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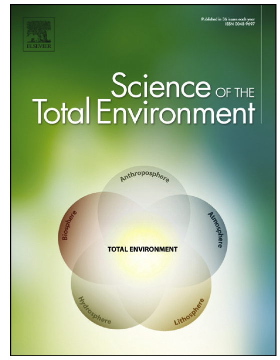

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Establishing nationally representative benchmarks of farm-gate nitrogen and phosphorus balances and use efficiencies on Irish farms to encourage improvements

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Abstract

Agriculture faces considerable challenges of achieving more sustainable production that minimises nitrogen (N) and phosphorus (P) losses and meets international obligations for water quality and greenhouse gas emissions. This must involve reducing nutrient balance (NB) surpluses and increasing nutrient use efficiencies (NUEs), which could also improve farm profitability (a win-win). To set targets and motivate improvements in Ireland, nationally representative benchmarks were established for different farm categories (sector, soil group and production intensity). Annual farm-gate NBs (kg ha^{-1}) and NUEs (%) for N and P were calculated for 1446 nationally representative farms from 2008-2015 using import and export data collected by the Teagasc National Farm Survey (part of the EU Farm Accountancy Data Network). Benchmarks for each category were established using quantile regression analysis and percentile rankings to identify farms with the lowest NB surplus per production intensity and highest gross margins (€ ha^{-1}). Within all categories, large ranges in NBs and NUEs between benchmark farms and poorer performers show considerable room for nutrient management improvements. Results show that as agriculture intensifies, nutrient surpluses, use efficiencies and gross margins increase, but benchmark farms minimise surpluses to relatively low levels (i.e. are more sustainable). This is due to, per ha, lower fertiliser and feed imports, greater exports of agricultural products, relatively high stocking rates (except for tillage, mixed livestock and non-suckler cattle), and higher gross margins. For the ambitious scenario of all non-benchmark farms reaching the optimal benchmark zone, moderate reductions in farm nutrient surpluses were found with great improvements in profitability, leading to a 31% and 9% decrease in N and P surplus nationally, predominantly from dairy and non-suckler cattle. The study also identifies excessive surpluses for each level of production intensity, which could be used by policy in setting upper limits to improve sustainability.

Keywords

Benchmarking, nutrient balance, nutrient use efficiency, sustainability, agriculture, FADN.

1. Introduction

Agriculture faces considerable challenges of achieving sustainable intensification to maintain global food security (Godfray et al., 2014; Paillard et al., 2009) whilst also meeting water quality and greenhouse gas (GHG) emissions targets. Intensive agricultural production relies upon nitrogen (N) and phosphorus (P) imports within chemical fertiliser and feed, but relatively low proportions of these costly non-renewable nutrients are converted into agricultural products (Cordell and White 2011; Sutton et al., 2013). This poor nutrient use efficiency (NUE) is associated with losses to the environment and impacts on water quality, GHG emissions (N_2O), air quality (ammonia), acidification and biodiversity (EEA, 2018; Reay et al., 2012; Davidson et al., 2015; Hanrahan et al., 2019). Furthermore, such inefficiencies (and price volatilities) can have significant economic implications for farmers (Buckley and Carney, 2013; Mihailescu et al., 2015). Stakeholders and policymakers are therefore increasingly interested in key performance indicators (KPIs) of farm nutrient management, efficiency and environmental sustainability, and the establishment of national benchmarks to set targets and motivate/measure improvements (Uwizeye et al., 2016; Dillon et al., 2010, 2016; Diazabakana et al., 2014).

Two of the most widely used KPIs of nutrient management are nutrient balance (NB) and NUE (McLellan et al., 2019; Halberg et al., 2005a). Farm-gate NBs (kg ha^{-1}) measure nutrient imports through the farm gate in the form of feed, chemical fertiliser and livestock, and subtract nutrients exported within agricultural products and organic fertiliser (Breembroek, et al., 1996; Nevens et al., 2006; Treacy et al., 2008). NUE (%) is calculated by dividing nutrient exports by imports, and indicates the efficiency of recovering imported nutrients in exported farm produce (Powell et al., 2010). Large NB surpluses and low NUEs, therefore, indicate a build-up of nutrients on the farm which are at risk of environmental losses, whereas NB deficits and very high NUEs (e.g. ≥ 90%) indicate mining of soil nutrient reserves which will reduce soil fertility over time and are unsustainable long-term (Aarts et al., 2000; Schröder et al., 2003; Murphy et al., 2015). The aim is therefore to achieve a nutrient balance and high NUE, to minimise environmental losses, and maximise agricultural productivity, profitability and long-term sustainability (a win-win scenario) (Davidson et al., 2015; Longphuirt et al., 2016).

Benchmarking uses KPIs to compare the performance of a system to others in order to rate/rank the performance, identify reasons for high performance, set targets for improvement, and measure and monitor changes over time (Hansen et al., 2005; Ondersteijn et al., 2003a,b; Nielson and Kristensen, 2005). Benchmarking approaches for nutrient management include comparative ranking schemes and percentile rankings (e.g. Cela et al., 2014a,b; Mu et al., 2016), modelling farm simulations and scenario analysis (Crosson et al., 2007), and efficient-frontier techniques (Malano et al., 2004) such as data envelopment analysis (DEA) (Buckley and Carney, 2013; Kelly et al., 2012; Barnes et al., 2009) or stochastic frontier analysis (Battese and Coelli, 1995; Lohr and Park, 2007; Van Passel et al., 2009). Importantly, benchmarks will vary depending on farm sector type, production intensity, climate, soil type and other environmental conditions (Oenema et al., 2003; Halberg et al., 2005a; Gourley et al., 2007). Furthermore, as farmers are more likely to respond to financial incentives (Buckley, 2012; Gourley et al. 2007; Lohr and Park, 2007), benchmarks that can relate environmental improvements to profit gains (e.g. Ondersteijn et al., 2003a) are more likely to motivate farmer behaviour.

National nutrient accounting systems (e.g. MINAS, OVERSEER, RAUMIS and STANK) and policy support tools (e.g. FADN, OECD, EUROSTAT and the Australian Dairy Industry Survey) have been developed across Europe, the US and Australasia to facilitate monitoring, benchmarking and motivating improvements (e.g. Breembroek et al., 1996; Halberg et al., 2005b; Öborn et al., 2003; Ondersteijn et al., 2002; Greppa Naeringen, 2011; Monaghan et al., 2007; Stott and Gourley, 2016). The EU Farm Accountancy Data Network (FADN, 2016) provides nationally representative, standardised annual accountancy data (physical, structural, economic, financial) over decades for over 80,000 EU farms. In countries (including Ireland) where FADN data collection has been expanded to include volume based and enterprise-specific import and export data, it has been increasingly used to estimate nationally representative farm NBs, NUEs and temporal trends across different sectors (Buckley et al., 2016a,b; Kelly et al., 2018, 2015; Ryan et al., 2016; Dalgaard et al., 2006Wrzaszcz and Zegar, 2016). Some studies have also benchmarked FADN-derived national averages against specialist cohorts of progressive, niche, experimental, commercial or pilot farms with similar farm characteristics (Dolman et al., 2014; de Vries et al., 2015; Oenema et al., 2012; Nevens et al., 2006).

However, no study has used the FADN data to establish nationally representative benchmarks of the top-performing farms (instead of calculating average KPI values/performers), across different sectors, or the worst-performing farms where the largest and potentially easiest and most cost-effective improvements could be achieved. Such an analysis could be used to encourage improvements in nutrient management performance as farms aim for benchmark targets, as well as establish upper limits on surpluses to reduce excessive nutrient surpluses and environmental losses from poorly performing farms (McLellan et al., 2018; Gourley et al., 2007). Furthermore, scenario analysis using this data could be used to demonstrate potential reductions in nutrient surpluses, (GHG) emissions and increases in farm profitability by reaching benchmark targets at farm and national scales.

This study aimed to establish nationally representative benchmarks of farm nutrient management for Ireland using the Teagasc NFS that could be used as standardised targets by farmers and policymakers to motivate improvements. The objectives of this study were to; (i) establish benchmarks (top performers) of farm-gate NB and NUE for each sector, soil group and production intensity, (ii) identify worst-performers with excessive nutrient surpluses for each category to establish maximum upper limits, (iii) identify the farm characteristics that explain differences in performance, and (iv) use scenario analysis to estimate potential improvements in environmental sustainability (lower nutrient surpluses and GHG emissions) and economic sustainability (higher gross margins and lower financial costs) that could be achieved through reaching benchmark targets at farm and national scales.

2. Methods

2.1 FADN data and calculating KPIs for each farm category

Prior to this study, nationally representative farm-gate N and P balances and use efficiencies from 2008-2015 were derived using an unbalanced panel of 1446 Irish farms in the Teagasc National Farm Survey (NFS; part of the FADN) (7326 farm year data points) using the methodology described in Buckley et al. (2015). These farms were randomly selected and population weighted according to size and farm sector system from the Central Statistics Office Census of Agriculture (Lynch et al., 2016), representing on average 85,415 farms nationally (61% of total farms) and 76% of the total utilised agriculture area (UAA; excluding commonage). They were then classified into different soil groups and sectors. Sectors include dairy, mixed livestock (dairy tends to be the main livestock enterprise), suckler cattle, non-suckler cattle, sheep, and tillage. Sector classifications were based on the dominant, but not exclusive, enterprise on the farm. Soil groups were based on soil quality, texture, altitude, climate, topography and drainage derived from the National Soil Survey of Ireland (Gardiner and Radford, 1980), and used as a proxy of land use potential (Table 1).

[Insert Table 1]

2.2 Identifying minimum sustainable balances prior to benchmarking

Prior to benchmarking farm-gate NBs and NUEs, data points with balances that in the long-term would be unsustainably low needed to be identified and removed. A literature review was therefore undertaken to identify minimum sustainable balances that; (i) are sufficient to offset unaccounted and unavoidable environmental losses, (ii) maintain agronomically optimum soil nutrient concentrations, (iii) meet livestock nutritional requirements, and (iv) comply with agri-environmental regulations.

For P, catchment monitoring studies in Ireland show that in-stream total P losses are typically < 2 kg ha^{-1} yr^{-1} in the wettest years, even in catchments with predominantly poorly drained soils and associated high runoff potential (Table 2). A meta-analysis of studies on P balances and soil P concentrations found that the agronomically optimum range of soil Morgan P concentrations related to a farm-gate P balance of 1.5-4.5 kg ha^{-1} for grassland livestock farms (predominantly dairy) (Fig. 1), and that balanced P fertilisation (rather than surpluses) can actually reduce herbage yields (van Middelkoop et al., 2016), which may be because of differences in soil P fixation and immobilisation which are not currently accounted for in recommended rates (see Roberts et al., 2017; van Leeuwen et al., 2019). Studies on livestock nutritional requirements demonstrate that the minimum dietary P requirement is between 3.0-4.2 g P kg^{-1} dry matter for moderate-to-high producing dairy cows (e.g. Odongo et al., 2007; Valk et al., 2000; Withers et al., 1999; Wu et al., 2001;Wang et al., 2014), including 3.6 g P kg^{-1} dry matter intake for high-yielding dairy cows in Northern Ireland (Ferris et al., 2010a,b; O'Rourke et al., 2010), which was related to dairy farm-gate P balances of 2.7 kg P ha^{-1} (Bailey, 2016). No other sector studies relating farm-gate P balances to optimum livestock dietary requirements were found.

For N, the high spatiotemporal variability and uncertainty in rates of environmental losses and other unaccounted input/output factors (biological N fixation, atmospheric N deposition, immobilisation and mineralisation) (McAleer et al., 2017; Oenema et al., 2003), and a poor or unclear relationship between N balances and nitrate leaching/groundwater concentrations in Ireland (Humphreys et al., 2008; Burchill et al., 2016), precludes identifying minimum farm-gate N balances that would offset unavoidable environmental losses. Also, as there are no widely adopted reliable soil tests for long-term soil N plant availability (see McDonald et al., 2014a,b), relating farm-gate N balances to agronomically optimal soil N levels was not possible. Furthermore, there is a lack of studies relating optimum livestock dietary N requirements to farm-gate N balances.

Based on the above findings, a minimum sustainable farm-gate P balances of 3 kg ha^{-1} was identified. Due to a lack of evidence, and the complexity of N cycling, a minimum sustainable N balance of 0 kg ha^{-1} was selected, as operating at a negative balance over time would degrade soil N fertility. Two copies of the NFS dataset were then used to treat N and P benchmarking separately. The data points below the minimum sustainable N balance (for the N dataset only) or P balance (for the P dataset only) were removed prior to benchmarking analysis, as well as a minimal number of data points which did not comply with the Nitrate Regulations 250 kg ON ha^{-1} stocking limit. Table 3 shows the number of NFS farms with minimum sustainable N and P balances used in the benchmarking analysis for each soil group within each sector (2008-2015), and national population weightings (number of farms represented nationally).

[Insert Figure 1]

[Insert Table 2]

[Insert Table 3]

2.3 Establishing benchmarks and worst performers, and explaining performance

The relationship between production intensity (total N or P exports in kg ha^{-1}) and the N or P balance (kg ha^{-1}) was then investigated for each soil group within each sector using quantile regression analysis (in R v3.4.1), which estimates the conditional mean or other quantiles of the response variable given certain values of the predictor variable. Percentile regression lines (10th, 25th, 50th, 75th and 90th percentiles) were fitted to the relationship (similar to Davidson et al., 2015; Nevens et al., 2006; Cela et al., 2014), to identify benchmark farms with the lowest nutrient surpluses for each level of production intensity (data points located beneath the 75th (Q75) or 90th (Q90) percentile lines). The 10% worst performing farms with the highest surpluses per production intensity were then identified for each category as the data points above the Q10 regression line.

Benchmark farms also need to be economically profitable (Buckley and Carney, 2013; Mihailescu et al., 2015; Ondersteijn et al., 2003a; Lynch, 2017), so for both N and P datasets, farm economic performance was benchmarked for each sector and soil group subcategory using percentile rankings of farm gross margin (gross output minus direct costs; € ha^{-1} UAA). Data points in each category scatter plot (showing the relationship between production intensity and nutrient balance) were then colour coded based on their gross margin percentile ranking. Thus the optimal benchmark zone for each category was identified as the zone encompassing farms with the lowest NB surpluses and highest gross margins (> Q75 for both).

The average farm characteristics and NB components of this optimal benchmark zone cohort were then compared to those from the poorer performing cohorts, to identify reasons for their benchmark nutrient management performance (Nevens et al., 2006; Halberg et al., 2005b). As the datasets used were from 2008-2015, benchmarking farm performance accounts for inter-annual variations in KPIs controlled by factors such as farm management, weather, grass/crop growth, housing periods, fertiliser/feed costs and market prices, as well as soil nutrient status, which can lead farms to have overall balance deficits or high surpluses temporarily to reach agronomic optimums (Murphy et al., 2015).

2.4 Scenario analysis

To assess potential environmental and economic benefits at farm and national scales that could be achieved by moving farms towards benchmarks in their category, three different benchmarking scenarios were explored:

1. all non-benchmark farms reach the next best performing zone
2. all worst-performing farms with excessive nutrient surpluses (highest 10%) reach the next best performing zone
3. all farms, including those with N surplus <0 kg ha^{-1} and those with P surplus <3 kg ha^{-1} (i.e. the complete NFS data set), reach the optimal benchmark zone

The first two scenarios used only data points with minimum sustainable NBs (N surplus >= 0 kg ha^{-1}; P surplus >= 3 kg ha^{-1}). For Scenario 3, the mean difference in NB, NUE, and balance components between each non-benchmark farm and the mean value of the optimal benchmark zone farms was calculated. For Scenario 1, the mean of the differences in the NBs, NUEs and balance components between a performance zone (e.g. Q26-Q50) and the mean of the next best performing zone (e.g. Q51-Q75) was calculated. For Scenario 2, the mean of the differences in values between Q1-10 and the mean of the Q11-25 zone calculated in Scenario 1 were used.

