March 2012
Cost £7.98

Project Report No. 484

The relationship between soil mineral nitrogen, applied nitrogen and yields in Scottish soils

by
AD Gilchrist, AG Christie, J Fraser, L Inglis

Scottish Agronomy, Kinross KY13 9SJ

This is the final report of a 36 month project (RD-2007-3375) which started in February 2007. The project was funded by a contract of £18,000 from HGCA.

CONTENTS

1. ABSTRACT

Understanding of the relationship between soil nitrogen, crop residues and crop nitrogen offtake in Scottish arable soils is limited. In this study, an average of 27 fields were soil sampled to measure SMN (soil mineral nitrogen) each year from 2007-2009, covering most of the main arable area of Scotland. The same fields were tested in February before applications of nitrogen and then post-harvest. Mean SMN in the February sampling was 47.9 kg/ha. The mean figure for the post-harvest sampling was 61.1 kg/ha. There were large season to season variations, with very low available nitrogen in February 2008, perhaps due to very heavy January rainfall. The influence of previous cropping was investigated, with oilseed rape crops leaving slightly higher soil nitrogen residues compared to cereals or potatoes. In 2007 the soil nitrogen following potatoes was over 20 kg/ha lower than following cereals. Soil type had some influence on available nitrogen, soils with higher clay content tending to have lower values than more sandy soils. This is possibly due to greater mineralisation of organic nitrogen in the lighter textured soils, as they tend to heat up more rapidly. This relatively limited sample confirms that amounts of inter-crop SMN are relatively low, and that current Scottish Nitrate Vulnerable Zone (NVZ) crop residue groupings may need to be revised.

A series of 39 replicated nitrogen dose response trials on winter and spring barley, and winter wheat was carried out in Scotland over 3 seasons (2007-2009). Trials had incremental doses of nitrogen applications, including nil, and were statistically analysed to determine optimum nitrogen inputs. This was based on a 5:1 break-even ratio of nitrogen to grain. The majority of trials were highly responsive to applied nitrogen and nitrogen optima exceeded the relevant maximum allowance for nitrogen under Scottish NVZ guidelines (Nmax) in 27 of the trials. All trials were also sampled for SMN, both before nitrogen was applied and for all nitrogen treatments post harvest. There was no general trend for any increase in soil nitrogen as applied nitrogen dose increased. As a predictor of likely crop response to nitrogen the early soil samples did not generally provide a good guide. The exceptions were the soil samples with the highest and lowest soil nitrogen levels (91.9 kg/ha and 16.0 kg/ha), which subsequently resulted in the most unresponsive and responsive trials to applied nitrogen respectively. These trials indicate a potential yield limiting situation for Scottish growers. There is no evidence to suggest that nitrogen usage in excess of Nmax limits is resulting in additional leaching of nitrates.

2. SUMMARY

2.1. Introduction

The introduction of Nitrate Vulnerable Zones (NVZ) to Scotland in 2002 focussed attention on the use of inorganic nitrogen in arable crops. A series of Action Programme measures to reduce nitrate loss from agricultural land was implemented, with guidelines to farmers to help them comply with these measures. The guidance includes nitrogen recommendation tables, which must be used to assess the spring nitrogen required for each crop. The tables are based on hybridised data, encompassing recommendations from the original Defra RB209 document (7th edition, 2000), and also using Scottish Agricultural College's recommendations. Much of the data, however, was generated in the 1980s and based on limited information on the relationship between soil nitrogen reserves, crop residues and crop nitrogen offtake. In addition, varieties used in original trials have now been superseded by modern, higher yielding varieties, that have higher nitrogen optima.

