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An examination of the factors which influence farmers' intentions towards the implementation of nutrient management planning

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Declaration of originality

I, Amar Daxini, hereby declare that all research herein is entirely my own work. The work here has not been submitted for any other degree or professional qualification. Although the following publications (Chapters 4, 5 and 6), have joint authorship, the work contained in them is solely my own. Co-authorship represents support in terms of comments, suggestions, advice and discussion of aspects of the research.

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Lay Summary

Nutrient inputs, in the form of synthetic fertiliser and manure, are essential for ensuring that food production is sustained. However, nutrient loss from farms to water courses and the atmosphere have led to the deterioration in water quality and contributed to global warming. Poor management of nutrients on farms has been suggested as one important reason for this. There are a host of farm nutrient management practices that farmers can adopt to minimise the risk of nutrient loss from farms. One such practice is called nutrient management planning. This practice involves collecting farm-specific information which is then used to create a customised plan which ensures that nutrients are allocated to areas of the farm that require them. This practice also helps farmers to improve production by targeting nutrients to areas of the farm that are most in need of them. One advantage of nutrient management planning is that it can help farmers to reduce costs. However, because nutrients are being appropriately targeted this can also help to minimise the risk of excessive nutrients being lost to the environment. Therefore, nutrient management planning offers both financial and environmental benefits. For these reasons it is surprising that low levels of nutrient management planning occur on farms. There has been a growing interest from policy makers to understand what motivates farmers to take up nutrient management planning. The current understanding remains limited as research in this area is scarce.

This thesis studies what influences farmers to implement nutrient management planning. A review of the literature highlights that two practices are particularly important aspects of nutrient management planning. These are: 1) applying fertiliser on the basis of soil test results and, 2) following a nutrient management plan. The first practice involves analysing the nutrient contents of a given field and then targeting nutrients based on these results. This means applying fertiliser only where it is needed and increasing it into areas where nutrients are a lower than required levels. The second practice is a document that farmers develop usually with a professional agricultural advisor who collects farm-specific information from

the farmer (e.g. soil fertility and type of farm) and uses this information to calculate suitable nutrient application rates for each field. A farmer must then follow this plan to gain the production and environmental benefits. To understand what previous researchers have found to influence farmers to use nutrient management planning, a review of the literature was conducted. It becomes apparent that some types of farmers and farms are more likely to adopt this practice. Whilst the evidence is not conclusive, these typically include those who are younger, more educated and operate their farm on a full time basis, among others. Larger farms, located on better soil and operated at a higher level of intensity are also found to be more likely to adopt nutrient management planning. However, the literature tells us much less about the attitudes, beliefs, ability of farmers and social pressure they may feel to implement nutrient management planning. Such issues have been explored among other studies but not in relation to nutrient management planning. Therefore, to gain a better understanding as to what influences farmers to implement nutrient management planning, this study analyses if these issues have any importance to the decision to implement.

To achieve the aim of this research, data is collected from a sample of 1009 farmers from the Republic of Ireland (Ireland). This country is chosen as it has ambitious targets to increase food production and the government is keen to ensure that the risk of environmental degradation from nutrients is minimised. Nutrient management planning is one practice that the government is keen for farmers to improve. The challenges faced by Ireland are also well-reflected more globally and therefore lessons learnt from this study can be applied more widely. The data were collected via a survey, sometimes referred to as a questionnaire, which elicited information from farmers regarding their socio-economic circumstances (e.g. age and education) and farm characteristics (e.g. type of farm and farm size). To ensure that the sample represented Irish farming in general, it was ensured that certain numbers of specific farm types and farm sizes were collected. Farmers were also read out a series of statements to gain an understanding of their beliefs towards the two practices under study and their future intentions to use these practices. Each of the questions were read out to farmers face-to-face and recorded by the interviewer. The information from the survey was then used to understand what influences farmers intentions to implement nutrient management planning.

To analyse the information collected in the survey a range of statistical methods were applied to the data. In total three separate analyses were conducted. The first focuses on the first practices which is farmers' intentions to apply fertiliser on the basis of soil test results. The second and third analysis both focus on farmers intentions to follow a nutrient management plan. Overall, the results from the analyses show that social pressure and farmers' perception of their ability to implement these practices are among the most important factors determining their intention to implement them. Agricultural extension is also another key factor influencing farmers; intentions. However, the results also show that the factors which influence farmers' intentions vary between groups. Finally, it is also found that farmers' place their trust in different sources of information and as trust increases farmers' perceptions of nutrient management planning are influenced. These results provide policy makers with useful information for increasing the use of nutrient management planning among farmers.

Based on the results a number of policy recommendations can be made. Firstly, efforts to increase the level of social pressure that farmers feel towards implementing nutrient management planning should be increased. Secondly, farmers need to be engaged further in nutrient management planning to improve their level of technical ability over implementing it. Thirdly, further efforts should be made to encourage farmers to engage with agricultural extension services, in particular combing both one-to-one contact and group based learning environments may be beneficial. Fourthly, information about nutrient management planning should be targeted through the sources of information farmers are more likely to trust. Finally, policy makers must target different groups of farmers with campaigns designed to increase implementation of nutrient management planning because the results show that farmers are likely to respond differently.

Abstract

Nutrients such as Nitrogen (N), Phosphorous (P) and Potassium (K) and other micronutrients such as such as magnesium, manganese and cobalt, are essential for the continued growth of global agricultural production. These nutrients are typically applied to agricultural fields in the form of synthetic fertiliser and/or manure. However, if not used efficiently, the risk of loss to water courses and the atmosphere can increase. Inefficient use has led to global deteriorations in water quality, algal blooms, fish kills and contributed to greenhouse gas emissions. Poor management of nutrients is one important reason contributing to the inefficient use of nutrients on farms. Key issues include the over application of the wrong nutrient source to fields that do not require it, using the wrong rate at the wrong time. Under application of nutrients is also an issue as this has been associated with the underperformance of crops and reductions in soil fertility levels. Farmers are advised to adopt certain nutrient management practices that have been proven to ensure that nutrients are targeted appropriately which has been associated with improvements in nutrient use efficiency, production and a reduction in the risk of nutrient losses to the environment. One such practice is called nutrient management planning. This is a process which involves the collection of site-specific information (e.g. stocking rate, soil fertility levels of crop type) which is then used to devise a nutrient management plan. A nutrient management plan is a document that is developed by farmers typically in conjunction with an agricultural advisor. This plan makes recommendations of how best to target nutrients in line with crop demand. However, despite widespread pressure and considerable promotion of the advantages of nutrient management planning, uptake of nutrient management planning by farmers remains limited globally. Policy makers are keen to understand what motivates farmers to implement nutrient management planning. The overall aim of the research presented in this thesis is to examine and explain the factors which influence farmers' intentions towards the implementation of nutrient management planning. The two practices under consideration are farmers' intentions to apply

fertiliser on the basis of soil test results (practice one) and to follow a nutrient management plan (NMP) (practice two).

A review of the literature demonstrates that there remains a dearth of studies specifically focusing on the uptake of nutrient management planning. Furthermore, among the existing studies, the focus is typically on explaining uptake as a function of farm (e.g. system and farm size) and farmer characteristics (e.g. age and education). A limited number of studies specifically in relation to nutrient management planning focus on the socio-psychological beliefs, including social pressure and perceptions of capability, of farmers. Those studies that do focus on these issues typically remain qualitative in nature and therefore generalising the results remains an issue. To accomplish the aim of this research the well-established socio-psychological Theory of Planned Behaviour (TPB) is used as a basis for understanding farmers' intentions towards implementing nutrient management planning. A number of additional variables are also chosen based on a review of the literature such as farm system, farm size, farmer age and education as well as use and trust in information sources. The data came from a sample (n=1009) of Irish farmers for the year 2016. A quota controlled system was set in place to ensure that the sample was representative in terms of predominant farm systems and sizes in Ireland. Ireland presents an interesting case study for analysis due to ambitious targets to increase food production, whilst also maintaining and improving water quality, whilst reducing overall greenhouse gas emissions from agriculture. The issues in this Irish case are reflected more widely and therefore results from this study can be generalised. A cross-sectional survey was designed to collect information from farmers regarding their beliefs and intentions towards the implementation of the aforementioned practices and information regarding the additional variables.

To analyse the data elicited by the survey a range of econometric techniques are applied. The primary techniques employed include binary logistic regression, principal component analysis, latent class analysis and structural equation modelling. In total three separate analyses are conducted which are presented as three empirical papers. The first analyses farmers' intentions to apply fertiliser on the basis of soil test results whereas the second and third both focus on farmers intentions to follow a nutrient management plan. Overall, the results from the analyses show that subjective norm (social pressure) and perceived behavioural control (farmers' perception of ease/difficulty of implementation) to implement these practices are among the most important factors determining their intention to use them. Agricultural extension is also another key factor influencing farmers' intentions. However, the results from the latent class analysis also show that the variables which influence farmers' intentions vary between groups in terms of significance, but also magnitude of influence (marginal effect). Finally, results from the structural equation model also highlight that farmers' place their trust in different sources of information and as trust increases farmers' perceptions of nutrient management planning are influenced. These results provide policy makers with useful information for increasing the use of nutrient management planning among farmers.

The results of this thesis suggest five main strategies to increase farmers' intentions to adopt nutrient management planning. First, increase social pressure on farmers to use this practice. Second, increase farmers' level of perceived behavioural control (ability) over implementing nutrient management planning. Thirdly, increase contact between agricultural extension and farmers, in particular combing both one-to-one contact and group based learning environments may be beneficial. Fourthly, information about nutrient management planning should be targeted through the sources of information farmers are more likely to trust. Finally, policy makers must target different groups of farmers with campaigns designed to increase implementation of nutrient management planning because the results show that farmers are likely to respond differently.

Future research should be directed at examining the best methods for increasing social pressure and perceptions of control and to encourage and enable farmers to implement nutrient management planning and how these campaigns should be tailored to specific groups of farmers.

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List of abbreviations

DAFM	Department of Agriculture, Food and the Marine
LCA	Latent Class Analysis
ND	Nitrates Directive
NMP	Nutrient Management Plan
PCA	Principal Component Analysis
SEM	Structural Equation Modelling
TPB	Theory of Planned Behaviour

Chapter 1: Introduction

1.1 General background

To meet rising global demand for food, agricultural production has intensified rapidly since the mid-twentieth century (Rudel *et al.,* 2009; Swain *et al.,* 2018). The increasing use of both artificial and natural fertilisers has been central to the intensification process which has led to higher crop yields, the ability to sustain greater animal numbers and the meeting of global food security for many people (Nesme *et al.,* 2018; Ickowitz *et al.,* 2019). However, there remains the global challenge of ensuring that the risk of nutrient (principally nitrogen (N), phosphorous (P) and potassium (K)) accumulation in soils and loss to both the aquatic and atmospheric environment is minimised whilst also ensuring that production is maintained (Sutton *et al.,* 2013; United Nations, 2016). Accumulation of nutrients in soils can lead to soil acidification (Goulding, 2016), whereas nutrient loss can negatively impact water quality (eutrophication) (Withers and Lord, 2002; Evans *et al.,* 2019) and contribute to global warming due to greenhouse gas emissions (Bell *et al.,* 2014; O'Brien *et al.,* 2014). Such losses of nutrients can lead to potential adverse effects on biodiversity and human health (Lu and Tian, 2017; Lun *et al.,* 2018). Furthermore, if nutrients are not supplied in adequate quantities then soil fertility can decline which can result in lower than expected crop yields and increased risk of soil erosion (Ingram, 2008; McGrath *et al.,* 2014). Ultimately, suboptimal use of nutrients can lead to a financial loss to farmers (Goulding *et al.,* 2008; Buckley and Carney, 2013). Such concerns have often led to regulation of nutrient use on farms and extensive efforts to encourage farmers to voluntarily improve the way in which they manage nutrients (Sutton *et al.,* 2013; Gibbons *et al.,* 2014; Gebrezgabher *et al.,* 2015; Buckwell and Nadeu, 2016). Moreover, improving nutrient management is an important concern for policy makers as it is believed to be one of the foundations for increasing resource use efficiency (Buckwell and Nadeu, 2016; McGlynn *et al.,* 2018).

The area of decision making farmers engage in towards application of synthetic fertiliser and manure is referred to as nutrient management (Oenema and Pietrzak, 2002). The goal of nutrient management is to target nutrient inputs, such as N, P and K and other micronutrients, to areas of the farm that require them, using the right source at the right rate and time (Roberts and Johnston, 2015). This strategy forms part of the globally recognised notion of the '4Rs (right rate, rate time, right source, right place) of Nutrient Stewardship' (Sutton *et al.,* 2013; Bruulsema, 2018). In order to effectively target nutrients to fields, farmers are advised to adopt a widely recommended process referred to as 'nutrient management planning' (Beegle *et al.,* 2000; Monaghan *et al.,* 2007; Genskow, 2012; Ulrich-Schad *et al.,* 2017; Brown *et al.,* 2019). Nutrient management planning is a process that begins by setting objectives, such as production goals and desired yields, for the particular farm system in question. The next step involves the periodic collection of farm specific data such as soil nutrient availability through soil nutrient testing, cropping history, animal stocking rate and yield potentials. This information is then used to develop a formalised nutrient management plan (NMP). An NMP is typically formulated in conjunction with an agricultural advisor and makes specific recommendation for the optimum nutrient management strategy for the specific farm situation. The two most important nutrient management planning practices and the foundation of a successful nutrient management planning strategy for any farm type are considered to be soil testing and the formulation of a NMP (Beegle *et al.,* 2000; Oenema and Pietrzak, 2002; Monaghan *et al.,* 2007). These two practices are the focus of this study.

Research has shown that the adoption of practices associated with nutrient management planning, such as soil testing and use of a NMP, can lead to a reduction in the risk of nutrient loss to water as well as an increase in profits (VanDyke *et al.,* 1999; Shepard, 2005; Thomas *et al.,* 2007; Genskow, 2012; Schulte *et al.,* 2009; Jat *et al.,* 2018). Among farmers and experts, nutrient management planning has been found to be perceived as one of the most effective measures towards improving P use efficiency on farms (Micha *et al.,* 2018). Christianson *et al.* (2014) found farmers have positive attitudes towards N nutrient management planning practices, however these positive perceptions did not always associate with practice adoption. Extensive efforts have also been made to promote nutrient management planning through both regulatory and voluntary methods (Genskow, 2012; Savage and Ribaudo, 2013; Osmond *et al.,* 2015; Perez, 2015). Despite this, adoption of nutrient management planning practices, such as soil testing and a NMP, remain below expectations globally (Lambert *et al.,* 2014; Darby and Heleba, 2015; Buckley *et al.,* 2015; Osmond *et al.,* 2015; Kelly *et al.,* 2016; Ulrich-Schad *et al.,* 2017; Umbers, 2017; DEFRA, 2018; Brown *et al.,* 2019). Moreover, a situation has been observed whereby farmers who conduct soil testing and construct a NMP do not always base nutrient application decisions on these (Genskow, 2012; Buckley *et al.,* 2015; Osmond *et al.,* 2015; Kannan and Ramappa, 2017). This potentially forgoes some of the benefits that otherwise could be gained and remains confusing for policy makers.

Fertiliser application rates, for example that are in excess of the optimum, are often accredited to issues associated with risk aversion to lower yields, incentive incompatible fertiliser pricing or information asymmetry (Sheriff, 2005; Buckley and Carney, 2013). Regardless, some have argued that if further reductions in the risk of nutrient loss to the environment as well as gains in productivity are to be made on farms then strict implementation of nutrient management planning is required (Roberts *et al.,* 2017; McDonald *et al.,* 2019). Both Reimer *et al.* (2014) and Ulrich-Schad *et al.* (2017) argue that the majority of studies focusing on the adoption of farm management practices, including nutrient management planning, examine adoption rather than actual use, which is required if the full benefits of the practice are to be derived. Therefore, in this study, farmers intentions towards *implementing* nutrient management planning are examined rather than the mere adoption of practices associated with nutrient management planning such as soil testing and a nutrient management plan. The uptake and full implementation of the nutrient management planning practices, remains below expectations globally as described above, and, yet there remains little consensus as to the reasons why (Baumgart-Getz *et al.,* 2012; Genskow, 2012; Buckley *et al.,* 2015; Osmond *et al.,* 2015; Kannan and Ramappa, 2017). This indicates that there is still a need for further in-depth research on potential ways farmers can be encouraged to continue to use, adopt and implement these nutrient management planning practices in the future. Thus, the overall aim of this thesis is to examine and explain the factors which influence farmers' intentions towards the implementation of nutrient management planning. The two conduct specific nutrient management planning practices which will be examined are farmers' intentions to: (1) apply fertiliser on the basis of soil test results and (2) follow a NMP.

1.2 Farmer adoption literature

Developing an understanding of the factors which influence farmers' intentions to implement nutrient management planning is vital for designing policy to stimulate further implementation (Borges *et al.,* 2014). Although intention implies future adoption of nutrient management planning, the literature on farmers' intentions to adopt a given practice is closely allied with the literature on agricultural management practice adoption which focuses on current levels of adoption. Lower than expected adoption rates have been observed not only in terms of nutrient management planning but also for other various recommended farm management practices more widely (Pannell *et al.,* 2006; Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). For this reason, extensive research efforts have been dedicated over a number of years to understand the factors which influence farmers to adopt widely recommended management practices and innovations (e.g. Feder *et al.,* 1981; Feder and Umali, 1993; Knowler and Bradshaw, 2007; Baumgart-Getz *et al.,* 2012; Liu *et al.,* 2018), and, to a lesser extent, the uptake of nutrient management planning (Monaghan *et al.,* 2007; Buckley *et al.,* 2015; Ulrich-Schad *et al.,* 2017). Whilst the empirical literature on agricultural adoption is vast, it does not consistently identify determinants of management practices (Knowler and Bradshaw, 2007; Baumgart-Getz *et al.,* 2012 Liu *et al.,* 2018). Reimer *et al.* (2014) argue that despite decades of research, there is still a large degree of unexplained variation and a lack of understanding about the factors that contribute to, or inhibit, farmers to adopt recommended practices, such as nutrient management planning. This indicates that there is still a need for further in-depth research on potential ways farmers can be encouraged to adopt and implement not only nutrient management planning practices, but also recommended management practices more generally.

Similar to the wider literature on farm management practice adoption, within the literature on nutrient management planning, determinants of practice adoption have been shown to be wide-ranging and context-specific, including farmer demographics, farmer attitudes and values, farm characteristics, and characteristics of the practices in question (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012; Reimer *et al.,* 2012c; Buckley *et al.,* 2015; Ulrich-Schad *et al.,* 2017; Yoshida *et al.,* 2018). Researchers have used a variety of approaches to investigate farmer nutrient management planning, including typologies that categorize farmers by shared values, attitudes, or behaviours (Barnes *et al.,* 2011; Buckley, 2012; Reimer *et al.,* 2012a), socio-psychological explorations of attitudinal antecedents of practice adoption (Reimer *et al.,* 2012c; McGuire *et al.,* 2013; Yoshida *et al.,* 2018) and analyses of variables contributing to practice adoption (Ribaudo and Johansson, 2007; Savage and Ribaudo, 2013; Buckley *et al.,* 2015; Ulrich-Schad *et al.,* 2017). In general, studies tend to show that adoption of nutrient management planning is influenced by farm characteristics (e.g. system, size and soil quality) (Ribaudo and Johansson, 2007; Lawley *et al.,* 2009; Price, 2011; Roberts *et al.,* 2017; Ulrich-Schad *et al.,* 2017), farmer characteristics (e.g. attitudes, age, education and off-farm job) (Buckley *et al.,* 2015; Ulrich-Schad *et al.,* 2017; Brown *et al.,* 2019), external influences (e.g. fertiliser price, farm-gate prices, policy and social pressures) (Ribaudo and Johansson, 2007;

Osmond *et al.,* 2015; Buckley *et al.,* 2016) as well as the characteristics of the practice to be adopted (e.g. cost, complexity and trialability) (Monaghan *et al.,* 2007; Reimer *et al.,* 2012b) and use of information (e.g. trust and engagement with sources of information) (Genskow, 2012; Stuart *et al.,* 2018).

Compared to the literature on adoption of farm management practices more widely (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012; Liu *et al.,* 2018), specific studies on nutrient management planning remain limited (Ulrich-Schad *et al.,* 2017). Those that do, typically focus on examining how certain farm and farmer socio-economic characteristics (e.g. farm size, farmer age, education levels and off-farm employment) can influence uptake. Moreover, the few studies that examine the influence of socio-psychological variables (e.g. attitudes, beliefs and social norms) on the uptake nutrient management planning (Reimer *et al.,* 2012a; Yoshida *et al.,* 2018) tend to be qualitative in nature and do not empirically test socio-psychological theory. Thus, the results from such studies, albeit useful for providing insights into farmer behaviour, are difficult to generalise more widely (Wilson *et al.,* 2014). The lack of focus on socio-psychological issues in relation to the uptake of nutrient management planning may be constraining our understanding of the factors which influence farmers' to implement nutrient management planning.

Studies which solely rely on explaining farmer adoption decisions as a function of farm and farmer socio-economic characteristics has been criticised for using an expected utility theoretical framework which assumes that farmers are rational profit maximisers and have access to perfect information (Edwards-Jones, 2006; Borges *et al.,* 2014). Some authors have highlighted that farm and farmer socio-economic factors often become insignificant predictors of adoption for analysing decision making on a small scale, since non-financial factors increasingly effect decision making (Poppenborg and Koellner, 2013). Despite this, recent studies focusing on the adoption of sustainable farm practices continue to focus on explaining adoption based on expected utility theory and as a function of a variety of farm and farmer socio-economic characteristics (Jara-Rojas *et al.,* 2012; Tsinigo and Behrman, 2017; D'Souza and Mishra, 2018; Holden *et al.,* 2018; Shuoxin Zhang, 2018; Wang and Zhu 2018). A number of authors have suggested that a lack of agreement regarding the variables which influence adoption among past studies could be due to a failure to adequately represent socio-psychological issues (e.g. beliefs and social pressure) in models used to explain farmer behaviour (Burton, 2004a; Edwards-Jones, 2006; Borges *et al.,* 2014; Zeweld *et al.,* 2017).

The underpinning assumption of human rationality in previous studies is challenged by the concept of 'bounded rationality' (Simon, 1955). This concept suggests that humans are limited by the information they have, the cognitive limitations of their minds, by the finite resources they possess and the political context in which decisions are made. Thus, humans are believed to be 'satisficers', in so far as they do not always conduct economically optimal decisions, but instead may choose to optimise other aspects such as social, intrinsic and/or expressive goals (Simon, 1957). Research has attempted to address the shortcomings of previous studies by capturing farmers' attitudes and beliefs and how these relate to the adoption of management practices (Gasson, 1973; Ilbery, 1983; Halliday, 1989; Carr and Tait, 1991; Holloway and Ilbery, 1996; Willock *et al.,* 1999). However, Burton (2004a) argues that early research over emphasises the role that attitude plays in farmer decision making which effectively removes farmers from the social context within which they operate. Furthermore, early research has been criticised for overlooking constraints imposed on farmer decision making (Beedell and Rehman, 2000). In essence, one of the key problems with early research is that it is not founded on a well-motivated behavioural theory (Beedell and Rehman, 2000; Burton, 2004a; Edwards-Jones, 2006) which, some have argued, continues to be a problem with more recent agricultural research (Feola and Binder, 2010; Feola *et al.,* 2015).

To address the weaknesses of previous research and to better inform policy initiatives designed to encourage the further uptake of farm management practices, a number of researchers have turned their attention to behavioural theory and quantitative methodologies used in the field of socio-psychology (e.g. Hansson *et al.,* 2012; Borges *et al.,* 2014; Adnan *et al.,* 2017a; Morais *et al.,* 2018). These studies tend to adopt 'intent' based behavioural theories which argue that intentions are a suitable predictor of future behaviour; i.e., implementation of a given practice. The results of such studies tend to highlight that farmers' intentions are influenced by a range of attitudinal, social and control based beliefs (Adnan *et al.,* 2018). Indeed, a number of researchers have observed an increase in the use of socio-psychological approaches which have been proven to better explain decision making (Gorton *et al.,* 2008; Wauters *et al.,* 2010; Wauters and Mathijs, 2013). This study also adopts a socio-psychological approach based on behavioural theory to better understand the factors which influence farmers' intentions to implement nutrient management planning. Applications of socio-psychological approaches in an agricultural context has been termed the 'behavioural approach' (Burton, 2004a).

1.3 Theoretical background

Over a number of years, a variety of theoretical perspectives have been developed across various disciplines (e.g. information technology, sociology and psychology) to explain human behaviour in general as well as to understand, predict and explain the factors that influence the adoption of technology and practices at individual as well as organisational levels (for a review see, Davis *et al.,* 2015). These theories can be broadly categorised into diffusion theories (e.g. Diffusion of Innovations and Technology Lifecycle Theory), user acceptance theories (e.g. Theory of Planned Behaviour, Technology Acceptance Modal, Motivational Model, Unified Theory of Acceptance and Use of Technology), decision making theories (e.g. Rational Choice Theory, decision making under uncertainty and risk management), personality theories (e.g. Technology

Lifecycle Theory and Social Cognitive Theory) and organisational structure theories (e.g. Disruptive Technology Theory and Creative Destruction Theory) (Hillmer, 2009). Overall, models of behaviour and adoption each have their advantages and disadvantages in terms of their suitability for studying the nature of the behaviour in question. For example, Diffusion of Innovations (DOI) (Rogers, 1962) is more suited to studying how a society adopts a given technology over time. The Technology Acceptance Model (TAM) (Davis, 1989) is useful for studying the adoption of given practice but is limited to two primary variables: perceived usefulness and perceived ease of use. The TAM2 (Venkatesh and Davis, 2000) and the UTAUT framework (Venkatesh *et al.,* 2003) build on previous theories of behaviour to overcome this criticism by introducing additional variables such as experience, relevance, age and voluntariness. However, the TAM2 and UTAUT frameworks have been criticised for including predictors that have been found to not be universal and for being too complicated for practical use (Bagozzi, 2007).

One of the most widely and successfully applied theories to understand human behaviour across a range of fields is Ajzen's (1985) Theory of Planned Behaviour (TPB) (Armitage and Conner, 2001; Davis *et al.,* 2015). The TPB explains that human behaviour is best predicted by intentions to engage in a given behaviour. Intentions are in turn a function of attitude (towards the outcomes of performing a given behaviour), subjective norm (social pressure) and perceived behavioural control (ease/difficulty) (see Chapter 2 for more details). Within an agricultural context the theory has gained prominence in recent years to understand farmers' intentions towards a range of agricultural practices (Micha *et al.,* 2015; van Dijk *et al.,* 2015; Borges and Oude Lansink, 2016; Lalani *et al.,* 2016; Senger *et al.,* 2017; Zeweld *et al.,* 2017; Hyland *et al.,* 2018a; Jiang *et al.,* 2018; Morais *et al.,* 2018; Rezaei *et al.,* 2018; Zeng and Cleon, 2018). The TPB is advantageous as it accounts for both social influences and constraints on behaviour which are often overlooked by other behavioural theories and research specific to agricultural studies (Burton, 2004a). Furthermore, the TPB is well suited to examining farmers' intentions towards implementing nutrient management planning in particular. This is because the decision to implement nutrient management planning is deliberate and conscious, which makes it ideally suited to applying the TPB (Krueger *et al.,* 2000). Second, the TPB controls for potential constraints or difficulties farmers may experience when implementing nutrient management planning. For example, using soil analysis results and following a NMP requires time, understanding and seeking of external support and thus a high degree of cognitive processing (McDonald *et al.,* 2019). Moreover, unlike some of the other theories discussed above, the TPB provides a simple and structured yet flexible framework for explaining intentions as it allows for the inclusion of additional, context specific, variables which are often relevant in an agricultural situation (Ajzen, 1991; Beedell and Rehman, 2000; Bagozzi, 2007; Williams *et al.,* 2011). Thus, the TPB is used as a basis for examining and explaining the factors which influence farmers' intentions towards the implementation of nutrient management planning.

Whilst, the TPB is said to be both parsimonious and successful in predicting behaviour (Webb and Sheeran, 2006), it has certain limitations. One key limitation is the omission of a number of variables which have been found to influence farmer decision making in relation to the uptake of farm management practices. Examples of influences include the policy context, farm size and system, farmer age and education (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). Due to these omissions from the TPB, Burton (2004a) argues that a strict application of the TPB within an agricultural context may not be desirable. Some authors have called for using an integrative approach to study farmer behaviour which combines socio-psychological variables with wider contextual factors such as farm and farmer socio-economic characteristics as well as the wider political setting in which farmers operate (Burton, 2004a; Edwards-Jones, 2006; Feola and Binder, 2010). Due to the proven influence of non socio-psychological variables on farmers' decisions to adopt management practices, this research extends the

TPB to include such variables and in doing so, addresses a key limitation of the theory (see Chapter 3 for more details). Thus, this approach seeks to provide a more comprehensive understanding of the factors which influence farmers' intentions to implement nutrient management planning.

1.4 Irish context

This study is based in the Republic of Ireland (henceforth Ireland). Around 4.9 million hectares (71%) of the total land area of Ireland (6.9 million hectares) is devoted to agricultural production (CSO, 2016), well above the EU average of around 40% (Regan *et al.,* 2012). Irish agriculture is predominantly pasture based grazing systems with 84% of total agricultural land area (4.1 million hectares) farmed being dedicated to grass based production (silage, hay and pasture), with the remaining composed of crop production (351, 500 hectares, 7%) and rough grazing (16, 300 hectares, 9%) (CSO, 2016). Mild seasonal temperatures combined with high rainfall rates throughout the year results in high levels of grass growth which makes farmers mostly independent from feed imports (Paul *et al.,* 2018). Food production is concentrated on milk and beef for export, benefiting from low input-costs by utilising grass based feeding systems, which give Irish production systems a competitive advantage over other ruminant producing countries in terms of low cost animal production (Hanrahan *et al.,* 2017). However, whilst cattle farms comprise the majority of farm systems (around 53%) they only provide 29% of total output whereas the dairy sector, which accounts for around 12% of farm systems, provides 32% of total output, rendering dairying the most significant agricultural sector in terms of contribution to the economy (Conefrey, 2018). Overall, the agri-food sector is important to the Irish economy which, in 2016, generated 7% of gross value added (€13.9 billion) and contributed to 7.9% of national employment (CSO, 2016).

The Irish government has set expansion targets for the agricultural sector in light of growing demands for food production globally which are detailed in the Food

Harvest 2020 and the Food Wise 2025 policy initiatives (DAFM, 2010, 2015). Key aims comprise of a 50% increase in milk production by 2020 where the abolition of milk quotas in 2015 have provided favourable market conditions for the Irish dairy industry to expand. The value of beef production is to increase by 20% by 2020 and to increase the national sheep flock from 2.5 million breeding ewes to 3.5 million. Whilst tillage land comprises only around 7% of agricultural land use, government food production targets call for a sustaining or increase in crop yields in the near future. Targets are to be met through increases in stock numbers, innovation, value added, premium market development and improved production efficiencies (Wall *et al.,* 2016). However, whilst an increase in production is likely to increase farm profits, an increase in production is also likely to lead to an increase in pressures on the environment (O'Boyle *et al.,* 2017).

Despite a general improvement in Irish water quality and a reduction in greenhouse gas emissions from agriculture over time, significant issues and threats to a reversal in this trend exist in light of national production targets (Wall *et al.,* 2016). For example, since the 2012 there has been a continual decline in the number of rivers being classified as 'good' or 'high' status (Trodd and O'Boyle, 2018), which has coincided with an increase, following a stagnation, in the overall value of gross output from agricultural production by 46% since 2010 (Conefrey, 2018). The link between agricultural activity and environmental deterioration has been confirmed with agricultural production having a significant impact on the aquatic environment with 90% of N and 50% of P loads originating from agricultural sources (Bradley *et al.,* 2015), with 50% of cases of river pollution being attributed to agricultural sources of nutrients (Wall *et al.,* 2016). Key impacts from diffuse sources of agricultural nutrient pollution include the enrichment of water courses which has led to eutrophication (Ulén *et al.,* 2007). The agricultural sector was also directly responsible for around 32% of national GHG emissions in 2014, mainly methane from livestock, and nitrous oxide due to the use of nitrogen fertiliser and manure management (EPA, 2016). Targets to reduce greenhouse gas emissions by 20% compared to 2005 levels are not likely to be met (Wall, 2016). Moreover, increasing fertiliser prices over time have been associated with reductions in the use in fertiliser inputs to agricultural land and a subsequent downward trend in national soil fertility levels have been observed (Dillon *et al.,* 2018a). Declining soil fertility levels are believed to be hindering national production targets from being met (Dillon *et al.,* 2018a). The simultaneous policy desire to increase national production levels whilst also minimising the environmental impact of agriculture has, among other efforts, led to an increase in the promotion of various farm management practices that have been proven to minimise the risk of nutrient loss to the environment whilst also maintaining or improving productivity such as improved grassland and/or crop management, altering stocking rates and fertiliser application methods (Melland *et al.,* 2018; Micha *et al.,* 2018).

Improving nutrient management planning on all farms has been advocated as one key strategy for addressing policy targets for an increase in production levels and reducing the risk of nutrient loss to the environment (Wall and Plunkett, 2016; Shortle, and Jordan, 2017). Irish research has found that improvements in nutrient management planning on farms could lead to cost savings (e.g. fertiliser cost or feed), improvement in production through a better targeting of fertilisers to areas of the farm that require them and subsequently a reduction in the risk of nutrient loss to the environment (Schulte *et al.,* 2009; Buckley and Carney, 2013; Roberts *et al.,* 2017). However, despite proven benefits and considerable promotion, adoption of nutrient management planning remains below expectation. For example, Buckley *et al.* (2015) found from a sample of Irish farmers that 66% adopted soil testing whereas only 27% adopted a NMP. Kelly *et al.* (2016) reported that only 45% of sampled Irish dairy farmers adopt soil testing on a voluntary basis. Interestingly, a situation has also been observed where farmers often adopt soil testing and a NMP, yet fail to fully translate these data into decision making surrounding fertiliser application (Buckley *et al.,* 2015; Kelly *et* *al.,* 2016). This issue has also been observed more widely (Genskow, 2012; Osmond *et al.,* 2015; Kannan and Ramappa, 2017; Ulrich-Schad *et al.,* 2017), yet there remains little understanding as to the reasons explaining low implementation. In Ireland, there is a target to use NMPs based on soil testing with 60% of farmers by 2025 (Teagasc, 2016).

Ireland presents an interesting case study for analysing the factors which influence farmers' intentions towards the adoption of nutrient management planning for a number of reasons. Firstly, on the one hand the Food Harvest 2020 and Food Wise 2025 strategies seek to increase the contribution of the Irish agri-food sector to the Irish economy, yet, on the other hand, ambitious environmental targets also exist (Donnellan *et al.,* 2018). Secondly, there is a significant policy interest in increasing uptake of nutrient management planning across all farms to address production targets whilst also minimising the risk of nutrient loss to the environment. Thirdly, despite significant promotion through advisory services, the media and extension campaigns, uptake of nutrient management planning remains below expectations. Fourthly, where farmers do adopt nutrient management planning it is often to satisfy policy requirements rather than to improve production. Finally, insights gained from the Irish context are applicable more widely as the challenges discussed, whilst prominent in Ireland, are not unique to the Irish situation.

1.5 Nutrient management policy

Nutrient management planning can be adopted voluntarily, where farmers heed to relevant nutrient management advice and adopt given recommended practices. However, due to the negative environmental consequences associated with the use of nutrients on farms, nutrient management has become regulated in various part of the world, requiring farmers to conduct nutrient management planning on a mandatory basis (Barnes *et al.,* 2011; Doole *et al.,* 2012; Van Grinsven *et al.,* 2012; Perez, 2015; Buckley *et al.,* 2016). The European Union Nitrates Directive

(ND) is one of the first pieces of EU legislation directed at maintaining and improving water quality (European Comission, 1991). The ND, now operating under the EU Water Framework Directive (WFD), was introduced in 1991 and imposes restrictions on the application of N to agricultural land with a view to minimising the related nitrogen losses to water bodies. The ND requires member states to identify areas, also known as zones, as vulnerable to nitrate leaching and to introduce measures in these areas. In contrast to the majority of other countries, the ND programme of measures was introduced uniformly across Ireland as opposed to targeted areas referred to as Nitrogen Vulnerable Zones (NVZs) (Buckley, 2012). Moreover, Ireland is one of few EU countries that also incorporated direct controls on P fertiliser use in its National Action Plans, commonly referred to as the Good Agricultural Practice (GAP) regulations which are implemented through statutory instruments (SIs) (Buckley *et al.,* 2016).

The ND, as manifested in an Irish context, intends to minimise surplus N and P losses from agriculture to the aquatic environment by constraining use to agronomic optima and restricting applications to periods where mobilisation risk is minimised (Buckley *et al.,* 2016). The GAP regulations require a minimum slurry storage requirement for the housing of livestock over the winter and closed periods where spreading of organic and synthetic fertilisers is prohibited over the autumn and winter months. The regulations constrain the amount of livestock manure deposited by livestock as well as applied to land to 170/kg/N/ha^{-1} or up to 250/kg/N/ha^{-1} where a derogation (allowance) has been approved. These restrictions indirectly limit stocking rates to the equivalent of two dairy cows per hectare or up to 2.9 dairy cows per hectare with a derogation. The application limit of synthetic N fertiliser is based by crop type at rates defined by demand (Wall and Plunkett, 2016). P spreading limits are predicated on a soil P index system using the measured concentration of available P in soil based on a Morgan's P test (Morgan, 1941), crop type and P demand (Wall and Plunkett, 2016). Most important to this research is the mandatory requirement for farmers' operating under a derogation to adopt periodic soil testing (one sample every five ha and valid for four years) and a NMP which must be developed by or in conjunction with a qualified agricultural advisor (DAFM, 2017).

In Ireland, the adoption of periodic soil testing and the development of a NMP is also mandatory for farmers who are granted entry into the ‘Green Low Carbon Agri-environmental Scheme’ (GLAS) (DAFM, 2016). GLAS is the main agri-environmental scheme operating in Ireland and is funded by the Rural Development Programme (RDP) 2014 to 2020 (Department of Agriculture Food and the Marine, 2016). The scheme promotes measures for farmers to adopt that aim to address the issues of climate change mitigation, water quality and the preservation of priority habitats and species (Gooday *et al.,* 2017).

1.6 Research aim, objectives and questions

The overall aim of this thesis is to examine and explain the factors which influence farmers’ intentions towards the implementation of nutrient management planning. This aim is fulfilled through three research objectives which are addressed in the thesis as separate empirical papers answering specific research questions as explained below.

Research objective 1: To examine the influence of attitude, subjective norm, perceived behavioural control and additional context specific variables on farmers’ intentions to apply fertiliser on the basis of soil test results;

Very few studies have examined the determinants of adoption of soil testing. Most of the literature focuses on the factors which influence the adoption of individual nutrient management planning practices (Bosch *et al.,* 1995; Caswell *et al.,* 2001; Monaghan *et al.,* 2007; Ribaudo and Johansson, 2007). Thus, less attention is given to the simultaneous adoption of a given nutrient management planning practice and its translation into on-farm decision making. A specific gap in the literature is therefore addressed by examining farmers’ intentions to simultaneously adopt soil testing and apply fertiliser on the basis of soil test results. As outlined previously, the TPB is used as a framework for analysis throughout the thesis. However, as the TPB leaves a substantial percentage of variance with no explanation in intention and behaviour (López-Mosquera *et al.,* 2014; Rezaei *et al.,* 2018), a contribution is made to the literature by extending the model to include a number of additional variables in order to explain farmers' intentions towards applying fertiliser on the basis of soil test results. We follow Zeweld *et al.* (2017) by adding the predictor variable 'perceived resources' to the model. This is because to perform the practice under study, additional resources are often required and, therefore, it is important to capture this aspect in the analysis. A number of farm and farmer characteristics are also included as explanatory variables in the analysis based on previous findings from the literature.

Nutrient management policy in the EU and in Ireland requires certain farmers to adopt periodic soil testing on a mandatory basis. In Ireland these are farmers who receive an allowance (derogation) to operate above the stocking rate restrictions imposed by the EU Nitrates Directive and those who enter and receive subsidy payments under the 'Green Low Carbon Agri-environmental Scheme' (GLAS). Thus, a policy variable is devised which includes farmers who are obliged to adopt periodic soil testing on a mandatory basis under the ND and GLAS. Whilst most previous studies acknowledge that nutrient management policy requires increased adoption of practices, such as soil testing, very few examine how the decision making behaviour differs between farmers subject to mandatory requirements and those that adopt voluntarily (Barnes *et al.,* 2013b). Therefore, a further contribution is made to the literature by analysing the factors which influence farmers' intentions between 'voluntary' and 'mandatory adopters'.

Therefore, the research questions addressed under objective 1 are:

Research question 1a: Are attitude, subjective norm, and perceived behavioural control significant predictors of farmers' intentions to apply fertiliser on the basis of soil test results?

Research question 1b: Is perceived resources an important addition to the TPB model in relation to farmers' intentions to apply fertiliser on the basis of soil test results?

Research question 1c: Are farm and farmer characteristics as well as policy significant predictors of farmers' intentions to apply fertiliser on the basis of soil test results?

Research question 1d: Are there differences in the drivers of intentions between 'mandatory' and 'voluntary adopters' of period periodic soil testing?