Changes in economic performance (i.e. gross margins, chemical fertiliser and feed costs, total costs, total direct costs and gross outputs) for each scenario were also calculated using the same approach as stated above. The potential impact of chemical fertiliser N use changes on direct GHG emissions were also estimated at the national level based on Irelands revised 1.24% emission factor (EF) for N_2O from fertiliser N applied to soils (i.e. 1.24 kg N_2O-N is emitted for every 100 kg fertiliser-N applied) (EPA, 2018; Lynch, 2018).

Results are for target farms only in each scenario (analysis did not include benchmark farms already in the optimal benchmark zone for Scenario 3, or benchmark farms located below the Q75 or Q10 percentile regression lines in Scenarios 1 and 2, respectively). Results were national farm population weighted and hence representative at the national scale, as with all other results in this report (except NUE which used median values due to large skewness).

3. Results and Discussion

3.1 Benchmarks, worst performers, and policy implications

As production intensity increases (with higher total N or P exports), N and P balances tend to increase for livestock farms (but with much greater variability for P), and decrease for tillage (Fig. 2 and 3). However, benchmark farms (below the Q75 line) minimise surpluses to relatively low levels for a given level of production intensity (Fig. 4 and 5, and Tables 4 and 5), which has also been shown in Northern Ireland (Adenuga et al., 2018) and Europe (Svanbäck et al., 2019). Within all farm types, large ranges in NBs between benchmark farms and poorer performers (e.g. above the Q10 line) show considerable room for reducing surpluses on many farms. This is also demonstrated when comparing mean balances with optimum benchmark zone balances (Fig. 6), although results indicate larger P inputs are needed on average to optimise suckler cattle, sheep and tillage sectors.

For all sectors, gross margins ha^{-1} tend to increase with production intensity (Fig. 4 and 5), but for tillage this relationship was less clear, likely due to undifferentiated crop types which have differences in market value (€ t^{-1}). Thus optimal benchmark zone farms with the lowest NBs and highest gross margins were predominantly high-intensity producers (Fig. 4, 5 and 7, and Tables 4 and 5). In the context of national policy (Food Wise 2025) driving agricultural intensification (DAFM, 2015), particularly for the dairy herd which increased by over 23% from 2014-17 (CSO, 2019), results indicate that nutrient surpluses, use efficiencies and gross margins are likely to increase (see also Dillon et al., 2016; Lynch, 2017; Ryan et al., 2016; Beukes et al., 2012). However, this study shows that optimal benchmark farms buck the trend by achieving high output and gross margins ha^{-1} while minimising nutrient surpluses (i.e. are more environmentally and economically sustainable).

Benchmark farm KPI values (NB, NUE and gross margin) in Tables 4 and 5 can be used as quantitative targets by farmers and policymakers wanting to achieve high nutrient management and economic performance and ambitious production targets while also meeting environmental policy commitments under the EU Water Framework Directive and UNFCCC (Lynch et al., 2019).. However, due to the many factors influencing the KPIs that may be outside a farmer's control (e.g. biophysical/environmental factors, farm fragmentation, or financial constraints), it may not be possible for a given farm to reach optimal benchmark zone targets. It may therefore be more practical and achievable to set more moderate, stepwise benchmark targets (like Scenario 1) whereby a farm aims to reach the next best percentile regression line (next best quartile of performance). To reach it, a farm must either

(i) lower its nutrient surplus, (ii) increase its exports, or (iii) do both (Fig. 7). It should be noted that the optimal benchmark zone does not define the absolute optimum level of performance achievable, as current (but not adopted) or future management practices, strategies and technologies can shift the boundaries of farm performance.

The 10% and 25% worst performers with the highest surpluses for a given production intensity are also identified in Fig. 4, 5 and 7, and Tables 4 and 5, as those above the Q10 or Q25 regression lines. These lines could therefore be used by farmers and policymakers to set upper limits, specific to each farm category and production intensity, to reduce excessive surpluses and environmental source pressures (similar to the concept by McLellan et al., 2018). Some EU countries have employed 'flat-rate' maximum permitted balances based on relationships with Nitrates Directive water quality targets or political decisions weighing agri-economic and environmental consequences (van Grinsven et al., 2016; Nevens et al., 2006; Del Hierro et al., 2005; Schröder et al., 2007); for example, 100 kg N ha^{-1} and 9 kg P ha^{-1} in Denmark in 2003 (Wright and Mallia, 2008), and 10 kg P ha^{-1} for derogated holdings in Northern Ireland (Government of Northern Ireland, 2010). However, it may be more appropriate for the maximum permitted surplus level to vary with production intensity, in order not to constrain production levels/economic performance, or permit excessive wasteful surpluses from lower intensity farms.

When comparing optimal benchmarks between different sector types, suckler cattle, non-suckler cattle and sheep farm benchmarks have lower N and P surpluses (25-33 kg N ha^{-1} and 3.8-4.4 kg P ha^{-1}), higher N-NUE (31-47%), variable P-NUE (53-73%) and lower gross margin returns (972-1351 € ha^{-1}), relative to dairy farm benchmarks (Tables 4 and 5). In comparison to all livestock sectors, optimal benchmark tillage farms had extremely high

NUEs for N and P (92% and 85%, respectively), very low N balance surplus (10.5 kg N ha^{-1}), relatively low P surplus (4.0 kg P ha^{-1}), and relatively high gross margins (1573-1720 € ha^{-1}).

[Insert Figure 2]

[Insert Figure 3]

[Insert Figure 4]

[Insert Figure 5]

[Insert Figure 6]

[Insert Figure 7]

[Insert Table 4]

[Insert Table 5]

3.2 Characteristics of benchmark farms explaining best performance

3.2.1 Nutrient imports and exports

Benchmark farms have lower fertiliser and feed imports and greater exports of agricultural products per hectare compared to the poorer performing categories (Tables 4 and 5), as has been found by other studies (Nevens et al., 2006; Öborn et al., 2003; Ondersteijn et al., 2003b). Fertiliser imports make up a much larger proportion of total N imports than feed (concentrates or forage crops) for all farm types and, therefore, have a much larger effect on N surpluses and use efficiencies. This reflects the fact that livestock agriculture in Ireland is dominated by a grazed grassland system. This indicates that most improvements in N balances and use efficiencies are to be obtained through lowering fertiliser imports and improving fertiliser management. However, care must be taken when lowering fertiliser imports that it does not come at the expense of reduced forage production, as associated increases in feed imports just externalises nutrient losses/inefficiencies to the farms where the imported feed was produced (Godinot et al., 2014; Schröder et al., 2003). Fertiliser P also dominated P imports for most farm types, but for dairy and mixed livestock, feed P imports were higher than fertiliser P imports for optimal benchmark farms.

Furthermore, for all sectors, optimal benchmark zone farms have relatively moderate total fertiliser and feed imports that are more typical of the 26-75th percentile zones, combined with a high level of agricultural exports. This highlights the need to also focus on the factors that would maximise these exports (and thus also KPIs) such as herd genetics (Beukes et al., 2012; Ryan et al., 2011), herd health (FAO, 2012), fertility management (Beukes et al., 2012; Huhtanen et al., 2011), grassland and grazing management (French et al., 2015; MacDonald et al., 2008; Finneran et al., 2012), labour, education, technology/machinery, and crop or soil management.

3.2.2 Stocking rates

Benchmark farms based on N or P balance alone had relatively low stocking rates for all sectors (Table 4 and 5), but optimal N benchmark farms had relatively high stocking rates to secure high gross margins ha^{-1}. Thus this study found that increasing stocking rate (and the higher associated fertiliser and feed imports required to support higher grass production) can be achieved without considerably affecting N or P surpluses, due to good fertiliser and feed management and high NUE (Ramírez and Reheul, 2009; Mihailescu et al., 2014). For mixed livestock, optimal benchmark farms are characterised by relatively low stocking rates compared to poorer performers but relatively high N exports in milk, crops and livestock. The importance of tillage as a component of these systems suggests that there may be advantages in nutrient cycling and efficiencies to mixed crop-livestock systems, as has been found elsewhere (Godinot et al., 2014; Schröder et al., 2003; Wilkins, 2008).

3.2.3 Farm size

Farm size (UAA) has been found to have a positive effect on production intensity and efficiency (Latruffe et al., 2008; Dolman et al., 2014), although not in all studies (e.g. Buckley and Carney, 2013). Results from this study show a mixed picture. Larger farm size tended to be associated with higher N balances for dairy, mixed livestock and tillage sectors (due to larger fertiliser inputs), whereas sheep farms showed the opposite trend and suckler/non-suckler cattle showed no trend (Tables 4 and 5). Farm size was larger, on average, for optimal N benchmark farms than that of the poorest performers (76-100th percentile) for suckler/non-suckler and mixed livestock farm types. For optimal sheep and tillage farms, UAA was approximately the same as the poor performers for N, whereas optimal dairy farms were smaller, suggesting that, for dairy farms, smaller land size encourages intensification in output per ha and higher N-NUE. It may also reflect an association between larger farm size and poorer soil land use potential (Table 4). For P, larger farm UAA size was associated with lower P balances for suckler/non-suckler cattle, whilst other farm types showed no consistent trend (Table 5). With regards to P benchmarks, dairy, suckler and non-suckler cattle farms had larger farm sizes compared to the worst P balance performers, whereas P benchmarks of the other farm types had similar UAA sizes to the worst performers. This indicates that, in general, economies of scale do not appear to be as important as other factors in determining benchmark performance on a per ha basis.

3.2.4 Soil group (land use potential)

For all sectors, optimal N and P benchmark zone cohorts had higher land use potential soils compared to poorer performing groups (i.e. a lower mean soil class; 1 being wide land use potential and 6 being extremely limited land use; Table 1) except for sheep N. This shows the importance of soil quality/type as a key driver of productivity and validates the use of the soil classification system by Gardiner and Radford (1980) as a proxy for land use potential. However, in terms of N or P balance percentile alone (which doesn't consider productivity or gross margins), no clear trend in soil class was found from the best performing to the worst performing cohorts. As other studies indicate the important influences of soil properties/types on nutrient balances (e.g. van Leeuwen et al., 2019), this suggests that using only three soil classes is too coarse, spatial variability in soil classes were not accounted for in each NFS farm, and/or individual farmer nutrient management decisions are more important than soil quality/land use potential in dictating nutrient management performance.

3.3 Scenario analysis

Table 6 shows the estimated mean changes in farm KPIs for the three different benchmarking scenarios. It should be noted that Scenario 3 represents an extreme case of all non-benchmark farms achieving benchmark performance, and was run to illustrate the maximum potential improvements possible currently. This is not to suggest that this is a realistically or easily achievable scenario; factors beyond the control of the farmer, such as environmental, financial, and climatic limitations or farm fragmentation, may well prevent many farms from achieving the benchmarked level of performance. Workload, farmer age and health are also factors determining any changes in management that might be adopted on a farm.

[Insert Table 6]

3.3.1 Scenarios 1 and 2 (farm scale)

For Scenario 1, in which all non-benchmark farms reach the next best performing zone (regression line) in their category, results for affected farms showed N surplus reductions of between -36.7 to -18.7 kg N ha^{-1} (dairy and sheep respectively), and N-NUE improvements of +3.3% (dairy) to +8.2% (tillage). Gross margins reduced in all sectors except mixed livestock, and for all sectors, although financial costs decreased, so did gross output. The N balance reductions were largely associated with reductions in fertiliser N use, and there was little change in N exports. For P, Scenario 1 resulted in relatively large mean P balance reductions for affected farms across all sectors, corresponding with moderate to high P-NUE increases, due to large reductions in P fertiliser. Gross margins increased for dairy, mixed livestock and sheep, but decreased for the other cattle sectors, and for all sectors, increases in total costs and direct costs were matched by the increases in gross output.

For Scenario 2, in which all farms with excessive nutrient surpluses (highest 10%) reach the next best performing zone (Q11-25), even greater reductions in N and P fertiliser use and balances were found across most sectors compared to Scenario 1, resulting in moderate to high increases in NUEs. For N, gross margins increased for mixed livestock and particularly sheep, but decreased for all other livestock sectors, whereas for P, gross margins increased markedly for dairy and non-suckler cattle and decreased markedly for all other sectors. Patterns of total costs, total direct costs and gross outputs were similar to those found in Scenario 1.

3.3.2 Scenario 3 (farm scale)

For the ambitious Scenario 3, in which all non-benchmark farms reach the optimal benchmark zone for their category, mean reductions in N surplus ranged from -12 to -35 kg N ha^{-1} (sheep and dairy farms respectively), which were similar to Scenario 1, and associated N-NUE increases of between +11% (dairy) to +28% (non-suckler cattle), which were much higher, indicating significant potential improvements overall (Table 6). This is principally due to a combination of reduced fertiliser N imports and increased N exports through agricultural produce. Results for N also indicate significant potential for improved gross margins across all sectors, ranging from +€428 ha^{-1} (suckler cattle) to +€919 ha^{-1} (dairy). This was because increases in total direct costs and total costs were far outweighed by the resulting increases in gross output.

For P, Scenario 3 increased gross margins ranging from +€320 ha^{-1} for suckler cattle to +€1010 ha^{-1} for mixed livestock, as for all sectors, increases in total costs/direct costs were matched or outweighed by gross output increases. Scenario 3 increased P fertiliser and/or feed inputs for all sectors, but as a result of greater increases in total P exports within agricultural produce, P surpluses decreased by a mean of 2.6, 0.6 and 0.5 kg P ha^{-1} for dairy, mixed livestock and non-suckler cattle, and increased P surpluses by approximately 1 kg ha^{-1} for sheep and tillage (Table 6). The need for increased P inputs (and even overall surplus) for a period of time on many farms to optimise productivity and soil P concentrations should be guided by frequent soil sampling (S.I. No. 605 of 2017) and smart redistribution of P within the farm (Cassidy et al., 2019) to prevent development of excessive or deficient soil P concentrations, and may not be desirable on critical source areas (Thomas et al., 2016), at-risk waterbody catchments or on some low intensity farms. There is thus the need to weigh-up risks and priorities, environmental and economic, before deciding if a particular benchmark should be targeted within a particular catchment or farm.

The results illustrate complex trade-offs between economic and environmental sustainability that need to be made. For dairy, for example, Scenarios 1 and 2 (which principally involve reductions in fertiliser imports) may lead to greater mean reductions in farm N and P surplus (environmental pressure) compared to Scenario 3, but with reductions in profitability when focusing on N management alone (unless combined with P reductions at the same time). However, to achieve the more substantial improvements in NUE and profitability associated with Scenario 3, it is necessary to focus both on optimisation of nutrient imports and nutrient exports, principally in milk, through numerous farm management factors discussed in section 3.2.1

3.3.3 Scenario 3 (national scale)

Scenario 3 led to a 31% decrease in the estimated national agricultural N surplus, from 258,893 t to 179,108 t, indicating the significant potential for reducing nutrient source pressure through benchmarking (Table 7). The largest proportion of this potential decrease came from dairy (30%) and non-suckler cattle (29%), reflecting the large contribution of these two farm types to the aggregate N surplus (Fig. 8 and 9). Despite the large reductions in total surplus N from dairy, Scenario 3 would leave dairy even more dominant as the major source of surplus N source pressure, at 49% (Fig. 9), further highlighting the importance of addressing N surpluses in this sector. For P, Scenario 3 led to a 9% reduction in the estimated national agricultural P surplus, from 15,925 to 14,447 t yr^{-1} (Table 8), almost entirely due to dairy and non-suckler cattle reductions which offset increases in P surpluses from sheep, tillage and, to a lesser extent, suckler cattle. As a result, Scenario 3 would cause the source of the aggregate P surplus to be much more evenly distributed between sectors, with non-suckler cattle the greatest contributor at 28% (Fig. 9).