Scottish growers historically established around 40,000 ha of grass/clover mixtures. Therefore an area of between 35% – 65% of Scottish arable land included grass in the rotation. Today, the majority of arable land is in continuous arable cropping with limited access to organic manure. High average yield levels have been maintained resulting in high off-take of nitrogen through both grain yield and removal of straw. Levels of intercrop soil nitrogen on these farms can be very low. With the exception of published Scottish Agronomy data, little evidence of systematic evaluation of Scottish soil nitrogen exists. An HGCA-funded project (HGCA Project Report PR438) indicated a wide range of results in what was considered to be predictable rotations. A more robust evaluation is required to prevent growers being financially penalised for using sub-optimal nitrogen regimes.

2.1.1. Objectives

The aim of this project was to provide up to date evaluation of available nitrogen (ammonium-N + nitrate-N) in Scottish arable soils, and its relationship with input and off-take levels. The objectives also included evaluation of whether soil nitrogen tests were consistent over seasons and the effect of varying nitrogen inputs on crop yield and soil reserves.

Specific objectives were:

1. To measure soil mineral nitrogen (SMN) on multiple sites over Scotland's main arable areas.
2. To repeat this analysis on the same soils over three seasons, to take account of climatic variability.
3. To establish a number of nitrogen response trials on cereals over a three year period.
4. To fit yield and grain nitrogen response curves to the above experiments on winter wheat, winter barley and spring barley, to determine optimum nitrogen inputs.
5. To measure SMN both pre- and post-nitrogen applications in these trials to examine any relationship between soil nitrogen and applied nitrogen.

2.2. Materials and methods

2.2.1. Soil survey

A total of eighty four typical arable fields were soil-sampled over the period 2007-2009. Spread of sampling covered most of the main arable areas in Scotland, ranging from the Scottish Borders to Easter Ross (Summary Figure 1). The fields sampled covered a range of soil types, climatic conditions and previous cropping. Fields were sampled in February, before the application of spring inorganic nitrogen, and were then sampled again post-harvest in August/September. This allowed a comparison of SMN (soil mineral nitrogen) at different times in the season. Where practicable, original fields sampled in 2007 were also sampled in 2008 and 2009.

Summary Figure 1. Soil sampling distribution 2007-2009 (Appendix)

A minimum of 25 core sub-samples were taken to a depth of 60 cm, in a "W-pattern" within the field, and then mixed to produce a bulk sample. Samples were refrigerated on the day of sampling and dispatched to Hill Court Farm Research in insulated containers. Samples were analysed for nitrate-N and ammonium-N to give a total available nitrogen in the 0-60 cm soil profile. Information on soil texture and previous cropping was collected for each of the fields sampled over the three-year period.

2.2.2. Nitrogen response trials

Replicated trials on winter wheat, winter barley and spring barley were established to examine yield response to nitrogen, as well as effects on grain nitrogen and SMN. A total of 39 randomised block trials were carried out over the three-year period 2007-2009. All agronomic inputs other than nitrogen were standardised in each trial. Varieties chosen were popular commercial varieties.

A range of applied nitrogen rates were chosen: six in winter and spring barley trials, and seven or eight in winter wheat. Nitrogen applications for the winter barley and wheat experiments were split over either two or three timings, depending on total amount applied. Nitrogen applications for the spring barley experiments were all completed by early crop establishment. Maximum nitrogen rates were 270 kg/ha for winter wheat trials, 240 kg/ha for winter barley, and 220 kg/ha for spring barley.

Grain samples were collected and analysed for grain nitrogen %. Statistical analysis of yields was by analysis of variance. Each trial area was soil-sampled in spring for available nitrogen, prior to any nitrogen applications. Following harvest, soil samples were taken from each nitrogen treatment and again analysed for available nitrogen.

Response curves were fitted to the yield data to determine the economic optimum nitrogen rates (optimum nitrogen) using the linear plus exponential (LEXP) function, as applied to other nitrogen response trials analysed to support recommended nitrogen rates in the latest version of RB209. Optimum nitrogen is expressed at a break-even price ratio between fertiliser nitrogen and grain of 5:1, again as applied to data analysed for RB209.

