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

by

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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.

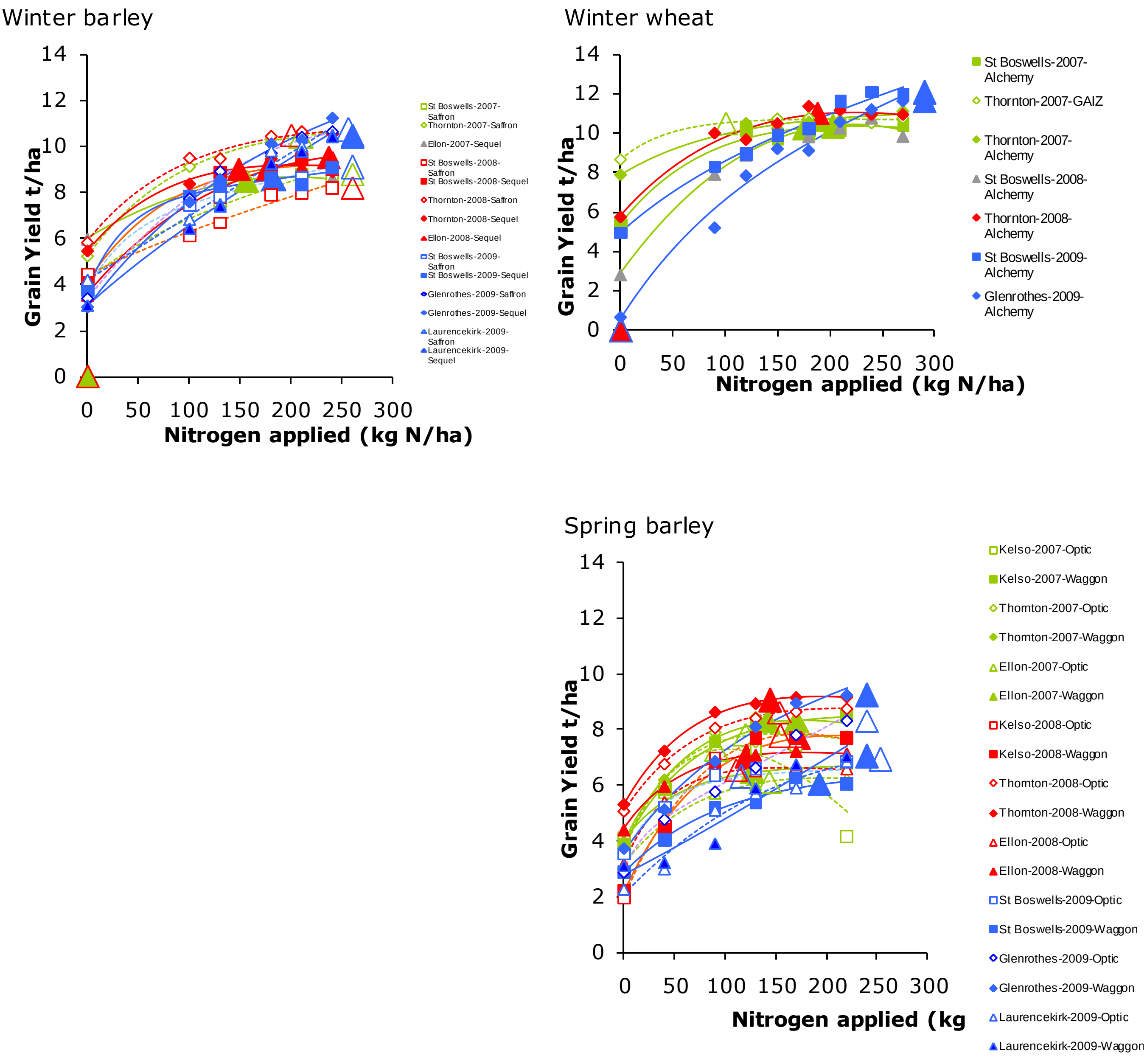
2.3.2. Nitrogen response trials

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.

3. TECHNICAL REPORT

3.1. Introduction

The introduction of Nitrate Vulnerable Zones (NVZ) to Scotland in 2003 focussed attention on the use of inorganic nitrogen in arable crops. In January 2003, the Scottish Executive implemented a series of Action Programme measures to reduce nitrate loss from agricultural land, and issued guidelines to farmers to help them comply with these measures (SEERAD, 2003). The guidance includes nitrogen recommendation tables, which must be used to assess the spring nitrogen required for each crop. Factors used in calculating the nitrogen requirement include soil type, previous cropping, intended market and rainfall levels. The tables are based on hybridised data, partly encompassing recommendations from the original MAFF RB209 document (MAFF, 2000) (recently revised), and partly using Scottish Agricultural College (SAC) derived recommendations (Sinclair *et al.*, 2002). Much of the data, however, was generated in the 1980s and based on limited information on the relationship between soil available nitrogen, 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 (Sylvester-Bradley, *et al*., 2008).

SAC's guidelines for nitrogen use have evolved over a 35 year period and are the result of the inclusion of generalities on the fertility status of soils. Scottish growers in the late 1970s and 1980s established around 40,000 ha of grass/clover mixtures per year (SEERAD, Archives) as undersown crop in spring barley. Typically these would be 2-5 year leys. Therefore an area of between 35%–65% of Scottish arable land included grass in the rotation, which would have been used to raise livestock.

Today, the majority of arable land is in continuous arable cropping with no source of organic manure produced on farm (SEERAD, Archives). Average yield levels have been increased through good agronomy, resulting in high off-take of nitrogen through both grain yield and removal of straw. Levels of intercrop SMN on these farms can be very low, e.g. 5 kg/ha available nitrogen in cereal stubbles in September, and 20 kg/ha nitrogen in ploughed ground in February (Phillips *et al*., 2006). With the exception of published Scottish Agronomy data (Phillips *et al.*, 2006), little evidence of systematic evaluation of Scottish soil nitrogen exists. This project indicated a wide range of results in what were considered to be predictable rotations. A more robust evaluation is required to prevent levy payers being financially penalised either from yield loss or deductions from their single farm payment.

3.1.1. Project objectives

The overall aim of this project was to provide up to date evaluation of available nitrogen in Scottish arable soils, and its relationship with nitrogen input and off-take. The objectives also included evaluation of whether soil available nitrogen was consistent over seasons and the investigation of the effect of varying nitrogen inputs on crop yield and soil reserves.

Specific objectives were (including the extension):

1. To measure soil available nitrogen on multiple sites over Scotland's main arable areas.
2. To repeat these measurements on the same fields/soils (where possible) 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 soil available nitrogen both pre-nitrogen application and post-harvest in these trials to determine relationship between soil nitrogen and applied nitrogen.

3.2. Materials and methods

3.2.1. Soil nitrogen survey

In the early spring (February), soil sampling was undertaken in typical arable fields, in different geographical areas, ranging from the Scottish Borders to Aberdeenshire. The fields sampled covered a range of soil types, climatic conditions and current and previous cropping (Figure 1 and appendix).

Fields were sampled in February, before the application of any spring inorganic nitrogen, and were then sampled again post-harvest in August or September. This allowed a comparison of soil available nitrogen levels. A minimum of 26 separate fields were sampled in each of the years 2007, 2008, 2009. Where practicable, original fields sampled in 2007 were also sampled in 2008 and 2009.

Figure 1. Soil sampling distribution 2007-2009

A minimum of 25 core sub-samples were taken to a depth of 60 cm with a soil auger, taken along a "W-pattern" within the field, and these were mixed to produce a bulk sample. Samples were refrigerated to 5-8 °C 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 0-30 cm and 30-60 cm soil profiles. Due to the shallow nature of the majority of Scottish arable soils it was not practical to sample below 60 cm. Information on soil texture and previous cropping was collected for each of the fields sampled over the three-year period (Appendix).

Method for calculating available nitrogen

Standard operating procedure for N-Min analysis – Hill Court Farm Research:

Available nitrogen (Nitrate-N & Ammonium-N): extraction in 1 M KCl for 1 hour

Bulk density used: Sandy Loam = 1.5 g/cm3; Silty Clay Loam = 1.1 g/cm3; Sandy Clay Loam = 1.3 g/cm3; Clay Loam = 1.2 g/cm3

Conversion from mg/kg to kg/ha: (Nitrate-N + Ammonium-N) x 10000 (ha) x 0.3 (metre depth) x bulk density/ 1000 (g to kg)

3.2.2. 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. In 2007 there was a total of 12 trials, with 13 in 2008 and 14 in 2009. Trials were situated in the Borders, Fife, Aberdeenshire and Kincardineshire. Trial design was randomised block. Plot size was 12m by 2m and there were 3 replicates per block. Plots were drilled by Hege plot drill. All agronomic inputs other than nitrogen were standardised in each trial, reflecting typical commercial practice. Details are contained in the Appendix.

Varieties

Popular commercial varieties were chosen. Winter barley varieties were Sequel and Saffron – representing the most popular 6 row and 2 row feed varieties. The winter wheat variety was Alchemy – with one trial using a four-way blend of Glasgow, Istabraq, Zebedee and Alchemy (GIZA). The spring barley varieties were Optic and Waggon – representing the most popular malting variety and the highest yielding feed variety in Scotland respectively.

Nitrogen treatments

On each winter and spring barley site six nitrogen rates were tested. This ranging from zero to 240 kg/ha for winter barley and zero to 220 kg/ha for spring barley. Each winter wheat site had a minimum of seven nitrogen rates ranging from zero to 270 kg/ha. Nitrogen was applied as ammonium nitrate (34.5% N) to individual plots using a Horstine Farmery fertiliser applicator. All trials had standard applications of potassium, phosphate and sulphur (Appendix).

Nitrogen splits

Nitrogen applications for the winter barley experiments were split over either two or three timings, depending on total amount applied as indicated in Table 1.

Table 1. Nitrogen treatments and timings for winter barley trials

Treatment	Timing			Total Applied nitrogen (kg/ha)
	Z 23-25	Z 30-31	Z 33-37	
1	0	0	0	0
2	50	50	0	100
3	50	80	0	130
4	50	100	30	180
5	50	100	60	210
6	60	120	60	240

Nitrogen applications for the winter wheat experiments were similarly split over either two or three timings, as indicated in Table 2. In the 2007 trials series, there were only seven nitrogen levels, with the 90 kg/ha treatment excluded.

Table 2. Nitrogen treatments and timings for winter wheat trials

Treatment	Timing			Total Applied nitrogen (kg/ha)
	Z 23-25	Z 30-31	Z 32-33	
1	0	0	0	0
2	20	70	0	90
3	50	70	0	120
4	50	70	30	150
5	50	100	30	180
6	50	110	50	210
7	50	140	50	240
8	60	150	60	270

Nitrogen applications for the spring barley experiments are described in Table 3. Nitrogen applications were completed no later than early post-emergence of the crop.

