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Identifying determinants of pesticide use behaviors for effective agri-environmental policies: A systematic review

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Abstract. Environmental problems demand for innovative interdisciplinary research to tackle problem complexity and provide insights for problem-solving. Along these lines, behavioral insights have the potential to improve the effectiveness of policies by identifying which behaviors are best tackled and how. In this paper, we present a systematic review of the literature on small-scale farmers' pesticide use in the Global South to identify (1) pesticide use behaviors and (2) their behavioral determinants. We defined our body of literature by establishing inclusion criteria and screened studies in a two-step process involving multiple coders. From the selected studies (k = 70), we extracted data about farmers' pesticide use behaviors. We also extracted the determinants of these behaviors with an established framework of behavioral change, the behavior change wheel (BCW). Finally, we show how the behavioral insights thus obtained can provide hypotheses on the suitability and ultimate effectiveness of policy instruments for agriculture and environmental protection. Overall, this systematic approach showcases how behavioral insights can be used to systematically gather new knowledge on what works and why in pesticide policy. Additionally, this paper illustrates that the current literature on pesticide use behavior in the Global South lacks standardized and consistent measures of behavior and determinants to provide valid and robust results. Overall, this hampers evidence synthesis and thus scientific progress in the field.

Keywords: Pesticide use, behavioral determinants, policy instruments, link behavior-policy, behavioral change wheel, Global South Submitted to: *Environ. Res. Lett.*

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1 Introduction

1.1 Background

Agricultural production plays two key roles in sustaining populations all over the world. It ensures food security and thus contributes to economic stability. And it provides regular incomes to farmers around the globe. Consequently, the agricultural sector contributes to both economic stability and an escape from poverty (Nematollahi and Tajbakhsh, 2020). Nevertheless, agricultural production is under pressure from a growing global population, and millions of people still suffer from hunger (FAO et al., 2018). Additionally, to increase agricultural production, many farmers rely on chemical inputs, which damage environmental and human health (Bourguet and Guillemaud, 2016; Tang and Maggi, 2021). The agricultural sector thus faces various challenges related to such issues as ecological sustainability, food sovereignty, and ethical concerns (Feindt et al., 2021). These challenges affect all actors along agricultural supply chains, such as input suppliers, farmers, the food industry, and consumers (Möhring et al., 2020). To regulate these actors' behavior, conventional state-led agri-environmental policy has been accompanied by self-regulation or co-regulation (Daugbjerg and Feindt, 2017). Typical state-led interventions include financial incentives to adopt clean technologies or sustainable farming practices, certifications, and production quotas that limit surplus production (Greer, 2005; Möhring et al., 2020).

However, these policies often have no effect or produce unintended effects (Chang, 2009). Ineffective polices are a threat to human and environmental health, as well as the transition to more sustainable food value chains. The actors along these value chains adopt various rationales for decision-making, and for agri-environmental policy to be effective, these rationales underlying individual behavior need to be investigated (Dessart et al., 2019). Ineffective policies for agricultural production can thus suffer from a misfit between policy instruments selected to change behavior and the determinants driving the targeted behavior, such as motivations, knowledge, and costs. For example, despite a newly introduced tax, individual actors might stick to their original behavior, because this is determined by habit rather than cost. Scholars blame decision-makers for their disregard of the factors that steer target group behavior (Flury-Kleubler and Gutscher, 2001; Howlett, 2018). We argue that policy effectiveness can be optimized if policy design uses techniques suitable for behavioral change to address the psychosocial determinants of the target group's behavior (Burger et al., 2015). Such behavioral insights can be provided by behavioral science, which can help to improve the suitability and thus effectiveness of policies. We will elaborate on (1) the role of individual behavior shaping agri-environmental policy, (2) theories of behavioral change, (3) the link between behavioral insights and policy, and (4) pesticide use as the critical behavior selected to apply behavioral science to agri-environmental policy.

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1.2 The role of individual behavior shaping agricultural production and agri-environmental policy

There is broad agreement on the fact that many complex agri-environmental problems are human-made and that individuals are crucial elements of solutions (Chang, 2009; Möhring et al., 2020). As much as we depend on ecosystem services and environmental integrity such as high levels of biodiversity (Tan et al., 2022) for agricultural production, as consumers and farmers, we exploit the environment and contribute to environmental degradation and thus hamper sustainable agricultural production (Horrigan et al., 2002; Olanipekun et al., 2019; Subramaniam and Masron, 2021). According to the World Wildlife Fund, species decline and biodiversity loss are alarming. "[B]ending the curve . . . is technologically and economically possible, but it will require truly transformational change in the way we produce and consume food" (Almond et al., 2020, 7). Farmers may adopt more sustainable farming practices (Adnan et al., 2019; Foguesatto et al., 2020; Chaudhuri et al., 2021) such as diversifying agricultural production (Senger et al., 2017) and making their own farming systems more resilient to climate change (Mase et al., 2017; Zhang et al., 2020). Farmers' choices can influence the food that reaches our plates as well as environmental changes such as land use and health-related outcomes such as chemical poisoning. These choices can affect both them and society as a whole. Consumers can also affect agricultural production. For example, consumers can affect agricultural supply chains through their attitudes, food preferences, and choices. Consumers' preferences for local or organic food (Yiridoe et al., 2005; Thilmany et al., 2008; Grebitus et al., 2017) or plant-based diets (Rosenfeld et al., 2022) can determine trends in agricultural production and ultimately affect health and the environment at a global scale.‡

Individual behavior thus shapes agricultural production and agricultural supply chains. To address individuals such as farmers and consumers as target groups, agri-environmental policy needs to take behavioral insights into account (Möhring et al., 2020). The decision-making processes, preferences, and choices of these two groups lie at the heart of challenges to agri-environmental policy. Its design can thus be enriched by a proper understanding of the behavioral determinants and motivations that lie at the heart of the behaviors that policies aim to change. Consequently, behavioral science approaches can inform policy makers when designing more suitable agri-environmental policies (Streletskaya et al., 2020) and ultimately help solve complex environmental problems (Vlek, 2000).

‡ We are well aware that other actors such as suppliers, traders, distributors, and retailers play crucial roles in shaping agricultural production. However, these actors are often large firms and corporate agencies, in which individual behavior is less relevant. At the farm level, especially for subsistence farmers, the farmers are the ones taking the decisions related to management (Waterfield and Zilberman, 2012).

