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THE ROLE OF PRECISION AGRICULTURE IN OPTIMISING SOIL NUTRIENT STATUS AND GRASSLAND PRODUCTIVITY IN NORTHERN IRELAND, WHILE REDUCING NUTRIENT LOSSES TO AIR OR WATER

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Abstract

Precision Agriculture (PA) is not widely practiced in Northern European grassland systems, yet production and environmental benefits could potentially be achieved through the adoption of this technology and a more precise approach to soil and nutrient management. Excessive application of nitrogen (N) and phosphorus (P) to agricultural land in Northern Ireland (NI) over several decades has contributed appreciably to greenhouse gas emissions (GHG) and the eutrophication of freshwater bodies. Agriculture is responsible for 28% of total GHG emissions in NI. Improving the efficiency of nutrient management on farms is therefore important if the UK target of an 80% reduction in GHG emissions by 2050 (relative to 1990), is to be achieved. The trophic status of our inland waterways and lakes are also cause for concern, with 63% of water bodies in NI not achieving the "Good or better" status required by the EU Water Framework Directive. The loss of nutrients from agricultural soils has been the single biggest cause of lake and river nutrient enrichment. With the introduction of a Nitrates Action Programme for NI (under the EU Nitrates Directive) in 2006, restrictions have been placed on fertiliser N and P use in an attempt to minimise nutrient surpluses in our soil and N and P losses to water. However, while nutrient surpluses are contributing to environmental problems, areas of nutrient deficiency also exist. Grass yield variation within individual fields can be as much as 4 t ha^{-1}, primarily as a result of variability in soil N mineralisation potential and N availability. Low soil sulphur (S) levels are also common and 64% of our soils have recently been reported as having sub-optimal pH. Adopting a PA approach to grassland management could potentially improve the efficiency of nutrient management decisions, and thereby enhance production while minimising detrimental environmental impacts. The pace of technology development in recent years has been rapid. Many new soil and crop sensors have come onto the market, along with navigation devices, Remote Sensing and Unmanned Aerial Vehicles (UAV). The uptake of new technology by grassland farmers however has been slow. Research is required to assess the feasibility, practicality, cost-benefits and environmental consequences of adopting PA management in grassland systems across Northern Europe.

Introduction

Permanent grassland systems cover more than 60 million hectares across the EU, accounting for 34.6% of the total utilised agricultural area (EIP-AGRI, 2016). The highest percentages are found in Ireland (80% of the utilised agricultural area), the UK (65%) and Slovenia (65%). In intensive dairy farming systems within the UK, Ireland, the Netherlands, parts of Germany, France and Denmark the mild, moist temperate climatic conditions support a prolonged grass growing season. Soils tend to be fertile, temperatures are moderate and there is sufficient rainfall. In these grassland areas the adoption of PA has been relatively poor (Fountas et al. 2005; Griffin et al. 2004; Pederson et al. 2004; Reichardt & Jürgens, 2008) compared to the adoption rate within arable areas, particularly in the main grain growing areas of Europe, where field sizes are large and where a business approach aimed at maximising profitability has long been practiced. The reasons for low adoption rates in grassland areas are numerous, and include the high investment in capital and education, plus the associated risks, and the relative complexity of grassland systems. However, by managing land in a more precise, site-specific manner, PA has potential benefits that could help optimise nutrient management within these grassland areas, thus enhancing productivity and profitability and reducing detrimental effects of nutrients on the environment.

Grassland Agriculture in Northern Ireland

In NI, which has a population of 1.86 million, 74% (998 ha) of the land area is in agricultural use, and 96% of this agricultural land is under grassland with just 4% under arable and horticulture production. There are approximately 25,000 farms in NI and average farm size is 40.1 ha. Field sizes tend to be small, 2-5 ha on average, often enclosed by hedgerows or low stone walls, and the topography is undulating. The soil is deep, rich and high in organic matter (10%) and along with the mild, moist climate, the conditions are ideal for grass production. Pastures are either grazed, harvested for hay and silage, or a combination of both. About 25% of pastures are used for dairy production and currently these receive moderate inputs of chemical N fertiliser (on average 150 kg N $ha^{-1}yr^{-1}$) together with organic manure. They are subject to regular biomass removal, reseeding and drainage, and are typically dominated by ryegrass (*Lolium perenne*) and clover (*Trifolium repens*). The remaining 75% of pastures are used predominately for beef and sheep production, and receive relatively low rates of chemical N fertiliser (on average < 60 kg N $ha^{-1}yr^{-1}$). They tend to have older swards (> 5 years old) which are comprised of mixtures of grasses, legumes and forbs. Average herd size for diary enterprises is 88 livestock units (LU), for beef enterprises it is 17 LU, and for sheep enterprises it is 200 – 300 LU. Milk constitutes 27% of NI's agricultural output (DARDNI, 2015).