Table 3. Nitrogen treatments and timings for spring barley trials

Treatment	Total Applied nitrogen (kg/ha) (applied pre- or early post-emergence)
1	0
2	40
3	90
4	130
5	170
6	220

Crop and soil measurements

Plots were harvested by plot combine. Yields were adjusted for moisture content to 85% dry matter and are presented as tonnes/ha. Sub-samples were collected (where appropriate) from each plot and mixed with similar treatments from other replicates to provide a composite sample for each nitrogen treatment. These samples were then analysed for grain nitrogen %.

Soil samples were collected from each trial area in February – prior to any nitrogen applications – for autumn sown trials, and before sowing for spring barley trials. These were analysed for available nitrogen in the same manner as for the soil mapping element of the project. Immediately following harvest, soil samples were taken from each nitrogen treatment. Five soil cores were taken in both February and after harvest from each plot and bulked per treatment to give a composite soil sample from each nitrogen regime. These were then tested for available soil nitrogen.

3.2.3. Statistical analysis

Grain yield was analysed using analysis of variance. Response curves were then fitted to determine the economic optimum nitrogen rates (optimum nitrogen). The linear plus exponential (LEXP) function was fitted to the data as this had been used to describe response curves in trials used to support recommended nitrogen rates in the Fertiliser Manual (RB209, 8th edition, Defra, 2010).

The LEXP function used is $y = a + b.r^N + c.N$, where y is yield in t/ha at 85% DM, nitrogen is total fertiliser nitrogen applied in kg/ha, and a, b, c and r are parameters determined by statistical fitting.

Optimum nitrogen is calculated at a break-even price ratio between fertiliser nitrogen and grain of 5:1, in line with the data presented in the Fertiliser Manual (RB209, 8th edition, Defra, 2010).

3.3. Results

3.3.1. Soil nitrogen survey

The data from the soil sampling are presented in Tables 4 and 5. The results in Table 4 show the influence of previous cropping and soil type on soil available nitrogen. The mean soil available nitrogen over the three years of the project in the February sampling period was 47.9 kg/ha. The comparative figure for the follow up sampling in the immediate post-harvest period in August – September was 61.1 kg/ha. There was a very large range of soil nitrogen levels, but there was a general consistency in results from the same fields when comparing February soil available nitrogen to August/September values. In other words, 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).

Where winter oilseed rape was the previous crop, soil available nitrogen in February was higher than for 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 as the preceding crop).

The influence of soil texture on soil nitrogen status was also investigated. 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 a higher available nitrogen in the February sampling. The post-harvest sampling indicated that the sandy loam soils had a higher mean level of available nitrogen compared to the sandy clay loams.

Soils at the higher end of the available nitrogen range tended to be on farms with livestock as well as arable enterprises, and which were utilising organic manures. Six samples were excluded from the survey as they had available nitrogen levels over 200 kg/ha. This was considered to be significantly above the mean of the tested samples, and as all six samples were taken from farms using farm yard manures, it was probable that they had become contaminated with organic matter.

Table 4. 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)
Previous crop: vining peas	3	52.4 (38.4-65.3)	29.8 14.2-42.0)
Previous crop: beans	1	71.0	44.0
Previous crop: set aside	2	32.5 (22.0-43.0)	60.1 (36.0-84.2)
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 & 2008 data only)	5	56.2 (24.0-68.8)	57.8 (24.7-109.6)

Table 5 shows the mean available soil nitrogen figures for each sampling year. 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 soil available nitrogen. 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 soil available nitrogen, where the previous crop was oilseed rape compared to cereals, was apparent in all three years of sampling. This trend was not apparent for the post-harvest sampling. In the years 2007 and 2009, the post-harvest soil nitrogen figure where the crop in the previous year was potatoes, was lower than for the February sampling period.

Table 5. Mean available soil nitrogen 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	-

3.3.2. Nitrogen response trials

The rainfall data over the period of the project (Figure 2) indicate that the three seasons were very contrasting. The extremely wet autumn and winter of 2006-07 compared to the dry conditions over the same period in 2008-09 for example. This variability in rainfall between the project's three seasons is likely to have affected SMN as well as influencing the uptake of applied nitrogen in the nitrogen response trials. One consistent trend over the three year period was the wet July and August weather. This created particular problems with harvesting of trials in 2008 and meant grain analysis was incomplete due to sprouting.

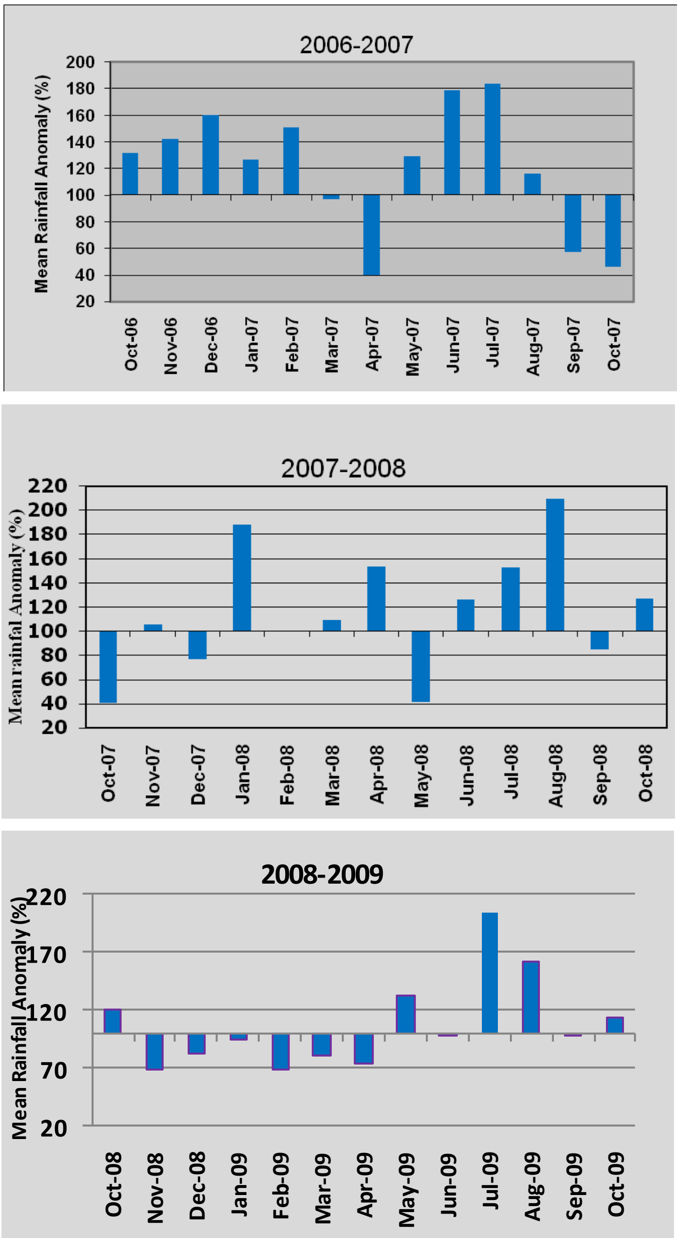


Figure 2 Monthly rainfall figures for Eastern Scotland October 2006-October 2009. Data represented as the percentage of the 30 year mean (1975-2005).

Winter barley trials

All the winter barley trials were responsive to nitrogen, particularly in the 2009 season. The yields are presented in Table 6. The Fife site produced the highest yields throughout the three-year period. There was little difference in yield performance between the two varieties tested. The biggest response in yield to nitrogen occurred in the zero to 100 kg/ha comparison, with correspondingly lower responses as nitrogen level was increased beyond 100 kg/ha.

Table 6. Winter barley yield response (t/ha) to applied nitrogen

Location	Variety	Total applied nitrogen (kg/ha)						LSD
		0	100	130	180	210	240	
Borders 2007	Saffron	4.22	6.16	7.60	8.53	8.79	8.66	1.049
Fife 2007	Saffron	5.22	9.13	9.50	10.34	10.38	10.59	0.485
Aberdeenshire 2007	Sequel	5.99	8.07	8.13	8.86	8.48	8.60	0.671
Borders 2008	Saffron	4.44	6.14	6.69	7.88	7.95	8.19	0.504
	Sequel	4.11	7.86	8.84	8.95	9.46	9.03	0.767
Fife 2008	Saffron	5.85	9.50	9.47	10.44	10.64	10.54	0.925
	Sequel	5.44	8.35	8.86	9.44	9.35	8.87	0.757
Aberdeenshire 2008	Sequel	3.57	7.62	7.81	9.31	9.14	9.56	0.976
Borders 2009	Saffron	3.73	7.48	7.80	8.58	8.68	9.11	0.472
	Sequel	3.77	7.83	8.29	8.63	8.36	9.05	0.358
Fife 2009	Saffron	3.41	7.72	8.90	9.69	10.38	10.62	1.028
	Sequel	3.02	7.58	8.57	10.12	10.28	11.24	0.508
Kincardineshire 2009	Saffron	4.23	6.85	7.51	9.82	10.02	10.50	0.360
	Sequel	3.11	6.45	7.42	9.28	9.80	10.44	0.596

Optimum nitrogen for the majority of the winter barley trials was greater than 200 kg N/ha (Table 7). In nine 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 seven trials where the optimum nitrogen was within the range of nitrogen rates tested.

Table 7. Winter barley Nopt and grain yield at Nopt

Location	Variety	Optimum nitrogen (kg/ha) (Yield at optimum nitrogen)		
		2007	**2008**	**2009**
Borders	Saffron	240	240	240
	Sequel		185 (9.09 t/ha)	240
Fife	Saffron	223 (10.51 t/ha)	215 (10.54 t/ha)	263 (10.78 t/ha)
	Sequel		156 (9.07 t/ha)	300
Aberdeenshire	Sequel	163 (8.56 t/ha)	246 (9.57 t/ha)	
Kincardineshire	Saffron			240
	Sequel			240

The dose response curves for the winter barley trials are represented in Figure 3. R^2 for LEXP in all cases was above 0.97 indicating a very good fit for the response curves.

The effects on grain N% of increasing rates of applied nitrogen are presented in Figure 4. The majority of the trials showed an increasing grain N% with increasing applied nitrogen. A number of the trials demonstrated a reduction in grain N% going from nil applied nitrogen to 100kg N/ha. Grain N% peaked at around 2.0%, with few of the trials exceeding this. The average grain N% at optimum nitrogen (where this could be measured) was 1.97 %.