Research objective 2: To create a typology of farmers according to a number of policy relevant farm and farmer characteristics and to examine whether there are differences in the drivers of intentions to follow a nutrient management plan between groups;

Previous studies which examine farmer uptake of nutrient management planning practices, but also farm management practices more widely, often treat farmers as a homogenous group. This is a strong assumption that must be addressed (Läpple and Kelley, 2013). The second paper in this thesis uses the TPB to examine farmers' intentions towards following a NMP. This paper contributes to the literature by using a latent class analysis (LCA) to develop a farmer typology based on a range of policy relevant farm and farmer characteristics. Whilst farmers were split into 'voluntary' and 'mandatory' adopters to address research objective 1, this split failed to account for heterogeneity among the population in terms of unobserved characteristics. Therefore, the generation of a typology using LCA allows for a more nuanced insight into how intentions and the decision making structures vary between specific groups of farmers' towards following a NMP. Furthermore, the majority of previous studies often rely on cluster analysis for creating a typology of farmers (Barnes *et al.,* 2013a) which involves arbitrary judgement in terms of how many clusters of farmers to retain. LCA, instead, uses robust algorithms and statistical criteria which can be used to select the exact number of classes of farmers' to retain and, thus, a further contribution is made to the literature by this paper.

Therefore, the research questions addressed under objective 2 are:

> **Research question 2a:** Can farmers be categorised into classes according to their operator and farm characteristics?
>
> **Research question 2b:** Are there significant differences in the levels of intentions to follow a NMP between the classes?
>
> **Research question 2c:** Are there differences in the factors which influence farmers' intentions to follow a NMP between classes of farmers?

Research objective 3: To explain farmers' intentions towards following a NMP whilst also exploring the interrelationships between the TPB variables (attitude, subjective norm and perceived behavioural control) and the influence of background variables on the TPB variables.

The TPB is also used a framework for analysing farmers' intentions to follow a NMP in the final empirical paper. However, a key limitation of previous applications of the TPB relates to the methodology adopted which does not allow interrelationships between the TPB constructs to be tested (Borges and Oude Lansink, 2016). Furthermore, previous studies also often fail to explore how external factors may influence farmers' attitudes, subjective norm and perceived behavioural control (Bijttebier *et al.,* 2018). External factors, such as trusted information sources, education and policy, are potential levers that can stimulate behavioural change (Barnes *et al.,* 2013b). These limitations are inherent in addressing research objectives 1 and 2, but can be addressed through structural equation modelling (SEM). Therefore, SEM is adopted for the purpose of the final research objective in order to examine multiple hypothesised relationships between the variables under study. This study contributes to the literature by providing an understanding of the interrelationships between the TPB variables (attitude, subjective norm and perceived behavioural control) and background influences on the TPB variables. The background variables include trust in information sources, education and policy. This approach improves the understanding of the cognitive foundations of key socio-psychological factors which can help to inform policy and interventions designed at encouraging the further use of NMPs (Conner and McMillan, 1999; López-Mosquera *et al.,* 2014; Ajzen, 2015; de Leeuw *et al.,* 2015; Bijttebier *et al.,* 2018).

Therefore, the research questions addressed under objective 3 are:

> **Research question 3a:** What is the relative importance of the influence of TPB variables on intentions to follow a NMP?
>
> **Research question 3b:** Are there significant interrelationships between the TPB variables?
>
> **Research question 3c:** Do background variables (trust in information, education and policy) significantly influence the TPB (attitude, subjective norm and perceived behavioural control) variables?

1.7 Structure of the thesis

The primary aim of this thesis is to examine and explain the factors which influence farmers' intentions towards the implementation of nutrient management planning. This is achieved by using Irish survey data and applying a range of econometric techniques. The core of the thesis comprises of three distinct empirical papers. However, the thesis begins by introducing the TPB in more detail and reviewing the variables that have been found to influence the adoption of agricultural management practices, including nutrient management planning practices in **Chapter 2**.

The data used to address each of the research objectives relies on the same structured survey. **Chapter 3** begins by providing a description of the design and development of the survey instrument which also includes details of the quota used to control for farm system and size in order to ensure that the population is nationally representative. In this section, a description of Irish agriculture is also provided and comparisons made between national socio-economic statistics for the farming population and the descriptive statistics for the survey.

Chapter 4 addresses research objective 1 which is to examine farmers' intention towards applying fertiliser on the basis of soil test results. Context to the problem is provided which is followed by a description of the TPB and the extensions to the theoretical model used for the purpose of the analysis. Following this section is a description of the design and development of the survey instrument, as well as the computation of variables that are used in the analysis. Next, the data analysis techniques, namely principal component analysis (PCA) and binary logistic regression are outlined and the results of the PCA discussed. The discussion section focuses on explaining the results from the binary logistic regression. The paper concludes with a number of policy implications and limitations to the study.

The second paper, addressing research objective 2, is presented in **Chapter 5** in which a farmer typology was generated in order to account for heterogeneity among the sample of farmers and then the factors influencing the intentions of each group to follow a NMP were calculated. Following a literature review, the theoretical model is described and an overview of the methodology is provided. A detailed description of LCA is provided in order to demonstrate how the typology of farmers is generated. In the results section, the composition is described of each of the classes generated by the LCA. Then, the results of the latent class logistic regression used to predict the factors which influence intentions are presented and subsequently discussed. The concluding section ends with a number of recommendations based on the results with an emphasis on informing policy makers of the heterogeneity that exists between farmers.

The final empirical paper is presented in **Chapter 6** which addresses research objective 3. This chapter uses SEM to explain farmers' intentions towards following a NMP whilst also exploring the interrelationships between the TPB variables and background variables on the TPB variables. The paper begins by reviewing the relevant literature which is used to build a series of hypotheses to be tested using SEM. This is followed by a description of the methodology with attention given to describing how SEM is employed to confirm the hypothesised model and test the relationships between the variables. The results of the SEM are then presented which show which hypotheses are confirmed and which are rejected. Following this is a discussion which provides potential reasons for the relative importance of the results.

Chapter 7 presents the conclusion of the thesis. This begins by summarising the key findings of this research and then synthesises the findings. A number of the key limitations are also discussed. The chapter concludes with a number of policy implications and directions for future research.

Chapter 2: Literature review

2.1 Introduction

Chapter 1 highlighted that the Theory of Planned Behaviour (TPB) is the most appropriate and best suited theoretical framework for addressing the overall research aim. This chapter begins by discussing the TPB in more detail and identifies key findings from the literature. The chapter then examines a key criticism of the theory which relates to the exclusion of a number of background factors. It is then demonstrated how a number of studies have overcome this limitation in an agricultural context. A review of pertinent background variables that have been found to influence farmers' uptake of management practices is provided. Variables reviewed include farm size, farm system, farmer education and information use. The chapter concludes by arguing that, due to the relevance of a number of key background variables, these will be incorporated separately into the theoretical frameworks in the empirical papers (Chapter 4, Chapter 5 and Chapter 6) which address the research objectives in this thesis.

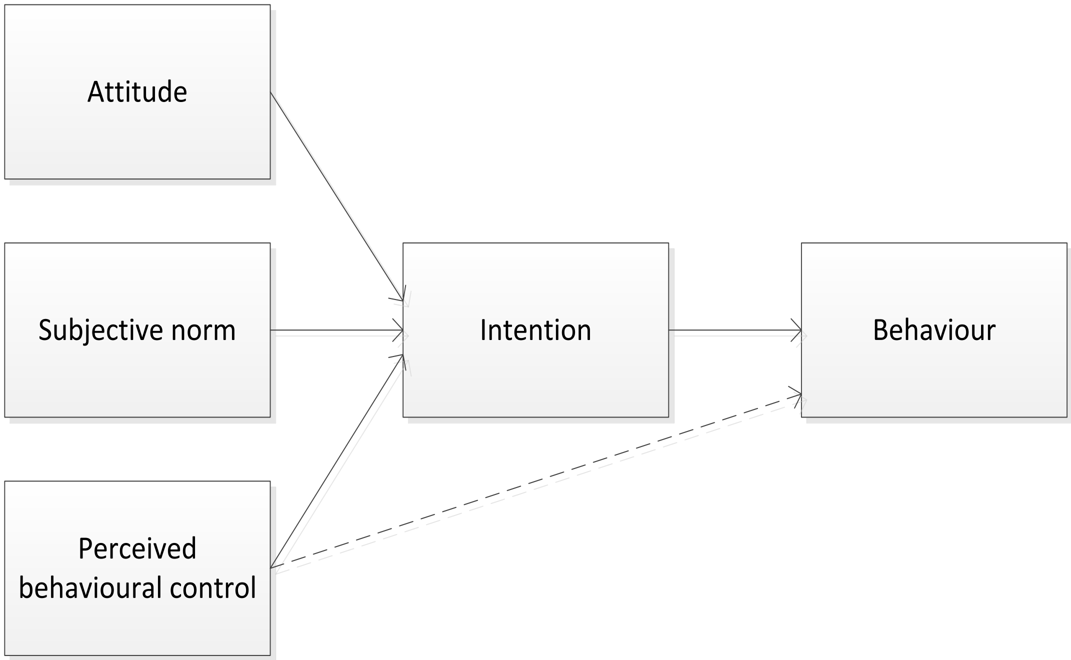
2.2 The Theory of Planned Behaviour

The TPB (Ajzen, 1985, 1991) is a socio-psychological theory which attempts to explain human behaviour and is an extension of the earlier Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 1975). According to the TRA, the proximal determinant (or cause) of behaviour is intention. Behavioural intention reflects a person's motivation in terms of his or her conscious plan or decision to apply effort to implement the target behaviour. The association between intention and behaviour reflects the fact that people tend to perform behaviours in which they intend to engage (Conner and Sparks, 1996). According to the TRA, a behavioural intention is determined by the attitude held by a person towards engaging in the behaviour and the level of social pressure (subjective norm) felt by the person to adopt the behaviour in question. Attitude is defined by the TRA as an individual's positive or negative evaluation of a given behaviour and is formed on the basis of the individual's beliefs at a given time. Subjective norm relates to perceived social pressure to adopt (or not to adopt) the behaviour in question. Subjective norm is a product of the individual's beliefs about the extent to which important referent groups would either approve or disapprove of their engagement in the given behaviour.

The TRA is limited in so far as it is only able to predict volitional behaviours (Ajzen, 2005). Behaviours that require skills, resources or opportunities that are not freely available are not considered to be within the remit of the TRA. As a consequence, they are often poorly predicted by the TRA (Conner and Norman, 2005). The TPB was formulated to expand the TRA beyond purely volitional behaviours by incorporating the concept of perceived behavioural control into the framework as an additional predictor of intention. According to the TPB, perceived behavioural control reflects an individual's perception of the extent to which the adoption of a given behaviour is easy or difficult. Similar to attitude and subjective norm, perceived behavioural control is measured by control beliefs held by an individual which relate to perceptions regarding the existence of factors that may promote or hinder the performance of a behaviour (Ajzen, 2002). These factors may be internal to the individual, such as confidence, abilities, and skills, or external, such as time, opportunity, or the availability of information. As a general rule, the more positive the attitude and subjective norm, and the greater the perceived behavioural control, the stronger should be an individual's intention to adopt the behaviour under study (Ajzen, 1991).

The addition of the concept of perceived behavioural control is important because it extends the applicability of the TRA beyond easily performed, volitional behaviours to more complex actions which are often dependent upon performance of a complex succession of other behaviours (Conner and Sparks, 1996). Moreover, the inclusion of perceived behavioural control in the TPB provides information about the potential constraints on action as perceived by the individual (Conner and Sparks, 1996). Thus, the concept of perceived behavioural control is arguably similar to the concept of self-efficacy (Bandura, 1982). Perceived behavioural control has been proven to add significantly to the prediction of intention and behaviour, even once the effects of TRA variables have been accounted for (Madden *et al.,* 1992; Armitage and Conner, 2001). However, Ajzen (1991) states that it is actual control (objective level of skills, resources and opportunities) over the performance of a behaviour which is most important, yet as measures of actual control are hard to obtain, perceptions of control are a suitable proxy for actual control. For behaviours where the prediction of behaviour from intention is likely to be hindered by the level of actual control, perceived behavioural control is also likely to have a direct influence on behaviour (Ajzen, 1991). This is predicated on the idea that increased feelings of control will increase the level of extra effort individuals are willing to expend in order to successfully adopt a given behaviour (Armitage and Conner, 2001). Figure 2:1 shows the TPB, with solid arrows representing influences between the TPB components and the dotted arrow representing actual behavioural control.

Figure 2:1: Theory of Planned Behaviour (Ajzen, 1991).



Meta-analytic reviews of the literature demonstrate that a large number of studies have successfully applied the TPB across various disciplines (Ajzen, 1991; Armitage and Conner, 2001; McEachan *et al.,* 2011; Cooke *et al.,* 2016; Hagger *et al.,* 2016; McDermott *et al.,* 2015; Riebl *et al.,* 2015). In terms of specific performance of the TPB, Armitage and Conner (2001), in a meta-analysis of the literature, found that the TPB variables (attitude, subjective norm and perceived behavioural control) account for 39% of the variance in intention and 27% of the variance in subsequent behaviour. Ajzen (2011b) summarises different meta-analyses and reports that, for a wide range of behaviours, attitudes have a mean correlation with intentions of between 0.45 and 0.60. The mean range for correlations between intentions and subjective norms was lower than attitude, between 0.34 and 0.42, whilst perceived behavioural control ranged between a mean of 0.35 and 0.46. These results also suggest that the relative importance of attitude, subjective norm and perceived behavioural control in the prediction of intention varies across behaviours and situations. For example, for a relatively easy behaviour to implement, the role of perceived behaviour is expected to diminish and the influence of attitude and subjective norm can increase (Armitage and Conner, 2001). Trafimow and Finlay (2001) argue that differences in the strength of influence of the TPB variables on intentions can be attributed to the fact that some people are motivated by attitudinal concerns whereas others are more motivated by normative issues and vice versa. Despite this, Armitage and Conner (2001) found that subjective norm is typically the weakest predictor of intentions, though they concluded that this was partly due to poor measurement of the construct, such as using single item measures.

While the TPB is one of the most influential theories in health psychology (Armitage and Conner, 2001; McEachan *et al.,* 2011; McDermott *et al.,* 2015; Hagger *et al.,* 2016), it has also been successfully applied, although to a lesser extent, to explain a variety of farmers' intentions and behaviours. Examples of such applications of the TPB include intentions towards conservation practices (Lynne *et al.,* 1995; Beedell and Rehman, 1999, 2000; Wauters *et al.,* 2010; Lalani *et al.,* 2016; Bijttebier *et al.,* 2018), sustainable practices (Menozzi *et al.,* 2015; Adnan *et al.,* 2017b; Zeweld *et al.,* 2017; Jiang *et al.,* 2018), diversifying agricultural production (Hansson *et al.,* 2012; Senger *et al.,* 2017a,b), adaptation to climate change (Arunrat *et al.,* 2017), engagement in agri-environmental schemes (Micha *et al.,* 2015; van Dijk *et al.,* 2015), organic farming (Läpple and Kelley, 2013), animal health (de Lauwere *et al.,* 2012; Bruijnis *et al.,* 2013; Jones *et al.,* 2016), pesticide use (Abadi, 2018), technology (Adnan *et al.,* 2018, 2017a; Hunecke *et al.,* 2017; Zeng and Cleon, 2018), on-farm food safety (Rezaei *et al.,* 2018) and farm management practices (Reimer *et al.,* 2012; Borges *et al.,* 2014, 2016; Borges and Oude Lansink, 2015, 2016, Hyland *et al.,* 2018 a,b). The majority of previous studies in an agricultural context find evidence in support of the TPB, however the extent of support varies between studies. These findings confirm the assertion that the relative importance of these constructs vary from one case to another, depending on the behaviour and population studied (Ajzen, 1991).

Although there is growing evidence pointing towards the ability of TPB to explain farmers' intentions, the TPB has been criticised on a number grounds. These criticisms (discussed in more detail in Chapter 7), relate to issues such as the rational underpinning of the model, exclusion of unconscious influences on behaviour such as habits, and the static nature of the theory which fails to account for feedback mechanisms which influence future behaviour (Sniehotta *et al.,* 2014). Whilst these limitations are important to consider, the research in this thesis primarily addresses one important limitation of the TPB which relates to the omission of variables, especially those that have been proven to be important predictors of the adoption of management practices within an agricultural context. Whilst the influence of socio-psychological factors on farmers' intentions are clearly important, understanding farmer behaviour and the factors which influence intentions is a complex issue and therefore requires consideration of additional factors (Feola *et al.,* 2015). In fact, Burton (2004a) argues that a strict application of the TPB is not desirable within an agricultural context because this would not allow for the exploration of other influences over farmer behaviour, such as political and structural factors, and thus would not provide a sufficiently broad understanding of farmer behaviour. The joint consideration of socio-psychological and wider contextual factors such as farm and farmer socio-economic characteristics as well as the political setting in which farmers make decisions has been termed the 'behavioural approach' (Burton, 2004a). This approach provides a more complete understanding of the factors which influence farmers' intentions and can improve the predictive power of the TPB model (López-Mosquera *et al.,* 2014; Yazdanpanah and Forouzani, 2015). In relation to this issue, Ajzen (1991) argues that the TPB is, in principle, open to inclusion of additional predictors as long as they increase the explained variance in behavioural intentions.

Within an agricultural context, some studies have endeavoured to extend and improve the predictive power of the TPB by including additional variables such as moral norms and knowledge (Rezaei *et al.,* 2018), observability, compatibility and relative advantage (Reimer *et al.,* 2012b), self-identity (Josefsson *et al.,* 2017; van Dijk *et al.,* 2016), training and social capital (Arunrat *et al.,* 2017; Zeweld *et al.,* 2017), trust and habit (Abadi, 2018), personal innovativeness (Pino *et al.,* 2017; Zeng and Cleon, 2018), communication (Adnan *et al.,* 2017b), self-identity and moral norm (Yazdanpanah *et al.,* 2014; Wauters *et al.,* 2016) and various farm and farmer socio-economic characteristics such as age, education, gender, farm size and income (Areal *et al.,* 2012; Micha *et al.,* 2015; Lalani *et al.,* 2016; Martinovska Stojcheska *et al.,* 2016; Wang *et al.,* 2018). These studies typically find mixed results in terms of the discovery of significant relationships between the additional predictors and intentions. Nevertheless, the studies tend to conclude that additional predictors help to improve our understanding of farmer decision making above and beyond the TPB predictors. The research presented in this thesis takes a similar approach to these studies by extending the TPB by incorporating additional variables into the TPB framework. These variables primarily revolve around a number of farm and farmer socio-economic characteristics as well as the policy context and trusted information sources which have been chosen as they have been proven to be important factors to consider when examining the uptake of farm management practices (Pannell *et al.,* 2006; Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012).

2.3 Extending the TPB

The TPB has the potential to be expanded by including other important variables which can influence intentions directly or indirectly through the global components of the TPB (attitude, subjective norm and perceived behavioural control) (Ajzen, 1991; Chen, 2017). However, the choice of these variables must be guided by the literature relevant to the behaviour under study (Prokopy *et al.,* 2008). Although the specific literature on the adoption of nutrient management planning is limited, the literature on the factors which influence the adoption of farm management practices, technology and innovations is both closely related and extensive (Feder *et al.,* 1981; Feder and Umali, 1993; Sunding and Zilberman, 2000; Pannell *et al.,* 2006; Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). Whilst the literature identifies a plethora of potentially relevant variables for inclusion in the TPB framework, this review is restricted to contextual issues pertaining to nutrient management policy, farm and farmer socio-economic characteristics and information use. The analysis is restricted to these variables because differences in the behaviour of farmers who adopt management practices due to mandatory policy requirements and those who adopt voluntarily remains underexplored (Barnes *et al.,* 2013b). Farm and farmer socio-economic characteristics and information use have been shown for a number of years to predict adoption of management practices (Pannell *et al.,* 2006; Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012), and if these were to be excluded a 'true' account of the factors which influence farmers' intentions may not be accounted for. Variables pertaining to biophysical factors (e.g. soil type and meteorological conditions), price (e.g. fertiliser and farm-gate prices) and general attitudes (e.g. towards, profit, the environment and risk) are not the focus of this research and therefore are not reviewed. The former are not considered as they are outside the control of the farmer and the latter (general attitudes) are not incorporated into the analysis because the focus of this research is on specific attitudes towards nutrient management planning, which remain underexplored in the literature.

The main extension to the TPB in this thesis is the inclusion of a variety of farm (e.g. system and size) and farmer characteristics (e.g. age and education). Some have argued that self-identity and moral norms are two other prominent extensions of the theory and are important within an agricultural context (Burton, 2004; Mcguire *et al.,* 2013; Rezaei *et al.,* 2018). However, within the context of nutrient management, farm and farmer characteristics have been suggested to be important from an agronomic point of view, as, for instance, larger farms typically use more nutrients and therefore the incentive to plan is higher (Beegle *et al.,* 2000). Furthermore, there is greater levels of support for the significance of farm/farmer socio-economic characteristics, more so than self-identity and moral norms (Mcguire *et al.,* 2013; Yoshida *et al.,* 2018) from both theoretical and empirical stand point (Ribaudo and Johansson, 2007; Prokopy *et al.,* 2008; Savage and Ribaudo, 2013; Buckley *et al.,* 2015; Ulrich-Schad *et al.,* 2017; Brown *et al.,* 2019). Therefore, the main extension to the TPB remains in terms of farm and farmer characteristics.

Policy context

As alluded to in Chapter 1, the adoption of periodic soil testing and the development of a nutrient management plan (NMP) is mandatory for farmers who enter and receive payments for actions under the 'Green Low Carbon Agri-environmental Scheme' (GLAS) and/or receive a derogation under the Nitrates Directive (ND). Breach of the requirements under these regulations can result in a financial penalty (DAFM, 2015b; Duffy and Hyde, 2016). The regulatory approach which requires the mandatory adoption of nitrogen (N) soil testing among certain farmers has been found to be more effective at inducing adoption than a voluntary approach based on education, technical assistance and cost-share (Fuglie and Bosch 1995). However, Bosch *et al.* (1995) argue that while the immediate goal of adoption may be more easily achieved by regulation, regulation does not necessarily lead to the proper or desired use of the practice. Other research has examined farmers' reactions to mandatory policy requirements and tends to show that farmers react in different and opposite ways to the same policy (Macgregor and Warren, 2006; Lamba *et al.,* 2009; Barnes *et al.,* 2009, 2011; Buckley, 2012). Other studies have focused on examining the influence of policy on farmer behaviour and demonstrate that policy can increase social pressure towards the adoption of farm management practices (Powell *et al.,* 2012; Savage and Ribaudo, 2013; Mills *et al.,* 2018) and induce attitude change (Barnes *et al.,* 2009; Macgregor and Warren, 2015).

Farm characteristics

It is commonly hypothesised across the literature that farmers who own larger farms are more likely to invest in management practices and new technologies due to economies of scale and the greater ability to absorb financial risk (Roberts *et al.,* 2004). Moreover, it is argued that larger farms have the ability to spread fixed costs and human capital costs over a larger number of acres, thus making the adoption of farm management practices more economical. Despite these assertions, mixed results have been found; while some studies have observed a significant positive association between farm size and the uptake of farm management practices (Khanna, 2001; Daberkow and McBride, 2003; Rahelizatovo and Gillespie, 2004; Roberts *et al.,* 2004; Walton *et al.,* 2008; Ghazalian *et al.,* 2009; Lamba *et al.,* 2009; Lambert *et al.,* 2014; Gebrezgabher *et al.,* 2015) others have found insignificant relationships (D'Emden *et al.,* 2008; Junior *et al.,* 2019) and even negative correlations (Howley *et al.,* 2012; Dill *et al.,* 2015). Where a negative relationship is observed, this can be explained by the fact that larger farms may represent extensive rather intensive farm enterprises (Howley *et al.,* 2012).

The type of farm system operated can also influence the overall nutrient management strategy adopted on the farm. For example, nutrient deficit farms where nutrient imports (e.g. feed and synthetic fertiliser) are less than exports (e.g. animal products) are typically farmed less intensively and therefore may have a stronger focus on maximising the efficiency of manure use on the farm (Beegle *et al.,* 2000; Svanbäck *et al.,* 2019). On the other hand, a nutrient surplus farm which produces more nutrients in the form of manure than is required to meet crop demands are often farmed more intensively and thus may have a larger emphasis on exporting manure (Beegle *et al.,* 2000). Furthermore, crop production decisions related to nutrient use on tillage (arable) crops (e.g. wheat, oats and potatoes) are typically more sensitive to agronomic criteria (e.g. significant yield variations depending on amount of fertiliser applied). It is important to note that the performance of livestock farms is also connected to the animal husbandry skills of farmers and not just on effective crop production. Therefore, in general, nutrient management planning may form a larger component of farm management on tillage farms. However, it may be argued that those farmers who operate a more intensive farm system would be expected to adopt resource management practices in order to maintain the productive capacity of their farm (Cary *et al.,* 2001). In an Irish context, high intensity of production (e.g. higher stocking rates, chemical fertiliser inputs and outputs e.g., animal products and tillage crops) is typically linked to tillage and dairy production systems whereas cattle (beef) and sheep systems are typically associated with low intensity of production (Dillon *et al.,* 2017). Empirical studies have generally found a positive association between farm systems with a higher intensity of production and rate of adoption of farm management practices compared to farm systems that are typically operated less intensively (Daberkow and McBride, 2003; Lawley *et al.,* 2009; Paul *et al.,* 2017; Adusumilli and Wang, 2018; Daxini *et al.,* 2018; Easton *et al.,* 2018).

Whilst variables such as farm size and system are often used as proxies to measure resource availability, it is also useful to measure farmers perceptions of the resources they have available as this may indicate the willingness to direct resources towards nutrient management planning. Resources are an important component of nutrient management practices and, for example, applying fertiliser on the basis of soil test results can require additional resources (e.g. fertiliser) to facilitate the process, this is an important construct to measure (Beegle *et al.,* 2000). For example, Monaghan *et al.* (2007) found resources to constrain the adoption of nutrient management practices. Maintaining consistency with the TPB, we follow Zeweld *et al.* (2017) in defining ‘perceived resources’ as the degree to which a farmer perceives that he/she owns or has access to the necessary resources (e.g. finance, labour and time) and technical infrastructure (information) to support him/her in adopting nutrient management practices.

Farmer characteristics

The majority of studies examining the relationship between age and the adoption of new farm management practices hypothesise that younger farmers are more likely to uptake such practices than older farmers (Baumgart-Getz *et al.,* 2012). Older farmers may be less likely to adopt as they have shorter planning horizons and may not wish to adopt farm management practices that require learning new skills as they are closer to retirement (Lambert *et al.,* 2007). Furthermore, younger farmers may be more educated and more likely to be involved with more progressive farming (Feder and Umali, 1993). It is also suggested that older farmers tend to be more risk averse to the adoption of new practices because they are likely to require a change in management style with uncertain results (Rahelizatovo and Gillespie, 2004). Furthermore, older farmers tend to have a greater level of experience which may result in a reliance on past knowledge and thus inhibit the adoption of new management practices that may not be deemed as necessary. Studies have confirmed that age correlates negatively with the adoption of farm management practices (Rahelizatovo and Gillespie, 2004; Roberts *et al.,* 2004; Walton *et al.,* 2008; Lamba *et al.,* 2009; Buckley *et al.,* 2015). However some studies have found age to be an insignificant variable (Tiwari *et al.,* 2008; Arbuckle and Roesch-McNally, 2015; Dill *et al.,* 2015; Paustian and Theuvsen, 2017; Ulrich-Schad *et al.,* 2017), or even positively correlated with uptake of farm management practices (Torbett *et al.,* 2007; Ghazalian *et al.,* 2009; Peterson *et al.,* 2015). Whilst older producers have shorter planning horizons than their younger counterparts, their lower debt-equity ratio can render it easier for them to fund the costs of implementing new management practices (Ghazalian *et al.,* 2009).

The education level of a farmer is assumed to positively influence adoption decisions because of the assumed link between education and knowledge (Knowler and Bradshaw, 2007). Education also has the ability to increase individuals' understanding of complex issues and is believed to increase efficacy of farm management though enhancement of technical skills and familiarity required to adopt new innovations (Ondersteijn *et al.,* 2002; Burton, 2014). Education can familiarise farmers with activities that require attention to detail and administration (Ruto and Garrod, 2009). Furthermore, education has the potential to change attitudes by dispelling myths about the outcomes of performing a behaviour (Burton, 2014a). Farmers with a higher level of education are also believed to have been exposed to more ideas and have more experience in making decisions and effectively using information (Prokopy *et al.,* 2008). There are numerous studies suggesting that education increases, for example, the uptake of farm management practices (Fuglie and Bosch, 1995; Roberts *et al.,* 2004; Lambert *et al.,* 2006; Paudel *et al.,* 2008; Walton *et al.,* 2008; Ghazalian *et al.,* 2009; Lamba *et al.,* 2009; Gebrezgabher *et al.,* 2015; Paul *et al.,* 2017). However, various studies have also discovered no relationship between education and uptake of farm management practices (D'Emden *et al.,* 2008; Lawley *et al.,* 2009; Dill *et al.,* 2015; Weber and Mccann, 2015; Ulrich-Schad *et al.,* 2017; Barnes *et al.,* 2019) or even a negative relationship (Peterson *et al.,* 2015). Insignificant or negative influences of education can be related to the fact that highly educated farmers often have an off-farm job that limits their time to adopt farm management practices (Peterson *et al.,* 2015).

In general it is hypothesised that income from farming is positively associated with the adoption of farm management practices. The adoption of management practices requires sufficient financial wellbeing, especially if changes to management strategies or the use of equipment are required (Ribaudo and Johansson, 2007). Thus, income can reflect an economic barrier to non-adopters. Moreover, farmers who derive the majority of their income from farming typically farm on a full-time basis and therefore may be more willing to invest in farm management practices that help to improve farm productivity. A number of studies have confirmed the positive relationship between income and the uptake of farm management practices (Gillespie *et al.,* 2007; Ribaudo and Johansson, 2007;

Paudel *et al.,* 2008; Lamba *et al.,* 2009; Peterson *et al.,* 2015; Barnes *et al.,* 2019). However, others have found no such relationship (Warriner and Moul, 1992).

Off-farm employment is typically said to constrain the adoption of farm management practices (Knowler and Bradshaw, 2007). One reason is due to time constraints to use farm management practices or the requirement to learn new skills or seek advice from an agricultural advisor. Moreover, if a farmer engages in off-farm employment then farming may not be the primary source of household income and therefore the farmer may be less likely to spend time and money investing in the use of management practices. Lambert *et al.* (2007) highlights that even if practices promise higher farm profits, they may not appeal to some farmers if they require lifestyle changes that are incompatible with household goals. Farm households that rely more heavily on farm earnings may feel a higher level of pressure to maximise yields by making full use of the farm's resources which can be facilitated through the adoption of farm management practices (Lambert *et al.,* 2007). Nevertheless, off-farm income may provide additional resources for adopting farm management practices (Knowler and Bradshaw, 2007). The presence of an off-farm job has been found to be positively correlated with uptake of farm management practices (Gedikoglu *et al.,* 2011) as well as negatively (Lambert *et al.,* 2007; Howley *et al.,* 2012; Buckley *et al.,* 2015) or even insignificantly (Fernandez-Cornejo *et al.,* 2005).

Information

Information sources can improve awareness and knowledge of farm management practices and thus improve uptake (Jabbar *et al.,* 2003). Without knowledge of the practices associated with nutrient management planning from some information or communication channel, uptake is unlikely (Knowler and Bradshaw, 2007). Studies of the role of innovation technology have long stated the importance of information and have found that its availability is positively correlated with the adoption process (Wozniak, 1987; Rogers, 1995; Fischer *et* *al.,* 1996). Some argue that information becomes particularly important as the level of complexity of the practice to be adopted increases (Nowak, 1987). Various information sources have been found to be positively correlated with the use of farm management practices and include, for example, agricultural advisors (Rahelizatovo and Gillespie, 2004; D'Emden *et al.,* 2008; Tamini, 2011; Pan, 2014; Buckley *et al.,* 2015; Peterson *et al.,* 2015), discussion groups (Hennessy and Heanue, 2012; Prager and Creaney, 2017; Ulrich-Schad *et al.,* 2017), agricultural training courses and events (Cary *et al.,* 2001; D'Emden *et al.,* 2008; Rezvanfar *et al.,* 2009; Genskow, 2012) and other farmers (Zeweld *et al.,* 2017). However, contact with information is not usually sufficient enough to promote uptake if it is disseminated ineffectively, inaccurately or inappropriately (Larson *et al.,* 2008). Therefore, the literature emphasises the importance of farmer trust in information sources for achieving behavioural change (Blackstock *et al.,* 2010; Sutherland *et al.,* 2013; Stuart *et al.,* 2018). For example, Peterson *et al.* (2015) found a negative relationship between government based natural resource conservation services and the adoption of recommended farm management practices. This counterintuitive relationship was attributed to a lack of trust and satisfaction with the service provided (Peterson *et al.,* 2015).

Within an EU context, the role that agricultural advisors, in both individual and group based settings play in supporting farmer decision making is significant (Kania *et al.,* 2014). Advisors are part of the wide group of actors or 'web of influencers' argued to be influential in shaping farmers' practices (Hilkens *et al.,* 2018). Farmer advisors interact with farmers in different ways such as in person, over the phone or on a farm visit. A desire to change farmers' practices can influence an advisor's interactions with farmers (Oreszczyn *et al.,* 2010). This desired change can mirror a normative model of 'ideal behaviour' held by the advisor and their employer or the regulatory setting they operate in, such as improving nutrient management planning (Hilkens *et al.,* 2018). Discussion groups are groups of farmers that meet frequently to discuss technical issues, share information and solve problems, facilitated by an agricultural advisor. Learning from experience can be built on farmers' own experiences, but also grounded on observing an experience on someone else's farm. Discussing experiences and observations with other farmers supports the process of practice adoption (Prager and Creaney, 2017). Discussion groups are a form a participatory approach towards extension where an advisor often plays the role of a facilitator who helps farmers to make their own decisions (Prager and Creaney, 2017). Both individual and group based extension contact have been shown to positively influence adoption of agricultural management practices (Baumgart-Getz *et al.,* 2012; Hennessy and Heanue, 2012; Prager and Creaney, 2017).

2.4 Conclusion

This chapter has provided details of the TPB and alluded to a key criticism of the theory which pertains to the omission of certain variables that have been shown to be important determinants of farmer decision making in relation to the uptake of farm management practices. This limitation has been overcome in previous studies by including additional variables in the TPB framework. The majority of these variables were reviewed and it was shown that, whilst the literature makes certain assumptions regarding the direction of influence of these variables, their association with adoption remains inconclusive (Knowler and Bradshaw, 2007; Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). However, by incorporating these variables into the TPB framework to create an 'extended' version of the theory, a more detailed understanding of the factors which influence farmers' intentions to adopt nutrient management planning can be gained. The 'extended' frameworks used in this thesis are presented in the empirical papers contained in Chapters 4, 5 and 6.

Chapter 3: Data and survey methodology

3.1 Introduction

The previous chapter provided details on the Theory of Planned Behaviour (TPB) which will be used as a basis to explain farmers' intentions towards the uptake of nutrient management planning. The previous chapter also highlighted that pertinent additional variables should be incorporated into the TPB framework in order to provide a more holistic understanding of the factors which influence farmers' intentions to implement nutrient management planning. In order to collect information from farmers regarding their beliefs and intentions towards nutrient management planning, as well as background information on the additional variables, a structured survey was developed. The purpose of this chapter is to provide details on the survey instrument used to collect the data for this research. A quota controlled system was designed in order to be nationally representative of Irish farm systems and sizes. Therefore, before outlining the survey methodology, this chapter begins by providing a brief overview of the structure of Irish agriculture. This chapter also provides a detailed description of the survey respondents and highlights where potential biases in the sample exist.

3.2 Structure of Irish agriculture

The following statistics were derived from the most recent agricultural farm structure survey in Ireland (CSO, 2018). Table 3.1 summarises the key features of Irish agriculture. Based on Table 3.1 there are approximately 137,500 registered farms in Ireland of which the majority are family farms. The main farming system is cattle in the form of beef production. The average farm size in Ireland is 32.4 ha with a mean standard output (average monetary value of the agricultural output at farm-gate price excluding direct payments, value added tax and taxes on products) of €45,945 per farm. The majority of farm holders are male with average farmer age being 56 years. Furthermore, 53% of farmers operate their enterprise on a full time basis, which implies that around half of all Irish farmers have an off-farm job. In general, farm income is highly dependent on direct payments, for example, in 2017 the average total payment received was €17,659 per farm which accounted for 56% of average farm income (Dillon *et al.,* 2018b).

Table 3.1: Overview of the structure of Irish agriculture (CSO, 2018).

Characteristic	Descriptive statistic
Total number of farms	N=137,500
Farm System	
Cattle	N=72,400 (53%)
Mixed	N=27,200 (20%)
Dairy	N=16,700 (12%)
Sheep	N=15,200 (11%)
Tillage	N=4,700 (3%)
Other	N=1,300 (1%)
Farm size(ha^{-1})	
<10	26,200 (19%)
10 to 20	33,600 (24%)
20 to 30	24,300 (18%)
30 to 50	28,700 (21%)
50 to 100	19,900 (14%)
100<	4,900 (4%)
Average standard output	€45, 945
Gender	
Male	88%
Female	12%
Age (years)	56
Off-farm job(yes)	47%

The following describes a number of important structural differences within Irish agriculture based on CSO (2018) which are summarised in Table 3.2. As there are a number of ‘mixed’ systems in Ireland with varying characteristics and as these are not considered for the purpose of this research as distinct categories (see ‘sampling’ section for a justification) they are not discussed in the following comparisons. As can be seen from Table 3.2, tillage and dairy farms are larger on average than cattle and sheep farms in terms of size and output. In terms of differences in the age profile of farmers by system, the proportion of farm holders aged 65 and over (oldest cohort) is the highest in cattle (around 33%) and sheep systems (around 30%). Off-farm employment is the lowest for dairy farmers who have the highest proportion of farmers operating their enterprise as their sole occupation (78%). The highest family farm income is observed among dairy farmers €86,069. Direct payments also vary by system with sheep farmers receiving the highest proportion of their income from direct payments (115%), followed by cattle (between 96% and 114% depending type of system operated), tillage (63%) and finally dairy (22%) (Dillon *et al.,* 2018b).

Table 3.2: Key structural differences in Irish agriculture (CSO, 2018).

Characteristic	Descriptive statistic
Average farm size (ha^{-1})by system	
Cattle	27
Dairy	58
Sheep	29
Tillage	59
Average standard output by system (€)	
Cattle	19,275
Dairy	176,944
Sheep	14,357
Tillage	97,227
Average age (years) by system	
Cattle	<54 (49%), >55 (51%)
Dairy	<54 (57%), >55 (43%)
Sheep	<54 (42%), >55 (58%)
Tillage	<54 (46%), >55 (54%)
Full time occupation by system (%)	
Cattle	48
Dairy	78
Sheep	46
Tillage	51
Direct payments as a proportion (%) of total income by system[a]	
Cattle	96-114
Dairy	22
Sheep	115
Tillage	63

Notes: [a]Based on Dillon *et al.* (2018b).

3.3 Research approach

The aim of this thesis is to examine and explain the factors which influence farmers' intentions towards the implementation of nutrient management planning. To address the aim of this research, a structured survey, also known as a cross-sectional survey, was developed to collect data from farmers in Ireland at one point in time (Krosnick, 1999). The overall research approach in which the survey is grounded is quantitative methodologies. The majority of previous studies which use the TPB, both across the literature more widely (Ajzen, 1991; Armitage and Conner, 2001), and within an agricultural context (e.g. Läpple and Kelley, 2013; Micha *et al.,* 2015; Borges *et al.,* 2016; Senger *et al.,* 2017b; Zeweld *et al.,* 2017; Hyland *et al.,* 2018a; Jiang *et al.,* 2018; Lalani *et al.,* 2016; Morais *et al.,* 2018; Rezaei *et al.,* 2018; Zeng and Cleon, 2018), adopt structured survey research methods to collect quantitative data from respondents. This is primarily because the aim of the TPB is to examine relationships between a dependent variable (intentions) and a number of explanatory variables (attitude, subjective norm and perceived behavioural control).

Compared to qualitative approaches, quantitative approaches are advantageous insofar as they utilise standardised, repeatable methods (Muijs, 2011). Nevertheless, a few instances of applications of the TPB using qualitative approaches are noted within an agricultural context (e.g. Sutherland, 2010; Sutherland and Holstead, 2014). Whilst qualitative studies allow for the deep exploration of issues and general principles can be extracted (Mason, 2002), such studies tend to utilise small sample sizes which renders the results difficult to generalise across a population. As the problem of uptake of nutrient management planning is not confined to a particular region in Ireland, the purpose of this study is to gain an understanding of farmer decision making on a national scale and therefore a quantitative approach is the most suitable for addressing the aim of this research. Moreover, by utilising a similar approach to the majority of previous studies that utilise the TPB to understand farmer decision making, direct comparisons of the results from this study can be made to these studies. Finally, surveys are well suited to gathering demographic data that describe the composition of the sample (Lioutas *et al.,* 2005), which is important in this research as it aims to use additional background variables to explain farmers' intentions towards the implementation of nutrient management planning.

3.4 Survey instrument

Overview

The survey used for the purpose of this research was designed in three sections to collect data from farmers across three key areas of interest: 1) farm and farmer characteristics; 2) background information of nutrient management activity; and, 3) two separate TPB sections (one for each practice under study). The first section was used to collect data on variables pertaining to farm and farmer characteristics such as farm size, farm system, farmer age and education. The inclusion of these variables was based on the literature review conducted in Chapter 2 which revealed a number of important farm and farmer characteristics that are a priori likely to influence farmers' intentions towards the uptake of nutrient management planning. Moreover, it was important to collect such information in order to establish similar groups of farmers based on such characteristics in order to address research question 2a. The majority of the questions in the survey pertaining to farm and farmer characteristics were taken from previous survey research.

