%) Never (0%) Don't know

Supplementary Table ST2: Listed options and variables for starred (*) items in Supplementary Table ST1.

List of pesticide active ingredients Costa Rica	Boscalid Carbendazim Chlorothalonil Mancozeb Propamocarb Propineb Glyphosate Paraquat Acephate Benfuracarb Carbofuran Chlorpyrifos Cypermethrin Fenamiphos Phorate
List of pesticide active ingredients Uganda	Mancozeb 2,4-D Glyphosate Paraquat Carbaryl Carbofuran Chlorpyrifos Cypermethrin Deltamethrin Diazinon Dichlorvos Dimethoate Lambda-Cyhalothrin Permethrin Profenofos
List of crops Costa Rica	Cabbage Carrot Cauliflower Chilly Coriander Egg plant Flowers Garlic Lettuce Onions Parsley Potato Tomato Other (specify)

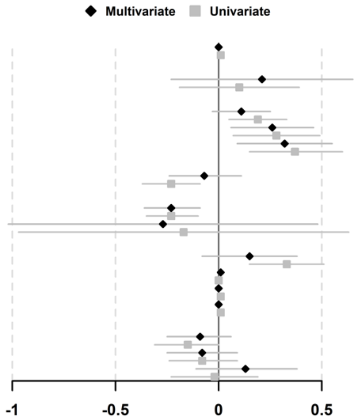
List of Crops Uganda	Banana Beans Cassava Ground nuts Maize Okra Onion Passion Fruit Pepper Sugar cane Sweet (potato) Water melon Yam Other (specify)
List of PPE	Hat Glasses Mask with carbon filter Mask without carbon filter Long-sleeved shirt Poncho Overall or kimono Rubber apron Gloves Long pants Waterproof pants Gaiters Rubber boots



Supplementary Figure SF1: Major crops grown by country and farming practice. Major indicates the crops cultivated by the most farmers, not applying any threshold.

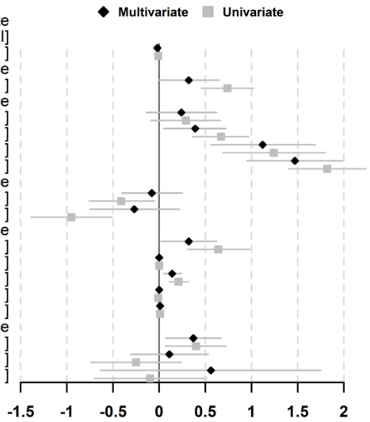
a) Costa Rica Household Income

		n	multivariate beta [95%-CI]	univariate beta [95%-CI]
Age	years	276	0 [-0.01 to 0.01]	0.01 [0 to 0.01]
Sex	Female	24	Reference	Reference
	Male	252	0.21 [-0.23 to 0.65]	0.1 [-0.19 to 0.39]
Education	Less than Primary	85	Reference	Reference
	Primary	107	0.11 [-0.03 to 0.25]	0.19 [0.05 to 0.33]
	Secondary	44	0.26 [0.06 to 0.46]	0.28 [0.07 to 0.49]
	More than Secondary	40	0.32 [0.09 to 0.55]	0.37 [0.15 to 0.6]
Nationality	Costa Rica	154	Reference	Reference
	Nicaragua	122	-0.07 [-0.24 to 0.11]	-0.23 [-0.37 to -0.09]
Civil Status	Married, Cohabitation	162	Reference	Reference
	Single, Separated, Divorced	112	-0.23 [-0.36 to -0.09]	-0.23 [-0.35 to -0.1]
	Widowed	2	-0.27 [-1.02 to 0.48]	-0.17 [-0.97 to 0.63]
Occupation	Farm Worker	181	Reference	Reference
	Farm Owner	181	0.15 [-0.08 to 0.38]	0.33 [0.15 to 0.51]
Working Hours	hours/week	276	0.01 [0 to 0.01]	0 [0 to 0.01]
Experience in Agriculture	years	276	0 [-0.01 to 0.01]	0.01 [0 to 0.01]
Experience with Pesticides	years	276	0 [-0.01 to 0.01]	0.01 [0 to 0.01]
Farming Practice	Conventional	136	Reference	Reference
	Mixed	63	-0.09 [-0.25 to 0.06]	-0.15 [-0.31 to 0]
	Organic	33	-0.08 [-0.25 to 0.09]	-0.08 [-0.24 to 0.09]
	Non-Applicator	44	0.13 [-0.11 to 0.38]	-0.02 [-0.23 to 0.19]



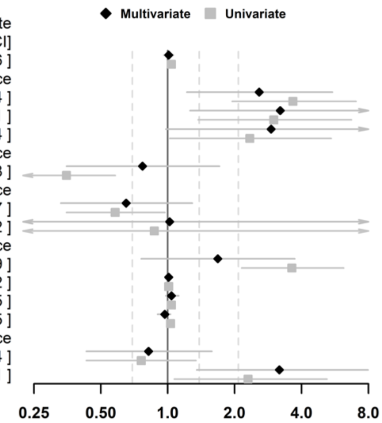
b) Uganda Household Income

		n	multivariate beta [95%-CI]	univariate beta [95%-CI]
Age	years	257	-0.02 [-0.03 to 0]	-0.01 [-0.02 to 0]
Sex	Female	91	Reference	Reference
	Male	166	0.32 [-0.01 to 0.65]	0.74 [0.46 to 1.02]
Education	Less than Primary	81	Reference	Reference
	Primary	58	0.24 [-0.14 to 0.62]	0.29 [-0.09 to 0.66]
	Up to lower Secondary	90	0.39 [0.05 to 0.72]	0.67 [0.36 to 0.97]
	Up to upper Secondary	13	1.12 [0.56 to 1.69]	1.24 [0.69 to 1.8]
	More than Secondary	15	1.47 [0.95 to 1.99]	1.82 [1.4 to 2.24]
Civil Status	Married, Cohabitation	184	Reference	Reference
	Single, Separated, Divorced	47	-0.08 [-0.4 to 0.25]	-0.41 [-0.76 to -0.05]
	Widowed	26	-0.27 [-0.75 to 0.22]	-0.95 [-1.39 to -0.51]
Occupation	Crop Farmer	194	Reference	Reference
	Other Occupation	194	0.32 [0.02 to 0.62]	0.64 [0.31 to 0.98]
Working Hours	hours/week	257	0 [-0.01 to 0.01]	0 [-0.01 to 0.01]
Farm size	hectars	257	0.14 [0.05 to 0.24]	0.21 [0.11 to 0.32]
Experience in Agriculture	years	257	0 [-0.01 to 0.01]	-0.01 [-0.02 to 0]
Experience with Pesticides	years	257	0.01 [0 to 0.03]	0.01 [0 to 0.02]
Farming Practice	Conventional	145	Reference	Reference
	Mixed	80	0.37 [0.07 to 0.67]	0.4 [0.07 to 0.72]
	Organic	22	0.11 [-0.31 to 0.53]	-0.25 [-0.74 to 0.24]
	Non-Applicator	10	0.56 [-0.64 to 1.75]	-0.1 [-0.7 to 0.51]



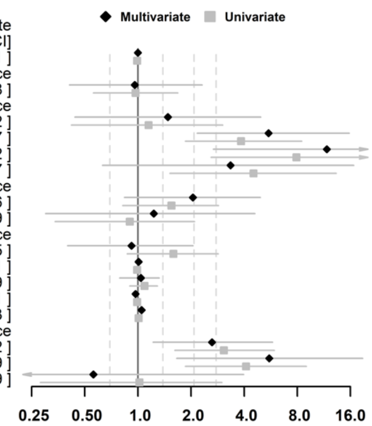
c) Costa Rica Pesticide Training

		n	multivariate OR [95%-CI]	univariate OR [95%-CI]
Age	years	250	1.01 [0.96 to 1.06]	1.04 [1.02 to 1.06]
Education	Less than Primary	73	Reference	Reference
	Primary	102	2.58 [1.22 to 5.51]	3.66 [1.95 to 7.04]
	Secondary	42	3.21 [1.26 to 8.38]	3 [1.37 to 6.71]
	More than Secondary	33	2.92 [0.98 to 8.95]	2.34 [1.02 to 5.44]
Nationality	Costa Rica	146	Reference	Reference
	Nicaragua	104	0.77 [0.35 to 1.71]	0.35 [0.2 to 0.58]
Civil Status	Married, Cohabitation	152	Reference	Reference
	Single, Separated, Divorced	96	0.65 [0.33 to 1.29]	0.58 [0.35 to 0.97]
	Widowed	2	1.02 [0.04 to 28.84]	0.87 [0.03 to 22.2]
Occupation	Farm Worker	148	Reference	Reference
	Farm Owner	148	1.68 [0.76 to 3.73]	3.62 [2.15 to 6.19]
Working Hours	hours/week	250	1.01 [0.99 to 1.03]	1.01 [0.99 to 1.02]
Experience in Agriculture	years	250	1.04 [0.98 to 1.12]	1.04 [1.02 to 1.05]
Experience with Pesticides	years	250	0.97 [0.9 to 1.03]	1.03 [1.02 to 1.05]
Farming Practice	Conventional	146	Reference	Reference
	Mixed	70	0.82 [0.43 to 1.58]	0.76 [0.43 to 1.34]
	Organic	34	3.18 [1.35 to 7.97]	2.3 [1.07 to 5.21]



