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# A systematic review of factors that influence farmers' adoption of sustainable crop farming practices: Lessons for sustainable nitrogen management in South Asia

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## Abstract

Despite the fact that sustainable agricultural technologies and practices have been developed and introduced to farmers in both developed and developing countries, there are concerns about low levels of adoption. Empirical evidence of the past 40 years shows that adoption of new practices can be hindered by a wide range of factors, from financial to attitudinal, from personal to social, from agronomic to regulatory. Conclusions that can be generalised across different contexts could help in moving the institutional and policy environment in a direction that strengthens the move towards a more sustainable food production. This is particularly important regarding hotspots of environmental pollution, for example, the release of reactive nitrogen compounds in South Asia. This paper followed the PRISMA protocol and systematically reviewed the adoption literature in South Asia to identify factors that affect farmers' decisions to adopt sustainable agricultural technologies and practices. We found that education, extension and training, soil quality, irrigation, income and credit are significant drivers of farmers' adoption decisions. Consequently, efforts to promote the adoption of sustainable nitrogen management technologies will have to be tailored to consider these factors. We conclude that the variables that explain adoption in the studies reviewed could provide a foundation invaluable to research and policies that facilitate the adoption of sustainable nitrogen management technologies and practices in South Asia.

## KEYWORDS

adoption, environmental pollution, nitrogen management, South Asia, sustainable agriculture

## 1 | INTRODUCTION

Until recently, technologies introduced to farmers were predominantly targeted at facilitating and increasing production, productivity and income, with little or no consideration for long-term environmental impacts. However, the environmental implications of food production, including soil degradation, biodiversity loss,

greenhouse gas emissions, water and air pollution, had become evident in the past decades (Lassaletta et al., 2014). While advances in technology in the past century, most notably the development of synthetic nitrogen fertilisers, have more than doubled the productivity of agricultural land and drastically increased food security, anthropogenic reactive nitrogen from agriculture is severely polluting the air, soil and water, with

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attendant implications on biodiversity, ecosystems and human health (Conijn et al., 2018; Erisman et al., 2008).

The environmental impacts of agriculture vary between global regions. South Asia (SA) features as one of the hotspot areas of reactive nitrogen losses (Xu et al., 2019), with limited prospects of improvements in the future, unless sustainability will be the key driver in societal change (Mogollón et al., 2018). SA supports 23.7% of the global population on 5.1 million km<sup>2</sup> of the land area (Hasnat et al., 2018). Most people live on the Indo-Gangetic Plain, where reactive nitrogen pollution is the highest. However, nitrogen use and management practices widely differ between regions, from the high-input-intensive systems on the Western Indo-Gangetic Plain (Taneja et al., 2019) to low-input organic farming in Bhutan (Feuerbacher et al., 2018) and agro-ecologic movements, like the Zero Budget Natural Farming (Khadse et al., 2018). The four largest agricultural producer countries in the region (India, Bangladesh, Pakistan and Sri Lanka) all show a declining trend in crop nitrogen use efficiency (low nitrogen use efficiency indicated high reactive nitrogen losses to the environment) (Lassaletta et al., 2014), suggesting that without a substantial change in farming practices, the environmental degradation caused by the nitrogen loss is only going to worsen.

Sustainable agricultural practices and technologies have proven to be crucial in addressing numerous environmental challenges worldwide (Xia et al., 2017). Sustainable agriculture refers to management procedures that complement natural processes in conserving the natural resource base to reduce waste and environmental impact while encouraging agroecosystem resilience, self-regulation, evolution and sustained production for the benefit of all (Velten et al., 2015). The adoption of sustainable practices and technologies can demonstrably improve environmental conditions, like excessive pollution of reactive nitrogen (Pretty, 2008). Denmark has reduced its nitrogen surplus in agriculture since the 1980s without decreasing its agricultural production (Dalgaard et al., 2014). Similarly, in the Netherlands, the nitrogen surplus has reduced by up to 50% between 1992 and 2014 (Fraters et al., 2016). Most of these improvements were achieved by maintaining tighter livestock nitrogen flows and utilising the organic and synthetic nutrients with higher efficiency in crop production. Although major challenges remain, the adoption of improved nitrogen management has been beneficial for society (Dalgaard et al., 2014, van Grinsven et al., 2016).

