

High rates of regular soil testing by Irish dairy farmers but nationally soil fertility is declining: Factors influencing national and voluntary adoption

E. KELLY¹, K. HEANUE², C. O'GORMAN³ and C. BUCKLEY²

ABSTRACT

Paradoxically, high rates of soil testing by Irish dairy farmers coexist with declining national soil fertility levels. This study investigates the anomaly further through identifying the characteristics of farms and farmers who regularly test soil in terms of policy, education, financial capacity, networks, and land-management practices. The study draws on data from a nationally representative sample of 231 specialist Irish dairy holdings. As policy mandates the use of soil tests for some farmers, a sub-sample of non-mandated farms is analysed separately. Findings comparing testers and non-testers show all farmers testing their soil on a regular basis are younger, have larger farms and herds, have larger gross output, have greater expenditure on nitrogen, and are more profitable, compared to farmers who do not. The analysis also shows nationally there is no significant difference in fertilizer and concentrate expenditure per hectare between soil test users and non-users, also reflected in the sub-sample. The logit regression analysis of the full sample suggests policy and extension programmes have a significant effect on adoption, however given national falling soil fertility trends farmers may not be using the results to achieve optimal outcomes. For the voluntary sub-sample farmers who attended part-time education courses and improved farmland through reseeded are more likely to regularly soil test. These findings are important in the context of the somewhat contradictory environmentally-focused and productivity-focused policy instruments that drive regular soil testing behaviour and the anomaly of high rates of soil testing with declining national soil fertility levels.

KEYWORDS: policy; legislation; soil fertility; voluntary use

1. Introduction

Soil testing and farm practice

Soil testing is a key, though not sufficient, tool for improving soil fertility, as the information generated from a soil test report must be implemented or translated into action via nutrient management practices for soil fertility improvements to occur. An improved understanding of the translation of scientific results to practical implementation may require examination of farmer nutrient management practices and soil fertility at a micro level. The research reported here is the first part of a larger social science-based mixed methods research project of Irish dairy farmers' use of soil test information (Kelly, 2014). The empirical context for the project is the anomaly in Ireland between high levels of soil testing (71%) and declining trends in soil fertility. The larger project seeks

to understand the process involved after a soil test is carried out on a farm, how that information is used in subsequent decisions together with other knowledge, and how the resulting actions impact soil fertility levels. Given the lack of prior research in an Irish context, this paper on explores the characteristics of Irish dairy farmers who regularly soil test.

Theoretically farmers test soil to assess its fertility with a view to matching nutrient supply with crop demand, thereby maximising production and profitability while also reducing the risk of nutrient transfer to the wider atmospheric and aquatic environment. The two main functions of soil testing, to determine soil nutrient status and soil pH value (Gallagher & Herlihy 1963), enables farmers to optimally manage the nutrients in their soil in terms of soil fertility and crop return. Achieving a balanced pH in soil ensures the efficient uptake of the

Original submitted April 2016; revision received September 2015; accepted August 2016.

¹ Corresponding author Edel Kelly, School of Agriculture, University College Dublin, Ireland. Email: edel.kelly@ucd.ie, Phone: 0035301 7167140, Postal address: Agri-Business and Rural Development, School of Agriculture & Food Science, University College Dublin (UCD), Belfield, Dublin 4, Ireland.

² Teagasc, Rural Economy Development Programme, Mellows Campus, Athenry, Co. Galway, Ireland.

³ Dublin City University School of Business (DCUBS), Glasnevin, Dublin 9, Ireland.

major nutrients. Nutrients to enhance soil fertility for crop production are applied on farms in two main forms, organic⁴ and inorganic. However, as soil is permeable, inappropriate application of nutrient in terms of volumes or timing may increase the risk of nutrient transfer from agricultural land to the aquatic environment. Soil testing is an established practice and has the potential, from a policy perspective, to deliver a double dividend of increased economic returns to agricultural production while helping to achieve environmental objectives in line with international commitments under the EU Nitrates Directive⁵, the Water Framework Directive⁶, the Kyoto Protocol agreement and EU 2020 targets to reduce greenhouse gas emissions. Soil testing is also considered a cost positive practice⁷: generally soil testers should save money through improved management of required inputs, specifically expenditure on chemical fertiliser or through spatially efficient use of nutrients at farm level.

The Irish Context

Ireland's temperate climate generates high yields in arable crops and ideal conditions for grass-based production which is the key input to low-cost milk production systems. This presents a comparative advantage to Irish dairy farmers compared to competing countries who tend to rely more heavily on concentrate feed usage. A challenge for Irish dairy farmers is to increase productivity in a sustainable manner (Culleton, 2013).

The index system for assessing soil nutrient availability across the Republic of Ireland ranges from 1-4⁸. These data are Teagasc⁹ samples currently available at national level and not for farm-level modelling due to confidentiality. It is only possible to assess trends nationally, regionally and by sector. In the 1950s soil fertility was very poor in Ireland, with over 90% of soil samples taken by Teagasc recording phosphorus and potassium levels at very low (index 1) levels, however this had reduced to 44% and 29% respectively by 1960 (Coulter, 2000). This positive trend, which continued into the following decade, may have been related to improved nutrient management practices and the productivist focus of Common Agricultural Policy (CAP) instruments. More recent trends over the period 2001-2011, however, show that the proportion of soils classified as having very low (index 1) and low (index 2) fertility levels have increased from approximately 15% to 55% overall, steadily increasing since 2007. In 2011 only 25% were at the optimum index (Plunkett, 2012). The greatest increase in this trend has been from 2009-2012 with increasing numbers of samples (peaks: 59% (P) and 54% (K)) in the low categories. This trend is reasonably consistent across all sectors and regions (Donnellan, Hanrahan & Lalor 2012; Wall *et al.* 2015).