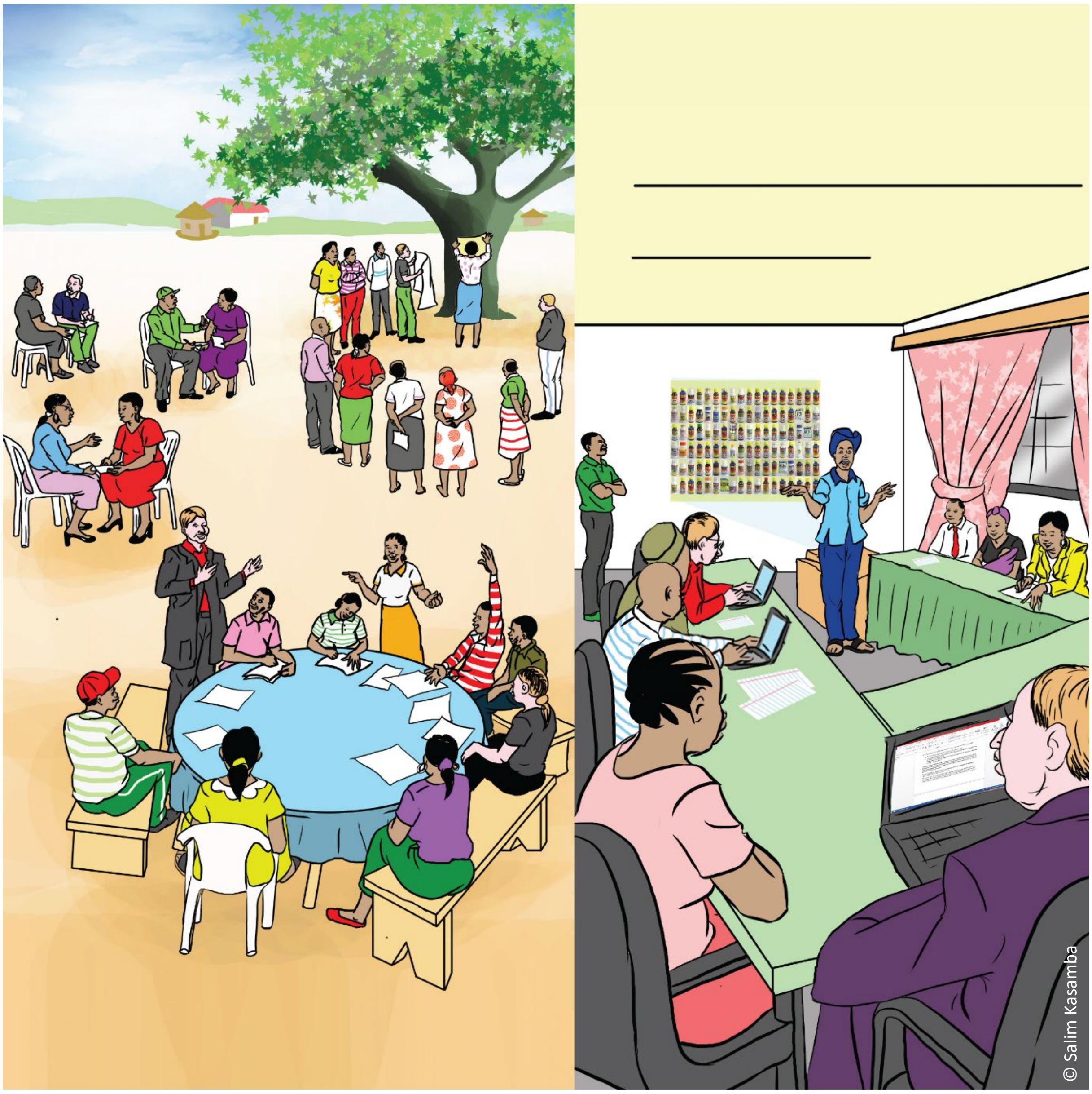
d) Uganda Pesticide Training

		n	multivariate OR [95%-CI]	univariate OR [95%-CI]
Age	years	260	1 [0.97 to 1.04]	0.99 [0.98 to 1.01]
Sex	Female	93	Reference	Reference
	Male	167	0.96 [0.41 to 2.31]	0.97 [0.56 to 1.68]
Education	Less than Primary	82	Reference	Reference
	Primary	58	1.48 [0.44 to 4.96]	1.15 [0.42 to 3.02]
	Up to lower Secondary	91	5.5 [2.17 to 15.74]	3.84 [1.86 to 8.47]
	Up to upper Secondary	13	11.76 [2.68 to 53.92]	7.91 [2.6 to 24.82]
	More than Secondary	16	3.35 [0.63 to 16.67]	4.52 [1.52 to 13.27]
Civil Status	Married, Cohabitation	185	Reference	Reference
	Single, Separated, Divorced	49	2.05 [0.84 to 4.93]	1.55 [0.82 to 2.86]
	Widowed	26	1.23 [0.3 to 4.6]	0.9 [0.34 to 2.09]
Occupation	Crop Farmer	197	Reference	Reference
	Other Occupation	197	0.92 [0.4 to 2.05]	1.59 [0.87 to 2.85]
Working Hours	hours/week	260	1.01 [0.99 to 1.03]	0.99 [0.97 to 1.01]
Farm size	hectars	260	1.04 [0.79 to 1.32]	1.09 [0.9 to 1.29]
Experience in Agriculture	years	260	0.97 [0.93 to 1.01]	0.99 [0.97 to 1.01]
Experience with Pesticides	years	260	1.05 [1.01 to 1.09]	1.01 [0.99 to 1.03]
Farming Practice	Conventional	145	Reference	Reference
	Mixed	81	2.63 [1.22 to 5.79]	3.07 [1.62 to 5.92]
	Organic	23	5.55 [1.66 to 18.74]	4.1 [1.86 to 9]
	Non-Applicator	11	0.56 [0.03 to 3.97]	1.02 [0.28 to 2.99]



Supplementary Figure SF2: a) and b): Forest plot with coefficients for robust regression of logarithmic household income and its predictors. c) and d) Forest plot with Odds Ratio for logistic regression of received pesticide training and its predictors.

Chapter 5



5 Stakeholder Dialogue and Solution Seeking through a Design Thinking Workshop

Submitted to Environmental Science and Policy (08.03.2021) as Wiedemann, R., Stamm, C., Staudacher, P. Promoting smallholder farmers' safe pesticide management in Uganda: Design thinking as a method to enhance academic knowledge.

5.1 Abstract

Uncertainty and knowledge gaps are potential barriers to better understanding complex and wicked problems. In this sense, science plays a crucial role in generating evidence for solution seeking and contributing to a societal transformation. However, researchers may perceive and study problems detached from practitioners' perceptions of the world. We use the example of smallholder pesticide management, a typical wicked environmental problem, to examine the gap between academic and non-academic knowledge. We use the three types of knowledge approach, a framework borrowed from transdisciplinary research, to disentangle knowledge gaps. In addition, we demonstrate the practical application of the design thinking method and its successful implementation in a topic-focused case study in Uganda to gather non-academic knowledge. We discuss and compare this with our own academic knowledge and experience and find that academic recommendations are often superficial and, in our case, too focused on the end-user of pesticides. Non-academic recommendations apply an inherently transdisciplinary and thus broader point of view, accounting for the roles of all stakeholders in pesticide management, for example agro-input dealers and policy-makers. The non-academic knowledge is thus more fine-grained and detailed, exemplifying how a knowledge integration is essential to avoid a gap between what researchers investigate and what practitioners need. Bridging the gap through participatory and actor-centered approaches is critical to align practice, research and policy in their pursuit of sustainability transformation.

Keywords: Design thinking, uncertainty, co-production, knowledge, pesticide management, Uganda

5.2 Introduction

"When the world we are trying to explain and improve [...] is not well described by a simple model, we must continue to improve our frameworks and theories so as to be able to understand complexity and not simply reject it"

– Elinor Ostrom, Nobel Prize Speech, 2009

In midst of ever the growing complexity of environmental issues, their inherent inter-dependencies between stakeholders, jurisdictions and sectors, society is seeking to treat wicked problems[1]. Science[2] has the fundamental task to investigate such wicked problems, reducing uncertainty through scientific investigation and providing evidence for solution design[3] (Cairney and Oliver, 2020; Lemos, 2015). While decision-makers often lack a detailed understanding of the problem characteristics and dynamics (Burger et al., 2015; Ingold et al., 2019), researchers may perceive and study problems detached from involved stakeholders[4] who are in need of applicable solutions (Schäfer and Kröger, 2016). To reach a societal transformation towards sustainability, it is therefore crucial to align research questions with practitioners' perceptions of real-word problems. This transformation is only possible if we take an actor-centered approach towards the co-production of knowledge to evade the "old and powerful myth that any and all science inherently meets society's goals" (Lemos et al., 2018). Using the example of smallholder pesticide management, we want to highlight where knowledge gaps appear between what practitioners need, what researchers investigate, and we discuss how closing these gaps might facilitate a transformation towards sustainability.

Global pesticide use has been growing over the last decades (Zhang, 2018) and has reached a quota of 3.5 billion kg active ingredients per year, amounting to a global market worth 45 billion dollars[5]. Most of the pesticides are used in agriculture to protect crops and yield from unwanted infestations. Benefits of pesticides include the protection of yield, reduction of input costs (i.e. labor and fuel), improving human health by controlling vector diseases (Bourguet and Guillemaud, 2016), improving food quality

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[1] Many environmental challenges facing society today, such as climate change and integrated water management, have been described as "wicked problems" due to their biological, physical, and social complexity Head, B. W., 2019. Forty years of wicked problems literature: Forging closer links to policy studies. Policy and Society. 38**,** 180-197, Rittel, H. W., Webber, M. M., 1973. Dilemmas in a general theory of planning. Policy sciences. 4**,** 155-169.

[2] As science we understand natural science as well as social sciences. Science is generally conceptualized as the quest for knowledge executed by researchers who investigate phenomena to generate academic knowledge.

[3] Solutions can come in different shapes. In this text, we consider public policies as one way of solving societal relevant problems. Other solutions can be market interventions or institutional reforms.

[4] Stakeholders are the ones affected by or influential in an issue, they can be academic or non-academic.

[5] See also: Global pesticide and agrochemical market to 2020: Market size growth and forecasts in over 60 countries, by Report Buyer, last accessed March 8th , 2021

(Aktar et al., 2009), hygiene, as well as pest free groceries due to pesticide use in the packaging process (Damalas and Koutroubas, 2018). As a result, pesticides are beneficial for humans, the environment and economic productivity. However, uncontrolled, excessive, “uneconomic or unnecessary” (Eyhorn et al., 2015) pesticide use outweighs the afore mentioned positive effects. When pesticides are applied in agriculture, entryways of the chemicals into the human body and the environment are multiple. For humans, direct pesticide exposure through skin contact or the inhalation of the sprayed chemicals is most common (Damalas and Eleftherohorinos, 2011). Environmental health is threatened through pesticide spraying in the environment, resulting in soil degradation, water contamination, pest resistance, biodiversity loss (Reynolds et al., 2015), and loss of ecosystem functions (e.g. pollination of crops (Gallai et al., 2009; Sánchez-Bayo and Wyckhuys, 2019)). Balancing benefits and cost of pesticide use poses a particular challenge for agriculture-based regions, which often are located in low–and middle–income countries (Khan et al., 2015; Rother et al., 2008). In these contexts, agricultural production is often dominated by smallholder, subsistence farming, where awareness and formal education are often lacking, making pesticide applications a risky business, with potential harmful effects on farmers’ and environmental health.