2.3. Results and conclusions

2.3.1. Soil nitrogen survey

The mean SMN over the three years of the project in the February sampling period was 47.9 kg/ha. The comparative figure for the sampling in the immediate post-harvest period in August–September was 61.1 kg/ha (Summary Table 1). There was a large range of soil nitrogen levels, but there was a general consistency in tests from the same fields when comparing February soil nitrogen levels to August/September samples. Samples which produced high nitrogen levels in February tended to have comparatively high nitrogen levels in the post-harvest tests (with the same trend for low nitrogen samples).

With winter oilseed rape as the previous crop, there tended to be higher SMN than for previous cropping of cereals or potatoes. Post-harvest samples indicated that soil available nitrogen was lower where potatoes were the preceding crop (compared to oilseed rape or cereals).

Soil texture also had an influence on soil nitrogen status. The majority of the samples were from sandy soil types – either sandy loams or sandy clay loams. The few samples collected from silty soils tended to have more available nitrogen in the February sampling than did other soil types. Post-harvest sampling indicated that the sandy loam soils had a higher mean level of available nitrogen than the sandy clay loams.

Summary Table 1. Available nitrogen from soil samples collected in 2007, 2008 and 2009

Sample situation	Number of samples	Mean available nitrogen (kg/ha) (range)	
		February	August
All	84	47.9 (10.6-148.5)	61.1 (12.7-184.6)
Previous crop: cereals	53	45.7 (12.6-126.0)	66.6 (21.9-184.6)
Previous crop: oilseed rape	13	55.2 (22.6-148.5)	67.7 (23.0-120.7)
Previous crop: potatoes	12	51.3 (22.5-113.9)	38.4 (12.7-61.4)
Soil type: sandy loam	38	48.1 (19.6-148.5)	74.6 (12.7-184.6)
Soil type: sandy clay loam	41	41.7 (12.6-113.9)	47.9 (14.2-139.7)
Soil type: silty clay loam (2007 and 2008 data only)	5	56.2 (24.0-68.8)	57.8 (24.7-109.6)

Soil samples tested at the higher end of the range tended to come from farms using organic manures or with grass in the rotation. Six samples with soil nitrogen levels over 200 kg/ha were excluded from the survey as it was considered that there was a high probability that they had become contaminated with organic matter.

There was considerable seasonal variation in SMN (Summary Table 2). The February samples taken in 2008 were lower than for the other two years. The post-harvest samples for the same year indicated an almost doubling of SMN. This contrasted with the other two years, where the mean post-harvest soil nitrogen was fairly similar to the February figures. The trend of higher SMN, where the previous crop was oilseed rape compared to cereals, was apparent in the early season tests in all three years of sampling. In the years 2007 and 2009, the post-harvest SMN figure where the previous crop was potatoes was lower than for the February sampling period.

Summary Table 2. Mean SMN by year

Sample situation	Mean available nitrogen (kg/ha) February			Mean available nitrogen (kg/ha) Aug – Sep		
	2007	**2008**	**2009**	**2007**	**2008**	**2009**
All	56.3	36.0	51.3	50.9	68.4	64.1
Previous crop: cereals	59.1	32.9	45.0	58.1	72.5	69.3
Previous crop: oilseed rape	64.2	35.8	65.7	54.0	79.1	70.1
Previous crop: potatoes	38.6	47.5	67.8	29.1	49.8	36.4
Soil type: sandy loam	52.3	39.5	52.4	49.5	95.4	78.8
Soil type: sandy clay loam	43.4	33.0	48.7	36.2	58.9	48.5
Soil type: silty clay loam (2007 and 2008 data only)	43.6	68.8	-	56.5	59.1	-

Scottish soils tend to differ from those in England with regards to the behaviour and classification of organic matter. The wetter and cooler climate, slower winter growth and cooler and moister summers tend to lead to less mineralisation of soil organic nitrogen. Scottish soils are also shallower with sampling only practical to 60 cm depth. Generally this survey suggested that there tends to be less SMN in Scottish soils than in English soils.