⁴ Commonly referred to as slurry or farmyard manure, the material contains mainly dung and urine potentially waste water (washings) collected in large tank at farm yards during periods of animal housing (winter). It is applied onto fields during the growing season excluding the closed period as stipulated by the nitrates directive.

⁵ European Council, 1991.

⁶ Official Journal of the European Community, 2000.

⁷ Two exceptions exist. On nutrient surplus farms costs may be incurred in exporting excess nutrients and secondly on nutrient deficient farms, where increased inputs are required (Beegel *et al.* 2000).

⁸ Developed by Teagasc Johnstown Castle (Conway 1986) and refined and changed over time. For a detailed report on changes in soil advice and management in Ireland see Coulter (2000). Since then, field studies (Schulte & Herlihy 2007) and a review (Schulte & Lalor 2008) have led to further changes in the parameters (Coulter & Lalor 2008).

⁹ The Irish Agriculture and Food Development Authority.

Declining soil fertility could reflect the introduction of increasingly stringent EU legislation and guidelines regarding on-farm nutrient use, with declining trends in fertiliser sales over the period 2001-2011 (Donnellan, Hanrahan & Lalor 2012). Fertiliser prices also accelerated over the same period peaking in 2008; with a decline in 2009 and 2010, but increasing in 2011, raising concerns regarding the volatility of this input price (Breen *et al.*, 2012, Buckley *et al.*, 2016). The declining trend in soil fertility over this period raise questions for policy makers regarding legislative obligations placed on farmers to test soil. Policy instruments which mandate use of soil testing have conflicting objectives, for example to increase soil productivity under agri-environment schemes such as the Rural Environmental Protection Scheme (REPS) and to restrict nutrient application use under the EU Nitrates Directive (91/676/EEC), yet both aim to achieve improved soil fertility levels which are agronomically and environmentally optimal. A soil test is compulsory for farmers in REPS and for farmers operating under derogation from the Nitrates Directive. The quantity of organic nitrogen applied on farms is limited to 170kg per hectare, increasing with a derogation to 250kg per hectare under the EU Nitrates Directive. Outside of the aforementioned groups, soil testing by Irish farmers is on a voluntary basis.

2. Understanding Farmers Adoption Decisions

Much of the literature on soil testing and conservation relates to tillage farms, focusing on binary adoption decisions. The classic work of Rogers (1962) examined the diffusion of innovations over time focusing on three factors: antecedents (population variables: needs, problems, and the social system), the process in terms of knowledge (characteristic of the decision-making unit) and persuasion relating to the innovation (relative advantage, compatibility, complexity, trialability and observability), the final decision stage is where ultimately there is continued or discontinued, adoption or rejection at the confirmation stage, with lesser focus on implementation. The body of research focuses on the decision to adopt or reject a technology with an overarching focus on the speed of the decision process (early adopters, early majority, late majority, laggards) (Rogers, 2003). There is some agreement on the explanatory variables that predict technology adoption in agriculture notwithstanding inconsistencies in research approaches and measures used (Baumgart-Getz, Prokopy & Floress, 2012). For example, the 'ADOPT'¹⁰ model (Kuehne *et al.*, 2013) incorporates research evidence on technology adoption to predict peak adoption levels and timing to reaching peak adoption. The model is based on variables relating to the population in terms of characteristics or orientation and available supports for the population such as the opportunities to learn about the innovation. The model accounts for the characteristics of the innovation itself, the relative advantage of using the innovation and possible experimental learning and use. The ADOPT elements are reflective of a broad adoption literature across a range of contexts. In the literature a range of variables are used including

¹⁰ The Adoption and Diffusion Outcome Prediction Tool.

Table 1: Variables used in models

Variable	Explanatory Variables	Note on variables	Hypothesised
1	Dairy Platform	Area of grassland devoted to dairy herd	+
2	Soil Quality	Soil with wide range use =1 Soil with moderate range use =2 Soil somewhat limited range use =3 Soil limited or very limited range use =4	-
3	FarmGM/UAA	Farm Gross Margin Euro per UAA (Utilizable agricultural area)	+
4	Cashflow	Having a cashflow budget: binary	+
5	Formal Agricultural Education	Having formal agricultural training (categorical) Full time third level/Farm Apprenticeship scheme/Certificate in farming/Year in Agricultural college=1 Part time course (< 60 hours & > 60 hours/other)=2 No formal agricultural education=0	+
6	Discussion Group Membership	Participation in groups are the main knowledge tool support best practice to farmers: binary	+
7	Grass covers	Conducting grass covers estimate quality of herbage matter in paddock: binary	
8	Reseeding	Farm reseeded in past three years: binary	+
	REPS/Derogation*	Participation in environmental scheme: binary	+

*REPS/Derogation participant were excluded from the voluntary model

resources, size and scale, human capital, farmer characteristics, skills and knowledge and potential constraints such as availability of information (risk), time and costs of adoption (credit availability) (Griliches, 1957; Feder, Just & Zilberman 1985; Feder & Umali 1993; Khanna, 2001; Rogers, 2003). Attitudinal factors, networking capacity and understanding structural and institutions differences are seen as increasingly important (Knowler & Bradshaw 2007; Prokopy *et al.*, 2008; Fischer & Qaim, 2014). Elsewhere, Baumgart-Getz, Prokopy & Floress (2012) synthesise three groups of explanatory variables: quality of information, financial capacity and networks, which in broad terms have the largest impact on adoption. As soil testing is a well-established practice, with high rates of adoption among Irish dairy farmers, variables selected in this paper align with these three groups of variables, to identify the likelihood of adoption based on characteristics rather than timing and saturation.