The second section of the survey was used to elicit information on background nutrient management practices, i.e., current adoption rates and motivation for adoption. The choice of questions used to account for background nutrient management questions were developed in conjunction with agricultural advisors and experts in Ireland who outlined key issues relating to the uptake of nutrient management planning. Such questions related to, for example, the extent of soil testing conducted on farms and who is involved in the development of NMPs. The question used to gain an understanding behind the motivation for adoption of nutrient management planning was important to include as it allowed data to be collected concerning whether farmers adopted mainly to comply with policy requirements or to primarily use nutrient management planning to aid production decisions. This was particularly useful for classifying farmers into 'voluntary' and 'mandatory' adopters in order to address research question 1d.

The final section of the survey was designed to collect information in line with the TPB regarding farmers' beliefs and intentions towards the uptake of the two nutrient management planning practices under study: 1) intention to apply fertiliser on the basis of soil test results and 2) intention to follow a NMP. The final survey instrument is presented in Appendix C. A number of questions presented in the survey, such as general farmer attitudes, are not used in the empirical papers presented in this thesis (Chapter 4, 5 and 6) as they were collected for the purpose of future research.

3.5 Survey development

Theory of Planned Behaviour: approach used in this study

In the original TPB, intentions are explained by attitude, subjective norm and perceived behavioural control using an expectancy-value framework (Atkinson, 1957; Eagly and Chaiken, 1993). This framework suggests that human behaviour is determined by expectation of the likelihood that an outcome will result from a behaviour (e.g. pros/cons and outcome beliefs), and the value the person places upon these outcomes (Jones *et al.,* 2016). The assumption underlying the the expectancy-value framework is that an individual is more likely to be motivated to perform a target behaviour that will result in an outcome that is highly valued (Ajzen, 1991). In the TPB (Ajzen, 1991), this expectancy-value framework is operationalised in research by asking respondents to evaluate the strength of a given belief that a consequence will result from the target behaviour being performed (outcome expectancy) which is multiplied by the respondents evaluation of the desirability of that consequence (outcome evaluation). Thus, attitude is measured through behavioural beliefs which are beliefs about the likelihood of a certain outcome of the behaviour and the evaluation of these outcomes. Subjective norm is elicited through normative beliefs about the expectations of important referent groups and the motivation to comply with the views of these referents. Finally, perceived behavioural control is deciphered through control beliefs pertaining to the presence of factors that may promote or impede the performance of a given behaviour and the perceived power of these factors to facilitate or inhibit the behaviour.

Strict applications of the TPB have been widely applied across the literature in general (Armitage and Conner, 2001; Rivis *et al.,* 2009) and with notable applications also in an agricultural context (e.g. Beedell and Rehman, 2000; Wauters *et al.,* 2010; Läpple and Kelley, 2013). However, Burton (2004a) argues that a strict application of the TPB is time consuming and therefore does not allow for the exploration of other influences on farmer behaviour, such as farm and farmer characteristics. Thus, a stringent application or testing of TPB is not always desirable within an agricultural context as this would not provide a sufficiently broad understanding of farmer behaviour (Burton, 2004a). Instead it is often recommended to use the TPB as a ‘starting point’ to obtain quantitative measures of socio-psychological variables that may influence behaviour, and to add additional predictors to the model based on past research and contextual consideration (Burton, 2004a; Micha *et al.,* 2015). This approach retains the structured repeatable methodological procedures that appeal to policy-makers but also allows a more holistic understanding of farmer behaviour to be gained.

In this instance, it is recommended to use ‘one arm’ of the belief based construct of attitude, subjective norm and perceived behavioural control. Typically, in an agricultural context, this means asking farmers to evaluate a number of beliefs (expectancy) without asking for them to attach an evaluation of the importance of the particular belief (value) (e.g. Micha *et al.,* 2015; Deng *et al.,* 2016; Martinovska

Stojcheska *et al.,* 2016; Zeweld *et al.,* 2017; Morais *et al.,* 2018; Rezaei *et al.,* 2018; Wang *et al.,* 2018). It should be noted that only using 'one arm' of the belief based construct of attitude, subjective norm and perceive behavioural control may result in a loss of information for differentiating subjects who have and those who do not have the intention to adopt a given behaviour (Gagné and Godin, 2000). However, by only using 'one arm', this allows for a reduction in the number of questions posed to subjects. This reduction minimises the likelihood of survey fatigue through boredom of answering repetitive questions, which is an issue with TPB style surveys (Gagné and Godin, 2000). Moreover, due to fewer questions, administration time is reduced and therefore there is scope to include additional questions which is important in this research as it aims to explore the influence of additional variables as well as the TPB variables on farmers' intention to implement nutrient management planning.

The constructs of the Theory of Planned Behaviour

The TPB consists of three variables which explain intentions to engage in a particular behaviour; namely, attitude, subjective norm and perceived behavioural control. These variables are referred to as 'latent' constructs (Hansson *et al.,* 2012). A latent construct is one that cannot be directly observed, such as an individual's attitude towards a given practice, but can be inferred from observable phenomena such as an individual's response to a given proposition or statement (Borsboom *et al.,* 2003). It is recommended that at least three statements, often referred to as items in survey research, are used to measure a given latent variable in order to provide minimum coverage of the construct's theoretical domain (Hair *et al.,* 2010). To guide the development of the statements used to elicit farmers' attitudes, subjective norm and perceived behavioural control advice was used from Ajzen (2002b) and Francis *et al.* (2004) who suggest to conduct preliminary qualitative interviews based on open ended questions which should be designed to reveal farmers' salient beliefs in line with the TPB variables. Prior to these interviews, a consultation of the literature to identify the theoretical underpinnings of the socio-psychological concepts was conducted.

Attitude

Attitude can be defined as the degree to which a person has a favourable or unfavourable evaluation of the behaviour in question (Beck and Ajzen, 1991). In the TPB, attitudes are assumed determined by the underlying salient beliefs held by an individual towards a given behaviour (Conner and Armitage, 1998). In general, a person typically possesses a wide variety of beliefs regarding a particular behaviour, but at a given time only a number of these are likely to be salient. It is these salient beliefs which are believed to determine a persons' attitude (Conner and Armitage, 1998). Theoretically, there are three components of attitude: cognitive, affective and conative (Rosenberg and Hovland, 1960; Trafimow and Sheeran, 1998). According to Fishbein and Ajzen (1975), the cognitive component refers to knowledge, opinions, beliefs and thoughts about the target behaviour whereas the affective component relates to a person's feelings towards the behaviour (e.g. fear, disgust or appreciation). Finally, conative refers to a behavioural inclination, intention or action. However, the conative component of attitude is removed from the TPB and instead is translated into a separate variable, namely intentions. The TPB has been criticised for over emphasising the cognitive component of attitude (beliefs) over affective (feelings and emotions) aspects (Manstead and Parker, 1995). Whilst the uptake of nutrient management planning is not typically an 'emotionally driven' topic compared to for example animal welfare, measuring farmers' general feelings towards the uptake of nutrient management planning is a worthwhile exercise. 'Direct measures' of attitude tend to be based on automatic reactions rather than belief-based items ('indirect measures') which require relatively reasoned responses (Gagné and Godin, 2000). Examples of direct measures include asking respondents whether performing a particular behaviour is a good idea, useful and important (Ajzen, 2002b).

Subjective norm

Subjective norm was originally conceptualised as an individual's perception that most people important to them think they should (or should not) perform a specific behaviour (Ajzen, 1991). However, studies have shown that that the weak link between subjective norm and intention across the literature may be due to the narrow conceptualisation of the concept (Sheeran and Orbell, 1998; Armitage and Conner, 2001). There is a key distinction in the literature on social influence between injunctive norms (i.e., what significant others think a person ought to do) and descriptive norms (i.e., what significant others themselves do) because these are separate sources of motivation (Rivis and Sheeran, 2003). The subjective norm component of the TPB is an injunctive social norm because it relates to perceived social pressure, that is, the person's potential to gain support or suffer disapproval from significant others for engaging in a given practice (Rivis and Sheeran, 2003). However, descriptive norms pertain to perceptions of significant others' own behaviours (Cialdini, 2001). Here, the opinions and actions of significant others offers information that people may adopt in determining what to do themselves (Cialdini *et al.,* 1991). In recognition of developments in the literature, the TPB developed over time to include two subcomponents of subjective norm, namely injunctive and descriptive norms (Fishbein and Ajzen, 2010). In the survey used in this research respondents beliefs regarding both injunctive and descriptive norms were elicited by asking farmers their perceptions of the level of social pressure they feel towards the uptake of the given practice, as well as whether they believe most other farmers adopt the given practice in question.

Perceived behavioural control

Perceived behavioural control is an individual's perception of the extent to which performance of a given behaviour is easy or difficult (Ajzen, 1991). It is important to note that perceived behavioural control is not related to the control over the attainment of an outcome (Ajzen, 2002a). Perceived behavioural control is associated with the perception of factors that are likely to facilitate or inhibit a behaviour from being performed and are referred to as control beliefs (Ajzen, 1991). Perceived behavioural control is closely related to the concept of self-efficacy which is concerned with judgments of how well one can execute courses of action required to deal with prospective situations which is strongly related to the confidence an individual places in his/her abilities to perform a behaviour (Bandura, 1982). Due to the close connection between perceived behavioural control and self-efficacy there has been considerable debate in the literature as to whether perceived behavioural control is in fact two concepts combined (Manstead and Van Eekelen, 1998; Armitage and Conner, 1999a, 1999b; Povey *et al.,* 2000; Kraft *et al.,* 2005).

Theoretically, perceived behavioural control comprises of perceived capacity and perceived autonomy (Ajzen, 2002a). Perceived capacity relates to the degree to which one believes that one is able to perform a particular behaviour. Perceived autonomy pertains to the degree to which one believes that one has control over the performance of a given behaviour (Yzer, 2012). Thus, ability is linked to ‘internal factors’ (e.g. acquisition of information, skills, and confidence to perform the given behaviour), whereas control is associated with ‘external factors’ (e.g. situational, environmental factors as well as resources and opportunities available to the individual) (Conner and Sparks, 1996; Tolma *et al.,* 2006). However, based on a review of the literature, Ajzen (2002a) concludes that perceived behavioural control should be conceived of as a singular, higher-order concept that consists of two (interrelated) aspects pertaining to the notion of self-efficacy and controllability. Thus, the self-efficacy part of perceived behavioural control relates to ease/difficulty over and confidence in performing a given behaviour, whereas the control component of perceived behavioural control involves people’s beliefs that they have control over the behaviour, and that performance or non-performance of the behaviour is up to them (Ajzen, 2002a). In summary, perceived behavioural control is associated with people's judgments about their ability to perform a behaviour and judgments about their autonomy over the decision to perform the behaviour (Yzer, 2012). Therefore, measures employed in a survey should include both perceived capacity and autonomy items to ensure that the full range of perceptions of perceived behavioural control are covered (Yzer, 2012).

Intentions

This study focuses on predicting the future behaviour of farmers rather than current behaviour and therefore future intentions is a suitable predictor. According to the TPB, intention implies individual readiness to accomplish a given behaviour and is viewed as the motivation which is necessary for engagement in a particular behaviour (Ajzen, 2002). The intention to perform a behaviour is the most substantial predictor of behaviour and is assumed to be an immediate antecedent of that behaviour (Ajzen, 2002). The more one intends to engage in a behaviour, the more likely will be its performance (Rezaei *et al.,* 2018).

Preliminary interviews

Before conducting qualitative interviews it is important to firstly specify the exact behaviour of interest in terms of its Target, Action, Context, and Time (TACT) (Ajzen, 2002b; Francis *et al.,* 2004). Following this guideline, in the context of this research, the target is farmers, the action is to implement a given nutrient management planning practice, the context is the particular nutrient management planning practice under study and the time is in the near future. The time frame 'near future' was chosen purposefully as there was non-census from the interviews described below as to what level of time frame should be imposed on farmers. Some farmers already have soil analysis conducted and NMPs drawn up whereas others do not and therefore time frames may vary between these groups of farmers. Furthermore, using a 'near future' time frame is advantageous as it slightly biases farmers' attention towards the 'why' of the practice under study rather than the ‘when’. Policy makers are keen to understand potential barriers towards the adoption of nutrient management planning and, whilst time frames are important, ensuring that a deep understanding of the ‘why’ is particularly important for the purpose of this study.

In terms of the interviews, a series of open ended questions were posed to farmers (four interviews), agricultural advisors (four interviews), and research specialists (four interviews) in Ireland. These were based on suggestions from Francis *et al.* (2004) and altered to suit the practice under consideration and the person being interviewed. The process involved asking a series of open ended questions to respondents. The structure of these questions were kept the same to maintain consistency. The interview lasted approximately 15 minutes. For example, to elicit attitude towards following a NMP the following statements were asked to the respondents: “what do you believe are the advantages of following a NMP?” and “what do you believe are the main disadvantages of following a NMP?” and “is there anything else you associate with your own views about following a NMP?”. For subjective norm the following questions were used: “Are there any individuals or groups who would approve of you following a NMP?” and “are there any individual or groups who would disapprove of following a NMP?” Finally, for perceived behavioural control the following statements were asked: “what factors or circumstances would enable you to follow a NMP?”, “what factors or circumstances would make it difficult or impossible for you to follow a NMP?” and “are there any other issues that come to mind when you think about following a NMP?”. The data gathered from the interviews was then summarised into a number of statements which could be used to measure farmers’ attitudes, subjective norm and perceived behavioural control as well as intention to adopt nutrient management planning. The wording of these statements as well as the final survey was cross-checked with previous studies, similar surveys and experts to check for consistency in style of wording.

Pilot

The final survey was piloted with a range of people, including eleven farmers, four agricultural advisors and five researchers with previous survey experience within an agricultural context. The aim of the pilot was to eliminate any potential problems with the survey such as timing, complexity and suitability. The decision to include non-farmers was important due to the technical nature of the TPB sections which required specific wording that farmers would be able to understand. The survey company conducted ten out of the eleven pilot surveys with farmers face-to-face whereas the remainder of the pilot surveys were solicited by me with the remaining respondents. The survey company was requested to ask pilot respondents to comment on the suitability of the questions, wording sequence, layout, question difficulty and usefulness of the instructions and 'prompts' included in the survey. A similar procedure was conducted by me in relation to the remaining pilot participants. After evaluation of the feedback from the pilot a number of changes were made to the survey. Firstly, the survey was reduced in length, primarily by reducing the number of statements used to elicit beliefs in the TPB sections. Secondly, wording of the questions was simplified and additional explanations were added to the 'prompts' which were included in case farmers needed further clarification on terminology. Finally, a number of alterations were made to the layout of the survey in order to improve the flow of the questions.

Scale design

Responses to questions designed to reveal farm and farmer characteristics as well as background nutrient management practice were based on a nominal scale where numbers are used to classify responses. For example, for farm system the interviewer asked farmers what type of farm system they operated and recorded the response as either cattle (1), dairy (2), sheep (3) or tillage (4). On the other hand the questions used to elicit farmers' beliefs, pertaining to attitude, subjective norm and perceived behavioural control as well as intentions, were measured using statements reflecting these constructs. Respondents were asked to specify on a five-point Likert scale the extent to which they agreed (strongly disagree (1), disagree (2), neither (3), agree (4) and strongly agree (5)) with the proposed statements. This type of scale is referred to as ordinal in so far as numbers are assigned to objects to indicate the relative extent to which a certain characteristic is possessed (Malhotra and Birks, 2006). Five-point Likert scales have been used in previous agricultural research (Gorton *et al.,* 2008; Hansson *et al.,* 2012; Martinovska Stojcheska *et al.,* 2016; Adnan *et al.,* 2017b; Morais *et al.,* 2018) and some argue that they are short enough to allow respondents to distinguish meaningfully between the response options (Hansson *et al.,* 2012). Following recommendations in the literature, all questions in the survey were written in a general and neutral way, kept simple and double-barrelled questions were avoided (Lietz, 2008). This was conducted in order to ensure every respondent should have been able to answer them and to reduce the likelihood of 'social-desirability' bias (Foddy, 1993).

Sample size

Choosing a suitable sample size to represent the population is important due to its effect on statistical power (the probability of observing an effect in the sample) (Singh and Masuku, 2014). A large sample size can reduce biases in the sample (the sample more closely represents the population) and therefore lead to a reduction in the likelihood of type two errors which refers to accepting the null hypothesis when there is a significant relationship between variables, also known as 'false negative'. However, with large sample sizes, the likelihood of type one errors can increase which involves rejecting the null hypothesis when there is no significant relationship, also known as 'false positive'. This means that if a study is 'over-powered' (sample size bigger than necessary) then the likelihood of results occurring due to chance can increase. To ensure that a suitable sample size is calculated, which is neither under or overpowered, the formula developed by Yamane (1967) was adopted and combined with researcher judgements and availability of resources. The sample size based on this formula, widely used by other researchers within an agricultural context (Ullah *et al.,* 2015; Saqib *et al.,* 2016; Zeweld *et al.,* 2017; Akhtar *et al.,* 2018; Zulfiqar and Thapa, 2018), depends on the population size and the level of precision. The level of precision (or margin of error) was set at 3% while determining the sample size.

$$n = \frac{N}{(1 + Ne^2)} \qquad (1)$$

where, n = sample size, N = Total number of registered farms in Ireland in 2013 (data available at the time) (139,600), e = precision which is set at 3% (0.03). The calculation produced a sample of 1102 farmers, however the final sample chosen was 1009 farmers as this was deemed sufficient by research experts in Ireland as well as due to resource constraints.

Sampling

The Central Statistics Office (CSO) conducts a Census of Agriculture every 10 years to record the population of farmers and the structure of farming in Ireland, the last of which was for the year 2010. Farm Structure Surveys (FSS) are conducted in the intervening periods (every three years), to generate estimates of the farm population, of which the most recent report available at the time of the survey was the 2013 FSS. The sampling frame used in this research is based on the 2013 FSS (CSO, 2015). However, as the 2016 FSS survey was released in 2018, descriptive results are compared to the earlier survey to maintain consistency between comparisons. In order to obtain a representative sample of farmers, the survey company first identified a number of sampling points across Ireland. The sampling points were chosen based on the seven main regions of Ireland as described in the agricultural census of 2010 (Mid-east and Dublin, Mid-west, South-east, South-west, Border, Midland and West) (CSO, 2012) and distributed in order to ensure that a level of geographical representation based upon the known proportion of farms in geographical area was achieved. This was important as some areas in Ireland (Mid-east and Dublin, South-east and South-west) are generally more productive (due to better weather and soil conditions) than others (Mid-west, South-east, Border, Midland and West). The survey company was also provided with a quota control matrix to which to adhere to when recruiting participants. This matrix was based upon the known proportion of farm types (farm system and farm size) across the Irish population which were derived from the 2013 farm structure survey.

Sampling techniques can be categorised broadly into probability or random sampling, and non-probability or non-random sampling methods (Malhotra and Birks, 2006). Probability sampling is considered to be advantageous over non-probability sampling as it has the potential to minimise potential biases in the sample, i.e. over or under representation of certain groups of respondents, compared to non-probability sampling methods (Malhotra and Birks, 2006). However, probability sampling techniques, such as stratified random sampling, are expensive and time consuming to adopt. Moreover, the use of probability sampling techniques requires contact details of respondents. In Ireland there is no database available consisting of farmers addresses that is available for research purposes and therefore utilising probability sampling becomes problematic (Howley, 2013).

Therefore, for the purpose of collecting the data for this research, a non-probability sampling method is utilised. The method chosen is a quota controlled sampling method in which participants are chosen on the basis of predetermined characteristics so that the total sample has a similar distribution of characteristics as the wider population (Taherdoost, 2016). Quota controlled sampling is similar to stratified random sampling in so far as a stratum or quota is used to select a predetermined number of participants based on a number of chosen characteristics, however quota controlled sampling relies on convenience to fill the strata. This could lead to over or under representation in the characteristics of the population that are not controlled for such as education, gender and location. Nevertheless, advantageously, quota controlled sampling allows for the control over certain important characteristics and presents lower costs and greater convenience to the interviewers (Malhotra and Birks, 2006).

To develop a quota, a number of population characteristics must be selected to control for, such as farm system, farm size, income, age, education and gender. For the purpose of this research, as mentioned above, farm system and farm size were selected as the control variables for a number of reasons. Firstly, nutrient management practices typically vary between farm systems and sizes. Secondly, farm system and size is regarded as an indicator of farming intensity in Ireland with tillage and dairy systems, as well as larger farms typically using higher levels of inputs, such as fertiliser (Dillon *et al.,* 2017). This is critically important to this study which focuses on the management of nutrients as there may be a natural propensity for certain farm systems and sizes to have a preference for using nutrient management planning to optimise returns from higher direct costs. Thirdly, farm system and farm size are the most commonly used stratification categories in national data bases across the EU, enabling comparisons of the data collected to national figures.

The next stage involved in the development of the quota was to define the proportion of farm types required in terms of farm system and farm size based on known national population figures. However, Malhotra and Birks (2006) suggest that it can sometimes be desirable to amend the quota to under or over sample certain elements of the population if deemed necessary by the researcher. It was decided to slightly over sample dairy farmers in the quota because, as mentioned in Chapter 1, the dairy sector is the most important to the Irish economy in terms of economic contribution. A similar procedure is utilised in the Teagasc National Farm Survey (NFS) which is collected as part of EU Farm Accountancy Data Network (FADN) requirements (Buckley *et al.,* 2016). The NFS records a detailed set of farm accounts and enterprise level data on a random representative sample of farms across Ireland (Buckley *et al.,* 2016). It was deemed necessary to over-sample dairy farmers in order to adequately capture their behaviour.

It is also important to note that it was decided not to include mixed farm systems as a separate category in the quota. This was because the definition of what comprises of a mixed system in Ireland is complicated and requires the collection of detailed information from the farmer in terms of the structure of the enterprise. Therefore, for the purpose of this research, farm systems are grouped into cattle (beef), dairy, sheep and tillage. Thus, farmers were asked to make a decision as to the predominant form of farm system they operate (over 50% of activity devoted to a particular form of enterprise). 'Other' farm systems, such as pig and poultry production, are not considered for the purpose of this study as they form a very small minority of Irish production systems. Secondly, in terms of farm size the decision was made to group the CSO (2012) farm size categories under 10 ha^{-1} and under 20 ha^{-1} into one category, namely under 20 ha^{-1}. This decision was made on the basis of past experience of difficulty in locating and contacting very small farms in Ireland. Finally, it was not required to ensure that these farm system and farm size categories overlapped. This means that a certain number of, for example, cattle farmers under 20 ha^{-1} were not required to be collected. Thus, the quota did not have control over the final sample of farmers that would be collected in terms of an overlap between farm system and size.

Data collection

The survey was administered between December 2016 and April 2017 by a professional recording company which was recruited through a tendering process primarily led by me. The tender was awarded to the recording company which demonstrated the best understanding of the requirements, proposed methodology for completion, timeline for data delivery and cost. Consideration was also given to past experience of administering similar types of surveys to farmers and reputation. Interviewers conducted a face-to-face interview with farmers which lasted around 25-30 minutes. It was ensured that the main decision maker on the farm, or principal farmer, was interviewed. Due to the length of the survey, a face-to-face approach was deemed more advantageous than over the telephone because this method reduces the chance of participants terminating the interview prematurely. Furthermore, face-to-face contact tends to allow for a higher level of trust and rapport to be established between the interviewer and the respondent. Moreover, in Ireland there is no database available consisting of farmers addresses that is available for research purposes (Howley, 2013). In order to obtain a representative sample of farmers, the survey company first selected a number of sampling points across Ireland which were strategically placed based on known population distribution figures in order to maximise response rates. At each sampling point, the interviewer adhered to a quota control matrix based farm system and farm size. Interviewers then visited residences that appeared to be a farm household (observing the surrounding landscape) and continued to interview farmers until they filled their quotas.

Upon approaching farmers, in order to build trust the interviewer made it clear that the survey was being conducted on behalf of Teagasc, which is a fairly widely known institution in Ireland. The interviewer provided the respondent with a brief introduction to the purpose of the survey and ensured the respondent that the data would remain anonymous and not passed on to any third party. This was set in place in order to address ethical issues. Interviewers then proceeded to read out the questions from the survey to farmers and recorded their responses on a computer using a Computer Assisted Personal Interviewing (CAPI) system. The advantages of CAPI over the traditional pen and paper approach include an improved error tracking rate, prevention of missing questions or asking the wrong questions (some questions did not require a response from all farmers). One key issue with using CAPI is ensuring that the interviewer is sufficiently trained in terms of using the software. Each interviewer had received technical training in the use of the software by the survey company so this was not deemed to be an issue. Interviewers were also provided with prompts that could be read out to farmers if there was a misunderstanding as to the meaning of certain questions, for example farmers were read out a description of the purpose of each measure in the TPB section in order to avoid confusion as to what each practice entailed.

Data cleaning

The data was received from the survey company in excel format and was transferred into the STATA statistical package. The survey company conducted a thorough data screening exercise before submission of the final data set, however the data was screened before analysis for any typographical errors, omissions or outliers that may have been overlooked. This was conducted using eye balling, scatter graphs and tabulations of the data. A small number of errors were noted which were reported to the survey company who corrected the errors and sent the data back. An example of an error is coding a question with a response of ‘6’ when there were only five potential responses available.

Weights

Weights are a statistical procedure that can be employed to account for under or over representation of certain groups of farmers by assigning differential weights to the data depending on the response rates. For the purpose of this research it was decided not to weight the data for a number of reasons. Firstly, as mentioned previously, a purposeful slight overrepresentation of dairy farms was included in the sample. Applying weights would have neutralised this effect. Secondly, the total number of farms sampled in terms of farm size were closely in line with national population distribution figures and therefore weights were not considered as necessary. Finally, mixed farm systems and farms under 10 ha, as mentioned previously, were not collected as separate categories. Therefore deriving reliable weights based on CSO data, which does collect these groups of farms separately, would lead to the calculation of unreliable weights. Overall, the sample collected was deemed to be sufficiently in line with the national population distribution figures and therefore using survey weights was considered to be an unnecessary exercise that would increase the standard errors of both the descriptive statistics and coefficients obtained in the analysis and thus would make the findings less precise and more variable (Skinner and Mason, 2012).

3.6 Descriptive statistics

Location of respondents

Farmers were recruited from each of the seven main regions in Ireland. Table 3.3 below illustrates the spatial distribution of the respondents in the sample. As can be seen the total proportions of farms closely reflect the national distribution.

Table 3.3: Spatial distribution of respondents compared to CSO (2012).

Region	National (%)	Survey sample (%)
Mid-east and Dublin: Dublin, Kildare, Wicklow and Meath	7	11
Mid-west: Clare, limerick and Tipperary	12	14
South-east: Carlow, Kilkenny, Waterford and Wexford	12	11
South-west: Cork and Kerry	16	16
Border: Cavan, Donegal, Monaghan, Sligo, Leitrim and Louth	21	18
Midland: Laois, Longford, Offaly and Westmeath	9	11
West: Galway, Mayo and Roscommon	23	19

Farm characteristics

Table 3.4, which provides an overview below, illustrates the number of farms by farm system and farm size in the sample and how these compare with estimated national figures. It is important to note that the CSO collects national statistics for other farm systems as well as the ones in this survey and therefore the number of farms may appear higher in each of the farm system categories for the sample in Table 3.4. In terms of farm system, the sample contained a large proportion of cattle farms, followed by dairy, sheep and tillage. In relation to farm size, there is a roughly equal spread across each category with a small number of farms classified as and 101 ha-1 and over (N=83, 8%). The average farm size category (mean) equates to the farm size category 31 ha-1 to 50 ha-1. Table 3.4 also illustrates the number of farms by type and farm size in the sample and how these compare with estimated national figures. For example, a farmer could be classified as mixed according to national standards but has been required to make a choice between cattle, dairy, sheep or tillage. Nevertheless, the statistics provide a general indication as to how the sample compares to the national situation. In terms of farm system, it can be deduced from Table 3.4 that the national distribution in terms of the proportions of farms are reflected by the sample; i.e. greatest numbers of farms are cattle, followed by dairy, sheep and tillage. In terms of farm size, there appears to be slight overrepresentation of larger farm sizes. For example, fewer farms fall into the under 20 ha-1 and 21 ha-1 to 30 ha-1 categories with more falling into the other larger farm size groupings.

Table 3.4: Distribution of sampled farms compared to national figures (CSO, 2012).

Farm characteristic	National (%)	Survey sample (%)
Farm system		
Cattle	53[a]	51
Dairy	12	26
Sheep	11	17
Tillage	3	6
Farm size		
< 20 ha^{-1}	43	19
21 to 30 ha^{-1}	24	22
31 to 50 ha^{-1}	21	29
51 to 100 ha^{-1}	14	22
101 + ha^{-1}	4	8

Notes: [a]CSO includes other farm systems and therefore numbers do not add up to 100%.

Table 3.5, below, shows the distribution of farms across the sample in terms of farm system and farm size. Overall, the results illustrate a slight skew towards larger farm sizes across each of the systems. For example, only 26% of the sample of cattle farmers are in the under 20 ha^{-1} size group whereas in the national population there are 48% in this category. Dairy farms have a slight over-representation in the sample of farmers in the category 101 ha^{-1} and over with fewer dairy farms in the under 20 ha^{-1} size category compared to the national figure. Sheep farms in the under 20 ha^{-1} category appear to be underrepresented with more farms in each of the larger size categories. Finally, tillage farms appear to be underrepresented in size category under 20 ha^{-1} in the sample whereas they are overrepresented in the 101 ha^{-1} and over category. In general, cattle, sheep and tillage farms appear to be overrepresented in the larger farm size categories whereas dairy appears to suitably reflect the national situation.

Table 3.5: Proportion of farms in sample by system and size (national figures in brackets).

	Farm size (%)				
Farm system	Under 20 ha^{-1}	20 to 30 ha^{-1}	31 to 50 ha^{-1}	51 to 100 ha^{-1}	101 ha^{-1} and over
Cattle	26(48)	27(21)	30(20)	13(9.2)	4 (1)
Dairy	3(7)	11(11)	30(32)	44(41)	12(10)
Sheep	28(55)	24(15)	29(16)	11(9)	8(4)
Tillage	3(26)	19(15)	21(21)	26(26)	31(15)

Notes: Rows add up to 100%. Rounding errors mean that rows do not always add up to 100%.

Farmer characteristics

According to Table 3.6, the majority of farm operators are male and the average (mean) age category is 51 to 64 years. The proportion of farmers with an off-farm job is 30%. In relation to education, 53% of farmers have obtained a formal education above second level.

Table 3.6: Farmer characteristics of sample compared to national figures (CSO, 2012)

Farmer characteristic	National (%)	Survey sample (%)
Gender		
Male	88	93
Female	12	7
Age (years)		
< 35	5	7
35 to 44	16	13
45 to 50 (45-54)[a]	24	15
51 to 64 (55-64)	25	38
65 +	30	27
Off-farm job		
Yes	53	30
No	47	70
Education		
Primary	20[c]	16
Some secondary	29	30
Leaving certificate	15	34
Professional qualification at diploma level	16	13
University degree	7	7
Income		
Average income (€)	15,000 to 25,000	20,000 - 29,999[b]

Notes: [a]CSO categories in brackets. [b]Farmers who refused to answer this question (n=284) were removed from the calculation which is based on both a mean and median value which gave the same result. [c]Do not add up to 100% as the CSO collects data in other categories as well.

Table 3.6 demonstrates that the farmers in the sample closely represent gender differences and have somewhat similar age ranges. However, it appears that the sample has a higher proportion of full time farmers who have received on average a slightly higher level of formal education. The average (mean) level of income is slightly higher than the national average, though the sample contains a higher proportion of larger farms which may be inflating the income statistics for the surveyed farms.

Biases in the structural characteristics of the sample

Comparison between the sample characteristics and national averages showed that the sample is slightly biased on a number of accounts. The sample contains more farmers who operate on a full-time basis, and farms that are classified as dairy and are larger in terms of size. However, these are, arguably, the more commercially orientated farms in Ireland which contribute more in terms of economic output and have the financial means to implement farm management practices and have a greater incentive to invest in management practices that can help to reduce costs. Moreover, these types of farms, tend to contribute to greater overall levels of nutrient loads entering, for example, water bodies in Ireland. Therefore, whilst the sample slightly under-represents smaller farms, operated on a part time basis, the sample suitably represents the Irish agricultural context. Finally, the level of formal education is slightly higher than the national average. Nevertheless, the sample closely represents national averages on a number of accounts and therefore it is possible to make a degree of generalisation of the results from the analytical chapters which follow this chapter.

Nutrient management planning

Current adoption rates

Information was collected in the survey regarding background nutrient management practices to gain an understanding of current levels of adoption and reasons for adoption (e.g. for policy compliance reasons or to improve production as discussed in Chapter 1). In terms of soil testing, 631 (63%) farmers test some of their land at least every 5 years (within national recommendations) with the remainder testing less than every five years (N= 254, 25%) or never (N=124, 12%). Farmers who soil test were asked their primary motivation for soil testing and, of those who tested, 35% stated that it was mainly to comply with policy requirements, whilst 61% stated that it was to improve production and 4% said other.

The survey also asked farmers questions in order to gain an understanding of the extent of nutrient management planning occurring on farms. The results from these questions are presented in Table 3.7. Farmers were asked to state what proportion of the farm area they get tested with only 44% testing 76% to 100% of their farm. Only 30% of the total number of farmers in the sample fell within the national recommendation of testing at least every five years across the whole farm (between 76% and 100%). According to Table 3.7, dairy and tillage farms test more of their land than cattle and sheep farms. Despite differences between farm systems, the results imply that whilst the majority of farmers (63%) have soil tested at some point in recent years, frequent and strict whole farm nutrient management planning is not as common.

In relation to the adoption of a NMP, 47% of farmers stated that they have a NMP, lower than the uptake of soil testing. Previous research has also found this trend, with farmers preferring soil testing over the use of a NMP (Buckley *et al.,* 2015; Ulrich-Schad *et al.,* 2017). 53% of farmers stated the main reason that they have a NMP is to comply with policy, with 43% adopting a NMP to improve production and 4% for other reasons. Farmers were also asked who developed their NMP to gain an understanding of the rate of participation in the development process. Of the farmers who adopt a NMP around two-thirds of farmers stated the plan was developed in conjunction with an advisor. NMPs are most common across tillage farms with higher proportions of cattle and sheep farms stating that the main reason they have one is to comply with policy.

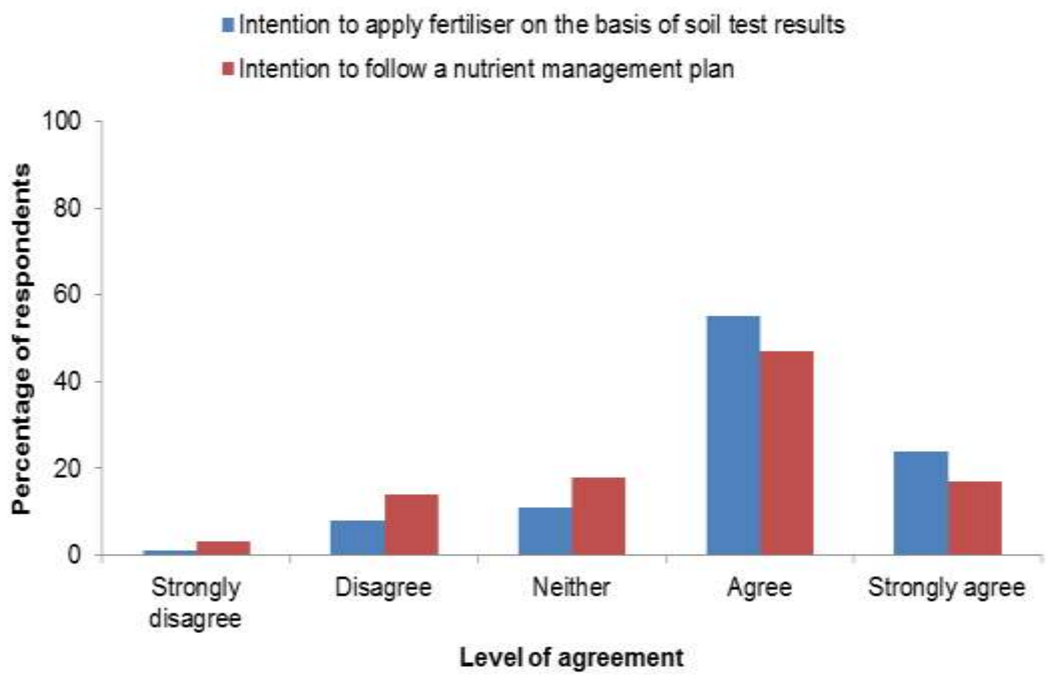
Table 3.7: Current rates of uptake of nutrient management planning.

Practice	Proportion of farmers (%)
Soil testing	
Frequency of soil testing: at least every 5 years	63
Main reason for soil testing: policy compliance	35
Proportion of farm soil tested: 76% to 100% of the farm	44
Extent of adoption of soil testing: at least every 5 years & 76% to 100% of the farm	30
Nutrient management plan	
Farmer is in possession of a NMP	47
Main reason for having a NMP: policy compliance	53
Farmer participated in the development of the NMP	64

Intentions and beliefs

The two measures under study are: 1) Intention to apply fertiliser on the basis of soil test results and 2) Intention to follow a NMP. The following descriptive statistics are not exhaustive, instead they are designed to give an overview of farmers' intentions towards these two practices and to compare a number of key beliefs pertaining to the TPB variables (attitude, subjective norm and perceived behavioural control) of the sample for both measures. In terms of intention to apply fertiliser on the basis of soil test results, as discussed previously, farmers were asked to respond on a five-point Likert scale from strongly disagree (1) to strongly agree (5) in response to being asked: "when it comes to applying fertiliser on the basis of soil test results, I intend to do so and "when it comes to following a NMP, I intend to do so". Figure 3:1 shows that the majority of farmers have a positive intention towards these practices.

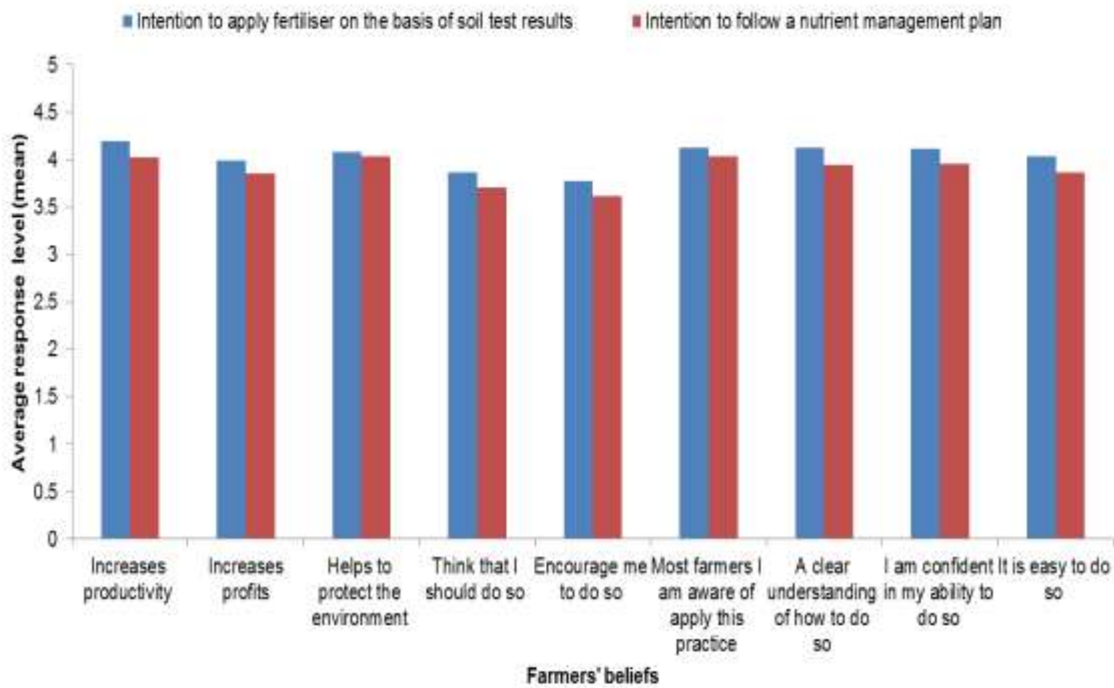
Figure 3:1: Farmers' intentions' towards implementing nutrient management planning.



Interestingly, the intention of farmers is higher than current adoption rates, as noted in Table 3.7. However, the optimism bias suggests that people tend to overestimate their capacity to adopt, for instance, a given behaviour. This leads people to state high levels of future intentions on which they often fail to follow through on. A meta-analysis by Sheeran (2002) confirms that people often state higher intentions than actual behaviour . The study reveals that intention, on average, is only able to predict 28% of the variation in behaviour. Thus, a significant gap exists between peoples' intention to perform a behaviour and actual performance, which is often referred to as the 'intention-behaviour gap' (Sniehotta *et al.,* 2005). People often fail to translate their intentions into behaviour due to withdrawing effort before completing a goal, cognitive ability (e.g. low will power), competing goals, emotions (e.g. disruptive thoughts and feelings), bad habits, failure to monitor progress, and forgetting to act (Sheeran and Webb, 2016).