Sustainable nitrogen management in crop production focuses on reducing reactive nitrogen losses mainly by improving the efficiency of how nitrogen inputs are converted into crop products and improving the utilisation of organic nitrogen sources (Miao et al., 2011). Commonly suggested solutions include avoiding overfertilisation by site-specific fertilisation planning (considering the available nitrogen sources and the crop requirements) and better timing and placement of fertilisers. Increased use of legumes as forages, grains and cover crops provides nitrogen to the subsequent crops, substantially reducing the need to add nitrogen fertilisers (Jagdeep-Singh & Varinderpal-Singh, 2022; Muhammad et al., 2022). Given that nitrogen inputs to soils from livestock are comparable to

synthetic sources and substantial losses from this source occur before they are applied to the soil (Bouwman et al., 2013), conserving the nitrogen in animal manure during storage and application (e.g., by covering the stores and incorporating the manure soon after fertilisation) is another key aspect of sustainable nitrogen management (Zhou et al., 2022). Finally, the 'end-of-pipe' solution can also be used to reduce the reactive nitrogen load to the immediate environment, for example, buffer strips around the fields and natural or artificial wetlands capturing the losses from the fields (Bowles et al., 2018).

Despite countless efforts to promote sustainable crop, soil and water management technologies and practices, they are still not practised widely enough (Olum et al., 2020; Takahashi et al., 2020). Availability of technology in itself is rarely sufficient for adoption. Adoption is a complex process, and farmers typically take into consideration several factors ranging from financial situation to environmental, market and regulatory circumstances (Azam & Shaheen, 2019; Baumgart-Getz et al., 2012). Furthermore, personal attitudes, the social environment and the relative advantages and disadvantages of the practice compared to the practice currently used by the farmer also play an important role in adoption decisions (Aryal et al., 2020).

The broader adoption literature on sustainable farm management practices is robust (see Dessart et al., 2019; Knowler & Bradshaw, 2007; Piñeiro et al., 2020). However, there are few studies focusing on the barriers and drivers of the adoption of sustainable nitrogen management technologies in the region. Though global synthesis of the behavioural factors explaining the adoption of sustainable farming practices is a useful starting point, regionally specific environmental, agricultural, social and political circumstances warrant a region-specific investigation of factors that determine adoption in SA and draw lessons for the adoption of sustainable nitrogen management technologies and practices in SA.

The main objective of this paper is to provide a systematic review of the literature on the factors that influence the adoption of sustainable agricultural technologies and practices in SA and present a holistic picture of the best available evidence. To achieve these objectives, the paper focuses on the adoption of a wider set of agronomic, water-, soil- and nutrient-related technologies and practices, as these technologies and practices are either closely related to or (indirectly) have elements of sustainable nitrogen management. The benefit of understanding the factors that affect farmers' adoption of sustainable technologies and practices is improvement in the design and dissemination of technologies and practices supported by better-informed programmes and policies. This knowledge will also help move the institutional and policy environment towards more sustainable food production.

The rest of the paper consists of six sections. Section 2 presents the theoretical perspective on adoption, Section 2 discusses the systematic review process and data analysis, Section 3 reports the results and discusses the findings, Section 4 draws lessons for the adoption of sustainable nitrogen management technologies and practice in SA and Section 5 concludes the paper.

## 2 | METHODS

Our review focused on empirical findings on factors driving or limiting the adoption of sustainable technologies and practices in crop production (up to the stage of harvest) by (particularly smallholder) farmers in SA. We included peer-reviewed empirical studies that were based on primary data and published in English in the past 40 years. Arising from limited information on drivers and barriers specific to nitrogen management technologies and practices in SA, this study focuses on broader agricultural technologies and sustainable practices that directly and indirectly affect crop nitrogen management. Although there is substantial heterogeneity in the methods used in examining farmers' adoption decisions, this paper does not primarily focus on this heterogeneity, but on the impact of the various factors identified in driving and inhibiting farmers' adoption decisions.