To capture the mandated effect, those more likely to adopt in a voluntary capacity, a sub-sample of voluntary users is considered in this paper. Two conflicting motivations may exist for voluntary users: (a) increasing production or (b) reducing the negative impact, environmental and/or economic, of inappropriate fertiliser application. The objective of this paper is to identify the cohorts of farmers who are more or less likely to soil test on a regular basis, for both the national sample and a sub-set of farmers who test in a voluntary capacity. Two research questions are addressed for each sample. First, to test what, if any, economic and structural differences exist between soil test users and non-users? Second, what are the farm and farmer characteristics of Irish dairy farmers who soil test on a regular basis?

3. Methodology

Data

Data were collected using the Teagasc National Farm Survey (NFS) which is a nationally representative weighted sample of farms in the Republic of Ireland (Connolly, 2010). The NFS is collected annually as part of the Farm Accountancy Data Network (FADN) requirements of the European Union (FADN, 2013). Collectively these data contain information relating to farm activities, financial

returns to agriculture and demographic characteristics. Specialist dairy farms, defined as systems where at least two-thirds of farm standard output is from grazing live-stock and where dairy cows are responsible for at least three-quarters of the grazing livestock output, are analysed in this paper based on 2009 NFS data. Standard output (economic based measures) are applied to each animal and crop output on the farm and only farms with a standard output of €8,000 or more (the equivalent of 6 dairy cows) are eligible for inclusion in the sample.

The sample of 231 specialist dairy farmers is representative of approximately 14,000 specialist dairy farms nationally. Table 1 lists and provides an explanation of all variables used in the regression analysis. The binary dependent variable in this model takes a value of one for farmers who conduct a soil test on a regular basis and value of zero if they do not. In total thirteen explanatory variable were considered in this analysis. The explanatory variables selected are based on the broad variable groups identified by Baumgart-Getz, Prokopy & Floress (2012) which have the largest impact on adoption: quality of information (education), financial capacity (farm gross margin, cashflow) and networks (discussion group membership) and two land-management practices (reseeding and grass covers). Grass covers and discussion group membership initially considered as independent are considered collectively in the final model as an interaction term given the strong association between membership and conducting covers. Two context specific variable were also considered, soil quality and policy instruments which mandate soil testing in Ireland. The soil quality¹¹ variable represents four categories of soil use classification. The policy variable selected represents farms who participate in the REPS scheme or those who have applied for a derogation under the nitrates directive. The remaining explanatory variables considered relate to farm characteristics (dairy platform, age, expenditure on lime and fertiliser per hectare and stocking intensity).

¹¹ The soil quality variable used in this analysis is a soil use classification variable based soil capacity (Gardner & Redford, 1980) based on six classifications of Irish soils. Soil use class 1 identifies soils with potential to grow the widest range of crops without limitation while soil use 6 have extremely limited use range. Only 5 categories were represented in this sample with no farm classified as category 6. Category 4 (limited use) and category 5 (very limited use) were combined due to the small numbers of farms in category 5 (n=12). This is as expected due to the nature and intensity of specialist dairy farming.

Table 2: National Sample of Specialist Dairy Farmers

Variable	All n=231 Mean (StdDev)	Regular Soil Test Users n=165 Mean (StdDev)	No regular Soil Test n=66 Mean (StdDev)	T test p-value
Age	50 (10)	48.7 (10)	53.4 (11)	0.00
Farm Size	57.6 (31)	60 (28)	49.1 (36)	0.00
Dairy Grazing Platform	33.8 (18)	36.8 (19)	26.3 (14)	0.00
Size of Dairy Herd (Avg)	64.1 (36)	68.9 (36)	52.1 (34)	0.00
Farm Gross Margin (GM) (€)/UAA	1227.48 (476)	1292.5 (468)	1064.87 (460)	0.00
Farm Gross Output (GO) (€)/UAA	2203.9 (754)	2295.7 (770)	1974.29 (664)	0.00
Nitrogen (Kg)/UAA	100 (51)	105 (53)	87.7 (44)	0.02
Grazing Days	227.1 (26)	229 (24)	222.3 (24)	0.08
Direct Cost(€)/UAA	976.4 (426)	1003.2 (446)	909.4 (367)	0.13
Fertiliser(€)/UAA	164.8 (67)	168.6 (69)	155.2 (60)	0.17
Concentrates(€)/UAA	344.8 (210)	351.4 (217)	328.3 (192)	0.45
Stocking Density	1.86 (0.50)	1.87 (0.486)	1.85 (0.49)	0.75

Table 3: Logit Model One National Sample of Specialist Dairy Farmers

Explanatory Variable	Estimated Coefficient Standard Error (SE)	Odds Ratio (êb)	95% CI
REPS/Derogation	2.52*** (0.40)	12.37	[1.73 3.29]
Discussion group and grass cover	2.00** (0.82)	7.39	[0.40 3.60]
Reseeding	0.919** (0.42)	2.51	[0.10 1.74]
Dairy Platform	0.04** (0.02)	1.04	[0.01 0.07]
Log pseudo likelihood -95.09 Pseudo R2 0.358			

Number of observations is 231. * p < 0.1, ** p < 0.05, *** p < 0.001

The latter three variables are dropped from the analysis due to collinearity (expenditure on lime and fertiliser, intensity are highly correlated with farm gross margin). Gross margin is theoretically preferred variable for comparability with broader literature. Age was also dropped from the analysis as it is highly correlated with education. Education is a preferred variable based on the policy implications. The final population model contains eight variables with the policy variable redundant for the voluntary model.