Estimated changes in N_2O emissions following changes in N fertiliser use under Scenario 3 were between +0.227 and -0.283 kg N_2O-N ha^{-1} yr^{-1} (from tillage and non-suckler cattle respectively) (Table 6). On a national scale, this represents a reduction of 553 t N_2O-N yr^{-1}, mostly coming from non-suckler/suckler cattle and dairy farms (Fig. 10). This would equate to a reduction of 0.259 Mt CO2-eq, or 4.2% of total N_2O emissions and 1.3% of total GHG emissions from the agricultural sector, nationally, based on 2016 emissions of 6.192 Mt CO_2-eq (EPA, 2018). These relatively moderate reductions in sectoral emissions reflect the fact that overall GHG emissions from the agricultural sector are strongly linked to livestock numbers, in particular via CH_4 emissions from livestock and N_2O emissions from dung and urine deposited by grazing cattle. Greater reductions could potentially be achieved if GHG emissions were included as a benchmark KPI.

[Insert Table 7]

[Insert Table 8]

[Insert Figure 8]

[Insert Figure 9]

[Insert Figure 10]

4. Conclusions

Modern agriculture is asked to produce more with less, whilst maintaining or enhancing environmental quality and ecosystem services. These competing demands present huge challenges. To reduce nutrient surpluses that contribute to diffuse pollution, nationally representative benchmarks of NBs and NUEs were established for Ireland using data from 1446 NFS farms, representing a range of sectors, soil groups and production intensities. Benchmark farms were found to maximise production intensity, NUE and gross margins ha^{-1} whilst keeping surpluses relatively low, by minimising excessive fertiliser and feed imports, based on farm characteristics explored in this study. The established benchmark targets could be used by farmers and policymakers to encourage improvements in nutrient management performance, reduce environmental losses and increase profitability, aiding national policy objectives for more sustainable agricultural production.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Figure captions

Fig. 1 – Relationship between farm-gate P balances and farm-average soil Morgan P concentrations on Irish farms based on literature studies (predominantly dairy). The range and mid-point of agronomically optimum Morgan P concentrations for grassland soils (dotted and thick horizontal lines) are used to determine agronomically optimum (sustainable) farm-gate P balances (see arrows).

Fig. 2 – Relationship between total N export (production intensity) and farm-gate N balance (kg ha^{-1}) for each sector for all data points. The zero farm-gate N balance (0 kg ha^{-1}) is indicated as a purple line. Data points are colour coded according to gross margin (€ ha^{-1}) percentile rankings.

Fig. 3 – Relationship between total P export (production intensity) and farm-gate P balance (kg ha^{-1}) for each sector for all data points. The zero farm-gate P balance (0 kg ha^{-1}) is indicated as a purple line. Data points are colour coded according to gross margin (€ ha^{-1}) percentile rankings.

Fig. 4 – Relationship between total N exports (production intensity) and N balances (both in kg ha^{-1}) for each sector and soil group (SG). Percentile regression lines of the relationship are plotted to indicate performance level and different benchmark zones. From top to bottom, these lines represent the 10th, 25th, 50th, 75th and 90th percentiles. Farms above the top line, Q10, are the bottom 10% of performers with the highest N surpluses, whereas farms below the bottom line, Q90, are the top 10% of performers with the lowest N surpluses. Data points are colour coded according to gross margin (€ ha^{-1}) percentile rankings. Benchmark farms are identified as those with the lowest N balances for a given production intensity (points below the Q75 (75^{th} percentile) line), and optimal benchmark zone farms are those that also have the highest gross margins (blue or dark green points below the Q75 line). Data points with unsustainable N balances (below 0 kg ha^{-1}) were removed prior to analysis. Tillage farms in SG3 did not have enough data points for benchmark analysis.

Fig. 5 – Relationship between total P exports (production intensity) and P balances (both in kg ha^{-1}) for each sector and soil group (SG). Percentile regression lines of the relationship are plotted to indicate performance level and different benchmark zones. From top to bottom, these lines represent the 10th, 25th, 50th, 75th and 90th percentiles. Farms above the top line, Q10, are the bottom 10% of performers with the highest P surpluses, whereas farms below the bottom line, Q90, are the top 10% of performers with the lowest P surpluses. Data points are colour coded according to gross margin (€ ha^{-1}) percentile rankings. Benchmark farms are identified as those with the lowest P balances for a given production intensity (points below the Q75 (75^{th} percentile) line), and optimal benchmark zone farms are those that also have the highest gross margins (blue or dark green points below the Q75 line). Data points with unsustainable P balances (below 3 kg ha^{-1}) were removed prior to analysis. Tillage farms in SG3 did not have enough data points for benchmark analysis.

Fig. 6 – Current (2008–2015), and optimal benchmark zone mean farm-gate N balances (top) and P balances (bottom) for each sector.

Fig. 7 – Illustration of how the benchmarking approach can be used by farmers and policymakers to improve nutrient management performance. Percentile regression lines act as zone-specific benchmark targets. For example, the circled farm located above the Q10 line

should be aiming to (1) reduce surpluses, (2) increase production intensity or (3) do both, until it reaches below the Q10 line. The ultimate aim is to (4) reach the optimal benchmark zone (gold) where benchmark farms with the lowest surpluses and highest gross margins ha^{-1} are located (> 75^{th} percentile for each KPI, i.e. blue and dark green points below the Q75 line). Policymakers could also use the Q10 regression line (highlighted in red) to set maximum permitted farm-gate surpluses for a given production intensity.

Fig. 8 –Estimated national aggregate agricultural N surplus (top) and P surplus (bottom) for each sector currently and under benchmarking Scenario 3.

Fig. 9 – Percentage of the estimated national aggregate agricultural N surplus (left) and P surplus (right) attributed to each farm type under benchmarking Scenario 3.

Fig. 10 – Estimated change in national aggregate agricultural N_2O emissions for each farm type from changes in fertiliser N use under benchmarking Scenario 3.

Table 1 – Soil group classifications for NFS farms, from the National Soil Survey of Ireland (Gardiner and Radford, 1980).

Soil group	Soil class	Soil class description
1	Class 1 - wide use range	Soils of wide use range have no limitations which cannot be overcome by normal management practices.
1	Class 2 - moderately wide use range	Moderately wide use-range refers to soils with minor limitations such as coarse texture, moderately high altitude, less favourable climatic conditions, somewhat shallow depth, hummocky topography and somewhat weak structure
2	Class 3 - somewhat limited use range	The somewhat limited use range category is used for soils with similar limitations to those of Class 2 but these are present to a greater degree. For example, soils with altitude limitations in this category usually occur between 150 m and 365 m, whereas those of the moderately wide use range with altitude limitations are at elevations mostly between 90 and 150 m
2	Class 4 - limited use range	Soils in this category- are generally unsuited to tillage but suited to a permanent grassland system. The predominant limitation is poor drainage
3	Class 5 - very limited use range	This class contains those soils whose agricultural potential is greatly restricted. They are widespread in the western and north-western regions, particularly in the mountain zones where high altitude and steep slopes are major limitations.
3	Class 6 - Extremely limited use range	This class contains soils in which agricultural potential is virtually non-existent. These are mostly mountain-top areas where steep slopes have contributed to the existence of very shallow soils with many boulders and rock outcrops. Because of these factors, the Burren, Co. Clare, has been included in this category although some extensive summer grazing is possible in the area.

Table 2 – In-stream total P losses measured in agricultural catchment monitoring studies in Ireland (values are the highest losses found within each study period).

Land use	Catchment	Soil drainage class (soil type)	Kg ha^{-1} yr^{-1}	Reference
Grassland	Grassland D	Karst	0.043	Mellander et al. (2013)
Grassland	Grassland D	Karst	0.034	Shore et al. (2017)
Grassland	Lough Neagh	Poorly drained	0.56	Jordan et al. (2007)
Grassland	Grassland C	Poorly drained	0.57	Shore et al. (2017)
Grassland	Oona	Poorly drained (Gleys, clay rich)	3.125	Jordan et al. (2005)
Grassland	Grassland B	Poorly drained (Groundwater/Surface water gleys)	0.541	Jordan et al. (2012)
Grassland	Grassland B	Poorly drained (Groundwater/Surface water gleys)	1.418	Mellander et al. (2015)
Grassland	Grassland B	Poorly drained (Groundwater/Surface water gleys)	0.99	Shore et al. (2017)
Grassland	Bellsgrove mini-catchment	Poorly drained (Groundwater Gleys)	0.35	Kirk McClure Morton (1999)
Grassland	National subcatchments	Poorly drained	0.25-0.5	Mockler et al. (2017)
Grassland	Clarianna	Well drained (Grey Brown Podzol)	0.685	Jordan et al. (2005)
Grassland	Grassland A	Well drained (Typical Brown Earths)	0.701	Jordan et al. (2012)
Grassland	Grassland A	Well drained (Typical Brown Earths)	0.877	Mellander et al. (2016)
Grassland	Grassland A	Well drained (Typical Brown Earths)	0.62	Shore et al. (2017)
Grassland	Grassland A	Well drained (Typical Brown Earths)	1.56	Murphy et al. (2015)
Grassland	Dripsey	Well-poorly drained (Brown Podzols)	2.658	Jordan et al. (2005)
Grassland	Nested Dripsey catchment, Co. Cork (17 ha)	Well-poorly drained	2.61	Lewis et al. (2013)
Grassland	Nested Dripsey catchment, Co. Cork (211 ha)	Well-poorly drained	2.48	Lewis et al. (2013)
Grassland	Nested Dripsey catchment, Co. Cork (1524 ha)	Well-poorly drained	1.61	Lewis et al. (2013)
Grassland	Northern Ireland 50 subcatchments	Well-poorly drained	0.83	Smith et al. (2005); McGuckin et al. (1999); McGuckin (2000)
Grassland and tillage	Arable A and B, Grassland A, B and C	Well-poorly drained	0.76 (0.28-1.17)	Shore et al. (2016)
Grassland and tillage	National scale	Well-poorly drained	0.5	Ulén et al. (2007)
Tillage	Arable A	Well drained (Typical Brown Earths)	0.175	Jordan et al. (2012)
Tillage	Arable A	Well drained (Typical Brown Earths)	0.42	Melland et al. (2012)
Tillage	Arable A	Well drained (Typical Brown Earths)	0.521	Mellander et al. (2016)
Tillage	Arable A	Well drained (Typical Brown Earths)	0.619	Mellander et al. (2015)
Tillage	Arable A	Well drained (Typical Brown Earths)	0.29	Shore et al. (2017)
Tillage	Arable B	Well-poorly drained	0.785	Jordan et al. (2012)
Tillage	Arable B	Well-poorly drained	0.83	Melland et al. (2012)
Tillage	Arable B	Well-poorly drained	1.17	Shore et al. (2017)
Tillage	Northern Ireland 50 subcatchments	Well-poorly drained	4.88	Smith et al. (2005); McGuckin et al. (1999); McGuckin (2000)

Table 3 – Number of NFS farms and data points for each soil group within each sector (2008-2015), and number with minimum sustainable N balances (≥ 0 kg ha^{-1}) or P balances (≥ 3 kg ha^{-1}) used in the benchmarking analysis. The national population weightings (number of farms represented nationally) each sample represents are also indicated (combined from all years).

	All data			Minimum sustainable N balances				Minimum sustainable P balances			
	Total data points	**Unique NFS farms**	**National population weighting**	**Total data points**	**Unique NFS farms**	**National population weighting**	**% of total weighting**	**Total data points**	**Unique NFS farms**	**National population weighting**	**% of total weighting**
Dairy	**1975**	**423**	**110,705**	**1936**	**415**	**108,134**	**97.7**	**1303**	**371**	**72,557**	**65.5**
Soil group 1	1134	244	62,452	1111	236	60,821	97.4	704	209	38,347	61.4
Soil group 2	723	156	41,525	710	156	40,745	98.1	519	142	29,527	71.1
Soil group 3	118	27	6,728	115	27	6,567	97.6	80	23	4,683	69.6
Mixed livestock	**581**	**210**	**37,500**	**568**	**204**	**36,309**	**96.8**	**338**	**142**	**20,900**	**55.7**
Soil group 1	346	125	18,615	335	120	17,462	93.8	193	83	9,655	51.9
Soil group 2	191	70	15,611	189	69	15,573	99.8	124	51	10,287	65.9
Soil group 3	44	17	3,273	44	17	3,273	100.0	21	9	958	29.3
Suckler cattle	**1329**	**372**	**146,557**	**1272**	**365**	**141,313**	**96.4**	**578**	**239**	**69,130**	**47.2**
Soil group 1	472	143	55,019	451	139	53,133	96.6	199	93	25,454	46.3
Soil group 2	686	188	76,014	654	185	72,928	95.9	312	119	37,186	48.9
Soil group 3	171	42	15,524	167	42	15,252	98.2	67	28	6,490	41.8
Non-suckler cattle	**1936**	**558**	**237,089**	**1859**	**547**	**228,126**	**96.2**	**961**	**371**	**122,286**	**51.6**
Soil group 1	1059	287	125,044	1014	283	119,780	95.8	528	191	64,120	51.3
Soil group 2	704	227	90,670	679	221	87,854	96.9	347	146	46,034	50.8
Soil group 3	173	49	21,375	166	48	20,493	95.9	86	38	12,132	56.8
Sheep	**936**	**231**	**111,057**	**857**	**215**	**99,763**	**89.8**	**360**	**132**	**45,148**	**40.7**
Soil group 1	331	89	40,643	300	83	37,145	91.4	153	55	19,277	47.4
Soil group 2	330	78	39,477	313	76	37,760	95.7	146	50	17,781	45.0
Soil group 3	275	68	30,938	244	60	24,858	80.3	61	29	8,091	26.2
Tillage	**569**	**137**	**40,414**	**490**	**128**	**34,611**	**85.6**	**260**	**102**	**19,831**	**49.1**
Soil group 1	492	119	35,300	416	112	29,733	84.2	221	90	17,733	50.2
Soil group 2	77	18	5,114	74	16	4,878	95.4	39	12	2,098	41.0
Soil group 3	0	0	0	0	0	0	0	0	0	0	0
All	**7326**	**1446**	**683,322**	**6982**	**1405**	**648,256**	**94.9**	**3800**	**1094**	**349,852**	**51.2**

Table 4 – Mean farm characteristics and N imports/exports/KPIs for benchmark farms and poorer-performing percentiles for each farm sector. This information be used as a guide for improving nutrient management performance.

