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Proceeding Paper

Grassland Reseeding—Improving Grassland Productivity and Reducing Excess Soil Surface Nutrient Accumulations †

Emma Hayes [1,*], Suzanne Higgins [2], Josie Geris [3] and Donal Mullan [1]

[1] Geography, School of Natural and Built Environment, Queen's University Belfast, Belfast BT7 1NN, UK; d.mullan@qub.ac.uk
[2] Agri-Food and Biosciences Institute, Belfast BT9 5PX, UK; suzanne.higgins@afbini.gov.uk
[3] Northern Rivers Institute, School of Geosciences, University of Aberdeen, Aberdeen AB24 3UE, UK; j.geris@abdn.ac.uk
* Correspondence: ehayes07@qub.ac.uk
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Abstract: Long-term phosphorus (P) accumulation in agricultural soils presents a challenge for water quality improvement. P is commonly elevated in soils managed for intensive livestock production due to the repeated over-application of slurry and fertilizers. High legacy nutrient accumulations can result in poor water quality via transport pathways such as surface runoff, subsurface drainage, and soil erosion. To achieve the EU Water Framework Directive (WFD) aims, improved management strategies are required for diffuse and point P sources. Reseeding is known to improve grassland productivity and enhance overall soil health. However, soil disturbance associated with reseeding could have positive and negative effects on several other soil functions that affect the nutrient balance (including improved microbial activity, but also increasing the potential for sediment and nutrient losses). This study investigated the role of reseeding in addressing nutrient surpluses in surface soils and identified potential trade-offs between production, environment, and soil health. At a study site in the Blackwater catchment in Northern Ireland, we collected high-resolution gridded soil samples pre- and post-reseeding for nutrient analyses and combined this with GIS-based interpolation. We found that decreases in sub-field scale nutrient content occurred following reseeding, but that this was spatially variable. This indicates that this strategy is effective in reducing soil surface P accumulations. However, more research is needed to determine whether this P becomes available for grass uptake during re-growth or whether it increases the pool of mobile P, which can be lost in surface runoff, subsurface drainage, and soil erosion.

Keywords: reseeding; tillage; phosphorus; water quality

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1. Introduction

Agricultural soils in intensively farmed livestock systems commonly contain elevated nutrients above the agronomic optimum [1]. These systems, typically within northwest Europe, focus on grassland agriculture, with animal grazing or silage off-taking as the predominant activities. Through repeated fertilizer and slurry applications (often of nutrient-enriched slurry through livestock enhanced feedstocks), slow nutrient uptake rates by grasslands, and a lack of tillage, soil nutrient surpluses can accumulate at the soil surface, which is the interaction zone that controls the leaching of runoff fractions [2,3]. Soil nutrient accumulation is of concern for nutrients such as phosphorus (P), which can contribute to poor water quality, with agricultural activities repeatedly identified as major contributors to poor water quality [4]. In response to widespread poor water quality, the EU Water Framework Directive 2000/60/EC (WFD) was introduced, with legislative requirements for EU member states to achieve good water quality by 2027.

Achieving the WFD's aims has been complicated by the widespread sources of diffuse agricultural pollution. Research has demonstrated that wide sub-field scale variability exists in soil nutrient content [5] and that the identification of point and diffuse nutrient sources requires changes to the normative soil sampling used within grassland agriculture. More specifically, it would require changing from the bulked W sampling of average field values to the usage of gridded sampling to explore nutrient content at various in-field locations. Soil P accumulations present particular challenges for waterway management. Soils that contain P above the agronomic optimum are at a higher risk of contributing to detrimental water quality through P-based losses in soil erosion, surface runoff, or subsurface field-drainage pathways [6]. Generalized water quality protection schemes fail to address the continued accumulation of soil nutrients; however, issues arise when trying to reduce excess soil nutrient levels.