Models

The study is based on two groups of specialist dairy farmers: the sample (n=231) and a voluntary sub-sample (n=86) of farmers not mandated to soil test. The latter group excludes REPS participants and derogation farmers. Scale and income variables (dairy platform¹², farm gross margin, cashflow) are hypothesised to have a positive impact on adoption (Prokopy *et al.*, 2008). The hypothesised relationship between adoption and soil quality varies with soil type. Wide ranging use soils are hypothesised to have a negative relationship on adoption while soils with limited range use soil classifications hypothesised to have a positive relationship (Khanna, 2001) although anecdotally it is thought better soils tend to support more productive orientated farmers who are more likely to test regularly.

Participation in agri-environmental schemes (REPS), used in the population model, is hypothesised to have a positive impact on adoption as is education and participation in extension networks (discussion groups) (Hennessy

& Heanue, 2012) reflecting quality of information received. Discussion groups also promote the use of practices complementary to soil testing (grass covers) and other associated practices (reseeding). Conducting a grass cover is included as an interaction term with discussion group membership as main focus of the groups is to promote grassland management. Farmers who conduct these practices are likely to be concerned with increased productivity of grass and, therefore, soil fertility, both variables are hypothesised to have a positive relationship with likelihood of soil testing.

Tables 2 and 4 show descriptive statistics and two sample t-tests¹³, testing if there is a statistically significant difference between adopters and non-adopters, for all model variables, addressing the first research question, examining the economic and structural differences for two independent groups. The results for the full sample (Table 3) and voluntary sub-sample (Table 5) address the second research question. Logit models are used to identify the probability that individuals with certain characteristics are likely to be in the regular testers group or not.

Given the dichotomous nature of the decision to soil test, the model is non-linear with a cumulative distribution function, with the estimated conditional probabilities between zero and one. The relationship between the probability (Pi) and the variable (Xi) is non-linear. This requires a non-linear functional form. The model fit is estimated by maximum likelihood (ML). The likelihood function indicates how likely it is that the data reflects the population parameters (Long & Freese 2006).

¹² Hectares of grazing allocated specifically for dairy cows.

¹³ Null hypothesis assumes the difference between the groups is zero.

Table 4: Voluntary sub-sample of Specialist Dairy Farmers

Variable	Sample n=86 Mean (StdDev)	Regular Soil Test Users n=39 Mean (StdDev)	No regular Soil Non Users n=47 Mean (StdDev)	T-Test p-value
Dairy Grazing Platform	33.14 (20.1)	42.7 (22.5)	25.2 (13.7)	0.00
Size of Dairy Herd (Avg)	61.4 (36.8)	76.4 (32.7)	49 (35.7)	0.00
Farm Gross Output(GO) (€)/UAA	2043.9 (713.6)	2266.3 (727.3)	1859.2 (653.5)	0.00
Farm Size	59.8 (38.8)	72.5 (32.8)	49.3 (40.6)	0.01
Farm Gross Margin (GM) (€)/UAA	1121.1 (492.5)	1263.8 (476.9)	1002.7 (478.4)	0.01
Nitrogen (Kg)/UAA	95.5 (50)	111.2 (54)	82.5 (42.8)	0.01
Grazing Days	226.5 (28.7)	234.2 (24.9)	220 (30.4)	0.02
Age	50.5 (12)	47.6 (11.2)	53 (12.2)	0.04
Fertiliser(€)/UAA	163.5 (70.1)	179.6 (78.7)	150.2 (59.7)	0.05
Direct Cost(€)/UAA	922.7 (369.0)	1002.5 (384.6)	856.5 (345.8)	0.07
Stocking Density	1.82 (0.542)	1.9 (0.514)	1.76 (0.561)	0.21
Concentrates/UAA	326.7 (188.7)	337.5 (182.1)	317.7 (195.5)	0.63

Table 5: Logit Model Two Voluntary Sub-sample of Specialist Dairy Farmers

Explanatory Variable	Estimated Coefficient Standard Error (SE)	Odds Ratio (\hat{b})	95% CI
Formal Ag. Training [category 2]	2.03** (0.80)	7.60	[0.45 3.60]
Reseeding	1.28** (0.62)	3.59	[0.07 2.49]
Dairy Platform	0.056** (0.02)	1.06	[0.02 0.10]
Log pseudo likelihood -2343.51 Pseudo R2 0.27			

Number of observations is 78. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

The conditional expectation of $E(Y_i|X_i)$, can be interpreted as the *conditional probability* that the event will occur given X_i as $\Pr(Y_i = 1|X_i)$, if $Y_i = 1$. The probability of an event occurring that is P_i and the probability an event does not occur: $Y_i = 0$. The probability of: $(1 - P_i)$.

4. Results

In comparing the national soil test users to non-users (Table 2), soil testers have higher incomes in terms of gross margin ($t=3.35$, $p=0.00$) and gross output ($t=2.98$, $p=0.00$) per hectare, are younger ($t=3.11$, $p=0.00$), have larger farms ($t=-2.64$, $p=0.00$), larger dairy grazing platforms ($t=-3.97$, $p=0.00$), have larger dairy herds ($t=-3.21$, $p=0.00$), and apply higher quantities of nitrogen per hectare ($t=2.34$, $p=0.02$), but show no significant difference in concentrate and fertiliser ($t=-1.37$, $p=0.17$) expenditure, ($t=-0.75$, $p=0.45$), stocking density ($t=-0.31$, $p=0.75$), and direct costs ($t=-1.51$, $p=0.13$).