			Overall performance	Optimal benchmark zone	Benchmark		Above average	Below average	Worst	
			N balance percentile	76-100	91-100	76-90	51-75	26-50	11-25	1-10
			Gross margin percentile	76-100	1-100	1-100	1-100	1-100	1-100	1-100
Sector	**Variable type**	**Variable**	**Unit**							
Dairy	Farm characteristics	UAA	ha	47.2	48.1	48.2	53.3	53.3	53.8	50.4
		Stocking rate	LU ha^{-1}	2.2	1.5	1.7	1.8	1.9	2.0	2.1
		Organic N loading	kg ON ha^{-1}	180.5	120.6	145.3	151.9	157.8	164.9	173.8
		Milk production intensity	l cow^{-1}	5596.9	4700.8	5006.3	5093.4	5083.2	5117.8	5122.5
		Milk production intensity	l ha^{-1}	8440.2	4612.5	5858.0	6255.3	6410.8	6556.0	7104.9
		Soil class	1-6	2.1	2.1	2.6	2.4	2.2	2.2	2.4
	N imports	Fertiliser	kg N ha^{-1}	135.9	78.3	112.8	136.5	165.5	197.7	251.4
		Concentrates	kg N ha^{-1}	36.1	20.8	29.5	35.4	37.8	41.2	51.9
		Forage crops	kg N ha^{-1}	6.0	2.9	3.7	4.0	5.2	7.3	10.6
		Livestock	kg N ha^{-1}	0.9	0.5	0.9	0.9	0.7	0.8	0.8
		Total N imports	kg N ha^{-1}	178.9	102.4	146.9	176.8	209.3	247.0	314.7
	N exports	Milk	kg N ha^{-1}	45.1	24.0	30.8	32.7	33.1	33.8	34.8
		Cash crops	kg N ha^{-1}	2.6	9.2	2.2	1.0	0.6	0.1	0.1
		Livestock	kg N ha^{-1}	9.0	6.7	8.2	8.1	8.3	8.6	8.5
		Wool	kg N ha^{-1}	0.1	0.1	0.0	0.0	0.0	0.0	0.0
		Total N exports	kg N ha^{-1}	56.8	39.9	41.2	41.8	42.1	42.5	43.4
	KPIs	N balance	kg N ha^{-1}	122.1	62.5	105.7	135.0	167.2	204.5	271.3
		N use efficiency	% (median)	30.7	36.5	27.6	23.4	20.0	17.2	13.8
		Gross margin	€ ha^{-1}	2733.8	1553.4	1815.3	1846.8	1841.9	1879.5	1909.0
	Finances	Fertiliser costs	€ ha^{-1}	110.0	54.7	91.2	115.3	137.6	171.3	220.6
		Concentrates costs	€ LU^{-1}	200.8	175.4	206.2	241.5	243.9	257.5	266.1
		Bulky feed costs	€ LU^{-1}	18.6	13.3	14.2	19.5	20.5	28.1	22.0
		Total direct costs	€ ha^{-1}	1241.2	766.0	974.0	1119.5	1200.9	1322.6	1424.1
		Total costs	€ ha^{-1}	2227.8	1397.7	1744.6	1909.2	2063.7	2186.8	2346.9
		Gross output	€ ha^{-1}	3976.4	2319.4	2789.7	2966.3	3042.8	3202.0	3333.1
	Population	Number of NFS data points	n	101	192	291	485	483	290	195
		Proportion of national population weighting	%	5.0	10.1	14.9	24.4	24.1	14.3	9.9
Mixed livestock	Farm characteristics	UAA	ha	83.1	42.2	55.7	53.5	56.9	58.3	59.9
		Stocking rate	LU ha^{-1}	1.2	1.1	1.2	1.4	1.5	1.8	1.8
		Organic N loading	kg ON ha^{-1}	94.7	63.1	75.9	107.9	117.4	140.5	133.3
		Milk production intensity	l cow^{-1}	5344.3	1619.3	2259.0	3552.8	4208.8	4574.1	3751.4
		Milk production intensity	l ha^{-1}	3240.6	783.4	1204.5	2286.9	2912.5	3189.8	3140.1
		Soil class	1-6	2.0	2.6	2.7	2.6	2.8	2.3	2.0
	N imports	Fertiliser	kg N ha^{-1}	87.7	30.4	54.1	75.5	107.4	143.9	166.0
		Concentrates	kg N ha^{-1}	15.1	7.8	10.8	22.4	27.7	31.5	35.7
		Forage crops	kg N ha^{-1}	3.2	2.3	3.4	3.6	2.8	2.8	6.3
		Livestock	kg N ha^{-1}	2.1	1.4	2.3	1.7	2.3	0.9	0.7
		Total N imports	kg N ha^{-1}	108.2	42.0	70.5	103.2	140.2	179.1	208.7
	N exports	Milk	kg N ha^{-1}	16.8	3.9	6.1	11.5	14.6	15.6	15.1
		Cash crops	kg N ha^{-1}	22.5	7.6	8.2	3.5	1.2	0.1	0.2
		Livestock	kg N ha^{-1}	9.4	8.7	9.7	10.8	10.4	11.4	9.3
		Wool	kg N ha^{-1}	0.1	0.6	0.7	0.2	0.1	0.1	0.0
		Total N exports	kg N ha^{-1}	48.8	20.8	24.7	26.1	26.5	27.2	24.7
	KPIs	N balance	kg N ha^{-1}	59.4	21.2	45.9	77.1	113.7	152.0	184.0
		N use efficiency	% (median)	40.4	50.3	34.8	24.2	19.0	15.7	12.8
		Gross margin	€ ha^{-1}	1857.5	765.9	875.6	1098.0	1114.5	1238.5	1415.3
	Finances	Fertiliser costs	€ ha^{-1}	47.7	14.1	41.7	59.1	85.3	117.6	122.6
		Concentrates costs	€ LU^{-1}	170.4	95.1	154.2	200.5	200.5	202.6	210.8
		Bulky feed costs	€ LU^{-1}	7.5	16.0	9.3	14.5	11.4	13.8	20.4
		Total direct costs	€ ha^{-1}	615.7	346.0	496.5	711.6	818.3	893.5	1120.8
		Total costs	€ ha^{-1}	1367.1	837.3	962.2	1272.8	1419.0	1539.1	1853.8
		Gross output	€ ha^{-1}	2473.2	1111.9	1372.1	1809.6	1932.8	2132.0	2536.1
	Population	Number of NFS data points	n	15	55	85	143	142	86	57
		Proportion of national population weighting	%	1.6	13.4	15.6	27.3	18.9	13.7	7.9
Suckler cattle	Farm characteristics	UAA	ha	38.0	33.9	36.4	34.5	31.6	32.1	29.4
		Stocking rate	LU ha^{-1}	1.2	0.9	0.9	1.0	1.1	1.3	1.3
		Organic N loading	kg ON ha^{-1}	92.0	65.5	67.3	74.1	83.9	95.0	99.9
		Soil class	1-6	2.5	3.2	2.8	3.0	3.1	3.0	2.7
	N imports	Fertiliser	kg N ha^{-1}	29.4	12.5	25.1	38.2	53.7	72.6	105.3
		Concentrates	kg N ha^{-1}	6.7	4.5	4.6	5.5	7.4	9.2	9.0
		Forage crops	kg N ha^{-1}	1.0	2.1	1.3	1.8	2.1	2.6	6.6
		Livestock	kg N ha^{-1}	1.2	0.9	1.2	1.4	1.0	0.7	0.7
		Total N imports	kg N ha^{-1}	38.3	20.1	32.2	46.9	64.1	85.2	121.6
	N exports	Milk	kg N ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cash crops	kg N ha^{-1}	1.1	0.5	0.1	0.1	0.1	0.0	0.0
		Livestock	kg N ha^{-1}	11.9	8.8	8.8	9.4	9.4	9.5	8.9
		Wool	kg N ha^{-1}	0.1	0.1	0.1	0.0	0.0	0.0	0.0
		Total N exports	kg N ha^{-1}	13.0	9.4	9.0	9.6	9.5	9.5	8.9
	KPIs	N balance	kg N ha^{-1}	25.3	10.7	23.2	37.4	54.6	75.7	112.7
		N use efficiency	% (median)	31.0	45.9	27.0	19.6	14.1	10.7	7.2
		Gross margin	€ ha^{-1}	1075.4	614.4	665.2	652.7	685.0	695.0	675.5
	Finances	Fertiliser costs	€ ha^{-1}	21.5	10.0	18.7	30.2	47.4	60.0	87.7
		Concentrates costs	€ LU^{-1}	71.0	72.9	68.9	73.7	85.2	95.8	89.2
		Bulky feed costs	€ LU^{-1}	5.7	18.5	12.3	14.4	14.5	15.1	19.5
		Total direct costs	€ ha^{-1}	332.2	235.0	269.4	311.5	381.7	434.9	516.7
		Total costs	€ ha^{-1}	819.7	560.2	606.5	683.6	789.6	857.9	1028.9
		Gross output	€ ha^{-1}	1407.4	849.3	934.6	964.3	1066.5	1129.8	1192.1
	Population	Number of NFS data points	n	76	127	190	318	318	191	128
		Proportion of national population weighting	%	5.1	8.9	12.6	23.1	25.1	15.2	11.5
Non-suckler cattle	Farm characteristics	UAA	ha	35.2	32.6	33.9	34.7	36.2	32.5	32.7
		Stocking rate	LU ha^{-1}	1.3	0.9	1.1	1.2	1.4	1.5	1.7
		Organic N loading	kg ON ha^{-1}	91.4	64.9	76.2	87.7	97.9	111.2	120.8
		Soil class	1-6	2.5	2.6	2.6	2.6	2.7	2.5	2.5
	N imports	Fertiliser	kg N ha^{-1}	33.5	11.6	27.9	44.3	62.9	82.7	124.2

		Concentrates	kg N ha^{-1}	12.0	5.2	7.9	9.8	13.2	16.2	18.7
		Forage crops	kg N ha^{-1}	3.6	1.8	1.6	1.7	2.9	4.4	7.8
		Livestock	kg N ha^{-1}	14.3	7.2	8.8	8.1	7.0	6.5	6.3
		Total N imports	kg N ha^{-1}	63.5	25.7	46.2	63.9	85.9	109.8	157.0
	N exports	Milk	kg N ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cash crops	kg N ha^{-1}	3.7	1.7	1.6	1.6	1.5	0.7	0.7
		Livestock	kg N ha^{-1}	26.2	13.9	16.7	16.4	16.3	16.6	16.4
		Wool	kg N ha^{-1}	0.2	0.1	0.2	0.2	0.2	0.2	0.2
		Total N exports	kg N ha^{-1}	30.2	15.6	18.4	18.2	18.0	17.5	17.4
	KPIs	N balance	kg N ha^{-1}	33.3	10.1	27.8	45.7	67.9	92.4	139.7
		N use efficiency	% (median)	44.7	58.0	36.5	24.9	18.4	14.6	11.1
		Gross margin	€ ha^{-1}	1239.2	625.5	692.0	765.1	801.4	798.9	847.8
	Finances	Fertiliser costs	€ ha^{-1}	18.6	10.3	19.5	35.4	51.7	71.6	103.5
		Concentrates costs	€ LU^{-1}	119.9	74.8	97.4	103.0	123.8	132.9	149.0
		Bulky feed costs	€ LU^{-1}	13.3	9.6	8.9	7.6	11.3	18.7	20.4
		Total direct costs	€ ha^{-1}	409.8	234.1	309.1	377.0	469.6	572.1	689.0
		Total costs	€ ha^{-1}	884.2	520.6	672.8	787.0	936.4	1077.0	1244.4
		Gross output	€ ha^{-1}	1649.2	859.7	1001.1	1142.2	1271.0	1371.0	1536.7
	Population	Number of NFS data points	n	84	182	281	466	464	279	187
		Proportion of national population weighting	%	4.4	9.9	14.4	24.0	22.8	15.3	9.9
Sheep	Farm characteristics	UAA	ha	33.2	42.5	61.1	51.9	40.0	35.7	32.0
		Stocking rate	LU ha^{-1}	1.6	1.1	1.2	1.2	1.5	1.5	1.6
		Organic N loading	kg ON ha^{-1}	84.9	58.3	61.8	65.9	79.9	80.1	79.1
		Soil class	1-6	3.2	3.3	3.4	3.4	3.2	3.2	2.4
	N imports	Fertiliser	kg N ha^{-1}	27.2	14.1	22.6	31.3	45.4	60.7	80.7
		Concentrates	kg N ha^{-1}	12.0	6.7	9.1	12.9	13.4	14.5	17.4
		Forage crops	kg N ha^{-1}	2.8	1.6	1.9	1.7	2.5	3.5	8.8
		Livestock	kg N ha^{-1}	6.5	3.1	3.8	3.6	2.8	2.1	2.2
		Total N imports	kg N ha^{-1}	48.6	25.6	37.4	49.4	64.1	80.8	109.1
	N exports	Milk	kg N ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.1	0.0
		Cash crops	kg N ha^{-1}	3.0	2.8	2.1	0.9	0.3	0.2	0.1
		Livestock	kg N ha^{-1}	18.5	10.7	12.1	13.2	12.9	12.8	12.8
		Wool	kg N ha^{-1}	1.9	1.4	1.4	1.5	1.8	1.8	1.8
		Total N exports	kg N ha^{-1}	23.3	15.0	15.6	15.6	15.0	14.8	14.7
	KPIs	N balance	kg N ha^{-1}	25.3	10.6	21.7	33.7	49.1	66.0	94.4
		N use efficiency	% (median)	47.2	64.5	40.9	30.1	22.8	17.9	13.5
		Gross margin	€ ha^{-1}	1315.3	802.5	710.6	736.7	857.5	840.7	693.9
	Finances	Fertiliser costs	€ ha^{-1}	23.0	9.4	21.1	30.9	44.9	66.9	76.8
		Concentrates costs	€ LU^{-1}	85.7	74.1	92.1	123.9	112.9	126.0	136.7
		Bulky feed costs	€ LU^{-1}	9.6	14.0	13.0	10.4	12.4	18.0	21.6
		Total direct costs	€ ha^{-1}	350.5	215.3	282.0	354.2	418.6	475.8	546.8
		Total costs	€ ha^{-1}	868.7	578.7	607.6	709.7	852.3	991.8	1114.2
		Gross output	€ ha^{-1}	1665.8	1017.7	992.7	1090.9	1276.0	1316.5	1240.4
	Population	Number of NFS data points	n	43	84	130	214	214	129	86
		Proportion of national population weighting	%	5.5	8.9	12.4	20.8	22.0	15.0	10.7
Tillage	Farm characteristics	UAA	ha	73.9	37.1	47.3	69.4	60.9	74.6	64.4
		Stocking rate	LU ha^{-1}	0.2	0.1	0.2	0.4	0.6	1.0	0.9
		Organic N loading	kg ON ha^{-1}	9.9	8.1	16.1	26.0	37.5	68.1	60.6
		Soil class	1-6	1.4	1.4	1.5	1.7	1.7	1.8	1.7
	N imports	Fertiliser	kg N ha^{-1}	121.6	80.7	90.8	105.6	121.2	123.0	149.7
		Concentrates	kg N ha^{-1}	1.9	0.5	1.6	3.0	4.3	7.8	12.3
		Forage crops	kg N ha^{-1}	0.8	0.7	1.0	2.0	2.7	3.8	5.1
		Livestock	kg N ha^{-1}	0.7	0.6	1.6	2.2	3.0	9.3	11.2
		Total N imports	kg N ha^{-1}	125.0	82.5	95.0	112.8	131.2	143.9	178.3
	N exports	Milk	kg N ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Cash crops	kg N ha^{-1}	110.8	74.1	73.6	76.3	68.8	52.5	62.7
		Livestock	kg N ha^{-1}	3.7	1.5	3.7	5.0	7.2	15.4	18.0
		Wool	kg N ha^{-1}	0.1	0.0	0.1	0.2	0.3	0.1	0.1
		Total N exports	kg N ha^{-1}	114.6	75.6	77.4	81.4	76.2	68.0	80.7
	KPIs	N balance	kg N ha^{-1}	10.5	6.9	17.6	31.4	54.9	75.9	97.7
		N use efficiency	% (median)	92.1	91.9	79.9	69.9	57.1	49.4	43.9
		Gross margin	€ ha^{-1}	1572.8	897.5	880.0	977.3	894.9	1208.9	1142.1
	Finances	Fertiliser costs	€ ha^{-1}	3.6	3.7	7.1	14.8	30.6	56.9	57.0
		Concentrates costs	€ LU^{-1}	91.5	24.4	44.6	81.1	77.3	93.4	156.1
		Bulky feed costs	€ LU^{-1}	3.0	1.8	3.4	5.2	18.7	5.8	5.1
		Total direct costs	€ ha^{-1}	610.9	458.2	510.2	577.7	635.2	619.4	759.1
		Total costs	€ ha^{-1}	1296.7	816.2	917.3	1108.4	1222.2	1330.5	1375.5
		Gross output	€ ha^{-1}	2183.6	1355.6	1390.9	1555.0	1529.5	1827.8	1901.1
	Population	Number of NFS data points	n	29	50	72	122	124	72	50
		Proportion of national population weighting	%	5.2	11.4	15.3	18.8	20.5	11.1	8.6

Table 5 – Mean farm characteristics and P imports/exports/KPIs for benchmark farms and poorer-performing percentiles for each farm sector. This information be used as a guide for improving nutrient management performance.