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1.3 Understanding behavior and its determinants

Individual behaviors are driven by many factors, such as risk aversion (Von Neumann and Morgenstern, 2007), by the behavior of their peers, friends, and family (Kollmuss and Agyeman, 2002), their individual beliefs and attitudes (Ajzen, 1991; Diekmann and Preisendörfer, 2003), and their individual habits and routines (Stern, 2000). Psychology and other behavioral science disciplines have developed comprehensive theories and models detailing the determinants of behavior change, including the theory of planned behavior (Ajzen, 1991) and the health action process approach (Schwarzer, 2008). These models can be and to some extent have been usefully applied to explain behaviors related to agricultural production and challenges (Senger et al., 2017; Rosas et al., 2022; Zaremohzzabieh et al., 2022). Psychological approaches first identify the determinants of a specific target behavior then suggest interventions to promote behavioral change by changing these determinants. This principle is referred to as theory-based behavior change intervention. In the past decade, the behavior change wheel (BCW, see Figure 1) has been established as a framework that enables the reliable characterization of existing and the development of new interventions (Michie et al., 2011). It is based on a systematic analysis of 19 different behavior change intervention frameworks (Michie et al., 2011), and links behavioral determinants ("conditions") to nine intervention functions that may change these determinants, and seven policy categories that may enable intervention implementation. It has been broadly applied to many different topics, and has been shown to reliably characterize behavior change interventions (including environmental issues, e.g., biodiversity protection; Marselle et al. 2021), and to inform intervention development (e.g., regarding COVID-19 prevention; West et al. 2020b).

At the center of the BCW are the four conditions (capability, opportunity, and motivation) that that form behavior (known as the COM-B model). These three conditions encompass the key behavioral determinants synthesized from multiple behavior change theories. The first condition, capability, may be physical, such as having the skill to wear personal protective equipment (PPE), or psychological, such as understanding the importance of wearing PPE. The second, opportunity, may be physical, such as owning PPE, or social, such as a norm favoring the wearing of PPE. The last, motivation, guides behavior through reflective processes (e.g., conscious decision making, forming a behavioral intention), and automatic processes (e.g., habits and emotions), such as feeling comfortable wearing PPE. See also Table 3. Which of the behavioral determinants is key can vary by behaviors and contexts, and therefore needs to be determined through research. The BCW further links these behavioral determinants to intervention functions, such as education and incentivization, and to behavior change techniques (for a definition of intervention functions, see Table A8 in the Supplementary Material (SM) Online). A behavior change technique is the smallest unit of an intervention that can bring about behavioral change. Finally, and uniquely, the BCW also links the behavioral determinants and intervention functions to policy instruments (see the BCW and the COM-B model in Figure 1).

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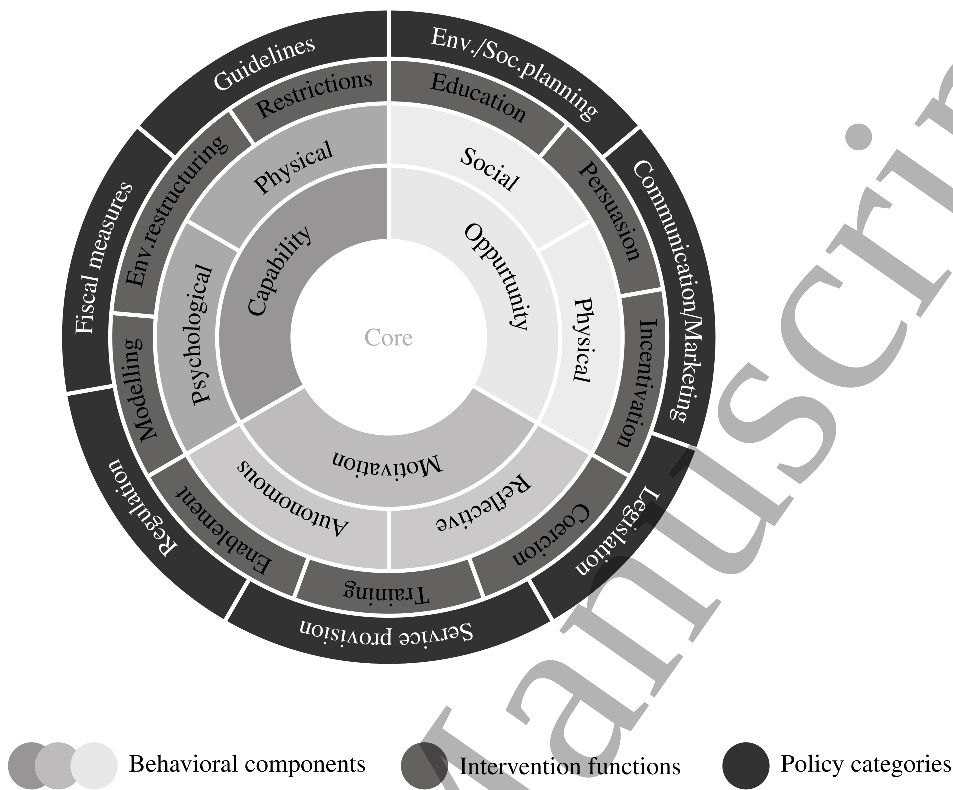

Figure 1: Behavior change wheel (adapted from Michie et al. 2011)

1.4 Linking behavioral science to policies

The policy categories within the BCW are similar to the conventional policy instruments in the public policy literature and facilitate the interventions. Public policies aim to change, trigger, or remove barriers to target-group behavior and to achieve predefined goals (Lasswell, 1958; Salamon, 2000). Policy making is thus about "designing programs and invoking policy tools which encourage behavior in the direction desired by government and discourage it in others" (Howlett, 2018, 103). These policy tools, or instruments, are the active ingredients of any policy that induces behavioral change (Kaufmann-Hayoz et al., 2001). These policy instruments are typically divided into three categories: command-and-control instruments, termed sticks, market-based ones, termed carrots, and persuasive ones, termed sermons. State intervention decreases from the first category to the third (Bemelmans-Videc and Rist, 1998). Sticks operate through mandates and bans that make the undesired behavior illegal, carrots provide rewards for the desired behavior as financial (dis)incentives, and sermons usually include public media campaigns to persuade target groups to engage in the desired behavior (see also Tummers 2019). A fourth category is often added when referring to individual behavioral change: nudges (Thaler and Sunstein, 2009; Campbell-Arvai et al., 2014). Nudges are policy interventions to re(design) choice environments "that facilitate

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personally and socially desirable decisions without restricting people in their freedom of choice" (Mertens et al., 2022, 1). These nudges can for example be used to set the desired behavior as the default, such as setting compensating CO_2 emissions as the default option when booking a flight, or by including information about plant-based options in a retailers' advertisement. These four categories of policy instruments fit neatly into the policy categories proposed by Susan Michie and her co-authors, the developers of the BCW (Cane et al., 2012; Michie et al., 2014). This allows a bridge to be built between social psychology and policy analysis, and the evidence provided by behavioral science to be used to inform decision-makers which policy instruments are suitable for behavioral change (see Table 1).