Figure 3:2 provides an illustration of farmers' responses to a number of the TPB style questions used to elicit farmers' beliefs regarding their attitude, subjective norm and perceived behavioural control using statements based on Likert scales in the survey. In terms of eliciting attitude, numerous statements were used and therefore only a few examples are given for illustrative purposes. Farmers were asked to respond to the following question: "In your opinion, applying fertiliser on the basis of soil test results, increases productivity (1), increases profits (2), helps to protect the environment (3)". In terms of measuring subjective norm, farmers were asked to reply to the following question: "When it comes to applying fertiliser on the basis of soil test results, most people whose opinion I value regarding farming, think that I should do so (1), encourage me to do so (2), most farmers I am aware of apply fertiliser on the basis of results from soil testing (3)". As discussed previously, response one and two refer to 'injunctive norms' and response three relates to descriptive norms. Finally, to gain an understanding of perceived behavioural control, farmers were asked to state their response to the following question: "If I want to apply fertiliser on the basis of soil test results I have, A clear understanding of how to do so (1), I am confident in my ability to do so (2), it is easy to do so (3)". In the context of the previous discussion in the theoretical discussion of the concept of perceived behavioural control, response statements one and two pertain to 'internal factors' whereas as response statement three is an example of an 'external factor', The same questions above also apply to intention to follow a NMP and average (mean) responses to the questions are displayed in Figure 3:2.

Figure 3:2: Farmers' beliefs towards implementing nutrient management planning.



3.7 Conclusion

This chapter provided details of the methodological approach used by this research and detailed the survey instrument used to collect the data. An overview of the survey and a number of descriptive statistics were provided to illustrate the composition of the sample. A number of areas were also highlighted that present potential biases in the sample. The chapter highlighted that, despite potential biases, the sample suitably represents the Irish farming population.

Chapter 4: Which factors influence farmers' intentions to adopt nutrient management planning?

Abstract

The adoption of nutrient management practices can lead to win-win outcomes in terms of both improving productivity and reducing the environmental impact of farming. However, adoption of key practices remains below expectations globally. Few studies specifically focus on the adoption of nutrient management practices and the majority overlook psychological factors in their analysis. This study examines the factors which influence Irish farmers' intention to apply fertiliser on the basis of soil test results. An expanded version of the theory of planned behaviour is used as a framework for analysis. The influence of policy is also accounted for by this study which requires certain farmers in Ireland to adopt soil testing on a mandatory basis. The results for the national sample (n=1009) show that attitudes, subjective norms (social pressure), perceived behavioural control (ease/difficulty) and perceived resources are significant and positively associated with farmers' intentions. In terms of the voluntary sample (n=587), only attitude, perceived behavioural control and perceived resources are significantly and positively associated with farmers' intentions. Whereas, for the mandatory sample (n=422), subjective norms, perceived behavioural control and perceived resources are significantly and correlated in a positive direction with intentions. A number of farm and farmer characteristics are also significantly associated with intentions. Policy recommendations are made based on these results.

Key words: Nutrient management planning, Farmer decision making, Farmer behaviour, Adoption, Intentions, Theory of planned behaviour, Logistic regression, Principal component analysis

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Although the following publication, has joint authorship, the work contained in them is solely my own. Co-authorship represents support in terms of comments, suggestions, advice and discussion of aspects of the research.

4.1 Introduction

The past five decades have seen a rapid increase in demand for food, owing to a persistent increase in the global population and a dietary shift towards a larger share of meat and dairy products (Lassaletta *et al.,* 2016; Swain *et al.,* 2018). To meet this demand, food production has intensified, with crop production per unit of area increasing due to increasing inputs of nutrients among other factors (Nesme *et al.,* 2018). Nutrients, such as nitrogen (N), phosphorous (P) and other micronutrients, such as magnesium, manganese and cobalt, are essential for the continued growth of global agricultural production. However, nutrients, especially N and P, also have the potential to cause environmental degradation (Lu and Tian, 2017; Lun *et al.,* 2018). Global concerns over the nutrient enrichment of both ground and surface waters and the direct emissions of nitrous oxide and ammonia into the atmosphere have led to the simultaneous regulation of nutrient use on farms in various countries (Sutton *et al.,* 2011) and the promotion of management practices that can both increase productivity and reduce environmental damage (Gebrezgabher *et al.,* 2015; Hyland *et al.,* 2018a). Effective nutrient management has been advocated as one key area requiring improvement globally (Mueller *et al.,* 2012; Pasuquin *et al.,* 2014; Xu *et al.,* 2016).

Nutrient management is a process of planning for manure and fertiliser applications to individual pastures or crop fields (Oenema and Pietrzak, 2002). However, decision making surrounding this process is often influenced by the particular farm system in question (e.g. cattle, dairy, sheep or tillage) (Beegle *et al.,* 2000). For example, livestock based farming systems may have a larger emphasis on decision making surrounding manure management whereas tillage farms may have a larger emphasis on decision making surrounding the use of chemical fertiliser. However, regardless of farm system, as the ultimate goal of nutrient management is to match nutrient supply with grass or crop demand, the decision to adopt is relevant across all farm systems (Goulding *et al.,* 2008b; Roberts and Johnston, 2015). However, it is important to note that whilst nutrient management is applicable to all farm systems the incentive to adopt may differ which can influence the decision to adopt. For example, intensive dairy or tillage farm systems often require larger quantities of fertiliser inputs and therefore the incentive to adopt practices that help to optimise returns from nutrients may be higher than low intensity cattle or sheep production systems (Beegle *et al.,* 2000). Soil testing is a key, though not sufficient, nutrient management practice that can be adopted to achieve the aims of nutrient management regardless of farm system (Kelly *et al.,* 2016).

Whilst soil testing remains readily available in a developed world context, adoption remains below expectations across all farm systems (Kelly *et al.,* 2016; Bruyn and Andrews, 2016). A situation has also been observed whereby farmers who do adopt soil testing often fail to fully translate these data into decision making surrounding fertiliser applications (Buckley *et al.,* 2015; Bruyn and Andrews, 2016; Kannan and Ramappa, 2017). This potentially forgoes some of the benefits that otherwise could be gained. Despite global efforts to improve uptake, there remains an international challenge in encouraging the use of soil analysis in decision making and the adoption of nutrient management practices on a wider scale (Osmond *et al.,* 2015; Collins *et al.,* 2016; Wang *et al.,* 2018). Research has shown that the lack of incorporation of soil analysis in decision making may be due to a lack of awareness, lack of perceived benefit, cost, difficulties with implementation and preference not to adopt (Brant, 2003; Osmond *et al.,* 2015; Micha *et al.,* 2018). Non-adopters may prefer to rely on, for example, personal experience, tradition and 'informed' intuition to influence nutrient management decisions (Nuthall and Old, 2018a). However, variance in adoption and use is often found to be contingent on factors which are under the control of the farmer such as the extent of adoption and management skill (Oenema and Pietrzak, 2002; Roberts *et al.,* 2017).

Very few studies have examined the determinants of adoption of soil testing. Moreover, most of the literature focuses on the factors which influence the adoption of individual nutrient management practices (Bosch *et al.,* 1995; Caswell *et al.,* 2001; Monaghan *et al.,* 2007; Ribaudo and Johansson, 2007). Thus, less attention is given to the simultaneous adoption of a given nutrient management practice and its translation into on-farm decision making. Thus, we address a specific gap in the literature by examining farmers' intentions to simultaneously adopt soil testing and apply fertiliser on the basis of soil test results. Furthermore, previous studies have primarily focused on examining the influence of farm and farmer socio-economic factors on adoption of nutrient management practices and, as such, the underlying psychological factors (e.g. beliefs and social pressure) which affect farmer decision making are often overlooked.

Some authors have argued that a failure to account for the influence of psychological factors on behaviour may lead to an incomplete understanding of farmers' intentions towards such management practices (Borges *et al.,* 2014; Wilson *et al.,* 2014; Zhang *et al.,* 2016; Zeweld *et al.,* 2017). Following these authors, we extend the literature by developing a conceptual framework based on the Theory of Planned Behaviour (Ajzen, 1991a) in order to advance our understanding of the factors which influence farmers' intentions to apply fertiliser on the basis of soil test results. This will help policy makers to better target initiatives at the factors which hinder and drive the uptake of this important nutrient management practice.

This study seeks to add to the literature by examining which factors influence farmers' intentions to apply fertiliser on the basis of soil test results, which has seldom been studied. As all farm types or systems have the potential to benefit from the use of soil testing, this study is not restricted to a particular farm system. This study uses the Republic of Ireland (henceforth Ireland) as a case study from which generalised lesson can be drawn for better targeting initiatives designed at encouraging farmers to apply fertiliser on the basis of soil test results. These recommendations are also relevant more widely as many countries face the challenge of encouraging farmers to improve their nutrient management practices.

4.2 Description of soil testing

Soil testing is a diagnostic tool which helps farmers to assess current soil fertility and pH levels of individual fields and make fertiliser application decisions based on these and expected crop yield (Adusumilli and Wang, 2017). Without analysing the nutrient status of fields, the risk of over or under applying nutrients to fields with suboptimal soil pH or fertility levels is increased (Robert, 1993). This can increase the risk of nutrient loss to the environment, lead to lower crop yields and an increase in the risk of sub optimal financial returns to the farmer (Sharpley *et al.,* 2003). The most commonly used test in Ireland is for pH and the macronutrients P and K which costs around €25 per sample. General recommendations for nutrient applications, including liming requirements, are provided in a soil analysis report by registered soil testing laboratories. It is typical for farmers to refine these recommendations based on personal experience, tradition, external advice and expected crop yields. Some of the benefits of following recommendations made by soil analysis include increased yields, improved crop quality and efficiency of input use (Robert, 1993). However, recommendations based on soil test results can incur additional costs such as the need to seek external advice and increase fertiliser and lime inputs in the short run. On the other hand, a soil test may indicate the need to reduce fertiliser application rates which the farmer may perceive as risky as application of fertiliser in excess is often viewed as a risk off-setting activity that helps to ensure high yields and economic stability (Sheriff, 2005; Stuart *et al.,* 2014). For these reasons, farmers may be averse to stringently following recommendations based on the results of soil analysis.

There are several factors which drive the adoption of soil testing in Ireland. These include water quality policy, nutrient management regulation, agri-environmental scheme entry and farm management (Shortle and Jordan, 2017). In Ireland, the adoption of periodic soil testing is mandatory for farmers who receive a derogation (allowance) to operate at a higher stocking rate, of above 170kg/N/ha^{-1}, under the European Union Nitrates Directive (ND) regulations (European Comission, 1991). Farmers who apply to enter and receive subsidy payments under the 'Green Low Carbon Agri-environment Scheme' (GLAS) are also required to conduct periodic soil testing (Image, 2016). However, there is evidence which suggests that farmers who adopt soil testing on a mandatory basis may not rigidly follow recommendations when making nutrient management decisions, which is not an explicit requirement as it is hard to regulate (Buckley *et al.,* 2015). Similar to other countries, a number of initiatives are also used to encourage farmers to voluntarily adopt soil testing and to translate the results into practice. These initiatives include knowledge transfer and exchange through, for example, agricultural education courses, national advisory services, open days, farm walks and farmer discussion groups (Prager and Thomson, 2014).

4.3 Conceptual framework

In order to examine the factors which influence farmers' intentions to apply fertiliser on the basis of soil test results, we developed a conceptual framework based on the Theory of Planned Behaviour (TPB), formulated by Ajzen (1991) to explain human behaviour. According to the TPB, intention is an appropriate predictor of actual human behaviour. Intention, in turn, depends on the beliefs held by the individual towards a particular behaviour which are based around three constructs. These include attitudes towards the behaviour, the perceived social pressure from significant others to perform the behaviour (subjective norms) and perceived behavioural control, which incorporates the perceived ability to perform the behaviour.

The TPB framework has been validated and shown to provide a structured yet flexible framework that can explain farmer decisions to adopt agricultural practices

(Lalani *et al.,* 2016; Zeweld *et al.,* 2017; Rezaei *et al.,* 2018; Zeng and Cleon, 2018). The TPB is flexible because it is allows for the inclusion of additional variables if they improve the models predictive power and can be shown to be conceptually independent of the models constructs (Ajzen, 1991a). As the TPB leaves a substantial percentage of variance with no explanation in intention and behaviour (López-Mosquera *et al.,* 2014; Rezaei *et al.,* 2018), we extend the model by including a number of additional variables.

The first addition to the model is the predictor 'perceived resources'. In the context of the TPB, we follow Zeweld *et al.* (2017) in defining perceived resources as the degree to which a farmer perceives that he/she owns or has access to the necessary resources (e.g. finance, labour and time) and technical infrastructure (information) to support him/her in adopting nutrient management practices. Resources are an important component of nutrient management practices and, as discussed previously, adopting soil testing and applying fertiliser on the basis of soil test results can require additional resources to facilitate the process (Beegle *et al.,* 2000). Previous research has shown that resources have been found to constrain the adoption of nutrient management practices (Monaghan *et al.,* 2007) and therefore it is important to capture this variable in our model.

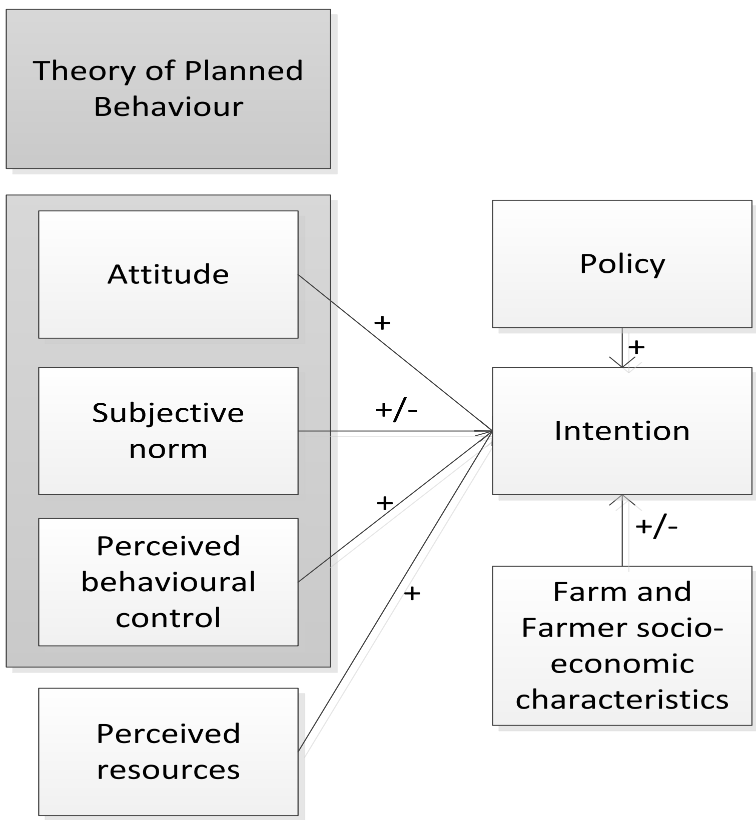
In the TPB, socioeconomic characteristics and background variables such the policy environment, are assumed to influence intention through attitude, subjective norms and perceived behavioural control. Yet, the TPB has been criticised for not accounting for such variables explicitly (Beedell and Rehman, 1999). A number of authors have addressed this limitation by explicitly including socioeconomic and background variables in their extended model of the TPB to explain farmers' intentions (Areal *et al.,* 2012; Borges and Oude Lansink, 2015; Micha *et al.,* 2015; Arunrat *et al.,* 2017). Based on previous research, discussed below, we also include a number of additional variables in our conceptual model to explain farmers' intentions to apply fertiliser on the basis of soil test results. These include farm size and system, farmer age, both formal and agricultral education, contact with an agricultral advisor and participation in a discussion group. A policy variable is also included in the analysis.

In terms of farm characteristics, farm size is frequently hypothesised to positively influence the decision to adopt due to issues associated with economies of scale. Ribaudo and Johansson (2007) found farm size to be positively and significantly associated with the probability of soil testing. Intensity of production is also generally found to be positively associated with the adoption of management practices because higher intensity farms tend to use larger quantities of inputs and therefore the scope for using practices that lead to potential cost savings, such as soil testing, is greater. Monaghan *et al.* (2007) showed that cost, complexity and compatibility with the current farm system to constrain the adoption of various nutrient management practices.

In relation to farmer characteristics, age is typically hypothesised to negatively influence the adoption of management practices because older farmers tend to be more risk averse. Buckley *et al.* (2015) found that the frequency of adoption of nutrient management practices, including soil testing, decreased with age. Higher levels of both formal and agricultural education have been found to positively increase the likelihood of adoption of nutrient management practices (Knowler and Bradshaw, 2007). Furthermore, contact with extension services such as an advisor or discussion groups have also been found to increase the likelihood of engagement of management practices. Pan (2014) found that farmers who based fertiliser application on the basis of soil test results were more likely to be in contact with agricultural extension. We incorporate these variables into our conceptual framework to explain farmers' intentions towards applying fertiliser on the basis of soil test results.

Due to the importance of policy in relation to the adoption of soil testing in Ireland (see section 2), we include an additional variable to capture the potential effect of policy on farmers' intentions to apply fertiliser on the basis of soil test results. Here we assume that farmers who have conducted soil testing to comply with policy may also have a propensity to use the results as they are available to them. Furthermore, research has found that nutrient management policy can influence farmers' attitudes towards nutrient management practices and therefore the potential drivers of intention between mandatory and voluntary adopters may also differ (Barnes *et al.,* 2009; Barnes *et al.,* 2013b; Macgregor and Warren, 2006, 2015). Potential differences in drivers are also explored in our study. The final conceptual framework used for the purpose of this study is shown in Figure 4:1.

Figure 4:1 Conceptual framework based on the theory of planned behaviour used for the purpose of this study.



4.4 Data and methodology

Survey

The data used in this study was derived from a structured survey of 1009 farmers across Ireland. A survey company was hired to carry out a face-to-face survey with farmers during the period December 2016 and April 2017. A quota controlled sampling procedure was set in place to ensure that the survey was nationally representative by the predominant farm system (cattle, dairy, sheep and tillage) and size (hectares) for the farming population aged 15 years and above (Hennessy & Moran, 2015). In Ireland there is no available database containing farmers' addresses that is available for research purposes. In order to obtain a nationally representative sample of farmers, the survey company initially stratified the target sample of farmers by Electoral Divisions. At each sampling point, the interviewer adhered to a quota control system based upon the known number of farm types within each area. Interviewers then proceeded to interview farmers until they filled their quotas. Quota sampling sets demographic quotas based on known population distribution statistics. The quotas used here were based on known population distribution figures in relation to specific farm types taken from the Irish Central Statistics Office (Hennessy & Moran 2015). It was ensured that the key decision maker on the farm participated in the interview.

Quota controlled sampling is a non-probability sampling technique which ensures that specified numbers (quotas) are obtained from each specified population subgroup (Elder, 2009a). A key assumption of this data collection method is that the main variability lies across, rather than within chosen subgroups, so that, once homogenous groups have been selected, it is not important which particular individuals within any groups are interviewed (Elder, 2009b). Here, for example, we controlled for farm system and size and therefore other factors such as age, income and education are not controlled for. Therefore, it cannot be guaranteed that the sample is nationally representative beyond farm system and size and therefore policy recommendations should be interpreted tentatively. Despite this limitation, quota controlled sampling remains a popular data collection method due to convenience and relatively low cost and has been successfully employed in previous agricultural research (Howley, 2013; Howley *et al.,* 2015).

A review of the literature, expert consultations, farmer interviews and a pilot study were used to develop the survey. The final survey was divided into three sections. First, questions were used to collect data on farm (e.g. farm size and system) and farmer characteristics (e.g. age, education and contact with an agricultural advisor) for use as independent variables in the analysis. The second section collected information on farmers' motivations for adopting soil testing, such as regulation or participation in an agri-environment scheme, for the identification and classification of farmers as 'voluntary' or 'mandatory' adopters. The final section was based on the TPB where farmers were asked to evaluate various statements designed to reveal their beliefs and intentions towards applying fertiliser on the basis of soil test results.

Measurement of latent variables

In line with the conceptual framework, four types of psychological latent constructs were of relevance to this study: attitude, subjective norm, perceived behavioural control and perceived resources. Statements reflecting the constructs were developed and used in the survey to measure these latent constructs. The content and wording of the statements was based on information collected during the survey development phase. Respondents were asked to respond on a five-point likert scale, from strongly disagree (1) to strongly agree (5), the extent to which they agreed with the statements read out to them by the interviewer. Five point-likert scales have also been utilised in previous agricultural research (Gorton *et al.,* 2008; Hansson *et al.,* 2012; Adnan *et al.,* 2017). Overall, for farmer intentions to apply fertiliser on the basis of soil test results, farmers had to evaluate eight statements regarding their attitudes towards the outcomes of performing this practice, four statements regarding subjective norm (social pressure), seven statements regarding perceived behavioural control (ability) and four statements regarding perceived resources. A principal component analyses (PCA) was utilised to determine the statements underlying the latent variables with a similar structure.

PCA is a data reduction technique which operates by examining the pattern of correlations among a number of variables (Abdi and Williams, 2010). PCA transforms a group of correlated variables into a smaller number of uncorrelated variables, or principle components, that account for the most of the variation in responses (Jolliffe, 2002). Before conducting the PCA a number of common statistical tests were employed to check the suitability of the statements for PCA. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was employed. The result of the measure was 0.94 where a value above 0.5 is acceptable (KMO values range between zero and one) (Kaiser, 1974). The Bartlett's test of sphericity was also used to calculated whether the correlation matrix of the statements differs significantly from the identity matrix (Bechtold and Abdulai, 2014). The Bartlett's test should reject the hypothesis that the correlation matrix is an identity matrix. The Bartlett's test was significant at the $p = 0.0000$ level and therefore the alternative hypothesis was accepted that there is a significant relationship between the variables.

Having obtained satisfactory results from the tests, the PCA was conducted and components extracted where eigen values were greater than one (Hair *et al.,* 2010). We employed a method called component rotation which was used in order to distinguish between components and facilitate the interpretation of components (Bechtold and Abdulai, 2014). The widely applied varimax rotation was used for the purpose of this study (Abdi and Williams, 2010). Based on the eigen values we retained four components. The decision about the number of relevant statements retained on each component is guided by theory and meaning of the components (Hair *et al.,* 2010). Similar to Hansson *et al.,* (2012), we decided to retain statements that loaded onto components if they were above 0.3. This is considered as acceptable if the components make theoretical sense (Hair *et al.,* 2010). The Cronbach's Alpha was also applied to the each of four principle components in order to assess internal consistency and reliability (Nunnally, 1978). A value of 0.6 is considered as acceptable (maximum value is one) (Bechtold and Abdulai, 2014). The Cronbach's Alpha was 0.90 and 0.89 for components one and two and 0.87 and 0.69 for components three and four. The final components can be utilised as explanatory variables in a regression analysis in place of the original categorical statements.

Appendix A shows the results from the PCA (only statements that produced components are shown). The results are in line with the conceptual framework shown in Figure 4:1. The first component is attitude, which reflects personal beliefs towards the outcomes of applying fertiliser on the basis of soil test results. This component had high component loadings on statements such as "increases profits" and "increases productivity". The second component (perceived behavioural control) consisted of statements reflecting the level of ease a farmer feels that he/she can conduct the behaviour. Such statements include "I am confident in my ability to do so" and "it is under my control to do so". The third component (subjective norm) relates to farmers' perceptions of the level of social pressure to apply fertiliser on the basis of soil test results. Some examples of statements that produced this component when farmers were asked what most people think were: "think that I should" and "encourage me to do so". Finally, the fourth component comprised of statements reflecting the farmers' perceptions of resources (perceived resources). This relates to the farmers perception of whether he/she has adequate resources, such as time and finance, to adopt the practice in question.

Explanatory variables

In additional to the psychological variables, a number of farm and farmer characteristics are also expected to influence farmers' intentions to apply fertiliser on the basis of soil test results. The chosen variables are based on the literature discussed previously (see section three) and include farm size and system, farmer age, formal and agricultural education, contact with an agricultural advisor, participation in a discussion group and policy. The smallest category of farm size (<20ha) was selected as the reference group for analysis of the effect of farm size on intention. This is because smaller farms generally cannot achieve the same economies of scale to engage in management practices that large farms can (Knowler and Bradshaw, 2007). In order to examine the effect of farm system on intentions, the sheep system was selected as the reference group for analysis. In Ireland, sheep farms are considered as the least intensive and generally use the least amount of fertiliser and, therefore, applying fertiliser on the basis of soil test results is not always considered a priority on such farms (Renwick, 2013). In relation to farmer age, the oldest category of farmer (65+) was selected as the reference category for analysis because older farmers tend to be more conservative when it comes to the adoption of management practices (Prokopy *et al.,* 2008). A policy variable was also developed which included farmers who participate in GLAS or receive a derogation under the ND. As discussed previously (see section two), both of these policy instruments make it compulsory for farmers to conduct periodic soil testing in Ireland.

Data analysis

The dependent variable for this study is farmers' intentions to apply fertiliser on the basis of soil test results. As the statement designed to measure this variable is based on an ordered five-point likert scale, it is typical to use an ordered regression model to analyse the data as there are more than two categories of response (Greene, 2008). However, from the full sample, only 14 farmers responded "strongly disagree" to the intention statement. Furthermore, when the sample was split into two further samples for further analysis (see below) only 13 farmers responded "strongly disagree" for the first sample and one and seven farmers responded "strongly disagree" and "disagree" respectively for the second sample. Due to insufficient responses in a number of response categories, it was not possible to decompose these categories. Therefore, similar to other studies (Läpple and Kelley, 2013; Hyland *et al.,* 2018), the responses “strongly disagree”, “disagree” and “unsure” are grouped into the category “do not intend” and labelled as 0 and the responses “agree” and “strongly agree” were grouped into the category “intend” and labelled as 1. As there are now only two levels of response, the following binary logistic model is employed to explore the relationship between the hypothesized psychological and additional variables on the probability that a farmer indicates a “yes” response (positive intention) to apply fertiliser on the basis of soil test results, which can be expressed as follows:

$$In[P_i/(1-P_i)] = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}$$

Where, subscript i denotes the i-th observation in the sample, P_i is the probability of the outcome, β_0 is the intercept, β_1, β_2, …, β_k are regression coefficients of variables X_1, X_2, ..., X_k, respectively (Timprasert *et al.,* 2014).

As discussed previously, policy requires certain farmers in Ireland to conduct periodic soil testing and therefore it was deemed necessary to account for this influence by splitting the full sample into ‘voluntary’ and ‘mandatory’ adopters. For the purpose of the analysis farmers who participate in GLAS and/or receive a derogation under the ND were classified as ‘mandatory’ adopters (n=422). The remaining farmers were grouped as ‘voluntary’ adopters (n=587), this group also includes farmers who do not necessarily conduct soil testing currently.

In order to select the logistic regression model with the best fit, the model was run for all of the hypothesised variables in the first instance for the full sample. The results showed that farm size was an insignificant predictor of intention. Therefore, a likelihood-ratio (LR) test was performed on the full sample which compared a model which did not contain farm size to the initial model containing farm size to see if farm size significantly improved the model fit. The result of the LR test was insignificant which implies that omission of farm size does not significantly alter the model's fit. Therefore, this variable was removed from any subsequent analysis. A similar procedure was applied to other insignificant variables in the full model (formal education, agricultural education and discussion group), however the LR test was significant and therefore we chose to keep these variables in the analysis.

For ease of interpretation, the regression results are also presented as marginal effects. The higher the marginal effect is, the higher the impact of the explanatory variable on the dependent variable is (Greene, 2008). The marginal effects for the dummy variables are estimated as the difference between the probabilities calculated at the sample mean when a dummy variable takes values of 1 and 0, respectively (Yiridoe *et al.,* 2010). Whereas for continuous variables, i.e., the PCA variables, the marginal effect is calculated at the sample mean of zero due to standardization of the PCA output (Jolliffe, 2002).

Multicollinearity between the independent variables was tested for by using the variance of inflation factor (VIF) where a VIF factor of 10 is used as a cut off value (Myers, 1990). The maximum VIF was 4.08 for the full sample, 3.37 and 5.29 for the voluntary and mandatory samples respectively. These figures suggests that multicollinearity was not an issue in our analysis.

4.5 Results and Discussion

Descriptive statistics

Table 4.1 provides a description of the variables used in the regression models. The following descriptive statistics are for the full sample of farmers (n=1009). In line with the quotas (see section 4.4), Cattle farms represent 51% of the sample whereas dairy accounts for 26% followed by sheep at 17% and tillage comprising 6% of the sample. The median farm size is 31-50ha whereas the median farmer age category is 51-64. These figures are in line with national averages (Dillon *et al.,* 2017). Furthermore, 54% of farmers have at least a second level education or higher whereas around 69% have some level of agricultural education. The descriptive results further indicate that around 63% of farmers are in contact with an agricultural advisor whereas only 29% participate in a discussion group. About 42% of farmers stated that they adopt soil testing on a mandatory basis. Finally, 63% of farmers currently soil test within national recommendations (at least every 5 years) (Wall and Plunkett, 2016). This result is similar to Buckley *et al.* (2015) who found from a sample of Irish farmers that 66% were conducting periodic soil testing.

Table 4.1: Variables used in the binary logistic regression analysis.

Explanatory variables	Description	Mean	Std. deviation
Attitude	Latent variable based on ordinal responses (5-point likert scale)	-	-
Subjective norm	Latent variable based on ordinal responses (5-point likert scale)	-	-
Perceived behavioural control	Latent variable based on ordinal responses (5-point likert scale)	-	-
Perceived resources	Latent variable based on ordinal responses (5-point likert scale)	-	-
Size[a]	Farm size (1 = <20ha, 2 = 20-30ha, 3 = 31-50 ha, 4 = 51-100ha, 5 = 101+)	2.78	1.22

Explanatory variables	Description	Mean	Std. deviation
System[b]	Main system of farming (1 = Cattle, 2 = Dairy, 3 = Sheep, 4 = Tillage)	1.78	0.94
Age[c]	Age of farm operator (1 = under 35, 2 = between 35 and 44, 3 = between 45 and 50, 4 = between 51 and 64, 5 = 65+)	3.65	1.21
Formal education	Highest level of formal education received by farm operator (1 = some secondary and above, 0 = otherwise)	0.54	0.50
Agricultural education	Has some level of agricultural education (1 = yes, 0 = otherwise)	0.69	0.46
Advisor	Farm operator is in contact with an agricultural advisor (1 = yes, 0 = otherwise)	0.63	0.48
Discussion group	Farm operator participates in a discussion group (1 = yes, 0 = otherwise)	0.29	0.45
Policy	Farm operator participates in the Irish GLAS agri-environmental scheme and/ or received a	0.42	0.49

Explanatory variables	Description	Mean	Std. deviation
	derogation in 2016 (1 = yes, 0 = otherwise)		

Notes: [a] Farm size under 20ha as reference group, [b] Sheep as reference group, [c] Age 65+ as reference group.

Farmers' intentions

Table 4.2 provides a descriptive overview of farmers' intentions to apply fertiliser on the basis of soil test result. The result is higher than actual adoption rates of soil testing alone which may be due to the use of behavioural measures which are the farmers' own perceptions of their behaviour and so are subject to acquiescence biases. This means that farmers' may provide responses to questions in a 'socially desirable' way (Beedell and Rehman, 1999; Armitage and Conner, 2001). Furthermore, farmers conducting periodic soil testing on a mandatory basis do not display a 100% level of intention to apply fertiliser on the basis of soil test results. This may suggest that farmers may adopt soil testing to comply with policy but do not intend to use the results from soil analysis to influence decision making, this concurs with the findings of Buckley *et al.* (2015).

Table 4.2: Farmers' intentions towards applying fertiliser on the basis of soil test results.

	Intention (% of farmers)		
Practice	National (n=1009)	Voluntary (n=587)	Mandatory (n=422)
Farmers' intentions to apply fertiliser on the basis of soil test results (0 = no intention, 1 = positive intention)	79	70	92

Factors influencing farmers' intentions to apply fertiliser on the basis of soil test results

Full sample

Results, presented in Table 4.3, highlight that for the full sample intentions are influenced significantly and in a positive direction by attitude (1% level), subjective norm (10% level), perceived behavioural control (1% level), perceived resources (1% level), dairy farm system (5% level), contact with an agricultural advisor (1% level), policy (1% level) and the age groups 45 to 50 and 51 to 64 at the 1% and 10% levels respectively. This means that these groups of farmers are more likely than their older counterparts (65 and over) to have a positive intention.

All of the significant variables also have significant marginal effects (Table 4.4). However, in addition, tillage also becomes significant at the 10% level. As the level of the psychological variables attitude, subjective norm, perceived behavioural control and perceived resources increase by one unit, the probability of a farmer applying fertiliser on the basis of soil test results increases by 2.3%, 1.6%, 3.3% and 3.2% respectively. Being classified as dairy, tillage, within the age band 45-50 or 51-64, contact with an agricultural advisor or subject to mandatory policy requirements increases the probability of uptake by 8.1%, 7.2%, 8.5%, 4.1%, 5.1% and 6.1% respectively.

Furthermore, the TPB variables alone for the full sample (n=1009) account for 35% of the explained variance in intentions. Perceived resources explains an additional 3% of the variation in intentions. The additional farm and farmer characteristics add a further 7% in the explained variation in intentions. This suggests that the TPB suitably explains farmers' intentions to apply fertiliser on the basis of soil test results, however the additional variables improve the model's explanatory power and therefore are worthy additions to the model.

The overall goodness of it of this model, as measured by $Pr > Chi^2$, is 0.0000 which implies significance at the one percent level. The r^2 value of the model is 0.45, which shows that the model has good explanatory power. Overall, the model correctly predicts 90.20% of the responses.

Next, the sample is divided into the two farmer groups, voluntary and mandatory adopters using the policy variable. Results show that different variables become significant across the regressions, that is, there is heterogeneity in the factors which influence intentions. A likelihood ratio-chow test is performed to test the null hypothesis that none of the model coefficients vary between the groups. The likelihood ratio-chow statistic test is significant at the three percent level and therefore we can reject the null hypothesis. This means that the two different groups should not be aggregated but instead should be examined separately.

Voluntary sample

Table 4.3 also illustrates the results for the voluntary adopters. The psychological variables, attitude, perceived behavioural control and perceived resources are each significant at 1% level and positively associated with intention, however subjective norms failed to reach significance. Similar to the national sample, dairy system, the age group 45-50 and contact with an agricultural advisor is correlated in a positive direction with intention and significant at the 1%, 10% and 1% level respectively.

In terms of marginal effects (Table 4.4), the variables attitude, perceived behavioural control, perceived resources increased the probability of applying fertiliser on the basis of soil test results by 5.8%, 7.0% and 5.5%. Other variables that increase the likelihood of adoption are dairy system (16.2%), age 45 to 50 (10.0%) and contact with an agricultural advisor (12.30%).

The regression model has a good fit with a $Pr > Chi^2$ of 0.0000 which implies significance at the one percent level. The r^2 value of the model is 0.47, which reflects adequate explanatory power. 88.42% of the sample responses are correctly predicted by the model.

Mandatory sample

For the mandatory sample (Table 4.3), attitude is not significant whereas subjective norm, perceived behavioural control and perceived resources are significant at the 10%, 5% and 5% level respectively. The variables pertaining to farmer age (age under 35, 35 to 44, 45 to 50 and 51 to 64) are all positively associated with intentions at the 1%, 10%, 1% and 5% levels respectively. Finally, the parameter for agricultural education is significant at the 10% level, with a positive effect on intention.

The estimated marginal effects suggest that subjective norm, perceived behavioural control and perceived resources increase the likelihood of a farmer applying fertiliser on the basis of soil test results by 1%, 1% and 1.4% respectively. Belonging to relatively (to over 65’s) younger cohorts of farmers significantly increases the probability of having a positive intention by 7.1% (45-44), 8.1% (45-50) and 5.2% (51-64).

29 observations (farmers under the age of 35) in this model perfectly predict the outcome and therefore are dropped from the analysis, which leaves a total of 393 farmers in the sample. This model is significant, as measured by $Pr > Chi^2$, at 0.0000 which implies significance at the one percent level. The r^2 value of the model is 0.29, which is illustrates moderate explanatory power. Furthermore, the model correctly predicts 94.31% of the sample responses.

Table 4.3: Results of the binary logistic regression for the prediction of farmer intention to apply fertiliser on the basis of soil test results (coefficients).

	National sample		Voluntary sample		Mandatory sample	
Explanatory variables	Coeff	Std.err	Coeff	Std.err	Coeff	Std.err
TPB						
Attitude	0.29***	0.06	0.40***	0.08	0.17	0.10
Subjective norm	0.20**	0.09	0.16	0.10	0.31*	0.18
Perceived behavioural control	0.42***	0.08	0.49***	0.11	0.27**	0.14
Additional TPB style variable						
Perceived resources	0.41***	0.10	0.38***	0.12	0.45**	0.20
Farm and farmer characteristics						
Cattle system[a]	0.46*	0.27	0.42	0.34	0.85*	0.51
Dairy system	0.96***	0.35	1.09***	0.41	0.49	0.63
Tillage system	0.81	0.50	0.83	0.58	1.05	0.98
Age < 35[8]	0.43	0.51	-0.29	0.58	-[d]	-
Age 35-44	0.04	0.36	-0.41	0.42	1.62*	0.97
Age 45-50	1.27***	0.41	0.84*	0.48	2.41***	0.88
Age 51-64	0.46*	0.25	0.27	0.31	0.92**	0.44
Formal education	0.22	0.25	0.39	0.31	-0.15	0.50
Agricultural education	0.18	0.23	-0.10	0.29	0.75*	0.42
Agricultural advisor	0.64***	0.23	0.85***	0.28	0.05	0.43

	National sample		Voluntary sample		Mandatory sample	
Explanatory variables	Coeff	Std.err	Coeff	Std.err	Coeff	Std.err
Discussion group	0.24	0.31	0.34	0.44	0.29	0.53
Policy[c]	0.78***	0.26	-	-	-	-
Pseudo R2	0.45		0.47		0.29	
Prob > chi2	0.0000		0.0000		0.0001	
% Correctly classified	90.20		88.42		94.31	
Number of observations	1009		587		393	

Notes: Significance levels *** p<0.01, ** p<0.05, * p<0.1, [a]reference group for farm system is sheep system, [b] reference group for age is group 65+, [c]Includes farmers who have a ND derogation and farmers participating in the GLAS agri-environmental scheme. This variable is also used to split the sample hence it is absent in the voluntary and mandatory samples, [d] perfectly predicted outcome.

Table 4.4: Results of the binary logistic regression for the prediction of farmer intention to apply fertiliser on the basis of soil test results (marginal effects).

	National sample (n=1009)		Voluntary sample (n=587)		Mandatory sample (n=393)	
Explanatory variables	Marginal effects	Std.err	Marginal effects	Std.err	Marginal effects	Std.err
TPB						
Attitude	0.0230***	0.0047	0.0577***	0.0112	0.0050	0.0035
Subjective norm	0.0158**	0.0070	0.0226	0.0146	0.0093*	0.0019
Perceived behavioural control	0.0326***	0.0061	0.0704***	0.0138	0.0082*	0.0020
Additional TPB style variable						
Perceived resources	0.0324***	0.0082	0.0554***	0.0180	0.0135***	0.0047
Farm and farmer characteristics						
Cattle system[a]	0.0468	0.0296	0.0762	0.0639	0.0316	0.0208
Dairy system	0.0805***	0.0309	0.1617**	0.0637	0.0211	0.0273
Tillage system	0.0717*	0.0387	0.1336	0.0829	0.0359	0.0283
Age < 35[b]	0.0390	0.0427	-0.0494	0.1049	-[d]	-
Age 35-44	0.0041	0.0375	-0.0724	0.0774	0.0707*	0.0405
Age 45-50	0.0848***	0.0265	0.1003*	0.0517	0.0811**	0.0338
Age 51-64	0.0413*	0.0242	0.0394	0.0447	0.0519*	0.0311
Formal education	0.0173	0.0196	0.0565	0.0447	-0.0045	0.0153
Agricultural education	0.0138	0.0188	-0.0147	0.0415	0.0225	0.0151
Agricultural advisor	0.0506***	0.0181	0.1230***	0.0400	0.0014	0.0128

	National sample (n=1009)		Voluntary sample (n=587)		Mandatory sample (n=393)	
Explanatory variables	Marginal effects	Std.err	Marginal effects	Std.err	Marginal effects	Std.err
Discussion group	0.0187	0.0241	0.0496	0.0624	0.0089	0.0163
Policy[c]	0.0609***	0.0203	-	-	-	-

Notes: Significance levels *** p<0.01, ** p<0.05, * p<0.1, [a]reference group for farm system is sheep system, [b] reference group for age is group 65+, [c]Includes farmers who have a ND derogation and farmers participating in the GLAS agri-environmental scheme. This variable is also used to split the sample hence it is absent in the voluntary and mandatory samples, [d] perfectly predicted outcome.

4.6 Discussion

This study uses a modified TPB approach to understand which factors influence farmers' intentions to apply fertiliser on the basis of soil test results. The significance of the policy variable in the regression analysis for the national sample provides further evidence to suggest that policy is an important driver of intention. To this end, this section focuses on discussing the significant results for the voluntary and mandatory groups only.

The first TPB variable, attitude, has a positive and relatively large influence on farmers' intentions to apply fertiliser on the basis of soil test results for the voluntary sample, however this effect is not noted for the mandatory sample. This means that farmers unaffected by policy are more likely to adopt the practice if they evaluate the outcomes of performing the behaviour more favourably than their counterparts. A possible explanation for this result is that certain groups of farmers who voluntarily intend to engage with the practice are more aware of the benefits that can be gained from doing so than other farmers within this group (Senger *et al.,* 2017a). This result is in line with previous TPB studies which found attitude to be a significant predictor of intention to adopt voluntary agricultural practices (Wauters *et al.,* 2010; Rezaei *et al.,* 2018; Zeng and Cleon, 2018).

It is suggested that social norms influence people's intentions and behaviour because people do not conduct decisions independently from social and cultural influences and, instead, they are constantly referring their behaviour back to important reference groups (Burton, 2004a). However, our results only partially support this assertion as subjective norm is only found to significantly influence the intentions of farmers classified as mandatory adopters. Whilst the relative magnitude of this effect is small, the result implies that farmers within this group who feel a larger degree social pressure are more likely to translate the results of soil analysis into practice. One possible explanation for this result is that a fear of further regulation, or fear of penalties, motivates farmers to behave in a way that is perceived as ‘socially desirable’ and to avoid further regulation in the future (Powell *et al.,* 2012; Savage and Ribaudo, 2013; Mills *et al.,* 2018).