			Overall performance	**Optimal benchmark zone**	**Benchmark**		**Above average**	**Below average**	**Worst**	
			P balance percentile	76-100	91-100	76-90	51-75	26-50	11-25	1-10
			Gross margin percentile	76-100	1-100	1-100	1-100	1-100	1-100	1-100
Sector	**Variable type**	**Variable**	**Unit**							
Dairy	Farm characteristics	UAA	ha	53.9	47.8	52.8	51.5	53.0	53.0	50.5
		Stocking rate	LU ha^{-1}	2.2	1.8	1.8	1.8	1.9	1.9	1.9
		Organic N loading	kg ON ha^{-1}	183.9	146.2	150.9	151.4	156.3	158.0	158.2
		Milk production intensity	l cow^{-1}	5691.4	4943.2	4919.8	5063.5	5086.2	5111.8	5085.5
		Milk production intensity	l ha^{-1}	8269.8	5818.1	5726.8	6111.4	6360.4	6509.8	6644.7
		Soil class	1-6	1.8	2.3	2.5	2.4	2.4	2.6	2.5
	P imports	Fertiliser	kg P ha^{-1}	6.6	5.1	6.0	8.1	11.0	15.3	22.0
		Concentrates	kg P ha^{-1}	8.2	6.5	6.6	6.9	7.5	8.0	10.9
		Forage crops	kg P ha^{-1}	1.2	0.7	0.9	0.9	1.1	1.3	2.1
		Livestock	kg P ha^{-1}	0.3	0.3	0.3	0.4	0.4	0.4	0.6
		Total P imports	kg P ha^{-1}	16.3	12.6	13.8	16.3	19.9	25.0	35.6
	P exports	Milk	kg P ha^{-1}	7.4	5.2	5.0	5.4	5.6	5.8	5.9
		Livestock	kg P ha^{-1}	4.1	3.4	3.6	3.5	3.2	3.2	3.0
		Cash crops	kg P ha^{-1}	0.3	0.5	0.4	0.3	0.2	0.2	0.0
		Wool	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total P exports	kg P ha^{-1}	11.8	9.0	9.0	9.2	9.0	9.1	9.0
	KPIs	P balance	kg P ha^{-1}	4.5	3.5	4.8	7.1	10.9	15.9	26.6
		P use efficiency	% (median)	71.9	70.3	63.5	55.0	44.6	35.7	26.0
		Gross margin	€ ha^{-1}	2698.3	1751.0	1772.7	1774.9	1784.5	1780.1	1699.7
	Finances	Fertiliser costs	€ ha^{-1}	159.8	106.5	114.4	128.4	147.4	176.3	181.9
		Concentrates costs	€ LU^{-1}	244.5	225.9	238.0	236.9	262.6	276.4	315.9
		Bulky feed costs	€ LU^{-1}	23.2	16.9	17.8	18.4	23.9	29.2	30.1
		Total direct costs	€ ha^{-1}	1586.0	999.2	1195.1	1162.2	1394.7	1457.1	1626.0
		Total costs	€ ha^{-1}	2807.9	1777.3	2127.6	2008.0	2345.6	2395.9	2643.0
		Gross output	€ ha^{-1}	4532.0	2709.5	3167.0	2998.1	3373.5	3402.5	3725.0
	Population	Number of NFS data points	n	89	129	198	323	327	195	131
		Proportion of national population weighting	%	4.2	6.9	9.7	16.1	16.5	9.7	6.6
Mixed livestock	Farm characteristics	UAA	ha	57.9	62.5	48.7	66.0	50.6	53.0	60.6
		Stocking rate	LU ha^{-1}	2.2	1.4	1.4	1.6	1.6	1.6	1.6
		Organic N loading	kg ON ha^{-1}	177.1	93.5	102.7	119.5	122.8	118.9	116.8
		Milk production intensity	l cow^{-1}	5226.7	2897.1	3322.7	4173.3	4174.3	3979.6	3601.0
		Milk production intensity	l ha^{-1}	5558.3	2043.0	2315.6	2612.8	2860.2	2626.1	3227.3
		Soil class	1-6	2.1	2.2	2.9	2.2	2.6	2.6	2.5
	P imports	Fertiliser	kg P ha^{-1}	4.6	4.6	5.6	7.5	9.0	12.5	17.5
		Concentrates	kg P ha^{-1}	9.5	3.8	4.0	5.1	6.2	5.5	7.0
		Forage crops	kg P ha^{-1}	1.7	0.6	0.7	0.9	0.8	0.8	0.6
		Livestock	kg P ha^{-1}	1.2	0.7	0.5	0.8	0.7	0.7	0.3
		Total P imports	kg P ha^{-1}	16.9	9.6	10.8	14.2	16.7	19.5	25.5
	P exports	Milk	kg P ha^{-1}	4.9	1.8	2.0	2.3	2.5	2.3	2.8
		Livestock	kg P ha^{-1}	7.0	3.6	4.0	4.7	4.7	4.2	3.5
		Cash crops	kg P ha^{-1}	0.7	0.9	0.8	1.1	0.5	0.7	0.2
		Wool	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total P exports	kg P ha^{-1}	12.6	6.3	6.7	8.2	7.6	7.1	6.8
	KPIs	P balance	kg P ha^{-1}	4.4	3.3	4.1	6.0	9.0	12.4	18.7
		P use efficiency	% (median)	73.3	58.9	57.0	54.6	43.4	34.3	24.1
		Gross margin	€ ha^{-1}	2069.2	1035.2	1025.1	1149.4	1108.1	1008.0	1652.9
	Finances	Fertiliser costs	€ ha^{-1}	134.3	52.7	63.4	72.2	88.5	97.1	120.9
		Concentrates costs	€ LU^{-1}	266.6	148.9	158.7	180.0	237.6	193.9	316.9
		Bulky feed costs	€ LU^{-1}	36.9	15.1	23.2	12.3	16.9	12.5	11.8
		Total direct costs	€ ha^{-1}	2337.6	839.7	890.1	1184.6	874.2	983.8	1497.6
		Total costs	€ ha^{-1}	3887.5	1507.2	1656.1	2175.9	1550.6	1731.2	2437.3
		Gross output	€ ha^{-1}	6344.7	2248.3	2416.1	3123.3	2128.7	2287.1	3360.2
	Population	Number of NFS data points	n	22	32	52	84	87	50	33
		Proportion of national population weighting	%	2.0	5.6	7.9	11.5	15.5	9.3	5.9
Suckler cattle	Farm characteristics	UAA	ha	34.7	34.5	35.1	32.9	32.9	30.1	23.2
		Stocking rate	LU ha^{-1}	1.3	1.0	1.0	1.2	1.1	1.1	1.2
		Organic N loading	kg ON ha^{-1}	100.4	74.5	78.2	87.6	83.2	81.6	91.7
		Soil class	1-6	2.5	2.9	2.9	2.9	3.2	2.6	3.0
	P imports	Fertiliser	kg P ha^{-1}	6.0	4.7	5.2	6.2	8.6	11.0	16.6
		Concentrates	kg P ha^{-1}	1.7	1.3	1.4	1.6	1.5	1.6	1.8
		Forage crops	kg P ha^{-1}	0.4	0.3	0.4	0.8	0.4	0.6	1.0
		Livestock	kg P ha^{-1}	0.4	0.3	0.4	0.4	0.8	0.4	0.3
		Total P imports	kg P ha^{-1}	8.5	6.5	7.5	8.9	11.3	13.6	19.7
	P exports	Milk	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Livestock	kg P ha^{-1}	4.5	3.3	3.4	3.8	3.8	3.5	3.5
		Cash crops	kg P ha^{-1}	0.2	0.0	0.1	0.0	0.0	0.0	0.0
		Wool	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total P exports	kg P ha^{-1}	4.7	3.3	3.5	3.8	3.9	3.6	3.5
	KPIs	P balance	kg P ha^{-1}	3.8	3.3	3.9	5.1	7.4	10.0	16.1
		P use efficiency	% (median)	53.3	46.8	43.8	39.7	31.1	24.8	17.8
		Gross margin	€ ha^{-1}	972.3	659.7	597.0	705.2	664.6	635.2	698.3
	Finances	Fertiliser costs	€ ha^{-1}	56.6	38.4	39.0	48.5	60.3	62.8	82.4
		Concentrates costs	€ LU^{-1}	81.7	81.3	86.8	88.3	83.9	87.4	76.2
		Bulky feed costs	€ LU^{-1}	9.4	7.2	18.1	24.4	14.7	18.0	19.0
		Total direct costs	€ ha^{-1}	187.4	132.9	142.0	133.0	136.3	111.6	92.6
		Total costs	€ ha^{-1}	380.7	290.3	293.7	278.7	272.7	226.7	174.2
		Gross output	€ ha^{-1}	574.4	386.8	387.0	373.6	364.2	278.8	212.9
	Population	Number of NFS data points	n	35	58	87	144	145	86	58
		Proportion of national population weighting	%	2.6	4.3	6.4	10.9	12.0	7.4	6.2
Non-suckler cattle	Farm characteristics	UAA	ha	46.1	39.0	38.1	35.8	33.4	29.9	24.6
		Stocking rate	LU ha^{-1}	1.6	1.2	1.3	1.3	1.4	1.5	1.6
		Organic N loading	kg ON ha^{-1}	111.4	84.2	95.1	95.2	100.2	103.9	116.6
		Soil class	1-6	2.1	2.7	2.6	2.5	2.7	2.6	2.8
	P imports	Fertiliser	kg P ha^{-1}	7.1	4.9	5.6	6.5	9.1	11.8	17.2

		Concentrates	kg P ha^{-1}	4.0	2.4	2.7	3.1	3.0	3.2	3.8
		Forage crops	kg P ha^{-1}	0.8	0.4	0.6	0.4	0.4	1.2	1.8
		Livestock	kg P ha^{-1}	5.2	2.8	2.8	3.6	3.3	3.1	3.1
		Total P imports	kg P ha^{-1}	17.2	10.5	11.8	13.6	15.8	19.4	26.0
	P exports	Milk	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Livestock	kg P ha^{-1}	12.2	6.5	7.3	7.6	7.2	7.2	7.2
		Cash crops	kg P ha^{-1}	1.0	0.6	0.3	0.3	0.3	0.4	0.3
		Wool	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total P exports	kg P ha^{-1}	13.1	7.2	7.6	8.0	7.6	7.5	7.5
	KPIs	P balance	kg P ha^{-1}	4.0	3.3	4.1	5.7	8.2	11.8	18.5
		P use efficiency	% (median)	72.9	60.3	58.2	51.1	43.5	35.3	26.2
		Gross margin	€ ha^{-1}	1280.7	707.1	763.3	827.8	775.6	748.2	678.5
	Finances	Fertiliser costs	€ ha^{-1}	59.7	38.3	44.7	50.8	58.9	67.2	90.2
		Concentrates costs	€ LU^{-1}	162.1	121.2	130.9	134.3	128.0	141.1	141.1
		Bulky feed costs	€ LU^{-1}	18.9	6.6	19.2	8.8	11.0	17.6	32.4
		Total direct costs	€ ha^{-1}	457.7	253.6	223.4	214.2	216.9	196.3	161.2
		Total costs	€ ha^{-1}	784.0	467.1	421.6	397.4	389.0	353.0	270.7
		Gross output	€ ha^{-1}	1267.6	682.4	602.8	564.5	528.3	457.8	339.7
	Population	Number of NFS data points	n	57	95	145	240	240	145	96
		Proportion of national population weighting	%	2.5	4.3	6.9	12.1	12.8	8.5	7.0
Sheep	Farm characteristics	UAA	ha	31.8	44.5	35.6	35.6	35.1	35.2	29.3
		Stocking rate	LU ha^{-1}	1.8	1.5	1.4	1.6	1.5	1.5	1.6
		Organic N loading	kg ON ha^{-1}	105.6	79.3	78.7	81.8	79.0	82.5	90.1
		Soil class	1-6	2.7	3.0	2.9	2.8	2.8	3.0	3.1
	P imports	Fertiliser	kg P ha^{-1}	5.6	5.0	5.2	7.0	8.4	12.4	18.6
		Concentrates	kg P ha^{-1}	4.9	3.1	3.0	3.1	2.9	3.5	3.4
		Forage crops	kg P ha^{-1}	1.0	0.6	0.9	0.5	0.6	0.9	2.4
		Livestock	kg P ha^{-1}	3.3	1.2	2.1	1.8	1.6	1.3	1.2
		Total P imports	kg P ha^{-1}	14.9	10.0	11.2	12.4	13.5	18.1	25.5
	P exports	Milk	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Livestock	kg P ha^{-1}	9.8	6.0	6.3	6.1	5.5	5.4	5.7
		Cash crops	kg P ha^{-1}	0.6	0.5	0.5	0.2	0.2	0.5	0.1
		Wool	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total P exports	kg P ha^{-1}	10.5	6.5	6.8	6.4	5.7	6.0	5.8
	KPIs	P balance	kg P ha^{-1}	4.4	3.5	4.4	6.0	7.8	12.1	19.7
		P use efficiency	% (median)	65.4	59.4	54.5	48.3	39.4	31.6	22.3
		Gross margin	€ ha^{-1}	1350.9	910.4	775.0	824.4	781.1	806.5	860.6
	Finances	Fertiliser costs	€ ha^{-1}	46.8	40.0	41.4	57.7	53.6	67.5	85.3
		Concentrates costs	€ LU^{-1}	177.9	131.4	135.1	126.5	130.0	160.0	144.6
		Bulky feed costs	€ LU^{-1}	17.7	14.8	22.0	12.1	15.2	18.9	38.5
		Total direct costs	€ ha^{-1}	154.6	181.8	155.3	160.2	185.4	222.7	196.7
		Total costs	€ ha^{-1}	327.9	388.3	310.0	306.7	349.1	420.8	350.6
		Gross output	€ ha^{-1}	550.9	570.4	438.8	445.8	494.1	556.9	457.8
	Population	Number of NFS data points	n	25	35	54	92	88	55	36
		Proportion of national population weighting	%	3.0	3.5	5.9	10.5	10.1	5.8	4.8
Tillage	Farm characteristics	UAA	ha	42.2	39.3	64.6	57.0	56.3	54.4	33.5
		Stocking rate	LU ha^{-1}	0.5	0.5	0.6	0.5	0.5	0.6	0.8
		Organic N loading	kg ON ha^{-1}	38.9	27.0	39.7	30.3	31.5	41.2	54.2
		Soil class	1-6	1.4	1.5	1.8	1.5	1.5	1.5	1.8
	P imports	Fertiliser	kg P ha^{-1}	23.2	17.7	16.7	20.9	24.0	27.2	37.8
		Concentrates	kg P ha^{-1}	0.7	0.8	1.3	0.7	0.8	1.1	1.0
		Forage crops	kg P ha^{-1}	0.4	0.4	0.6	0.6	0.6	0.8	0.2
		Livestock	kg P ha^{-1}	3.0	0.8	2.1	1.2	1.0	1.5	3.9
		Total P imports	kg P ha^{-1}	27.2	19.6	20.6	23.4	26.5	30.5	43.0
	P exports	Milk	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Livestock	kg P ha^{-1}	5.2	2.2	4.0	2.5	2.4	3.4	5.8
		Cash crops	kg P ha^{-1}	18.0	14.0	12.0	13.8	13.7	11.6	9.0
		Wool	kg P ha^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total P exports	kg P ha^{-1}	23.2	16.2	16.0	16.3	16.0	15.0	14.8
	KPIs	P balance	kg P ha^{-1}	4.0	3.5	4.7	7.1	10.4	15.5	28.2
		P use efficiency	% (median)	84.5	80.0	74.8	66.7	58.1	45.4	35.0
		Gross margin	€ ha^{-1}	1719.9	982.6	958.1	883.1	854.7	907.7	1342.0
	Finances	Fertiliser costs	€ ha^{-1}	38.3	18.9	32.7	18.6	31.0	44.3	49.6
		Concentrates costs	€ LU^{-1}	128.2	104.4	143.2	64.0	65.5	86.6	50.6
		Bulky feed costs	€ LU^{-1}	1.8	21.4	5.3	8.7	12.1	13.9	2.6
		Total direct costs	€ ha^{-1}	491.0	394.2	675.0	560.6	645.4	621.1	437.5
		Total costs	€ ha^{-1}	1017.2	766.9	1323.3	1092.8	1177.3	1256.4	990.0
		Gross output	€ ha^{-1}	1627.4	1009.8	1833.7	1468.8	1488.0	1641.0	1069.0
	Population	Number of NFS data points	n	12	26	40	63	65	39	27
		Proportion of national population weighting	%	2.3	5.7	5.8	10.3	12.1	7.6	7.5