The insignificant t-tests for the expenditure variables¹⁴ is noteworthy as cost saving is portrayed as a key characteristic of soil testing, yet there is no significant difference between the groups in relation to direct costs and fertiliser cost per hectare, this holds for full and the sub-sample. While it is expected that adopters benefit in terms of reduced cost on fertiliser, the strong positive relationship between intensity and expenditure on fertiliser ($t=0.52$) and quantity of nitrogen (0.57) used per hectare indicates more intensive farmers use greater quantities of chemical fertiliser. Interestingly, both

¹⁴The calculation of continuous variables is standardised on a per hectare basis.

groups, those who soil test and those who do not soil test, have an almost equivalent expenditure on fertiliser in both samples.

Factors affecting the adoption of soil tests nationally

Results highlight agricultural policy as a key driver in the adoption of soil testing for the full sample (Table 3). Participation in either incentivised schemes (REPS) or complying with regulations such as the Nitrates Directive (derogation) increases the likelihood of soil testing on a regular basis. This is a positive finding for policy which aims to increase rates of adoption, with participants 12 times more likely to test regularly. However, based on national soil fertility data, this is accompanied by falling soil fertility rates, representing a disconnect between policy and practice implementation with a non-convergence around the desired optimum levels of soil fertility.

Having a larger dairy platform¹⁵ also increases the likelihood of soil testing, for each additional increase in the size of the dairy platform there is a 3.8% increase in the likelihood of soil testing. A larger dairy platform may be more intensively grazed and therefore may require more demanding nutrient management. It is generally proximate to the holding and may traditionally receive more organic manure and, if so, may warrant more regular testing. Farmers who reseed are 2.5 times more likely to soil test regularly than those who do not while those who are discussion group members and conduct grass covers are 7.3 times more likely to soil test. The characteristics of the farm such as having a larger dairy platform is also associated with farm size and intensity. With more intensive farming there is also greater nutrient requirement from land and so it is not surprising the associated practices such as reseeded and performing grass covers are also significantly associated with regular soil testing.

In summary, national soil testers are more likely to (i) participate in REPS/Derogation ($z=6.33$, $p=0.000$), (ii) have larger dairy platforms ($z=2.63$, $p=0.009$), (iii) be a member of a discussion group and complete grass covers ($z=-2.45$, $p=0.014$) and (iv) have re-seeded in previous three years ($z=2.19$, $p=0.029$).

¹⁵Hectares of grazing allocated specifically for dairy cows.

Factors affecting adoption by the voluntary sub-sample

As farmers have different motivations for soil testing, it is important to consider those soil testing in a voluntary capacity. Therefore, mandated users (REPS and derogation farms) are dropped from the analysis to examine voluntary behaviour. This reduces the sample to 86 participants, 39 users and 47 non-users, representing approximately 5500 holdings.

Voluntary soil test users (Table 4) have higher incomes in terms of gross margin ($t=-2.52$, $p=0.01$) and gross output ($t=-2.73$, $p=0.00$) per hectare than non-users. They also have larger farms ($t=-2.87$, $p=0.01$), and grazing platforms ($t=-4.43$, $p=0.00$), larger dairy herds ($t=-3.68$, $p=0.00$) and are, on average, younger ($t=2.09$, $p=0.04$).

The comparative descriptive statistics for the sub-sample (Table 4) are in line with full sample (Table 2) regarding the significantly larger expenditure on fertiliser and concentrates by soil testers than non-users, one exception is the number of days at grass: the soil test users in the voluntary group achieve significantly more days at grass than the non-users. This may be a reflection of their productive orientated grazing-intensive farming, also reflected in the logit analysis. In the voluntary logit model the policy REPS/Derogation farmers are dropped (Table 1), all other variables used in the national model are analysed. For the voluntary population results show (Table 5) farmers with formal agricultural education are more likely to soil test on a regular basis, as are the farmers who reseed and have larger dairy platforms.

In looking at the level of education attained by farmers, those farmers who have attended part-time courses are 7.6 times more likely to soil test than those who have no formal agricultural education. Farm size (measured by dairy platform) also has a positive and significant impact on the likelihood of soil testing. For each additional (hectare) increase in the size of the dairy grazing platform there is a 5.6% increase in the odds of testing. Farmers who have reseeded their farms are 3.6 times more likely to tests on a regular basis. This may reflect a broader nutrient management or productivity capacity of the farmers also reflected in the full sample of farmers.

In summary, voluntary soil testers are more likely to (i) have larger dairy platforms ($z=2.71$ $p=0.007$); (ii) have a formal agricultural education ($z=2.52$, $p=0.012$), and (iii) have re-seeded in the previous three years ($z=2.08$, $p=0.038$).

5. Discussion

The t-tests highlight the economic and structural differences which exist between soil test users and non-users for the full sample and the voluntary sub-sample addressing the first research question of this study. The most notable results highlight that there is no significant difference between the average expenditure on fertiliser and concentrates for soil testers than non-testers. Higher fertilizer expenditure on more intensive farms is to be expected. Moreover, if implementing soil test results accurately at farm level there should also be convergence around optimal fertility trends, but we know that this is not the case over the past decade (Wall *et al.*, 2015). These findings highlight an anomaly, where the benefits

of the widely adopted farm practice are not being realised by users. This raises questions concerning the on-farm implementation of soil test results. Furthermore users pose a greater threat to the environment with higher chemical nutrients utilised on their farms.

In exploring this further the second research question identifies those most likely to soil test on a regular basis for the sample and for the subsample. For the sample, results show larger farm size (dairy platform) reflecting intensity, farm practices (reseeding), farmers who are members of discussion groups and perform grass covers are more likely to soil test on a regular basis. The strongest factor influencing adoption for the full sample is policy (REPS/Derogation). This finding suggests that participation in schemes which mandate adoption (REPS/Derogation) does not perfectly predict soil testing on a regular basis. If participation in such schemes and regular practice use were perfectly correlated the variable would be automatically redundant in the model. From a policy perspective these findings are of interest given the importance of other farm practices such as reseeding and grass covers. The importance of soil for the sustainability of agriculture the development of a nutrient management capability may be an area farmers are interested in developing through further education.