In theory, farmers who have a strong belief in their own capability of applying fertiliser on the basis of soil test results should be more likely to do so (Ajzen, 1991a). Our results support this assertion as perceived behavioural control is found to be statistically significant and has a positive influence on farmers’ intentions, for both farmers classified as voluntary and mandatory adopters. However, this effect is relatively larger for farmers categorised as voluntary adopters. Previous research has found that farmers often do not lack the motivation to adopt recommended nutrient management practices, instead they lack the suitable levels of perceived efficacy to take action (Wilson *et al.,* 2014; Zhang *et al.,* 2016; Wilson *et al.,* 2018). Recommendations made by soil analysis laboratories in Ireland are based on national average fertiliser recommendations (Wall, and Plunkett, 2016) and therefore a level of technical expertise is required to refine the recommendations to suit the particular farm situation.

The variable perceived resources significantly and positively influences both groups of farmers’ intentions to apply fertiliser on the basis of soil test results. Albeit, the effect is relatively larger for farmers classified as voluntary adopters. The result implies that farmers who believe that they have the necessary resources such as time, finance and labour to apply fertiliser on the basis of soil test results are more likely to do so. Whilst this result is contrary to the finding of Zeweld *et al.* (2017), who did not find a significant relationship between perceived resources and farmers’ intentions to adopt sustainable practices, it conforms to expectations as the practice in question can require changes in management such as applying additional fertiliser, increased frequency of application, or to fields that may be difficult to access with machinery. Such practices often require additional finance, time and labour to which a farmer may not have access and which may hinder adoption (Sheriff, 2005).

In terms of farm and farmer characteristics, the dairy system is significantly and positively associated with intention for the voluntary sample. A possible explanation for this result is that dairy farms in Ireland receive the majority of their income from the market and inputs are relatively higher compared to other systems (Dillon *et al.,* 2017). Therefore, the incentive is greater to optimise returns from nutrient inputs versus other systems through the use of soil testing (Beegle *et al.,* 2000). A key implication of this result is related to the need to make practices which have both economic and environmental win-win outcomes more relevant to low intensity farms (e.g. sheep and cattle in Ireland) and perhaps emphasising longer time frames for implementation for such farms.

Younger farmers are said to be more likely to adopt farm management practices (Weaver, 1996; Rahelizatovo and Gillespie, 2004). The results for the regression analysis for the mandatory sample strongly support this assumption (relatively large marginal effects) and demonstrate that the younger cohorts of farmers compared to their older counterparts (65 and over) are more likely to have an intention to apply fertiliser on the basis of soil test results. This result concurs with Buckley (2012) who found certain cohorts of farmers in Ireland to be 'benefit accepters' of nutrient management practices despite having to adopt them for policy compliance purposes. One possible explanation for this result is the fact that relatively younger cohorts of farmer have a longer planning horizon and therefore are more likely to adopt practices which maintain or increase production (Knowler and Bradshaw, 2007a).

The positive influence that agricultural advisors can have on the adoption of agricultural management practices has been well established (Baumgart-Getz *et al.,* 2012). In our study, the role of an agricultural advisor is positively associated with intention to apply fertiliser on the basis of soil test results for the voluntary sample. The marginal effect for this result is also relatively large. This result is consistent with Ingram (2008) who found that agricultural advisors were critical to helping farmers to improve soil management decisions. Agricultural advisors can help farmers to implement management practices by providing knowledge and technical expertise, which can help to explain our result.

4.7 Conclusion

This study sought to determine which factors influence farmers' intentions to apply fertiliser on the basis of soil test results. Most previous studies of this nature tend to focus on the adoption of individual nutrient management practices but few examine nutrient management as a process which requires both adoption and implementation of practices, as such, this study addresses a gap in the literature. Furthermore, we build on the literature further by also incorporating psychological variables into the analysis which have seldom been explored in relation to nutrient management practice adoption. Overall, the results demonstrate that both psychological and farm/farmer characteristics as well as policy are important drivers of intention.

Based on the results, we suggest a number of policy implications. Efforts should be made to encourage farmers to further engage with technical support and to possibly increase levels of support during implementation. This may help to increase the levels of control that farmers feel over applying fertiliser on the basis of soil test results (Blackstock *et al.,* 2010). Perceptions of resources were important to farmers and therefore initiatives must also further acknowledge the diversity of resources farmers have available to them to incorporate soil testing into decision making. In terms of specifically encouraging farmers to apply fertiliser on the basis of soil test results who do not have to adopt periodic soil testing on a mandatory basis, an emphasis on highlighting the benefits of adopting this practice should be made in order to reinforce positive attitudes. On the other hand, in order to encourage farmers operating under mandatory policy requirements, efforts should be directed at increasing the level of social pressure for farmers to incorporate the result of soil analysis into decision making. This can be achieved by further encouraging or incentivising farmers to join group learning environments which can include farmer led knowledge exchange platforms which have a specific focus on this practice (K L Blackstock *et al.,* 2010a). Finally, encouraging younger farmers operating under mandatory requirements to participate in decision making related to nutrient management may help to increase the use of soil test results.

In terms of limitations, this study examines intentions rather than actual adoption levels. Nevertheless, previous studies have shown that intentions have a strong direct effect on future behaviour (Bamberg, 2003). A future study could examine whether farmers actually acted on their intentions. Secondly, the study relies on self-reported behaviour which tends to result in respondents answering questions in a ‘socially desirable’ way (Floress *et al.,* 2018). Despite these limitations, this study provides fresh insights into identifying what determines the decision making-behaviour of farmers and possible ways of further encouraging farmers to apply fertiliser on the basis of soil test results.

Chapter 5: Using a farmer typology to understand the implementation of nutrient management planning

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Abstract

Optimising resource use efficiency is high on many national policy agendas. Inappropriate management in agricultural production can result in increased risk of nutrient loss to the environment. Best practice in nutrient management can help to mitigate this. However, policy initiatives aimed at encouraging farmers to follow a nutrient management plan (NMP) appear to be limited in their success. We employ a typology to classify farms/ farmers based on a number of policy relevant farm and farmer characteristics. The theory of planned behaviour is applied to understand the variables which influence farmers' intentions to follow a NMP across the Republic of Ireland. The typology resulted in a total of three classes of farmers, namely 'traditional', 'supplementary income' and 'business-orientated'. The findings from the regression analysis reveal that attitude towards the outcomes of following a NMP is a weak predictor of intentions whereas subjective norm (social pressure) and perceived behavioural control (ease/difficulty) are strong predictors of intentions across the classes. Furthermore, contact with agricultural extension (a combination of one-to-one and group based extension) is found to be critical in determining the intentions of both traditional and supplementary income classes of farmers. The results also indicate that policy, which requires certain farmers in Ireland to develop a NMP on a mandatory basis, has consistent but mixed levels of influence on intentions. Initiatives designed to further encourage farmers to follow a NMP must account for the diversity that exists among the farming population and how different groups of farmers may respond to such initiatives.

Key words: Nutrient management plan, Farmer decision making, Theory of planned behaviour, Intentions, Latent class analysis

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Although the following paper has joint authorship, the work contained in them is solely my own. Co-authorship represents support in terms of comments, suggestions, advice and discussion of aspects of the research.

5.1 Introduction

Farmers often receive mixed political messages concerning their use of resources. On the one hand they are told to reduce their use of inputs whereas on the other they are encouraged to intensify food production to meet growing demand (Borges and Oude Lansink, 2016). To address this conflicting demand, farmers are increasingly being encouraged to improve the efficiency of agricultural input use (Buckley and Carney, 2013; McGlynn *et al.,* 2018). One important area of attention is improving the efficiency of organic and chemical fertiliser on farms (Sutton *et al.,* 2011; Buckwell and Nadeu, 2016; McGlynn *et al.,* 2018). Such substances, whilst vitally important to crop production, remain important sources of diffuse pollution to water and air (Montemurro and Diacono, 2016; Rohila *et al.,* 2017). In the European Union (EU), nutrient inputs are regulated under the Nitrates Directive (ND) (European Comission, 1991). However, there is a growing interest in moving away from traditional command and control methods towards encouraging voluntary adoption by stimulating individual responsibility for the maintenance of normative standards (Barnes *et al.,* 2013b; Peth *et al.,* 2018). Moreover, due to limited financial resources, policy makers are keen to improve their use of differential targeting of resources, in order to ensure maximum uptake of recommended practices (Blackstock *et al.,* 2010; Walder and Kantelhardt, 2018).

Best practice in the area of nutrient management has received increasing interest from policy makers due to the ability of associated practices to deliver both financial and environmental benefits (Sutton, *et al.,* 2013; McGlynn *et al.,* 2018). Nutrient management is a set of “specialized activities dealing with all nutrient sources and transformations within a defined system so as to achieve both economic and environmental targets” (Oenema and Pietrzak, 2002: 160). One important and widely recommended practice for achieving more efficient management of nutrients is the development and implementation of a nutrient management plan (NMP), typically in conjunction with an agricultural advisor

(Beegle *et al.,* 2000; Easton *et al.,* 2017; Ulrich-Schad *et al.,* 2017). Research has suggested that following a NMP is essential for ensuring that fertiliser (chemical and organic) is applied in line with crop requirements (Roberts *et al.,* 2017). This results in better targeting of nutrient applications to crops (just enough and just in time) with a reduced risk of loss of excess nutrients to the environment (VanDyke *et al.,* 1999; Thomas *et al.,* 2007; Schulte *et al.,* 2009; Amon-Armah *et al.,* 2013). Despite proven universal benefits (regardless of farm system) and extensive promotion, uptake and use of key nutrient management practices, such as NMPs, remains limited globally (Buckley *et al.,* 2015; Osmond *et al.,* 2015; Ulrich-Schad *et al.,* 2017; Brown *et al.,* 2019).

A limited number of studies have sought to reveal the motivations and barriers to development of a NMP. Development of a NMP has been found to be positively and significantly associated with farm size (Ribaudo and Johansson, 2007; Lawley *et al.,* 2009; Ulrich-Schad *et al.,* 2017), number of animals (Lawley *et al.,* 2009), intensity of production (Savage and Ribaudo, 2013), income (Ribaudo and Johansson, 2007), education (Savage and Ribaudo, 2013) and contact with agricultural extension (e.g. advisor, workshops and demonstration meetings) (Genskow, 2012; Ulrich-Schad *et al.,* 2017). Although rarely in relation to the adoption of a NMP, studies have also shown that socio-psychological variables (e.g. attitudes and beliefs towards the practice and farming can both promote and constrain the uptake of nutrient management practices (e.g. soil testing, variable rate fertiliser application, liming and erosion control) more widely (Reimer *et al.,* 2012a; McGuire *et al.,* 2013; Buckley *et al.* 2015; Reimer *et al.,* 2018). There is a growing recognition that farmers do not always act in terms of self-interest and may adopt farm management practices based on external social pressures (Burton, 2004a; Yoshida *et al.,* 2018). Farmers' perceptions of their ability to adopt nutrient management practices (e.g. timing and subsurface application of fertiliser) are also believed to be important constraints on adoption, yet have received limited attention in the literature (Zhang *et al.,* 2016; Wilson *et al.,* 2018).

Despite providing important insights into farmer decision making surrounding the adoption of nutrient management practices, including NMPs, previous studies have three primary limitations. Firstly, studies typically consider the adoption of a NMP as 'being in possession of a NMP' rather than the implementation of the plan (following the plan), which is required if full benefits are to be achieved (Ulrich-Schad *et al.,* 2017). Secondly, studies which examine socio-psychological issues (e.g. attitudes and beliefs) in relation to the uptake of NMPs, are typically from the sociological literature and apply qualitative methods and therefore generalising the results from such studies is often problematic (Chouinard *et al.,* 2008; Wilson *et al.,* 2014; Floress *et al.,* 2017). Finally, previous studies which examine the uptake of NMPs often treat farmers as a homogenous group, which is too strong an assumption if a comprehensive understanding of farmer decision making is to be gained (Läpple and Kelley, 2013; Hammond *et al.,* 2017; Novikova *et al.,* 2017).

We address the limitations of previous research in this paper in a number of ways. Firstly, we examine farmers' intentions to follow (implement) a NMP rather than solely focusing on adoption (uptake). Secondly, we incorporate socio-psychological variables (attitude, perceptions of social pressure and abilities) into our analysis using the Theory of Planned Behaviour (TPB) (Ajzen, 1991). Thirdly, a typology is generated in order to account for heterogeneity among the sample of farmers according to a number of policy relevant characteristics such as farm size, farm system, farmer age and education (Guillem *et al.,* 2012; Hammond *et al.,* 2017). Such typologies have been useful for increasing the relevance of recommendations for farm improvement and the provision of extension services (Chikowo *et al.,* 2014; Kamau *et al.,* 2018), as well as better targeting of policy initiatives (Emtage *et al.,* 2007; Walder and Kantelhardt, 2018).

In this article, we aim to explain farmers' intentions towards following a NMP using Irish farm survey data. Specifically we address whether there are differences in the drivers of intentions to follow a NMP between groups of farmers. Ultimately, we use this information to provide policy makers with insights into farmer behaviour that can be used to better target initiatives designed to further encourage farmers to follow a NMP.

The Republic of Ireland (henceforth, Ireland) provides a suitable context to study farmers' intentions towards following a NMP for a number of reasons. First, agricultural area accounts for around 70% of the total land area, thus covering a range of climatic conditions and soil types (CSO, 2016). Second, the structure of Irish agriculture is diverse in terms of farm and farmer characteristics, which provides an opportunity for classifying farmers (CSO, 2016). Third, Irish food policy (DAFF, 2010; DAFM, 2015) reflects the global focus on increasing food production whilst ensuring that such increases do not lead to a greater risk of nutrient discharge from agricultural sources to water and to air (Buckwell and Nadeu, 2016; FAO, 2017). Finally, similar to elsewhere (Osmond *et al.,* 2015; Ulrich-Schad *et al.,* 2017; Brown *et al.,* 2019), the number of farmers who follow a NMP remain limited and it is unclear as to the best method(s) for increasing the number of farmers who follow a NMP in the future (Buckley *et al.,* 2015).

5.2 Nutrient management plans

NMPs are management tools that divide farms into management units (usually fields or sub-field plots/paddocks). NMPs ensure that the optimal quantity of nutrients (both chemical fertiliser and organic manure) are made available to areas of farms that require them, using the right source, at the right rate and time (Roberts and Johnston, 2015; Sharpley, 2015). NMPs can be simple or complex; they can be written with a paper and pencil or developed using a computer (Beegle *et al.,* 2000). The fundamental principle underpinning NMPs is the allocation of nutrients in a way that maximises the economic benefit of the nutrients, while minimising the risk of environmental impact (Genskow, 2012). NMPs are developed by collecting farm specific information such as stocking rate, existing soil fertility levels, farmer objectives, availability of financial resources and expected crop/animal yields (Amon-Armah *et al.,* 2013). Agricultural advisors often play a key role in the development of NMP due to the technical nature of the information required (Lawley *et al.,* 2009).

Whilst farmers may choose to voluntarily develop a NMP, typically to aid production decisions, others may be required to develop one on a mandatory basis due to policy requirements (Beegle *et al.,* 2000; Ketterings *et al.,* 2017). As manifested in an Irish context, the Nitrates Directive (ND) mandates farmers to develop a NMP as a condition of a permit (derogation) to operate above and beyond the regulatory limits on livestock density (McDonald *et al.,* 2019). Furthermore, farmers are also required to develop a NMP if they participate in the main national agri-environment scheme (GLAS: Green Low Carbon Agri-environmental Scheme) (Image, 2016). However, whilst policy makers can enforce farmers to develop a NMP and penalise those farmers who have not developed a NMP, monitoring whether farmers follow the NMP is difficult and hard to regulate (Perez, 2015). Therefore, policy makers are keen to understand what motivates farmers not only to develop a NMP but also to follow it (Tao *et al.,* 2016; Ulrich-Schad *et al.,* 2017).

5.3 Theoretical framework

Socio-psychological models of behaviour take into account the variety of beliefs that individuals' hold and how these beliefs and cognitive processes influence decision making (Burton, 2004a). One widely applied model to understand how salient beliefs may promote or restrict adoption of certain practices within the agricultural domain is the Theory of Planned Behaviour (TPB) (Ajzen, 1991). According to the TPB, human behaviour is driven by the intention to accomplish the behaviour in question. For the purpose of this study we examine the intention of farmers' to follow a NMP in the near future.

Intention is in turn determined by an individual's attitude, subjective norm and perceived behavioural control. In line with the TPB, attitude can be defined as an individual's positive or negative evaluation of the outcomes of performing the behaviour. Subjective norm is the level of social pressure or approval an individual perceives to be exerted on them to engage in a particular behaviour. Finally, perceived behavioural control relates to whether an individual feels that s/he is capable of carrying out the behaviour, which is also connected to the presence of factors that may promote or hinder the performance of the behaviour. In general, the more favourable the attitude, the higher the level of social pressure and perception of control, the stronger the intention will be to perform the given behaviour (Ajzen, 1991).

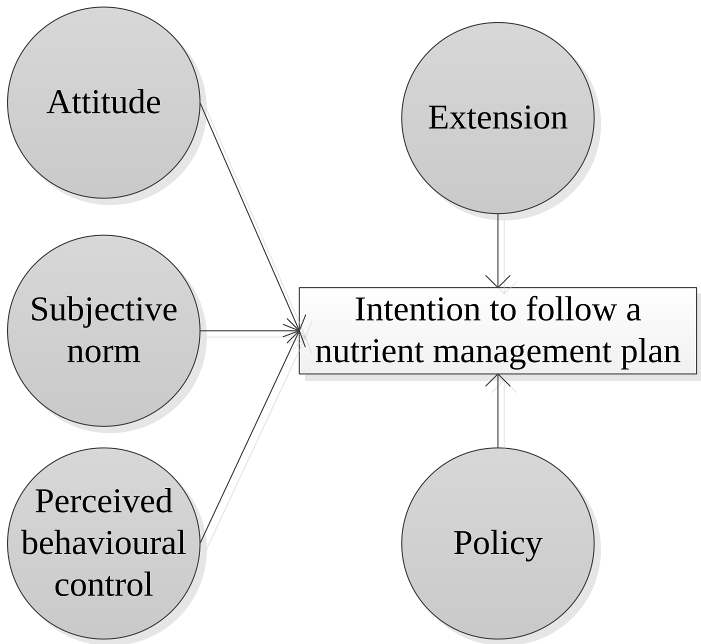
The TPB has been used to explain farmers' intentions to adopt agricultural practices in a variety of contexts. Previous studies, such as Wauters *et al.* (2010) and Rezaei *et al.* (2018), found attitude to be the most important variable determining farmers' intentions towards the use of soil conservation in Belgium and on-farm food safety practices in Iran. Whereas, Läpple and Kelley (2013) and Borges and Oude Lansink (2016) found subjective norm to be the most important variable to be positively associated with farmers' intentions to convert to organic farming in Ireland and to adopt improved grassland management in Brazil. Elsewhere, perceived behavioural control was found to be an important positive predictor of farmers' intentions to reuse agricultural biomass in China (Jiang *et al.,* 2018) and to adopt nutrient management planning in Ireland (Daxini *et al.,* 2018). The mixed results for TPB variables are expected, as the relative importance of the influences typically vary across behaviours and situations (Ajzen, 1991).

Despite these successful applications of the TPB, various researchers have argued for the inclusion of other context specific variables (Yazdanpanah and Forouzani, 2015; Martinovska Stojcheska *et al.,* 2016). Ajzen (1991) suggests that if additional predictors can help to increase the predictive utility of the TPB then they can be included. We use a number of background variables (e.g. farm size, system and education) to create our typology (see section four); however, we hypothesise that two context specific variables will directly influence farmers' intentions to follow a NMP. This approach is similar to other TPB research within the agricultural domain, which often only focus on the direct relationships (as opposed to indirect relationships) between additional background variables and intentions (e.g. Areal *et al.,* 2012; Micha *et al.,* 2015; Daxini *et al.,* 2018; Wang *et al.,* 2018). The additional variables include policy and agricultural extension which both play a pivotal role in terms of the adoption of NMPs in an EU context (Buckley *et al.,* 2015; Macgregor and Warren, 2015) but also elsewhere (Perez, 2015; Osmond *et al.,* 2015).

As manifested in an Irish context, the Nitrates Directive (ND) mandates farmers to adopt a NMP as a condition of a permit (derogation) to operate above and beyond the regulatory limits on livestock density (McDonald *et al.,* 2019). Furthermore, farmers are also required to adopt a NMP if they participate in the main national agri-environment scheme (GLAS: Green Low Carbon Agri-environmental Scheme). However, it is not uncommon for farmers adopting a NMP as part of mandatory policy requirements to fail to fully translate them into practice both in Ireland (Buckley *et al.,* 2015) but also more widely (Osmond *et al.,* 2015). Therefore, for the purpose of this study, we also capture the intentions of such ‘mandatory adopters’ (ND derogation holders and GLAS participants).

The role that extension services play in the promotion of agricultural management practices is well established (Kania *et al.,* 2014). Both individual and group based extension contact (also known as discussion groups - groups of farmers that meet frequently to discuss technical issues, share information and solve problems, facilitated by an agricultural advisor) have been shown to positively influence adoption of agricultural management practices (Baumgart-Getz *et al.,* 2012; Prager and Creaney, 2017). Therefore, it is important to capture the influence of extension services on farmers’ intentions to follow a NMP. Figure 5:1 presents the final theoretical framework used for the purpose of this study.

Figure 5:1: Theoretical framework based on the Theory of Planned Behaviour



5.4 Methodology

Survey design

In order to explain farmers' intentions towards following a NMP, data were collected using a cross-sectional survey. The survey comprised of three sections, with the first section containing questions on farm and farmer characteristics, which were used to generate a farmer typology. The second section collected information on farmer engagement with extension and policy, to be used as explanatory variables in the regression analysis. In the final section, participants were asked to evaluate a number of statements on a five-point Likert scale, which were designed to reveal their intentions and beliefs (based on the TPB) towards following a NMP.

The statements on farmers' beliefs were designed to measure the three variables of the TPB (attitude, subjective norm and perceived behavioural control). In order to measure respondents salient beliefs, recommendations by Ajzen (1985) were followed and scales containing multiple statements were developed. Following suggestions from Ajzen (2002) and Francis *et al.* (2004), the construction of these statements was based partly on information obtained from a series of interviews with farmers and agricultural advisors and partly on an in-depth literature review (e.g. Läpple and Kelley, 2013; Borges *et al.,* 2014; Yazdanpanah and Forouzani, 2015; Martinovska Stojcheska *et al.,* 2016). Survey respondents were asked to rank the statements on a five-point Likert scale from strongly disagree (1) to strongly agree (5). Five-point Likert scales have been used in previous TPB style agricultural research (e.g. Gorton *et al.,* 2008; Adnan *et al.,* 2017b; Morais *et al.,* 2018) and are deemed to be short enough to allow respondents to distinguish meaningfully between the response options (Hansson *et al.,* 2012). Examples of the statements used to measure attitude, subjective norm and perceived behavioural control are shown in Appendix B.

Intention was measured using one statement on a similar five-point Likert scale designed to reveal respondents beliefs. Respondents were asked to state their level of agreement with the statement "when it comes to following a NMP in the near future, I intend to do so". In order to ensure that respondents had a consistent understanding of what a NMP was, survey recorders read out a definition prior to the farmers answering questions pertaining to this measure. Furthermore, in order to eliminate any potential problems with the survey such as timing, complexity and suitability, a pilot survey was conducted prior to administering the survey to the full sample. Feedback from the pilot resulted in a number of minor changes to the survey, which included a reduction in length, improvements in the wording of questions and a restructuring of the order of some of the questions.

The survey data were then collected through face-to-face interviews with farmers between December 2016 and April 2017. A survey company was hired to conduct the interviews with farmers. In all cases, the main decision maker on the farm participated in the interview. A quota controlled sampling method was used to ensure that the sample was representative of Irish farms by the dominant farm systems (cattle, dairy, sheep and tillage) and sizes (hectares) (see Daxini *et al.,* 2018 for further detail). The quotas used were based on known population distribution figures in relation to specific farm types taken from the Irish Central Statistics Office (Hennessy & Moran, 2016). In order to acquire a representative sample of farmers, the survey company began by stratifying the sample by electoral divisions. At each sampling point, the interviewer followed a quota control scheme, based on the known quantity of farm types and population distribution statistics within each location (Howley *et al.,* 2015). Interviewers then visited residences that appeared to be a farm household (observing the surrounding landscape) and proceeded to interview farmers until they filled their quotas (Howley, 2013). The final sample consisted of 1009 farmers.

Principal Component Analysis (PCA)

The statements describing the TPB variables (attitude, subjective norm and perceived behavioural control) were condensed using principal component analysis (PCA) which was rotated using the varimax method to form a reduced number of interpretable variables (Howley *et al.,* 2015). PCA helps to determine the statements underlying the TPB variables with a similar structure, reduce complexity and prevent any issues associated with multicollinearity (Hair *et al.,* 2010; Chinedu *et al.,* 2018). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.94 which suggests suitability of the data for PCA (Kaiser, 1974). The Bartlett's test of sphericity is significant at the $p = 0.0000$ level which leads us to accept the alternative hypothesis that a significant relationship among the variables exists (Field, 2009). Predicated on the eigen values, we keep three components where component loadings are above 0.30. The choice about the quantity of relevant statements loaded on each component is led by theory and interpretation of the components (Hair *et al.,* 2010). The final components are also assessed for internal consistency and reliability using the Cronbach's Alpha (Nunnally, 1978). The results of the Cronbach's Alpha are all above 0.88 where a value of 0.60 is considered as acceptable (Jolliffe, 2002). The statements that successfully produced the TPB variables are shown in Appendix B. These derived variables can then be used as independent variables to explain farmers' intentions to follow a NMP.

Latent class analysis (LCA)

A common approach used to quantify unobserved heterogeneity that exists among a population is a latent class analysis (LCA) (Schreiber, 2017). LCA is a model-based approach to defining the underlying structure of the data, in order to predict the probability that each observation belongs to a particular class (Hair *et al.,* 2010). The central assumption of the latent class model is that different and distinct classes of farmers exist and that respondents in each class share homogenous characteristics, but characteristics of respondents differ between classes (Zhang *et al.,* 2016). The optimal number of discrete classes and the class to which a farmer belongs are determined by the data, such as the characteristics of the farm and farmer. LCA is based on robust estimation algorithms for choosing the correct number of classes among a population for a given criteria of characteristics and therefore, unlike cluster analysis, the choice of cluster criteria are less arbitrary (Morey *et al.,* 2008; Rhead *et al.,* 2018).

For latent classes to be generated, a number of 'classifying variables' must be chosen on which to assess heterogeneity (Dean and Raftery, 2010). Variables that have been highlighted as important attributes of heterogeneity include the characteristics of the farm and the farm operator (Knowler and Bradshaw, 2007; Valbuena *et al.,* 2008; Daloğlu *et al.,* 2014). Therefore, we need to control for the fact that the psychological decision making process may vary between groups of farmers based on such characteristics.

As alluded to in the introduction, a number of variables have been shown to influence the uptake of farm management practices, such as a NMP, across the literature. For example, farmers operating more intensive farm systems (such as dairy and tillage), those located on favourable soil conditions (free draining, fertile, mineral soils), operating larger (hectares) enterprises on a full-time basis and generating higher incomes, have typically been found to have a preference towards adopting farm management practices (Knowler and Bradshaw, 2007; Baumgart-Getz *et al.,* 2012). Furthermore, age has often been found to be negatively associated with the adoption of farm management practices, whereas education levels are usually positively associated with adoption (Prokopy *et al.,* 2008). Thus, based on the literature, the final set of classifying variables used in the LCA includes farm system (cattle, dairy, tillage or sheep), farm size (hectares), perception of soil drainage (well or poorly drained), total income from farming (euros), off-farm job (yes/no), formal education level and the age of the farm operator. It is important to note that different farm systems typically generate varying levels of income per hectare. For example, dairy farms in Ireland on average generate a higher income rate per hectare due to higher returns from the market (Dillon *et al.,* 2018b). The inclusion of the 'total income' variable, used as part of the classification process in the LCA, is important in accounting for this issue in our model.

To test for potential multicollinearity between the chosen classifying variables, Variance of Inflation (VIF) values were computed. The maximum VIF was 1.2, suggesting that multicollinearity is not an issue between the classifying variables (Hair *et al.,* 2010). In fact, some correlation amongst the classifying variables should be expected as no correlation would suggest there is no latent structure within the data, on which to classify farmers (Higgins *et al.,* 2016).

The final stage involved in the generation of latent classes is the identification of the optimal number of classes. An exploratory approach is used where additional classes are added and a number of statistical information criteria are evaluated to judge the best model fit (Barnes *et al.,* 2013b). The number of classes retained is based on examining the log-likelihood (LL), Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC), with smaller values indicating better fit (Nylund *et al.,* 2007). Entropy values (from 0 to 1 = perfect fit), which are a measure of correctly classifying individuals and goodness of class separation, are also examined (Ulbricht *et al.,* 2018).

Table 5.1 illustrates the results for the fit statistics of the latent classes, which are estimated from one to five classes. From a statistical point of view, the addition of the fourth and fifth classes results in only a marginal improvement of the LL. The AIC is minimised at a four class solution whereas the BIC is minimised at a three class solution. The BIC is recommended over the AIC when larger sample sizes are under consideration (Forster, 2000; Nylund *et al.,* 2007). The AIC has also been reported to often overestimate the number of classes (Nylund *et al.,* 2007). Entropy is the highest for the three class model. Based on these criteria, we deem the three class solution to be the best model fit.

Table 5.1: Fit statistics for the latent classes

Number of classes extracted	LL	AIC	BIC	Entropy
1	-8403.37	16862.74	17000.41	NA
2	-8006.93	16127.86	16408.11	0.73
3	-7822.10	15816.20	16239.04	0.77
4	-7763.11	15756.23	16321.65	0.74
5	-7739.41	15756.82	16440.25	0.73

Latent class binary logistic regression

In order to assess which variables influence farmers' intentions to follow a NMP for each class, during the generation of latent classes we set farmers' intentions to follow a NMP as the dependent variable. Ordered regression estimation methods are frequently applied to explain ordinal outcomes such as intentions. However, such models require the proportional odds assumption to be met (Hair *et al.,* 2010). If this assumption is violated then the scale used to measure intention in our case, may be collapsed to form a binary outcome variable and a binary logistic regression adopted. For the purpose of this study we group together the farmers who respond “strongly disagree”, “disagree” and “unsure” and label this group as “no intention” (0) with the remaining farmers being classified as “intenders” (1).

Here, the hypothesized TPB and additional variables (policy and extension) are utilised as independent variables to explain farmers’ intentions towards following a NMP.The effects of the explanatory variables on intentions are estimated at the same time as the latent classes are generated, i.e., with the membership of class probabilities. This approach does not change class membership probabilities and therefore is deemed as more statistically advantageous, as it allows for the removal of estimation bias from the two-step approach (Vermunt, 2010). A limitation of this study relates to the fact it does not test indirect relationships between the additional variables (extension contact and policy) and intentions mediated via attitude, subjective norm and perceived behavioural control. One reason why indirect relationships are not considered is due to an issue with sample size once farmers are assigned to distinct groups (see section four). Nevertheless, as mentioned previously, this study adopts a similar approach to previous research which focuses on the direct relationships between additional variables and intentions.

Apart from the TPB variables, a number of additional variables are also included in the latent regression analysis used to explain farmers’ intentions. These variables include a measure of agricultural extension contact and a policy variable. In relation to extension contact, we develop a variable where zero contact is labelled as 0, contact with an agricultural advisor is labelled as 1 and termed ‘extension contact 1’ and contact with an agricultural advisor and a discussion group is labelled as 2 and called ‘extension contact 2’. The combination of one-to one and group based extension is considered as the highest level of contact due to the combination of expert and peer influence. No contact (0) was set as the reference category for analysis. The policy variable, on the other hand, comprises of farmers who are obliged to adopt a NMP due to policy requirements (GLAS and/or the ND) (see section three). The variables used in the regression analysis are shown in Table 5.2. To test for potential multicollinearity between the independent variables, a separate binary logistic regression model is run with intention to follow a NMP set as the dependent variable and the TPB, extension and policy variables inserted as independent variables. VIF values are then assessed. The maximum VIF value is 2.01, which is below the cut-off point of 10 (Hair, 2010). This suggests that multicollinearity is not an issue in our analysis.

The results of the regression analysis are also shown as marginal effects. A larger marginal effect represents a greater influence of the independent variable on the dependent variable (Hair *et al.,* 2010). In terms of calculation, the marginal effects for the binary variables are measured as the discrete change from 0 to 1, holding all other variables constant, whereas for continuous variables, the marginal effects are interpreted as the instantaneous rate of change in the probability of the outcome, caused by a change in the independent variable (Hair *et al.,* 2010).

Table 5.2: Description of the explanatory variables

Variable	Description
TPB	
Attitude	PCA result
Subjective norm	PCA result
Perceived behavioural control	PCA result
Additional variables	
Extension contact	Level of extension contact by farm operator (0 = zero contact, 1 = contact with an agricultural advisor only, 2 = one-to-one contact with an agricultural advisor and a discussion group)
Policy	Farm operator participates in the Irish GLAS agri-environmental scheme and/or receives a permit (derogation) to farm above the restrictions imposed by the ND (1 = yes, 0 = otherwise)

5.5 Results

Farm and farmer socio-economic characteristics

The ensuing descriptive statistics represent the entire sample of farmers surveyed (n=1009). Based on the quotas (see section four), around 50% of the sample consists of cattle farms whereas dairy comprises 26%, with sheep at 17% and tillage consisting of 6% of the total population. In terms of farm size, the median is 31-50ha whereas for farmer age, the grouping 51-64 is found to be the median. These figures correspond with national averages (CSO, 2018). In terms of education, just over half of the sample has an education above secondary level. In relation to extension contact, 39% of farmers are in contact with just an agricultural advisor whereas only 29% are in one-to-one contact with an agricultural advisor and participate in a discussion group. In total, 47% of farmers report that they have a NMP. Approximately 42% of farmers in our sample are either part of GLAS and/or have been granted a derogation to farm above the limits imposed by the ND (see section 2). As discussed previously, adoption of a NMP is mandatory for these farmers. However, as alluded to earlier, it is important to include these farmers in the sample because research has demonstrated that farmers who have a NMP that was developed to comply with policy, do not necessarily follow the plan. This problem was key in selecting the "intention *to follow* a NMP" as a component of this research. As our sample and the national farming population contain a similar proportions of farmers who are mandatory adopters of NMPs (42% of sample versus 40% of population) (Image, 2016; DAFM, 2018), generalisations from our results can be made to the wider population.

Description of latent classes

The LCA analysis produced three classes of farmers. The first latent class is estimated to have a class membership probability of around 33%, this means that about 33% of the sample is estimated to be in this class. The estimated class membership probability for Class 2 is approximately 38% and around 29% for Class 3. Table 5.3 provides descriptive statistics for the classes in terms of the unobserved variables used to classify farmers. Chi-square statistics show that all variables are statistically different across the three classes. Statistical differences are also computed between classes in order to interpret classes based on what is typical for a particular class compared to other classes.

The following section provides an overview of the dominant characteristics of each latent class and makes a number of important comparisons between classes in order to illustrate these dominant characteristics. Therefore, the description of each latent class does not necessarily follow the same structure. We draw on suggestions made by Daloğlu *et al.* (2014) to interpret and label our classes.

Table 5.3: Percentage response probabilities by class (rows, by variable, sum to 100%[1])

		Full sample	Class 1	Class 2	Class 3	Chi-square
Classification variables		%	%	%	%	p-value
Drainage	Well drained	75	68[a]	69[a]	86	***
	Poorly drained	25	32[a]	31[a]	14	-
Farm system	Cattle	51	70[a]	68[a]	22	***
	Dairy	26	5[a]	5[a]	60	***
	Sheep	17	22[a]	24[a]	6	***
	Tillage	6	3[a]	3[a]	12	***
Total income from farming per annum (€)	4,000 to 9,999	15	27[a]	21[a]	0	***
	10,000 to 19,999	16	26[a]	21[a]	3	***
	20,000 to 29,999	13	16[a]	18[a]	7	***
	30,000 to 39,999	10	6	11[a]	12[a]	**

		Full sample	Class 1	Class 2	Class 3	Chi-square
Classification variables		%	%	%	%	p-value
	40,000 to 49,999	7	1	4	13	***
	50,000 to 59,999	4	0[a]	1[a]	10	***
	60,000 and over	7	0[a]	0[a]	17	***
	Refused	28	23[a]	23[a]	37	***
Farm size (ha)	Under 20	19	35	26	0	***
	20 to 30	22	29[a]	33[a]	8	***
	31 to 50	29	28	32	27	***
	51 to 100	22	7[a]	8[a]	45	***
	101 and over	8	1[a]	1[a]	19	***
Farmer age (years)	Under 35	7	0	12[a]	10[a]	***
	35 to 44	13	1	23	15	***
	45 to 50	15	1	22[a]	21[a]	***
	51 to 64	38	32	43[a]	39[a]	*
	65 and over	27	66	0	14	***
Off-farm job	Yes	30	21	65	11	***

		Full sample	Class 1	Class 2	Class 3	Chi-square
Classification variables		%	%	%	%	p-value
	No	70	79	25	89	-
Education	Above secondary level	54	7	88	70	***
	Secondary level or below	46	93	11	30	-

Notes: [1]Due to rounding the probabilities do not always sum to 100. [2]Calculated between Class 1, Class 2 and Class 3. Where two classes share a superscript this means there is no significant difference (as per chi-square test) between the classes in terms of the particular variable.

Class: Traditional farmers (33%)

Class 1 has features that are typically related to low likelihood of NMP uptake. This class is dominated by cattle (70%) and sheep (22%) farm systems, which tend to be farmed less intensively in Ireland (Dillon *et al.,* 2017). Around 68% of farmers in this class perceive their land to be well drained. A large proportion of farms (53%) earn under €19,999 a year and a substantial number of farms (64%) are under 30ha. A large proportion of farmers in this class are over 65 years of age (66%). Education levels among this class are low with only 7% having attained an education beyond secondary level. Finally, only a relatively small proportion (21%) of farmers in Class 1 have an off-farm job. In summary, Class 1 is defined by older, less educated farmers, managing small holdings consisting predominantly of cattle and sheep systems on a full time basis, generating low incomes. Based on these characteristics we call Class 1, ‘traditional farmers’.

Class 2: Supplementary farmers (29%)

The characteristics of Class 2 are akin to a medium likelihood of NMP uptake. Similar to Class 1, Class 2 also contains a large proportion of cattle (68%) and sheep farms (24%). In terms of perceptions of land drainage, 69% of farmers in this class perceive their land to be well drained. A significant numbers of farms earn a low income with 42% earning under €19,999 a year. In terms of farm size, 59% of farms in this class are below 30ha. In relation to farmer age, a significant proportion of farmers are under the age of 44 (35%) with significantly high levels of off-farm employment (65%) and formal education above secondary level (88%). Overall, this class is defined by cattle and sheep farms with low to middle level incomes and farm sizes. Such farms are operated on a part time basis, by relatively younger farmers, who are highly educated. This leads us to define Class 2 as ‘supplementary farmers’.

Class 3: Business-oriented farmers (38%)

Class 3 presents a structure that is usually associated with high levels of uptake of NMPs. A defining feature of Class 3 is its significantly higher proportion of dairy (60%) and tillage (12%) farm systems, compared to the other classes. Such farm systems tend to operate more intensively in Ireland compared to cattle and sheep enterprises (Dillon *et al.,* 2017). A large proportion of these farms are operating larger farms (i.e., 64% of farms are above 51ha) on well drained land (86%). Farmers in this class tend and generate high levels of income (e.g. 52% earn over €30,000). In terms of farmer age, the majority (60%) are middle aged (45 to 64) and few have an off farm job (11%). Education levels above secondary level are fairly high (70%). To summarise the key features of Class 3, this class is dominated by full time farmers, earning high incomes from operating dairy and tillage systems on relatively productive agricultural land. Predicated on the dominant characteristics of Class 3 we term this class ‘business-oriented farmers’.

Intentions to follow a NMP

In terms of the dependent variable, intentions to follow a NMP, Table 5.4 shows that 61% of traditional farmers stated a positive intention whereas 66% of supplementary farmers and 67% of business-oriented farmers indicated a positive intention. Business-oriented farmers have a significantly higher level of intention compared to traditional farmers (x^2= 4.63, p = 0.03). No other significant differences are detected. Interestingly, it appears that regardless of class, the level of intention to follow a NMP is relatively similar.

Table 5.4: Percentage response probabilities[a] by class (rows, by variable, sum to 100%)

		Full sample	Traditional farmers	Supplementary farmers	Business-orientated farmers	Chi-square[1]
Dependent variable		%	%	%	%	
Intention	Yes	65	61[a]	66[ab]	67[b]	*
	No	35	39	34	33	

Notes: Where two classes share a superscript this means there is no significant difference (as per chi-square test) between the classes in terms of the particular variable. [1]Calculated between traditional farmers, supplementary farmers and business-orientated farmers.*p<0.1.

Latent class binary logistic regression analysis: Traditional farmers

In relation to the variables which influence farmer's intentions, Table 5.5 shows that for traditional farmers' intentions are influenced significantly and in a positive direction by attitude (5% level), subjective norm (1% level), perceived behavioural control (1% level), extension contact 2 (5% level) and policy (5% level). All of the significant variables also have significant marginal effects (Table 5.6). As the level of the psychological variables (attitude, subjective norm and perceived behavioural control) increase by one unit, the probability of a farmer following a

NMP increases by 3.0%, 7.6% and 4.6% respectively. In terms of the additional variables, farmers with high levels of extension contact (i.e. extension contact 2) and those who participate in policy are around 20% and 10% respectively, more likely to have a positive intention towards following a NMP.