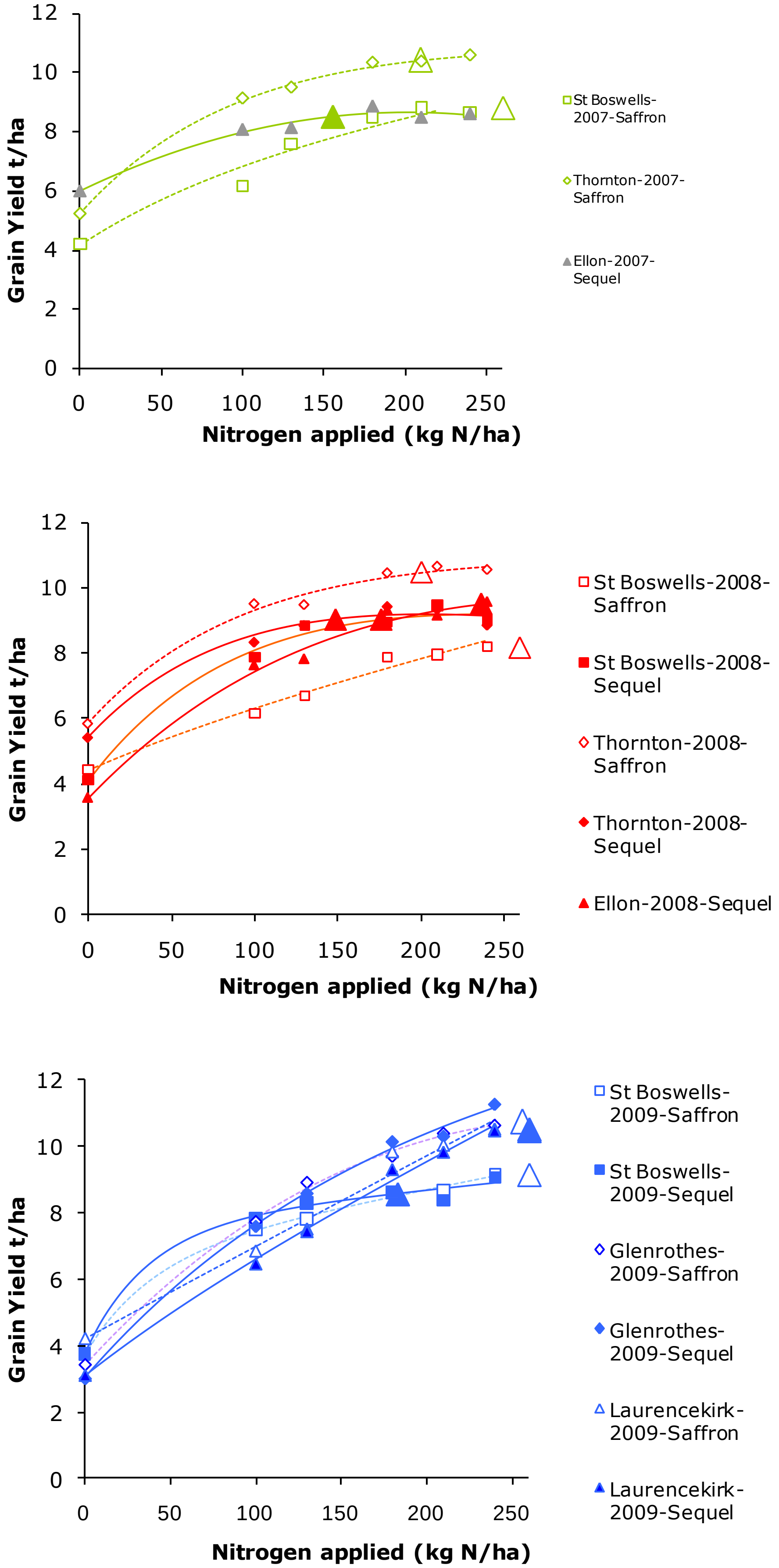


Figure 3. Winter barley dose response curves for 2007 (top), 2008 (middle) and 2009 (bottom) trials.

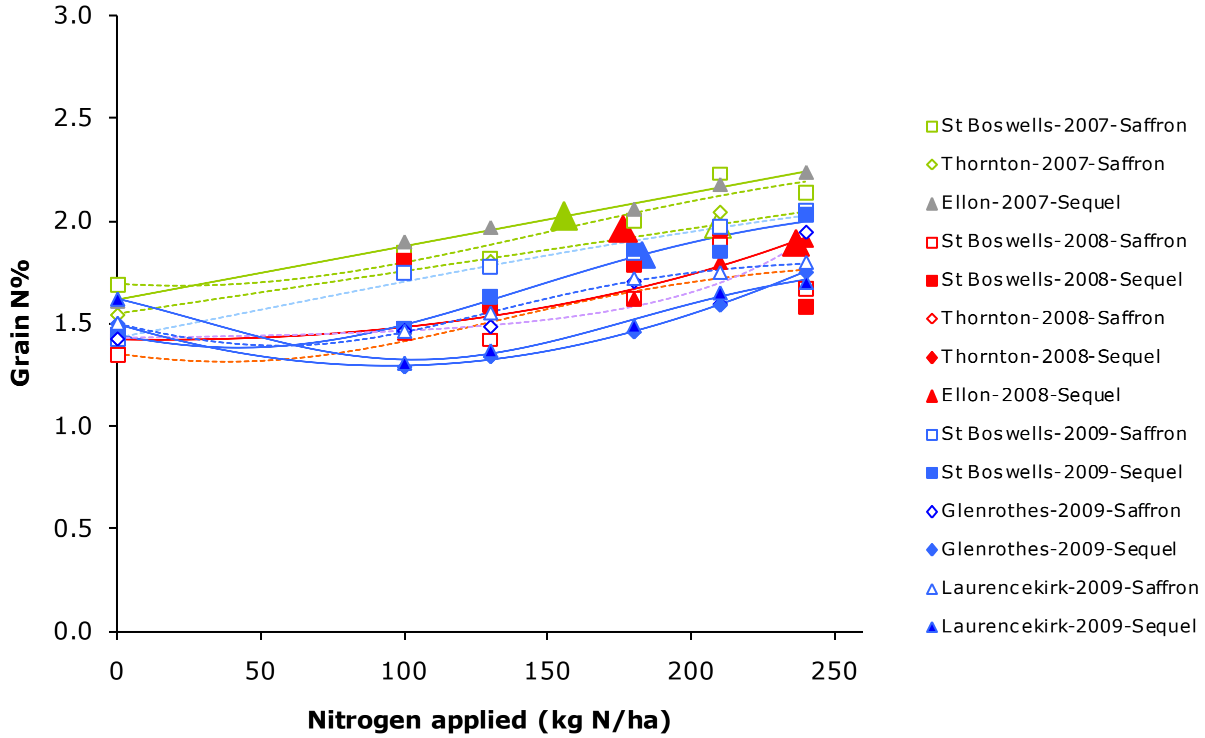


Figure 4. Winter barley grain N% vs applied nitrogen 2007-2009

Soil available nitrogen was measured pre nitrogen application and post crop harvest. The post-harvest samples were taken from each nitrogen treatment to compare the effect of increased nitrogen input on soil available nitrogen. The results are plotted in Figure 5. In 2007 the pre-application soil available nitrogen was 45.2 kg N/ha. Post-harvest sampling produced a range of soil available nitrogen of 22.4 – 60.4 kg N/ha from the nil to 240 kg N/ha applications. At only the two highest nitrogen application rates was there more soil available nitrogen after harvest than there was pre-nitrogen application. In contrast the 2008 sampling saw post-harvest samples all above the pre-application level of 34.3 kg N/ha. There appeared to be a small trend for increasing soil available nitrogen with increased applied nitrogen. The 2009 trial series was similar to 2008 with all post-harvest samples having greater soil available nitrogen than the pre application sample.

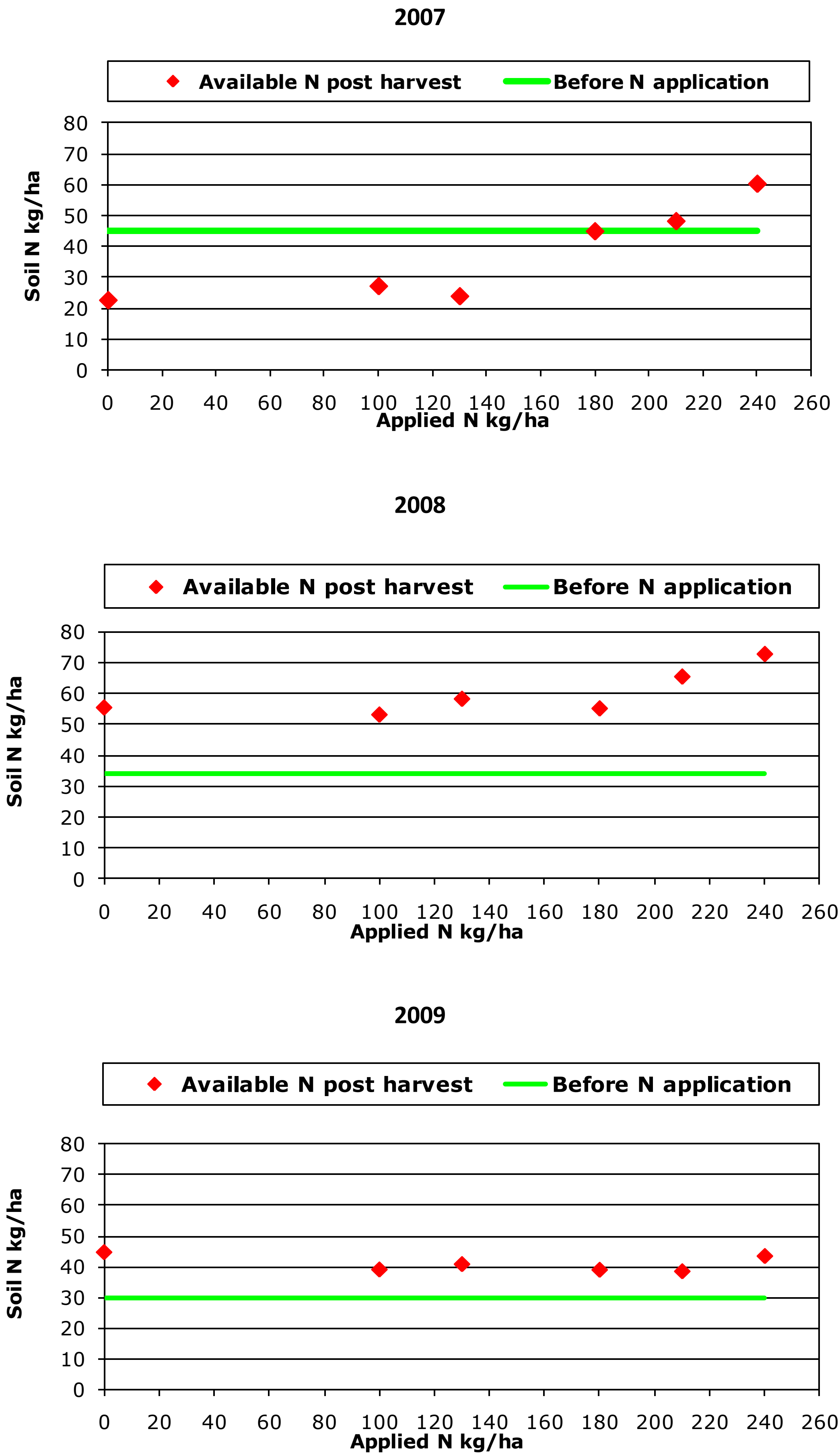


Figure 5. Winter barley pre-application soil available nitrogen vs. post-harvest soil available nitrogen at all applied nitrogen levels 2007-2009

Winter wheat trials

The majority of trials responded to applied nitrogen (Table 8). There were differences between trials in yield at nil applied nitrogen. The yield from the 2007 Fife GAIZ (Glasgow/Alchemy/Istabraq/Zebedee blend) trial at the nil input level was 8.64 t/ha. This compared to the 2009 Fife Alchemy nil input yield of only 0.65 t/ha. Similar to the winter barley the greatest degree of response to applied nitrogen was from the zero rate to the 90 kg or 120 kg level. The harvest period in 2008 was very wet and resulted in late lodging, particularly in the Borders trial. No grain sampling was undertaken for nitrogen analysis as samples had a significant degree of sprouting.