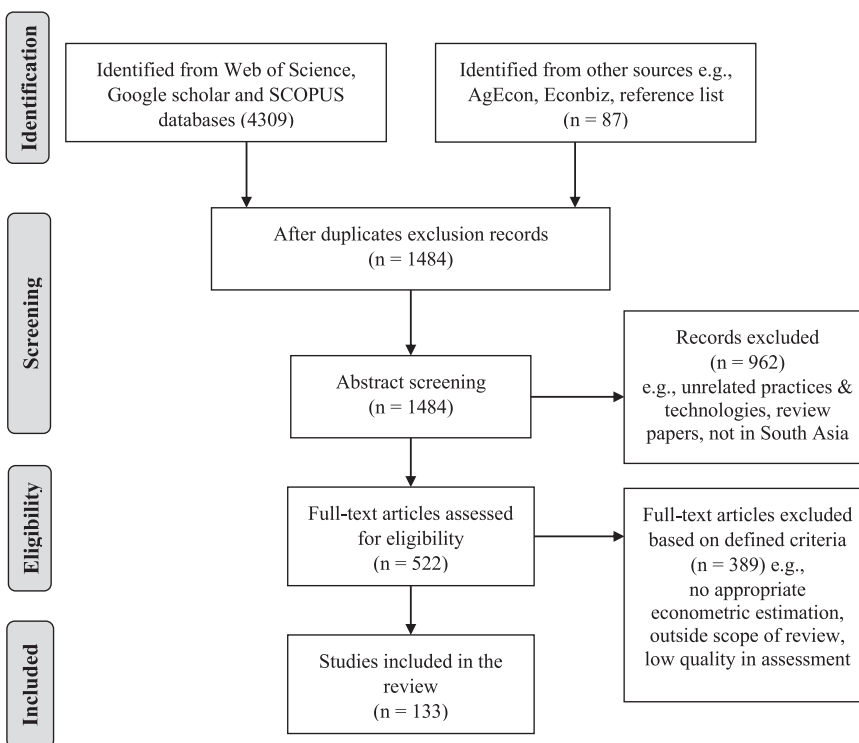
We pay particular attention to the adoption of agronomic, water-, soil- and nutrient practice-related technologies and practices in general, rather than a predefined set of individual practices. This facilitates finding a wide range of reports on nitrogen-related sustainable practices and technologies. Identifying the practices and technologies individually would have risked missing some studies, as the number of relevant practices and technologies is high, and numerous synonyms are often used to describe them. Within the broad nitrogen management categories mentioned in the introduction, the technologies and practices can take various forms, for example, to optimise the fertiliser application rate to the crops' needs, approaches range from the use of printed guidance, soil sampling, portable decision aids (e.g., leaf colour chart, chlorophyll meters) to

complex technologies, for example, nutrient management plans or precision farming techniques.

We conducted the review around three broad themes (i.e., context, estimation methods and outcomes). From each of the selected papers, we collected relevant information such as the author, year of publication and the country where the study was conducted. We also collected information on the sample size, farm characteristics, analytical methods, specific agricultural technologies or practices and adoption variables (drivers and barriers).

### 2.1 | Systematic review process

We use the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses adapted from Moher et al., 2009) technique in the systematic search involving a detailed search strategy presented in Figure 1. The main information was sourced from searching three databases (Web of Science, Google Scholar and SCOPUS) using a Boolean search, which allowed for a combination of relevant subject headings and keywords with modifiers. The search terms used were ('deter\*', 'barrier', 'obstacle', 'limit', 'prevent', 'discourage') AND ('driver', 'determinant', 'encourag\*', 'motivat\*', 'factor') AND ('farmer', 'landholder', 'farming house\*') AND ('choos\*', 'switch\*', 'adopt\*', 'adapt\*', 'disseminat\*', 'uptake', 'behavio\*', 'behavio\*change', 'decision\*', 'transition\*', 'conversion', 'implement\*') AND ('soil', 'crop', 'water', 'best', 'conserv\*', 'manag\*', 'sustainab\*', 'environ-ment\*', 'pollut\*', 'emission\*', 'nitr\*', 'ammoni\*', 'greenh\*gas', 'methane') AND ('Afghanistan', 'Bangladesh', 'Bhutan', 'India', 'Maldives', 'Nepal', 'Pakistan', 'Sri Lanka', 'South Asia').



**FIGURE 1** PRISMA flow diagram showing the steps involved in the systematic review (adapted from Moher et al., 2009).

## 2.2 | Inclusion criteria

To be eligible for further consideration in the systematic review, a study must (1) examine the adoption of agricultural technologies and practices as an outcome; (2) involve respondents from South Asian countries; (3) analyse primary data to investigate factors that affect the adoption of agricultural technologies and practices; (4) apply statistical estimation techniques in examining the determinants of adoption of agricultural technologies and practices and (5) examine a farm practice relevant to sustainable nitrogen management. We identify all potentially relevant studies comprising both peer-reviewed and other published research (e.g., theses, conference proceedings and working papers). We use a two-step screening process based first on titles and abstracts, followed by the entire content of the article. A decision guided by the above eligibility criteria was made at each stage on whether or not to include an article.