Latent class binary logistic regression analysis: Supplementary farmers

Table 5.5 also illustrates the results for supplementary farmers. Intentions are influenced significantly and in a positive direction by the psychological variables subjective norm (1% level) and perceived behavioural control (1% level), however attitude fails to reach statistical significance. Extension contact 2 and the policy variable are also positively associated with intentions at the 5% and 1% levels respectively. In terms of marginal effects (Table 5.6), the variables subjective norm and perceived behavioural control increase the probability of a farmer following a NMP by 8.2% and 4.6% respectively. Extension contact 2 and policy both significantly increase the probability of having a positive intention by 19%.

Latent class binary logistic regression analysis: Business-orientated farmers

For business-orientated farmers, intentions are positively and significantly correlated with three variables. These include subjective norm (1% level), perceived behavioural control (1% level) and policy (1% level). All of the significant variables also have significant marginal effects. However, in addition, attitude also becomes significant at the 10% level. The estimated marginal effects (Table 5.6) show that attitude, subjective norm and perceived behavioural control increase the likelihood of a farmer following a NMP by 2.4%, 7.3% and 9.5% respectively. Being subject to mandatory policy requirements increases the probability of a farmer displaying a positive intention by 9.4%.

Table 5.5: Results of the latent class logistic regression (coefficients)

	Traditional farmers		Supplementary farmers		Business-orientated farmers	
Explanatory variables	Coeff.	Std.err	Coeff.	Std.err	Coeff.	Std.err
TPB						
Attitude	0.23**	0.09	-0.02	0.11	0.27	0.19
Subjective norm	0.59***	0.12	0.66***	0.16	0.82***	0.18
Perceived behavioural control	0.36***	0.12	0.37***	0.14	1.06***	0.36
Additional variables						
Extension contact 1[a]	0.16	0.35	0.54	0.47	-0.31	0.45
Extension contact 2[a]	1.55**	0.62	1.46**	0.60	0.08	0.54
Policy	0.81**	0.37	1.54***	0.46	1.10***	0.40
Cons	-0.64	0.26	-0.77	0.34	1.16	0.45

Notes: *** p<0.01, ** p<0.05, * p<0.1. [a]Reference category: no extension contact.

Table 5.6: Results of the latent class logistic regression (marginal effects)

	Traditional farmers		Supplementary farmers		Business-orientated farmers	
Explanatory variables	Marginal effect	Std.err	Marginal effect	Std.err	Marginal effect	Std.err
TPB						
Attitude	0.0297***	0.0113	-0.0247	0.0137	0.024*	0.0141
Subjective norm	0.0762***	0.0144	0.0816***	0.0170	0.0730***	0.0125
Perceived behavioural control	0.0461***	0.0149	0.0458***	0.0157	0.0947***	0.0183
Additional variables						
Extension contact 1[a]	0.0233	0.0531	0.0776	0.0672	-0.0276	0.0400
Extension contact 2[a]	0.2042***	0.0760	0.1898**	0.0763	0.0068	0.0463
Policy	0.1043**	0.0452	0.1923**	0.0588	0.0939**	0.0383

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. [a]Reference category: no extension contact.

5.6 Discussion

Efforts to encourage farmers to follow a NMP have been less than successful globally (Osmond *et al.,* 2015; Brown *et al.,* 2019) and in Ireland (Buckley *et al.,* 2015). This study addresses the limitations of previous studies by utilising a unique approach based on combining the TPB with a LCA in order to explain farmers' intentions towards following a NMP. The typology reveals that there are three discrete classes of farms/farmers and thus confirms that farm and farmer characteristics are a useful way to categorise the farming population and account for heterogeneity (Emtage *et al.,* 2007; Daloğlu *et al.,* 2014). Whilst the results reveal that intentions are somewhat similar across classes of farmers, the reasons why farmers intend to follow a NMP vary by class. This suggests that dissimilar groups of farmers are likely to respond in different ways to the same intervention designed to further encourage them to follow a NMP. These diverse reactions must be taken into account when designing policy interventions aimed at further encouraging farmers to follow a NMP (Emtage *et al.,* 2007; Guillem *et al.,* 2012).

According to previous studies (Ribaudo and Johansson, 2007; Prokopy *et al.,* 2008; Ulrich-Schad *et al.,* 2017), business-orientated farmers display characteristics that should be associated with a higher propensity towards following a NMP than traditional and supplementary income classes. One reason for the relatively similar level of intention across the classes may pertain to the 'optimism bias', which suggests that people often overestimate their goals (Weinstein, 1980; Sharot, 2011). Alternatively, the survey data collected were 'self-reported' which often results in individuals responding to questions in a 'socially desirable' way that paints them in a positive light (Floress *et al.,* 2018). However, it is important to note that behavioural intention is an antecedent of behaviour but not a flawless predictor of it (Fishbein and Ajzen, 2010). Thus, farmers may indeed have a positive intention, but due to barriers associated with, for instance, personal ability to follow a NMP, they are unable to act on their positive intentions.

In line with previous studies (Reimer *et al.,* 2012a; Borges *et al.,* 2014; Adnan *et al.,* 2018), traditional and business-orientated farmers who have a positive attitude towards following a NMP are more likely to do so than their counterparts. For the majority of these classes of farmers, farming is their main occupation and therefore they are highly reliant on income generated from farm production. Thus, such farmers are generally attentive to financial concerns, yield and profitability (Daloğlu *et al.,* 2014). Our measure of attitude focuses mainly on the production benefits of following a NMP, which may explain why attitude is an important determinant of the intentions of these classes of farmers. Pannell *et al.* (2006) put forward the argument that farmers will adopt a management practice if s/he perceives that the innovation in question will enable them to achieve their personal goals. In line with others, our result implies that it is important to consider how the underlying motivation for farming varies between groups and how this potentially influences intentions towards following a NMP (Buckley *et al.,* 2015).

Interestingly, the influence of attitude towards following a NMP on intentions is relatively weak compared to previous findings (Burton, 2004; Garforth *et al.,* 2006; Reimer *et al.,* 2012a; Rezaei *et al.,* 2018). Wauters *et al.* (2010) found that attitude was the most important determinant of farmers' intentions in relation to soil conservation practices in Belgium. However, they also concluded that farmers in their study perceived it to be easy to adopt the practices in question. One possible reason for the relatively low influence of attitude, compared to Wauters *et al.* (2010), may be due to the fact that following a NMP is relatively difficult compared to other farm management practices (Walters and Shrubsole, 2014). Developing and following a NMP requires the collection of site specific data (e.g. soil fertility levels and stocking rate) to be translated into nutrient application rates and potential changes to management routines (Beegle *et al.,* 2000; Walters and Shrubsole, 2014). This requires learnt skills and knowledge which farmers may not possess (Osmond *et al.,* 2015). Without such expertise or access to affordable advice, following a NMP becomes more difficult and thus the role of perceived behavioural control becomes more important relative to other variables, such as attitude towards following a NMP (Ajzen, 2002b).

Perceived behavioural control is an important predictor of farmers' intentions regardless of class. This means that farmers who perceive that they are able to and have the necessary knowledge to follow a NMP, are more likely to have an intention to do so (Ajzen, 2002b). This finding supports the results of both Zhang *et al.* (2016) and Wilson *et al.* (2018) who found perceptions of ability to be positively associated with farmers' intentions to adopt various nutrient management practices (e.g. fertiliser application timing and placement) in the US. These practices, like following a NMP, also require technical expertise to conduct and therefore issues of perceived behavioural control are important (Wilson *et al.,* 2018). However, the marginal effect for perceived behavioural control is the largest for business-orientated farmers. This class is focused on high-value products (e.g. milk and arable crops), short-term returns from production and are less constrained by financial resources (Daloğlu *et al.,* 2014). Therefore, a lack of capability or confidence in following a NMP on their farm is likely to take a more prominent role as farmers become more concerned with the 'how' instead of the 'why' (Prochaska and Velicer, 1997).

The significant influence of subjective norm on intentions across the classes concurs with the studies of Läpple and Kelley (2013) and Borges and Oude Lansink (2016). Both studies found subjective norm to be a highly important determinant of farmers' intentions to adopt farm management practices in Ireland and Brazil respectively. This result may be because farmers are increasingly subject to external social pressures from food chain actors and policy makers to adopt management practices that offer both environmental and financial benefits (Yoshida *et al.,* 2018). Furthermore, farmers are typically reliant on external support from consultants and agricultural advisors for making decisions associated with nutrient applications to fields/crops (Lawley *et al.,* 2009; Stuart *et al.,* 2018). Such actors may increase social pressure on farmers to follow a NMP and, due to this pressure, farmers may want to behave in a way that would be approved of by important referents (Martínez-García *et al.,* 2013).

The characteristics of the traditional (e.g. low income, small farm sizes, low levels of formal education) and supplementary income (e.g. low income, small farm sizes, high levels of off-farm employment) classes are typically associated with a low level of likelihood of following a NMP (Baumgart-Getz *et al.,* 2012; Savage and Ribaudo, 2013; Läpple *et al.,* 2015). However, the results indicate that traditional and supplementary income farmers who are in one-to-one contact with an agricultural advisor and participate in a discussion group are more likely to have an intention to follow a NMP than their counterparts. This may be because extension can enable farmers to understand the applicability of following a NMP on their particular farm system, dispel myths about the perceived costs of following a NMP and alleviate pressures associated with time constraints by assisting in the development of a NMP (Burton, 2014; Wilson *et al.,* 2018).

Policy is an important driver of intention to follow a NMP across all three classes. A number of authors have suggested that nutrient management policy initiatives can have a positive influence on the adoption of farm management practices because farmers will often undertake voluntary action as a means of demonstrating stewardship and protecting themselves from future policy (Savage and Ribaudo, 2013; Reimer *et al.,* 2018). However, the results in Table 7 show that the magnitude of the effect is the greatest for supplementary income farmers. Policy makers could capitalise on the fact that the majority of farmers in this class are highly educated and relatively younger than farmers in the other classes and design appropriate measures to improve the likelihood that farmers follow their NMP.

Overall, the mixed influence of policy on intentions confirms previous findings across the literature which suggest that different groups of farmers often respond in different ways to the same policy (Barnes *et al.,* 2011; Buckley, 2012). Further research is required to explore potential reasons for the mixed effects in the context of following a NMP.

Increasing social pressure on farmers to follow a NMP is likely to increase the likelihood that they do so across the classes. Barnes *et al.* (2013a) suggest increasing the use of catchment management approaches which raise the visibility of individual farmer practices and encourage group sharing of information. This can stimulate an increase in social pressure to adopt given practices. However, whilst there has been a growing emphasis on farmer-to-farmer learning in recent years (Prager and Creaney, 2017; Laforge and McLachlan, 2018), not all farmers will know, trust or even talk with one another and therefore careful targeting of behavioural change strategies is required (Blackstock *et al.,* 2010). Social pressure is often best leveraged by people that farmers trust and these may not be the same for traditional, supplementary income and business-orientated farmers (Blackstock *et al.,* 2010). Further research is required to establish the most effective ways of leveraging social pressure among different groups of farmers in a way that further encourages them to follow a NMP.

Ensuring that individuals understand the benefits of a given practice is an important aspect for inducing positive behavioural change (Wilson *et al.,* 2014). Based on the results, convincing farmers classified as traditional and business-orientated of the specific benefits of following a NMP on their particular farm, is likely to increase their intentions towards following a NMP. This effect is linked to an improvement in attitude towards this practice. Demonstration events are a popular and effective method for illustrating the benefits of adopting farm management practices (Prager and Creaney, 2017). However, in line with Wilson *et al.* (2018), we argue that greater opportunities should be presented at such events for farmers to engage in discussion about the costs and benefits of, in this case, following a NMP, and ways to better tailor NMPs to particular farming situations.

Motivational theories suggest that an individual is likely to act to solve a problem when they feel they have the ability to act on their values and motivations (Zhang *et al.,* 2016). The results suggest that improving farmers' level of perceived behavioural control over following a NMP is likely to have a positive influence on the likelihood of them following the plan in the future. In line with McDonald *et al.* (2019), we argue that increasing the level of engagement between agricultural advisors and farmers in terms of both developing and assisting farmers to follow a NMP may help to increase perceived levels of control across each class of farmers. However, targeting business-orientated farmers with an intervention to improve perceived behavioural control is likely to have a greater influence on their intentions to follow a NMP. This provides policy makers with a potentially cost-effective strategy for increasing the probability of farmers following a NMP among this class of farmers.

The results also imply that an increase in effort to engage traditional and supplementary income classes of farmers with both one-to-one and group based agricultural extension should be made. This is because increased levels of engagement is likely to have a large impact on the likelihood of these classes of farmers following a NMP in the future (Micha *et al.,* 2018). Supplementary income farmers are also found to be highly receptive to mandatory policy. Therefore, efforts should be made to provide additional information alongside policy requirements to further stimulate farmers to follow their NMP. This information should be tailored to the characteristics of this group of farmers and explains, for instance, how to effectively follow a NMP on their type of farm (Osmond *et al.,* 2015).

Finally, a limitation of this study lies in the fact it does not test indirect relationships. Variables such as extension contact and policy, may have an indirect influence on intentions mediated via attitude, subjective norm and perceived behavioural control. One reason why indirect relationships are not considered is due to an issue with sample

5.7 Conclusion

NMPs offer a pathway for addressing dual policy interests which aim to encourage farmers to improve or increase production whilst also reducing the risk of nutrient loss to water and air. This paper extends the literature on the development of NMPs by specifically examining farmers' intentions towards following (rather than just developing) a NMP. Moreover, this study also accounts for heterogeneity among farmers and incorporating socio-psychological variables into the analysis. A key result emerging from this study relates to the diversity in the variables which influence the intentions of farmers across the classes. This diversity is likely to be due to the varying composition of the classes in terms of farm and farmer characteristics. This result suggests that we cannot assume that farmers with different characteristics who operate varying types of farms will always respond in the same way to initiatives designed to stimulate them to follow a NMP. Therefore, for policies to effectively encourage farmers to follow a NMP, it is important to target specific groups (Emtage *et al.,* 2007). Overall, the results from this study confirm that farmer typologies are critical for representing diversity in the variables which influence farmers' intentions to follow a NMP. Interventions that are carefully planned and targeted at the different classes of farms/farmers are likely to further encourage farmers to follow a NMP in the future.

Chapter 6: Understanding farmers' intentions to follow a nutrient management plan using the theory of planned behaviour

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Abstract

Farmer decision making in relation to chemical fertiliser and manure use is of great concern to policy makers. Inefficient use can lead to both environmental pollution and financial losses to farmers. Following a nutrient management plan (NMP) can help to mitigate these impacts and improve farm incomes. As the use of NMPs remains below expectation globally, this study aims to provide insights into the drivers of farmers' intentions to follow a NMP and to understand how behavioural change can be encouraged. An extended version of the theory of planned behaviour is adopted and structural equation modelling is used to analyse survey data collected from a sample of Irish farmers. Results show that intention to follow a NMP is primarily driven by perceived behavioural control (ease/difficulty) over following a NMP, followed by subjective norm (social pressure) and finally attitude (negative/positive evaluation) towards following a NMP. We also find that subjective norm is an important predictor of both attitude and perceived behavioural control. Furthermore, policies that require certain farmers to develop a NMP on a mandatory basis, plays a significant role in influencing famers' attitude, subjective norm and perceived behavioural control. Finally, trust in technical sources of information (e.g. advisor and discussion group) is found to be a more influential determinant of farmers' attitude, subjective norm and perceived behavioural control than trust in social information sources (e.g. family and the media). These results provide a comprehensive understanding of the variables driving farmers' intentions to follow a NMP and highlight the importance of both socio-psychological and institutional variables in the analysis of farmer decision making.

Key words: Theory of Planned Behaviour, Structural Equation Modelling, Nutrient Management Planning, Farmer Decision Making,

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Although the following paper has joint authorship, the work contained in them is solely my own. Co-authorship represents support in terms of comments, suggestions, advice and discussion of aspects of the research.

6.1 Introduction

Farmer decision making surrounding the use of agricultural nutrient inputs, such as chemical fertiliser and manure, is a critical issue and of significant importance to policy makers (Sutton *et al.,* 2013; McGlynn *et al.,* 2018). Nutrient applications to agricultural fields has contributed to substantial improvements in crop yields which has led to a significant increase in the ability of the earth to sustain more humans (Smil, 2002). However, inefficient or over-use of nutrient inputs has led to significant negative environmental and social impacts (Tilman, 1999; Jones *et al.,* 2014; Wagena and Easton, 2018). On the other hand, under-application of nutrients can contribute to declining levels of soil fertility and below expected crop yields (Bai *et al.,* 2013) and ultimately, an under-utilisation of productive agricultural land. Both over and under-application of nutrients to crops can also lead to financial losses to farmers (Buckley and Carney, 2013). Therefore, from both a policy and societal perceptive, it is of paramount importance that farmers manage nutrient inputs properly and efficiently in order to minimise the risk of nutrient loss to the environment whilst also ensuring that natural resource use is optimised and appropriate soil fertility levels are maintained (Jakrawatana *et al.,* 2017; Macintosh *et al.,* 2019).

To mitigate the negative impacts associated with inefficient nutrient use and improve farm incomes, farmers are encouraged to adopt various recommended management strategies (Price *et al.,* 2011; Micha *et al.,* 2018). One important and widely promoted management practice is nutrient management planning (Osmond *et al.,* 2015; Ulrich-Schad *et al.,* 2017). Nutrient management planning is a process which involves using farm-specific data to formulate a written plan (document) also known as a nutrient management plan (NMP), typically with an agricultural advisor (Beegle *et al.,* 2000). The purpose of an NMP is to ensure that nutrients are applied in the right quantities, at the right time, in the right place and using the right source (Genskow, 2012; Roberts and Johnston, 2015). Use of NMPs has been associated with environmental and financial benefits due to improvements in the way in which fertiliser and manure is managed on farms (Thomas *et al.,* 2007; Amon-Armah *et al.,* 2013). However, despite proven benefits and considerable promotion, adoption and use of NMPs remains below expectations globally (Lawley *et al.,* 2009; Buckley *et al.,* 2015; Osmond *et al.,* 2015; Ulrich-Schad *et al.,* 2017). Thus, the focus of this research is on uptake and use of NMPs.

Several socioeconomic variables, such as farm system, farm size and farmer age, have been suggested to examine the low levels of uptake of management practices, such as NMPs (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). However, there remains a lack of clear evidence as to why farmers choose to follow a NMP (Ulrich-Schad *et al.,* 2017). Moreover, there is a general discontent across the literature with the ability of previous studies to provide a comprehensive understanding of farmer decision making (Edwards-Jones, 2006; Feola *et al.,* 2015; Zeweld *et al.,* 2017). This is possibly due to the poor level of inclusion of socio-psychological factors such as attitudes and beliefs, in the analysis of farmer decision making (Hansson *et al.,* 2012; Borges and Oude Lansink, 2016). Once such aspects are taken into account, the influence of socio-economic variables on adoption tends to lose explanatory power (Poppenborg and Koellner, 2013). For this reason, there has been a growing shift towards incorporating theoretical frameworks from social psychology to improve the understanding of farmer decision making (Wauters *et al.,* 2010; Borges *et al.,* 2014; Adnan *et al.,* 2017). One such theoretical model that has received interest in the literature is the Theory of Planned Behaviour (TPB) (Ajzen, 1991).

The TPB suggests that an individual’s decision to engage in a particular behaviour is primarily driven by their intentions, which are in turn affected by three independent constructs: attitude, subjective norm (social pressure) and perceived behavioural control (ease/difficulty) (Ajzen, 1991). There is wide support for the TPB across the literature (Armitage and Conner, 2001; Fielding *et al.,* 2005; Hansson *et al.,* 2012; Lapple and Kelley, 2013; Hyland *et al.,* 2018; Adnan *et al.,* 2018; Rezaei *et al.,* 2018; Wang *et al.,* 2019). Despite this, there are a number of limitations of past applications of the TPB in an agricultural context. Firstly, whilst a number of authors, such as Sok *et al.* (2016) and Morais *et al.* (2018), have examined inter-relationships between the TPB constructs, these studies focus on examining correlations instead of causal pathways. That is, Sok *et al.* (2016) and Morais *et al.* (2018) did not investigate the specific direction of influence between the TPB constructs and the likely reasons for these relationships. Secondly, previous studies within an agricultural context often fail to explore how institutional variables may influence farmers' attitudes, subjective norms and perceived behavioural control (Bijttebier *et al.,* 2018). Institutional variables, such as communication, extension, education and policy are potential levers that can stimulate behavioural change (Barnes *et al.,* 2013).

This study extends the literature by providing an understanding of the causal relationships between, and institutional influences on, the TPB constructs in relation to farmers' intentions to follow a NMP. This method enables the provision of a more comprehensive insight into farmer decision making which can be used to inform policy that is designed to encourage further use of NMPs at a global scale.

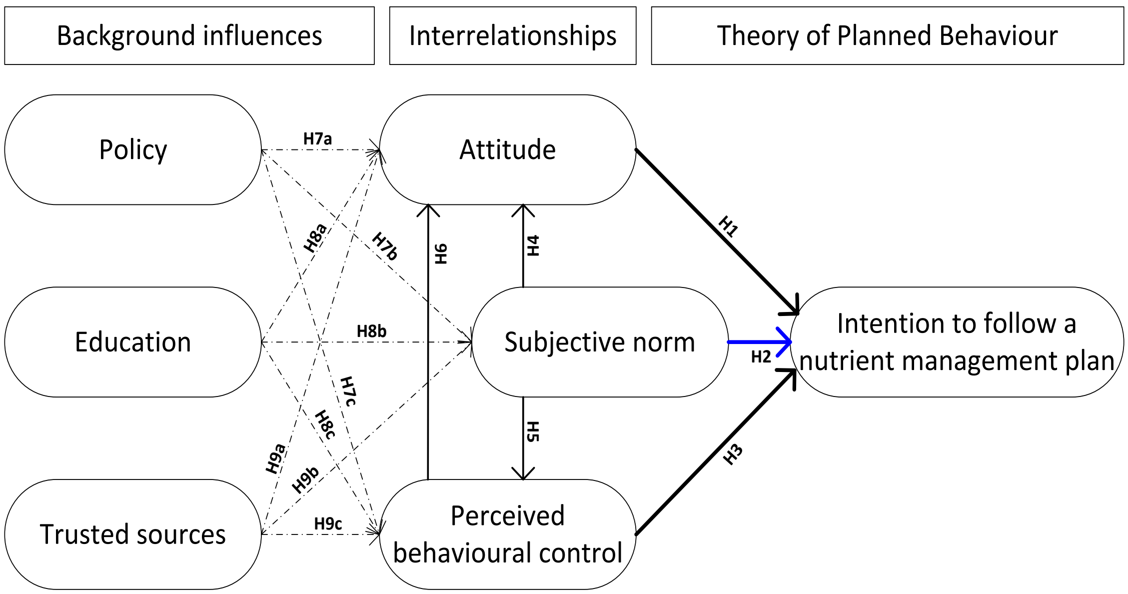
The objectives of this study are as follows: 1) to identify the effect of attitude, subjective norm and perceived behavioural control on farmers' intentions towards following a NMP 2) to explore relevant inter-relationships between the TPB components and 3) to investigate the cognitive foundations of the TPB constructs, i.e., the background influences on farmers' attitudes, subjective norm and perceived behavioural control. These objectives are fulfilled by analysing Irish survey data collected as part of a wider research project (see Daxini *et al.,* 2018 for further detail).

6.2 Theoretical framework and hypotheses

Theory of planned behaviour

In order to address the three main research objectives of this paper, we develop a theoretical framework (see Fig. 1) based on the TPB (Ajzen, 1985; Ajzen, 1991).

Figure 6:1: Conceptual framework based on the TPB



The TPB, which is an extension of the Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 1975), attempts to explain and understand why an individual may undertake a certain behaviour (McEachan *et al.,* 2016). According to the TPB, intention is the most important predictor of behaviour, which relates to an individual's motivation or willingness to invest effort in performing the behaviour (Ajzen, 2002; Bamberg *et al.,* 2007). The greater the intention, the more likely an individual is to enact the behaviour. Intention, in turn, is determined by three socio-psychological constructs: attitude, subjective norm and perceived behavioural control (Ajzen, 1991).

In line with the TPB (Ajzen, 1991), attitude is defined as a positive or negative evaluation of performing a given behaviour. Thus, the intention of farmers to follow a NMP will increase if they perceive that using this practice is useful and beneficial and will lead to positive results for them. Subjective norm encapsulates the level of social pressure or expectations felt by an individual from significant reference persons to engage or not to engage in a particular behaviour. It is argued that people tend to conform to subjective norms due to a fear of social exclusion (Bamberg and Moser, 2007). Thus, if farmers feel that people whose opinion they value confirm a given behaviour then their own intention to perform the behaviour should increase (Rezaei *et al.,* 2018). Finally, perceived behavioural control is an individual's perception of the ease or difficulty related to their performing a given behaviour, which is also related to the presence of facilitating conditions, sometimes referred to as situational constraints (Ajzen, 2002; Bamberg and Moser, 2007). This construct reflects the extent to which an individual perceives that the behaviour in question is under his/her volitional control (Ajzen, 1991). Therefore, farmers' intentions to follow a NMP should increase as the degree of their perceived control over performing this behaviour becomes greater (Adnan *et al.,* 2017). As a general rule of thumb, the more positive the attitude, subjective norm and perceived behavioural control, the greater the likelihood of adopting the behaviour in question (Ajzen, 1991).

Previous research has shown that attitude, subjective norm and perceived behavioural control are positively associated with farmers' intentions to adopt riparian zone management in Australia (Fielding *et al.,* 2005), improved grassland management in Brazil (Borges *et al.,* 2014) and on farm food safety management in Iran (Rezaei *et al.,* 2018). However, Wauters *et al.* (2010) only found attitude to be an important factor determining farmers' intentions to adopt soil management practices in Belgium. Elsewhere, Hyland *et al.* (2018) confirmed the importance of attitude and perceived behavioural control, but did not find subjective norm to be a significant determinant of farmers' intentions to adopt grazing management practices in Ireland. Typically, the influence of the TPB constructs on intentions varies depending on the behaviour and context under study (Ajzen, 1991). Finally, although not applying the TPB, various studies have also confirmed the importance of farmers' attitudes (Flett *et al.,* 2004; Reimer *et al.,* 2012), social pressures (Welch and Marc-Aurele, 2001; Ribaudo and Johansson, 2007; Yoshida *et al.,* 2018) and perceptions of control or efficacy (Zhang *et al.,* 2016; Wilson *et al.,* 2018) in the decision to adopt various nutrient management practices. Founded on the assumptions of the TPB and based on the literature above, we develop the following hypotheses:

H1. Attitude has a positive influence on farmers' intentions towards following a NMP.

H2. Subjective norm has a positive influence on farmers' intentions towards following a NMP.

H3. Perceived behavioural control has a positive influence on farmers' intentions towards following a NMP.

Inter-relationships between the TPB constructs

Whilst the TPB framework has three independent socio-psychological constructs that influence intentions, results from previous studies also indicate that the TPB constructs are correlated (Trafimow and Finlay, 2001; Bamberg and Moser, 2007; Quintal *et al.,* 2010; Borges and Oude Lansink, 2016; Morais *et al.,* 2018). Here, we focus on examining two key causal relationships between the TPB constructs which pertain to the influence of subjective norm on attitude and perceived behavioural control. We specifically focus on these two relationships and directions of influence, rather than between other constructs or directions, due to wide theoretical and empirical support for these specific causal pathways (Oliver *et al.,* 1985; Taylor and Todd, 1995; Bamberg *et al.,* 2007; Bamberg and Moser, 2007; Quintal *et al.,* 2010; Peters *et al.,* 2011; Lopez-Mosquera *et al.,* 2014; Park and Ha, 2014; Rezaei *et al.,* 2019; Ru *et al.,* 2019).

Kallgren *et al.* (2000) suggest that the influence of subjective norms on behaviour possibly relies less on individuals' fear of social sanctions but on their use of subjective norms as an easy source of information on how others validate particular behavioural options. Therefore, the influence of subjective norm on attitude is in line with the notion that individuals may use subjective norms for evaluating how advantageous the adoption of a given behaviour would be (Bamberg and Moser, 2007). Thus, people tend to take into consideration the view of important referent groups when forming their own attitudes towards a given behaviour (Burton, 2004; Quintal *et al.,* 2010; Lopez-Mosquera *et al.,* 2014). While the opposing relationship is that attitude can influence subjective norm, it has been demonstrated that it is more probable that attributes of the external social environment will influence attributes of the individual (Ryan, 1982; Quintal *et al.,* 2010). Schaak and Mushoff (2018) found that subjective norm positively influenced farmers' perceptions of the benefits of management practices in Germany. Therefore, the fourth hypothesis is as follows:

H4. Subjective norm has a positive influence on attitudes towards following a NMP.

In a similar fashion, it is also likely that subjective norms will influence individuals' perceptions of how easy or difficult it is to perform a given behaviour (Quintal *et al.,* 2010). Bamberg and Moser (2007) suggest that subjective norms also provide individuals with guidance or information as to whether the behaviour is likely to be easy to perform. Thus, subjective norms have an influence on individuals' perceptions of control over performing the behaviour (Bamberg *et al.,* 2007). For instance, positive encouragement or approval from significant others can lead to a sense of confidence (control) over performing a particular behaviour (Nair and Little, 2016; Ru *et al.,* 2019). Numerous studies have also shown that subjective norm influences individuals' perceptions of confidence and potential external impediments to acting, thus confirming that subjective norm influences perceived behavioural control over performing a given behaviour (Quintal *et al.,* 2010; Peters *et al.,* 2011; Sanchez *et al.,* 2018). Overall, this suggests that external social pressure originating from what others believe, can influence individuals' perceptions of the ease or difficulty in acting and facilitate the way in which individuals act (Lopez-Mosquera *et al.,* 2014) and, therefore we assume the following hypothesis:

H5. Subjective norm has a positive influence on perceived behavioural control over following a NMP.

Influence of institutional variables on the TPB constructs

In order to promote behavioural change, the mere knowledge of the influence of the TPB constructs on intentions is not always sufficient (Ajzen, 2011; Bijttebier *et al.,* 2018). Rather, an understanding of the key variables which are likely to influence farmers'attitudes, subjective norms and perceived behavioural control must also be developed. Such variables can include policy, education and trusted information sources (Bosch *et al.,* 1995; Blackstock *et al.,* 2010; Aarts and Lokhorst, 2012; Lam *et al.,* 2017). We treat these variables as 'institutional variables'which leads to the development of H6, H7 and H8 which are presented below.

Policy

Certain nutrient management policies, such as the Nitrates Directive (ND) in the European Union (EU), require certain farmers to develop a NMP on a mandatory basis (European Commission, 1991). Whilst research has shown that policy can increase the number of NMPs that are developed (Savage and Ribaudo, 2013; Perez, 2015), this does not always translate into use of such plans (Osmond *et al.,* 2015). It thus remains inconclusive as to whether policy, which requires the mandatory development of NMPs, is an effective tool for encouraging farmers to follow such plans. Therefore, it is interesting to explore the potential effect of policy on attitude, subjective norm and perceived behavioural control in order to inform more effective policy design.

Buckley (2012) found that a number of farmers displayed a positive attitude towards the ND policy in Ireland. These farmers believed that the policy had led to positive farm management benefits and agreed that the policy had made them more aware of the nutrient requirements of their crops and stimulated them to improve the way in which they plan the use of fertilisers on their farm. Elsewhere, Macgregor and Warren (2015) found that over time, farmers' attitudes towards the ND regulation improved in Scotland. Policy makers can make the development of a NMP mandatory by using policy compliance as a tool and imposing financial penalties on those farmers who do not develop a plan if they are required to do so. However, monitoring the use of NMPs is difficult and hard to regulate (Perez, 2015). Nevertheless, farmers who are obliged to develop a NMP on a mandatory basis may feel a higher degree of social pressure to follow the plan. This pressure may arise from the desire of the farmer, who is subject to policy compliance requirements, to go above and beyond the requirements in order to receive the approval and respect of significant others with whom they interact (Grasmick and Bursik, 1990). Examples of likely sources of such social pressure include other farmers subject to mandatory policy requirements, agricultural advisors, the media and family. Moreover, over time, such desires may have a socialising effect on the farmers who develop a NMP on a mandatory basis which may lead to a shift in norms and further normative commitment towards following a NMP (Winter and May, 2001). Finally, farmers subject to mandatory policy requirements are also often provided with additional education and training regarding the use of NMPs, which tends to have a positive influence on the use of NMPs due to improved confidence and technical ability in relation to use (Osmond *et al.,* 2015). Thus, we assume the following hypotheses:

H6a. Policy has a positive influence on attitude.

H6b. Policy has a positive influence on subjective norm.

H6c. Policy has a positive influence on perceived behavioural control.

Formal education

Formal education has the ability to foster positive attitudes towards the use of nutrient management practices, as it helps to increase understanding of complex issues (Bosch *et al.,* 1995). Education can also foster positive attitudes by helping to dispel myths about the outcomes of performing a given behaviour. For Bourdieu (1986), education is a form of cultural capital, while Burton and Paragahawewa (2011) observe a connection between education and the level of cultural capital possessed by an individual. Cultural capital contributes to status generation, often through improved management skills (Burton, 2014). Education can thus lead individuals to be drawn into behaving in ways that are socially acceptable. Finally, education is also known to increase efficacy of farm management through improvement in technical abilities or improvements in understanding of management issues such as nutrient management planning (Burton, 2014). Thus we hypothesise that:

H7a. Education has a positive influence on attitude.

H7b. Education has a positive influence on subjective norm.

H7c. Education has a positive influence on perceived behavioural control.

Trusted information sources

Information sources that farmers trust, such as agricultural advisors, other farmers, family and the media, play an important role in shaping farmers' attitudes and perceptions towards the adoption of management practices (Sutherland *et al.,* 2013; Hunecke *et al.,* 2017; Liu *et al.,* 2018). Trust is an important concept as it is viewed as a catalyst that encourages the conversion of information into usable knowledge (Fisher, 2013). Moreover, the ability to change attitudes and the success of information interventions depends on individual’s trust in the source of the message (Blackstock *et al.,* 2010). Therefore, the type of information sources that are trusted by farmers and their likely influence on perceptions towards management practices, are also important to consider (Gervais *et al.,* 2001; Genius *et al.,* 2006; Stuart *et al.,* 2014). For example, trust in a professional agricultural advisor would generally be reassuring and have a strong, positive influence on attitudes, social pressure felt and perceptions of control over following a NMP (Genius *et al.,* 2006; Wilson *et al.,* 2018). Whereas, this effect may not be as strong for the media or other farmers, who might have mixed opinions regarding the use of NMPs. For example, Zeweld *et al.* (2017) found that technical training and important referent groups, such as family, neighbours and friends, increased farmers’ levels of social pressure to adopt sustainable management practices, whereas the media did not have a significant influence. Zeweld *et al.* (2017) also demonstrated a positive influence between technical training and farmers’ attitudes towards such practices. We therefore propose the following hypotheses:

H8a. Farmers’ levels of trust in information sources have a positive influence on attitude.

H8b. Farmers’ levels of trust in information sources have a positive influence on subjective norm.

H8c. Farmers’ levels of trust in information sources have a positive influence on perceived behavioural control.

6.3 Methodology

Survey

The data used for the purpose of this study were derived using the same survey and sample of Irish farmers described in Daxini *et al.* (2018). A structured survey was designed to collect information pertaining to the socio-demographic characteristics of the sample, trusted information sources and a series of items were used to measure the TPB constructs. The content of the survey was developed based on a literature review of past TPB research in an agricultural domain (e.g. Lapple and Kelley, 2013; Borges *et al.,* 2014; Micha *et al.,* 2015; Lalani *et al.,* 2016; van Dijk *et al.,* 2016), previous survey experience of the authors and a series of preliminary interviews (Francis *et al.,* 2004; Sutton *et al.,* 2004). These interviews were conducted with farmers and agricultural advisors prior to the development of the survey and were designed to reveal key attitudes and perceptions towards following a NMP. Prior to the administration of the survey, a pilot test was conducted and, as a result, minor amendments were made to the wording of some of the questions.

The data were collected between the months of December 2016 and April 2017 using face-to-face interviews with farmers. Survey recorders read out the questions to respondents who were the main decision maker on the farm. A total of 1009 farmers were interviewed. To ensure that the sample of farmers was representative, the survey company first stratified the sample by Electoral Divisions (Howley, 2013). At each sampling point, the interviewer followed a quota controlled system based upon the known proportion of farm systems and sizes within each area. Interviewers then continued to interview farmers until they filled their quotas. Quota controlled sampling is a non-probability sampling method which guarantees that the sample has the same proportions of individuals as the entire population in relation to a set of specified characteristics (Elder, 2009). For the purpose of this study, the quota was designed in order to ensure that the sample was representative of Irish farming by farm systems and sizes. The quotas used for the purpose of this study were based on known national population figures in relation to specific farm types (Hennessy and Moran, 2015).

Variables

Theory of Planned Behaviour (TPB)

The TPB constructs (attitude, subjective norm, perceived behavioural control and intentions), can be measured either directly or indirectly from respondent's beliefs (Adnan *et al.,* 2018). In this study, we use direct measures as they are considered to be adequate for predicting intention (Fishbein and Ajzen, 2010) and have been used previously in agricultural research (Borges and Oude Lansink, 2016). A total of 14 measurement items are used to symbolise the four TPB constructs. The questions used to measure the TPB constructs are all anchored on a 5-point Likert scale from strongly disagree (1) to strongly agree (5), which are regarded as short enough to allow respondents to distinguish meaningfully between the categories (Hansson *et al.,* 2012).

Policy

A variable describing farmers who engage with policy that requires them to develop a NMP on a mandatory basis (as discussed previously) is developed. In Ireland, farmers who receive an allowance under the ND to farm at a higher stocking rate or are part of the 'Green Low Carbon Agricultural Environment' scheme are required to adopt a NMP. A dummy variable was developed to reflect farmers who engage in policy (1) against those who do not (0).

Formal education

Education is measured on a 5-point Likert scale with increasing levels of formal educational attainment from primary level (1); secondary (2); leaving certificate (3); professional diploma (4) and higher education (5). A dummy variable is developed to indicate farmers who have completed secondary level education and above and labelled as 1 and those who have not are labelled as 0.

Trusted information sources

As discussed previously, farmers are influenced by a range of information sources.In order to understand the influence of different information sources, farmers were asked to respond on a 5-point Likert scale from very unlikely (1) to very likely (5) to the question: “how likely are you to follow advice from the following people/sources regarding nutrient management on your farm?” The response options included: ‘family’; ‘discussion group’; ‘agricultural advisor’; ‘other farmers’; ‘scientific literature’; ‘farming press and magazines’; ‘information events’ such as farm walks, open days and demonstration events and the ‘media’ such as TV and radio. It is also important to identify the underlying structure and commonalities in trust preferences. To achieve this aim, we employ a principal component analysis (PCA) with varimax rotation.

Theoretically, trust is considered to be a latent variable which cannot be measured directly (Zawojska, 2010). Trust can be defined based on repeated interactions over time (Zawojska, 2010). Therefore, trust can be measured directly by asking respondents the likelihood of following a particular source of information. Trust in information is expected to vary across different sources and, as Lobb *et al.* (2007) argue, trust in information from dissimilar sources (e.g., media, government, scientists) is likely to have a dissimilar impact on behavioural intention. Similar to Lobb *et al.* (2007) and Emtage and Herbohn (2012), PCA is utilised in this study to identify dimensions of trust. This enables an identification of a limited number of ‘‘trust components’’ that still preserve the required differentiation. Moreover, this process helps to account for correlations across information sources perceived as comparable and provides estimates (principal component scores) for the latent trust constructs (Lobb *et al.,* 2007). Emtage and Herbohn (2012) identified five dimensions of trust whereas this study identifies only two. This result may be explained by the fact that Emtage and Herbohn (2012) considered a larger number of different types of information sources than considered by this study.

The suitability of the data for PCA was initially checked using a Kaiser-Meyer-Olkin measure which is 0.86, indicating suitability (Kaiser, 1974). Furthermore, the Bartlett's test of Sphericity was 0.0000 which suggests that there is a significant relationship between the variables. The decision regarding the number of components to retain is based on evaluating the eigen values, where values above 1 should be retained. A total of two components are retained, with coefficients above 0.3 (Hair *et al.,* 2010). The internal consistency of the components is checked using Cronbach's alpha. The values of each component are both over the recommended threshold value of 0.5 (Nunnally, 1978).

The results of the PCA (Table 6.1) are presented below and are interpreted on the basis of the type of information source that farmers are more likely to trust. Component one reflects farmers who are more likely to trust advice from 'technical' sources of information, which includes agricultural advisors, discussion groups, agricultural training courses and information events. On the other hand, component two comprises farmers who are more likely to trust advice from 'social' sources which includes other farmers, family, agricultural press and the media. Subsequently we label component one as 'technical information' and component two as 'social information'. Importantly, this leads to a modification of the hypothesised theoretical framework which decomposes the variable 'trusted sources' into two separate forms of 'trusted sources' which are:'technical information' and 'social information'.

Table 6.1: Principal components - trusted information sources (factor loadings >0.4 highlighted in bold).