Given the importance of policy in the national model, an analysis of a sub-sample of specialist dairy farmers focuses on farmers acting in a voluntary capacity. For the voluntary sub-sample formal agricultural education is a significant factor, soil testers are more likely to have participated in short part-time courses. This could be an indication of a farmers who select specific programmes or courses which fit with their farm needs. Reseeding and size of the dairy platform are also significant factors in identifying farmers likely to soil test regularly.

Seminal writers (Griliches, 1957; Mansfield, 1961) relate adoption to a single activity. However, more recent research views adoption as part of a social process (Rogers, 2003; Leeuwis, 2004). This paper not only identifies the characteristics of those adopting but also highlights the realities farmers are faced with in decision making, through identifying potential issues surrounding policy which mandates activity. This suggests there may be a need for research that moves beyond examining of rates of adoption and that takes a broader view of decision making, considering factors such as farmers' goals, objectives and perceptions towards using nutrient management practices and the willingness of farmers to develop a holistic approach in the development of a broader nutrient management capability. Ultimately implementation of practices and achieving the desired outcome should be the end policy goal. Policies to encourage uptake of new practices should consider end users motivations for adoption to ensure management tools aid the achievement of user goals (Pannell *et al.*, 2006).

The findings in this paper highlight that high rates of adoption associated with policy mandating practice use does not always result in the achievement of desired outcomes, in this case improved soil fertility. This paper suggests that the focus of future adoption studies should relate more closely to outcome measures. Policy should not only focus on increasing the rate of adoption or the time associated with spread and diffusion but should also incorporate, where possible, a focus on the benefits of using and implementing the farm practices in meeting

farmer objectives. The findings from this study have identified policy as the key driver in adoption of soil testing but national trends indicate successful implementation is not being achieved.

Building on the findings of this research, five possible explanations for the anomaly between high rates of soil testing and low soil fertility levels in Ireland are suggested. These are as follows.

- Farmers test to fulfil mandatory obligations but may not use results.
- The introduction of increasingly stringent legislation regarding nutrient use is hindering farmers in reaching optimal agronomic production levels.
- Farmers do not wish to achieve optimal agronomic fertility levels.
- Multiple sources of information from the wider environment such as peers, personal experience, industry, media etc. may conflict and so hinder optimal decision making. For example inherent soil characteristics such as root development and water retention capacity (Karlen, Ditzler & Andrews 2003, Karlen & Stott 1994) are not captured by soil tests but may be an important consideration in decision making for farmers.
- Farmers only test poor quality soils and so the results show no apparent improvement over time.

There is a need for a greater understanding of the factors which motivate farmers to adopt practices in a volitional capacity rather than in incentivised fashion, as reward based systems are a powerful motivator of behaviour (Lawson & Samson 2001). This is important in an agricultural context given the existence of incentivised schemes which focus on increased rates of practice adoption. Where motivation to adopt is mandated by a policy instrument the longer term adoption in the absence of such policy may not occur. There is currently less emphasis on additional tailored supports which would aid farmers to achieve their 'soil based' objectives. Sufficient policy attention needs to be given to the outcomes and benefits of the practice in line with farmers objectives. For example, developing a mechanism to track successful changes and demonstrate benefits post adoption could encourage more long term commitment to practice use.

6. Conclusion

In the context of the anomaly between high rates of soil testing and low soil fertility levels in Ireland this paper presents the results of an analysis of the factors associated with soil testing in a nationally representative sample of 231 Irish dairy farmers, including an analysis a sub-sample of farmers who soil test in a voluntary capacity. The results suggest that policy is a key driver of soil testing behaviour in the full sample, as is participation in discussion group networks and conducting grass covers. Farm size and farm practices such as reseed-ing also increase the likelihood of regular soil testing for both the full sample and the voluntary sub-sample. Moreover, having formal education is a significant factor in increasing likelihood of soil testing amongst voluntary users. In both samples, there are no significant differences in fertiliser costs per hectare between soil test users and non-users. This suggests that soil test users are not reaping the efficiencies that might be expected.

These findings raise questions regarding the impact of policy and regulation on practice implementation and the motivations surrounding the adoption of regular soil testing.

The results of this study suggest that there may be issues with the mandated adoption of farm management practices specifically for REPS and derogation farmers. There are a number of considerations for future agricultural policy approaches associated with this. One is the level of commitment to using the practice; is practice adoption based on fulfilment of programme requirements? A second consideration is establishing if the benefits of the technology correspond with the objectives of the farmer and reflect the productive capacity of the farm's resources. In a system where it is mandatory to adopt practices this is not considered. From a policy perspective, introducing a tailored response to needs may be more beneficial to the farmer and a focus on on-farm outcomes. Rewarding farmers who reduce their environmental pressure and risk to soil and water pollution, but also providing further extension to farmers who are currently farming on soils at less than optimal levels through tailoring and targeting farms is one approach which may be effective. Soil testing is a management intensive tool which requires the development of a skill: implementing the soil test results, and furthermore, the development of an overall farm nutrient management capability in making farm scale decisions. It is important to identify cohorts of adopters as a targeted approach can be taken to improve this capability through implementation supports and the use of outcome data in evaluating benefits of policy instruments. In agriculture the reliance on chemical fertiliser is not only of interest from a farm level economics perspective but also for the wider eco-system. The volatility of market prices for fertiliser does little to stabilise farm input cost and unpredictable weather conditions hinder nutrient management activities. It is for these reasons soil testing and its appropriate implementation is a key farm practice for sustainable agriculture.