Policy instruments	Policy categories	Education	Persuasion	Incentivisation	Coercion	Training	Restriction	Environmental restructuring	Modelling	Enablement
Sermon/nudge	Marketing	X	X	X	X				X	
Stick/sermon/nudge	Guidelines	X	X	X	X	X	X	X		X
Carrot	Fiscal			X	X	X		X		X
Stick	Regulation	X	X	X	X	X	X	X		X
Stick	Legislation	X	X	X	X	X	X	X		X
Stick/nudge	Environmental/Social planning							X		X
Stick/carrot	Service provision	X	X	X	X	X			X	X

Table 1: Linking policy instruments with the policy categories and intervention functions of the BCW

1.5 Setting the focus on small-holder pesticide use in the Global South

As one example where the BCW may provide useful insights into policy suitability in agriculture, we choose to focus on smallholder farmers' pesticide use in the Global South. In these countries, a majority of the people sustains their livelihoods in agriculture (Perrings and Halkos, 2015). Along the agricultural supply chain, farmers fundamentally shape agricultural production and thus influence public and environmental health outcomes. Farmers are a relevant target group for agri-environmental policy and farmers' decision-making is shaped by multiple behavioral determinants including risk perception, access to extension services, and knowledge about alternative farming practices (Wyckhuys et al., 2019).

In the Global South, small-scale farmers are often exposed to high levels of pesticides due to lack of protective equipment, climatic conditions, and overuse of pesticides (Abadi, 2018; Akter et al., 2018). Although pesticides can contribute to the small-scale farms' productivity, pesticide also pose a threat to environmental ecosystems and to human health (Bonner and Alavanja, 2017; Hayes and Hansen, 2017; Deknock et al., 2019). While countries in the Global North continue to make pesticide regulation more stringent, in the Global South, regulation and monitoring of pesticide use is challenging, and enforcement is lacking. (Handford et al., 2015). Additionally, small-scale farmers operate in a complex system that involves neighbors, family, extension services, and community-based organizations to obtain information and make decisions (Rees et al., 2000; Lwoga et al., 2011; Diemer et al., 2020). Small-scale farms operate as family

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businesses in which the farmers spray their crops themselves, whereas large-scale farms often employ farm workers and specially trained sprayers to apply the pesticides.

The scope of this research is to bridge the gap between behavioral insights and public policy, using the BCW as a tool. We aim to showcase the value of behavioral science to inform agricultural policy, using safe pesticide use in the Global South as case. The contribution of this paper to literature is thus twofold: first, by synthesizing literature on pesticide use, we gather knowledge about pesticide-related behaviors for definitions and operationalizations as well as pesticide research in general. While such syntheses exist for the Global North (see for exampleDessart et al. 2019; Ranjan et al. 2019), such a synthesis is currently lacking for the Global South. Second, we use a systematic behavioral science approach, the behavior change wheel, to provide insights into the behavioral determinants of safe pesticide use behaviors. From these behavioral insights, we derive policy instruments that are most suitable for steering farmers' pesticide use behaviors.

In the following chapter, we introduce the systematic literature review as our main approach to data gathering. The results section is divided into four subsections, the first focusing on the trend in the reviewed literature, the second on the different behaviors investigated, the third on the behavioral determinants driving small-scale farmers' pesticide use in the Global South and the fourth on the relationship between behavioral determinants and pesticide use behaviors in the Global South. We close with a discussion of suitable policy instruments and an outlook for future research.

2 Methods

2.1 Data collection

A systematic literature review of existing research on pesticide use behavior was conducted to identify the most important behavioral factors (for a similar approach, see Lilje and Mosler 2017). To systematically review existing literature, we followed the PRISMA guidelines (Page et al., 2021) (see section 1 in the SM Online for the detailed checklist). To identify small-scale farmers' pesticide-related behaviors and behavioral determinants in the Global South, we chose four concepts: farmer, behavior, pesticides, and use practices. We identified various terms related to each concept (see Table 2), and we combined these concepts with AND operators and defined keywords, which we combined with OR operators. To exclude irrelevant studies and include relevant research, we developed the search query iteratively (see section 2 in the SM Online for the detailed search string). We conducted a search on the following databases: Web of Science, PsychInfo, Agricola, and Scopus. Over all four databases, we found 1,943 peer- reviewed articles and reviews that were published in the English language between 2000 and 2021 (August 11, 2021).

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Main concepts	**Farmer**	**Behavior**	**Pesticides**	**Use practices**
Keywords	agricultural worker farm* smallhold small hold* small-hold* small-hold* small scale small-scale*	behavior* psychological determinant* psychological driver* psychological factor* social psychology "knowledge, attitude and practice*" attitude* health behavior environmental behavior motivation capabilit* opportunit* "reasoned action"	insecticide* fungicide* nematicid* acaricid* rodenticide* "crop protection product*" "plant protection product*"	"pesticide use" "safe use" "unsafe pesticide use" "pesticide practice" agricultural pesticide* "pesticide management" "sustainable use"

Table 2: Concept and search terms used to define the search string

This primary body of literature was screened in a two-step approach to exclude irrelevant studies and others that did not meet our inclusion criteria. We first screened title and abstract to ensure that the studies were quantitative, questionnaire based, related to small-scale farmers (as opposed to workers, etc.) and to pesticide use behavior. This first step yielded a list of 474 relevant articles, of which we selected 70 after full-text screening (the second step) by seven inclusion criteria: (1) the full text is available; (2) small-scale farmer in the Global South is the unit of analysis; (3) the study is related to pesticide management in agriculture, as opposed to, for instance, pesticide poisoning or suicide; (4) the study provides primary data, as opposed to secondary data from a census or a previous survey; (5) the study collected survey-based data for quantitative analysis; (6) the study specifically investigates determinants of pesticide use behavior as independent variables; and (7) the study explains why farmers do or do not use pesticide safely: pesticide use is explicitly defined as the dependent variable, as opposed to pesticide knowledge or perception.

These screening processes were conducted by the first author and one other coder in parallel. To ensure intercoder reliability during the screening process, a 10% overlap in studies was implemented between the first author and the other coder. To enhance consistency in the application of the inclusion criteria, consistency checks were performed a priori and criteria adapted accordingly. The coders also held periodic meetings to address disagreements about the exclusion or inclusion of specific articles in this review and addressed other related issues.