Trusted source	Technical information	Social information
Family	-0.05	**0.43**
Agricultural advisor	**0.46**	-0.07
Discussion group	**0.48**	0.00
Other farmers	-0.05	**0.51**
Scientific literature	**0.34**	0.14
Farming press	0.08	**0.47**
Information event	**0.40**	0.11
Media	-0.02	**0.54**
Agricultural training course	**0.51**	-0.08
Eigen value	4.3	1.1

Following the results of the PCA we revise H8a, H8b and H8 and the additional H9a, H9b and H9c are also formulated as follows:

H8a. Farmers' levels of trust in technical information sources have a positive influence on attitude.

H8b. Farmers' levels of trust in technical information sources have a positive influence on subjective norm.

H8c. Farmers' levels of trust in technical information sources have a positive influence on perceived behavioural control.

H9a. Farmers' levels of trust in social information sources have a positive influence on attitude.

H9b. Farmers' levels of trust in social information sources have a *positive influence on subjective norm.*

H9c. Farmers' levels of trust in social information sources have a positive influence on perceived behavioural control.

Data analysis

Structural equation modelling (SEM) is adopted to test the proposed research hypotheses. SEM is a commonly used technique to test models with observed and latent variables (Toma *et al.,* 2013). A two-step procedure is adopted to test the research hypotheses (Anderson and Gerbing, 1988). In the first step, confirmatory factors analysis (CFA) is used to assess the fit of the measurement model and assess the reliability and validity of the constructs. In the second step, the structural model is used to test the hypothesised relationships. Because the skew and kurtosis statistics demonstrated deviations from normality assumptions, the model is estimated using the Satorra–Bentler method which is robust against violations of non-normality (Satorra and Bentler, 1994; Kline, 2011).

6.4 Results

Socio-economic characteristics of the sample

The majority (51%) of respondents in the sample are cattle farmers, 26% are dairy, 17% are sheep and around 6% are tillage. The median farm size is 31–50 hectares. In terms of age, the median is 51–64 years old. These figures are in line with national averages (CSO, 2018). The farmers in the sample have a high level of farming experience with a mean of 36 years of experience. In relation to the highest level of formal education attained, around 16% have a primary level of education, 30% have some secondary level of education, 34% have formally completed secondary level (leaving certificate obtained), 13% have received a professional diploma and only 7% have acquired a university degree. Due to policy requirements, 42% of farmers are obliged to develop a NMP on a mandatory basis. In terms of intentions, 67% of farmers either agree or strongly agree that they have an intention to follow a NMP in the near future.

Descriptive statistics of the measured items

Table 6.2 presents an overview of the measured items and illustrates that farmers show a moderately positive intention to follow a NMP. The three items used to measure intention have a mean of 3.65. In general, farmers also show a positive attitude towards following a NMP, with a mean score of 3.98 for the items used to measure attitude. Farmers stated that they felt a moderately high level of social pressure to follow a NMP with a mean of 3.71 between the items used to measure subjective norm. Finally, in relation to perceived behavioural control, farmers revealed a positive level of control with a mean of 3.91 among the items used to measure this construct.

Table 6.2: Descriptive statistics of the items used to measure the TPB constructs and results of the measurement model.

Item measure	Mean	Std.Dev	Item loadings	CR	AVE
Attitude				**0.96**	**0.86**
In your opinion, following a NMP is: a good idea?	4.01	0.67	0.93***		
In your opinion, following a NMP is: useful?	4.00	0.67	0.94***		
In your opinion, following a NMP is: reliable?	3.98	0.68	0.91***		
In your opinion, following a NMP is: important?	3.94	0.75	0.92***		
Subjective norm				**0.92**	**0.80**
When it comes to following a NMP, most people whose opinion I value regarding farming: would approve if I do so?	3.80	0.74	0.87***		
When it comes to following a NMP, most people whose opinion I value regarding farming: encourage me to do so?	3.62	0.89	0.91***		
When it comes to following a NMP, most people whose opinion I value regarding farming: think that I should do so?	3.71	0.81	0.90***		
Perceived behavioural control				**0.97**	**0.93**
When it comes to following a NMP: I am confident in my ability to do so?	3.97	0.74	0.87***		
When it comes to following a NMP: it is easy to do so?	3.87	0.77	0.82***		

Item measure	Mean	Std.Dev	Item loadings	CR	AVE
When it comes to following a NMP: I have a clear understanding of how to do so?	3.95	0.79	0.79***		
Intention				**0.97**	**0.92**
When it comes to following a NMP in the near future: intend to do so?	3.62	1.02	0.98***		
When it comes to following a NMP in the near future: it is likely that I will do so?	3.63	1.01	0.98***		
When it comes to following a NMP in the near future: I would consider doing so?	3.71	0.98	0.94***		

Notes: CR = Composite reliability, AVE = Average variance extracted. ***P < 0.01.

Measurement model

The results of the CFA show (Table 6.2) that all of the standardised factor loadings are statistically significant ($p < 0.01$) and are all above the recommended threshold value of 0.70 (Hair *et al.,* 2010). In terms of model fit, given the over-sensitivity of the chi-square test to sample size, we utilise other fit statistics which account for the bias against large samples (de Leeuw *et al.,* 2015; Martinovska Stojcheska *et al.,* 2016). These fit indices include the Comparative fit index (CFI=0.993), Tucker-Lewis index (TLI=0.991), Root mean square error of approximation (RMSEA=0.031) and Standardized root mean square residual (SRMR=0.023). Each of these values conforms with recommended limits (CFI/TLI > 0.95; RMSEA/SRMR < 0.08) and therefore we conclude that the model has good fit to the data (Hu and Bentler, 1995; Hair *et al.,* 2010).

All of the latent constructs are assessed for both reliability and validity. Reliability is associated with the internal consistency of the multiple indictors used to measure each construct (Lopez-Mosquera *et al.,* 2014). The composite reliability (CR) scores are between 0.87 and 0.97, which are all above the acceptable value of 0.70 (Hair *et al.,* 2010). Validity is associated with the degree to which the observed variables accurately measure the intended construct (Li *et al.,* 2018). We measure validity using both convergent and discriminant validity (Fornell and Larcker, 1981). The average variance extracted (AVE) is estimated for each construct to measure convergent validity. The AVE value must exceed a threshold value of 0.50 (Hair *et al.,* 2010). All AVE scores are between 0.68 and 0.93, suggesting suitable convergent validity. Discriminant validity is confirmed as the AVE values for each construct are found to be greater than the square of the corresponding inter-construct correlations, see Table 6.3, (Sharifzadeh *et al.,* 2017).

Table 6.3: Inter-construct correlation and square root of AVE (along the diagonal)

Factor	ATT	SN	PBC	INT
ATT	**0.86**			
SN	0.34	**0.80**		
PBC	0.52	0.35	**0.68**	
INT	0.47	0.44	0.53	**0.93**

Notes: ATT = Attitude; SN = Subjective norm; PBC = Perceived behavioural control; INT = Intention.

We also check for multicollinearity between the variables in the model by computing variance inflation factors (VIF). A maximum VIF value of 3.43 is found, which is below the recommended threshold value of 10 which suggests that multicollinearity is not an issue in our model (Hair *et al.,* 2010).

Structural model

The goodness of fit indices of the structural model are as follows: CFI (0.970), TLI (0.961), RMSEA (0.057) and SRMR (0.078). The fit indices are within the recommended thresholds and therefore they indicate suitable model fit (Hair *et al.,* 2010). Table 6.4 shows the results of the hypothesis testing results which are presented as standardised path coefficients which show the significance and strength of association between the variables in the hypothesised relationships (Hair *et al.,* 2010). In terms of the influence of attitude, subjective norm and perceived behavioural control on intention, each construct has a positive and significant influence on intentions. This leads us to accept H1, H2 and H3. However, the coefficients also reveal that perceived behavioural control has the greatest effect on intentions (0.37) followed by subjective norm (0.30) and then attitude (0.28). In relation to the inter-relationships between the TPB constructs, subjective norm is positively and significantly associated with attitude (0.47). Likewise, subjective norm positively influences perceived behavioural control

(0.46). Thus the results of the inter-relationships examined between the TPB constructs leads us to accept H4 and H5. The results also indicate that the institutional variable policy, has a significant effect on attitude (0.09), subjective norm (0.11) and perceived behavioural control (0.14). This offers support for H6a, H6b and H6c. Education is only significantly and positively related to perceived behavioural control, although the magnitude of the influence is relatively small (0.07). Thus, we accept H7c but reject both H7a and H7b. The effect of trust in technical information sources on attitude (0.14) and perceived behavioural control (0.17) is positive and significant, however this variable has the largest influence on subjective norm (0.46). This leads us to accept H8a, H8b and H8c. Finally, trust in social information sources is positively and significantly associated with attitude (0.08) and a relatively larger influence is found on subjective norm (0.11) compared to attitude. Based on this result we reject H9c but accept H9a and H9b.

Table 6.4: Hypothesis testing results

Hypotheses	Path	Standardized estimate	S.E	P	Result
TPB					
H1	ATT → INT	0.28	0.03	***	Accept
H2	SN → INT	0.30	0.05	***	Accept
H3	PBC → INT	0.37	0.04	***	Accept
Inter-relationships					
H4	SN → ATT	0.47	0.04	***	Accept
H5	SN → PBC	0.46	0.04	***	Accept
Background influences					
H6a	Policy → ATT	0.09	0.03	***	Accept
H6b	Policy → SN	0.11	0.03	***	Accept
H6c	Policy → PBC	0.14	0.03	***	Accept

Hypotheses	Path	Standardized estimate	S.E	P	Result
H7a	Education → ATT	0.02	0.03	NS	Reject
H7b	Education → SN	-0.03	0.03	NS	Reject
H7c	Education → PBC	0.07	0.03	**	Accept
H8a	Trust (Technical information) → ATT	0.14	0.04	***	Accept
H8b	Trust (Technical information) → SN	0.46	0.04	***	Accept
H8c	Trust (Technical information) → PBC	0.17	0.04	***	Accept
H9a	Trust (Social information) → ATT	0.08	0.04	**	Accept
H9b	Trust (Social information) → SN	0.11	0.04	***	Accept
H9c	Trust (Social information) → PBC	0.05	0.04	NS	Reject

Notes: ATT = Attitude; SN = Subjective norm; PBC = Perceived behavioural control; INT = Intention; NS = Not significant. **$p < 0.05$, ***$p < 0.01$.

6.5 Discussion and conclusion

Understanding the socio-psychology of the decision making process of farmers is critical to encouraging further use of beneficial management practices, such as nutrient management planning (Blackstock *et al.,* 2010; Okumah *et al.,* 2018). However, without understanding the complexity of the formation of attitudes and perceptions and how institutional variables (e.g. policy, education and information sources) may contribute to these formations, it is difficult to design effective policy and behavioural change solutions (Fleming *et al.,* 2010; Bijttebier *et al.,* 2018). The results of this study show that the majority of the hypotheses are validated which confirms the importance of considering both internal (attitudes and perceptions) and external (policy and information) drivers of farmers' decision making processes (Edwards-Jones, 2006; Feola and Binder, 2010; Mills *et al.,* 2018).

The results demonstrate that perceived behavioural control is the most important determinant of intentions to follow a NMP, which implies that farmers' perceptions of the level of easiness, self-confidence and degree of control over following a NMP is important in determining the intention to follow one. Nutrient management planning is a technical management practice which requires specialist knowledge, skill and attention to detail and therefore is often considered to be among the more complex of farm management practices (Beegle *et al.,* 2000; Walters and Shrubsole, 2014). Madden *et al.* (1992) suggest that perceived behavioural control typically plays a significant role in determining intention to perform a given behaviour when engagement in that behaviour is difficult. Whilst agricultural advisors typically support farmers in an EU context, not all farmers engage with advisors and therefore they may not feel competent or confident to follow a NMP (Kania *et al.,* 2014). This could lead to a continued reliance on intuitive judgement instead of using formalised NMPs (Nuthall and Old, 2018). Previous studies have also shown that perceived behavioural control and efficacy are particularly important determinants of nutrient management practice adoption (Wilson *et al.,* 2014; Zhang *et al.,* 2016; Wilson *et al.,* 2018).

Previous studies have found subjective norm to be a particularly important determinant of farmers' intentions towards adopting, for example, improved grassland management (Borges *et al.,* 2014), diversified agricultural production (Senger *et al.,* 2017) and grazing management practices (Schaak and Mushoff, 2018). The results of this study also confirm the important influence of subjective norm on farmers' intentions to follow a NMP. This means that farmers who feel a higher degree of social pressure or approval to follow a NMP are more likely to do so. This may be due to a fear of social exclusion from not conforming to what is deemed to be good practice (Bamberg and Moser, 2007). Burton (2004) explains that subjective norms influence intentions and behaviours because individuals do not make decisions without considering their actions in relation to that of others, nor are individuals independent of social and cultural influences. Moreover, the highly influential role of subjective norm in our study may be related to an increase in focus on improving nutrient management on farms in recent years, which may have stimulated an increase in social pressure on farmers to voluntarily use best management practices, such as NMPs (Savage and Ribaudo, 2013; Reimer *et al.,* 2018).

The influence of attitude on intentions is positive and significant which implies that farmers who view the outcomes of following a NMP more favourably, are more likely to have a positive intention to follow a plan. This result supports previous TPB studies which found attitude to be an important determinant of farmers' intentions to adopt various agricultural practices (Wauters *et al.,* 2010; Zeweld *et al.,* 2017; Hyland *et al.,* 2018). However, it has been well-established that attitudes are not, in themselves, adequate for the prediction of individuals' intentions (Floress *et al.,* 2017). Our result also implies that farmers' evaluation of the importance and benefits of following a NMP are perhaps less important than their ability and the social pressure felt towards following a NMP. For example, Trafimow and Finlay (2001) argue that depending on the behaviour in question, people can be more attitude-driven or subjective norm driven. When it comes to following a NMP, farmers are perhaps more motivated by external social pressures over their own internal opinions (attitude). Burton (2004) suggests that people often push aside their personal opinions and rational considerations in favour of the views of important referent groups. Our result also resonates with the findings of Yoshida *et al.* (2018) who demonstrated that farmers often forgo their own attitudes in favour of external social pressures and demands on production.

A number of inter-relationships are also examined between the TPB constructs. As mentioned previously, the results confirm the positive significant influence of subjective norm on attitude, thereby confirming the results of previous studies (Bamberg and Moser, 2007; Zhang *et al.,* 2017; Rezaei *et al.,* 2019). This suggests that farmers' attitudes towards following a NMP are represented by social considerations. Petty and Cacioppo (1996) put forward the argument that individuals' attitudes are influenced by other individuals and the environment around them. Likewise, Quintal *et al.* (2010) assert that individuals consider others' expectations when they form their personal attitudes. It is likely that farmers are using subjective norms as a source of information to evaluate how advantageous following a NMP may be, which may be contributing to attitude formation (Bamberg and Moser, 2007). This relationship may be further explained by the fact that there is no absolute definition of what a correct attitude is (Festinger, 1954). Therefore, individuals' views of what important referent groups expect of them may influence their attitude towards a certain practice (Park and Ha, 2014).

Subjective norm is also found to positively and significantly influence perceived behavioural control. This means that farmers who feel a higher degree of social pressure and/or encouragement to follow a NMP are more likely to perceive a greater degree of control over doing so. The result supports the notion that external social pressure or encouragement arising from the opinions of others can facilitate perceptions of how easy or difficult farmers feel, in this case, it is to follow a NMP (Bamberg and Moser, 2007). Thus, in terms of following a NMP, it is probable that farmers are evaluating how easy it is to do so through an evaluation of other farmers' perceptions (Bamberg *et al.,* 2007). Quintal *et al.* (2010) also suggest that the exertion of social pressure on individuals to behave in a certain way can influence their understanding of the barriers to carrying out the behaviour in question. Therefore, positive encouragement or approval from individuals whose opinions are valued by farmers, may result in an increase in confidence in following a NMP due to a decrease in the perceptions of the magnitude of the barriers that may exist (Nair and Little, 2016; Ru *et al.,* 2019). The effect of subjective norm on perceived behavioural control has also been confirmed by previous studies (Peters *et al.,* 2011; Park and Ha, 2014; Rezaei *et al.,* 2019).

Farmers who are obliged to develop a NMP on a mandatory basis are more likely to feel a higher degree of social pressure and level of control over following the plan. One potential explanation for these results relates to the nature of policy requirements in Ireland. Farmers must have a NMP developed by a qualified agricultural advisor to comply with GLAS or ND derogation requirements. Furthermore, farmers participating in GLAS must attend specific agricultural training courses where nutrient management planning forms a part of the course (DAFM, 2017). Previous research has shown that engagement with advice and support systems can help stimulate interest, responsibility and a sense of personal and social norm (Dwyer *et al.,* 2007; Mills *et al.,* 2016) as well as improve control over following a NMP (Osmond *et al.,* 2015). Policy also has significant positive influence on farmers' attitudes towards following a NMP, but this relationship is weak.

A positive, but weak, association is found between education and perceived behavioural control. Nutrient management planning is a technical process and requires attention to detail and the ability to comprehend the complexities associated with optimising nutrient use (Beegle *et al.,* 2000). A probable explanation for this result is that education increases efficacy of farm management through an enhancement of technical skills and familiarity required to use technical innovations, such as NMPs (Burton, 2014).

The findings also suggest that trust in technical sources of information has a critical influence on subjective norm followed by perceived behavioural control and attitude; whereas, trust in social sources has a positive influence on subjective norm and attitude only. Importantly, trust in technical sources has a higher magnitude of influence on the TPB constructs than social sources. This suggests that expertise and professional sources are more crucial in terms of the development of farmers' perceptions, than generalist sources such as family and the media. Blackstock *et al.* (2010) suggest that the higher the credibility of the advice source, such as people from farming backgrounds or trusted networks, the higher the persuasion factor will be. O'Keefe (2016) argues that highly credible sources, such as approved advisors, are often important when messages or procedures are complex. Following a NMP requires the initial collection and then synthesis of farm specific data such as stocking rate, soil fertility and yield potential (Beegle *et al.,* 2000). Thus, technical assistance is often crucial, especially in terms of the synthesis, interpretation and formulation of a NMP and guidance for following the plan (Osmond *et al.,* 2015).

This study extends the literature by examining the socio-psychological determinants of farmers' intentions to follow a NMP whilst also examining the causal relationships between, and institutional influences on, the TPB constructs. We argue that this approach is better suited to understanding the complexities of farmer decision making and prescribing potential policy and behavioural change intervention strategies.

The main policy implication emerging from the results relates to the importance of perceived behavioural control and subjective norm which was not only shown to directly influence farmers' intentions but also farmers' attitudes and perceptions of control over following a NMP. Thus, we suggest that it is crucial that policy makers continue to explore novel ways of improving farmers' own capabilities over following a NMP and increasing social pressure on farmers to follow a NMP as a way to establish long term norms. Overall, in line with others (Feola *et al.,* 2015; Wang *et al.,* 2019), we stress the importance of continuing to develop an understanding of farmer psychology in relation to the use of management practices that have the ability to provide both environmental and financial benefits. Without doing so, solutions may be prescribed that are not geared towards maximising the influence they have on farmers' perceptions towards the use of such innovations.

Chapter 7: Discussion and conclusions

7.1 Introduction

This concluding chapter begins by summarising the main findings of this thesis as they relate to the overall research objectives and questions outlined in Chapter 1. Within this summary of the results, key contributions that are made to the literature are also highlighted. Following this summary is an overall synthesis of the results presented in Chapters 4 - 6 which draws a number of important similarities but also highlights key differences between the results. Based on the results a number of policy implications are then identified. Limitations to the research are then discussed and directions for future research suggested. The final section provides an overview of the main conclusions arising from the thesis.

7.2 Summary of the thesis and key findings

The principal aim of this thesis, as set out in the introduction (Chapter 1), is to examine and explain the factors which influence farmers' intentions towards the implementation of nutrient management planning. More specifically, the intention of farmers to apply fertiliser on the basis of soil test results (explored in Chapter 4) and following a nutrient management plan (NMP) (explored in Chapters 5 and 6). By incorporating socio-psychological variables into the analysis of farmers' intention using the Theory of Planned Behaviour (TPB), this thesis makes several important contributions to the literature surrounding the implementation of nutrient management planning but also the farm management practice literature more widely.

Chapter 1 provides the motivation for this research. Primarily, there has been a rise in the global population which has led to an increase in demand for food production. This demand has, in the past, largely been met through the intensification of food production and, in part, through the increasing use of fertiliser including both inorganic fertiliser and the recycling of manure. Whilst these substances are vital for sustaining and increasing food production, improper use (e.g. applying too much at the wrong time) can increase the risk of nutrient loss to water and the atmosphere. Such losses have been associated with deterioration in water quality and increased greenhouse gas emissions. Moreover, under-application of fertiliser has also led to decreasing soil fertility which has been associated with underperformance of crops. One key solution that has been advocated globally to address these issues is for farmers to increase their level of nutrient management planning. This involves collecting site specific information which is then used to devise a nutrient management plan (NMP). However, despite demonstration of benefits, uptake of key practices associated with nutrient management planning remains below expectations globally. Despite political interest in improving uptake, very few studies have examined the factors which specifically influence adoption of nutrient management planning. Moreover, the studies that do focus on aspects of nutrient management planning often concentrate on farm and farmer socio-economic characteristics and how these influence uptake. Where attention has been paid to socio-psychological drivers of farmer uptake decisions surrounding the use of nutrient management planning, these studies tend to be qualitative in nature. This study contributes by extending the literature by incorporating socio-psychological issues using a framework based on the TPB to study the intentions of farmers towards the implementation of nutrient management planning.

The literature review, presented in Chapter 2, describes the TPB in more detail and further justifies its choice to achieve the aims of this study. The TPB is a socio-psychological theory which suggests that human behaviour is best predicted as a function of intentions. In turn, intentions are influenced by attitude, subjective norms and perceived behavioural control. Whilst the TPB has been applied successfully to understand peoples' intentions across a range of disciplines, including agriculture, a key limitation of the TPB is its omission of variables that have been found to be important predictors of adoption in specific contexts or in relation to particular behaviours. Advantageously, the TPB remains open to the inclusion of additional predictors if they can improve the model's ability to explain intentions. After providing details on the TPB and addressing a key limitation of the theory, Chapter 2 reviews the farm management practice adoption literature and demonstrates that variables associated with policy, information use as well as farm and farmer characteristics are important predictors of the adoption of practices associated with nutrient management planning. Therefore, it is suggested that such variables should also be incorporated into the TPB framework in order to provide a more holistic representation of the factors which influence farmers' intentions towards the implementation of nutrient management planning.

In order to fulfil the aim of this research, data were collected from a sample of Irish farmers. Chapter 3 provides details on the methodology used to collect the data, including the development of the structured survey, pilot testing and the quota system used to ensure a level of national representation by farm systems and sizes. The survey is designed to collect data from farmers pertaining to farm and farmer socio-economic characteristics, background nutrient management practice and questions used to elicit farmers' beliefs and intentions towards the uptake of the two practices under study: 1) intention to apply fertiliser on the basis of soil test results and, 2) intention to follow a NMP. Comparisons between the descriptive statistics of the sample with national figures, demonstrates that the sample suitably represents the national farming population. The data collected from the survey is used as the basis of the analysis conducted in each empirical paper (Chapters 4, 5 and 6) discussed below.

The first paper (Chapter 4) addresses **Research objective 1,** which is to examine the influence of attitude, subjective norm, perceived behavioural control and additional context specific variables on farmers' intentions to apply fertiliser on the basis of soil test results. The additional variables include 'perceived resources' (i.e., whether a farmers believes that s/he has enough resources such as time, finance and labour to apply the practice) and a range of farm and farmer socio-economic characteristics. The influence of policy which requires the mandatory adoption of soil testing for certain farmers was also examined. In order to address Research objective 1, a number of empirical methodologies were employed. All of the TPB variables as well as ‘perceived resources’ are initially validated and confirmed using principal component analysis (PCA). A binary logistic regression model is then used to examine the influence of the TPB and additional variables on intentions. In addition, in order to distinguish between farmers who are obliged to adopt periodic soil testing on a mandatory basis and those who do not, the sample was split for further analysis into ‘mandatory’ and ‘voluntary’ adopters. A separate binary logistic regression model was applied for each sample.

A number of research questions were developed to address Research objective 1. The first research question **(Research question 1a)** asks whether attitude, subjective norm, and perceived behavioural control are significant predictors of farmers’ intentions to apply fertiliser on the basis of soil test results? The results from binary logistic regression from the full sample (N=1009) confirm that the traditional TPB variables (attitude, subjective norm, and perceived behavioural control) are significantly correlated with intentions. This supports the applicability of the TPB in this context and demonstrates that socio-psychological variables can provide insight into farmer decision making. The results for the full sample also support that the variable ‘perceived resources’ is significantly associated with intentions which confirms **Research question 1b** which inquires whether perceived resources is an important addition to the TPB model in relation to farmers’ intentions to apply fertiliser on the basis of soil test results? A number of farm and farmer characteristics as well as contact with an agricultural advisor and participation in policy are found to significantly explain farmers’ intentions. These results provide mixed support for **Research question 1c** which asks whether farm and farmer characteristics as well as policy are significant predictors of farmers’ intentions. The results also confirm **Research question 1d** which inquires whether there are differences in the drivers of intentions between ‘mandatory’ and ‘voluntary adopters’ of period periodic soil testing? A number of differences were found in terms of the factors which influence the different groups. For example, attitude was important to voluntary adopters where as it was not to the mandatory adopters. On the contrary, subjective norm was an important determinant of the intentions of the mandatory adopters but not for the voluntary adopters. Furthermore, whilst perceived behavioural control and 'perceived resources' are common predictors across the two groups, the magnitude of the influence is greater for the 'voluntary adopters'.

The aim of the second paper (Chapter 5) is to address **Research objective 2** which is to create a typology of farmers according to a number of policy relevant farm and farmer characteristics and to examine whether there are differences in the drivers of intentions to follow a nutrient management plan (NMP) between groups. The variables used to predict intentions include the TPB variables (attitude, subjective norm and perceived behavioural control) as well as two additional predictors which include extension contact. In order to achieve Research objective 2, a number of empirical methodologies are used in this paper. Firstly, PCA is used to empirically confirm the TPB components and simultaneously avoid multicollinearity in the regression analysis. Secondly, Latent Class Analysis (LCA) is applied to the aforementioned farm and farmer characteristics in order to generate a typology which enables heterogeneity among the sample to be accounted for. The final step is embedded in the LCA which involves using the TPB variables and the additional variables (i.e. extension contact and policy) to explain farmers' intentions towards following a NMP using a latent class binary logistic regression.

To approach Research objective 2, a number of research questions were formulated. The findings in Chapter 5 reveal support for **Research question 2a** which asks: Can farmers be categorised into classes according to their operator and farm characteristics? The LCA revealed that three classes of farmers exist among the sample namely: 'Traditional', 'Supplementary' and 'Business-orientated' farmers. However, there was limited support for **Research question 2b** which endeavoured to investigate whether there are significant differences in the levels of intentions to follow a NMP between the classes? The levels of intentions were in fact somewhat similar across the classes. However, different variables significantly influence intentions across the classes with varying levels of magnitude. This finding provides support for

Research question 2c which asks whether there are differences in the factors which influence farmers' intentions to follow a NMP between classes of farmers?

Chapter 6 presents the findings of the final empirical paper which addresses **Research objective 3**. This objective sought to explain farmers' intentions towards following a NMP whilst also exploring the interrelationships between the TPB variables (attitude, subjective norm and perceived behavioural control) and the influence of background variables on the TPB variables. The main empirical methodology used to address Research objective 3 was structural equation modelling (SEM). However, PCA was also utilised in order to empirically confirm which types of information sources different farmers are more likely to trust. The results of the PCA reveal that two groups of farmers exist; namely, those who prefer to trust 'technical' sources of information (i.e. agricultural adviser, discussion group, information event and agricultural training course) and those who prefer to trust 'social' sources of information (i.e. family, other farmers, farming press and the media). The hypothetical model is then tested using SEM which is conducted in two steps. The first step involves evaluating the measurement model which uses confirmatory factor analysis (CFA) to test whether the measurement items of intention, attitude, subjective norm and perceived behavioural control are reliably represented as constructs. The second step involves assessing the structural model which is used to determine: 1) the effect of attitude, subjective norm and perceived behavioural control on intentions, 2) a number of influences between the attitude, subjective norm and perceived behavioural control and 3) the influence of the aforementioned background variables on attitude, subjective norm and perceived behavioural control.

A series of research questions were developed to address Research objective 3. The first research question **(Research question 3a)** asks what is the relative importance of the influence of TPB variables on intentions to follow a NMP? The results from the SEM reveal that perceived behavioural control is the most important and significant predictor of intentions to follow a NMP, which is followed by subjective norm and finally attitude. The second research question under Research objective 3 (**Research question 3b)** seeks an answer to the following question which asks whether there are significant interrelationships between the TPB variables? Strong support is found for this question, for example, subjective norm is found to be a highly important predictor of perceived behavioural control and a significant predictor of attitude. The final research question is **Research question 3c** which asks whether background variables significantly influence the TPB (attitude, subjective norm and perceived behavioural control) variables? To this end, a number of important background influences were identified which suggests research question 3c must be accepted. For example, trust in 'technical' sources of information (e.g. advisor and discussion group) has a relatively large positive influence on subjective norm followed by perceived behavioural control and attitude. Whereas, trust in 'social' information sources (e.g. family and the media) has a positive influence on subjective norm followed by attitude, albeit the influence on attitude is relatively small.

7.3 Contributions

The research presented in Chapters 4-6 offers a number of important contributions to the literature. A number of these are cross-cutting whereas others are unique to each chapter. Firstly, whilst adoption of farm management practices have been examined extensively across the literature (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012; Liu *et al.,* 2018), studies specifically examining the adoption of nutrient management planning remain limited. Those that do focus on nutrient management planning tend to focus on adoption (e.g. existence of a NMP) rather than implementation (e.g. use of a NMP) of given practices.

Secondly, previous studies in this area tend to explain adoption as a function of farmer and farmer characteristics with a limited consideration for socio-psychological variables (e.g. attitudes and beliefs). Furthermore, those studies that do consider socio-psychological variables in relation to the adoption of nutrient management planning tend to rely on qualitative methods and, whilst providing important insights into farmer decision making, the results from such studies are typically difficult to generalise due to small sample sizes. Based on the limitations of previous studies, the research presented in Chapter 4, 5 and 6 makes a number of cross cutting contributions to the literature, Namely, these contributions include, the consideration of nutrient management planning, the focus on implementation rather than mere uptake of given practices and the incorporation of socio-psychological variables into the analysis using the TPB and empirically testing relationships between variables and intentions. Furthermore, each paper (Chapter 4, 5 and 6) has a specific focus and therefore each paper makes further unique contributions to the literature surrounding farm management practice adoption.

The first paper (Chapter 4) has a specific focus on farmers' intentions to apply fertiliser on the basis of soil test results with a particular consideration of the policy context in which farmers make decisions. This paper contributes by not only analysing the full sample of farmers, but also examines whether there are differences in the variables which influence intentions between 'voluntary' and 'mandatory' adopters of periodic soil testing. Barnes *et al.* (2013b) highlight that comparisons are rarely made in the literature between the decision making structures of farmers operating under varying levels of regulatory requirements. This paper also contributes by extending the TPB by in addition by also considering the influence of the concept of 'perceived resources' and a number of farm and farmer characteristics on intentions. Calls have been made by agricultural researchers to ensure that the applications of the TPB suitably reflect the unique conditions (e.g. policy, resource and socio-economic constraints) under which farmers operate (Burton, 2004a; Borges and Oude Lansink, 2015), yet TPB studies in an agricultural context (e.g. Wauters *et al.,* 2010; de Lauwere *et al.,* 2012; Bruijnis *et al.,* 2013; Läpple and Kelley, 2013; Borges *et al.,* 2014; Borges and Oude Lansink, 2016; Deng *et al.,* 2016; Andow *et al.,* 2017; Senger *et al.,* 2017a; Adnan *et al.,* 2018) do not always incorporate additional variables which have been proven to influence the decisions of farmers in previous research (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). The results presented in Chapter 4 successfully demonstrate that the

TPB is a suitable framework for analysing farmers' intentions towards nutrient management planning but also demonstrates the importance of incorporating additional context specific variables into the analysis of farmer decision making. Moreover, the results confirm the importance of taking into account possible underlying motivations for the adoption of soil testing in particular (i.e. 'voluntary' vs. 'mandatory').

The second paper, presented in Chapter 5, uniquely focuses on farmers' intentions towards following a NMP. The main contribution of this paper to the literature is the use of latent class analysis (LCA) to generate a farmer typology with the intention to account for heterogeneity among the sample. This typology is based on policy relevant farm and farmer characteristics which are identified in the literature as important factors which may indirectly influence the decision making structures of farmers. Most previous studies which explicitly focus on the uptake of NMPs fail to account for heterogeneity among farmers (e.g. Ribaudo and Johansson, 2007; Lawley *et al.,* 2009; Genskow, 2012; Savage and Ribaudo, 2013; Ulrich-Schad *et al.,* 2017). Wider criticisms have also been made which highlight that studies examining farmer decision making often fail to adequately account for heterogeneity among farmers, which has led to inadequate policy solutions which prescribe 'one-size fits all' recommendations to promote behavioural change (Läpple and Kelley, 2013; Hammond *et al.,* 2017; Novikova *et al.,* 2017). Thus, this study not only contributes to the literature on NMP adoption, but to the wider debate in the agricultural literature surrounding how best to target policy initiatives towards different groups of farmers who may react differently to different policy initiatives designed to encourage, in this context, the further use of NMPs. The LCA in this study demonstrates that three distinct classes of farmers and differences in the variables that influence the intentions of farmers to follow a NMP, are found. Thus, the results confirm the importance of accounting for heterogeneity among the farming population and provide important insights for better targeting policy initiatives. Such initiatives, as suggested by the results, can be targeted taking account of the variations in farm and farmer characteristics and how likely these groups of farmers are to respond to initiatives designed to, for example, influence attitudes, social norms and perceptions of control.

The final paper, presented in Chapter 6, also focuses on the intentions of farmers to follow a NMP but has a unique focus on exploring the cognitive foundations of the TPB variables. Previous studies in relation to the adoption of NMPs (e.g. Ribaudo and Johansson, 2007; Lawley *et al.,* 2009; Genskow, 2012; Savage and Ribaudo, 2013; Ulrich-Schad *et al.,* 2017) but also TPB studies within an agricultural context more widely (e.g. Beedell and Rehman, 2000; Läpple and Kelley, 2013; Borges *et al.,* 2014; Micha *et al.,* 2015; Jones *et al.,* 2016; Pino *et al.,* 2017; Adnan *et al.,* 2018; Hyland *et al.,* 2018b) typically focus on direct relationships between a set of explanatory variables and the decision or intention to adopt a given practice. However, this does not provide information on how the TPB variables influence each other, nor do these studies identify which background variables potentially influence farmers' beliefs (attitudinal, social and control). Therefore, there remains an insufficient understanding of which levers (e.g. policy, information and education) are most likely to influence farmers' beliefs. The cognitive foundations of these variables are rarely considered not only in relation to nutrient management planning but farm practice adoption more widely (Bijttebier *et al.,* 2018). This paper contributes to the literature by employing structural equation modelling (SEM) in order to examine farmers' intentions towards following a NMP. Advantageously, SEM allows for the testing of relationships between the TPB variables (attitude, subjective norm and perceived behavioural control) and enables the influence of background variables (policy, education and trust in information sources) which are viewed as 'behavioural change levers' to be simultaneously incorporated into the analysis of farmers' intentions. Thus, this study extends the literature on the use of NMPs by considering indirect relationships between the TPB variables, which enables a deeper understanding of the cognitive foundation of farmers' beliefs. The SEM reveals multiple significant pathways, and thus the use of SEM enables a more comprehensive understanding of farmers' cognitive decision making process to be gained.

7.4 Synthesis of results

This section synthesises and discusses a number of key results of the three empirical studies (Chapter 4, Chapter 5 and Chapter 6) in the context of the wider literature.

A key result from each of the papers (Chapter 4, Chapter 5 and Chapter 6) is that the TPB variables were mostly significantly associated with intentions. These findings suggest that the implementation of nutrient management planning depends on the three socio-psychological components of the TPB: farmers' evaluation of the outcomes of implementing nutrient management planning (attitude), their perceptions about the social pressure to implement nutrient management planning (subjective norm) and their perceptions about their own capability to use this practice (perceived behavioural control). Similar to the findings of previous studies, these results confirm that the TPB is an appropriate framework, for examining and explaining the factors which influence farmers' intentions towards the implementation of nutrient management planning (e.g. Micha *et al.,* 2015; Borges and Oude Lansink, 2016; Lalani *et al.,* 2016; Adnan *et al.,* 2017b; Zeweld *et al.,* 2017; Jiang *et al.,* 2018). Moreover, the results also support the arguments made by researchers that socio-psychological issues must be taken into account when studying farmer decision making (Burton, 2004a; Borges *et al.,* 2014; Zeweld *et al.,* 2017).

Whilst each of the studies (Chapter 4, 5 and 6) confirmed the importance of the TPB for studying farmers' intentions towards implementing nutrient management planning, it is also clear from the results that overall subjective norm and perceived behavioural control are more important than farmers' attitudes as variables influencing their intentions. This is somewhat surprising given that a vast number of studies have shown that attitude is often the most important variable influencing farmer decision making (e.g. Garforth *et al.,* 2006; Wauters *et al.,* 2010; Reimer *et al.,* 2012; Borges *et al.,* 2014; Rezaei *et al.,* 2018). However, the result concurs with Borges and Oude Lansink (2016) and Deng *et al.* (2016) who both used the TPB to study farmers intentions towards agricultural practices and found that subjective norm and perceived behavioural control were more important than farmers attitude towards the practice. Moreover, the mixed results for the TPB variables are expected because, according to Ajzen (1991), the relative importance of attitude, subjective norm, and perceived behavioural control in the prediction of intention varies across behaviours and situations. The result perhaps implies that social pressure is critical to farmers' intentions to engage in nutrient management planning. Burton (2004a) suggests that individuals do not act independently of cultural and social influences, but are frequently referring their behaviour to a significant reference group. Therefore, social pressure may motivate farmers to implement nutrient management planning regardless of their attitude towards it. Furthermore, due to the complexity of, for example interpreting a nutrient management plan and implementing it, issues of control are expected to have a significant importance.

Whilst the studies presented in Chapter 4, 5 and 6 confirm the importance and relevance of the TPB to studying nutrient management planning, Chapter 4 and 5 in particular also demonstrate that contextual factors such as policy, extension, as well as farm and farmer characteristics, are further important predictors of intentions, albeit the results are mixed. The mixed results are similar to meta-analyses of the farm management literature which found few factors that consistently predict practice adoption across various contexts (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). These results also confirm arguments made in the literature for the inclusion of additional predictors alongside the original TPB variables to improve its ability to predict peoples' intentions (Conner and Armitage, 1998; Burton, 2004a; Rezaei *et al.,* 2018). The results also provide some support towards the best management practice literature which tends to focus on identifying non socio-psychological determinants of adoption (Prokopy *et al.,* 2008; Baumgart-Getz *et al.,* 2012). Moreover, the results also provide support for researchers who argue that farmer decision making is complex and arguments that state that it is important to consider both internal (e.g. attitudes and beliefs) and external drivers (e.g. farm system, information provision and policy) of farmers' decision making processes (Edwards-Jones, 2006; Feola and Binder, 2010). The results of the study resonate with the notion that farmer behaviour is driven by both ‘intrinsic’ and ‘extrinsic’ motivations espoused by Mills *et al.* (2018) who found that farmers’ motivations for providing unsubsidised environmental benefits were driven by both ‘intrinsic’ (e.g. personal views) and ‘extrinsic’ factors (e.g. agronomic concerns and social pressure). Moreover, the results concur with Yoshida *et al.* (2018) who argue that farmers are constantly consolidating their actions between personal interest and external pressures to produce food in an environmentally friendly way.

To overcome the limitations inherent to Chapter 4 and 6, Chapter 5 employed a latent class analysis (LCA) to account for unobserved heterogeneity among the sample. Chapter 5 demonstrated that heterogeneity exists among farmers and the factors which influence their intentions. These results support the literature which employs farmer typology approaches using either clustering techniques or LCA and reveal that heterogeneity among the farming population exists (e.g. Barnes *et al.,* 2011, 2013a; Poppenborg and Koellner, 2013; Läpple and Kelley, 2013; Hammond *et al.,* 2017). Moreover, these results provide support for using targeted intervention strategies designed to encourage farmers to adopt desirable agricultural management practices (Blackstock *et al.,* 2010). Therefore, the results of this study concur with Mills *et al.* (2018) who suggest that to achieve a change in farmer behaviour a mix of targeted and appropriate tools must be employed under a coherent policy and advice framework to stimulate change.

7.5 Policy implications

Farmer level

Overall, at the individual farmer level the results of this study show that perceived behavioural control and subjective norm (social pressure) are more important drivers of intention than attitude. These results potentially imply that farmers are perhaps aware of the general benefits of nutrient management planning but are not quite sure how to reap the benefit on their individual farm (perceived behavioural control) and do not necessarily feel a high enough level of social pressure to do so. Therefore, whilst policy makers should continue to convince farmers of the benefits of nutrient management planning, the results of this study suggest that greater efforts should be made towards increasing perceived behavioural control and social pressure. Specific recommendations include: 1) greater levels of farmer engagement with nutrient management planning to improve control, capability and confidence, 2) increasing social pressure to implement nutrient management planning as a way to establish norms, 3) improving the relevance of nutrient management planning to individual farmers as a means to improve attitude and perceived behavioural control.