About the authors

Edel Kelly is a social scientist in Agri-Business and Rural Development, at the School of Agriculture in University College Dublin (UCD), she is Lecturer/Assistant Professor and working in the area of nutrient accounting and benchmarking management practices. Her interests are in cross-cutting topics within agriculture, firm level decision making, knowledge exchange and extension and organisational change and the impact of social interactions.

Kevin Heanue is an economist at the Rural Economy and Development Programme, Teagasc, Ireland. Specialising in innovation and technological change, his research in Teagasc focuses on understanding aspects of the Agricultural Knowledge and Innovation System (AKIS) such as the specific innovation systems that support farmers' capabilities building; farmers' technology and best practice adoption; and the evaluation of knowledge transfer and extension programmes and methods.

Colm O' Gorman is Professor of Entrepreneurship at Dublin City University Business School. His research focuses on entrepreneurs, entrepreneurship, internationalisation and growth processes in new ventures. He

is co-author of the annual Global Entrepreneurship Monitor for Ireland. He has published his work in leading international peer reviewed journals (e.g. *Entrepreneurship and Regional Development*, *International Marketing Review*, *Journal of Small Business Management*, *Organizational Dynamics*, *R&D Management*, *Small Business Economics*, and *Venture Capital*).

Cathal Buckley is a researcher in the area of agricultural and environmental economics. He is part of a multi-disciplinary research and extension team that work of the Agricultural Catchments Programme (ACP). The ACP provide a comprehensive scientific and socio-economic evaluation of the effectiveness of EU Nitrates Directive regulations as implemented in the Republic of Ireland to address diffuse pollution from agriculture.

Acknowledgements

The authors would like to acknowledge funding from the Teagasc Walsh Fellowship programme, this work was conducted at the Rural Economy Development Programme in Teagasc Ireland and Dublin City University Business School where Edel conducted her PhD studies with the support of this scholarship. We would also like to thank the anonymous journal reviewers for their useful comments.

REFERENCES

- Baumgart-Getz, A., Prokopy, L.S. and Floress, K. (2012) Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *Journal of Environmental Management*, 96(1), pp.17-25. DOI:10.1016/j.jenvman.2011.10.006
- Beegle, D.B., Carton, O.T. and Bailey, J.S. (2000) Nutrient Management Planning Justification, Theory, Practice. *Journal of Environmental Quality*, 29 (1) pp. 72-79. DOI: 10.2134/jeq2000.00472425002900010009x
- Breen, J., Clancy, D., Donnellan, T. and Hanrahan, K. (2012) Estimating the Elasticity of Demand and the Production Response for Nitrogen Fertiliser. Paper presented at the *Agricultural Economics Society Annual Conference*, University of Warwick, United Kingdom 16th-18th April. [Online]. Available from: http://ageconsearch.umn.edu/bitstream/134965/2/James%2520P_Breen_Estimating%2520the%2520Elasticity%2520of%2520Demand%2520and%2520Production%2520272Response%2520for%2520Nitrogen%2520Fertiliser%2520on%2520Irish%2520Farms.pdf [Accessed 14/01/2015].
- Buckley, C., Wall, D., Moran, B. and Murphy, P. (2016) Developing the EU Farm Accountancy Data Network to derive indicators around the sustainable use of nitrogen and phosphorus at farm level. *Nutrient Cycling in Agroecosystems*, 102, pp. 319-333. DOI: 10.1007/s10705-015-9753-y
- Connolly, L., Kinsella, A., Quinlan, G. and Moran, B. (2010) *The National Farm Survey 2009*. Teagasc, Athenry, Ireland.
- Conway, A. (1986) Soil analysis and fertiliser recommendations. *An Foras Taluntais*, Johnstown Castle, Wexford.
- Coulter, B. (2000) The Development of Agronomic Advice on the use of Nutrients and Trace Elements for Grassland and Tillage Crops. Proceedings of the Spring Scientific Meetings No. 38, *Fertiliser Association of Ireland Proceedings* [Online] available at http://www.fertiliser-assoc.ie/publications/6_Developmen.of_Agro_B_Coulter.pdf [accessed on 21/12/2013].
- Coulter, B. and Lalor, S. (2008) Major and micro nutrient advice for productive agricultural crops, third edition. Teagasc. [Online] available from: <http://www.agresearch.teagasc.ie/johnstown/Nutrient%20Advice%203rd%20edition.pdf> [accessed on 21/12/2013].
- Culleton, N. (2013) The impact of achieving targets set out in Food Harvest 2010 on phosphorus and nitrogen fertiliser usage. Proceedings of the Spring Scientific Meeting 2013, Horse and Jockey, Tipperary, 5th February 2013. *Fertiliser Association of Ireland Proceedings* No 48 "Outlook and best practice for fertiliser use and soil fertility".
- Donnellan, T., Hanrahan, K. and Lalor, S. (2012) Food Harvest 2020 and the Demand for Fertiliser. Proceedings of the Spring Scientific Meeting 2012, Horse and Jockey, Tipperary, 7th February 2012. *Fertiliser Association of Ireland Proceedings* No 47 "Role of fertiliser and soil fertility in achieving Food Harvest 2020 targets".
- European Council. (1991) Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. *Official Journal of the European Communities*, L 375. Brussels. [Online]. Available from: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991L0676:EN:HTML> [Accessed 24/06/2011].
- Farm Accountancy Data Network. (2013) *Concept of FADN*. [Online]. Available from: http://ec.europa.eu/agriculture/rica/concept_en.cfm [Accessed 07/05/2016].
- Feder, G., Just, R.E. and Zilberman, D. (1985) Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, 33(2), pp. 255-298.
- Feder, G. and Umali, D.L. (1993) The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change*, 43(3-4), pp. 215-239. DOI: 10.1016/0040-1625(93)90053-A
- Fischer, E. and Qaim, M. (2014) *Smallholder Farmers and Collective Action: What Determines the Intensity of Participation?* *Journal of Agricultural Economics*, 65, 683-702. DOI: 10.1111/1477-9552.12060
- Gallagher, P.A. and Herlihy, M. (1963) An Evaluation of Errors Associated with Soil Testing. *Irish Journal of Agricultural Research*, 2(2), pp. 149-167.
- Gardiner, M. and Radford, T. (1980) Soil associations of Ireland and their land use potential. *An Foras Taluntais*, Dublin ISBN 0-905442-49-0
- Griliches, Z. (1957) Hybrid corn: An exploration in the economics of technological change. *Econometrica*, 25(4), pp. 501-522. DOI: 10.2307/1905380
- Hennessy, T. and Heanue, K. (2012) Quantifying the Effect of Discussion Group Membership on Technology Adoption and Farm Profit on Dairy Farms. *Journal of Agricultural Education and Extension* 18(1) pp. 41-54. DOI: 10.1080/1389224X.2012.638784
- Karlen, D.L., Ditzler, C.A. and Andrews, S.S. (2003) Soil quality: why and how. *Geoderma*, 114(3-4), pp. 145-156. DOI: 10.1016/S0016-7061(03)00039-9
- Karlen, D.L. and Stott, D.E., (1994) A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W, et al. (Eds.), *Defining Soil Quality for a Sustainable Environment*. SSSA Special Publication No. 35. SSSA, Madison, WI, p. 53-72.
- Khanna, M., (2001) Sequential Adoption of Site Specific technologies and Its Implications for Nitrogen Productivity: A Double Selectivity Model. *American Journal of Agricultural Economics*, 83(1), pp. 35-51. DOI: 10.1111/0002-9092.00135
- Knowler, D. and Bradshaw, B. (2007) *Farmers' adoption of conservation agriculture: A review and synthesis of recent research*. Food Policy, 32(1), pp. 25-48. DOI: 10.1016/j.foodpol.2006.01.003
- Kuehne, G., Llewellyn, R., Pannell, D., Wilkinson, R., Dolling, P. and Ouzman, J. (2013) ADOPT: the Adoption and Diffusion Outcome Prediction Tool (Public Release Version 1.0, June 2013) [Computer software] Adelaide SA; CSIRO. Available from www.csiro.au/ADOPT [Accessed 07/05/2016].
- Lalor, S., Coulter, B., Quinlan, G. and Connolly, L. (2010) A Survey of Fertilizer Use in Ireland from 2004-2008 for Grassland and Arable Crops. Teagasc, Johnstown Castle Environmental Research Centre, Wexford ISBN 1-84170-557-8 [Online]. Available from: http://www.teagasc.ie/publications/2010/13/13_Fert_Use_Survey_2008-Final.pdf [Accessed 07/05/2016].