Table 8. Winter wheat yield response to applied nitrogen

Location	Variety	Total applied nitrogen (kg/ha)								LSD
		0	90	120	150	180	210	240	270	
Borders 2007	Alchemy	5.36		10.10	9.66	10.14	10.14		10.42	1.07
Fife 2007	Alchemy	7.85		10.48	10.20	10.55	10.63	10.91	11.10	0.52
	GAIZ	8.64		10.50	10.70	10.80	10.51	10.53	10.79	0.93
Borders 2008	Alchemy	2.82	7.93	8.91	9.96	9.84	10.28	10.79	9.86	0.92
Fife 2008	Alchemy	5.76	10.00	9.67	10.48	11.30	11.16	10.94	10.94	0.95
Borders 2009	Alchemy	4.92	8.30	8.95	9.89	10.20	11.59	12.09	11.97	0.94
Fife 2009	Alchemy	0.65	5.21	7.86	9.23	9.14	10.60	11.24	11.66	0.81

Optimum nitrogen varied from 100 kg N/ha to beyond the highest nitrogen level tested (270 kg/ha). Yields at optimum nitrogen were between 10.22 – 10.99 t/ha (Table 9).

Table 9. Winter wheat Nopt and grain yield at Nopt

Location	Variety	Optimum nitrogen (kg/ha) (Yield at optimum nitrogen)		
		2007	2008	2009
Borders	Alchemy	175 (10.22 t/ha)	203 (10.37 t/ha)	270
Fife	Alchemy	190 (10.70 t/ha)	188 (10.99 t/ha)	270
	GAIZ Blend	100 (10.50 t/ha)		

The dose response curves for the wheat trials are presented in Figure 6. R^2 for curve fit was greater than 0.97 in all cases.

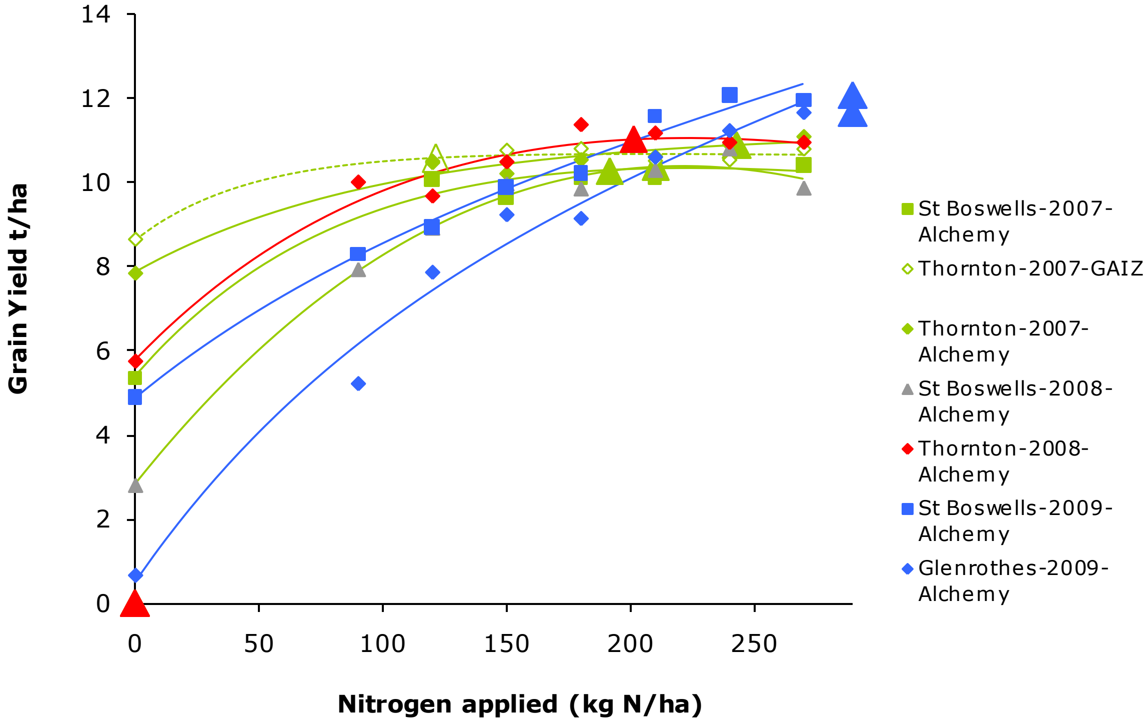


Figure 6. Winter wheat nitrogen dose response curves for 2007, 2008 and 2009 trials

The grain N% response curves are presented in Figure 7. The data is limited due to an absence of samples from the 2008 season. There was a gradual increase in grain N% with applied nitrogen apart from the Fife trial in 2009 which showed no increase in grain N% from nil applied nitrogen to 270 kg/ha. The average grain N% at optimum nitrogen (where this could be measured) was 1.87%.

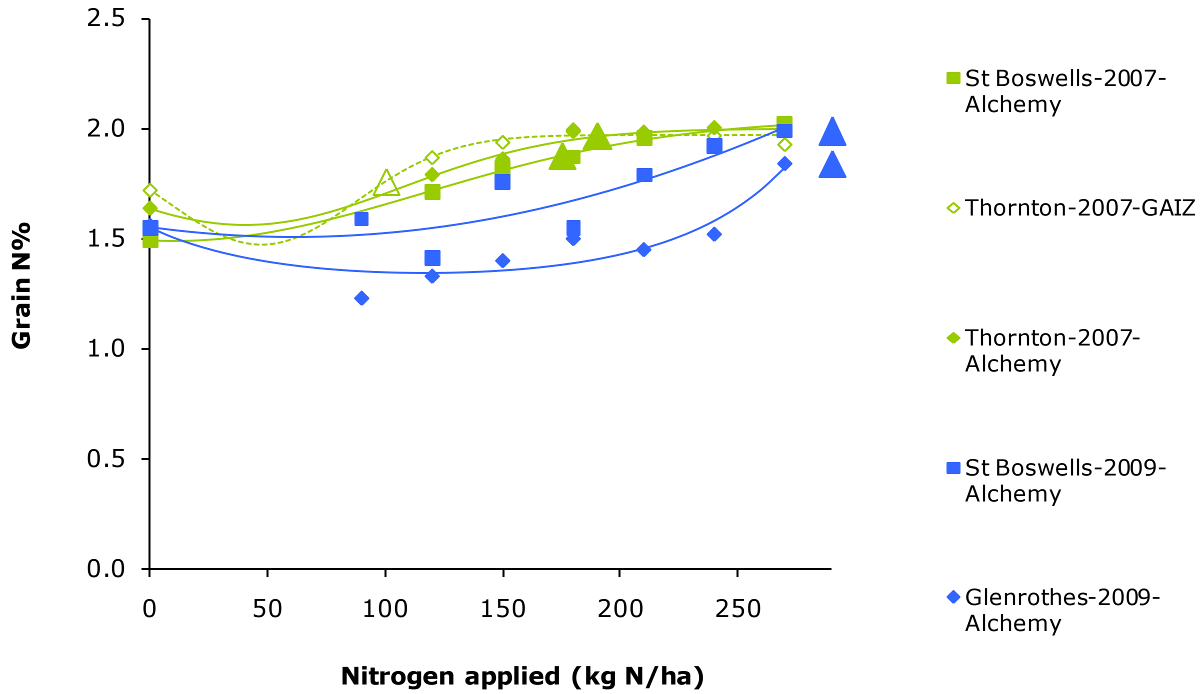


Figure 7. Grain nitrogen % vs applied nitrogen, winter wheat trials 2007-2009

The results of soil nitrogen sampling from the wheat trials are reported in Figure 8. The 2007 season post harvest samples all had available nitrogen below the February sampling level, apart from the highest applied nitrogen treatment (270 kg/ha). In 2007, there was less soil available nitrogen post-harvest than there was pre-N application (92 kg N/ha) in all but the highest nitrogen treatment (270 kg N/ha). The 2008 trials had a much lower soil available nitrogen in February pre-application (37.5 kg N/ha). All post-harvest samples were above this level. In 2007 and 2008, there was no indication of increased post-harvest soil available nitrogen with increasing applied nitrogen. In 2009 there was less post-harvest soil available nitrogen than there was pre-N application in all but the highest two nitrogen treatments (240, 270 kg N/ha).