Table 6 – Mean changes in N and P imports, exports and KPIs for each farm type if benchmark targets were met, for each scenario. Also indicated are potential changes to N_2O emissions based on changes in N fertiliser use (using a 1.24% emissions factor). Results are for affected farms only in each scenario (farms in the optimal benchmark zone would not change in Scenario 3, and farms located below the Q75 or Q10 percentile regression lines would not change in Scenarios 1 and 2, respectively).

				Scenario 1		Scenario 2		Scenario 3	
Sector	**Variable type**	**Variable**	**Unit**	**N**	**P**	**N**	**P**	**N**	**P**
Dairy	Nutrient imports	Fertiliser	kg N or P ha^{-1}	-30.3	-3.3	-53.9	-6.4	-20.3	-1.5
		Concentrates	kg N or P ha^{-1}	-5.2	-0.8	-11.1	-2.9	+0.5	+1.4
		Forage crops	kg N or P ha^{-1}	-1.4	-0.2	-4.0	-1.0	+0.5	+0.2
		Livestock	kg N or P ha^{-1}	-0.0	-0.1	-0.1	-0.2	+0.1	-0.1
		Total nutrient imports	kg N or P ha^{-1}	-37.0	-4.4	-69.1	-10.5	-19.1	+0.1
	Nutrient exports	Milk	kg N or P ha^{-1}	-1.3	-0.3	-1.5	-0.2	+13.4	+1.9
		Cash crops	kg N or P ha^{-1}	+1.0	+0.2	+0.1	+0.2	+1.3	+0.0
		Livestock	kg N or P ha^{-1}	-0.0	+0.2	+0.1	+0.3	+0.9	+0.8
		Wool	kg N or P ha^{-1}	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
		Total nutrient exports	kg N or P ha^{-1}	-0.3	+0.1	-1.3	+0.2	+15.6	+2.7
	KPIs	Nutrient balance	kg N or P ha^{-1}	-36.7	-4.5	-67.8	-10.7	-34.7	-2.6
		Nutrient use efficiency	% (median)	+3.3	+8.8	+2.9	+9.1	+11.2	+13.5
		Gross margin	€ ha^{-1}	-9.0	+20.9	-35.4	+79.0	+919.3	+895.2
	Finances	Fertiliser costs	€ ha^{-1}	-27.3	-17.8	-51.5	-6.7	-21.8	+28.4
		Concentrates costs	€ LU^{-1}	-16.4	-17.0	-11.1	-40.7	-29.4	+12.7
		Bulky feed costs	€ LU^{-1}	-3.1	-3.7	+4.0	-2.7	-1.6	+3.1
		Total direct costs	€ ha^{-1}	-116.8	+220.6	-124.4	+262.6	+110.1	+629.9
		Total costs	€ ha^{-1}	-156.2	+460.9	-178.9	+506.1	+291.6	+1191.0
		Gross output	€ ha^{-1}	-125.7	+680.5	-159.9	+686.9	+1031.0	+2098.3
	Emissions	N_2O	kg N_2O ha^{-1}	-0.376	N/A	-0.669	N/A	-0.252	N/A
Mixed livestock	Nutrient imports	Fertiliser	kg N or P ha^{-1}	-15.1	-2.1	-13.9	-4.9	+9.1	-1.4
		Concentrates	kg N or P ha^{-1}	-5.2	-0.2	+0.7	+0.0	-6.3	+4.8
		Forage crops	kg N or P ha^{-1}	+0.1	+0.0	-3.1	+0.2	+0.7	+0.5
		Livestock	kg N or P ha^{-1}	+0.3	+0.0	+0.3	+0.6	-0.1	+0.1
		Total nutrient imports	kg N or P ha^{-1}	-19.9	-2.3	-15.9	-4.2	+3.4	+4.0
	Nutrient exports	Milk	kg N or P ha^{-1}	-1.0	+0.2	+3.3	+0.2	+5.2	+2.7
		Cash crops	kg N or P ha^{-1}	+5.1	+0.4	+0.1	+0.4	+21.0	+0.1
		Livestock	kg N or P ha^{-1}	+0.2	+0.2	+2.7	+1.2	-0.1	+1.9
		Wool	kg N or P ha^{-1}	+0.1	+0.0	+0.1	+0.0	-0.2	+0.0
		Total nutrient exports	kg N or P ha^{-1}	+4.4	+0.8	+6.0	+1.5	+25.8	+4.6
	KPIs	Nutrient balance	kg N or P ha^{-1}	-24.3	-3.1	-21.8	-5.7	-22.4	-0.6
		Nutrient use efficiency	% (median)	+4.9	+7.3	+2.7	+6.9	+22.9	+10.7
		Gross margin	€ ha^{-1}	+24.4	+51.8	+13.1	-399.0	+845.5	+1010.4
	Finances	Fertiliser costs	€ ha^{-1}	-15.1	-2.8	+0.7	-8.0	-12.7	+60.0
		Concentrates costs	€ LU^{-1}	-22.9	-17.5	+6.3	-77.6	-20.9	+90.2
		Bulky feed costs	€ LU^{-1}	-2.2	-0.4	-6.6	+0.4	-7.1	+12.0
		Total direct costs	€ ha^{-1}	-112.6	+985.4	-148.2	+890.7	-63.0	+2545.3
		Total costs	€ ha^{-1}	-127.9	+1827.0	-191.4	+1824.8	+154.0	+4002.0
		Gross output	€ ha^{-1}	-88.2	+2691.6	-135.1	+2247.7	+782.5	+6839.2
	Emissions	N_2O	kg N_2O ha^{-1}	-0.187	N/A	-0.172	N/A	+0.113	N/A
Suckler cattle	Nutrient imports	Fertiliser	kg N or P ha^{-1}	-19.9	-2.7	-36.4	-5.9	-19.9	+1.0
		Concentrates	kg N or P ha^{-1}	-1.2	-0.1	+0.2	-0.1	+0.4	+0.6
		Forage crops	kg N or P ha^{-1}	-1.1	-0.2	-4.1	-0.4	-1.6	+0.2
		Livestock	kg N or P ha^{-1}	+0.0	-0.1	+0.0	+0.1	+0.5	+0.1
		Total nutrient imports	kg N or P ha^{-1}	-22.2	-3.0	-40.3	-6.3	-20.6	+1.9
	Nutrient exports	Milk	kg N or P ha^{-1}	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
		Cash crops	kg N or P ha^{-1}	+0.1	+0.0	+0.0	+0.0	+1.2	+0.3
		Livestock	kg N or P ha^{-1}	-0.5	-0.2	+0.0	-0.1	+3.3	+1.4
		Wool	kg N or P ha^{-1}	+0.0	+0.0	+0.0	+0.0	+0.1	+0.0
		Total nutrient exports	kg N or P ha^{-1}	-0.5	-0.2	+0.0	-0.1	+4.6	+1.7
	KPIs	Nutrient balance	kg N or P ha^{-1}	-21.7	-2.8	-40.4	-6.3	-25.2	+0.2
		Nutrient use efficiency	% (median)	+5.1	+5.9	+3.2	+6.5	+20.7	-0.6
		Gross margin	€ ha^{-1}	-17.0	-47.1	-13.2	-86.8	+428.0	+319.6
	Finances	Fertiliser costs	€ ha^{-1}	-18.7	-13.4	-32.6	-22.8	-22.3	+14.2
		Concentrates costs	€ LU^{-1}	-3.0	+7.3	+9.5	+16.7	-7.1	+10.9
		Bulky feed costs	€ LU^{-1}	-2.2	-0.6	-5.5	-2.7	-10.1	-2.1
		Total direct costs	€ ha^{-1}	-79.0	+80.7	-109.9	+64.6	-33.2	+188.4
		Total costs	€ ha^{-1}	-128.7	+169.2	-218.2	+145.9	+53.0	+353.0
		Gross output	€ ha^{-1}	-95.9	+231.6	-123.3	+172.1	+394.7	+545.9
	Emissions	N_2O	kg N_2O ha^{-1}	-0.247	N/A	-0.452	N/A	-0.247	N/A
Non-suckler cattle	Nutrient imports	Fertiliser	kg N or P ha^{-1}	-20.4	-2.4	-39.7	-5.1	-22.8	+1.1
		Concentrates	kg N or P ha^{-1}	-2.8	-0.1	-1.5	-0.2	+4.1	+1.9
		Forage crops	kg N or P ha^{-1}	-1.1	-0.2	-4.4	-0.9	+4.3	+0.7
		Livestock	kg N or P ha^{-1}	-0.0	-0.3	-0.5	-0.1	+11.2	+3.5
		Total nutrient imports	kg N or P ha^{-1}	-24.4	-3.0	-46.1	-6.3	-3.2	+7.2
	Nutrient exports	Milk	kg N or P ha^{-1}	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
		Cash crops	kg N or P ha^{-1}	+1.1	+0.2	+0.6	+0.4	+4.9	+1.1
		Livestock	kg N or P ha^{-1}	-0.8	-0.1	-0.2	+0.0	+15.5	+6.6
		Wool	kg N or P ha^{-1}	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
		Total nutrient exports	kg N or P ha^{-1}	+0.2	+0.1	+0.5	+0.3	+20.4	+7.6
	KPIs	Nutrient balance	kg N or P ha^{-1}	-24.6	-3.2	-46.6	-6.6	-23.7	-0.5
		Nutrient use efficiency	% (median)	+6.2	+6.9	+3.5	+9.8	+28.0	+9.4
		Gross margin	€ ha^{-1}	-57.5	+13.1	-35.9	+77.8	+526.1	+534.2
	Finances	Fertiliser costs	€ ha^{-1}	-19.9	-9.2	-34.6	-21.6	-27.7	+16.2
		Concentrates costs	€ LU^{-1}	-13.1	+3.9	-7.4	+17.9	+24.7	+57.2
		Bulky feed costs	€ LU^{-1}	-1.7	-1.5	-4.4	-16.2	+16.7	+15.5
		Total direct costs	€ ha^{-1}	-101.4	+213.1	-124.0	+257.6	+55.9	+698.6
		Total costs	€ ha^{-1}	-167.3	+383.9	-188.1	+475.7	+108.6	+1089.2
		Gross output	€ ha^{-1}	-158.9	+557.7	-159.9	+640.5	+582.0	+1822.2
	Emissions	N_2O	kg N_2O ha^{-1}	-0.253	N/A	-0.493	N/A	-0.283	N/A
Sheep	Nutrient imports	Fertiliser	kg N or P ha^{-1}	-15.3	-2.6	-21.3	-5.4	-7.9	+1.6
		Concentrates	kg N or P ha^{-1}	-2.9	-0.2	-3.1	-0.2	+1.3	+2.6
		Forage crops	kg N or P ha^{-1}	-1.3	-0.2	-5.7	-1.5	+1.9	+0.6
		Livestock	kg N or P ha^{-1}	+0.1	+0.2	+0.1	+0.2	+5.2	+2.3
		Total nutrient imports	kg N or P ha^{-1}	-19.5	-2.9	-30.0	-7.0	+0.5	+7.0
	Nutrient exports	Milk	kg N or P ha^{-1}	+0.0	+0.0	+0.1	+0.0	-0.0	+0.0