## 2.3 | Quality assessment

To ensure that the quality of the studies included in the review met the necessary standard for inclusion (conceptual framing, transparency, appropriateness, validity, reliability and cogency), we adapted the UK Department for International Development (DFID) guidance for assessing the strength of evidence. The checklist is made up of 20 questions that we use to appraise the research quality. Use of these clear criteria to assess individual adoption studies reduced the chances of inclusion of poor-quality studies, and any resultant bias that would otherwise arise from including such studies was avoided.

The early search stages yielded 4309 records from Web of Science, Google Scholar and SCOPUS, as shown in Figure 1. Of these records, we excluded 2825 duplicates. These were then subjected to screening of abstracts; where 962 studies were excluded because they were not carried out in South Asian countries or had unrelated technologies and practices. Based on examination of the full text, we excluded other articles that were either review papers, did not have an appropriate study design, used only secondary data, had no statistical estimation, included technologies that were beyond the scope of the review and had major deficiencies in attention to principles of quality. Finally, 133 articles fulfilled the criteria and were included in the review.

## 2.4 | Data collation and analysis

The results in this paper are obtained via summative qualitative content analysis. In using vote counting, we group the effects of the various variables based on their statistical significance. We had three main groups: significantly positive, significantly negative and not statistically significant. Synthesis of the findings from multiple evaluations was possible by counting the number of times across the studies that a variable fell into the above-mentioned groups. This

paper, however, does not develop a ranking of the importance of factors (drivers and barriers), given their context-specific attributes. We categorise the factors following Liu et al. (2018): information and awareness, financial incentives, social norms, macro factors, farmers' demographics, knowledge and attitudes, environmental consciousness, farms' characteristics and interactions between the practices. The practices and technologies were categorised as water, soil and nutrient and general agronomic management practices following Branca et al. (2011) and Baumgart-Getz et al. (2012). However, many of these technologies overlap, and the aim of classifying these technologies in this paper is merely for descriptive purposes.

## 3 | RESULTS AND DISCUSSION

### 3.1 | Study area and publication statistics

Regarding the geographic location of the studies, only six South Asian countries with relevant papers featured in the literature, specifically, Bangladesh (18), Bhutan (2), India (37), Nepal (26), Pakistan (32) and Sri Lanka (18) (no relevant papers were found for Afghanistan and the Maldives). As shown in Figure A1 in the Appendix, the timeline of the studies included in this review is between 1980 and 2020, with most of the studies (73%) published within the last 10 years. The sample sizes across the studies ranged from 60 to 2726.

### 3.2 | Research design of the reviewed studies

Most of the studies (109 papers) did not build their investigation around any adoption theory. As a result, many of the drivers and barriers in most reviewed studies are not chosen within the context of specific theories and do not directly test or improve the existing adoption theories. Since variables in many of these studies were most likely chosen based on previous studies (which perhaps were not theory-centred either), the risks of failing to consider other important variables becomes high. Among those that used adoption theories, the approach was heterogeneous. Only nine studies adopted a holistic approach, wherein clearly defined theories informed the literature review, guided the objectives, determined variables examined and shaped the corresponding discussions. The main theories considered across these studies were the Theory of Planned Behaviour (TPB), the Theory of Reasoned Action, Innovation diffusion, Economic constraint, Value-Belief-Norm and Derived Demand theories.

Each paper used at least one regression analysis: Probit, Logit or Logistic, Tobit, Ordinary Least Squares (OLS) and stepwise regression models. Specifically, the most widely used estimation models were the Probit and Logit/logistic regressions, which accounted for 28% and 33%, respectively. This suggests that the adoption decision is commonly captured as a yes/no or binomial outcome. Other methods used in addition to regression models include correlation, non-parametric  $\chi^2$  tests and multiple classification analysis.





factors that affect adoption is presented in Table 1. In the discussion that follows, we categorised the factors that influence farmers' adoption broadly into farmer characteristics, features of the farm, external support and technology-specific attributes. Then, we highlight the main findings.