Nutrient Surpluses and the Environment

A number of environmental issues exist within NI. Agriculture is responsible for 28% of total GHG emissions. The UK has set a target of achieving an 80% reduction in GHG emissions by 2050 (relative to 1990), and NI must contribute to this reduction. In terms of water quality, 63% of water bodies in NI are not achieving the "Good or Better" status required by the EU Water Framework Directive. Long-term overuse of nutrients, particularly N and P, and the transfer of these nutrients from agricultural land to water, is the single biggest cause of lake and river nutrient enrichment and eutrophication. Over a number of decades, blanket (uniform) applications of fertilisers across fields, followed by less than uniform removal of nutrients in grass biomass, and spatially heterogeneous returns of nutrients in animal excreta, has resulted in nutrient 'hotspots' being formed within fields. Hotspots of N are potential sites for nitrous oxide (N_2O) emission to the atmosphere and for nitrate leaching to waterways. Hotspots of P, where soil Olsen-P levels are high (26 – 45 mg P l^{-1}) or even very high (46 – 70 mg P l^{-1}), are potential sites for diffuse P losses to streams and rivers. High annual rainfall (1000 – 2000 mm rainfall per year) and wet soil conditions exacerbate such losses via leaching and overland flow. Many soils, particularly in the west of the province where rainfall is highest, are saturated (at field capacity) for more than 250 days in the year.

Nutrient Deficiencies and Sub-Optimal Grass Yields

Notwithstanding the problems caused by nutrient over-use in NI agriculture, nutrient deficiencies are also an issue. Between 1995 and 2010, there was a 73% reduction in inorganic P fertiliser purchases. This was mainly attributed to an increase in fertiliser price, but also to the 2006 Nitrates Action Programme for NI which imposed restrictions on N and P fertiliser use in an attempt to reduce N and P losses to waterways. Decades of over-use of P fertiliser prior to 1995 had resulted in more than 50% of grassland being over-supplied with P (Bailey, 2015). Despite the reduction in P fertiliser use post-1995, 50% of dairy farms in NI still have farm P surpluses > 10 kg P ha^{-1}. Notwithstanding this, 29% of grassland has sub-optimal soil Olsen-P status (< 20 mg P l^{-1}) (Bailey, 2015) and evidencing P deficiency (Bailey et al., 2014), and silage swards are frequently under-supplied with N for 2^{nd} and 3^{rd} cut crops (Bailey et al., 2001; Bailey, 2015a). Grass yield variation of 4 t ha^{-1} within individual fields (McCormick 2005) has been attributed to spatial variation in N mineralisation and resultant localised undersupplies of N (Bailey et al. 2001; Jordan et al. 2003). Problems with P and N deficiencies have been further compounded by the under utilization of lime across much of NI in recent decades, and the resultant decline in soil pH which has hampered nutrient uptake and utilization by grass and arable crops.

Sulphur use has also been neglected, even though it as important as P and K in terms of grass growth and quality (Bailey, 2016). In fact, S is now one of the major yield-limiting nutrients in many northern European agricultural systems (Pedersen et al. 1998), largely because of the dramatic reduction in atmospheric S deposition since the 1980s, and the increased use of S-free fertiliser products.

Precision Agriculture

Precision Agriculture, by applying nutrients in quantities to match the needs of the crop as they vary across the field, has the potential to increase production through reducing nutrient surpluses and deficiencies and simultaneously minimising detrimental environmental impacts. There have been great advances in PA technologies in recent years. However, many of these technologies have yet to be trialled in grassland systems and are not at a stage of 'readiness' for farmer adoption. For technologies to be successful they needs to facilitate decision making on farms, be affordable, simple to use and provide a cost benefit through increases in efficiency and yield and/or savings in fertiliser, time or energy use.