Climate can also have a large effect on soil available nitrogen. Very high rainfall in January 2008 was possibly a factor in the relatively low mean available soil nitrogen in the February sampling of that year. There was less variation in the post-harvest sampling period over the three years. This again could perhaps be related to the above average rainfall experienced in the July and August of all three years.

Although oilseed rape and potatoes as previous crops are placed in higher nitrogen residue status tables (compared to cereals) within current NVZ guidelines, in this survey it was only winter oilseed rape that tended to leave behind more available nitrogen over the three year period. This trend was only very marginal in 2008. On average, soil available nitrogen after potato harvest was only 6 kg/ha greater than after cereals. This was very variable, and in 2007 soil nitrogen levels following potatoes were over 20 kg/ha lower compared to after cereals.

These findings suggest revision of current nitrogen residue groups in Scottish NVZ guidelines should be considered. Historically potato crops were commonly treated with very large amounts of organic manures prior to planting, resulting in higher fertility and subsequent higher nitrogen residues carried over into the following crop. This is not the case with modern crops, and fertility levels post-potatoes are now lower. It is arguable on the basis of the survey results that there should be no differential between cereals and these other break crops in terms of residue status.

Soil available nitrogen tended to be lower where the soil had a higher clay content. This was particularly so in post-harvest sampling. This trend was consistent over the three-year testing period. As lighter soils tend to cool down more slowly and heat up more quickly, there is a likelihood that there has been more mineralisation of organic nitrogen which is reflected in greater SMN. The elevated soil nitrogen levels post harvest may also reflect poorer yield potential in the lighter soils leading to less efficient utilisation of applied nitrogen.

It is sensible to be cautious in drawing too firm conclusions from what was a relatively limited survey. The nature of SMN testing means that there is inherent risk of variability. It would be unwise to rely on individual samples to provide an accurate 'snapshot' guide of soil nitrogen status. This survey does provide, however, some general trends regarding the fertility status of Scottish soils.