1.1. Reducing Soil-Nutrient Accumulations

Studies modelling soil P decline rates have indicated wide time frames of between three and twenty years to reduce excessive soil P to optimum levels [7,8]. They have also indicated that schemes of zero-P applications and increased silage off-taking are the most effective means to reduce soil P. Farms that use these methods must sell baled silage to farms that are deficient in soil P due to the potential for nutrient returns via slurries and animal grazing. Furthermore, fields that use grazing alongside off-taking experience slower decline rates due to nutrient return from animal excretion [9]. The usage of these schemes requires a full understanding of all the essential nutrients, as a deficiency in one nutrient limits grassland growth and the effectiveness of these schemes [8]. Complexities arise due to differences in the ability of farms to implement such programs, given the need to remove slurries from farmyards. Furthermore, it may be several decades before any effects of reducing soil P accumulations in these ways are seen in terms of improved water quality status. The development of natural soil P drawdown is slow due to the large soil P reservoir compared to low annual P crop removal [7,10]. Therefore, the development of a rapid method to reduce soil surface P accumulations is vital.

1.2. Grassland Reseeding and Tillage

Research has indicated the potential for reseeding to reduce soil surface P and N (nitrogen) accumulations through the actions of tillage and grass growth, which involves the implementation of a vertical stratification of the nutrient content and an increase in nutrient uptake [2,11,12]. However, exploring the trade-offs between the actions of reseeding and tillage in terms of reducing nutrient content and potential sediment and nutrient losses through soil surface disturbance is needed to determine the suitability of this technique for its use in catchment management. Several studies have concluded that a one-time tillage inversion thoroughly mixes soil-surface layers and reduces overall P content. Mixing P-rich surface soils (0–5 cm in depth) with lower-P subsoils (5–20 cm in depth) decreased the weighted mean soil P content of both layers by between 66–90% [11,13]. Furthermore, before inversion, the total P runoff losses were at 3.4 mg L^{-1}, which declined to 1.79 mg L^{-1} following tillage [11]. Using tillage has immediate effects on soil-surface P content through the movement of P down the soil profile and overcomes the long timescales associated with other techniques. Furthermore, the non-tillage systems commonly associated with permanent grassland systems promote the development of macropores within the soil structure. These can move runoff fractions directly through the upper soil layers (of elevated P content), bypassing the normative soil matrix [2]. When this coincides with subsurface field-drainage systems, which are often in place in grasslands, this runoff can enter waterways and elevate P loading rates [2].

For N, research by Cuttle and Scholefield (1995) [14] on the management options used to reduce grassland leaching concluded that reseeding is a potential strategy. Scholefield et al. (1993) [15] demonstrated that N leaching from plots of permanent pasture was consistently higher than from ploughed and reseeded plots, with both plot types receiving

400 kg ha^{-1} N. Permanent plots leached an annual average of 80 kg ha^{-1} N compared to 27 kg ha^{-1} N from reseeded plots [15]. Four years after reseeding, the N leaching rates had increased significantly, despite the lack of increases in animal stocking rates or fertilizer application rates [14]. This suggested that the sward age influences leaching rates due to ongoing nutrient accumulation. In agreement with these findings, for two different grass cultivars, Li et al. (2017) [16] found reduced N-based losses in runoff when used for reseeding. However, this work found that the N losses in the runoff initially increased during the first year of reseeding, before decreasing in subsequent years. This initial increase occurred because the applied amount of N for reseeding exceeded the amount that is required for grassland establishment [16]. This highlights the need for gridded sampling to understand the spatial variability in nutrient contents to determine the appropriate fertilization levels for grassland establishment and to reduce nutrient losses. The second-year reduction in runoff-based losses occurred as a consequence of the cultivar root structure. With a deep root structure, losses are reduced due to improved soil water retention, which in turn reduces surface flooding and soil erosion [16]. The potential for reseeding to reduce nutrient-based runoff and soil erosion losses is important to consider as a management strategy to reduce sediment- and nutrient-based losses.

Whilst previous studies have recognized the benefits of using reseeding and tillage to reduce soil surface P content, few studies have explored the changes in sub-field scale variability and soil nutrient content of multiple soil nutrients before and after reseeding through using gridded soil sampling to visualize spatial changes in soil nutrient content. This paper explores the changes in soil nutrient content for several nutrients following reseeding and the specific removal of P hotspots as a case study to discuss the viability of this technique for usage in catchment management. The potential implications of reseeding and tillage for removing other nutrients are considered. Whilst these nutrients are less important in terms of contributing to poor water quality, deficiencies in one plant-essential nutrient arguably affect agricultural productivity.