Problems related to pesticide management are characterized by a high level of uncertainty regarding causes, effects and solutions, and are thus, typically for environmental issues, considered wicked problems (Balint et al., 2011). The inherent interdependence between application, consumption, and public health falls in line with other sustainable development challenges like water management or climate change. Solution-seeking is typically challenged by opposing interests and underlying conflicts. Public policies failing to capture societal problems and context, or mismatch means and ends are unlikely to succeed as solutions (Ansell et al., 2017; Howlett, 2009). Researchers can ameliorate this situation by facilitating innovation and exchange of knowledge (Delgado et al., 2019).

Transdisciplinary (TD) research distinguishes between academic and non-academic knowledge. An integration of both is necessary to create a common understanding of wicked, real-world problems and to reach societal transformation (Hoffmann, 2016; Hoffmann et al., 2017). Problems have to be studied across different scales and levels (Costanza, 2003) and a knowledge exchange beyond academia needs to be facilitated (Klein, 2020; Liu et al., 2018), resulting in a "co-production of knowledge" (Kläy et al., 2015; Pohl, 2008). In TD research, knowledge is typically conceptualized as "three types of knowledge": systems, target and transformation knowledge, which are gathered, exchanged, compared and synthesized from various sources, involving academic as well as non-academic stakeholders to find solutions to real-world problems (Sachs et al., 2019; Schneider and Buser, 2018).

Currently, there is little scientific evidence on the integration of academic with non-academic knowledge to better understand problems or identify solutions for pesticide-related issues in smallholder farming (for an exception, see Galvin et al. (2016); Le Bellec et al. (2012)). Where integration occurs, misunderstandings can be avoided through the creation of a dynamic relationship, which enhances mutual learning and ownership for solutions (Binder and Schöll, 2010). With this paper, we want to close this research gap and consciously integrate academic and non-academic knowledge to answer the following first research question (RQ):

- RQ 1: What is the evidence for a gap between non-academic and academic knowledge related to smallholder pesticide management?

Wicked problems in the Global South are often investigated in collaboration with researchers from the Global North. In this research context, mutual familiarization to overcome socio-economic and cultural differences between researchers and practitioners is necessary (Hurni and Wiesmann, 2014). Additionally, the complexity of sustainability issues requires integrative approaches, which challenge conventional knowledge production and problem solutions (Maher et al., 2018). TD approaches[6] apply participatory and actor-centered tools (Jacobi et al., 2020; Lux et al., 2019) to identify practitioners'[7] needs, disentangle their problems and gather a comprehensive understanding of the problem context. Design Thinking (DT) is such a TD method to identify, define and address complex problems by developing a detailed systems understanding through a holistic and iterative process (Buchanan, 1992; Fischer, 2015). The participatory, bottom–up approach bears possibilities for the involved actors to assume ownership for the proposed solutions and commit themselves to further develop targeted interventions. DT explicitly addresses characteristics of wicked problems such as multi-stakeholder perspectives, social complexity and the difficulty to define a straight-forward solution. With this technique, we stay true to TD approaches as we "start with the issue or problem and, through the processes of problem solving, bring to bear the knowledge [...] that contributes to a solution or resolution" (Meeth, 1978). The DT method has been applied in the Global South to resolve design issues in architecture (Katoppo and Sudradjat, 2015), urban planning (Delz et al., 2015; Raynor et al., 2017) and sustainable business models (Geissdoerfer et al., 2016). Thus far, the DT method has not been applied in situations involving smallholder farmers' pesticide management in the Global South. In this sense, we also want to address the following second RQ:

[6] For an extensive overview of methods applied in TD, see https://naturwissenschaften.ch/co-producing-knowledge-explained (last accessed: March 8th , 2021)

[7] Practitioners are the actor group corresponding to practice, we capture non-academic knowledge through their perspective, for more information who they are within our research, see Methods section.

- RQ 2: How does design thinking successfully support gathering non-academic knowledge related to smallholder pesticide management?

This paper is innovative, as we match the consecutive steps of DT to the three types of knowledge and enable practitioners to co-produce knowledge. To apply the DT method, we use different tools which we implement in a workshop with 33 participants from different sectors (i.e. health, environment, trade) and levels (i.e. national and local) in Uganda related to smallholder farming. Based on the results from the workshop we then compare our own academic knowledge and with the experience of practitioners. In addition, we conclude how our approach contributes to problem definition, solution identification and facilitates a cross-fertilization of knowledge from practice and research, thereby contributing to sustainability transformation (Wickson et al., 2006).

In this research, we expect to find a gap for the three types of academic and non-academic knowledge. Systems knowledge lays out how stakeholders perceive the problem. We therefore expect different prioritizations of systems' boundaries, components and processes. Target knowledge grasps the actors' values and beliefs related to a more desirable future. Here we expect practitioners prioritizing targets, which are covered only to a limited degree by academic work. Furthermore, we expect a target knowledge gap to be a potential explanation for non-effective interventions, focusing on 'artefact' problems deduced from prior research as opposed to 'real' needs of affected non-academic stakeholders. Transformation knowledge captures how to move from the problem situation to a more desirable future. We expect non-academic knowledge to be more fine-grained and adapted to the specific context, thereby providing insights on obstacles hindering successful implementation of research-recommended solutions.

The remainder of this paper is structured as follows: in the Methods section, we introduce our case, the DT method, our expectations related to its application, and our criteria for the workshop evaluation. In the Results section, we elaborate on the findings from the workshop and the three types of knowledge gathered from practitioners, as well as whether the workshop can be considered a success in terms of knowledge production. We then discuss the gaps within the three types of knowledge and assess crucial aspects of DT workshop implementation. We close this paper, with a brief conclusion including recommendations related to closing the gap and an outlook for future research.

5.3 Methods

5.3.1 Case

Our case is located in Uganda, serving as typical example of smallholder pesticide management turning into a wicked problem: Agriculture is considered to be the backbone of the country's economy (Rwakakamba, 2009), accounting for around 40 percent of the GDP and employing 80 percent of its labor force (Karungi et al., 2011). Many of the farmers operate as smallholders, cultivating their own land, providing food for their own families and selling surplus on local markets. A growing number of farmers are cultivating products for commercial purposes. Major crops are beans, maize, (sweet) potato, banana, cassava, coffee, tomatoes, and groundnuts (Staudacher et al., 2020). Pesticides are applied for crop protection, to protect livestock and for vector control. On-farm pesticide management is a growing issue and Kateregga (2012) identifies various challenges regarding pesticide management in Uganda, such as a lack of information on agro-chemicals, violation of the transportation and storage rules, lack of proper storage facilities, inadequate use, handling and application of the products, and inappropriate disposal of empty containers (see also Staudacher et al. (2020)). The various steps along the pesticide value chain (see Figure 1) are governed by a regulatory framework including acts, regulations and policies (e.g. The Agricultural Chemicals Control Act from 2006). Despite the existing regulations, previous studies underlined a lack of compliance, difficult enforcement and illegal practices (Oesterlund et al., 2014; Okonya and Kroschel, 2015).

In Uganda, responsibilities are decentralized, making the local governments the protagonists of enforcement and even of formulating by-laws (Bazaara, 2003). Even more, in relation to pesticide use and management, donor organizations, non-governmental organizations (NGOs) play a crucial role in sensitizing and capacitating smallholder farmers (Delgado et al., 2019). This is why in this case pesticide management and considerations related to the promotion of safe pesticide use are bottom-up processes where a multitude of state and non-state, as well as academic and non-academic stakeholders from different sectors interact and potentially collaborate.

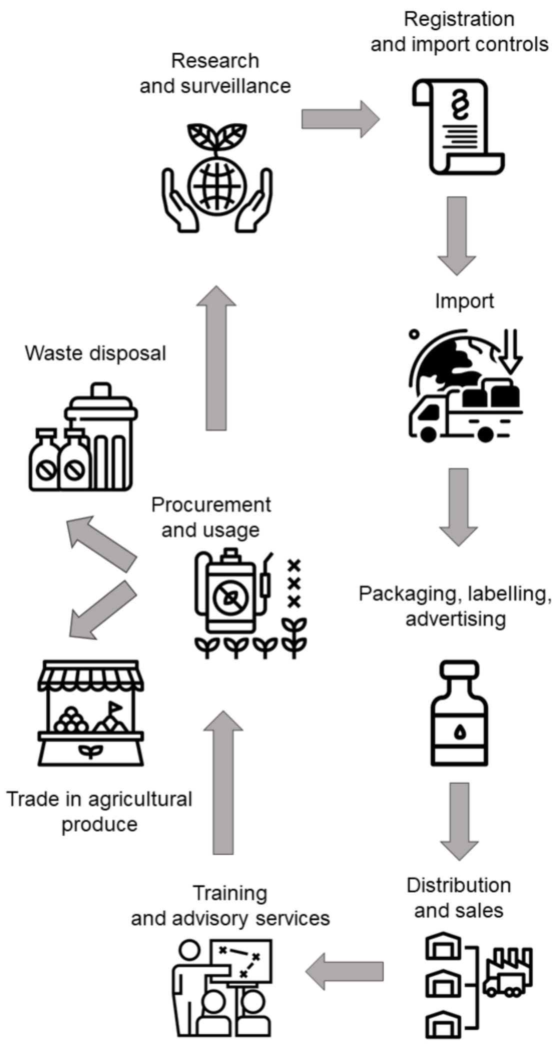

Figure 1: The different steps along the pesticide value chain, own elaboration (This is an ideal-typical representation of a complex value chain; in this simplified chain, we illustrate only the consecutive steps, not interactions which are happening across and between steps.)