		Cash crops	kg N or P ha^{-1}	+1.0	+0.2	+0.2	+0.6	+4.1	+0.9
		Livestock	kg N or P ha^{-1}	-1.5	+0.0	-0.6	-0.1	+7.9	+5.1
		Wool	kg N or P ha^{-1}	-0.3	+0.0	-0.1	+0.0	+0.2	+0.0
		Total nutrient exports	kg N or P ha^{-1}	-0.8	+0.2	-0.4	+0.5	+12.2	+6.0
	KPIs	Nutrient balance	kg N or P ha^{-1}	-18.7	-3.1	-29.6	-7.5	-11.7	+1.0
		Nutrient use efficiency	% (median)	+7.0	+5.7	+3.6	+9.7	+24.2	+4.2
		Gross margin	€ ha^{-1}	-97.5	-41.3	+61.1	-67.3	+515.8	+567.7
	Finances	Fertiliser costs	€ ha^{-1}	-17.5	-10.3	-16.4	-16.6	-15.8	+10.2
		Concentrates costs	€ LU^{-1}	-9.6	-3.0	-3.9	-1.3	-15.7	+68.2
		Bulky feed costs	€ LU^{-1}	-1.5	-3.2	-6.4	-22.8	+3.1	+3.8
		Total direct costs	€ ha^{-1}	-97.5	+102.1	-90.6	+175.1	+18.7	+70.9
		Total costs	€ ha^{-1}	-203.6	+201.1	-235.7	+336.5	+136.6	+176.9
		Gross output	€ ha^{-1}	-194.9	+295.9	-29.2	+465.6	+534.6	+356.8
	Emissions	N_2O	kg N_2O ha^{-1}	-0.190	N/A	-0.264	N/A	-0.098	N/A
Tillage	Nutrient imports	Fertiliser	kg N or P ha^{-1}	-13.5	-5.2	-19.0	-10.4	+18.3	+4.6
		Concentrates	kg N or P ha^{-1}	-1.5	+0.2	-3.6	+0.3	-1.8	+0.1
		Forage crops	kg N or P ha^{-1}	-0.5	+0.2	-0.3	+0.9	-0.9	+0.1
		Livestock	kg N or P ha^{-1}	-1.8	-0.2	-4.5	-2.4	-2.5	+1.2
		Total nutrient imports	kg N or P ha^{-1}	-17.3	-5.0	-27.4	-11.6	+13.1	+6.1
	Nutrient exports	Milk	kg N or P ha^{-1}	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
		Cash crops	kg N or P ha^{-1}	+5.5	+0.3	+2.7	+3.0	+39.4	+3.5
		Livestock	kg N or P ha^{-1}	-2.5	+0.1	-4.9	-1.9	-2.2	+1.8
		Wool	kg N or P ha^{-1}	+0.0	+0.0	+0.1	+0.0	-0.0	+0.0
		Total nutrient exports	kg N or P ha^{-1}	+3.0	+0.4	-2.0	+1.1	+37.1	+5.3
	KPIs	Nutrient balance	kg N or P ha^{-1}	-20.3	-5.3	-25.4	-12.7	-24.0	+0.8
		Nutrient use efficiency	% (median)	+8.2	+7.3	+6.1	+11.0	+23.3	-5.5
		Gross margin	€ ha^{-1}	-30.3	-60.1	-4.4	-350.9	+601.9	+630.3
	Finances	Fertiliser costs	€ ha^{-1}	-13.7	-1.2	-11.5	+3.1	-18.3	+5.8
		Concentrates costs	€ LU^{-1}	-7.5	+35.0	-47.8	+53.2	+32.0	+116.7
		Bulky feed costs	€ LU^{-1}	-3.5	-1.8	+2.4	+6.5	-2.5	-5.0
		Total direct costs	€ ha^{-1}	-70.5	+284.4	-122.6	+533.1	-1.1	+128.1
		Total costs	€ ha^{-1}	-121.8	+538.7	-47.7	+978.4	+191.0	+341.9
		Gross output	€ ha^{-1}	-100.6	+781.9	-127.2	+1506.2	+600.7	+858.4
	Emissions	N_2O	kg N_2O ha^{-1}	-0.167	N/A	-0.236	N/A	+0.227	N/A

Table 7 - Estimated aggregate national agricultural N balances currently (2008-15) and following benchmark Scenario 3. Also estimated are changes to N_2O emissions following changes to N fertiliser use.

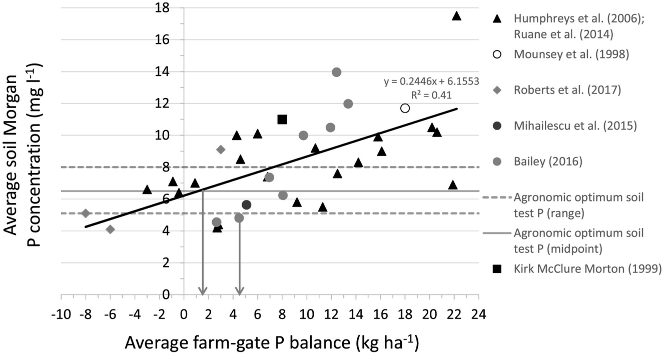
	Current (2008-15)									Scenario 3							
	Mean number of farms the annual NFS sample represents nationally	Mean farm size (UAA ha)	Total utilised agricultural area (ha)	%	Mean N balance (kg ha^{-1} yr^{-1})	Aggregate N balance (t yr^{-1})	% of total	Optimal benchmark zone mean N balance (kg ha^{-1} yr^{-1})	Optimal benchmark zone total UAA (ha)	Mean national N balance change (kg ha^{-1} yr^{-1})	Aggregate N balance change (t yr^{-1})	Aggregate N balance (t yr^{-1})	% of total	% change compared to current	Proportion (%) of total change to aggregate N balance	Mean aggregate N_2O emission changes (kg N_2O-N ha^{-1} yr^{-1})	Aggregate change to N_2O emissions (t N_2O-N)
Dairy	15,629	51.4	711,945	20.5	156.2	111,210	43.0	122.1	32,459	-34.7	-23,578	87,632	48.9	-21.2	29.6	-0.252	-171.2
Mixed livestock	5,304	54.3	254,395	7.3	87.6	22,287	8.6	59.4	6,323	-22.4	-5,557	16,730	9.3	-24.9	7.0	0.113	28.0
Suckler cattle	19,236	33.2	608,586	17.5	50.6	30,816	11.9	25.3	35,580	-25.2	-14,440	16,377	9.1	-46.9	18.1	-0.247	-141.5
Non-suckler cattle	29,165	34.2	1,014,043	29.1	59.4	60,269	23.3	33.3	45,440	-23.7	-22,956	37,313	20.8	-38.1	28.8	-0.283	-274.1
Sheep	14,508	42.9	595,688	17.2	40.9	24,372	9.4	25.3	25,164	-11.7	-6,675	17,697	9.9	-27.4	8.4	-0.098	-55.9
Tillage	6,797	58.1	293,392	8.4	33.9	9,939	3.8	10.5	19,254	-24.0	-6,579	3,359	1.9	-66.2	8.2	0.227	62.2
Total	90,638		3,478,049	100.0		258,893	100.0		164,220	-23.6	-79,785	179,108	100.0	-30.8	100.0	-0.090	-552.5

Table 8 - Estimated aggregate national agricultural P balances currently (2008-15) and following benchmark Scenario 3.

	Current (2008-15)									Scenario 3					
Sector	Mean number of farms the annual NFS sample represents nationally	Mean farm size (UAA ha)	Total utilised agricultural area (ha)	%	Mean P balance (kg ha^{-1} yr^{-1})	Aggregate P balance (t yr^{-1})	% of total	Optimal benchmark zone mean P balance (kg ha^{-1} yr^{-1})	Optimal benchmark zone total UAA (ha)	Mean aggregate P balance change (kg ha^{-1} yr^{-1})	Aggregate P balance change (t yr^{-1})	Aggregate P balance (t yr^{-1})	% of total	% change compared to current	Proportion (%) of total change to aggregate P balance
Dairy	15,629	51.4	711,945	20.5	7.0	4,994	31.4	4.5	31,604	-2.6	-1,769	3,225	22.3	-35.4	119.8
Mixed livestock	5,304	54.3	254,395	7.3	4.8	1,233	7.7	4.4	5,421	-0.6	-149	1,083	7.5	-12.1	10.1
Suckler cattle	19,236	33.2	608,586	17.5	3.7	2,224	14.0	3.8	16,803	0.2	118	2,343	16.2	5.3	-8.0
Non-suckler cattle	29,165	34.2	1,014,043	29.1	4.4	4,498	28.2	4.0	33,664	-0.5	-490	4,007	27.7	-10.9	33.2
Sheep	14,508	42.9	595,688	17.2	3.4	2,033	12.8	4.4	13,388	1.0	582	2,615	18.1	28.6	-39.4
Tillage	6,797	58.1	293,392	8.4	3.2	943	5.9	4.0	5,001	0.8	231	1,174	8.1	24.5	-15.6
Total	90,638		3,478,049	100.0		15,925	100.0		105,881	-0.3	-1,477	14,447	100.0	-9.3	100.0

Highlights

- Benchmarks minimised surpluses and had highest gross margins and efficiencies
- This was due to lower fertiliser/feed imports and more exports and livestock per ha
- If benchmarks are met, 31% and 9% decrease in N and P surplus nationally
- Focus on dairy and non-suckler cattle systems which dominate national surpluses
- Identified excessive surpluses could be used by policy to set upper limits



Average soil Morgan P concentration (mg l-1)
18
16
14
12
10
8
6
4
2
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
Average farm-gate P balance (kg ha-1)
y = 0.2446x + 6.1553
R² = 0.41
Humphreys et al. (2006); Ruane et al. (2014)
Mounsey et al. (1998)
Roberts et al. (2017)
Mihailescu et al. (2015)
Bailey (2016)
Agronomic optimum soil test P (range)
Agronomic optimum soil test P (midpoint)
Kirk McClure Morton (1999)

Figure 1

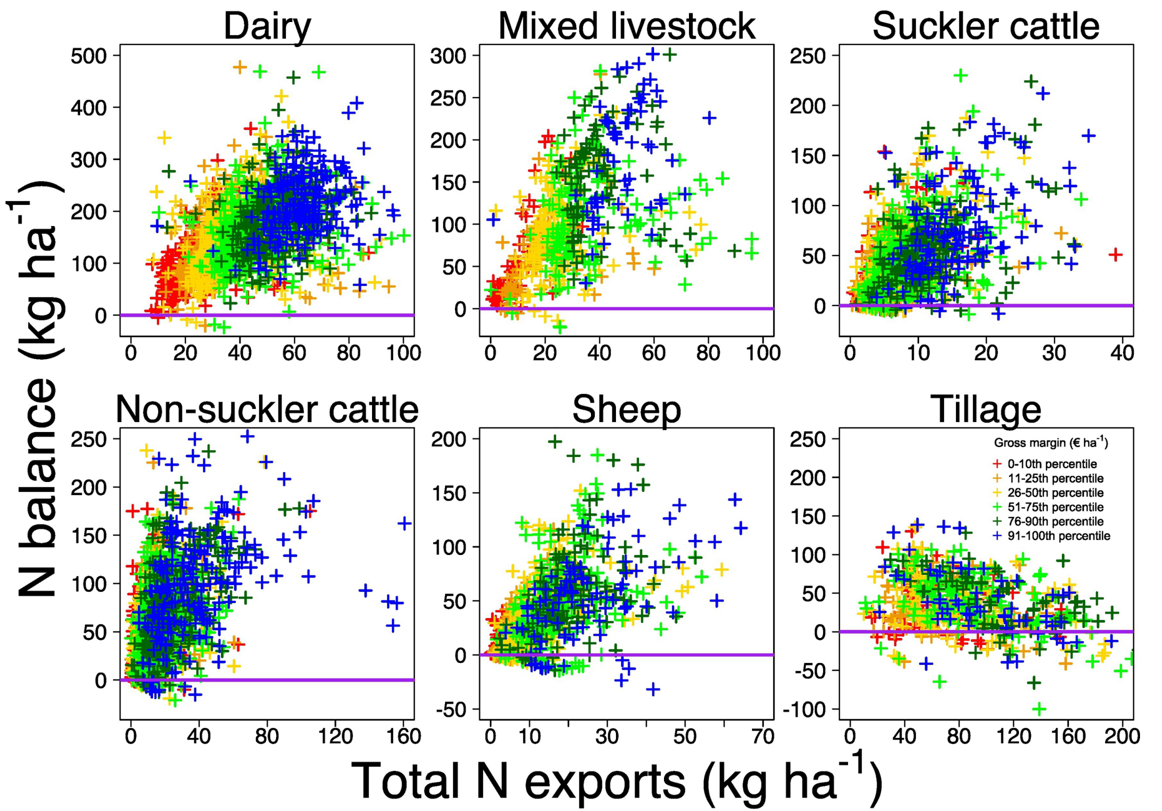
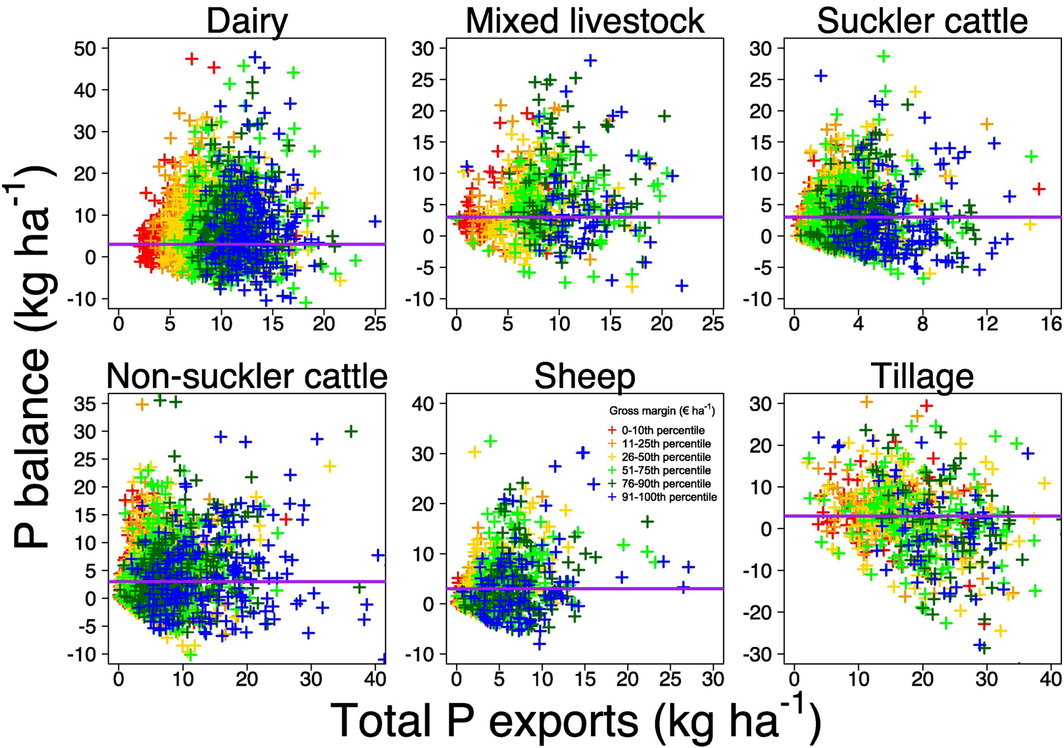

Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage
N balance (kg ha-1)
Total N exports (kg ha-1)
Gross margin (€ ha-1)
0-10th percentile
11-25th percentile
26-50th percentile
51-75th percentile
76-90th percentile
91-100th percentile

Figure 2



Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage
P balance (kg ha-1)
Total P exports (kg ha-1)
Gross margin (€ ha-1)
0-10th percentile
11-25th percentile
26-50th percentile
51-75th percentile
76-90th percentile
91-100th percentile