- Lawson, B. and Samson, D. (2001) Developing Innovation Capability in Organisations: A Dynamic Capabilities Approach. *International Journal of Innovation Management*, 5(3), pp. 377-400. DOI: 10.1142/S1363919601000427
- Leeuwis, C. (with contributions by A. van den Ban.) (2004) *Communication for Rural Innovation: Rethinking Agricultural Extension*, third ed. Oxford: Blackwell Science.
- Long, J.S. and J. Freese, (2006) *Regression Models for Categorical Dependent Variables Using Stata*, second ed. College Station, Texas: Stata Press.
- Mansfield, E. (1961) Technical change and the rate of imitation. *Econometrica*, 29(4), pp. 741-766.
- Pannell, D. J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F. and Wilkinson, R. (2006) Understanding and Promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture*. 46(11), pp. 1407-1424. DOI: <http://dx.doi.org/10.1071/EA05037>
- Plunkett, M. (2012) Using Soil Test Results for Soil Fertility Management. Proceedings of the Spring Scientific Meeting (2012), Horse and Jockey, Tipperary, 7th February 2012. *Fertiliser Association of Ireland Proceedings* No 47 "Role of fertiliser and soil fertility in achieving Food Harvest 2020 targets".
- Prokopy, L.S., Floress, K., Klotthor-Weinkauff, D. and Baumgart-Getz, A. (2008) Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation*, 63(5) pp. 300-311. DOI: 10.2489/jswc.63.5.300
- Rogers, E.M. (1962) *Diffusion of Innovations*, first ed. New York, The Free Press.
- Rogers, E.M. (2003) *Diffusion of Innovations*, fifth ed. New York, The Free Press.
- Schulte, R.P.O. and Herlihy, M. (2007) Quantifying responses to phosphorus in Irish grassland interactions of soil and fertilizer with yield and P concentration. *European Journal of Agronomy*, 26 (2), pp.144-153. DOI: 10.1016/j.eja.2006.09.003
- Schulte, R.P.O. and Lalor, S.T.J. (2008) Phosphorus on grassland: agronomically and environmentally sustainable advice. Proceedings of Spring Scientific Meetings No. 43, *The Fertiliser Association of Ireland Proceedings*.
- Wall, D., Murphy, P. and Plunkett, P. (2015) National Soil Fertility Status and Trends. Proceedings of the Spring Scientific Meeting 2015, Horse and Jockey, Tipperary, 3th February 2015. *Fertiliser Association of Ireland Proceedings* No 50 "Profiting from Soil Fertility".