5.3.2 Workshop design and participants

The PESTROP project involves four disciplinary studies within Wakiso district, Uganda. The study site is located just 15km north of the country's capital Kampala, which is surrounded by a belt of farms, providing agricultural products to its demanding citizens (for a summary of the project and results, see Winkler et al. (2019)). The study area of the environmental assessment covered parts of the Mayanja river catchment, where streams, wells and boreholes were studied for pesticide residues. In parallel, in the health assessment, 302 farmers from the area were assessed regarding their pesticide exposure, knowledge, attitude and practices, as well as human health effects (Staudacher et al., 2020). Additionally, an institutional analysis, assessed legislation on district and national level regarding their suitability and enforcement of protection from downsides of pesticide use. And lastly, through the socio-psychological assessment farmers' information behavior (Diemer et al., 2020), as well as behavioral factors affecting the use of PPE were investigated.

Our goal was to present our research findings and validate their relevance with the local stakeholders. We consciously chose this stage of the research process to conduct a TD workshop, going against ideal-typical TD setting, where the knowledge exchange is facilitated at the beginning and/or throughout the research process (Hoffmann et al., 2019). To be more specific, we took the dissemination of 'new' academic knowledge (i.e. output from PESTROP project) as point of entry for the TD workshop and used the workshop to confront and validate this knowledge with non-academic knowledge to redefine research questions and problems for two follow–up projects (i.e. two PhD projects, one investigating agro–input dealers and their crucial role in safe pesticide management and one assessing policy actors and their network as determinant of feasible measures to address pesticide risks. See also discussion). To disseminate the results from this research, and integrate academic and non-academic knowledge, we invited a diverse group of 33 stakeholders from different levels and sectors (see Table 1 for more detail) for a participatory two-day workshop. Through our previous field work in the case study area, we were familiar with the relevant stakeholders influencing or affected by pesticide management (see Figure 1). It was our goal to include stakeholders who are crucial for the different steps along the pesticide value chain in Uganda and Wakiso District, respectively. With the support from our local collaborators, we were able to find suitable participants to cover eight of the nine pesticide value chain steps (waste disposal was not covered through our participants) (see Table 1). Stakeholders were originating from different decision levels and sectors, which represents the complexity of the issue covered in the workshop. We furthermore accomplished a balanced distribution among genders, age and hierarchies. However, we did not collect socio-demographic data of our participants.

Workshop facilitation and organization was provided by the first and third author of this manuscript. The two authors selected this format to gather more fine–grained and practice–oriented knowledge to help (re)define research questions for their own PhD projects. They did not have any previous experience in conducting a DT workshop. The middle author was active participant of the workshop and had never participated in a similar format.

Table 1: Participants of the design thinking workshop

Actor type	Level	Group size
Representatives of the Ministry of Agriculture (MAAIF)	National	4
Agricultural extension workers	Local	4
Officers (environmental and agricultural) from district government	Local	4
Farmers	Local	5
Representatives of agro-input business (synthetic or organic pest management)	Local/national	6
Representatives of NGOs engaged in the promotion of safe pest management	Local/national	6
Foreign scientists, three of which lead the process of the workshop	International	7
Total number of participants		*36*

5.3.3 Structure of the workshop to gather three types of knowledge

Two crucial elements of the DT method are the participants (Paulus, 2000), and the structure of the workshop (Dorst and Cross, 2001) involving different stakeholders, thereby co-producing all three types of knowledge (see Table 2): The DT process is composed of six separate, consecutive steps: understand, observe, define, ideate, prototype and test[8]. Understand, observe, and ideate are the steps allowing participants to fully explore values, worldviews, problem and solution perceptions of other stakeholders, which are key traits of wicked problems. The define, prototype and test[9] stages are targeting a synthesis of these different problem perceptions and solutions.

Table 2: The three types of knowledge of TD and DT as a method to gather them

Type of knowledge	Step of DT	Tool
Systems knowledge: *Analytical or descriptive knowledge about specific societal problems*	Understand	Rich picture: grasp mental models of stakeholders (Checkland, 2000; Cristancho et al., 2015)
	Observe	Speed–meeting: exchange problem perceptions (Long, 2009)
Target knowledge: *Normative knowledge about values and norms related to a more desirable future*	Define	"Who needs what because of what?" and "5 why's": come up with a problem statement (Lewrick et al., 2018; Plattner, 2010)
Transformation knowledge: *Practical knowledge about how to transform an existing problematic situation into a better one*	Ideate	Brainwriting: brainstorm about potential solutions (Heslin, 2009)
	Prototype	Storyboard: develop one solution in detail (Andriole et al., 1989)

Gathering systems knowledge. In first two steps of the DT process, "understand" and "observe" we gathered the systems knowledge, which informs about the specific societal problem (i.e. pesticide management) by defining the boundaries, the components and the relevant processes in the system. The outcomes from the first step are the rich pictures (see Table 2). These drawings are a commonly used tool to illustrate the different elements of a problem situation, comprising interactions and relationships (Checkland, 2000). Participants illustrate the different components of a complex situation, share their own perceptions and learn from the exchange with others (Bell et al., 2019; Cristancho et al., 2015). In the second step, "observe", participants discussed, during speed meetings, their open questions regarding 'the issue of pesticides' with other participants. This step was followed by group-wise collection of key insights of the day. To conclude the first part of the workshop, we asked participants to prioritize key insights (see Figure 3).

Gathering target knowledge. The third step "define" unveils the target knowledge, which informs about the perspectives on what a desirable future might look like. While the overall target, safe

[8] For an extensive overview of DT tools, see Plattner, H., 2010. Bootcamp bootleg. Design School Stanford, Palo Alto. and Lewrick, M., et al., 2018. The design thinking playbook: Mindful digital transformation of teams, products, services, businesses and ecosystems. John Wiley & Sons..
[9] The sixth step "test" was not conducted due to lack of time.

pesticide management, was predefined by the workshop facilitators, we used this step to better characterize what sub-targets may be critical for a transformation towards safe pesticide management. Based on the insights prioritized earlier (see previous paragraph), the needs and goals of stakeholders related to the selected insights are compiled and evaluated to define a so-called problem statement (Plattner, 2010). The formulation of a group's problem statement is the essence of the "define" step, where participants enter in a focusing phase (Lewrick et al., 2018). The groups developed clearly understandable and communicable problem statements based on the following formula: *Who (stakeholder group)* needs *what* because of *what (insights)?* (see Table 2 and Table 4).

Gathering transformation knowledge. In the fourth step "ideation", we asked participants to search for new potential solutions to their previously identified and defined problem statement, thus capturing their transformation knowledge. In this phase of divergence, participants opened their minds to anything (im)possible. Using the brainwriting technique, each participant started explaining a potential solution silently in written form, before passing it on to their group members to complement (Lewrick et al., 2018). After three iterations, all options were discussed within the group and each group constructed three main ideas to solve the issue. After a plenary presentation of their three main ideas, each group received feedback from the other workshop participants, where after each group selected one of their three main ideas to be specified in 190 more detail during the "prototype" phase (see Table 2 and Table 4).

5.3.4 Workshop evaluation

Our second research question concerns the feasibility and the implementation of the DT method to capture non-academic knowledge. We gathered feedback from the workshop participants at the very end of the workshop to conduct a critical evaluation. We asked them for one positive and one negative statement about the workshop each. All participants named one or more positive aspects (36 positive remarks) and most of the participants named one or more negative aspect (24 negative remarks). For this publication, we applied the evaluation criteria from (Tobias et al., 2019) (see Table 3), which are typically used to evaluate TD research. We therefore translated and interpreted the participants' feedback to match the evaluation criteria (see Supplementary Table ST 1 for the original feedback).

Table 3: Evaluation of the DT workshop (excerpt and adapted from Tobias et al. (2019))

Objectives	Criteria specifying the objectives
1. Achieve a feeling of joint problem ownership among the project participants	All group members' knowledge is considered important.
2. Facilitate the interaction between stakeholders with different problem perceptions	New perspectives/ideas are developed due to the confrontation with other group members' problem perceptions. Joint products are developed (i.e. definition of new pathways for safer pesticide management).
3. Enable the workshop participants to link abstract (academic) with case-specific (non-academic) knowledge	Experiences with other knowledge types (both academic and non-academic) are integrated. New interfaces between the different types of knowledge (academic and non-academic) are discovered.
4. Encourage the workshop participants to incorporate the shared knowledge in their real-world situations	The participants are motivated to disseminate the jointly developed knowledge in their real worlds. Ideas are generated for new approaches/activities in the participants' own real worlds. Ideas are developed for new cooperations between groups that have not yet worked together.

5.4 Results

The following sub-chapters present the workshop results grouped by the three types of knowledge, following the DT steps applied during the workshop.

5.4.1 Systems knowledge

Participant's systems knowledge was gathered in the first two workshop steps: the participants illustrated their perspectives on how they experience and interact with pesticides in their daily life first individually (Figure 2), followed by a group discussion among peers from the same stakeholder type (Figure 2, see also Table 1). In the following step, participants paired up, and discussed and confronted their worldview with their partners', noting down the most important insights. These key insights were then gathered group-wise, followed by a prioritization across all key insights. Figure 3 displays the summarized results: *Agro-input dealers' services*, as well as *Gaps in policies and regulation* received the most first priority votes, and the most votes overall.

From these two first steps, we gathered that the main stakeholders of interest within the system are farmers, agro-input dealers, government agencies and society as a whole. Processes concern on-farm management (e.g. pesticide exposure, PPE use), distribution of pesticides (e.g., agro-input dealers and illegal pesticides) as well as regulatory processes (e.g. governmental policy formulation and sensitization). The boundaries of the system correspond in major parts to the pesticide value chain (see Figure 1), but components such as training and advisory service as well research and surveillance are of lesser importance.