Figure 3

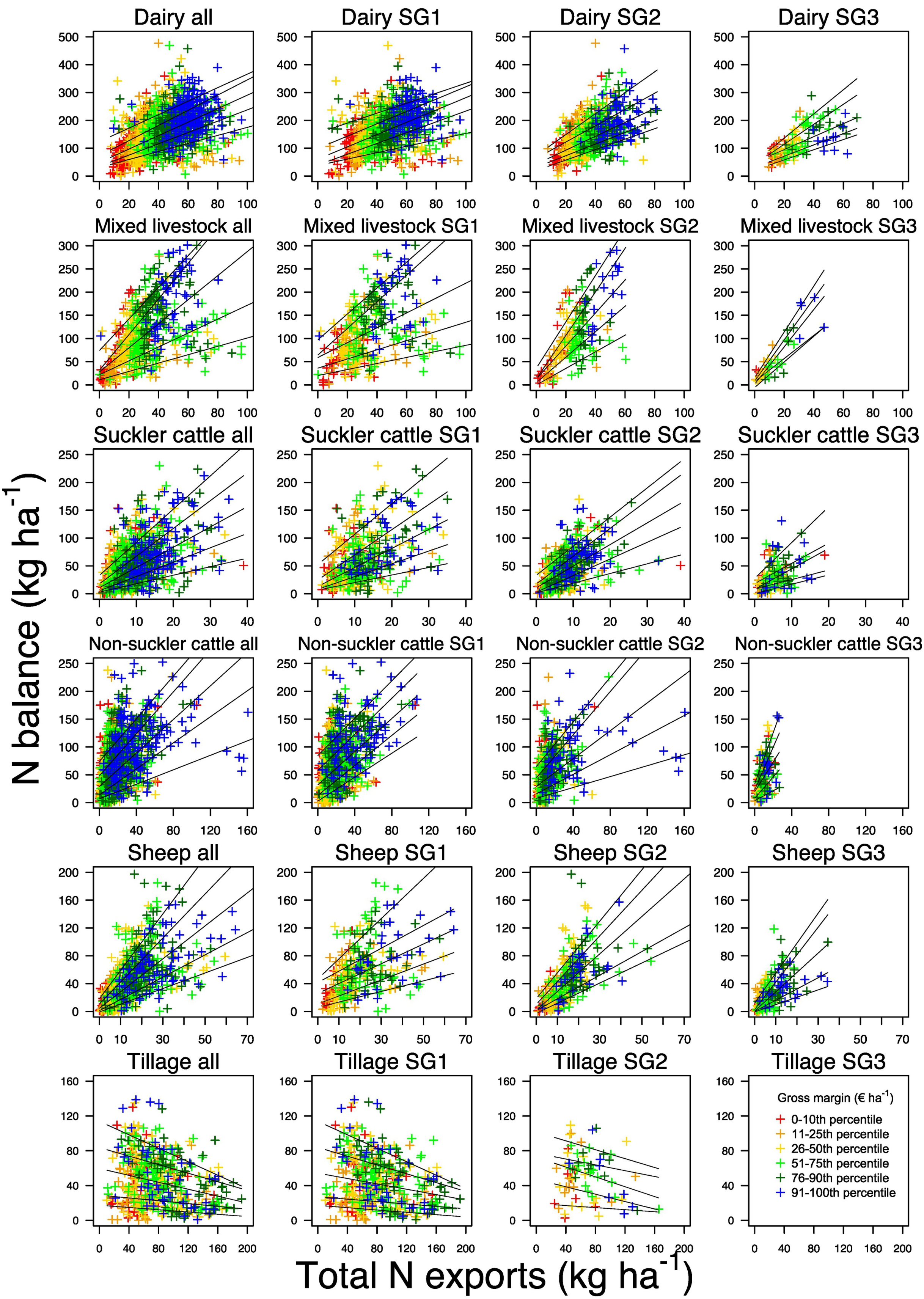
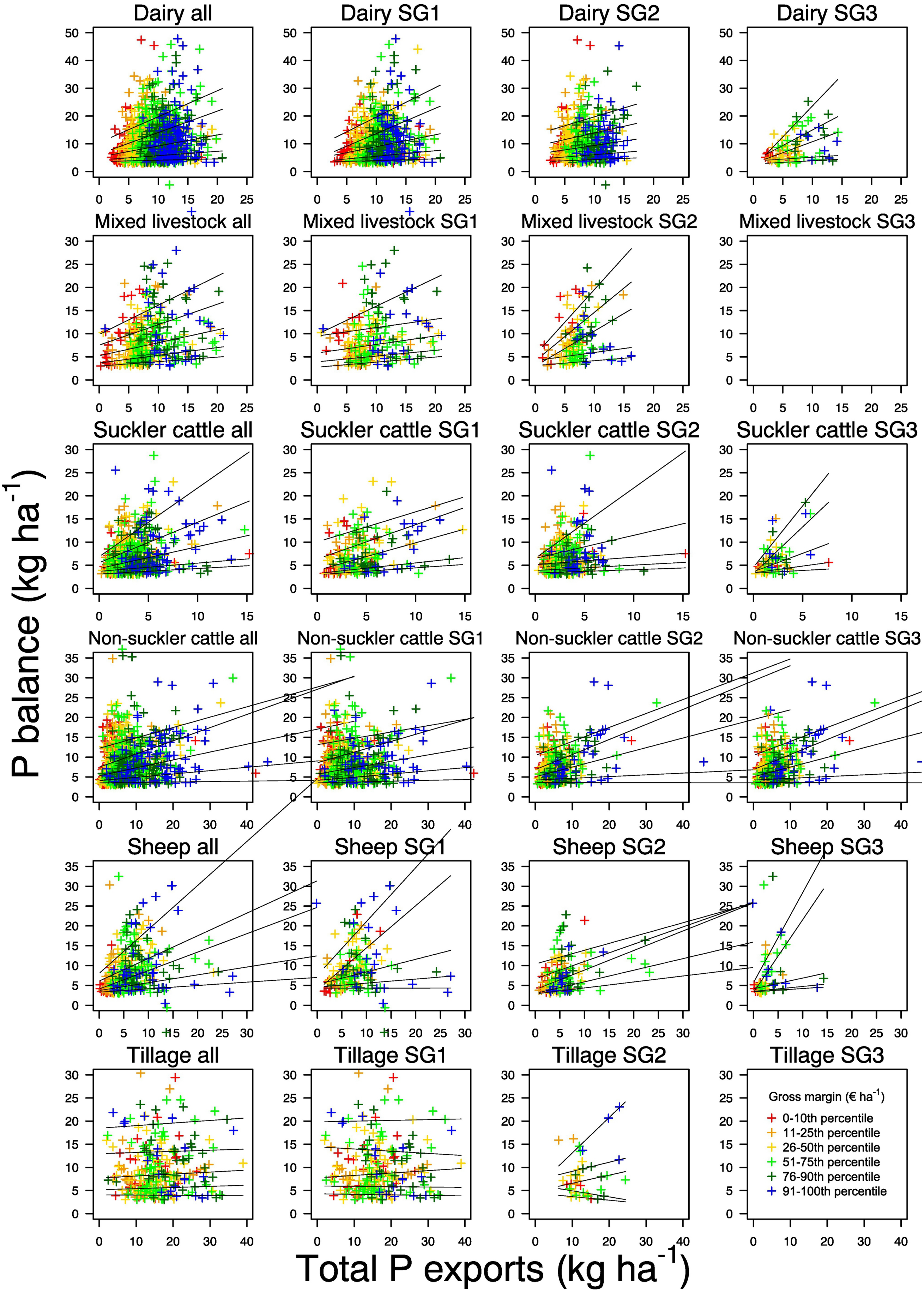
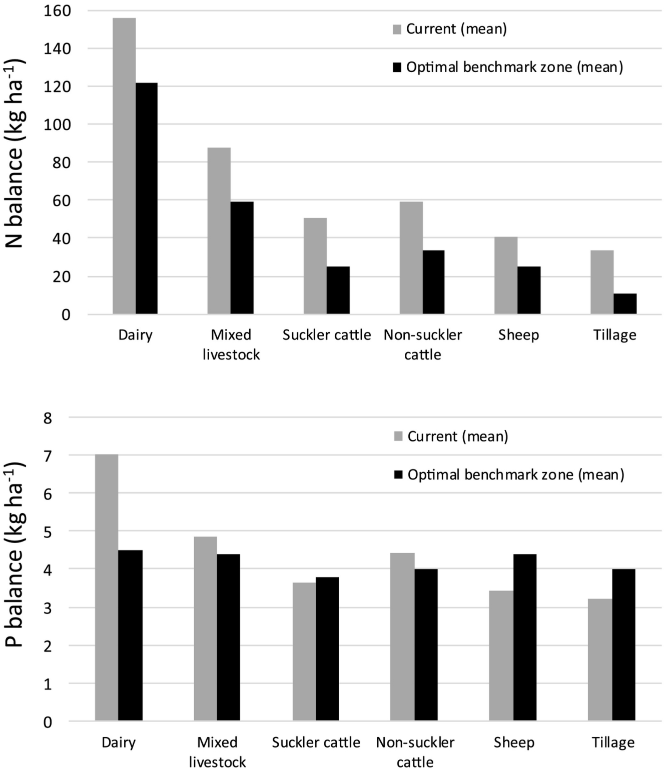

Dairy all
Dairy SG1
Dairy SG2
Dairy SG3
Mixed livestock all
Mixed livestock SG1
Mixed livestock SG2
Mixed livestock SG3
Suckler cattle all
Suckler cattle SG1
Suckler cattle SG2
Suckler cattle SG3
Non-suckler cattle all
Non-suckler cattle SG1
Non-suckler cattle SG2
Non-suckler cattle SG3
Sheep all
Sheep SG1
Sheep SG2
Sheep SG3
Tillage all
Tillage SG1
Tillage SG2
Tillage SG3
N balance (kg ha-1)
Total N exports (kg ha-1)
Gross margin (€ ha-1)
0-10th percentile
11-25th percentile
26-50th percentile
51-75th percentile
76-90th percentile
91-100th percentile

Figure 4



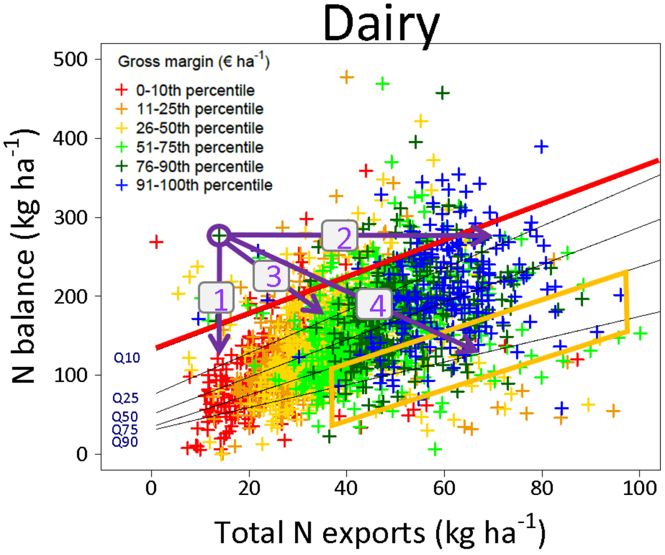
Dairy all
Dairy SG1
Dairy SG2
Dairy SG3
Mixed livestock all
Mixed livestock SG1
Mixed livestock SG2
Mixed livestock SG3
Suckler cattle all
Suckler cattle SG1
Suckler cattle SG2
Suckler cattle SG3
Non-suckler cattle all
Non-suckler cattle SG1
Non-suckler cattle SG2
Non-suckler cattle SG3
Sheep all
Sheep SG1
Sheep SG2
Sheep SG3
Tillage all
Tillage SG1
Tillage SG2
Tillage SG3
P balance (kg ha-1)
Total P exports (kg ha-1)
Gross margin (€ ha-1)
0-10th percentile
11-25th percentile
26-50th percentile
51-75th percentile
76-90th percentile
91-100th percentile

Figure 5



N balance (kg ha-1)
160
140
120
100
80
60
40
20
0
Current (mean)
Optimal benchmark zone (mean)
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage
P balance (kg ha-1)
8
7
6
5
4
3
2
1
0
Current (mean)
Optimal benchmark zone (mean)
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage

Figure 6



Dairy
Gross margin (€ ha-1)
0-10th percentile
11-25th percentile
26-50th percentile
51-75th percentile
76-90th percentile
91-100th percentile
N balance (kg ha-1)
Total N exports (kg ha-1)
500
400
300
200
100
0
0
20
40
60
80
100
Q10
Q25
Q50
Q75
Q90
1
2
3
4

Figure 7

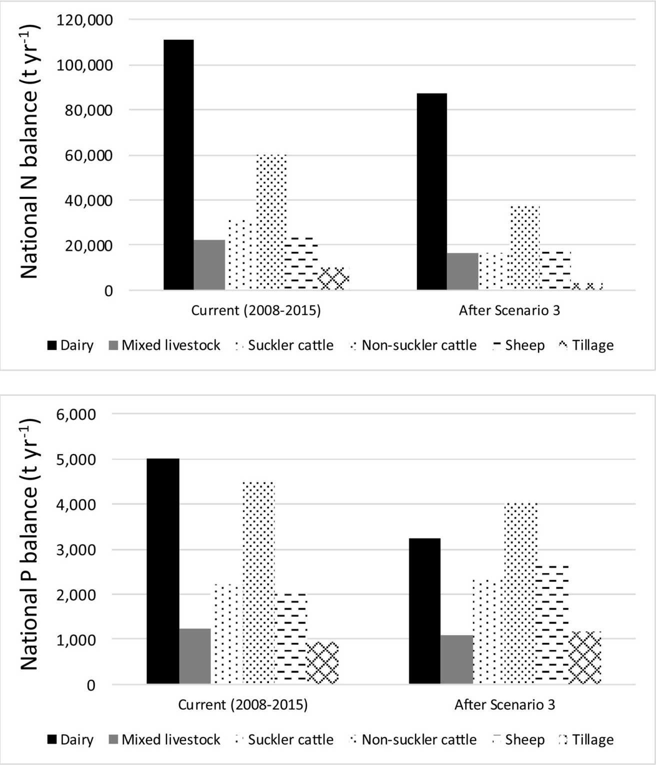

National N balance (t yr-1)
120,000
100,000
80,000
60,000
40,000
20,000
0
Current (2008-2015)
After Scenario 3
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage
National P balance (t yr-1)
6,000
5,000
4,000
3,000
2,000
1,000
0
Current (2008-2015)
After Scenario 3
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage

Figure 8

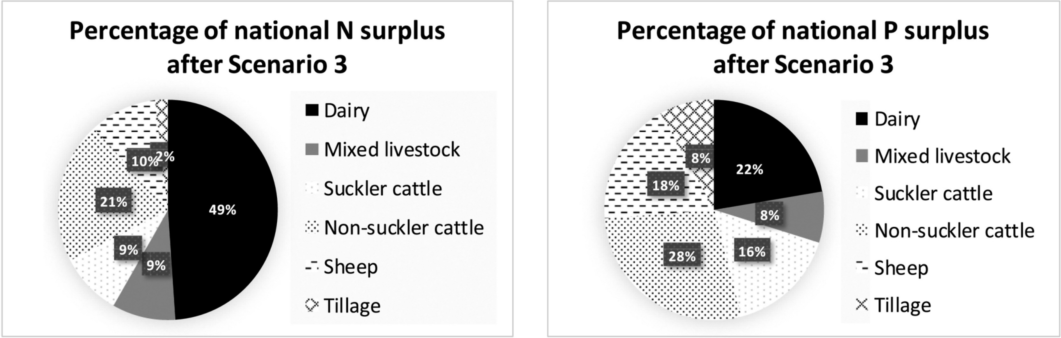
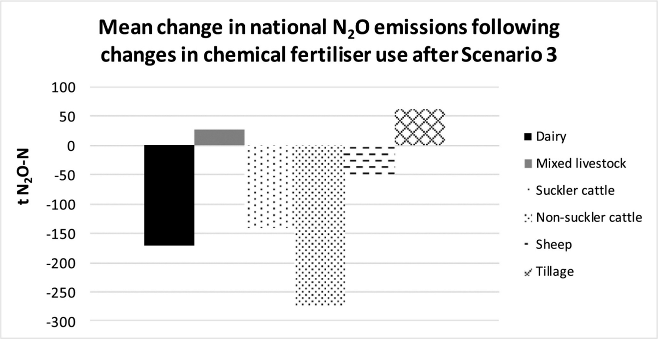

Percentage of national N surplus after Scenario 3
49%
9%
9%
21%
10%
2%
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage
Percentage of national P surplus after Scenario 3
22%
8%
16%
28%
18%
8%
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage

Figure 9



Mean change in national N_2O emissions following changes in chemical fertiliser use after Scenario 3
t N_2O-N
100
50
0
-50
-100
-150
-200
-250
-300
Dairy
Mixed livestock
Suckler cattle
Non-suckler cattle
Sheep
Tillage

Figure 10