2. Methods

2.1. Study Catchment

The Blackwater catchment covers an area of 1480 km^2, with 90% of land use classed as agricultural [17]. As the Blackwater catchment is an intensively farmed area, this research helps to identify techniques to improve water quality from a nutrient perspective for use in other regions. Within Northern Ireland and the Republic of Ireland, soils commonly contain nutrient accumulations that contribute significant quantities of nutrients to waterways due to excessive post-war application rates of slurry and fertilizers, due to the intensification of agriculture [18]. Grasslands tend to be reseeded on an infrequent basis (once every ten years or more), unless in a grass-arable rotation.

This paper focuses on one specific field, typical of the region (0.7 ha, stagnosols as the predominant soil type, and agricultural activities of silage and dairy-cattle grazing). The study field underwent reseeding and tillage in the spring–summer of 2020. Gridded soil sampling was conducted before reseeding and again following reseeding, to assess changes in sub-field scale nutrient content.

2.2. Soil Sampling and GIS-Based Analysis

In brief, 35-meter gridded soil sampling was used with between 20 and 30 cores collected per sampling point (comprising six individual soil sampling locations) using a 7.5 centimeter-deep auger to produce one bulked sample per point [19]. This grid interval was determined as the best compromise between maintaining sampling efficiency and interpolation accuracy [20]. Sampling occurred before reseeding in January 2020 and after reseeding in February 2021.

Samples were air-dried at 30 °C and sieved through a 2-millimeter-aperture sieve before analysis for the nutrients of plant-available phosphorus (P), potassium (K), magnesium (Mg), and sulphur (S). P, K, and Mg were determined using methodologies stated in MAFF (1986) [21]. S was determined following the methodology in Islam and Bhuijan (1988) [22]. Presented results focus on the nutrient index, which classifies soil nutrient content as either deficient (indices 0–1), optimum (Index 2, split as indices 2− and 2+ for P and K), or excessive (indices greater than 3) [23].

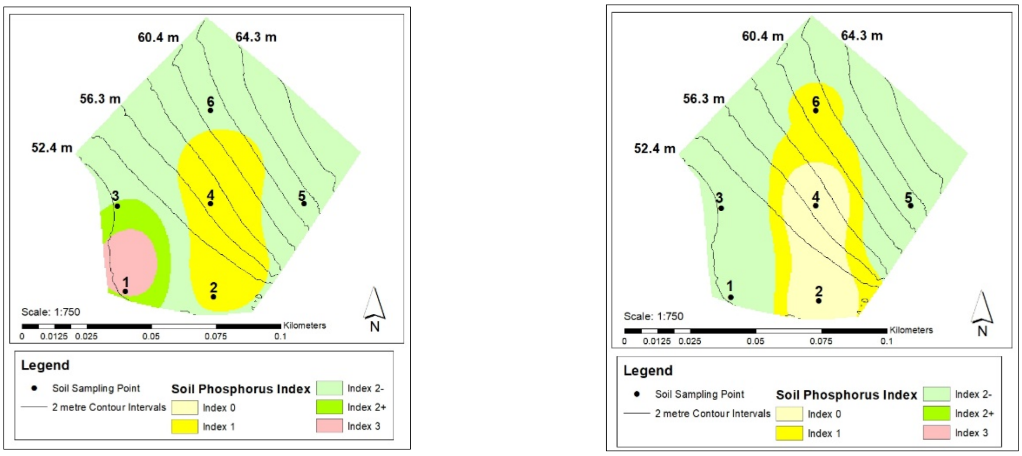
Geostatistical interpolation was used to provide information on nutrient content across the field through kriging. This is a local estimator based on a continuous model of stochastic spatial variation to explore properties' spatial variation in line with the variogram [24]. Ordinary kriging was used to generate a continuous surface of soil nutrient index values using the Ordinary Kriging spatial analysis tool in ArcMap 10.5. Interpolated figures allow the visualization of changes in soil nutrient content following reseeding.