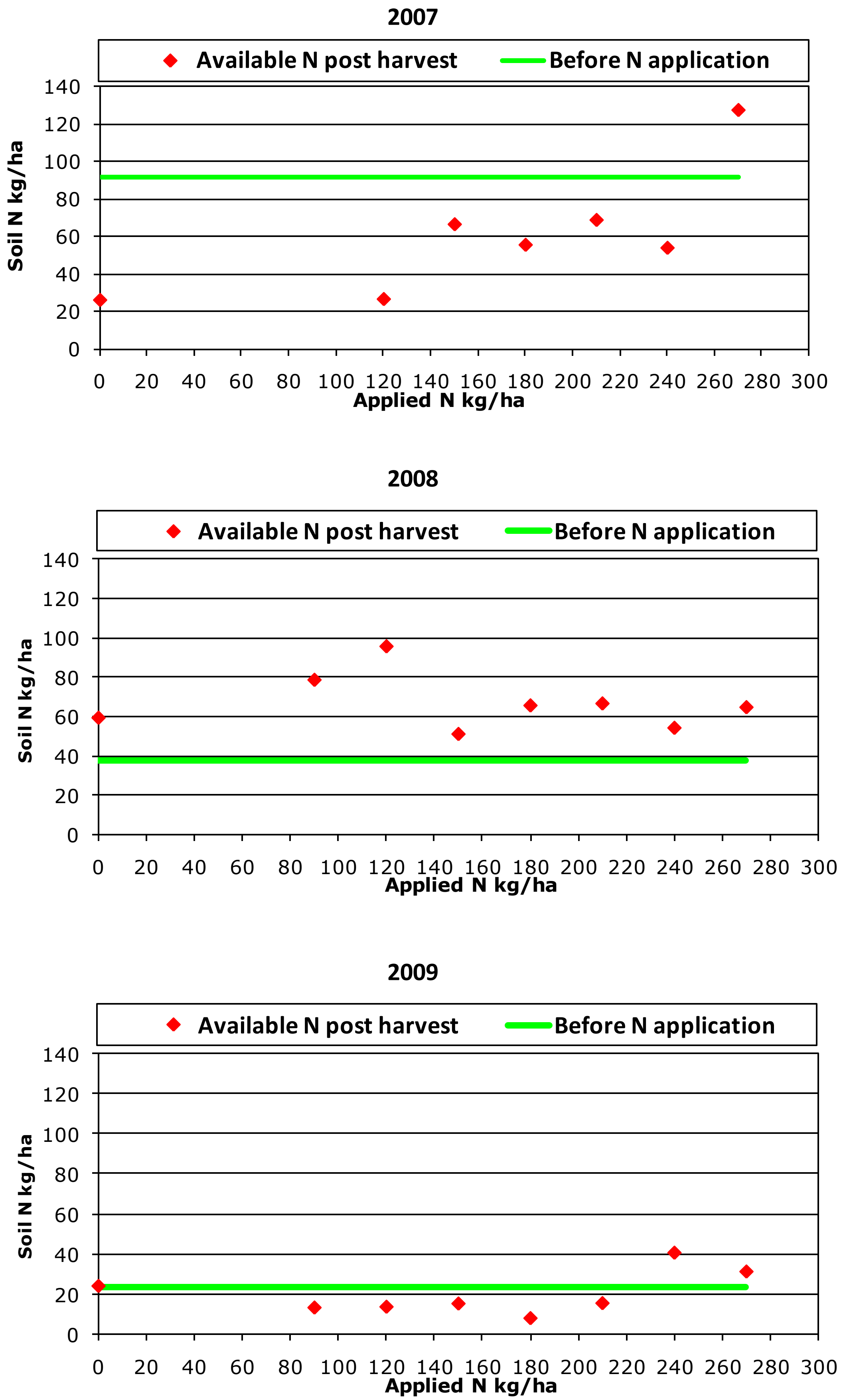


Figure 8. Winter wheat trials pre-application Soil nitrogen availability vs. post-harvest availability at all applied nitrogen levels 2007-2009

Spring barley trials

The yields from the three-year series are shown in Table 10. All trials were responsive to nitrogen. The Fife sites tended to produce the highest yields. Lodging was not significant apart from at the highest nitrogen treatment in the Borders Optic trial in 2007, which experienced significant lodging during the grain-filling period.

Table 10. Spring barley yield response to applied nitrogen (t/ha)

Location	Variety	Total applied nitrogen (kg/ha)						LSD
		0	40	90	130	170	220	
Borders 2007	Optic	4.09	5.73	6.78	7.34	7.42	4.14	0.38
	Waggon	3.86	5.86	7.53	8.16	7.98	8.55	0.39
Fife 2007	Optic	3.65	6.04	7.90	7.56	7.71	7.75	1.06
	Waggon	3.96	6.20	7.66	8.46	8.08	8.33	0.76
Aberdeenshire 2007	Optic	3.14	4.57	5.69	6.01	6.21	6.23	0.66
	Waggon	4.05	5.28	6.48	6.42	6.42	6.81	0.59
Borders 2008	Optic	1.97	4.54	6.95	7.68	7.57	7.70	0.58
	Waggon	2.23	4.39	6.42	7.67	7.70	7.66	0.50
Fife 2008	Optic	5.06	6.76	8.07	8.42	8.65	8.76	0.69
	Waggon	5.32	7.22	8.61	8.91	9.13	9.15	0.55
Aberdeenshire 2008	Optic	3.16	5.37	6.49	6.49	6.64	6.56	0.37
	Waggon	4.41	5.95	6.83	7.06	7.19	7.11	0.46
Borders 2009	Optic	3.51	5.22	6.36	6.58	6.12	6.83	1.03
	Waggon	2.87	4.02	5.18	5.35	6.26	6.03	0.62
Fife 2009	Optic	2.89	4.78	5.77	6.63	7.80	8.31	0.69
	Waggon	3.71	5.12	6.86	8.11	8.97	9.25	0.37
Kincardineshire 2009	Optic	2.24	2.98	5.10	5.71	5.91	6.87	1.29
	Waggon	3.09	3.20	3.89	5.89	6.75	7.04	0.87

Optimum nitrogen for the majority of the spring barley trials was well in excess of nitrogen rates that are used commercially. In four of the six trials in 2009, the optimum nitrogen exceeded the maximum nitrogen rate tested (Table 11).

Table 11. Spring barley Nopt and grain yield at Nopt

Location	Variety	Optimum nitrogen (kg/ha) (Yield at optimum nitrogen t/ha)		
		2007	2008	2009
Borders	Optic	92 (7.28 t/ha)	155 (7.78 t/ha)	116 (6.32 t/ha)
	Waggon	170 (8.29 t/ha)	173 (7.70 t/ha)	193 (6.05 t/ha)
Fife	Optic	120 (7.80 t/ha)	153 (8.61 t/ha)	240
	Waggon	142 (8.28 t/ha)	144 (9.05 t/ha)	240
Aberdeenshire	Optic	144 (6.12 t/ha)	110 (6.53 t/ha)	
	Waggon	127 (6.46 t/ha)	121 (7.04 t/ha)	
Kincardineshire	Optic			253
	Waggon			240

Dose response curves for the spring barley trials are represented in Figure 9. R^2 for LEXP was greater than 0.94 for all trials indicating a good fit for the response curves.

Response in grain N% to increased nitrogen application is shown in Figure 10. The majority of trials followed the expected trend of increasing grain N% with increased applied nitrogen. This was not the case in 2009 where there was a relatively flat response, apart from at the highest nitrogen treatment. In this year, optimum nitrogen in four of the six trials exceeded the highest nitrogen rate tested, and this may have resulted in a greater dilution of grain nitrogen than in the previous two years.

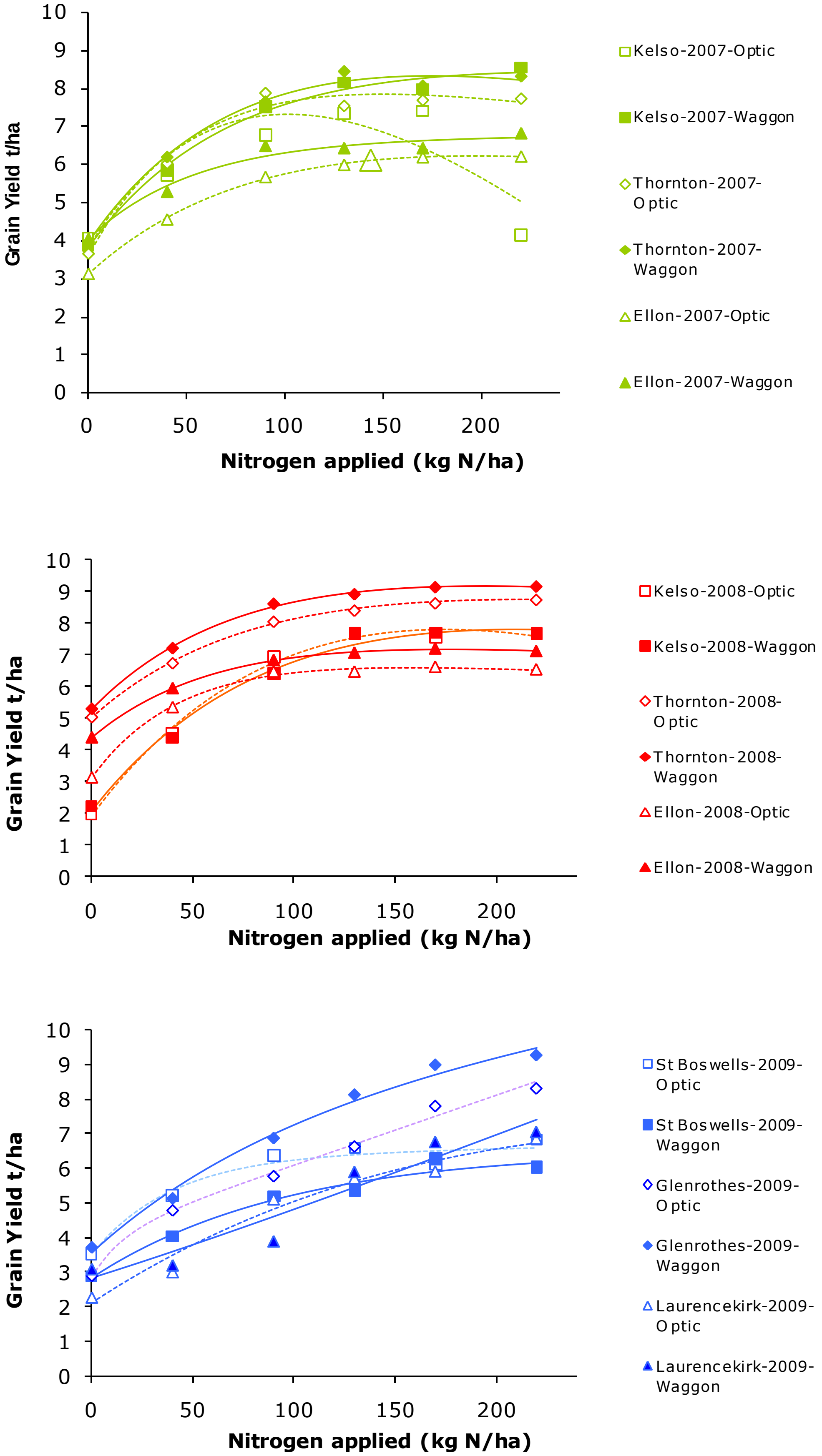


Figure 9. Spring barley nitrogen dose response curves for 2007, 2008 and 2009 trials