2.2 Data extraction

To organize the database and extract data, we compiled three coding sheets and one synthesis sheet. To complete the database, we coded metadata indicators such as country, region, farming activity, farming type, study design, sample size, data gathering, use and name of theoretical behavioral

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change model, and methods of data analysis. To extract data about the the dependent variable in the selected studies, we coded the behavior, its definition, and the operationalization by which the authors made the behavior measurable. Next, we organized the data on behavioral determinants, the independent variables of the selected studies, by coding the behavioral determinants, their definition, operationalization, and the scale of measurement. Additionally, we assigned the behavioral determinants to the COM subcomponents (see Table 3). To facilitate the coding, we defined questions and examples to help the coder assign behavioral determinants to one or more subcomponents (Table 3). This code book was developed by both authors, and adjustments were made after various primary iterations of assigning the COM subcomponents to the behavioral determinants (see Table 3, and section 3 of the SM Online). Similar to the screening step, we held periodic meetings to discuss issues and to enhance consistency in the extraction of the data. To ensure intercoder reliability, 25% of the behavioral determinants were assigned in parallel by both authors and a research assistant. There was an 83% coherence in their coding. Finally, we also coded the significant positive (1) and negative (-1) correlation and nonsignificant (0) relationships (for the detailed code book, see section 3 of the SM Online). §

§ In this review, we synthesize literature by showing trends across the studies reviewed. Our synthesis thus remains descriptive: we do not use specific methods for synthesis. We discuss these limitations in the final section of the paper.

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Component	Questions	Subcomponent	Examples
Capability: *understanding why and how to make the change, and having the self-regulatory capacity and skills needed to sustain the change*	1. Do farmers know what safe pesticide use is? 2. Are farmers physically capable of using pesticides safely? 3. Do farmers have the mental or physical skills required? 4. Do farmers understand why safe pesticide use is important for them to do it and how to do it? 5. Do farmers have the self-control required to use pesticides safely and keep doing it if necessary?	**Physical**: Involves a person's physique and musculoskeletal functioning (e.g., balance and dexterity), skill, strength, stamina **Psychological**: Involves a person's mental functioning (e.g., understanding and memory), psychological strength, stamina or skill to engage in the necessary mental processes (understanding and reasoning)	To be able to use product (does the farmer know how to wear the protective equipment?) To have an understanding of how their dependency on pesticides works and knowledge of behavioral triggers
Opportunity: *having the financial and material resources, having sufficient time; exposure to social or other prompts; and having a supportive culture, family and social network*	1. Do farmers have the time, financial or material resources to use pesticides safely? 2. Do farmers have the social support required? 3. Is it seen as normal in the farmers' social environment?	**Physical**: Involves inanimate parts of the environmental system and time (e.g., financial and material resources, time, locations, cues physical 'affordance') **Social**: Involves other people and organizations (e.g., culture and social norms, opportunity afforded by interpersonal influences, social cues and cultural norms that influence the way we think about things, e.g. the words and concepts that make up our language	Having the instructions on how to use pesticides safely at hand, reminders set to use the instructions. Can the farmer go to a shop? More people around them making a quit/switch attempt or non-users around them
Motivation: *truly wanting or needing to engage in the behavior, habits and routines, and possessing values and identity that embrace the behavior*	1. Do farmers intend to engage in safe pesticide use? 2. Do farmers find safe pesticide use genuinely more attractive than competing behaviors? 3. Is safe pesticide use an established part of farmers' routine?	**Reflective**: Involves conscious thought processes (e.g., plans like self-conscious intentions, and evaluations, such as what is good or bad) **Automatic**: Involves habitual, instinctive, drive-related and affective processes (e.g., desires, e.g., wants and needs, and habits), emotional reactions, impulses, inhibitions, drive states and reflex responses	I am convinced that wearing protective equipment is important for my health Wearing my PPE is part of my daily routine.

Table 3: Code book for components, adopted from Michie et al. 2014; West et al. 2020a)

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3 Results

In this review, we selected 70 studies for data extraction. The body of literature is rather uniform in terms of study design with a majority being quantitative and a minority mixed methods, but it is diverse in terms of sample size, ranging from 70 to over 1000 participants. Additionally, studies differ in data analysis, using ANOVA, t tests, and chi-square tests as well as correlations, regression analyses, structured equation models, and path analyses (see section 4 of the SM Online for a synthesis of all 70 studies).

3.1 Trends in the literature explaining pesticide use behavior of small-scale farmers in the Global South

3.1.1 Publication trends We extracted data from 70 studies published between 2000 and 2021 (see Figure 2). Publications related to small-scale farmers pesticide use in the Global South have been growing over the last 20 years, with more than half of the studies published between 2017 and 2021.

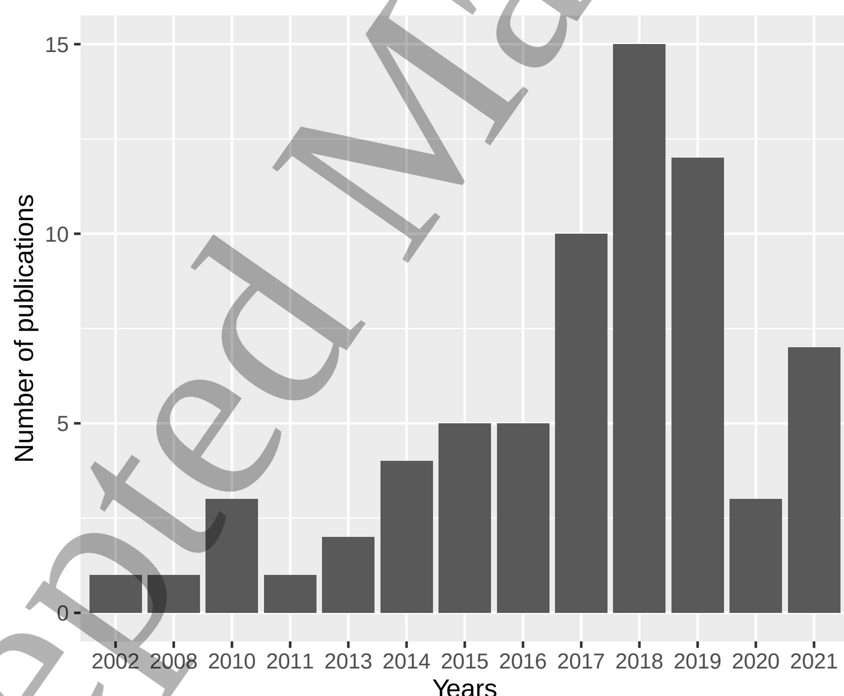

Figure 2: Distributions of publications across time (2000-2021)

3.1.2 Regional trends The current literature trends towards an investigation of small-scale farmers in Asia, with 17 studies in Iran (see for example Monfared et al. 2018; Bagheri et al.

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2019; Rezaei et al. 2019), 11 in China (see for example Gong et al. 2016; Jin et al. 2017; Wang et al. 2018a), five in Pakistan (see for example Bakhsh et al. 2017), four in Bangladesh (see for example Ali et al. 2020), and several single studies in countries such as Kuwait (Jallow et al., 2017), Laos (Heong et al., 2002), and Sri Lanka (De Costa et al., 2021) (see Figure 3). Investigations on the African continent concentrate in Ghana (three studies, see for example Denkyirah et al. 2016; Danso-Abbeam and Baiyegunhi 2017, 2018) and are then found as single studies in Tanzania (Mwatawala and Yeyeye, 2016), Cameroon (Oyekale, 2018), Ethiopia (Agmas and Adugna, 2020), Kenya (Macharia et al., 2013), Morocco (Berni et al., 2021), Nigeria (Sofoluwe et al., 2013), Rwanda (Okonya and Kroschel, 2015), Uganda (Clausen et al., 2017), and the Zambia (Goeb et al., 2020). South American countries studied include Bolivia (Jørs et al., 2014), Brazil (Leite et al., 2014), Ecuador (Orozco et al., 2011), and Colombia (Feola and Binder, 2010b,a) (see also Figure 3).