Remote Sensing can be used to gather point- or area-data at a range of spatial resolutions, from less than 2 cm to over 10 metres. It is useful for monitoring large areas of land and crops at various stages of development. Grassland vegetation characteristics such as standing biomass, canopy characteristics, biomass production (Maselli et al. 2006), sward height, floristic composition (Feilhauer et al. 2013) and area of soil cover (Zha et al. 2003), can all be mapped in this way. Good relationships have been found between yield and the Normalized Difference Vegetation Index (NDVI). However, in many areas of NW Europe, extensive cloud cover during key monitoring periods (i.e. prior to harvests) can impinge on data collection. In a study in NI, IKONOS 4m true colour orthoimagery was investigated as a predictor of yield. However, only one image was available for the growing season in question. Other drawbacks included the low repeat cycle (14 days), low resolution (4m) and relative expense of the data. New and more advanced satellites are emerging all the time. Data from Landsat TM/MSS, SPOT, AVHRR, MODIS and RapidEye® sensors are most commonly used for land cover classification purposes and land cover change mapping. For managed grasslands and paddocks, sensors with high spatial and temporal resolution are more effective, for example GeoEye, RapidEye and QuickBird. These provide imagery with relatively high spatial resolution and revisit time, thereby permitting the detection of spatio-temporal patterns at scales closer to that of field surveys. Integrating multispectral and multi-temporal remote sensing data with local knowledge and simulation models has been successfully demonstrated as a valuable approach for identifying and monitoring a wide variety of agriculturally related characteristics (Yiran et al. 2012; Oliver et al. 2010). However, with all forms of remote sensing, it is essential to have high quality ground-truth data for cross validation.

Unmanned Aerial Vehicles (UAVs), provide a platform for the rapidly developing sensor technology, and allow aerial imagery of fields to be produced using a range of passive panchromatic multispectral and hyperspectral sensors covering wavelengths from the visible, to the thermal. Using UAVs as a remote sensing platform, is advantageous because of the relatively low cost of the UAV, and because imagery taken from this platform is less hindered by cloud cover than imagery taken from satellites. UAVs therefore have potential application within grassland environments, particularly in NW Europe, where cloud cover is prominent.

A large range of soil and crop sensors are currently available but have not yet been trialled for use in grassland farming systems. These include gamma-radiometric soil sensors, soil moisture detectors, and meteorological devices such as thermometers and hygrometers, and sensors to quantify the physiological status of crops (for example N sensors), and to map the electrical conductivity of surface and sub-soils. Where automatic measurement of a specific variable is difficult to achieve, the use of a surrogate measure may offer an alternative. Electromagnetic Induction (EMI) scanning (Williams & Baker, 1982; Lesch et al. 1995a, b), direct electrical methods (Halvorsen & Rhoades, 1974; Halvorsen et al. 1977), ground penetrating radar and soil spectral reflectance can all provide useful information about soil. McCormick (2003, 2005) measured soil apparent electrical conductivity (EC_a) in grassland fields in NI. As in many other studies, soil EC_a was influenced by a combination of factors, including soil water content, stones, and nutrients, particularly extractable Mg and soil P. In individual soils, one or more of these factors may dominate the measured EC_a (Johnson et al. 2001). The number and combination of factors can be variable and inconsistent; creating problems for data interpretation, hence the usefulness of such data – which can be very site dependent (Delin & Söderström, 2002). Nevertheless, one of the big advantages of EMI scanning is the ease and speed with which subsurface information can be acquired, and this makes it an ideal precursory tool. Although it is unlikely that precision tools such as EMI scanning will replace traditional soil sampling, they may reduce labour and costs by providing more focus to land surveys.

'Barriers' to PA adoption

There is currently a certain amount of 'risk' involved in implementing PA, particularly in grassland environments. Although technology developments have been rapid, much of it has yet to be demonstrated sufficiently within grassland systems to reassure farmers of its benefits. In NI, and in similar grassland farming regions, field sizes tend to be small. This can present difficulties for machinery such as variable rate fertiliser applicators. Grassland fields are heterogeneous in both soil properties and grass yields. Olsen P levels may vary by as much as 90 mg P l^{-1} across individual fields (McCormick et al. 2009). Such variability ought to merit variable rate fertiliser management, but only if management zones are both large enough and temporally stable (Shi et al., 2002).

Many farms in NI tend to be family run enterprises, and in some cases farming is only a part-time occupation. In these situations there is usually limited finance available for investment in new technology, particularly without some assurances of the likely benefits or success of the approach. The current older generation of farmers are also lacking in knowledge about new technology developments, but younger, emerging farmers may be more technically aware. Data interpretation can be complex and difficult and this is currently one of the major barriers to PA adoption.

Conclusions

Farmers are under huge pressure to increase efficiency of production, not only to 'produce more with less', but to ensure the environmental sustainability of their enterprises. Managing grassland more precisely at sub-field scales, if feasible, has enormous potential for improving crop yields, minimising inputs and costs, and helping farmers to meet the stringent requirements of environmental legislation. The technology is evolving rapidly, with an increasing number of real-time applications. An investment in research is clearly merited to assess the feasibility, practicality, cost-benefits and environmental consequences of adopting PA management in grassland systems across Northern Europe.

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