### 3.4.1 | Farmers' demographics

The effect of farmers' age on adoption was assessed in 110 papers. Notably, only half of them found this factor to be significantly correlated with adoption, and those studies almost equally split

Factor	Drivers	Barriers	Insignificant	% Significant
<b><i>Farmers' demographics, knowledge and attitudes</i></b>				
Age (older)	27	29	54	50.9
Gender (male)	9	9	31	36.7
Household size (number)	9	11	32	38.5
Education (higher level of)	71	7	47	62.4
Labour (availability of)	11	9	11	64.5
Farming experience (more years of)	25	12	29	56.1
Knowledge (indigenous or related practice)	10	0	4	71.4
Farm income (higher)	22	4	16	61.9
Off-farm income (availability of)	8	3	6	64.7
Risk attitudes (being risk averse)	6	1	2	77.8
Attitude towards the technology	2	0	0	100.0
<b><i>Environmental consciousness</i></b>				
Attitude towards the environment	6	0	0	100.0
<b><i>Characteristics of the farm</i></b>				
Farm size (larger farm size)	46	11	27	67.9
Land tenure (landowner)	16	1	11	60.7
Land and soil characteristics	22	11	7	82.5
Irrigation (availability of)	14	5	22	46.3
Livestock (ownership or number of)	21	0	8	72.4
<b><i>Characteristics of and interactions between technology and practices</i></b>				
Perception of relative advantage	8	0	0	100.0
<b><i>Information and awareness</i></b>				
Information (access to)	25	1	14	65.0
Association membership	13	5	23	43.9
Extension visit (number of)	51	8	20	74.7
Training (tailored to technology or practice)	20	1	5	80.8
<b><i>Financial incentives</i></b>				
Credit (access to)	18	7	22	53.2
Adoption subsidy (access to)	2	0	1	66.7
Cost of adoption (high)	0	6	1	85.7
<b><i>Other external factors</i></b>				
Distance (less travel from resources)	19	1	27	42.6
Regulatory environment	1	0	0	100

**TABLE 1** Selected drivers and barriers to adoption of technologies and practices

between a positive and a negative effect (Table 1). This is an important finding that deserves investigation in further studies. On the one hand, it is suggested that the accumulation of knowledge and experience that accrue over the years of farming makes older farmers better equipped to process information compared to younger farmers. Other studies, however, argued that adoption of new technology is likely to be higher among younger farmers having more years of formal education. Given both sets of findings, there is the possibility of a nonlinear relationship (e.g., a quadratic relationship) such that young age increases the likelihood of adoption, and so does older age, with those of 'intermediate' age being less likely to adopt.

The association between education and adoption was examined in 125 papers. More often, the relationship between adoption and a higher level of education was positive (as shown in Table 1), such that the more educated farmers showed higher chances of adopting technology or practices. In addition, education was credited with increasing farmers' ability to handle technical information, which demands some degree of numeracy or literacy.

Gender disparity is postulated to be prevalent, particularly over access to and management of farm resources and adoption decision-making (Olum et al., 2020; Peterman et al., 2014). As a result, gender effects on adoption received considerable attention. Across the South Asian countries, gender as a factor influencing adoption was analysed in 49 studies. However, this variable did not show statistical significance in two-thirds of the studies (Table 1). We discuss the possible reasons for these findings in Section 3.5.

Farmers' income from on-farm was examined in 42 studies. The hypothesis is that those with higher income status may be the first to adopt agricultural innovation, particularly if such innovation has significant input cost. The findings of 22 of these studies (as shown in Table 1) positively supported this hypothesis, while in 16 studies, income was not a significant factor. In addition, some studies suggested that farmers' wealth increased their ability to take risks, access credit and crucially broaden information sources.

### 3.4.2 | Characteristics of the farm

Eighty-four studies considered farm size effect on farmers' adoption, with findings varying across technologies, practices and countries. Most of the studies that found a statistically significant relationship show farm size as being positively correlated with adoption. The effect of farm size was often linked to cost/returns, labour and time. From the cost perspective, farmers with large farms adopting technologies or practices can spread any high fixed costs across their large farms. On the other hand, the fact that more labour is required on bigger farms can be a barrier to the adoption of labour-intensive practices and technologies.

Twenty-nine studies examined the effects of land ownership, with almost unanimous findings suggesting that land owned by a farmer was a driver of adoption. Arising from the insecurity associated with tenancy (for instance, when the technology is tied to the land), the predominant findings justify a lower adoption rate among the tenant farmers.

However, no study in the region investigated whether farmers adopted technology on their land, but not on rented land. The findings from papers reviewed in this study differ from those of the broad adoption literature (see Liu et al., 2018).