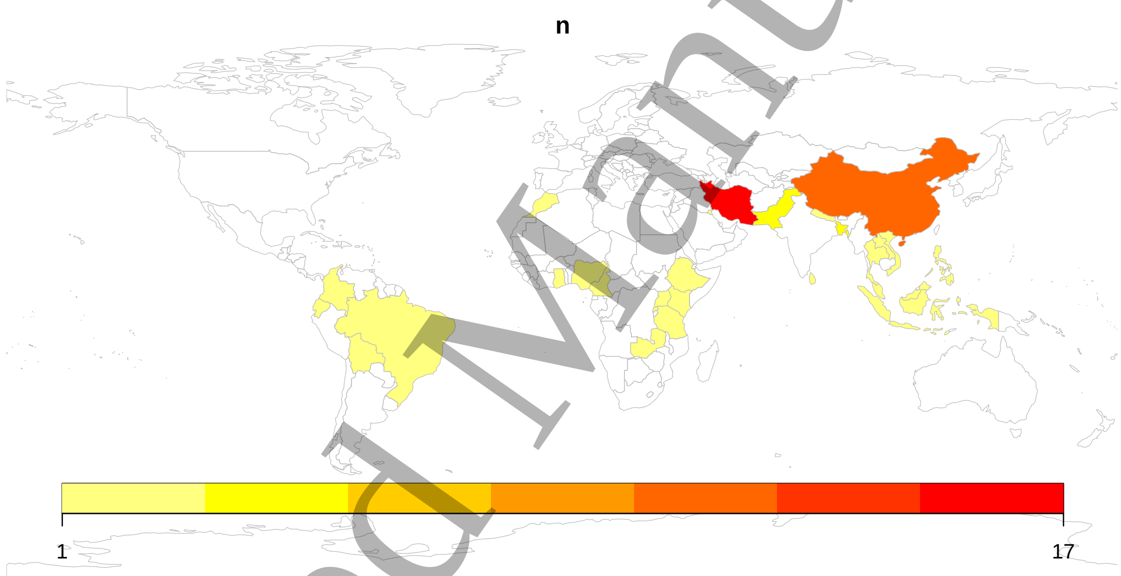

Figure 3: Distributions of publications across countries

3.1.3 Theoretical trends Within the sample, fewer than half the studies (28/70) use a theoretical model to explain behavior. Among these, the theory of planned behavior or an extended version of the latter (Ajzen, 1991) is used most frequently. Other theoretical models include the health belief model (Rosenstock, 1974), the integrated agent centered framework (Feola and Binder, 2009), and the technology acceptance model (Davis, 1989).

3.2 Farmers' pesticide use behavior

Across the 70 studies, some investigated more than one behavior; we identified a total of 81 reported behaviors related to pesticide use, which we grouped into six behavioral categories (see

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the definitions and detailed list of behaviors in section 5 of the SM Online) and coded whether the behavior is related to health, environment, or both. The majority of studies investigated safe use behavior in general (25/70) or one specific safe use behavior, such as disposal of containers (3/70), use of PPE (13/70), or use of alternatives to pesticides such as integrated pest management (11/70). The other studies either investigated pesticide application, for instance the frequency of spraying (19/70), or investigated misuse of pesticides such as overuse or handling without following recommendations (9/70). Some of the studies investigated farmers' intentions, willingness to pay or to accept as proxies for behavior (see Figure 4). For the remaining synthesis, we consider both behavior and behavioral intention in the six behavioral categories.

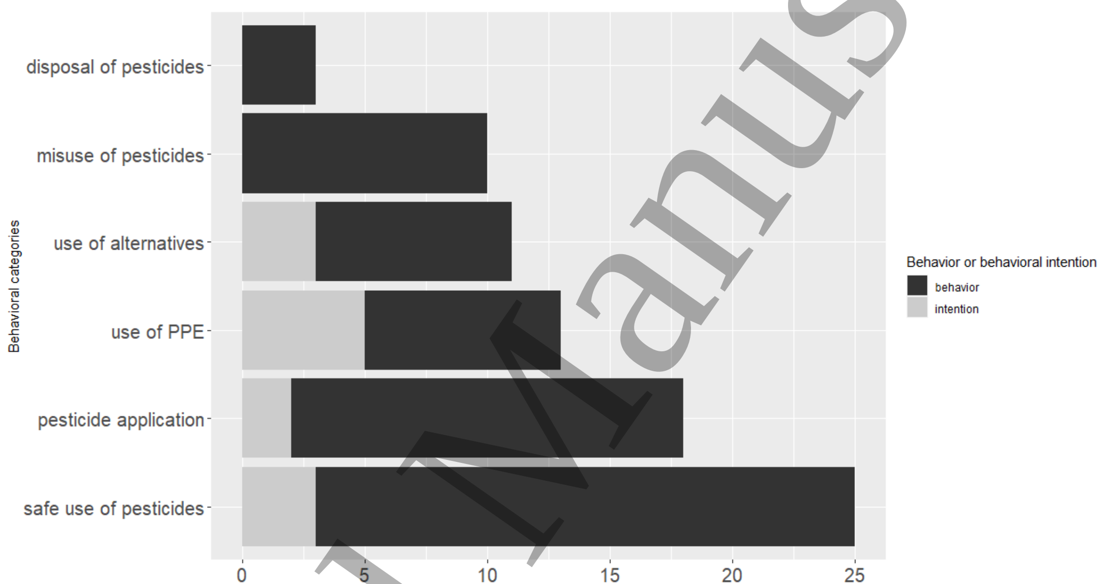

Figure 4: Behaviors investigated

Across the studies with a focus on safe use, we observe a broad spectrum of definitions and measurements to operationalize the investigated behavior. While some studies provide an extensive catalog of items covered in the farmers' survey (Vaidya et al., 2017; Masruri et al., 2021), including questions about PPE, reading of labels, and use of alternatives, other studies are less extensive in operationalization (Damalas and Khan, 2016; Wang et al., 2018b) or do not provide indications of how behavior was measured (Bagheri et al., 2019; Nining et al., 2019) (see section 5 of the SM Online for a detailed list of behaviors covered in the literature). Given the broad spectrum of definitions, 41 (66%) of the investigated behaviors are clearly related to safe use to enhance environmental integrity, 13 (17%) to protect occupational or general health, and 23 (30%) affect both environment and human health.