3. Results and Discussion

Comparisons were made between the sampling results collected before and after reseeding. Table 1 shows the calculated percentage change for each sampling point's soil nutrient content (mg L^{-1}) from 2020 to 2021 following reseeding. Furthermore, Figure 1a–b shows interpolated phosphorus content for 2020 side-by-side with interpolated phosphorus nutrient content for 2021.

Table 1. Percentage change in soil-nutrient content (mg L^{-1}) from 2020 to 2021 per sample point.

Sample Point ID	Soil P Content	Soil K Content	Soil Mg Content	Soil S Content
1	36.7% decrease	2.9% decrease	0.9% increase	8.9% increase
2	30.0% decrease	7.7% decrease	6.0% decrease	4.9% decrease
3	11.9% decrease	32.3% decrease	17.3% decrease	9.1% decrease
4	52.0% decrease	37.5% decrease	14.2% decrease	18.9% decrease
5	5.1% increase	4.6% increase	6.9% decrease	0.8% decrease
6	47.7% decrease	24.1% decrease	14.8% increase	25.7% decrease



(**a**) (**b**)

Figure 1. Interpolated phosphorus content with (**a**) soil P content in 2020 and (**b**) soil P content in 2021.

Table 1 shows the percentage change in soil-nutrient content from 2020 to 2021 following reseeding and tillage. It is evident that decreases occurred in the soil nutrient content. P and K show significant decreases in the nutrient content at point 4. A decrease in P was recorded at point 6, which is located on the steepest slope of this field. This may suggest runoff-based P losses. However, the third-largest decrease in soil P was recorded at point 1, which is located along a flat slope base and is unlikely to generate significant runoff. It could be theorized that if significant P losses from point 6 had occurred, given the location of point 1 (directly below point 6), an increase in soil P content would have occurred here. This decrease can be observed by comparing Figure 1a to Figure 1b with the disappearance of the Index 3 P hotspot and the area of Index 2+ in 2021; there was also an increase in P deficiency at Index 0 in 2021. However, the magnitude of the decreases between the nutrients at the same sampling point was not uniform, producing highly variable spatial patterns. Variations in nutrient decreases may relate to differences in the spatial pattern of tillage inversion across a field or due to differences in grassland nutrient uptake rates, based on available forms of nutrients or organic matter present in soils [25]. Some increases were recorded for P and K at point 5, suggesting that nutrient accumulation occurred at the field's edge, potentially due to fertilizer spreading patterns. S and Mg showed accumulation at point 1; however, only Mg showed an accumulation at point 6. The sampling results from both pre- and post-reseeding indicate that a large soil reservoir of Mg was present and that S was over-applied during reseeding.

These variations in nutrient deficiencies and accumulations mean that any future slurry or fertilizer applications must only occur for deficient nutrients or at maintenance rates (to maintain the agronomic optimum), to prevent the development or continuation of nutrient accumulation (particularly Mg for this field). Improved nutrient stewardship is of great importance for improved water quality, and the usage of gridded sampling to quantify sub-field scale nutrient content is key to managing nutrient accumulations.

Tillage practices reduce surface soil P concentrations, but, over time, they may cause the accumulation of P throughout the soil profile. Subsequent fertilizer applications must only resume once there is a demonstrated crop requirement [11,12]. By reseeding, the productivity of permanent grasslands can be increased, with greater P utilization by young swards. It is necessary to balance the need for reseeding against the potential risks of sediment and nutrient losses due to tillage increasing particulate P losses and vulnerability to soil erosion. Whilst reseeding has immediate effects on soil P content, reducing nutrient accumulation trends within agriculture requires changes to nutrient management practices.