Seventeen studies considered land quality and soil type for inclusion in their analysis. Poor-quality land could be a driver of adoption if the technology offers significant gains in soil productivity. On the other hand, it is conjectured that channelling the effort or allocating resources to a plot with medium yield is better than taking the same action on a low-yielding plot, especially if both will result in similar levels of increase in yield or financial benefit. The evidence on the effect of land quality and soil type on adoption varies with different technologies or practices.

### 3.4.3 | Information and awareness

The findings on access to information were almost unanimous, as 25 of the 26 studies that reported statistical significance show that access to information is a driver of adoption. Similarly, indigenous knowledge or knowledge of similar technology or practice had a significant positive effect on adoption. On the other hand, despite the likelihood of training being an important determinant of adoption, only 26 out of the 133 studies have looked at this factor. Moreover, this was predominantly measured using the binary response format. Nevertheless, the findings mostly corroborate the wider literature, with 20 studies reporting a positive relationship between training and adoption.

The association between access to extension and adoption was investigated in 79 articles. This consists of studies in which extension contact was measured as access to extension services using binary or categorical responses and studies that estimated the frequency of extension visits. The consensus in the broad adoption literature is that access to extension services increased technology and practice adoption. The findings from these studies in SA on the effect of extension on adoption align with the broader literature. However, there are a few exceptions where access to extension constitutes a barrier to adoption. The reasons for this unusual finding vary across studies.

### 3.4.4 | Financial factors and incentives

Two studies out of three that investigated the effect of subsidies on adoption found that it had a statistically significant positive effect. Given the widespread use of subsidies in SA, the expectation is that there will be more studies examining its effect on adoption. While the limited available evidence suggests that it may positively influence adoption, there is the argument in the literature that subsidies on agri-environmental schemes may be unsustainable as farmers may simply be attracted by economic gains (Dessart et al., 2019). Access to credit is another determinant of adoption as it enhances farmers' capacity to purchase inputs needed for the new technology or practice, particularly for those with significant capital requirements (Liu et al., 2018). Of 47 studies, 18 findings support the hypothesis



that having access to credit has a significant positive effect on the probability (and the intensity) of adoption.

The association between the cost of the new technology or practice and adoption was investigated in seven papers. Six of these found that high costs of technology, particularly in the initial phases of the diffusion process, impede adoption. This corroborates findings in studies across other regions of the world (Liu et al., 2018) that an increase in direct or indirect costs was a recurring barrier to adoption.

### 3.5 | Important gaps and methodology issues

Many of the findings in Section 3.5 align with adoption review studies globally (Jones-Garcia & Krishna, 2021; Knowler & Bradshaw, 2007). However, contrary to the broader literature, the adoption of sustainable farming practices has not been given adequate coverage in SA. Also, studies in SA that include environmental consciousness factors are equally lacking. Most of the papers that constitute the adoption literature in SA did not inquire whether farmers have previously used technology and quit. This information is necessary to provide the background for differentiating between non-adopters and dis-adopters; otherwise, both categories, despite their substantial differences, would erroneously be treated as the same.

Notably, the factors discussed in this paper might not consistently be drivers or barriers, as the studies are not selected in a way that only causality studies are included. Hence, these are mainly correlations. We also postulate that there may be selection bias in the samples on which this study rests. This is mainly because we do not have sufficient data on the design underpinning many of the studies, if any, and how these studies addressed selection bias.

Contextual differences may have resulted in the lack of convergence around some key factors. Similarly, the finding that gender did not appear to be as significant as many other factors might be attributed to the difficulty in conceptualising what needs to be measured and finding reliable ways of measuring it. Besides, many of the findings are difficult to compare due to the different designs and theoretical and methodological approaches. Thus, the findings should be generalised with caution to avoid undue emphasis on certain barriers and drivers.

The understanding of causal relationships in adoption theories is also not conspicuous. This highlights the need for path analysis rather than dependence on regression tools, considering that there are multiple relationships between independent variables (and plausible scenarios can be created about how all of these are strongly linked).