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3.3 Explaining farmers' pesticide use behaviors

Figure 5 shows which behavioral determinants of COM-B were investigated in the studies across the six behavioral categories of the BCW (see Figure 1). All three components were covered in the studies sampled. However, only misuse of pesticides was investigated by taking all six subcomponents into account. Many of the reviewed studies are knowledge, attitude and practice (KAP) investigations (see for example Rezaei et al. 2018; Bagheri et al. 2019; Rostami et al. 2019). Knowledge is covered in the subcomponent psychological capability and attitude in reflective motivation, which is the most frequently used subcomponent across all studies. The heat-map also shows that physical opportunity, such as having the resources to buy PPE, and social opportunity, such as social influences or trust in extension officers, have been investigated to a great extent to explain small-scale farmers' pesticide use behavior in the Global South. Other subcomponents such as physical capability, having the physical skills to wear PPE, and automatic motivation, making safe use a habit, have been investigated to a far lesser extent.

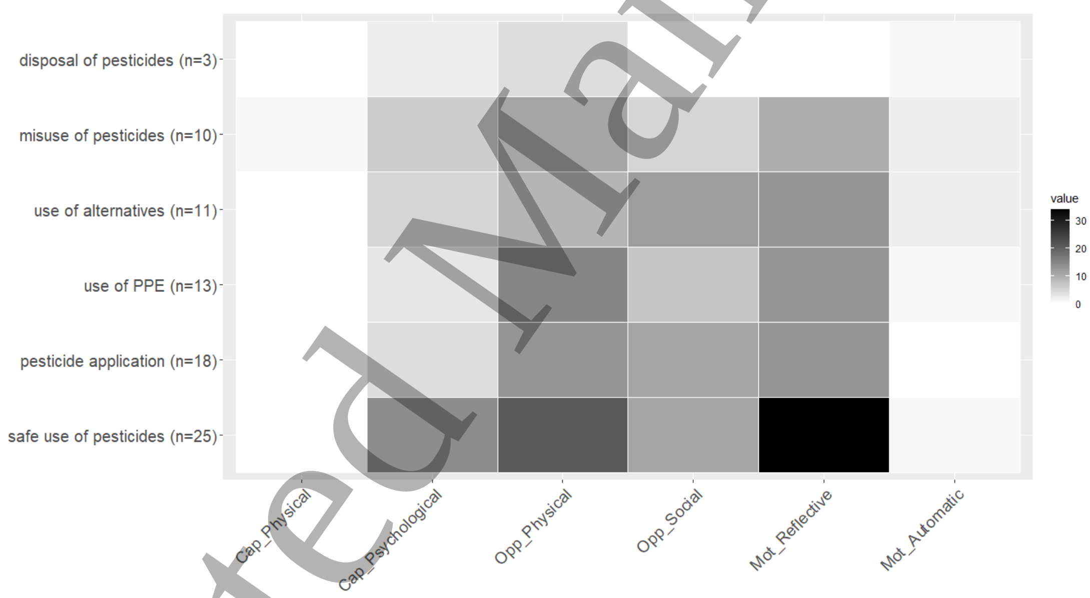

Figure 5: Distribution of the subcomponents across the investigated behaviors

To further illustrate the distribution of subcomponents, Figure 6 shows how well the subcomponents are connected. Physical opportunity and reflective motivation are the subcomponents that researchers most frequently investigated together to explain farmers' pesticide use behaviors. Both are also linked to investigations that included social opportunity, but only reflective motivation is well connected to psychological capability, which confirms the trends in Figure 5 related to the KAP studies. Overall, opportunity appears to be the most densely studied component, because its two subcomponents, physical and psychological opportunity, are

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well connected within the studies. Again, physical capability and automatic motivation are the subcomponents that appear to be the least connected subcomponents.

Figure 6: Subcomponent linkages in reviewed the literature

3.4 *Synthesis: facilitators for farmers' pesticide use behavior*

To estimate the relationships of the behavioral determinants and the behaviors, we coded the statistically significant positive, negative, and nonsignificant correlations. We grouped the behavioral determinants in the three main components of the COM-B model (see Figure 7 and section 6 in the SM Online for more details).

The figure shows all behavioral determinants which were significantly correlated with the behavior at least twice. We defined three categories of correlations: facilitators (in green, more than 50% positive significant correlation reported between determinant and behavior), mixed evidence (in yellow, if the reported correlations are 50% positive significant and 50% negative significant, 50% positive significant and 50% nonsignificant, or 50% negative significant and 50% nonsignificant), and no correlation (in orange, more than 50% nonsignificant correlation reported between determinant and behavior)||. The round icons represent the six pesticide use behaviors found in the 70 studies.

|| Some behavioral determinants are barriers for the investigated behavior, but within our sample, the negative significant correlation reported between determinant and behavior never reached 50%, see also section 7 in the SM Online

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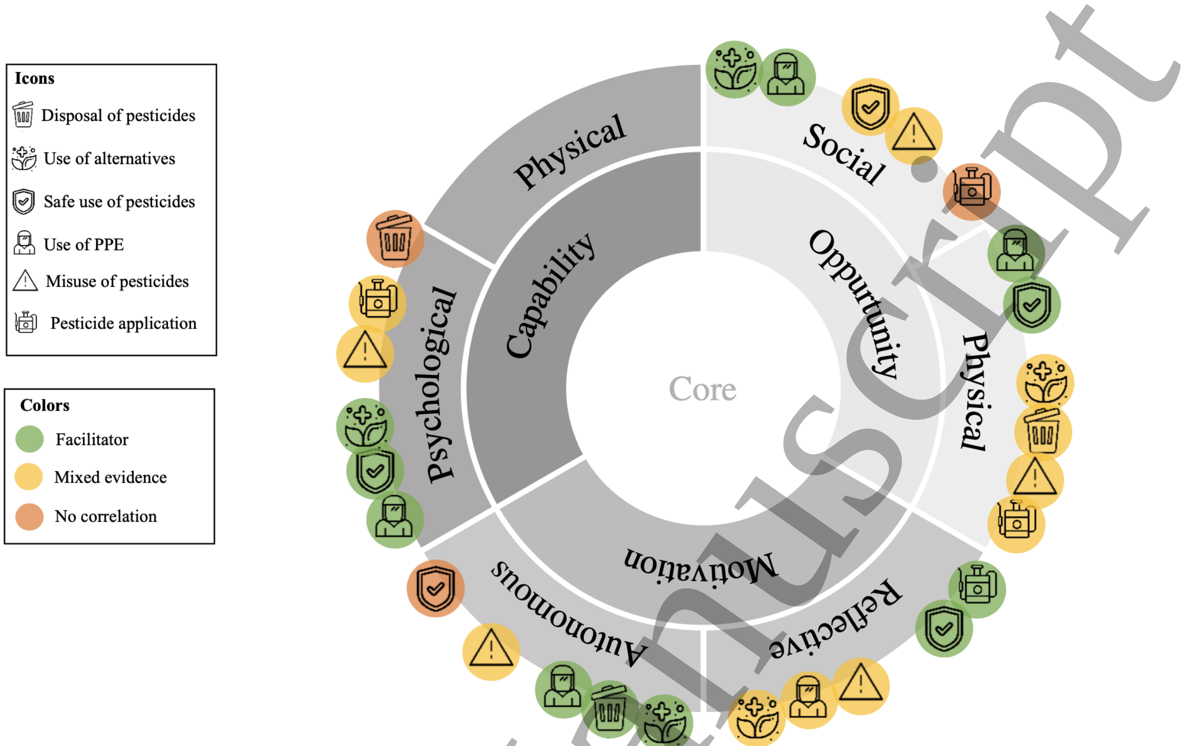

Note: only determinants that significantly correlate with the behavior at least twice are reported here.

