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Department for Environment Food & Rural Affairs

Evidence Project Final Report

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Project identification

1. Defra Project code
2. Project title
   Analysis of the Yield Enhancement Network (YEN) database to investigate nitrogen use efficiency (NUE) and influencing factors
3. Contractor organisation(s)
   RSK ADAS Ltd
   Spring Lodge
   172 Chester Road
   Helsby
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4. Total Defra project costs (agreed fixed price): £ 10000
5. Project: start date 25/9/22
   end date 20/12/22

6. It is Defra's intention to publish this form.
   Please confirm your agreement to do so...YES x☐ NO ☐

   (a) When preparing Evidence Project Final Reports contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.
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   In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

   (b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Glossary

Crop Quality – Measure of grain or seed nutrient content required to meet the needs of the end market e.g., protein content of milling wheat grain, oil content of oilseed rape seed.
Nitrogen Harvest Index (NHI) – Proportion of N in the grain or seed in relation to the N in the whole crop (Grain N offtake / Total crop N uptake).
Nitrogen Use Efficiency (NUE) – How efficiently applied nitrogen (N), or N available in the soil, is used by the crop in terms of either crop N output (grain or seed N content), or crop dry matter output (i.e., yield). The most appropriate NUE measure to use depends on the objective and context of the question being investigated.
Plant Growth Regulator (PGR) – Chemicals used to modify crop growth, such as reducing height and increasing branching.
RB209 – Nutrient management guide for UK growers and advisors to make the most of organic materials and balance the benefits of fertiliser use against the costs, both economic and environmental.
Restricted Maximum Likelihood (REML) – Analysis using linear mixed models i.e. linear models that can contain both fixed and random effects. This means it can thus be used to analyse unbalanced designs with several error terms (which cannot be analysed by ANOVA).
Yield Enhancement Network (YEN) – Industry funded networks established by ADAS connecting agricultural organisations and farmers who are striving to improve crop performance. Network focuses range from crop performance across the main arable crops, crop nutrition, and crop carbon footprints.

Summary

Nitrogen (N) fertiliser is a key component supporting and enhancing crop productivity. However, there are significant concerns over the environmental and economic costs associated with N inputs on farm. Consequently, it is essential to improve the efficiency of the use of N fertilisers to ensure optimum crop productivity and minimal losses to the environment. One of the barriers to achieving this goal is the multitude of ways nitrogen use efficiency (NUE) is defined in the agriculture industry.

To better understand how a range of crop types on UK farms are performing in terms of NUE, the Yield Enhancement Network (YEN) database was analysed. The YEN networks were established by ADAS >10 years ago to support on-farm learning-by-sharing and thus enhance farming progress. During this time a large dataset has been formed which consists of more than 4,000 crop yields and over 650,000 points of explanatory data.

Before the analysis was undertaken, 12 NUE metrics were defined to ensure NUE was assessed across a range of contexts including crop yield, crop quality, and environmental perspectives. The most useful NUE metric to use depends on the question being asked. For example:

1. To indicate efficiency of crop N use to produce yield:
   kg grain yield/kg N available (kg/kg)
2. To indicate efficiency of fertiliser to improve crop quality (protein content):
   N removed in harvested grain (%)
3. To indicate potential risk of losing applied N to the surrounding environment:
   N balance for crop N offtake (kg N/ha), which calculates the net amount of applied N fertiliser left in the field after harvest

The YEN dataset was exploited in this project to calculate the average and variation in the range of NUE metrics defined across the main crop types in the YEN dataset of winter wheat, barley, oats, oilseed rape (OSR), beans and peas. Spring and winter crops for beans, peas, barley, and oats were grouped into the same dataset to ensure it was of a sufficient size for analysis. It should be noted that crops entered into the YENs generally produce above UK-average yields.

The key findings from the analysis of NUE metrics included:

- **kg yield per kg N available (kg/kg)**: this was similar among all cereals ranging between 33 and 34 kg/kg, with a much lower average for OSR (15 kg/kg). Generally, the analysis indicated lower efficiency of OSR crops in using N available to produce yield, due to the higher N content and energy demand of OSR seed.
- **N utilisation efficiency (NUtE; kg yield /kg N taken up):** this was greatest for barley and oat crops (41 and 45 kg DM yield/kg N taken up, respectively, compared to 35 kg DM yield/kg N taken up for winter wheat), likely due to the lower total N rate applied. Changing rotations to include more barley and oats could improve farm-level NUE.
- **N uptake efficiency (NUpE; % of total crop N in relation to the N available from the soil and N applied)**: this demonstrated that bean and pea crops fix around two to three times more N than what was available from the soil. NUpEs for beans and peas were, on average, 325 and 224% respectively compared to a range of 68 to 80% NUpE for the other crop types. Including more pulses in rotations could improve overall farm-level NUE.
- **Apparent N fertiliser recovery (%):** on average the results from YEN agreed with the RB209 standard figure of 60%, but the range was very large (10% to >100%) indicating opportunities for improvement; the average recovery for YEN wheat crops was 73% likely due to the high yields.
- **Soil N balance (kg N/ha; the net amount of N left in the soil after harvest)**: an appropriate balance is important: ensuring they are not too high risking N leaching, but they are not too low to compromise the fertility of the soil. Here, soil N balances were between 25 and 50 kg N/ha for the cereal crops and 86 kg N/ha for OSR crops when grain offtake only was considered. These values reduced to between -5 and +19 kg N/ha for the cereal crops if grain and straw were removed. This indicates that if straw is removed there is a risk of soil N balances being depleted, demonstrating the importance of monitoring crop N offtake, and ensuring offtake is sufficiently replaced to maintain soil health and support future crop yields.
- **Grain N offtake:** the data indicated that 7% of YEN crops were over-applied with N fertiliser due to achieving a protein of $\geq$2 % more than the varietal norm and 2% of crops were under-applied. By measuring grain N levels in the harvested product it is possible to assess the success of crop N management and gain accurate N offtake figures to guide future applications.

A restricted maximum likelihood (REML) statistical analysis was undertaken to understand which agronomic factors were associated with the NUE metrics analysed in the YEN database. The datasets for the oat, barley, beans, and pea crops were too small to analyse using REML; associations could only be determined for wheat and barley. This analysis identified similar associating factors to previous analyses which includes a significant influencing ‘farm’ factor, indicating that the farm the data originated from is having a large influence on NUE related metrics. A better understanding is required to identify what components make up the farm factor, but it is likely to include technology used on farm, farmer mindset, staff training, resources used to make nutrient management decisions etc.
The rate at which N fertiliser was applied associated differently with the different NUE metrics; to increase grain N offtake and N balance, N rate should be increased whereas, to increase kg grain yield/kg N available, NUtE, and grain N recovery, N rate should be reduced. Consequently, decisions on changing N rates to alter NUE should be based on what outcome is desired, e.g., improving crop quality or reducing environmental impact. Use of Plant Growth Regulators (PGRs) and fungicides associated positively with NUE metrics of wheat and barley crops, indicating that it is important to optimise crop management to improve NUE on farm, as N efficiency is increased when yields are increased under the same N application rate. Associations with rainfall and NUE indicated that good establishment and conditions conducive to successful grain fill improved NUE, likely due to the positive impacts on yield.

Based on the analysis undertaken in this report several strategies can be recommended to improve NUE on farm:

- Include more barley and oat crops in the rotation which have a higher NUtE compared to wheat crops
- Include more legumes such as beans and peas in the rotation which do not require N fertiliser and fix around 2-3 times more N than the other main arable crop types
- Monitor grain N offtake by measuring grain nutrient content to make an assessment on the success of the N management approach in a particular crop. Specifically for wheat, grain protein levels can be compared to varietal protein values in the Recommended List to determine whether N was over or under applied
- Monitor grain and straw N offtake to ensure soil N balances are not being depleted and soil fertility compromised
- Enhancing crop yields using the same N rates will improve NUE. Crop yields can be improved through good crop management, such as use of PGRs and fungicides, and ensuring good establishment and optimal grain/seed fill conditions

One limitation of using the YEN dataset to better understand NUE on farm is the limited information available on the use of organic materials. The YEN database includes data on manure history within a particular field, the main type of manure used and whether manure was applied to the current crop, but completing this information was not mandatory so there are many entries with no data on organic materials. This is being addressed in newer networks such as YEN Zero, but the analysis reported here cannot conclude on the role of organic materials in NUE on UK farms. However, understanding how efficiently organic materials are being used on farm to ensure their value is being fully realised is very important.

Based on the findings of this study, further work was suggested to build a better understanding of NUE of the main UK arable crops and how it can be improved. Suggestions included sourcing ‘farm level’ data from the YEN entrants where the dataset used in this study originates, to better understand what is behind the ‘farm factor’ explaining the biggest proportion of the variation in the NUE metrics. Additionally, producing a dataset which collates on farm trials of Enhanced Efficiency Fertilisers (EEFs) to understand the benefit of these products on NUE. The recent Defra project NM0102 reviewed their potential effectiveness in improving NUE, however, information on their use is limited within the YEN database and the majority of on farm trials experimenting with these products are privately funded. Therefore, it would be beneficial to collate experimental data together to understand which products have the most potential to improve NUE on farm.