Figure 2: Individual (left) and group (right) rich picture

5.4.2 Target knowledge

Once the participants had selected their key insights (see Figure 3) they formed seven groups according to their interests in these insights. In each group a problem statement was drafted according to the following formula: W*ho (stakeholder group)* needs *what* because of *what (insights)*? The problem statements inform on the importance of goals, or in other words what they regard as relevant sub–target knowledge in the system to reach the overall target of safe pesticide management (see Table 4). Due to the large interest in the topic, 'the future of organic farming' was split in two groups (Figure 3). Participants perceive farmers, extension officers, agro-input dealers and government agencies to be the main stakeholders mentioned in the different sub-targets for safer pesticide management. While these stakeholders are covered along the steps of the pesticide value chain (see Figure 1), industry, research agencies as well as large-scale pesticide distributors were not regarded key stakeholders within the sub–targets, hence they are not as crucial in a system of safe pesticide management. Sub–targets in the quest for safe pesticide management are related mainly to enhanced skills, information and training.

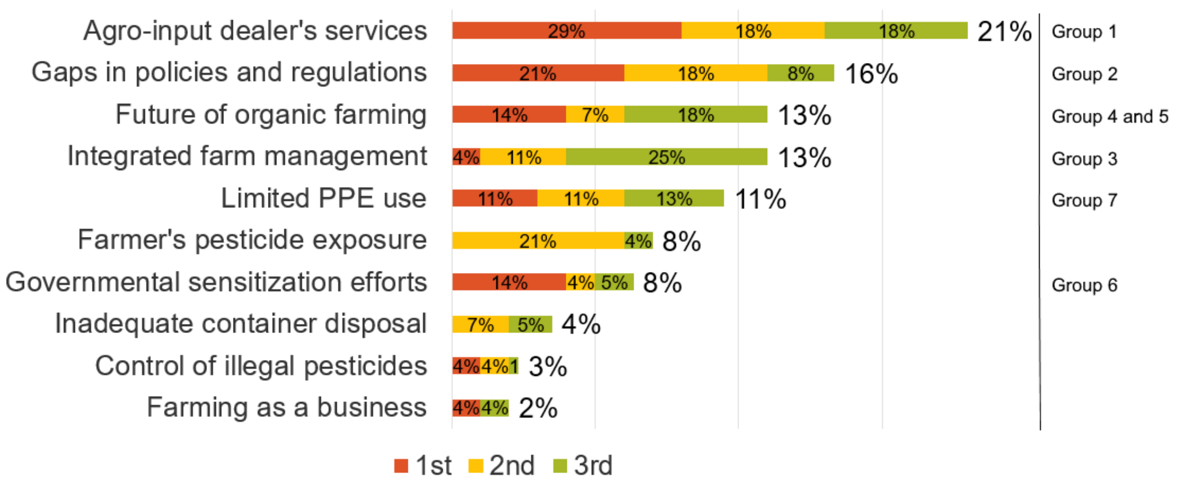

Figure 3: Prioritization of insights: Numbers inside color band indicate share within respective color. Number at outer end indicates share of total votes independent of color. PPE: Personal protective equipment.

*Table 4: Summary of the three types of non–academic knowledge. *Original: indicating unchanged phrasing from the workshop. Abbreviations: CSO, community service organisation, IPM, integrated pest management, MAAIF, Ministry of Agriculture, Animal Industries and Fisheries, MoH, Ministry of Health, MoWE, Ministry of Water and Environment, NGO, non-governmental organization, PPE, personal protective equipment, PR, Policy and Regulation*

System knowledge (Group formation, original*)	**Problem statement (Original*)**	**Target knowledge (Authors' interpretation)**	**Transformation knowledge (Original*, selected solutions in italics)**
Group 1 Agro-Input De*alers:* *Are they offering the best service to farmers?*	Agro-input dealers need more professionalization because they need to give accurate subscription and instructions along with safe use and handling of chemicals to the farmer.	Professionalized agro-input dealers.	*Customized, decentralized training at low cost.* Certification label of for good practices. Restrictions and penalties for noncompliance.
Group 2 Policy and Regulation: Gaps in PR and PR implementation challenges	The government of Uganda needs to revise the existing public health and environmental policies because they need to safeguard consumers from indirect pesticide exposure in food and water.	Revised existing public health and environmental policies.	*Research: there is need to undertake research by both public and private players (Research institutions, CSO), to generate facts on consumer exposure to pesticides and existing policy groups.* Bench-marking: relevant policymakers (MAAIF, MoH, MoWE, Parliamentarians on selected committees) need to undertake visits to countries with good consumer protection policies to learn best practices. Stakeholder consultations: The relevant policymakers (see above), need to spearhead the process of consulting different players at different levels to generate ideas on protecting consumers from pesticide exposure to inform policy formulation.
Group 3 Integrated Farm Management: Prevention before curation	Extension workers need more support because they need to close the farmer knowledge gap for adopting integrated pest management.	Supported farmers by extension officers to adopt IPM.	*Recruitment and training of extension staff.* Coordinate and harmonize activities of involved partners. More resources for doing extension work.
Group 4 Future of Organic Farming A: market access, policies, volumes of bio-pesticides	Farmers and the entire community need organic farming information and accessibility of organic inputs because they don't know the benefits of organic farming.	Farmers and entire community informed about benefits of organic farming.	*Sensitization through organized community meetings, development of flyers, radio talk shows on organic farming, WhatsApp groups to farmer communities, establish demonstration sites.* Avail organic farming inputs to the community through establishment of organic agro–input centres within the farming communities. Government develop policies that support promotion of organic farming; these can incorporated in work plans and budgets for extension workers.
Group 5 Future of Organic Farming B: market access, policies, volumes of bio-pesticides	Extension workers need technical explanations because they are the ones who can change farmers' attitude towards organic farming.	Technically skilled extension officers.	Refresher courses for extension workers. *Farmer group formation and establishment of demo sites/exchange visits.* Regular Monitoring + Evaluation.
Group 6 Sensitization: Missing on all levels	Farmers need more information on pesticide use from the extension workers, NGOs and other organizations because some agro input dealers also lack information about pesticide use.	Farmers informed by extension workers, NGOs and other organizations about pesticide use.	Government trains extension workers and agro–input dealers and awards them certificates. Employ agents which routinely visit the farmers and report back to the extension workers. *Drama group with live music about pesticide use.*
Group 7 PPE use and Pesticide knowledge: Lack of best practice	Farmers need PPE to be less expensive because they cannot afford it.	Affordable PPE.	*Bulk purchase of PPE: Farmers form association/groups for bulk purchase of PPE at discounted amount and reduced transport cost.* *Tax reduction: Government to reduce tax on PPE and compensate by increasing a relative percentage of tax on pesticides. Also should create policies that encourage local production of PPE, e.g. low interest rate loan for local manufacturers.* Increasing farmers income: through encouraging formation of savings groups/cooperatives /farmer union/associations for cheap and quick access to loan for the purchase of PPE.

5.4.3 Transformation knowledge

In the "ideate" and "prototype" phase of the workshop, participants were encouraged to brainstorm about potential new ways forward. The proposed solutions (Table 4, 4th column) show which aspects are crucial to consider prior to designing interventions and public policies. On a macro level, one important aspect is the decentralization of training and services provided by central government agencies (Group 1). Extension officers and agro-input dealers often lack the financial resources to attend or reach a training in a bigger town (Group 3). Training activities might thus fail and these actors lack proper education, which is essential as they are the information providers to farmers. Incentives such as certificates of attendance (Group 6) as well as restrictions or penalties (Group 1) are furthermore considered key to enhance professionalization of these actors. On a meso level, coordination is a key aspect for successful interventions and public policies (Group 3). Coordination among central and decentralized agencies is key. To achieve coordination, workshop participants have mentioned consultations as a potential platform for fostering collaboration and exchange, or linking these agencies via research projects (Group 2). Furthermore coordination among different initiatives (e.g. interventions by NGOs and training by extension officers) is also crucial to avoid overlaps and inefficiency. On a micro level, financial and human resources are key for compliance and success. Farmers, extension staff and agro-input dealers need financial support to afford equipment, transportation and gasoline costs (Group 6 and 7). A lack of financial as well as human resources impedes the system to reach a transformation towards safe pesticide use (see Table 4 for a summary of the gathered non–academic knowledge).

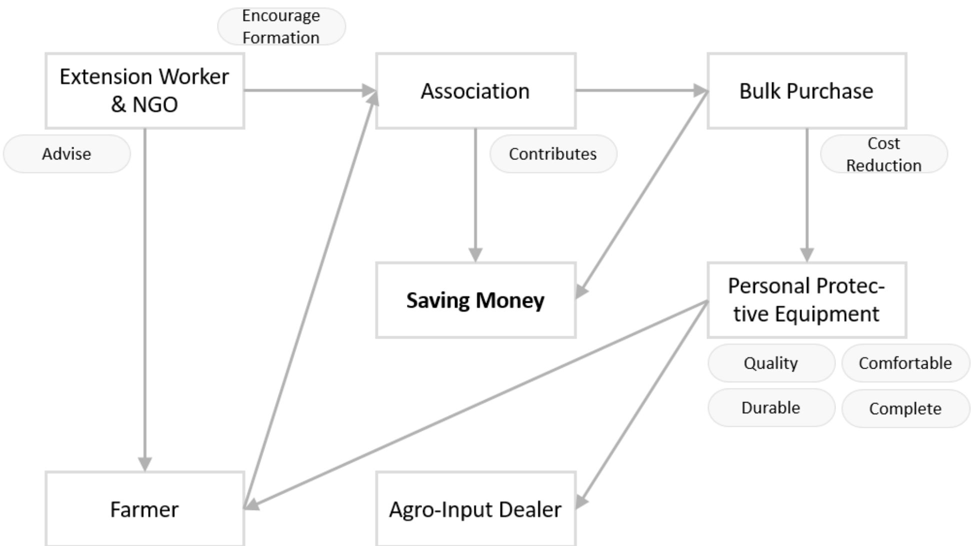

Figure 4: Prototype of the PPE group to purchase PPE in bulk. The original drawing is missing contrast, we here display an own digital rendering of the drawing.

In the paper-based "prototype" step of the workshop, in which participants elaborated on their preferred solution, these macro, meso and micro components become even more evident. We show one illustrative example for a prototype: the PPE group, which elaborated to the bulk purchase of PPE (see Figure 4). The group suggested farmer associations buy durable, comfortable personal protective equipment of quality in bulk. The saved money will be forwarded, benefiting agro-input dealers and farmers.