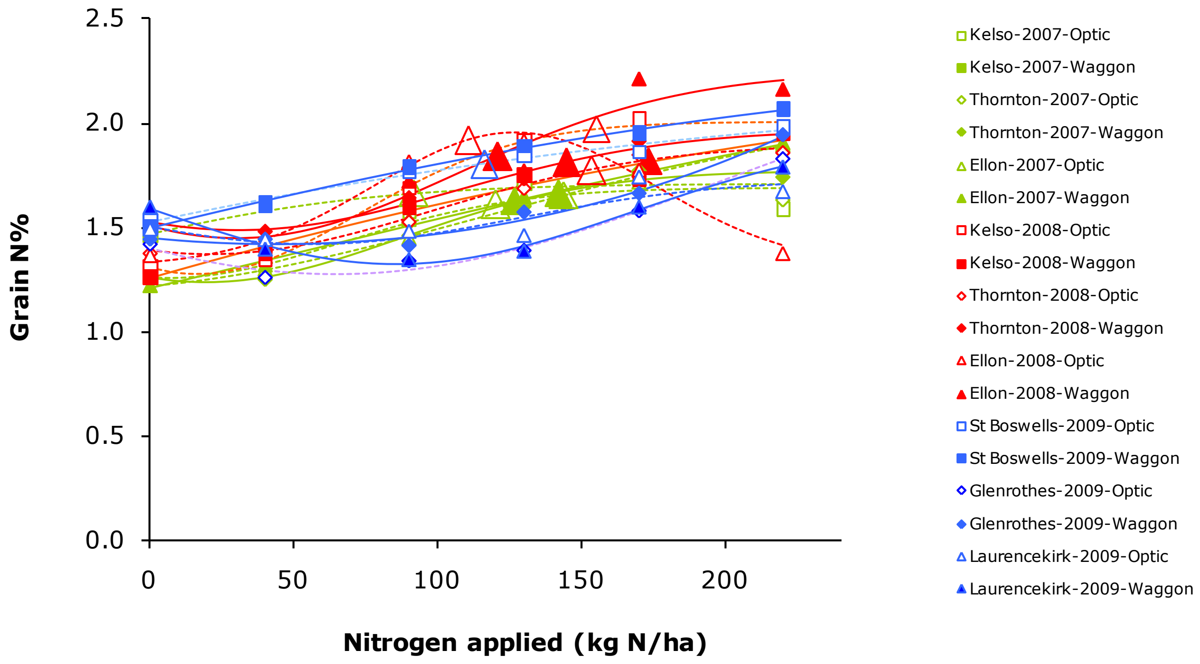


Figure 10. Grain N% vs applied nitrogen, spring barley trials 2007-2009

Soil available nitrogen results for the spring barley trials are presented in Figure 11. The 2007 post harvest sampling revealed soil available nitrogen values that were all greater than than the average pre application value (48.1 kg N). In this year, there was no apparent effect of increasing amount of applied nitrogen on soil available nitrogen post-harvest. In 2008 all but the two highest nitrogen application treatments produced soil available nitrogen values which were below the pre-N application value. In 2009 all post-harvest soil available nitrogen values were less than half of the original pre-N application value (86.2 kg N).

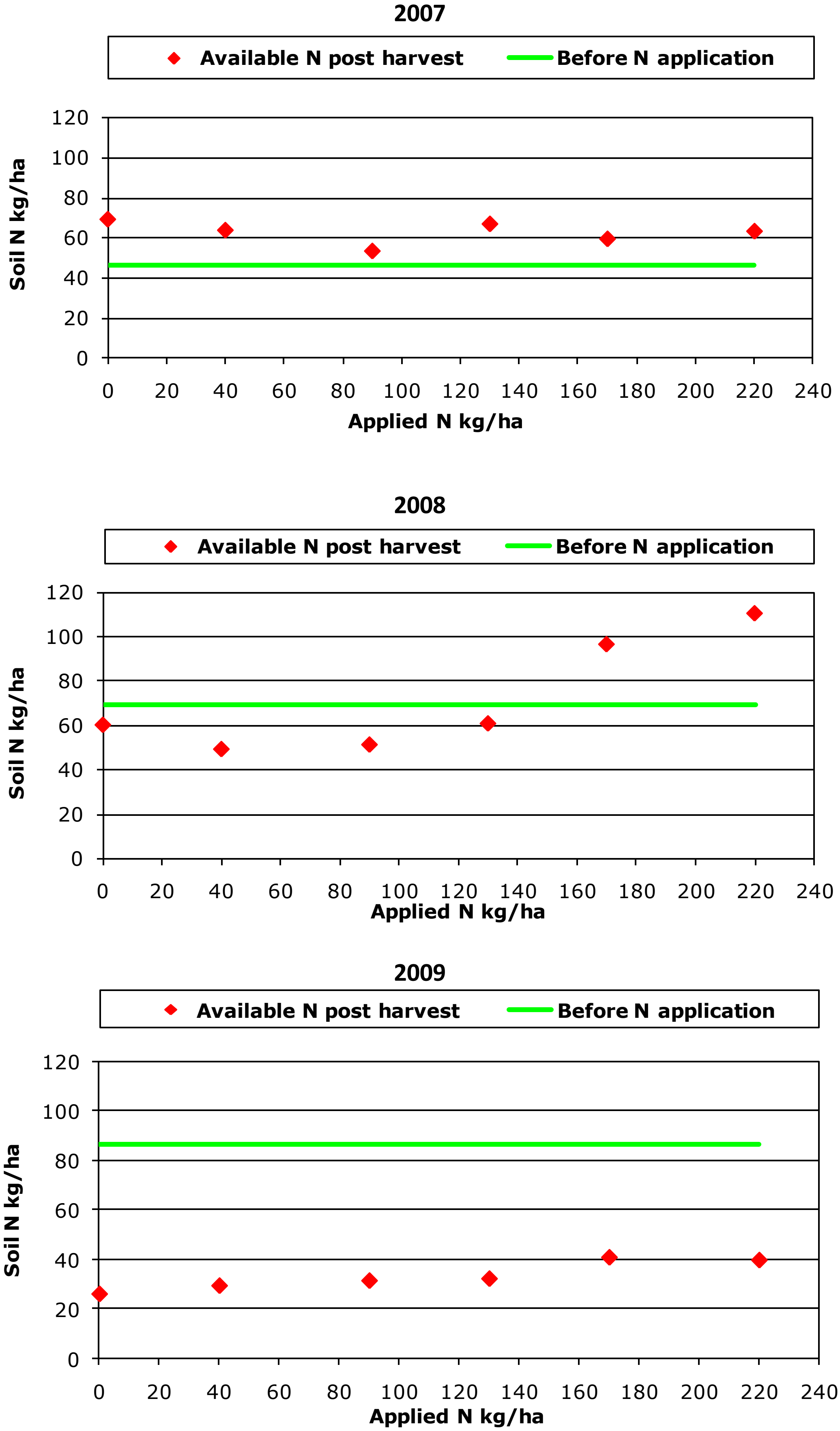


Figure 11. Spring barley trials pre-application Soil nitrogen availability vs. post-harvest availability at all applied nitrogen levels 2007-2009

3.4. Discussion and conclusions

3.4.1. Soil nitrogen survey

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, as explained by Sinclair *et al.* (2002). One further key difference between Scottish and English soils is depth, with Scottish soils tending to be shallower. In practice this means that most soil analysis for soil mineral nitrogen can only be taken up to a depth of 60 cm, rather than the more common 90 cm for English soils. In general terms, measurable soil nitrogen levels in Scottish soils tend to be lower than for English soils (Sinclair *et al.*, 2002).

The sampling of the same fields over a three-year period highlighted the influences of climate on soil available nitrogen. The very wet January of 2008 was possibly a factor in the relatively low mean soil available nitrogen (due to leaching) in the February sampling of that year. There seemed to be less variation in the post-harvest sampling results 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.

The influence of previous cropping on soil available nitrogen was only evident in the February samples. Averaged over three years, there was slightly less soil available nitrogen in February where the previous crop had been oilseed rape or potatoes than where the crop had been cereals. Although this reflected common belief that break crops leave more residual nitrogen in the soil than cereals, there was less than 6 kg N/ha difference between potatoes and cereals as a previous crop. There was a greater differential between oilseed rape and cereals as a previous crop, but even this was less than 10 kg N/ha. This trend was not consistent over the three years of testing. In 2007, where potatoes were the previous crop, the soil available nitrogen was more than 20 kg/ha lower compared to cereals as the previous crop. In the following year (2008) this trend was reversed. In this year, oilseed rape as a break crop left only marginally more soil available nitrogen than cereals.

These findings are at odds with current nitrogen residue groups in Scottish NVZ guidelines. These place cereals as a previous crop in group 1 and oilseed rape and potatoes in group 2 (higher nitrogen residues). It is arguable on the basis of results presented here that there should be no differential between cereals and these other break crops in terms of residue status.

The placement of potatoes in the higher residue group historically relates to the management of potato crops in Scotland in the 1980s and 1990s, where applied nitrogen rates to the crop tended to be significantly higher than they are for modern crops. Also, organic manures, particularly straw-based, were commonly applied to potato ground ahead of planting. This practice largely came to an end with the widespread uptake of de-stoning equipment, and the subsequent impracticalities of employing both practices. Because of this, fertility levels in potato crops (and therefore nitrogen residues available to following crops) have dropped significantly in the past 20 years. This has only partly been recognised with potatoes dropping from residue group 3 to 2 in the latest version of Scottish NVZ guidelines.

There was more consistency in post-harvest results. Soil N values were very similar when comparing oilseed rape and cereals as the previous crop. This contrasted with potatoes, where soil N post-harvest was consistently lower over the survey period. Potatoes utilise less phosphate than that which is applied to the crop. Soluble phosphate levels tend to be higher in the following crops, leading to more vigorous and extensive rooting which in turn may lead to more efficient scavenging of soil nitrogen. There was a clearer effect of soil type on soil available nitrogen. Although the tested soils reflected typical Scottish types (predominantly sandy loams) those with clay content tended to have lower soil available nitrogen. This was particularly so in the post harvest sampling results. This trend was consistent throughout the three-year testing period. As the 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 the higher soil nitrogen levels. The elevated soil available nitrogen post harvest could also be a reflection of slightly 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 project – although this has been the most comprehensive undertaken to date in Scotland. SMN testing carries inherent risk of variability; sampling, storage and carriage of samples, variations in the laboratory analysis, climatic and seasonal variation. Although all samples were handled in the same manner, and sampled by the same laboratory using the same technique, it would be unwise to rely on individual samples to provide an accurate 'snapshot' guide of soil nitrogen status. This survey, together with the previous study by Phillips, *et al*., (2006) which analysed 243 samples, does provide, however, some general features regarding the fertility status of Scottish soils.

3.4.2. Nitrogen response trials

Yield responses to nitrogen tended to be very similar over the three-year period, with a few exceptions. Restricting the selected varieties to no more than two in each crop reduced the potential for variability, and gave continuity over the project period. This was also the case with site/soils selection, where if possible, the same general locations, were used throughout the project period.