Greater levels of farmer engagement with nutrient management planning to improve control, capability and confidence

In terms of the first recommendation, perceived behavioural control was a highly significant result throughout the empirical studies (Chapter, 4, 5 and 6). This means that farmers who feel they have control over implementation and feel confident in their ability to do so are more likely to have an intention to do so. As nutrient management planning is a technical practice, farmers tend to be highly reliant on external support for making decisions in this area of farm management (Osmond *et al.,* 2015; Stuart *et al.,* 2018). Thus, farmers may not always feel they have control or ownership over the way in which they manage nutrients on their farm due to this dependency on external support. This study concurs with McDonald *et al.* (2019) who argue that there is a need to improve farmer engagement with nutrient management planning.

In terms of the context of this study, farmers could be more engaged in the interpretation of the results of soil analysis and further participate in the development of nutrient management plans. This may help to increase farmers' level of perceived behavioural control due to a sense of ownership over the nutrient management planning process and understanding of the logic behind the recommendations being made. Thus, increasing perceptions of control may increase the likelihood of farmers implementing nutrient management planning.

Research has shown that farmers who participate in nutrient management planning courses, for instance, are more likely to change their nutrient management behaviour as a result (Genskow, 2012). Studies have also demonstrated that knowledge exchange is most effective when there is two-way dialogue (Moschitz *et al.,* 2015). Indeed, participatory approaches that involve a ‘bottom-up approach’ are a more recent trend in terms of extension service provision and should be focused on more (Prager and Creaney, 2017). However, ownership alone may not be enough and therefore a further recommendation is made here. The literature on goal setting suggests that a concrete plan should be set in place to ensure that an individual is able to act on their ‘good’ intentions (Locke and Latham, 2002). For example, participatory sessions used to develop a nutrient management plan with farmers could end with a planning exercise which maps out the steps that the farmers intends to take to implement the plan. This approach could help an individual to act on their intentions due to a potential increase in confidence over their ability to do so (Wilson *et al.,* 2018). Therefore, it is recommended that this type of exercise is also incorporated into the extension programme design.

Increasing social pressure to implement nutrient management planning as a way to establish norms

The prominence of the influence of subjective norm (social pressure) on farmers intentions throughout each paper (Chapter 4, 5 and 6) provides support for increasing the level of social pressure that farmers feel towards implementing nutrient management planning. There are a range of actors that could possibly exert social pressure on farmers to implement nutrient management planning (e.g. public and private advisory services, farmer-based organisations, non-governmental organisations and research institutes) (Prager *et al.,* 2017). However, the results in Chapter 6 demonstrate that farmers who trust information from either ‘technical sources’ (e.g. advisors, discussion groups and courses) or ‘social sources’ of information (e.g. other farmers, the media and family) in terms of nutrient management planning on their farm are likely to feel a greater level of social pressure to implement nutrient management planning.

A key form of social pressure is nutrient management policy that requires the mandatory adoption of certain nutrient management practices. Regulation can increase adoption rates of practices such as soil testing and a nutrient management plan. Moreover, research has shown that a fear of future regulation can stimulate pressure to voluntary use such practices in decision making (Savage and Ribaudo, 2013). However, some argue that the use of soil testing and following a NMP remain voluntary as these practices are hard to regulate (Perez, 2015). Therefore, it important to couple regulation with other social pressures. For example, asking farmers to make a commitment made in public may lead to greater adherence because of the possible negative social sanctions that may ensue for breaking it (Lockhortst *et al.,* 2011). Furthermore, advice given to farmers regarding nutrient management planning could be delivered at the community level through farmer/peer groups which, some have argued, might prove more effective at influencing and engaging farmers in environmental behaviours than advice to individual farmers (McGuire *et al.* 2013). There is evidence that messages delivered through a group can create a positive social norm (if most farmers in the group take up the message) (Mills *et al.,* 2016). Through group distribution of information and best practice with their peers, views of what is deemed suitable behaviour become more established and this increases feelings of personal responsibility (Barnes *et al.* 2013a). In the case of agri-environmental change, it can also intensify response efficacy, as individuals perceive they are more likely to achieve a positive outcome if all members are working towards resolving the same issue (Mills *et al.,* 2016). For advisory approaches to function at this level needs an understanding of who is in the farmer's network (their reference group), whom they trust and could possibly take a local delivery, partnership working approach (Mills *et al.,* 2016).

Reed *et al.* (2014) suggest that trust is often more important than the method in which information is provided to farmers. Therefore, it is suggested that further efforts are made to engage farmers with a diverse range of information sources, especially those that they trust. This is likely to indirectly increase the level of social pressure farmers feel towards implementing nutrient management planning. This recommendation concurs with Prager *et al.* (2017), who suggest that a diverse range of advisory methods should be employed within the advisory system to influence farmers from individual one-on-one advice, to group extension, through to the use of mass media as different farmers will respond better to certain forms of extension than others. In line with Micha *et al.* (2018), it is recommended that policy makers should more actively seek farmer participation in such extension programmes rather than simply providing the means for voluntary engagement.

Whilst increased engagement with information sources that farmers trust is likely to indirectly increase social pressure, active efforts to increase levels of social pressure should also be explored. In line with Barnes *et al.* (2013b), it is suggested that there is a need to further increase the visibility of good practices on individual farms among peers. Coupling such efforts with key messages from the individuals that farmers trust may help to increase levels of social pressure. Klerkx *et al.* (2017) suggest that in many countries the time spent and depth of certain topics discussed by extension services is not always adequate. Therefore, it is recommended that, if appropriate, a larger degree of time is spent by, for instance, advisory services discussing the merits of nutrient management planning and exerting pressure on farmers to implement nutrient management planning.

Improving the relevance of nutrient management planning to individual farmers as a means to improve attitude and perceived behavioural control

The final recommendation made at the farm level is to improve the relevance of nutrient management planning to individual farmers as a means to improve attitude and perceived behavioural control. From the results it appears that if farmers are aware of how nutrient management planning can benefit them individually and if they feel that it is under their capability to do so then they are more likely to implement it. Thus, making nutrient management planning more relevant to individual farmers and farms (e.g. systems) may increase implementation. One possible method for achieving this is through the provision and increased use of decision support tools among farmers (Rose *et al.,* 2016, 2018). In line with Gibbons *et al.* (2014) and Macintosh *et al.* (2019), despite the existence of various nutrient management tools, there remains scope for the provision of better and more simple tools in the realm of nutrient management planning. These authors argue that such tools must enable farmers to quantify the specific benefits to their individual farm as well as highlighting indirect environmental benefits. Wall *et al.* (2012) also suggest that a better farm-scale nutrient auditing tool could enable farmers to better target areas of the farm that most need them. It is recommended here that a tool should be developed that not only helps farmers to quantify the benefits for their particular farm (which can improve attitudes) but also enables better decisions (e.g. quantity and timing of fertiliser application) to be made (improve behavioural control).

These benefits and suggestions for decision making should all be made within the remit of farmers resource and time capacity as well as goals and objectives for production (Rose *et al.,* 2018a). However, the uptake of existing tools can often be limited across the farming community (Gibbons *et al.,* 2014; Rose *et al.,* 2018a). Therefore, it is recommended that such tools are locally developed, involving multiple stakeholders (e.g. agricultural advisers, farmers and technology specialists) (Jakku and Thorburn, 2010; Rose *et al.,* 2018b) and promoted by people that farmers trust (Gourley *et al.,* 2007).

National level

At the national level a number of key recommendations can be made based on the results from this study (Chapters 4, 5 and 6). These include to: 1) better target different audiences when delivering behavioural change initiatives designed to promote positive attitudes, social pressure and perceived behavioural control, 2) incentivise the trialling of nutrient management planning, 3) ensure social pressure and technical assistance is promoted alongside mandatory policy requirements.

Better target different audiences when delivering behavioural change initiatives designed to promote positive attitudes, social pressure and perceived behavioural control

Based on the results of Chapter 5, which identified heterogeneity within the farming sample, it is recommended that policy makers focus on the diversity among the farming population in terms of targeting the factors which are most likely to motivate positive behavioural change. The results from Chapter 5 revealed that whilst most farmers are likely to react positively to social pressure exerted on them to implement nutrient management planning, at this point in time some farmers are more likely to respond positively to campaigns designed to enforce positive attitudes whilst others may react more positively to campaigns specially designed to increase behavioural control over implementation.

Chapter 4 found that farmers operating under mandatory policy requirements are more likely to have an intention to implement nutrient management planning if they feel a higher degree of social pressure. Therefore, more emphasis could be given to different campaigns designed to increase the implementation of nutrient management planning. In line with Blackstock *et al.* (2010), it is argued here that just as physical scientists appreciate that not all catchments are the same, in the context of nutrient management planning, policy makers need to make greater efforts to take into account how receiver characteristics differ. Thus, greater efforts need to be made to tailor advice and engagement strategies upon different farming contexts (e.g. system and farm size, farmer age and education) and behavioural components (e.g. attitudes, perceptions, locus of control and ability to comprehend) (Pornpitakpan, 2004; Mills *et al.,* 2016). Advice therefore needs to be tailored to target these differences and judgements about the message and the source therefore need to understand the different social contexts of the receivers within farming communities (Blackstock *et al.,* 2010). For example, whilst there has been a growing emphasis on farmer-to-farmer learning in recent years (Prager and Creaney, 2017; Laforge and McLachlan, 2018), not all farmers will know, trust or even talk with one another and therefore careful targeting of behavioural change strategies is required (Blackstock *et al.,* 2010).

Incentivise the trialling of nutrient management planning

Perceptions of resources (Chapter 4) and perceived behavioural control (Chapter, 4, 5 and 6) and farm system (Chapter 4) are key results emerging from this study. These results potentially imply that the resource capacity of farmers as well as the level of ease or difficulty and confidence in their ability to implement nutrient management planning may be hindering implementation. Therefore, one way of improving farmers' perceptions of resources available to them and perceptions of control are programmes that incentivise the trialling of nutrient management planning (e.g. soil testing, nutrient management plans) and the provision of financial support for trialling new ways of managing nutrients on small areas of farms. Such programmes can help to provide resources to remove the potential barriers surrounding risk of changing from the existing way of managing nutrients. Osmond *et al.* (2015) and Reimer *et al.* (2018) both found that financial support and trialling are effective ways for encouraging farmers to alter their nutrient management strategies. Wilson *et al.* (2018) argues that building perceived control among farmers may require creating low-risk opportunities for individuals to test out a practice at a small scale on their farm. Furthermore, there has been a shift in promoting 'whole farm nutrient management planning', and whilst this is beneficial from a financial and environmental perspective, it ignores the fact that if farmers currently conduct low levels of nutrient management planning, switching to whole farm nutrient management planning (which requires a deviation from the status quo) may be viewed as too risky.

Research has suggested that farmers prefer to reduce risk by only making changes to management after conducting 'small tests' or 'field trials' and then implementing incremental changes (Olhmer *et al.,* 1998). Therefore, providing financial support and assistance for trialling nutrient management planning on individual farms may help encourage farmers to increase their use of nutrient management planning in the future.

Ensure social pressure and technical assistance is promoted alongside mandatory policy requirements

The final implication relates to the role of policy which requires the mandatory adoption of nutrient management planning by certain groups of farmers. The results reveal that policy positively influences intentions (Chapter 4 and 5) and therefore policy is potentially a useful tool for promoting behavioural change. The results of chapter 6 showed that farmers engaged in policy also feel a higher degree of social pressure and level of control in engaging in nutrient management planning. Based on these results it is recommended mandatory policy continues (if already not in place) to be coupled with initiatives designed to increase social pressure and perceived behavioural control over implementation of nutrient management planning. For example, increasing the visibility of farmers in breach of policy requirements may increase social pressure to implement a nutrient management plan to help stay within policy requirements due to a fear of embarrassment or future regulation. Coupling regulation with increased levels of on-to-one engagement with farmers in terms of developing and implementing, for example, nutrient management plans may help farmers to implement plans that have been developed due to policy requirements (Perez, 2015).

7.6 Limitations to the research

Despite providing a detailed examination and explanation of farmers' intentions towards implementing nutrient management planning in Ireland, a number of important limitations to the research exist. These limitations are discussed and are organised into two key themes: theoretical limitations and methodological limitations.

Theoretical limitations

The theory underpinning this research was the TPB. As mentioned previously, the TPB has been used to explain farmers' intentions in a variety of contexts (e.g. Micha *et al.,* 2015; van Dijk *et al.,* 2016; Senger *et al.,* 2017; Hyland *et al.,* 2018b; Jiang *et al.,* 2018; Rezaei *et al.,* 2018). Furthermore, the TPB is widely acclaimed for being able to provide a structured, theoretically rational and replicable methodology for better understanding the determinants of peoples' intentions (Beedell and Rehman, 2000). However, the TPB is not without limitations and whilst these were addressed to some extent in the empirical papers, primarily through the addition of a number of context and practice specific variables not addressed by the theory, these limitations are now discussed.

Firstly, some have argued that the TPB is limited insofar as it focuses on rational decision making by implying that humans are rational beings that make systematic use of information available to them to inform decision making (Sniehotta *et al.,* 2014). In essence, the TPB focuses on 'conscious' influences on behaviour and therefore an important omission from the TPB is the role that unconscious influences on behaviour play (Sheeran *et al.,* 2013). Humans decision making also has a 'non-conscious' component which relies on impulsive mental processing of which the decision maker is often unaware (Sheeran *et al.,* 2013). An assumption made by the TPB is that changing a person's conscious cognitions will produce a change in behaviour, which research has shown is not always guaranteed (Sheeran *et al.,* 2013). However, as Simon (1955) argues, people make decisions under 'bounded rationality' which alludes to the process by which decision makers are limited by cognitive constraints (computational capacity) in the search for, and evaluation of, the information used in making decisions. This then results in a bounded rational choice as opposed to an optimal choice being made, a choice which is described as a 'satisficing' rather than 'optimizing' response to a decision choice. These 'satisfactory' decisions are typically arrived at through heuristics which are a type of simple decision rule that lowers the cost of accessing and processing information as a means to simplify a complex problem (Collentine *et al.,* 2004). One component guiding heuristics is the notion of cognitive biases, such as acquiescence bias, optimism bias and self-serving bias amongst many, which can lead to systematic errors of judgment (Tversky and Kahneman, 1973; Kahneman, 2011).

Rational choice models, such as the TPB, implicitly assume that individuals make decisions by carefully calculating the costs and benefits of different courses of actions and selecting the options that maximise their expected overall benefits (Yazdanpanah and Forouzani, 2015). Therefore, a key underpinning assumption of the TPB is that people act always in their own self-interest to attain rewards and thus ignore moral and other values that may underpin individuals' behaviours. Whilst farmers' motivations are still dominated by production-oriented attitudes and they often identify themselves primarily as 'producers of food' (Burton and Wilson, 2006; McGuire *et al.,* 2013), like most people, farmers are not always exclusively motivated by narrow self-interest but also by the welfare of others such as their local community or the environment (Van Vugt, 2009; Czap *et al.,* 2012; Reimer *et al.,* 2012; Yoshida *et al.,* 2018). A body of research has also shown that farmers are also motivated by other attitudes and goals such as towards environmental stewardship (Gasson, 1973; Willock *et al.,* 1999; Prokopy *et al.,* 2008). Studies often show that farmers who display a higher level of positive attitude towards the environment and stewardship in general are more likely to adopt farm management practices that have the potential to reduce environmental impact even if this means forgoing some profit (Chouinard *et al.,* 2008; Reimer *et al.,* 2012b; Thompson *et al.,* 2015).

Two prominent variables from social theory that have been added to the TPB by various researchers include the concepts of 'self-identity' and 'moral norms', both of which are not considered by this research (Conner and Armitage, 1998; Fielding *et al.,* 2008; Yazdanpanah *et al.,* 2014; Wauters *et al.,* 2016; van Dijk *et al.,* 2015, 2016; Rezaei *et al.,* 2018). Here the concept of 'self-identity' is pertinent. It is derived from identity theory which suggests that the self is a set of socially constructed roles that reflect the extent to which a person sees him or her self as fulfilling the criteria for a particular societal role (Stryker, 1968).

For example, a farmer may see him or herself as a farmer who is concerned with the environment and may therefore perform unsubsidised agri-environmental management even though it may lead to a financial loss which counteracts the identity of a farmer as an business owner (van Dijk *et al.,* 2016). 'Moral norms', on the other hand, stem from the norm activation theory and refer to internalised values that are experienced as feelings of personal obligation to engage in a certain behaviour (Schwartz, 1977). As 'good management' is seen as part of the 'good farmer identity' (Burton, 2004b) and use of fertiliser can have a negative impact on the environment, exploring 'self-identity' and 'moral norms' could form the basis of future research.

Another omission from the TPB, and considered as beyond the scope of this research, is the influence of past behaviour; i.e., habits (Triandis, 1980). Habits can be defined as the repetition of deliberate choices which are made because the outcomes of the choices are viewed to be satisfactory to the decision maker (Jager *et al.,* 2000). Moreover, past behaviour is directly a predictor of intention and behaviour (Conner and Armitage, 1998). Wood and Neal (2009) conclude that people who are less driven by habits tend to behave based on their intentions, whereas people with strongly embedded habits typically continue to respond to past routines regardless of their intentions. Research within an agricultural domain has demonstrated that habits are a key component guiding farmer decision making which only tend to be broken once a problem in the current situation or decision making sequence has been detected (Olhmer *et al.,* 1998; Mccown and Carberry, 2005; Abadi, 2018). Therefore, in the context of this research, farmers may be aware of the benefits of nutrient management planning. However, due to a lack of a perceived significant problem with current management practices they may not be inclined to implement new nutrient management planning strategies that deviate from the norm. Moreover, as described previously, cognitive biases and limited cognitive processing power (e.g. ability to seek and synthesise information) may restrict farmers from breaking current habits of non-adoption and to continue with conducting somewhat unconscious, routine behaviours guided by habit but also by tradition and 'informed intuition' (Nuthall and Old, 2018a).

Another criticism of the TPB, and thereby the research presented in this thesis, is that it does not accommodate the dynamic nature of the decision making process and thus it is considered to be static. The TPB constructs are measured using cross-section data by asking respondents at a single point in time to state their beliefs and intentions (Beedell and Rehman, 2000). However, farmer decision making is regarded as dynamic and cyclical which is influenced by feedback they receive from experience and external sources of information (Olhmer *et al.,* 1998; Mccown and Carberry, 2005). Therefore, farmers' beliefs and intentions towards nutrient management planning may change over time. Therefore, the approach used by this research does not capture information about the process of adoption and the changes that may have occurred over a period of time. In order to address this issue, a similar survey could be repeated among the same farmers to analyse changes in beliefs and intentions over time.

The focus of this research is on the association of explanatory variables with behavioural intention. Whilst behavioural intention is an important antecedent to behaviour, it is not a faultless predictor of it (Fishbein and Ajzen, 2010). Therefore the recommendations based on this research (see 'policy implications') are limited to making suggestions on how to increase the likelihood that farmers will act on their intentions, but cannot guarantee future behaviour. Thus, this research does not examine the relationship between intentions and behaviour. A meta-analysis by Sheeran (2002), which is based on a number of previous meta-analyses of the literature, reveals that intention, on average, predicts 28% of the variation in behaviour. Thus, a significant gap exists between peoples' intention to perform a behaviour and actual performance, which is often referred to as the 'intention-behaviour gap' (Sniehotta *et al.,* 2005). Various explanations and variables are believed to hinder people from translating their intentions into behaviour such as withdrawing effort before completing a goal, cognitive ability (e.g. low will power), competing goals, emotions (e.g. disruptive thoughts and feelings), bad habits, failure to monitor progress, and forgetting to act (Sheeran and Webb, 2016). As farmers were asked to state their intentions towards the uptake of nutrient management planning practices in the 'near future', ideally future research would look to see whether farmers who displayed an intention to uptake went ahead and acted upon these intentions and to study the reasons preventing those that did not from doing so.

Another key criticism of the TPB is the overall focus of the TPB which is primarily on predicting behaviour and therefore it has been criticised for not being able to suggest how to influence and change behaviour (Dwyer *et al.,* 2007). Chapter 6 overcame this criticism to an extent by introducing a number of variables that have been shown to be 'levers' of behavioural change in the literature. The paper correlated these variables (policy, education and trusted information sources) with the TPB components (attitude, subjective norm and perceived behavioural control) to try and explain which 'levers' are the most likely to influence farmers' beliefs and ultimately promote further uptake of nutrient management planning in the future. However, among other limitations, the results of this paper did not reveal how best to frame messages, why certain trusted sources are likely to induce positive behavioural change on farmers than non-trusted sources or how to enhance the perceived quality of the information source (Dwyer *et al.,* 2007). Insights from 'persuasion theories' could be used in future work to gain an understanding of how exactly farmer behaviour can be altered by changing certain beliefs towards nutrient management planning (Haugtvedt and Petty, 1992).

Methodological limitations

Definition of intentions

The first set of methodological limitations relate to the way in which intention was approached by this study. The research presented in this thesis is limited to two, albeit important, nutrient management planning practices. It was demonstrated that the chosen practices under study are critical to improving nutrient management planning and have the potential to both reduce the risk of nutrient loss from farms whilst also improving financial returns from nutrients. However, applying fertiliser on the basis of soil test results and following a nutrient management plan are just two critical management planning practices among a host of practices. Others directly linked to nutrient management planning include manure testing, adjusting stocking rates, record keeping, nutrient budgeting, plant tissue testing and decision making surrounding nutrient application methods. It is also important to note that nutrient management planning is only one aspect of recommended nutrient management practices more widely. Others relate to erosion and runoff control to prevent soil erosion and decrease the mobilisation of nutrients; and installation of barriers and buffers to intercept sediments and nutrients transported from the field (Hassanzadeh *et al.,* 2019). However, the results of this research are generalisable to practices that offer both financial and environmental benefits as the drivers and constraints on adoption may be similar but less applicable to practices that only present environmental benefits e.g. conserving biodiversity, preserving traditional animal genetics and fencing off-water courses.

The empirical papers presented in this thesis (Chapter 4, 5 and 6) also treat the intention to apply the practices under study as singular decisions rather than a series of possibly interrelated decisions. For example, a farmer who conducts soil testing may also be inclined to develop a nutrient management plan based on the results of the soil analysis. By omitting this influence, this can lead to an oversimplification of the decision making process that farmers face in reality and ignore the fact that farmers often adopt such practices together as they have the benefit of complementarity (Tsinigo and Behrman, 2017; Adusumilli and Wang, 2018; Ward *et al.,* 2018). Cooper (2003) found that identifying and packaging farm management practices that are viewed to be jointly beneficial can increase adoption and reduce the costs of voluntary adoption agricultural programs. Disregarding the interdependencies and simultaneities in the adoption of nutrient management planning practices might underestimate or overestimate the influence of factors on decision making

(Teklewold *et al.,* 2013). Future research could look to build on the research presented in this thesis by identifying opportunities surrounding the promotion of co-dependent practices using statistical techniques such as multivariate probit analysis (Tsinigo and Behrman, 2017).

As alluded to in each of the empirical papers (Chapter 4, 5 and 6) farmers' intentions were measured on an ordered Likert-scale from strongly disagree (1) to strongly agree (5). However, as discussed in these chapters, it was not possible to use the scale due to a violation of the proportional odds assumption. Therefore, the scale is collapsed by grouping farmers who strongly disagree (1), disagree (2) and responded neither (3) and labelling them as 'non-intenders' and grouping those who agree (4) and strongly agree (5) and labelling them as 'intenders'. Whilst this research successfully provides insights into the factors which influence farmers to implement nutrient management planning using this method, this approach is limited in some ways. Firstly, it does not allow for quantification of the extent to which farmers intend to implement nutrient management planning. Secondly, it groups together potentially divergent groups of farmers, for example, farmers who strongly disagree may have different behaviours to those who responded neither. A multinomial logit model was developed to try and overcome this limitation but was not successful as too few farmers fell into the strongly disagree and disagree categories.

Survey

The second set of limitations relate to the survey approach used to collect the data for the purpose of this thesis. The data collected in this research was obtained via a cross-section survey and therefore a limitation of this approach relates to the fact that time-series data was not incorporated into the analysis. It was highlighted in Chapter 1 that the focus of this thesis is on the factors largely (but not exclusively) within the control of farmers and therefore variables such as fertiliser price, farm-gate prices, weather, soil fertility and water quality levels over time are not incorporated into the analysis. It is probable that a number of these variables may increase the incentive to adopt nutrient management planning. For example, cheap fertiliser prices may be a disincentive towards strict planning as fertiliser is often viewed as a way to reduce the risk of low yields and thereby over application may be incentivised by low fertiliser prices (Buckley *et al.,* 2016). Moreover, the current models do not include the adoption costs as a potential explanatory variable and thus suggestions cannot be made in terms of incentive-based policies like payments for these practices due to the difficulty of accurately measuring the adoption costs for a particular practice at the field or farm level (Zhang *et al.,* 2016). Future research may look to incorporate time series data into the analysis of farmers' intentions towards the implementation of nutrient management planning and to calculate the specific costs and benefits involved in implementation.

The studies presented in this thesis rely on data that has been self-reported, presenting a number of limitations. Whilst such data is easier to obtain than 'true' beliefs held by individuals, self-reported behaviour is vulnerable to self-representation bias due to a tendency for some respondents to overstate performance of socially desirable behaviours (Ajzen and Fishbein, 2004). For example, Armitage and Conner (2001) found from a meta-analysis, that when behaviour measures were self-reported, the TPB accounted for 11% more of the variance in behaviour than when behaviour measures were objective or observed. An additional criticism of using surveys which elicit self-reported beliefs and intentions is that responses to survey items may not measure existing beliefs and intentions, but may in fact create new beliefs and intentions or change existing views (Ogden, 2003). Therefore, individuals may in fact also misreport their behaviour unintentionally. Another reason for biased reports from farmers is linked to the potentially controversial nature of the behaviour being examined in the study, which may lead farmers to deflect attention from their actions (Floress *et al.,* 2018). Nutrient management policy is prevalent in Ireland and as alluded to in Chapter 4, fear of future policy regulating nutrient use may be leading farmers to represent their behaviour in a positive light.

The data was collected from a sample of Irish farmers. Whilst it was argued in Chapter 1 that the results can be applied more widely they should still be treated with caution when making generalisations. The main issue relates to the structure of farming which is, on average low intensive, low income generating and highly dependent on subsidies to maintain viability (Ryan *et al.,* 2016). Läpple *et al.* (2015) suggests that many cattle and sheep farms in Ireland are particularly impervious to technological innovation when compared to other farming systems, due to lower incomes. For example, the average farm size in Ireland is around 32ha whereas in the UK the average is 57ha, in the US it is 180ha, in Australia it is 4331ha. The relatively large farm sizes in Australia have also demonstrated relatively high rates of return for investment and overall profits (Sheng *et al.,* 2015). A positive relationship has also been found to exist between farm size, productivity and other indicators of performance in the US and EU (Hallam, 1991; Mundlak, 2005). The results showed that issues of resources and perceived behavioural control were particularly important to this study which may reflect overall structure of Irish agriculture and be less important in areas of the world where farmers are less resource constrained.

Empirical methods

The final set of methodological limitations pertains to the empirical methods applied to the data which are also subject to limitations. For example, the methodology used in Chapter 4 and Chapter 5 did not enable testing of all hypotheses underlying the theoretical framework employed for the purpose of the study. That is, using a binary logistic regression, it was only possible to assess the direct associations between the independent variables and intentions. Here, logistic regression models assume that the relationship between the independent variables and the dependent variable is uniform (Aggarwal and Ranganathan, 2017). This assumption may not hold true for particular relationships, for example, farmers' attitudes towards nutrient management planning may be higher if they are in contact with an agricultural advisor. This limitation was overcome in Chapter 6 where structural equation modelling (SEM) was used to enable a number of indirect relationships between the TPB variables and a number of background variables to be assessed. On the other hand, a limitation inherent to Chapter 4 and 6 is that farmers are assumed to to be a homogeneous group. However, Chapter 5 used latent class analysis (LCA) to overcome this limitation which enabled farmers to be classified according to a number of farm and farmer socio-economic characteristics based on findings from the literature.

A key methodological challenge in this research was to reliably represent the latent constructs, especially those associated with the TPB (attitude, subjective norm and perceived behavioural control), that is, how to assure that the items used to measure these variables 'truly' represent these latent constructs. One way to achieve this is to measure construct validity, which is the extent to which a set of items represent the theoretical latent construct those items are intended to measure (Hair *et al.,* 2010). There are two aspects of construct validity which are: convergent validity and discriminant validity. When items used to measure a single construct (e.g. attitude) share a high proportion of variance, then there is convergent validity. Discriminant validity refers to the extent to which a construct is truly independent from other constructs. In Chapter 4 and 5 the constructs attitude, subjective norm and perceived behavioural control (also perceived resources in Chapter 4) were measured by using a principal component analysis (PCA) to group highly correlated item responses to represent the latent variables. To check the reliability of the groups of statements used to measure these variables Cronbach's alpha was used. However, Cronbach's alpha is only one particular method that can be used to check reliability, and reliability is only one of the indicators of convergent validity. Thus, convergent validity was only partly analysed in Chapter 4 and 5. Alternative methods for assuring convergent validity are accessible when confirmatory factor analysis (CFA) is utilised. Furthermore, in Chapter 4 and 5, discriminant validity was not evaluated. These issues were addressed by using SEM in Chapter 6. Here, CFA was utilised both to compute the latent construct scores for each respondent and to test whether the measurable items reliably represented the constructs intention, attitude, subjective norm and perceived behavioural. Thus, convergent and discriminant validity was assured. However, SEM requires large sample sizes and as Chapter 4 and 5 split farmers into groups, albeit using different techniques, it was not possible to apply SEM to analyse the data in these chapters.

7.7 Future research

There are various ways in which this work could be extended, relating to both theoretical and methodological approaches. Here, five important suggestions are provided: 1) conduct a mediation analysis to investigate potential 'indirect' effects of explanatory variables on farmers' intentions, 2) incorporate variables not considered by this research (e.g. attitudes toward farming (e.g. environment, risk, profit, stewardship), moral norms and self-identity) into the analysis of farmers intentions using the TPB, 3) investigate how agricultural extension methods could be improved in terms of better targeting of information and messages in line with socio-psychological variables (e.g. beliefs and intentions), 4) conduct a spatial analysis by overlaying behavioural variables with biophysical risk of nutrient loss areas to investigate whether patterns of 'behavioural risk hotspots' (low current adoption and future intentions to implement) and 'nutrient risk hotspots' (high chance of loss from soil to water and air and areas of poor water quality) exist, and 5) employ a cost benefit analysis to quantify the financial and environmental implications from implementing different levels of nutrient management planning on different farm systems.

The first direction for future research considers examining mediation effects within the TPB framework. The TPB has been criticised for assuming that the variables in the model (and additional variables) are additive (or linear) in their effects on intentions and behaviour (Conner and McMillan, 1999). The research presented in Chapter 6 addresses this issue to an extent by examining indirect relationships between the TPB variables (e.g. the influence of perceived behavioural control on attitude) but mediation effects were not examined. This means that the paper did not examine to see whether, for example, attitude mediates the effect of perceived behavioural control on intentions. Nor did Chapter 6 investigate the indirect influence of background variables on intentions through (mediated by) attitude, subjective norm and perceived behavioural control. The approach used in Chapter 6 is favoured on grounds of parsimony and was focused on establishing the cognitive foundations of farmers beliefs, but leaves scope for future research (Conner and McMillan, 1999). For example, Abadi (2018) found that attitude towards pest and disease management forecasts indirectly influences pesticide use behaviour by the mediation of attitude, perceived behavioural control and behavioural intention. Floress *et al.* (2017) found that environmental stewardship attitudes mediate the relationship between farm business as well as awareness and farmers' willingness to take up actions to protect water quality in Indiana, USA. Okumah *et al.* (2018) found that agri-environmental scheme participation mediates the relationship between environmental awareness of diffuse pollution mitigation measures and their compliance with them. However, studies which employ the TPB in an agricultural context (Wauters *et al.,* 2010; Borges *et al.,* 2014; Läpple and Kelley, 2013; Micha *et al.,* 2015; Borges and Oude Lansink, 2016; Adnan *et al.,* 2017, 2018; Hyland *et al.,* 2018a, 2018b; Jiang *et al.,* 2018) typically do not investigate mediation effects and therefore future research should look to investigate potential effects. Whilst there are several ways (e.g. causal step approach, Sobel Test) to test the mediation effects, bootstrapping interprets the mediation effect more strongly and therefore it is recommended for this future research (Wang *et al.,* 2018). This type of analysis will help to further unravel the farm decision making process and provide useful information on better designing interventions.

This research was confined to specific beliefs and attitudes towards a specific practice. It therefore conforms to what Ajzen (2011a) describes as the principle of compatibility which suggests that all of the variables in the TPB should be measured at the same level of specificity. However, researchers within an agricultural domain (Gasson, 1973; Willock *et al.,* 1999; Austin *et al.,* 2005; Edwards-Jones, 2006), has demonstrated that general attitudes towards farming (e.g. traditions, towards the environment, stewardship and profit), concepts of self-identity and moral aspects as well as general 'world views' (Reimer *et al.,* 2012a,b; McGuire *et al.,* 2013; Reimer *et al.,* 2018; Yoshida *et al.,* 2018) influence farmer behaviour. However such studies tend to be qualitative in nature and thus results are hard to generalise. The study by Buckley *et al.* (2015) confirmed that farmers motivated by stewardship, production and environmental attitudes were more likely to adopt a greater number of nutrient management practices (e.g. nutrient management plan, soil testing and liming). However, they did not specifically examine implementation of nutrient management planning and therefore there remains scope for further research in this area. This type of research would help to situate farmers' nutrient management planning decisions into a wider social context, and provide information on how to best design messages that farmers most closely resonate with (Mills *et al.,* 2018b). This type of research is important because messages that are personally relevant are more likely to be responded to (Blackstock *et al.,* 2010).

The research in this study revealed important variables which influence the intentions of farmers and made policy recommendations based on these. However, based on the results it was not possible to say exactly how behavioural interventions should be designed. For example, the effectiveness of different messages targeted toward changing farmers' attitudes were not tested in the current research. Whilst an array of 'budges' (e.g. policy and tax) and nudges (information and persuasion) have been suggested to change farmer behaviour (Barnes *et al.,* 2013b), how best to design such interventions is less clear. Moreover, Wilson *et al.* (2018) argue that despite the wealth of knowledge in the behavioural sciences, most of these strategies have not been explicitly identified or evaluated to assess to what extent they can successfully change farmer behaviour or how these behavioural mechanisms can be incorporated into the design of policy aimed at achieving farm level outcomes. Furthermore they suggest that future research should design and evaluate interventions aimed at building, for example, perceived behavioural control, to decipher how best to design education and extension efforts that will be more effective at removing barriers to change at the individual level and increasing adoption of recommended agricultural practices. Prager *et al.* (2017) emphasise the importance of qualitative interviews in future research with key stakeholders involved in the design of agricultural extension services to identify areas for improvement.

Mills *et al.* (2016) suggest that future research should employ approaches involving action research and work closely with farmers in the co-production of knowledge and understanding, which could help to clarify and test the most appropriate engagement messages and approaches required in different situations. Thus, future research could look to conduct qualitative interviews with various stakeholders to identify how best to design such interventions that would, for example, leverage greater levels of social pressure or improve perceived behavioural control among farmers. Furthermore, this is an important area for future research, as it will provide insight into the value and merit of cognitive fixes like education, outreach and improved messaging, relative to structural fixes like regulation and incentives, for policy makers striving to change farmer behaviour and reduce the risk of nutrient loss to water and air from farms (Wilson *et al.,* 2014).

As this study revealed heterogeneity in the farming population based on farm and farmer characteristics and differential drivers of intentions, this potentially calls for spatially targeted nutrient management policies. To develop such strategies, future research could look to overlay intentions to implement nutrient management planning with data on areas of land that are vulnerable to nutrient loss to air and water from a biophysical stand point. This would help to see whether farmers who are a risk from a behavioural standpoint (lower intention) are located in areas of high risk from a biophysical standpoint. Initiatives can then be designed and targeted to areas that are of most concern to policy makers (high biophysical risk and high behavioural risk). This type of research would require the integration of different data sets including the present survey with national soil data, for instance.

On the basis of empirical studies, this research assumed that improved nutrient management planning increases profitability/productivity at the farm level. However, the actual increase at the farm level was not quantified. As the model employed in this research does not include the adoption costs as a potential predictor it was not possible to model incentive-based policies like payments for these practices (Zhang *et al.,* 2016). Research that quantifies the specific benefits of nutrient management planning whilst exists (Whitmore *et al.,* 2012; Buckley and Carney, 2013) remains limited. Veltman *et al.* (2018) argue that in relation to farm management practices there are few that comprehensively evaluate the efficacy of farm management practices to reduce multiple environmental impacts and that include an assessment of productivity and farm profitability. Similarly, Melland *et al.* (2018) recommend that there is a great need to provide sufficient information to farmers for balanced decisions about changing practices, the ratio of costs to benefits of implementing practice changes should be calculated. This is particularly important to nutrient management planning which often requires farmers to make alterations to management if positive outcomes are to be achieved. Future research may wish to quantify actually observed contribution of nutrient management planning to productivity, profitability and also risk of nutrient loss to the water and air at the field or farm level. Such an analysis would be important for developing better farm and field specific nutrient management planning strategies.

7.8 Main conclusions

The main conclusions of this thesis are:

- Nutrient management planning is a key practice for addressing farm productivity and minimising the risk of nutrient loss to the environment (Chapter 1).
- Implementation of nutrient management planning remains limited globally (Chapter 1).

- The TPB is a useful framework for examining and explaining the factors which influence farmers' intentions towards the implementation of nutrient management planning (Chapters 2, 4, 5 and 6).

- Farmer intentions towards nutrient management planning are generally positive (Chapters 4-6).

- Farmers that have a positive intention to implement nutrient management planning on their farm in the near future are more likely to evaluate this practice more favourably (attitude), feel a greater level of social pressure (subjective norm), and feel a higher capability (perceived behavioural control) to do so (Chapters 4-6).

- Intention of farmers to implement nutrient management planning is mainly determined by their perceptions about social pressure (subjective norm), followed by their perceptions about their own capability (perceived behavioural control) and finally their evaluation of the use of this practice (attitude) (Chapters 5 and 6).

- Attitude is generally the weakest predictor of intentions among the TPB variables (Chapters 4-6).

- Agricultural extension and policy are consistent, significant and positive predictors of intentions (Chapters 4 and 5).

- Farmers are a heterogeneous group and this is likely to influence what types of policy initiatives they are likely to respond which are designed to that encourage the further use of NMPs (Chapters 5).

- Farmers are motivated by both 'intrinsic' (e.g. beliefs) and 'extrinsic' (e.g. social pressure, information and type of system) variables when it comes to implementing nutrient management planning (Chapters 4-6).

- Farmers' beliefs towards nutrient management planning are influenced by by sources of information they trust (Chapter 6).

- Increasing farmer implementation of nutrient management planning will require a range of policy solutions that are tailored to different groups of farmers and delivered by people/sources that they most trust (Chapter 7).

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Appendix A

PCA result for farmers' intentions to apply fertiliser on the basis of soil test results.

	Component 1	Component 2	Component 3	Component 4
Statement	Attitude	Perceived behavioural control	Subjective norm	Perceived resources
Increases productivity	0.38			
Produces better quality grass/crop	0.39			
Increases profits	0.35			
Reduces input costs	0.33			
Saves time	0.33			
Helps to protect the environment	0.33			
Improves soil fertility	0.33			
Soil testing increases knowledge about your fields	0.35			
Think that I should do so			0.52	
Encourage me to do so			0.50	

	Component 1	Component 2	Component 3	Component 4
Statement	Attitude	Perceived behavioural control	Subjective norm	Perceived resources
Would approve if I do so			0.50	
Most farmers I am aware of base fertiliser application on recommendations from soil test results			0.47	
A clear understanding of how to do so		0.30		
I am confident in my ability to do so		0.39		
It is under my control to do so		0.45		
It depends entirely on me and not on factors enabling or preventing me from doing so		0.43		
It is easy to do so		0.33		
Is expensive				-0.51
Enough time to do so				0.37

	Component 1	Component 2	Component 3	Component 4
Statement	Attitude	Perceived behavioural control	Subjective norm	Perceived resources
Access to enough labour to do so				0.38
Enough financial resources to do so				0.51
Eigen value	10.21	2.01	1.73	1.20

Appendix B

Principal components (PC) with loadings for farmers' intentions to follow a NMP (only statements that produced PCs are displayed).

	PC 1	PC 2	PC3
Survey question	Attitude	Perceived behavioural control	Subjective norm
Following a NMP increases production levels	0.36		
Following a NMP produces higher quality grass and/or crop	0.34		
Following a NMP improves profits	0.34		
Following a NMP decreases input costs	0.30		
Following a NMP saves time	0.31		
Following a NMP improves soil fertility levels	0.32		
Following a NMP improves knowledge about your fields	0.31		
Following a NMP makes fertiliser application decisions easier	0.31		
If I want to follow a NMP, I have a clear understanding of how to do so		0.35	

	PC 1	PC 2	PC3
Survey question	Attitude	Perceived behavioural control	Subjective norm
If I want to follow a NMP, I have access to sufficient information and/or sources to do so		0.33	
If I want to follow a NMP, I have confidence in my ability to do so		0.42	
If I want to follow a NMP, it is under my control to do so		0.48	
If I want to follow a NMP, it depends completely on me and not on the factors permitting or inhibiting me from doing so		0.45	
If I want to follow a NMP, it is easy to do so		0.36	
When it comes to following a NMP, most people whose opinion I value regarding farming think that I must do so			0.53
When it comes to following a NMP, most people whose opinion I value regarding farming encourage me to do so			0.53

	PC 1	PC 2	PC3
Survey question	Attitude	Perceived behavioural control	Subjective norm
When it comes to following a NMP, most people whose opinion I value regarding farming would agree with my decision to do so			0.49
Most farmers I am aware of follow a NMP			0.39

Appendix C: Survey

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[1] For information on the survey, contact the author: amardaxini@hotmail.com.