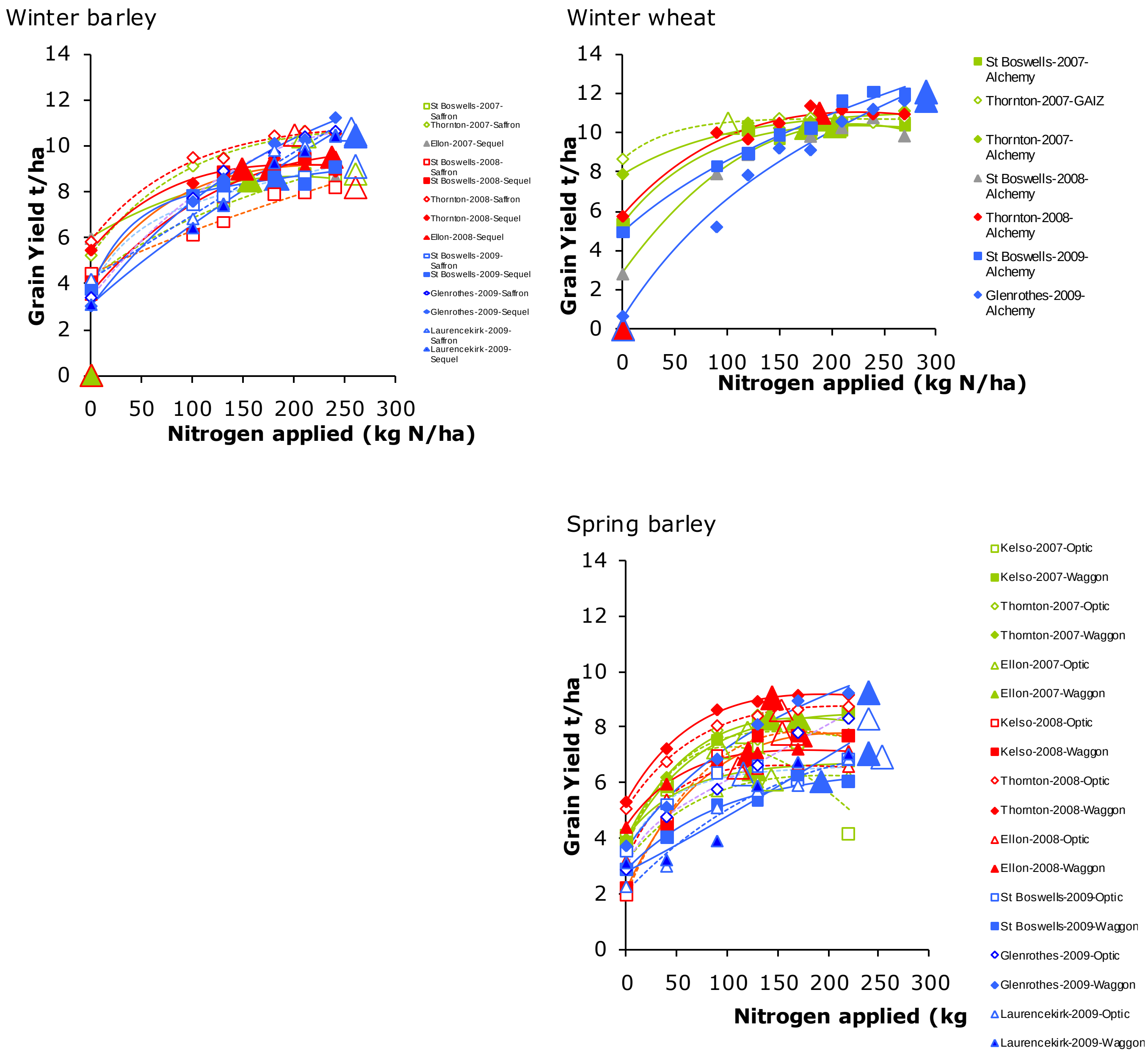
2.3.2. Nitrogen response trials

Rainfall patterns over the period of the project were very variable. The extremely wet autumn and winter of 2006-07 contrasted with the dry conditions over the same period in 2008-09. This variability is likely to have affected SMN as well as influencing the uptake of applied nitrogen in the replicated trials. One consistent trend over the three year period was the wet July and August weather.

The overwhelming majority of trials were responsive to nitrogen, particularly in the 2009 season. The Fife sites produced the highest yields throughout the 3 year period. The biggest response in yield to nitrogen occurred between the zero nitrogen programmes to the first incremental application (Summary Figure 2).

For the majority of the winter barley trials, optimum nitrogen was over 200 kg/ha. In nine out of the fourteen trials the optimum nitrogen exceeded the maximum level of nitrogen tested (240 kg/ha). The grain yields at optimum nitrogen could only be calculated for those five trials where the nitrogen optima were within the tested range. For the wheat trials, optimum nitrogen varied from 100 kg/ha to beyond the highest nitrogen level tested (270 kg/ha). Yields at optimum nitrogen were between

10.22 – 10.99 t/ha. Optimum nitrogen for the majority of the spring barley trials was well in excess of the levels that are used commercially. In four out of six trials in 2009, optimum nitrogen exceeded the maximum nitrogen level tested (220 kg/ha).



Summary Figure 2. Yield response curves for winter barley, winter wheat and spring barley – 2007-2009

The relationship between applied nitrogen and grain nitrogen followed a generally predictable pattern with increasing grain nitrogen with incremental applied nitrogen. There was, however, a trend in some of the trials for a decrease in grain N% when going from nil applied nitrogen to the first incremental application. This seemed to be an effect of the 2009 season, in which five trials showing an obvious initial drop in grain nitrogen. This may be explained by a greater responsiveness to nitrogen in these specific trials, which would have possibly resulted in an initial dilution of grain nitrogen. Grain nitrogen peaked at around 2.0%, with few of the trials exceeding this level.