5.4.4 Implementing the DT method to facilitate co-production of non-academic knowledge

We successfully gathered and confronted different types of knowledge in the workshop. To evaluate this success, we translated the feedback given by the participants (see Supplementary Table ST 1) to evaluation criteria as defined in the Methods' section. First, our workshop process reached its first objective of achieving joint problem ownership by all participants. By mixing individual, group-wise and plenary sessions and by integrating non-academic and academic participants in each group everybody's voice was heard and participants felt part of both problem and solution. Additionally, at the beginning of the workshop, rules were defined, guiding through the entire process and enhanced ownership of the process. Participants mentioned in the feedback session that they felt it was a truly participatory process and that the academic knowledge was integrated well in the workshop. Second, the workshop enabled stakeholders to interact, but only to a limited extent. The workshop delivered some practical ideas for solution (see Figure 4). However due to time constrains, the workshop lacked the development of a joint product. Participants thus criticized the workshop for being too short and lacking the inclusion of all relevant stakeholders (e.g., stakeholders representing waste disposal, see Figure 1). Third, workshop participants linked academic and non-academic knowledge. Non-academic participants were confronted with research findings, which was generally considered a positive output. Researchers were confronted with non-academic knowledge which led to the formulation of new research questions and follow-up research projects (see Discussion). Forth, even though participants were encouraged to incorporate and apply the gained knowledge in future projects (by gathering commitments in the very last part of the workshop), we lack an account of whether these commitments yielded action. Lastly, we provided space through the extensive breaks, allowing participants to make new acquaintances, developing new opportunities for collaboration.

The workshop was implemented successfully thanks to different organizational and more informal aspects. First, the same moderators guided through the process and followed a pre-defined time-line. Second, the venue of the workshop provided a large hall with space for group tables as well as a plenary with a sound system, beamer setup and complete catering. Participants felt very comfortable in this space and appreciated the venue. Third, we kept participants active in extensive opening and closing activities on each day. We provided coffee breaks and lunch, made sure to take a group photo and to include ice breakers, energizers and warm-ups to keep the atmosphere friendly. The entertainment component of this workshop was also highly appreciated and participants underlined that "it was never boring" (see Supplementary Table ST 1).

5.5 Discussion

5.5.1 Discussing the knowledge gap...

In this paper, we gathered non-academic knowledge on pesticide management, as an example for a wicked problem in need of well-designed solutions. The following chapter discusses to what extent this gathered non-academic knowledge is different from our own academic-knowledge and whether we find a knowledge gap within each of the three types of knowledge. We also discuss to what extent the DT method lends itself to gather and integrate different types of knowledge, and close potential gaps.

5.5.1.1 ... in systems knowledge

To our best knowledge, research on pesticide management in contexts related to the Global South has been focusing on on-farm management among smallholder farmers in the Global South, whereas agro-input dealers' practices and knowledge have gained little attention so far (for an exception, see Lekei et al. (2014)). Even more, pesticide policies, their formulation and enforcement have been investigated only to a limited degree (Karlsson, 2004; Mengistie et al., 2017; Van Hoi et al., 2013). However in the workshop it became evident that farmers are not exclusively responsible, but fall victim to the system actors surrounding them: the agro-input dealers as most immediate source of information on pesticide management and the government agencies as regulator of pesticide management practices. Such gaps in research could be closed through integration of insights from participatory approaches: In our case, the participation of practitioners from a diverse background (i.e., farmers, local government officials and pesticide retailers) enabled us to gather more detailed systems knowledge, confirming our expectation related to systems knowledge (i.e. differences in the academic and non–academic prioritization of systems' boundaries, components and processes).

5.5.1.2 ... in target knowledge

Safe pesticide management is not a straight–forward target, and the participants of the workshop selected seven different sub–targets which ought to be reached to ensure safe pesticide management in Wakiso District and Uganda (shown in Table 4). The first identified sub-target was "Professionalized agro-input dealers" (Group 1). Often these actors are the major source of information for the farmers and primarily contribute to how pesticides are applied on the field. There is little research on agro-input dealers and their information behavior (receiving and providing information). However some studies acknowledge agro-input dealers (or retailers) as crucial actors of the system and see their key role as information-providers (Jallow et al., 2017a; Jallow et al., 2017b; Wang et al., 2015). The second sub–target is "Revised existing public health and environmental policies" (Group 2). This sub-target was taken up by research and pesticide policies related to environmental and health protection are subjects of scientific investigation (Loha et al., 2018; Mengistie, 2016; Mol, 2009). Most of these studies come to similar conclusions: policy revisions are necessary to protect humans and the environment from pesticide risks. However, we could not find studies investigating how this revised legislation could look like and how politically feasible these different options are. Sub–targets three, four and six revolve around informed farmers who need more information related to organic and conventional farming to improve pesticide management decisions. As mentioned before, research on individual farmers is dense and many studies investigate their knowledge, attitudes and practices related to pesticide management. Even more, the effect of better information and training on the farmers' willingness to adopt organic farming or more sustainable farming practices have been investigated (Aidoo and Fromm, 2015; Ma et al., 2017). Group 5 considered "Technically skilled extension officers" a crucial sub–target for safe pesticide management. Research on extension officers and agents themselves is rare, but they are considered key in farmers' pesticide management practices and clearly play an important part in resolving farmers' unsafe pesticide management (Abadi, 2018; Hashemi et al., 2012; Timprasert et al., 2014). And lastly, "Affordable PPE" is regarded another key sub–target for safe pesticide management. Making PPE more affordable to farmers has been discussed in research, which even proposed several ways of reaching this target (Feola et al., 2012; Henry and Feola, 2013). Target knowledge is the normative component in transdisciplinary research and it is neither right nor wrong. However, we find key actors of the system and their needs to be covered only to a limited extent by research, such as questions related to agro-input dealers, government agencies or consumers. Their needs have to be considered a fundamental target in research to eventually design situation-improving interventions. By applying a TD approach and taking non-academics and their target knowledge into account, researcher can learn to shift their focus and provide the desired evidence.

5.5.1.3 ... in transformation knowledge

We acknowledge that some solution proposals from the workshop have been covered previously, e.g., sensitization programs in communities to inform about the (dis)advantages of pesticide use (Hashemi et al., 2012; Jørs et al., 2014), necessity to establish farmers cooperatives (Zhu et al., 2014) or the importance of monitoring and surveillance along different steps of the pesticide value chain (Houbraken et al., 2016; Vaidya et al., 2017). Nevertheless, the workshop provides necessary, context-specific details to enhance intervention or even policy effectiveness on the macro-, meso- and micro-level as well as the feasibility and enforcement of interventions or public policies. Coordination among different agencies, as well as the provision of financial and human resources are key for successful solutions and a transformation towards safe pesticide management.

5.5.2 Making a participatory process work

The following paragraph discusses the various aspects contributing to a successful implementation of the workshop, as well lessons learned for future research.

An exchange between academic and non-academic stakeholders is desirable at the very beginning of a project, e.g., to formulate research questions or to test feasibility, or throughout the project to enable feedback and enhance mutual learning. We conducted the workshop at the very end of a research project (in the dissemination phase) and just before two–follow up projects. We conclude, that this timing is in many ways beneficial as well. First of all, in the complex thematic and societal context in which we operated, case knowledge, familiarity with the needs of stakeholders and an established network is necessary to conduct and implement a workshop. Thanks to our exceptional long-standing research collaboration with local partners (established even before the PESTROP project started), we had access to a diverse set of participants and had already been in touch with a majority of them prior to the workshop. Second, by conducting the workshop at the end of the research project, we were able to reflect upon results with the stakeholders involved in the issue under investigation. The workshop enabled us to validate our findings and unveil the gap between academic and non–academic knowledge. A major finding of the workshop was the need to investigate agro-input dealers, which play a crucial role as pesticide distributors and information source for farmers. This insight was used to design and conduct a follow-up project investigating knowledge, attitudes and practices of 402 agro-input dealers in Uganda (Staudacher et al., submitted).Other key insights, such as the need to revise legislation, has brought about another research project investigating how stakeholders from different levels and sectors collaborate to regulate pesticide management. Both these follow-up studies have benefited largely from the timing of the workshop at the project end. This shows that while the timing for a TD setting is described to be most adequate at project beginning, it can also be beneficial at a later stage. This is due to a dynamic research setting, where projects often cascade into each other, expanding the necessary knowledge along the way.

5.5.2.1 Critical self–reflection of authors as facilitators and as participant in the workshop

Our dual roles as authors of this paper and either facilitators or participant of the workshop demands for critical self–reflection. We consider three aspects critical and use them as point of entry to discuss our dual roles. First of all, transparency about our dual roles is crucial to ensure our credibility. Throughout the manuscript, we remain transparent about our roles and dedicated a part of the Methods' section to it. In our dual role as facilitators and lead authors, we organized the workshop as a dissemination event, without considering its effect on our own research agendas. Within the PESTROP project, integration of the different disciplines and stakeholder groups was challenging and the workshop was a tool to facilitate integration. We, the lead authors, had little experience in organizing a similar event and were surprised about the positive outcome. Academic and non–academic participants engaged actively throughout the two days and feedback was overall positive. This way of confronting our own academic experience and knowledge with non–academic knowledge proved beneficial for our own research agendas (e.g., we reformulated research questions, extended our network and gained trust of stakeholders). Even more, this way of co–producing knowledge changed our own approach to research and we shared our experience in various conferences and presentations. The middle author also held a dual role, as co-author and active participant in the workshop. As a participant, he had no prior experience with a DT workshop and has no active role in planning and implementing the event. Even more, he was skeptical regarding the process and the challenging structure of the workshop and therefore questioned whether it would generate a useful output. However, he was positively surprised that stakeholders participated so actively in the workshop and that as a researcher he gained additional knowledge.

Secondly, our dual-role might tempt us to be biased towards presenting the workshop as successful. To measure success, we collected feedback from the participants which is reported on in the results' section. We also used the newly gained knowledge of the workshop to re-define our research agenda and set up a completely new study investigating knowledge, attitudes and practices of agro-input dealers in Uganda. On the one hand, we claim that this workshop was successful, because participants exchanged knowledge and on the other hand, because it informs our own research. This shows that participation at such workshops can enhance researchers' own understanding of complex problems, and support project design as in our case.