The dose response curves were generally a very good statistical fit using the LEXP function, with virtually all the trials having an R^2 figure greater 0.9. The few exceptions were where yield at zero applied nitrogen was exceptionally high, resulting in a very flat response to applied nitrogen (winter wheat, Thornton, 2007), or where lodging at the higher nitrogen rates reduced the yield significantly (spring barley, Kelso, 2007).

In general, the relationship between applied nitrogen and SMN was not strong. The post harvest soil testing indicated no general increase in soil available nitrogen in relation to the stepped increases of applied nitrogen to the crop. In a number of cases the soil available nitrogen in the nil applied nitrogen treatments was just as high as that in the maximum applied nitrogen treatment. 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 a resultant reduction in leaching risk. There was some evidence in limited trials that there was an increase in soil available nitrogen in the highest applied nitrogen treatments.

There was some indication that soil available nitrogen can act as a guide to responsiveness of the growing crop to applied nitrogen. In the case of the wheat trials, the Fife site in 2009 had a very low soil available nitrogen of 16.0 kg/ha when tested in February (the lowest tested figure in any of the trials over the three-year period). The yield from the zero applied nitrogen treatment was also very low at 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 available nitrogen of 91.9 kg/ha – the highest value in the trials series. Both wheat varieties on this site proved 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 inherent knowledge of historical crop performance on different soil types and on different farms remains a very important tool to the grower and advisor in estimating the likely return on investment in applied nitrogen.

The relationship between applied nitrogen and grain N% followed a generally predictable pattern of increasing grain N% 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 (Fife – Sequel/Alchemy/Optic; Kincardine – Sequel/Waggon). In the case of the Fife Alchemy and Optic trials, this may be explained by the highly significant yield response to nitrogen. In both cases there was a highly significant increase in grain yield from nil applied nitrogen to the first incremental application. This would have possibly resulted in a dilution of grain nitrogen.

The values of grain nitrogen as used to help adjust applied nitrogen recommendations for wheat in RB209 could not be properly validated in trials as the samples from 2008 harvest were too badly sprouted to be analysed. It is worth noting, however, that none of the wheat samples tested from 2007 and 2009 exceeded 2% nitrogen. This was also the case with both winter and spring barley samples, where the majority were below 2% nitrogen.

In this series of replicated trials optimum nitrogen tended to exceed current Scottish NVZ Nmax. In 27 of the 39 trials optimum nitrogen was in excess of the relevant Nmax (180kg/ha for winter barley, 190kg/ha for winter wheat, 130kg/ha for spring barley). These Nmax figures relate to sandy loam or other mineral soils in nitrogen residue group 1 for barley, and residue group 2 for winter wheat, which is relevant to the soil types and rotational position of the trials.

This project has pointed to 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%. It is therefore unusual to grow the crop with more than the current Nmax of 130kg/ha, as this would have a high probability of producing grain nitrogen above the target for this quality sector.

3.5. Recommendations

- Arable soil fertility levels have changed significantly in the past 30 years, and there is likely to be less risk of nitrate leaching from arable cropping rotations because of this and because of overall reduction in inorganic nitrogen use in that period. The soil survey suggested that inter-crop soil nitrogen levels are moderate to low – particularly in situations where no organic manures are used. The results from this project may be helpful in adding to the existing understanding and prediction of soil nitrogen supply – particularly in context to Scottish soils. It would be useful to continue to monitor some of the existing arable soils analysed in this project.
- The current nitrogen residue groups places cereals in group 1, and potatoes and oilseed rape in group 2. The soil sampling undertaken in the project indicates no major differences in soil nitrogen residues left following cereals or potatoes, and only marginal increases from oilseed rape previous cropping. It would be useful to continue this testing and encompass soils where other previous crops were involved (e.g. legumes, grass), with a view to potentially re-classifying the current residue groups.
- The restriction of the amount of inorganic nitrogen allowed under NVZ guidelines is potentially highly significant in terms of restricting profitable crop production. NVZ guidelines are designed to balance environmental and economic priorities. On the basis of this project and previous soil surveys (Phillips, *et al*., 2006), there is no compelling data to support the belief that current Scottish arable cropping practices are causing excessive 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 so 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.

3.6. References

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APPENDIX

Site Details

SPRING BARLEY – AGRONOMY SITE DETAILS 2007

	South	**Central**	**Tipperty**
Location	Manorhill Farm Makerstoun Kelso	Skeddoway Thornton Fife	Tipperty Farm Tarsets Ellon
Grid Reference	NT 660 316	NT 251 981	NJ 984 284
Elevation	88 meters	67 meters	40 meters
Soil Type	SL	SL	SL
Drilling Date	20/03/2007	22/03/2007	28/03/2007
Seed Rate	400 seeds/m^2	400 seeds/m^2	400 seeds/m^2
Previous Crop	W Wheat	W Wheat	S Barley
Fertiliser Seedbed NPKS	6:26:0 kg/ha 20/03/2007 0:40:60:2 kg/ha 04/04/2007	6:26:0 kg/ha 22/03/2007 0:40:60:2 kg/ha 28/03/2007	6:26:0 kg/ha 28/03/2007 0:40:60:2 kg/ha 05/04/2007
Herbicides	Ally Max 0.025 kg/ha 30/04/2007 Prompt 1.0 l/ha 15/05/2007	Harmony M SX 0.07 kg/ha 02/05/2007 Prompt 1.0 l/ha 14/05/2007	Harmony M SX 0.07 kg/ha 01/05/2007 Prompt 1.0 l/ha 24/05/2007
Insecticides	Hallmark Zeon 0.05 l/ha 06/06/2007	Hallmark Zeon 0.05 l/ha 07/06/2007	Hallmark Zeon 0.05 l/ha 14/06/2007
Trace Elements	Mn DF 3.0 kg/ha 30/04/2007 Mantrac 500 1.0 l/ha 15/05/2007 -	Mn SO_4 2.0 kg/ha 16/04/2007 Mn SO_4 3.0 kg/ha 02/05/2007 Mantrac 500 1.0 l/ha 14/05/2007	Mn SO_4 3.0 kg/ha 24/04/2007 Mantrac 500 1.0 l/ha 24/05/2007 -
Harvested	24/08/2007	23/08/2007	07/09/2007
Trial Type	Randomised Small Plots		

SPRING BARLEY – AGRONOMY SITE DETAILS 2008

	South	Central	Tipperty
Location	Manorhill Farm Makerstoun Kelso	Skeddoway Thornton Fife	Tipperty Farm Tarsets Ellon
Grid Reference	NT 712 312	NT 245 988	NJ 982 282
Elevation	106 meters	70 meters	41 meters
Soil Type	SL	SL	SL
Drilling Date	03/04/2008	27/03/2008	21/04/2008
Seed Rate	400 seeds/m^2	400 seeds/m^2	400 seeds/m^2
Previous Crop	W Wheat	S Oats	S Barley
Fertiliser Seedbed NPKS	6:26:0 kg/ha 03/04/2008 0:40:60:2 kg/ha 08/04/2008	6:26:0 kg/ha 27/03/2008 0:40:60:2 kg/ha 31/03/2008	6:26:0 kg/ha 21/04/2008 -
Herbicides	Ally Max 0.025 kg/ha 08/05/2008 Prompt 1.0 l/ha 21/05/2008 -	Harmony M SX 0.07 kg/ha 05/05/2008 Prompt 1.0 l/ha 20/05/2008 -	Harmony M SX 0.07 kg/ha 16/05/2008 Prompt 1.0 l/ha 02/06/2008 Axial 0.3 l/ha & Adigor 1% 24/06/2008
Insecticides	Hallmark Zeon 0.05 l/ha 16/06/2008	Hallmark Zeon 0.05 l/ha 12/06/2008	Hallmark Zeon 0.05 l/ha 24/06/2008
Trace Elements	Mn DF 3.0 kg/ha 08/05/2008 Mantrac 500 1.0 l/ha 21/05/2008	Mn DF 3.0 kg/ha 05/05/2008 Maple DF Mn 2.0 kg/ha 20/05/2008	Mn DF 3.0 kg/ha 16/05/2008 Mantrac 500 1.0 l/ha 02/06/2008
Desiccated		Roundup 360 3.0 l/ha 14/08/2008	
Harvested	12/09/2008	29/08/2008	10/09/2008
Trial Type	Randomised Small Plots		

SPRING BARLEY – AGRONOMY SITE DETAILS 2009

	South	Central	North
Location	Clintmains Farm St Boswells Roxburghshire	South Parks of Balgonie Coaltown of Balgonie Glenrothes	Coldstream Farm Laurencekirk Kincardineshire
Grid Reference	NT 606 329	NT 311 993	NO 668 727
Elevation	93m	60m	69m
Soil Type	SL	SL	SL
Drilling Date	18/03/2009	20/03/2009	25/03/2009
Seed Rate	400 seeds/m^2	400 seeds/m^2	400 seeds/m^2
Previous Crop	W Wheat	Potatoes	W Oats
Fertiliser Seedbed NPKS	6:26:0 kg/ha 18/03/2009 0:40:60:2 kg/ha 02/04/2009	6:26:0 kg/ha 20/03/2009 0:40:60:2 kg/ha 01/04/2009	6:26:0 kg/ha 25/03/2009 0:40:60:2 kg/ha 03/04/2009
Herbicides	Ally Max 0.025 kg/ha 28/04/2009 Prompt 1.0 l/ha 12/05/2009	Harmony M SX 0.07 kg/ha 02/05/2009 Prompt 1.0 l/ha 11/05/2009 Starane 2 0.5 l/ha 01/06/2009	Harmony M SX 0.07 kg/ha 02/05/2009 Prompt 1.0 l/ha 20/05/2009
Insecticides	Hallmark Zeon 0.05 l/ha 22/06/2009	Hallmark Zeon 0.05 l/ha 16/06/2009	Hallmark Zeon 0.05 l/ha 23/06/2009
Trace Elements	Mn DF 3.0 kg/ha 28/04/2009 Mn DF 1.0 l/ha 12/05/2009	Mn DF 3.0 kg/ha 02/05/2009 Mn DF 1.0 l/ha 11/05/2009	Mn DF 3.0 kg/ha 02/05/2009 Mn Liquid 1.0 l/ha 20/05/2009
Desiccated			Gallup 360 4.0 l/ha 24/08/2009
Harvested	25/08/2009	22/08/2009	12/09/2009
Trial Type	Randomised Small Plots		