## 4 | LESSONS AND RECOMMENDATIONS FOR ADOPTION OF SUSTAINABLE NITROGEN MANAGEMENT TECHNOLOGIES AND PRACTICES IN SA

There are important lessons to be learnt from the adoption literature that could aid in addressing the nitrogen pollution problem through increased levels of adoption of sustainable nitrogen management

technologies and practices. Besides, better and sustainable management of nitrogen input specifically and farming practices, in general, will contribute to achieving some of the sustainable development goals (SDGs), that is, SDG 13 (climate action) and SDG 12 (responsible consumption and production). Some key strategies guided by the findings from the reviewed literature are highlighted as follows:

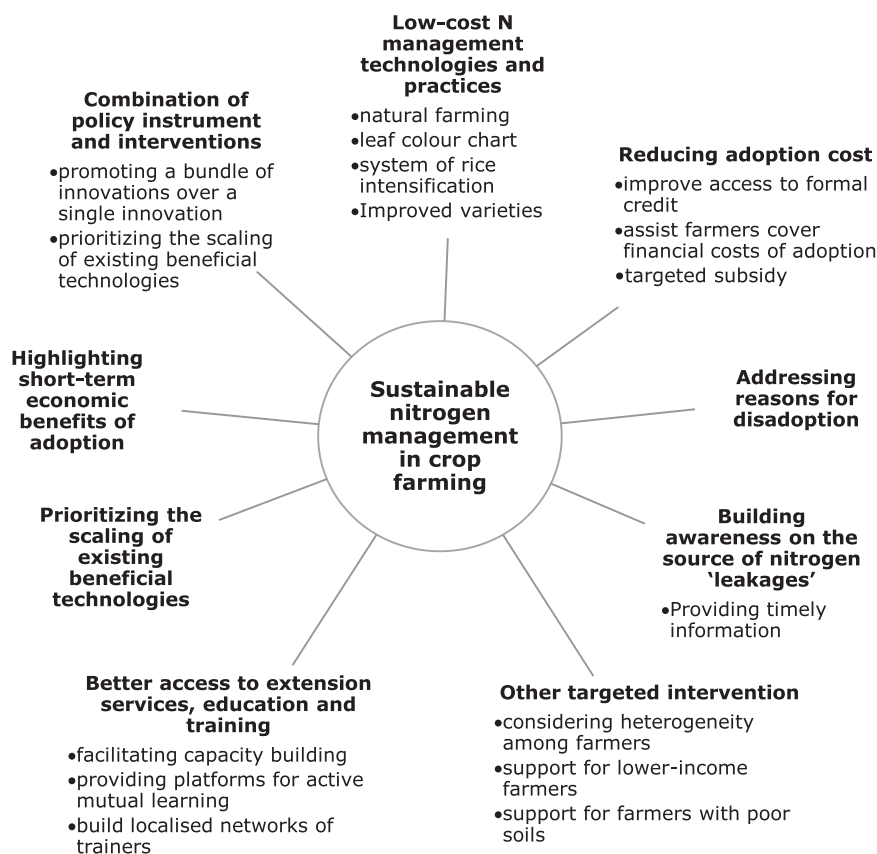
Farmers in SA have adopted different practices and technologies that directly or indirectly promote sustainable nitrogen management. Where applicable, enhancing their nitrogen management potential and scaling some beneficial technologies and practices may be more cost-effective and generally accepted than introducing new ones.

Access to extension services, education and training are strong adoption drivers that enhance access to information and improve knowledge. To encourage the adoption of sustainable crop management practices, farmers should be encouraged to recognise (agricultural and adult) education and training as a continuous process. This can be achieved by facilitating capacity building and providing platforms for active mutual learning. Stakeholders may also partner with NGOs to build localised networks of trainers by identifying and training local leaders, for example, from farmers' cooperative members who will deliver regular training to fellow farmers. Education and training should also be incorporated into existing programmes, and farmers should be supported to participate in such educational programmes.

Information accessibility, credibility and content should also be taken into cognisance at all stages of dissemination. It is crucial that farmers obtain necessary information exactly when it will be most effective in encouraging adoption. There is also the need to create awareness among farmers on the source of nitrogen 'leakages' and provide corresponding training at the farmer's level on any nitrogen management innovation, be it either new or advancement of existing innovations. Linking information sharing with social networks could also be very productive.

Considering the cost implications that act as a barrier to adoption for many smallholder farmers in SA, low-cost N management technologies and practices such as encouraging natural farming, use of leaf colour chart, the system of rice intensification and affordable technologies that enable a need-based application of N fertilisers will not only result in minimising losses to the environment but also provide economic benefits to farmers. In a similar vein, pursuing a credit policy that will improve access to formal credit and decrease dependence on noninstitutional sources of lending will help farmers cover the financial costs associated with the adoption of sustainable nitrogen management technologies and practices.