Lastly, we discuss a gap between non–academic and academic knowledge and while we gather the non–academic knowledge systematically, we fall back on our 'own' academic knowledge to analyze the gap. In this sense, we don't claim that our 'own' academic knowledge represents the entire academic knowledge, but the workshop and the insights into non-academic knowledge enable us to unveil aspects of pesticide management which we were not able to deduce from existing literature. Furthermore, these non-academic insights are key for a better understanding of real–life problems (which is the justification to engage in TD research), hence we were able to gain knowledge which is of utmost importance to the academic world.

5.5.2.2 Strengths and limitations of the design thinking method

The DT method lends itself well to discuss wicked problems and innovative solutions: First, it enables the participants to follow a clear structure with alternating elements of flare and focus. The DT "recipe" of the six consecutive steps forces a systematic approach on the participants, which helps to keep heterogeneous groups in line with the process and worked nicely despite the various backgrounds of participants. Second, even though the structure is set, within the different steps, facilitators are free to try different methods and experiment with innovative participatory approaches (see different tools used, Table 2). Third, the approach is balancing rigidity and flexibility, thereby remaining adaptable to various settings and groups of participants.

A major limitation of the DT method is its dependency on an adequate participation of stakeholders. The application of flare and focus elements needs to be clearly guided, to avoid participant distraction. Heterogeneity and group dynamics can further impede the DT process: Hierarchies, societal norms, prejudice, different levels of mental ability or courage need to be addressed by the facilitators and resolved where possible (in our case through ice breakers and an informal setting, such as coffee breaks and first-name basis). Additionally, long-lasting learning and a shift towards more responsible pesticide management are not guaranteed through this process, but the application of such knowledge exchanges as standard tools can support the formulation of research questions.

5.6 Conclusions

Our expectations related to the knowledge gap in all three knowledge types were confirmed and unveiling these gaps enabled us to provide novel insights. A major finding of this research was, that not all conducted research represents the practitioners' problem-perception and needs. Some links (e.g., between actors and sub–targets) that we unveiled within the workshop would not be deducible by simply consulting existing academic knowledge. Research may fail to incorporate and reflect the reality of people living within the studied system. While previous studies investigate farmers' attitudes and risk perception, the workshop has shown that for a transformation towards safe pesticide use, research needs to broaden its scope away from applicators to other stakeholders such as agro-input dealers or decision-makers. By studying the various stakeholder from local applicators to international manufacturers, research can provide a systemic understanding of the problem situation, thus leading to better-informed decisions. To close the knowledge gaps, it is necessary to build strong bridges between research and practice through participatory approaches, fostering exchange and enhancing understanding. Closing this gap however, has at least two pre-requisites that seem difficult to be met in research: first, establishing long-term relationships, which are however not always compatible with funding schemes. Second, maintaining long-term relationships which is conflicting with the time researchers dedicate to writing publications and applying for funding.

Closing the gap between academic and non-academic knowledge or between research and practice contributes in various ways to a sustainability transformation: for practice, closing the gap can foster ownership and acceptability of solutions. The more different stakeholder groups participate in knowledge production, the more the feel part of the solution (Fischer, 2015). By closing the gap, research can escape the pit-falls of disciplinary silos and oversimplification of complex issues (Francis et al., 2008) and instead use innovative, integrative approaches to understand complex real-world problems (Söderbaum, 2006). For policy, closing the gap is fundamental, as decision-makers are in need for evidence to design, targeted public policies, select policy instruments for behavioral change and implement these to reach a desirable societal outcome. By including the perspective of stakeholders prior to decision-making, issues related to compliance as well as differences between decision-makers and target-groups can be addressed and solved upfront (Podesta et al., 2013; Turnpenny et al., 2009). Participatory approaches are therefore valuable to policy analysts to "focus carefully and reflexively on the nature of the policy problems, their evolution, the experience and knowledge of relevant stakeholders and the prospects of effective action in different situations" (Head, 2019).

Participatory and actor-centered approaches to collect non-academic and academic knowledge help bridging knowledge gaps across practice, research and policy, as they allow us to grasp the full complexity of (wicked) problems, aligning the different problem perceptions and formulating project goals and research questions accordingly. Most importantly, when stakeholders feel comfortable and secure, they are more inclined to voice their needs and knowledge. It is therefore crucial to provide venues with room for exchange and collaboration, to foster a broader understanding within and across stakeholder groups.

Furthermore, testing and implementing new tools and methods to facilitate participatory approaches contributes to closing the gaps. It is thus important to consider the following aspects before planning a participatory process: First, to fully include non-academic knowledge, workshops should be conducted at the very beginning of a research project, and thereafter repeated at various stages of the project, including at dissemination. Second, practice makes perfect: For beginners it is recommended to pilot workshops prior to their execution with "real" stakeholders. Third, to obtain the desired results of knowledge exchange, participant selection should be executed carefully. Forth, it is important to plan sufficient time and space to flexibly adapt to unexpected events or problem complexity. Fifth, to avoid process domination by single stakeholders, it’s important to address hierarchical and other obstacles openly and alleviate them where possible.

Lastly, we want to briefly address potential research outlooks to investigate aspects of interest from this kind of knowledge integration. First and foremost, any research project targeting a socially relevant research question should be planned in a way to include a knowledge exchange from the beginning. Second, future research should investigate the effect of these workshop formats on participants. To be more precise, a long–term evaluation of the degree to which researchers include the non-academic knowledge in their projects and to which practitioners further develop interventions and solutions as proposed in the participatory process is suggested. Third, to further legitimize the inclusion of participatory methods in research projects, participants' acceptance and support of these methods should be investigated.

5.7 Acknowledgements

The icons used in Figure 1 are obtained under creative commons license from thenounproject.com ("regulation" by Martin Markstein, "importers" by priyanka, "chemical" by DinosoftLab, "distribution" by monkik, "training" by Creative Mania, "Farmer market" by Becris, "PESTICIDE" #2208129, "garbage dumb" by Eucalyp, "sustainable development" by Vectors Point).

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5.10 Supplementary Materials

Supplementary Table ST 1: Participant feedback

	Positive	Negative
Organization	Clear plan, good first try Everything very clear Process was easy to understand Never boring	Too few time/more days needed Workshop should consider more/all stakeholders Number of participants should be increased Too little time for the speed dating Role of researchers not clear from the beginning
Methodology	Interaction nice Positive, because they moved a lot Didn't know what to expect, good to have everybody on board Engagement of people Looking forward to the second da Participatory/interactive approach Practical approach Group discussions "one was to use the brain"	Tasks were challenging (writing down things) Difficult to articulate themselves precisely, some might more time than others
Facilitation	Participants had their first name on the name tags Introduction of participants missing Time keeping Good communication Creativity	Give examples of exercise/tasks Time management Music sound interactions More guidance needed throughout tasks/table hosts needed Facilitator per table would be needed The person passing by should give more detailed instructions at the beginning, not when the group is already in the process of working
Content	Research findings very vital/understandable Looking forward to the second day	Provide recommendations Topics not fully exhausted
Technical issues		Sometimes noisy Voice of speakers sometimes too low/microphone requested Slides presented too briefly Handout of presentations requested
Other	Energizer Atmosphere rated positively Enhancing contacts Commitment to actions Welfare (food and hosting) Ambience in the room, venue was perfect	Too much food makes tired

Chapter 6

6 Conclusion

This chapter summarizes the main findings of the research and presents corresponding recommendations to reiterate and close the dissertation.

This four-year PhD dissertation presents findings from three major data collection campaigns. The first two data collections were conducted within the framework of the transdisciplinary research project named ‘*Comparative appraisal of pesticide use in tropical settings: exposure pathways, health effects and institutional determinants*’, commonly abbreviated as PESTROP project, for ‘pesticide use in tropical settings’. One of the dimensions this project explored, was the difference in health effects due to occupational pesticide exposure between smallholder farmers applying synthetic pesticides, and those who did not. This dissertation provides crucial contextual insights to interpret the findings from the study sites in Costa Rica and Uganda, and identify strategies to reduce pesticide exposure in farmers. The preliminary findings of the PESTROP project were shared with stakeholders in a series of workshops in both Costa Rica and Uganda, divided into national and local, academic and non-academic and farmers-specific workshops. For one of these workshops in Uganda, an interactive approach, the design thinking method, was used to validate the findings with the respective stakeholders and foster ownership of the presented results. Following the communication of these results, the third data collection was conducted based on insights gained in these workshops. By taking a step away from the focus on individual smallholder farming towards a more systemic approach, we shed light on agro-input dealers in Uganda, their pesticide sales and advice as well as the safety of their shops. We collected data on both stated and observed behavior. Together these studies provide critical data on farming practices, exposure pathways, information behavior and sales interaction between dealers and farmers, summarized below.

In the subsequent paragraphs we are following the pathway of a smallholder farmer from developing a need and seeking for pest management information in chapter *two* of this dissertation, to buying pesticide products in chapter *three*, handling and applying the products in chapter *four*, and designing solutions to reduce risk situations with other stakeholders in chapter *five*, revisiting the major findings of this dissertation.

Qualitative interviews conducted with smallholder farmers in Uganda revealed that there are two major ways how smallholders develop an information need in pest management: Either when they start a new farming practice (e.g. a new crop), or when receiving disruptive information (e.g. adverse effects experienced in current practice), resulting in a ‘teachable moment’. Following this information need, farmers then actively seek out information from sources within or external to their communities, or they are passively exposed to information, e.g. by listening to what other farmers discuss, without actively reaching out to them. Access to information on organic alternatives is not well integrated within farmer communities, thus most smallholder farmers follow the conventional farming paradigm.

Following this narrative, smallholder farmers sooner or later end up at an agro-input dealer shop, willing to buy synthetic pesticides. While smallholders perceive agro-input dealers as important source of information, not all agro-dealers can fulfill this expectation. The mixed-methods approach we applied in Uganda revealed a gap between self-perception and behavior in terms of advising farmers. Many dealerships are missing appropriately trained staff, they are often neither certified nor licensed by authorities, and rarely present a flawless picture of recommended safe handling practices of chemicals. Furthermore, the knowledge, attitudes and practices of agro-input dealers not always reflect best practice, thereby withholding crucial information on potential negative effects of pesticide use from the smallholder farmers.