In general, the relationship between applied nitrogen and SMN was not strong. The post-harvest soil testing indicated no general increase in available nitrogen in relation to the stepped increases of applied nitrogen to the crop. In a number of cases soil available nitrogen in the nil applied nitrogen treatments was just as high as that in the maximum applied nitrogen treatments. This may suggest that plants that are adequately supplied with applied nitrogen develop stronger root systems, more capable of utilising soil nitrogen. This also suggests that plants supplied with optimal nitrogen use this nitrogen more efficiently than sub-optimal amounts, with no subsequent increase in leaching risk. There was some evidence in limited trials that there was an increase in soil available nitrogen at the highest applied nitrogen treatments.

There was an indication that extreme values of soil available nitrogen gave some guidance to crop response to applied nitrogen. The Fife wheat site in 2009 had a very low soil nitrogen level of 16.0 kg/ha when tested in February, and produced a yield from the zero applied nitrogen treatment of 0.65 t/ha. This trial proved to be the most responsive to applied nitrogen. At the other end of the scale the Fife wheat trial in 2007 produced a soil nitrogen level of 91.9 kg/ha – the highest test in the trials series. This site proved to be unresponsive to applied nitrogen. Other than these extremes, there was little evidence to suggest that soil nitrogen could provide an accurate guide to estimating optimum applied nitrogen levels.

The values of grain nitrogen could not be properly validated in trials as the samples from 2008 harvest were too badly sprouted to be analysed. However, none of the wheat samples tested from 2007 and 2009 exceeded 2% nitrogen. Grain nitrogen in the majority of winter and spring barley samples, was also below 2%.

In 27 out of the 39 trials the optimum nitrogen exceeded the relevant Scottish NVZ Nmax figure. This could indicate a potential profit-limiting situation for Scottish growers. This is particularly the case for feed barley and wheat, where optimising yield is the primary target. The situation for spring barley grown for the malt distilling market differs, in that one of the primary objectives to meet malting specification is to produce barley with grain nitrogen no higher than 1.6%. This inherently limits the amount of nitrogen that can be applied.

2.4. Recommendations

- The change in cropping patterns and subsequent reduction in soil fertility along with an overall reduction in the usage of inorganic nitrogen is likely to have resulted in less risk of nitrate leaching over the past 30 years. The soil survey has confirmed that inter-crop SMN levels are moderate to low – particularly in situations where no organic manures are used. It would be useful to share this information with the water monitoring authority in Scotland (SEPA). The results may be helpful in adding to the existing understanding and prediction of soil nitrogen supply – particularly in the context of Scottish soils. It would be useful to continue to monitor some of the arable soils analysed in this project.
- The current nitrogen residue groups place cereals in group 1, and potatoes and oilseed rape in group 2. This survey indicated no major differences in soil nitrogen residues left following cereals or potatoes, and only marginal increases from oilseed rape previous cropping. The continuation of this testing and inclusion of crops in other residue groups would help to inform a potential re-classification of current residue groups.
- The nitrogen response trials, using modern higher yielding varieties, have highlighted a potential yield limiting situation for Scottish growers. It is recommended that Scottish Government is consulted on this with a view to a review of the current Nmax limits. NVZ guidelines are designed to balance environmental and economic priorities. On the basis of this project and a previous soil survey (HGCA Project Report PR438) there is no evidence to suggest existing nitrogen usage is causing excessive detectable nitrate leaching, even when applied nitrogen rates are well in excess of economic nitrogen optima.
- The production of nitrogen response curves is a useful tool in guiding practical agronomy advice to growers. This information is very limited, particularly on current, popular varieties. As genetics improve, nitrogen use efficiency is likely to change, and it would be beneficial to the industry to monitor this with ongoing replicated trials. These trials are simple and relatively inexpensive to implement.