Figure 7: Synthesis

For safe pesticide use, we found evidence that psychological capability, physical opportunity, and reflective motivation facilitated farmers' behavior, whereas social opportunity shows mixed evidence of reported correlations, and automatic motivation is not significantly correlated with the behavior. Farmers were more inclined to use alternatives to chemical pesticides such as IPM or biological control if they were knowledgeable about alternatives, had the social opportunity to engage in the behavior or had established routines and habits. Neither physical opportunity nor reflective motivation showed any uniform relationship, thus leading to mixed evidence. Again, knowledge plays a key role in facilitating the use of PPE, as does farmers' physical opportunity through having PPE at their disposal and farmers' automatic motivation, which includes habits and routines. For PPE, reflective motivation shows mixed evidence across the studies, being significantly as well as nonsignificantely correlated with the behavior. Pesticide application is facilitated by farmers' reflective motivations, while the other subcomponents show mixed or nonsignificant correlations. The misuse of pesticides show no uniform relationship with any of the subcomponents, thus leading to mixed evidence (for detailed figures of the relationships between of the behavioral determinants and the six behaviors, see section 7 in the SM Online).

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4 Discussion

4.1 Summary of behavior and determinants

Our systematic review of studies that investigated the pesticide-related behaviors of small-scale farmers in the Global South revealed that this topic has received increasing attention in recent years. The 70 studies that fit our inclusion criteria originated from a wide range of countries, with a focus on Asia. The studies investigated an impressive variety of pesticide-related behaviors, which we categorized into six behavioral domains that addressed health- or environment-related behaviors or a combination thereof. Our findings underline the complexity of behavioral issues related to pesticides, which may benefit intervention and policy regulation. Our findings are rendered more complex by the fact that studies use many different terms for the behaviors studied, and these behaviors are often poorly defined. What is more, the behaviors are predominantly assessed with nonstandardized measures that lack validation. Overall, this hampers evidence synthesis and thus scientific progress in the field. Psychology and other behavioral sciences may assist in developing taxonomies and validated measures of pesticide-related behaviors.

The most frequently studied behaviors include safe pesticide use, such as adherence to regulated safety procedures when handling pesticides. Further, pesticide application behaviors such as frequency of application were studied often. Our review points to behaviors that may require further attention from researchers, such as disposal of pesticides, which have been rarely studied thus far. Only about half of the studies used behavior change theory in their research. This is unfortunate, because behavioral science has advanced frameworks of behavior change that help select the behavioral determinants to study, provide unified definitions and measures of the determinants, and thus facilitate the accumulation of evidence.

Physical opportunity, especially training, and reflective motivation such as attitude, were the predominantly investigated behavioral determinants, followed by psychological capabilities, especially knowledge. Hence, conclusions drawn from the studies about these behavioral determinants may be considered the most robust. Overall, the lack of studies that have investigated automatic motivation is notable, even though psychological research indicates that habit and affect can be powerful motivators of behavior. Another neglected group of behavioral determinants are physical capabilities, which include skills for performing behaviors, such as for integrated pest management. Finally, physical opportunities, such as the availability of protective equipment, have not received sufficient attention. These provide avenues for future research.

To identify suitable policy instruments, we coded the correlations between determinants and behaviors. Although the results provide some insights into facilitators of farmers' pesticide use behaviors, the results also show that many of the determinants do not significantly correlated with the behaviors, especially determinants that are attributable to a farmer's opportunity (such

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as access to extension services or training). Additionally, determinants that are attributable to physical capability have only been investigated in one study. This makes it impossible to report any relationship between this subcomponent and the investigated behaviors. As mentioned before, this provides a direction for future research and underlines the necessity of using theory-based approaches and relying on standardized tools for measurement.

4.2 Linking behavioral insights to policy instruments

Our approach enabled us to generate fine-grained knowledge about interventions and policy instruments that support these interventions (Michie et al., 2008, 2011). The second aim of this paper was to use the knowledge gathered by the literature review within the behavioral change wheel (BCW) to link behavioral determinants to potential policy instruments. We show that the behavioral determinants investigated cover all components and subcomponents of the BCW. For this discussion, we focus on policy instruments that can enhance safe use practices, such as use of PPE. Additionally, we focus on those subcomponents which act as facilitators for at least two safe use behaviors, psychological capability, physical and social opportunity.¶

First, to enhance farmers' psychological capability, suitable policy instruments need to make farmers knowledgeable about safe pesticide use practices. Small-scale farmers often rely on neighbors, family members, and other farmers for information about pesticides and related behaviors (Rees et al., 2000; Byamugisha et al., 2008; Ismet and Orhan, 2010). Information can also come through extension officers (Munyua and Stilwell, 2013); however, in the Global South, extension services are often underfunded and are unable to reach the entire farming community. According to the BCW, education can target knowledge and promote behavioral change. Policy makers can use regulatory instruments to promote education, for instance by increasing the human resources of extension services or introducing agricultural practices into school curricula, or use informative instruments to enhance knowledge, for example with awareness campaigns or the introduction of voluntary guidelines. Information instruments can be highly effective, especially when information is framed to target the context (Weiss and Tschirhart, 1994). However, such an approach entails further evidence gathering to better understand information behavior and farmers' reactions to various modes of information delivery (Diemer et al., 2020).

Second, to enhance farmers' physical opportunity, suitable policy instruments need to target their environmental context and resources. Various intervention functions, such as training, environmental restructuring, modelling, and enablement, can trigger this behavioral determinant. To provide training, policy makers can work with the full range of policy instruments to regulate,

¶ Automatic motivation has also yielded significant correlations for three behaviors, but behavioral determinants fitting to this subcomponent are only adduced to a limited extent for explaining behavior, which is why we consider these results less robust and do not use this finding to deduce suitable policy instruments.