The lack of appropriate advice provided by agro-input dealers may be one of the factors, why farmers in both Costa Rica as well as Uganda primarily apply highly hazardous pesticides and not less toxic ones, or alternatives to these chemicals. Our research showed, that farmers which are using the highly hazardous pesticides are less trained in using such chemicals, than those who are not using them (anymore), indicating the possibility that smallholders stopped using pesticides after learning about their effects in detail. Smallholder farmers are not only using hazardous products, but are also rarely expressing preventive behaviors, such as the use of personal protective equipment, or recommended disposal practices of pesticide containers.

Undoubtedly, the results from this research needed to be shared with stakeholders in both countries. Besides conventional meeting formats conducted with local and national governments, NGOs and farmers in both countries, we carried out a two-day workshop in Uganda, embracing members of all the above stakeholders together. A particular focus of this workshop was on developing possible solutions to the identified issues, while in parallel closing the gap between academic and non-academic knowledge. Through the application of an innovative and integrative approach we escaped the pitfalls of disciplinary silos, often leading to oversimplification of complex issues. The participatory- and actor-centered approach allowed to align different problem perceptions, thus identifying opportunities for improvement as well as new research questions, while fostering ownership and acceptability of these solutions.

The following five key insights from the stakeholder workshop on pesticide management were derived from the sharing of problem perceptions, deviating from the original problems studied and identified by the researchers: First, local governments, need strengthening in terms of financial resources, personnel and information to implement regulations as mandated. Second, enhancing collaboration between national and local level governments, as well as coordination across sectors is warranted. Third, policy measures need to be target group specific. Fourth, decision makers on the national level need to be made more aware about human health and ecosystem problems related to pesticide use. Fifth, scientific evidence needs to be presented in appropriate forms such as policy briefs.

From all the above insights, the following recommendations can be derived: A crucial entry point to provide information on choice of pest management strategies is when farmers develop a need and seek out for information. Established information channels should be leveraged to reach farms in these moments, to promote safe use practices, and to make information on integrated pest management as well as organic farming more continuously accessible in farmers' lives. This could for example be achieved by shifting agro-input dealer's business model away from selling products, more towards providing services, thereby also reducing conflicting incentives for themselves. Within the already formalized economic system, governmental and private actors can streamline the flow of necessary information together with products along the value chain. Back with the farmer, context-specific and target-group oriented pesticide training is warranted, focusing on matching the farmers' perceived risk of pesticides with public health evidence. These trainings should be inclusive of not only proper application practices and protection (e.g. following dosage recommendation, triple rinsing of empty containers), but also agronomic measures (e.g. IPM). The large number of farmers with comparably low training suggests that preventive efforts could also be fruitful when leveraging the multiplier effect of other actors along the pesticide value chain, such as agro-input dealers or agricultural extension. Health effects investigated in parallel to this research were studied on a preliminary level, but may have laid the groundwork for much needed, future longitudinal studies.

Our retrospective analysis of the conducted design thinking workshop gave strong insights into what made it successful. Stakeholders are more inclined to voice their needs and share their insights when they feel comfortable and secure. Therefore the choice of venue and program design with room for exchange and collaboration fostered a broader understanding within and across stakeholder groups. Future projects are recommended to follow these five suggestions: First, conduct such integrative workshops at the very beginning of a project with repetitions at later stages. Second, piloting a workshop if it is your first or if it is a new design. Third, careful selection of participants to represent all stakeholders. Fourth, planning for sufficient time and space to adapt to unexpected issues. Fifth, addressing hierarchies and other obstacles openly, thereby alleviating them wherever possible. Future research needs to assess the effect of participatory research projects on participants, as well as participants' acceptance of such workshop formats.

This dissertation reveals, that despite efforts on various levels (farms, local- and national authorities, private pesticide sector), the need for better protection of human health and ecosystems in both study areas remains. Unintended, yet poor practices on all levels jointly contribute to the situation as displayed in this research. While preventive actions on the farm level are important, most problems appear on a systemic level, thus demanding a systemic solution. To convince a larger number of conventional farmers to shift to more sustainable farming practices, best practice examples and showcase projects on a regional or local level are required. These projects are to be managed in close collaboration with local actors, such as farmer associations, private businesses and local authorities. This is to ensure that educational aspects go hand in hand with making appropriate products and services (including non-chemical alternatives) accessible to everyone. Furthermore, farmers should be instructed to always seek advice on best pest and disease management strategies from agricultural experts in their communities before purchasing chemicals intended as solution of last resort.

This research project has exemplified, that for projects with partners in different geographical regions a knowledge exchange in the conceptual phase is necessary and useful to align perceived needs and gaps in knowledge. Closely established, mutually beneficial and equitable partnerships strengthen collaborations across disciplines, ministries and sectors, between academics, practitioners, policy-makers, NGOs and civil society. By transforming the ways in which we work together, we can produce relevant, timely and impactful knowledge to tackle the present challenges of our generation in a holistic manner.

Abbreviations

AD	Agro-input dealer(s)
Agro-Input	Landwirtschaftliche Betriebsmittel
AID	Group in DT Workshop: Agro-Input Dealers
ANOVA	Analysis of variance
AVPM	Agriculture, veterinary, pharmacy or medicine
CCSP	Certification of competency on safe handling of pesticide from the MAAIF Department of Crop Inspection and Certification
CIA	Central Intelligence Agency of the federal government of the United States
CR	Costa Rica
CRC	Costa Rican Colón
Crop Life	Umbrella Pesticide Importer Association
CSOs	Civil society organizations
DAO	District Agricultural Officer
DDT	Dichlorodiphenyltrichloroethane
DT	Design Thinking
Eawag	Swiss Federal Institute of Aquatic Science and Technology
EKNZ	Ethikkommission Nordwest- und Zentralschweiz, Switzerland
ETH	Swiss Federal Institute of Science and Technology
ETH4D	ETH for Development
FAO	Food and Agriculture Organization of the UN
FAOSTAT	Global statistical database of the FAO
FAW	Fall armyworm
FEV1	Forced expiratory volume in 1 second
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
h/wk	Hours per week
HDREC	Higher Degrees, Research and Ethics Committee of Makerere University, Uganda
HHP	Highly Hazardous Pesticide(s)
Ia	Extremely hazardous according to WHO toxicity classification
Ib	Highly hazardous according to WHO toxicity classification

II	Moderately hazardous according to WHO toxicity classification
III	Slightly hazardous according to WHO toxicity classification
IBP	Institute of Biogeochemistry and Pollutant Dynamics at ETH Zürich
IFM	Group in DT Workshop: Integrated Farm Management
IPM	Integrated pest management
IPW	Institute of Political Science at University of Bern
IRAC	Insecticide Resistance Action Committee (modes of action classification)
IRET	Central American Institute for Studies on Toxic Substances at UNA
KAP	Knowledge, attitude and practice(s)
kg/ha	Kg active ingredient per hectare
LD_{50}	Median lethal dose
LMICs	Low- and middle-income countries
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries, Government of Uganda
MoH,	Ministry of Health, Government of Uganda
MoWE	Ministry of Water and Environment, Government of Uganda
MYS	Mystery shopping
NA	Not available
NADEL	Center for Development Economics at ETH Zürich
NGO	Non-governmental organization(s)
NOGAMU	National Organic Agricultural Movement of Uganda
OBS	Sales observation
ODK	Open Data Kit
OFA	Group in DT Workshop: Future of Organic Farming A
OFB	Group in DT Workshop: Future of Organic Farming B
OR	Odds Ratio
p	*p*-value, probability value
PAN	Pesticide Action Network
PESTROP	Pesticide use in tropical settings (Project Title)
PhD	Doctor of Philosophy (from lat. *philosophiae doctor*)
PMC	Pesticide management cycle

PPE	Personal protective equipment; also: Group in DT Workshop: PPE use and Pesticide knowledge
PR	Group in DT Workshop: Policy and Regulation
RQ	Research question
SD	Standard deviation of the mean
SEN	Group in DT Workshop: Sensitization
SNIS	Swiss Network for International Studies
Swiss TPH	Swiss Tropical and Public Health Institute
TD	Transdisciplinary
U	Unlikely to present an acute hazard according to WHO toxicity classification
UBOS	Uganda Bureau of Statistics
Uchem	Department for Environmental Chemistry at Eawag
UG	Uganda
UGX	Ugandan Shilling
UN	United Nations
UNA	Universidad Nacional, Costa Rica
UNACOH	Uganda National Association of Community and Occupational Health
UNADA	Uganda National Agro-Input Dealers' Association
USAID	United States Agency for International Development
USD	United States dollar
WFSC	World Food System Center at ETH Zürich
WHO	World Health Organization of the UN

Curriculum Vitae

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Pesticides are used globally in agriculture, and can have negative effects on human health and ecosystems, especially when not handled as intended. Still, an increasing number of smallholder farmers in low- and middle-income countries are using expensive pesticide products to increase their yield. Little is known about how smallholders develop a need for information and seek out appropriate sources, whether this process differs for organic and conventional pest management strategies and if farmers also focus on risks of pest management practices. Agro-input dealer are supposed to provide information on pesticide risks, but they often focus more on selling products than services. This in turn leads to farmers not knowing about risks, or not considering them to be relevant. Together with a lack in pesticide training, farmers are not always following good agricultural practices, thereby affecting their own health, their communities' and ecosystems. These issues are not resolved in disciplinary silos, but only through cross-sectoral and participatory research and interventions.
In conclusion, this dissertation found that the responsibility of why pesticides are not managed, handled and applied as intended is shared throughout actor levels. Crucial information does not reach the end-user, and where it does, the appropriate tools and equipment to follow the corresponding guidelines are missing. Meanwhile, a lack of awareness from farmers as well as conflicting interests prevent agro-input dealers from providing much needed advice.

Philipp Staudacher pursues trans-disciplinary research on pesticides on the nexus between human health, environment and policy, with a focus on information exchange.
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