4. Conclusions

The results of this study demonstrate the potential for reseeding to reduce soil nutrient content within the uppermost soil layers, the zone of the soil profile most at risk of generating nutrient losses via runoff. This is particularly true for an area such as the Blackwater catchment, where soils contain legacy nutrient accumulations that are not readily removed through annual silage crop uptake requirements. The immediate effects of reseeding, including a reduction in P hotspots, can lead to reductions in the risk of nutrient losses. Undertaking gridded soil sampling shows the importance of this technique to understand the spatial variability of in-field nutrient contents. For example, following reseeding, some P and K deficiencies are evident; however, Mg is over-supplied and S is at the agronomic optimum. These nutrient deficiencies are likely to limit yields and, thus, affect agricultural productivity at this site as well as the subsequent removal of nutrients such as P by grass growth, and limit the usage of silage offtakes to reduce soil nutrient content [8]. Without more precise site-specific soil sampling and interpolation, these specific deficiencies and accumulations would not be known. These results have implications for the management of field- and farm-nutrient inputs. New technology and precision management, e.g., variable-rate applications of P and K, are key to minimizing nutrient surpluses and deficiencies and should be considered for usage during reseeding, tillage, and associated fertilization processes for promoting grassland growth. Future research on the usage of grassland reseeding as a water quality improvement tool must focus on the potential risks associated with this action in-depth, including monitoring runoff-based nutrient losses and the occurrence of soil erosion, along with potential tradeoffs in terms of overall emissions and soil health.

Supplementary Materials: The poster presentation can be downloaded at: https://www.mdpi.com/article/10.3390/IOCAG2022-12182/s1.

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References

1. McDonald, N.; Wall, D.; Mellander, P.; Buckley, C.; Shore, M.; Shortle, G.; Leach, S.; Burgess, E.; O'Connell, T.; Jordan, P. Field scale phosphorus balances and legacy soil pressures in mixed-land use catchments. *Agric. Ecosyst. Environ.* **2019**, *274*, 14–23. [CrossRef]
2. Baker, D.B.; Johnson, L.T.; Confesor, R.B.; Crumrine, J.P. Vertical Stratification of Soil Phosphorus as a Concern for Dissolved Phosphorus Runoff in the Lake Erie Basin. *J. Environ. Qual.* **2017**, *46*, 1287–1295. [CrossRef] [PubMed]
3. Wang, Y.T.; Zhang, T.Q.; Hu, Q.C.; Tan, C.S.; Halloran, I.P.O.; Drury, C.F.; Reid, D.K.; Ma, B.L.; Ball-Coelho, B.; Lauzon, J.D.; et al. Estimating Dissolved Reactive Phosphorus Concentration in Surface Runoff Water from Major Ontario Soils. *J. Environ. Qual.* **2010**, *39*, 1771–1781. [CrossRef] [PubMed]
4. Zia, H.; Harris, N.R.; Merrett, G.; Rivers, M.; Coles, N. The impact of agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. *Comput. Electron. Agric.* **2013**, *96*, 126–138. [CrossRef]
5. Hayes, E.; Higgins, S.; Geris, J.; Nicholl, G.; Mullan, D. The importance of soil phosphorus sub-field scale sampling for understanding and managing surface runoff-based phosphorus losses. *CATENA*, 2022; *in review*.
6. Taylor, M.D.; Drewry, J.J.; Curran-Cournane, F.; Pearson, L.; McDowell, R.W.; Lynch, B. *Soil Quality Targets for Olsen P for the Protection of Environmental Values*; Massey University: Massey, New Zealand, 2006.
7. Schulte, R.; Melland, A.; Fenton, O.; Herlihy, M.; Richards, K.; Jordan, P. Modelling soil phosphorus decline: Expectations of Water Framework Directive policies. *Environ. Sci. Policy* **2010**, *13*, 472–484. [CrossRef]
8. Bailey, J.S. Assessing the effectiveness of manure export plus intensive silage cropping for lowering the Olsen-P status of P-enriched grassland. *Soil Use Manag.* **2015**, *31*, 438–439. [CrossRef]
9. Wall, D.P.; Jordan, P.; Melland, A.R.; Mellander, P.-E.; Mechan, S.; Shortle, G. Forecasting the decline of excess soil phosphorus in agricultural catchments. *Soil Use Manag.* **2013**, *29*, 147–154. [CrossRef]
10. Dodd, R.J.; Mcdowell, R.W.; Condron, L.M. Predicting the changes in environmentally and agronomically significant phosphorus forms following the cessation of phosphorus fertilizer applications to grassland. *Soil Use Manag.* **2012**, *28*, 135–147. [CrossRef]
11. Sharpley, A.N. Soil Mixing to Decrease Surface Stratification of Phosphorus in Manured Soils. *J. Environ. Qual.* **2003**, *32*, 1375–1384. [CrossRef]
12. Watkins, M.; Castlehouse, H.; Hannah, M.; Nash, D. Nitrogen and Phosphorus Changes in Soil and Soil Water after Cultivation. *Appl. Environ. Soil Sci.* **2012**, *2012*, 157068. [CrossRef]
13. Kleinman, P.J.A.; Sharpley, A.N.; Withers, P.J.A.; Bergström, L.; Johnson, L.T.; Doody, D.G. Implementing agricultural phosphorus science and management to combat eutrophication. *AMBIO* **2015**, *44*, 297–310. [CrossRef] [PubMed]
14. Cuttle, S.; Scholefield, D. Management options to limit nitrate leaching from grassland. *J. Contam. Hydrol.* **1995**, *20*, 299–312. [CrossRef]
15. Scholefield, D.; Tyson, K.C.; Garwood, E.A.; Armstrong, A.C.; Hawkins, J.; Stone, A.C. Nitrate leaching from grazed grassland lysimeters: Effects of fertilizer input, field drainage, age of sward and patterns of weather. *Eur. J. Soil Sci.* **1993**, *44*, 601–613. [CrossRef]
16. Li, Y.; Liu, Y.; Harris, P.; Sint, H.; Murray, P.J.; Lee, M.R.; Wu, L. Assessment of soil water, carbon and nitrogen cycling in reseeded grassland on the North Wyke Farm Platform using a process-based model. *Sci. Total Environ.* **2017**, *603–604*, 27–37. [CrossRef]
17. Bastola, S.; Murphy, C.; Sweeney, J. The role of hydrological modelling uncertainties in climate change impact assessments of Irish river catchments. *Adv. Water Resour.* **2011**, *34*, 562–576. [CrossRef]
18. Cassidy, R.; Thomas, I.A.; Higgins, A.; Bailey, J.S.; Jordan, P. A carrying capacity framework for soil phosphorus and hydrological sensitivity from farm to catchment scales. *Sci. Total Environ.* **2019**, *687*, 277–286. [CrossRef]
19. McCormick, S.; Jordan, C.; Bailey, J.S. Within and between-field spatial variation in soil phosphorus in permanent grassland. *Precis. Agric.* **2008**, *10*, 262–276. [CrossRef]