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incentivize, and persuade farmers to participate in occasions to enhance skills and knowledge about the desired behavior. One way of providing training to farmers is Farmer Field Schools (FFS), at which farmers gain access to specialized knowledge, enhance farming skills, and are empowered (Settle et al., 2014; Waddington et al., 2014). Policy makers can foster these FFS by providing funds and personnel or directly targeting farmers with financial incentives for instance to participate or to train other farmers after participation. Another way in which policy makers can shape capacity-building for farmers is by promoting participatory training and field demonstrations, for example at model farms (Dasgupta et al., 2007; Akter et al., 2018).

Third, farmers' safe use behavior is determined by social opportunities available in the social influences in their surroundings. Social influences can be triggered by intervention functions such as environmental restructuring and modeling. These intervention functions can be targeted by nudges that influence farmers' choice architecture rather than reducing the farmers' choice set with conventional regulatory policy instruments. Nudges can be implemented by information provision and the use of social norms and salience (Barnes et al., 2013). In the case of small-scale farmers' safe pesticide use, nudges can be used to provide information about best practices, unveil social differences between farmers and enhance connections in the social network between farmers to support safe use behavior (My et al., 2022).

5 Conclusions

5.1 Reflections on our approach and future research

By linking the systematic literature approach to theory-based behavioral science, we both synthesize and generate knowledge. Through thorough data coding and extraction, we generated a rich and detailed data set of the metadata from the studies reviewed and information about the definition and operationalization of both behaviors and behavioral determinants. We used this information within the BCW to derive suitable policy instruments, which provides recommendations for future and effective efforts to tackle pesticide use as an agri-environmental challenge.

We aimed at understanding behavior and identifying policy options for behavioral change, the first two steps of the BCW. This model contains both ways to identify behavioral change techniques and modes of delivery for various intervention functions (Michie et al., 2014). Full adoption of the complete BCW would require further investigation of such interventions. Furthermore, our research has focused on the farmers as one group of agricultural supply chain actors, but we disregarded extension officers, pesticide retailers, and even consumers (Staudacher et al., 2021; Rosenfeld et al., 2022), all of whom play crucial roles in this system. For future research to propose comprehensive and integrative policy instruments for agri-environmental policies, these

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actors and their behaviors also need to be taken into consideration. Additionally, our research focused on farming in the Global South, thus including mostly studies from Asia, South America, and Africa. These regions vary greatly in macroeconomic determinants, GDP, environmental conditions, food security, and agricultural production. Future syntheses should examine regional clusters and investigate behavior and behavioral change within these to also take into account contextual and regional characteristics to identify effective policy instruments, similar to Dessart et al. 2019 and Ranjan et al. 2019 who reviewed specific regions and countries to better grasp farmers' pesticide use behavior. Additionally, even though pesticide use is a typical cross-sectoral policy matter (Wiedemann and Ingold, 2021), we suggest conducting reviews for specific safe use behaviors to provide more fine-grained policy insights. To be more specific, different behaviors raise different issues, and a focus on a specific behavior such as the use of PPE might provide insights for specific policy fields such as health, education or trade.

5.2 Limitations

This study focused on one specific group of individuals, who are without doubt part of the agricultural supply chain, but our focus shifts the "burden of responsibilities onto the users" (Stein and Luna, 2021, 95) with the inherent assumption that environmental problems can be solved by the voluntary and informed actions of individual actors (Wiebe, 2016; MacKendrick, 2018). Pesticide use practices and related problems are not solved solely by changing farmers' behavior. Individual behavior is therefore only one component that shapes the problem. To grasp the complexity of pesticide use, a systemic perspective covering all cultural, economic, ecological factors (Haggblade et al., 2017; Shattuck, 2021b) and the underlying structural constraints (Luna, 2020) need to be brought together in an even wider interdisciplinary perspective, for instance involving anthropologists and sociologists. Targeting individual actors with knowledge provision might be suitable but is not a sufficient solution for pesticide-related problems. To design truly suitable agri-environmental policy, decision-makers have to take local realities into account, such as the social, cultural, and economic factors that drive farmers' communities to use pesticides (Shattuck, 2021a). As an example, we briefly elaborate on pesticide labels, a commonly used policy instrument to force industry to elaborate on toxicity levels and associated risks on the pesticide containers, as a means of providing information and making farmers more knowledgeable about pesticide risks (see also Rother 2018). This simple measure may fail because, in some cultures, the word for pesticide means medicine, and as a result, pesticides are seen as something positive that cures pests, and farmers do not consult the labels for risks (Rother, 2018). Additionally, some farmers might not be able to read the text due to illiteracy or not understand the symbols indicating risk due to 'visual illiteracy' (Rother, 2018). These aspects have to be taken into account in decision-making, and thus a more participatory approach to agri-environmental policy is needed when targeting individual behavior. Policies also need to target cooperative behaviors, large firms, and industries

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by using regulatory policy instruments to ban highly toxic pesticides and promote nonchemical pest management practices.

Additionally, due to our thorough data selection process, especially excluding studies which do not specifically aim at explaining a pesticide use behavior (i.e., treating pesticide use behavior as the dependent variable for the analysis) led to the exclusion of all studies covering India and countries like Morocco, Vietnam, Nicaragua, and others. Therefore, the findings of our review might not generalize to all of the Global South.

Finally, our study faces some limitations in the quality of the studies reviewed. Fewer than half the studies use a theory-based model or framework to investigate behavioral determinants of behaviors. Accordingly, only a limited number of the studies provided definitions, operationalizations, or measures for the behaviors and their determinants. Some of these studies provided summary statistics, such as means or percentages for the variables used in the statistical models. However, the majority did not, which made it impossible to synthesize or present the data in the literature, beyond effect direction. We were unable to perform a meta-analysis or check the robustness of the studies. This is why no definitive conclusions can be drawn about the key determinants driving pesticide-related behaviors: first, because not enough studies have been conducted for most of the behaviors, and second, the studies investigated selections of behavioral determinants and neglected others. For example, we found a lack of studies on automatic motivation and physical capability for behavior. Hence, we cannot draw conclusions about the relationships between these determinant and the behaviors investigated. Finally, most studies used observational designs, predominantly cross-sectional, which impede causal conclusions about the influence of the behavioral determinants.

In conclusion, our paper has shown that behavioral science can help bridge the behavior – policy gap by fostering our understanding of behavior, which can inform policy. The behavior change wheel has served as a helpful tool in this process, because it provides a systematic and reliable framework to synthesize the often-heterogeneous evidence of behavior and its determinants and links these insights to interventions and policy categories. Overall, this approach has proven valuable for the field of pesticide-related policy, and potentially further environmental policies. Future research in this field would benefit from doing behavior change research using validated behavior change frameworks, using clear definitions of the behaviors studied, and well-defined and validly measured behavioral determinants. This would maximize the potential impact of behavioral insights into agri-environmental policy.

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