In light of the findings that subsidies also motivate adoption and that governments in SA have widely provided subsidies to agriculture, a well-thought-out and targeted subsidy to reduce cost, spur interest and minimise initial risk could be a reliable approach to encourage adoption. For example, the government could subsidise farmers' voluntary adoption, particularly in cases where adopting such nitrogen technologies and practices may not provide as much economic benefit to the farmer (compared to environmental



**FIGURE 3** Systemic highlight of key recommendations.

rewards). However, it is necessary to err on the side of caution as previous findings show that subsidies may also have unintended consequences.

Intervention across all groups may be usefully applied to promote widespread adoption. However, once this objective is achieved and further interventions become necessary, a change to a more targeted intervention should be made. This could be achieved by considering the extent of heterogeneity in farmer-related characteristics such as age, gender, education and attitudes. For instance, a possible policy recommendation could be to target lower-income groups in the short term. It may be more cost-effective to provide additional support to lower-income farmers, considering that they are likely to encounter higher opportunity costs from adopting sustainable practices. Similarly, given the finding that soil quality is a very strong driver, this raises the concern of equity, that is, farmers with better resources may find it easier to adopt new practices that will further strengthen their resource base. To address this issue, where soil quality is poor, targeted support for disadvantaged farmers should be coupled with improving soil quality.

It is important to observe constructively what technologies or practices farmers have previously adopted. Investigating whether farmers have used similar technology or practice and quit will help understand the farmers' background and differentiate between non-adopters and dis-adopters. The benefit is that different categories of

adopters can be given adequate support. This information can be obtained from existing studies and future purpose-designed adoption studies across SA.

Crucially, uniform policy prescription to fit all farm and farmer heterogeneity is not realistic. Besides, a combination of policy instrument and interventions is likely to be more effective. Promoting a bundle of innovations over a single innovation may also be efficient as the benefits are more evident. Considering Piñeiro et al. (2020) finding that the adoption rates for programmes with short-term economic benefits are higher than those with strictly ecological service, considerations of economic benefit, particularly for small and marginal farmers, are crucial when designing and implementing programmes on sustainable nitrogen management. We summarise this discussion in Figure 3.

## 5 | CONCLUSION

This paper provides a systematic review of the literature on the factors that affect technology and practice adoption in SA. The studies included in this review from six South Asian countries comprised 133 articles that fulfilled the criteria for inclusion. We conducted count analysis for the variables that determine the adoption of agricultural technology and practices examined the

comparability of determinants of adoption and the consistency of their respective associations with sustainable management practices. We find that the adoption of crop-related technologies and practices stood out as the most widely studied, in addition to several factors related to farmers' demographics, knowledge and attitudes, information and awareness, characteristics of farms, financial incentives, macro factors, characteristics of and interactions between the practices and technologies influences farmers' adoption of agricultural technologies and practices in SA.

This systematic review is relevant for policy and research. From the policy perspective, the scope of technologies and practices that this paper covers will be relevant in helping policymakers make informed decisions focused on identifying and reducing constraints to adoption. Where lacking, the main significant factors, or example, education, extension, training and income, can be addressed using short-term targeted policies. Others, such as land area, soil quality and irrigation, may require long-term policy intervention. This recommendation is in line with evidence that suggests that policy instruments that consider the characteristics of the target group tend to meet their goals effectively.

This paper serves as an evidence-based information repository that identifies scope for future research in aspects such as theory-centred work, which will explore relationships between adoption and drivers and barriers that are yet to be subjected to empirical research. In future research, there is the need for clearer reporting with respect to the definition of the factors, which factor gets measured in the first place, how these factors were measured if the method can establish causality or just correlation and reporting of factors that were measured but left out in the model reporting.

#### AUTHOR CONTRIBUTIONS

Toritseju Begho was involved in the conceptualisation, methodology, investigation, resource procurement and visualisation of this study, and writing – original draft and writing – review and editing of the manuscript. Klaus Glenk was involved in the conceptualisation, investigation, validation and resource procurement of this study, and writing – review and editing of the manuscript. Asif R. Anik was involved in the conceptualisation, investigation, validation and resource procurement of this study, and writing – review and editing of the manuscript. Vera Eory was involved in the conceptualisation, methodology, investigation and validation of this study, writing – review and editing – of the manuscript and project administration.

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#### CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

#### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

#### ETHICS STATEMENT

The authors confirm that they have adhered to the ethical policies of the journal.

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APPENDIX

Figure A1



**FIGURE A1** Duration of publication of papers that constitute the review