20. Shi, Z.; Wang, K.; Bailey, J.; Jordan, C.; Higgins, A. Temporal changes in the spatial distributions of some soil properties on a temperate grassland site. *Soil Use Manag.* **2006**, *18*, 353–362. [CrossRef]
21. MAFF (Ministry of Agriculture, Fisheries and Food). *The Analysis of Agricultural Materials*, 3rd ed.; Reference Book 427; Her Majesty's Stationary Office: London, UK, 1986.
22. Islam, M.M.; Bhuijan, N.I. Evaluation of various extractants for available sulphur in wetland rice (*Oryza sativa*) soils of Bangladesh. *Indian J. Agric. Sci.* **1988**, *58*, 603–606.
23. AHDB. *Nutrient Management Guide (RB209) Section 3 Grass and Forage Crops*; January 2019; Agriculture and Horti-Culture Development Board: Kenilworht, UK, 2019.
24. Webster, R.; Oliver, M.A. *Geostatistics for Environmental Scientists*, 2nd ed.; Webster, R., Oliver, M.A., Eds.; John Wiley & Sons Ltd.: Chichester, UK, 2007; p. 330.
25. Thomas, C.L.; Darch, T.; Harris, P.; Beaumont, D.A.; Haefele, S.M. The Distribution of Soil Micro-Nutrients and the Effects on Herbage Micro-Nutrient Uptake and Yield in Three Different Pasture Systems. *Agronomy* **2021**, *11*, 1731. [CrossRef]