WINTER WHEAT – AGRONOMY SITE DETAILS 2006-2007

	South	**Central**
Location	Ploughlands St. Boswells Roxburgshire	Skeddoway Thornton Fife
Grid Reference	NT 627 322	NT 260 978
Elevation	83 meters	70 meters
Soil Type	SL	SL
Drilling Date	11/10/2006	07/10/2006
Seed Rate	400 seeds/m^2	400 seeds/m^2
Previous Crop	Potatoes	WOSR
Fertiliser NPKS (kg/ha)	50:17:17:6.7 kg/ha 08/03/2007	50:17:17:6.7 kg/ha 19/02/2007
Herbicides	Javelin Gold 2.0 l/ha Treflan 1.0 l/ha 07/11/2006 Starane XL 1.0 l 17/05/2007 -	Flight 3.0 l/ha IPU 1.0 l/ha 06/11/2006 Starane XL 1.0 l 18/04/2007 Grasp 1.4 l 02/05/2007
Insecticides	Mavrik 0.15 l/ha 07/11/2006 Hallmark Zeon 0.05 l/ha 06/06/2007	Mavrik 0.15 l/ha 06/11/2006 Hallmark Zeon 0.05 l/ha 07/06/2007
Molluscicides	Lupus Wetex 5.0 kg/ha 07/11/2006	Lupus Wetex 5.0 kg/ha 06/11/2006
Trace Elements	Mn Liquid 3.0 l/ha 07/11/2006 Mn Liquid 3.0 l/ha 04/04/2007	Mn DF 1.0 kg/ha 06/11/2006 Mn DF 1.5 kg/ha 31/03/2007
Desiccated		Roundup 4.0 l/ha 26/08/2007
Harvested	29/08/2007	04/09/2007
Trial Type	Randomised Small Plots	

WINTER WHEAT – AGRONOMY SITE DETAILS 2007-2008

	South	**Central**
Location	Ploughlands St. Boswells Roxburgshire	Skeddoway Thornton Fife
Grid Reference	NT 638 325	NT 265 977
Elevation	81 metres	70 metres
Soil Type	SL	SL
Drilling Date	16/10/2007	03/10/2007
Seed Rate	400 seeds/m^2	400 seeds/m^2
Previous Crop	Potatoes	WOSR
Herbicides	Pico 2.0 l/ha IPU 1.0 l/ha 22/10/2007 Starane XL 1.0 l 08/05/2008	Hurricane 0.1 l/ha IPU 1.5 l/ha Treflan 1.25 l/ha 19/10/2007 Starane XL 1.0 l Axial 0.3 l Adigor 1% 01/05/2008 CMPP 1.0 l 05/05/2008
Insecticides	Hallmark Zeon 25 ml/ha 22/10/2007 Hallmark Zeon 25 ml/ha 16/11/2007 Hallmark Zeon 50 ml/ha 16/06/2008	Hallmark Zeon 25 ml/ha 19/10/2007 Hallmark Zeon 25 ml/ha 15/11/2007 Hallmark Zeon 50 ml/ha 20/06/2008
Molluscicides	Hyde 5.0 kg/ha 19/10/2007 Hyde 5.0 kg/ha 16/11/2007	Hyde 5.0 kg/ha 19/10/2007 Hyde 5.0 kg/ha 06/11/2007
Trace Elements	Mn DF 3.0 kg/ha 16/11/2007 Mn Liquid 3.0 l/ha 15/04/2008	Mn DF 3.0 kg/ha 15/11/2007 Mn SO_4 4.0 kg/ha 14/03/2008
Harvested	23/09/2008	08/09/2008
Trial Type	Randomised Small Plots	

WINTER WHEAT – AGRONOMY SITE DETAILS 2008-2009

	South	Central
Location	Broomhall Farm St Boswells Roxburghshire	South Parks of Balgonie Coaltown of Balgonie nr. Glenrothes
Grid Reference	NT 609 309	NT 307 996
Elevation	63 metres	68 metres
Soil Type	SL	SL
Drilling Date	22/10/2008	13/10/2008
Seed Rate	400 seeds/m^2	400 seeds/m^2
Previous Crop	Potatoes	W Oats
Fertiliser NPKS (kg/ha)	0:40:60 kg/ha 02/04/2009	0:40:60 kg/ha 01/04/2009
Herbicides	Picona 2.0 l/ha Defy 2.0 l/ha 26/11/2008 Starane XL 1.0 l/ha 12/05/2009	Othello 1.0 l/ha Biopower 1.0 l/ha 25/11/2008 Starane 0.75 l/ha 11/05/2009
Insecticides	Hallmark Zeon 25 ml/ha 26/11/2008 Hallmark Zeon 50 ml/ha 22/06/2009	Hallmark Zeon 25 ml/ha 25/11/2008 Hallmark Zeon 50 ml/ha 16/06/2009
Molluscicides	Jeckyll 7.5 kg/ha 22/10/2008 Jeckyll 8.3 kg/ha 18/11/2008	Karan 5.0 kg/ha 13/10/2008 Jeckyll 8.3 kg/ha 18/11/2008
Trace Elements	Mn Liquid 1.0 l/ha 26/11/2008 Mn DF 2.0 kg/ha 02/04/2009	Mn Liquid 1.0 l/ha 25/11/2008 Mn SO_4 4.0 kg/ha Mid April
Desiccated	Gallup 360 4.0 l/ha 13/08/2009	Gallup 360 4.0 l/ha 24/08/2009
Harvested	03/09/2009	10/09/2009
Trial Type	Randomised Small Plots	

WINTER BARLEY – AGRONOMY SITE DETAILS 2006-2007

	South	Central	North
Location	Ploughlands St. Boswells Roxburgshire	Skeddoway Thornton Fife	Tipperty Farms Tarsets Ellon
Grid Reference	NT 643 332	NT 255 979	NJ 958 274
Elevation	98 meters	72 meters	45 meters
Soil Type	SL	SL	SL
Drilling Date	26/09/2006	28/09/2006	22/09/2006
Seed Rate	400 seeds/m^2	400 seeds/m^2	400 seeds/m^2
Previous Crop	W Wheat	WOSR	W Wheat
Fertiliser Seedbed NPKS	0:8:8:3 kg/ha 16/10/2006	0:8:8:3 kg/ha 10/10/2006	0:8:8:3 kg/ha 13/10/2006
Herbicides	Panther 1.0 l/ha & IPU 500 1.0 l/ha 07/11/2006 Starane XL 1.0 l/ha 17/04/2007	Flight 3.0 l/ha & IPU 500 1.0 l/ha 06/11/2006 Starane XL 1.0 l/ha 16/04/2007	Flight 3.0 l/ha & IPU 500 1.0 l/ha 03/11/2006 Starane XL 1.0 l/ha 21/04/2007
Insecticides	Mavrik 0.15 l/ha 07/11/2006	Mavrik 0.15 l/ha 06/11/2006	Mavrik 0.15 l/ha 03/11/2006
Trace Elements	Mn Liquid 3.0 l/ha 07/11/2006 Mn Liquid 3.0 l/ha 04/04/2007	Mn DF 1.0 kg/ha 06/11/2006 Mn DF 1.5 kg/ha 31/03/2007	Mn Liquid 3.0 l/ha 03/11/2006 Mn Liquid 3.0 l/ha 05/04/2007
Molluscicides	Lupus Wetex 5.0 kg/ha 07/11/2006	-	Lupus Wetex 5.0 kg/ha 03/11/2006
Desiccated	Gallup Hi-Active 2.9 l/ha 13/07/2007	Roundup 4.0 l/ha 17/07/2007	Roundup Gold 3.2 l/ha 27/07/2007
Harvested	24/07/2007	30/07/2007	08/08/2007
Trial Type	Randomised Small Plots		

WINTER BARLEY – AGRONOMY SITE DETAILS 2007-2008

	South	Central	North
Location	Ploughlands St. Boswells Roxburghshire	Skeddoway Thornton Fife	Tipperty Farms Tarsets Ellon
Grid Reference	NT 631 323	NT 264 977	NJ 964 274
Elevation	80 metres	68 metres	40 metres
Soil Type	SL	SL	SL
Drilling Date	27/09/2007	26/09/2007	02/10/2007
Seed Rate	400 seeds/m^2	400 seeds/m^2	400 seeds/m^2
Previous Crop	W Wheat	W OSR	W Barley
Fertiliser Seedbed NPKS	0:8:8:3 kg/ha 19/10/2007	0:8:8:3 kg/ha 18/10/2007	0:8:8:3 kg/ha 18/10/2007
Herbicides	Hurricane 0.1 l/ha, IPU 1.5 l/ha & Treflan 1.25 l/ha 22/10/2007 Starane XL 1.0 l/ha 02/05/2008	Hurricane 0.1 l/ha, IPU 1.5 l/ha & Treflan 1.25 l/ha 19/10/2007 Starane XL 1.0 l/ha 25/04/2008 Axial 0.3 l/ha Adigor 1% Starane XL 1.0 l/ha 05/05/2008	Hurricane 0.1 l/ha, IPU 1.5 l/ha & Treflan 1.25 l/ha 23/10/2007 Harmony M SX 0.07 kg/ha 16/05/2008
Insecticides	Hallmark Zeon 25 ml/ha 22/10/2007 Hallmark Zeon 25 ml/ha 16/11/2007	Hallmark Zeon 25 ml/ha 19/10/2007 Hallmark Zeon 25 ml/ha 06/11/2007	Hallmark Zeon 25 ml/ha 23/10/2007 Hallmark Zeon 25 ml/ha 12/11/2007
Trace Elements	Mn DF 3.0 kg/ha 16/11/2007 Mn Liquid 3.0 l/ha 17/03/2008	Mn DF 3.0 kg/ha 06/11/2007 Mn SO_4 4.0 kg/ha 14/03/2008	Mn Liquid 3.0 l/ha 12/11/2007 Mn Liquid 3.0 l/ha 03/04/2008 Mn DF 3.0 kg/ha 16/05/2008
Molluscicides	Hyde 5.0 kg/ha 19/10/2007 Hyde 5.0 kg/ha 16/11/2007	Hyde 5.0 kg/ha 19/10/2007 Hyde 5.0 kg/ha 06/11/2007	Hyde 5.0 kg/ha 23/10/2007 Hyde 5.0 kg/ha 12/11/2007
Desiccated	Gallup 360 3.0 l/ha 21/07/2008	Gallup 360 3.0 l/ha 23/07/2008	Gallup 360 4.0 l/ha 28/07/2008
Harvested	24 & 25/07/2008	27 & 30/08/2008	13 & 14/08/2008
Trial Type	Randomised Small Plots		

WINTER BARLEY – AGRONOMY SITE DETAILS 2008-2009

	South	Central	North
Location	Broomhall Farm St Boswells Roxburghshire	South Parks of Balgonie Coaltown of Balgonie nr. Glenrothes	Coldstream Farm Laurencekirk Kincardineshire
Grid Reference	NT 613 312	NT 307 996	NO 668 727
Elevation	71 metres	68 metres	69 metres
Soil Type	SL	SL	SL
Drilling Date	09/10/2008	06/10/2008	03/10/2008
Seed Rate	400 seeds/m^2	400 seeds/m^2	400 seeds/m^2
Previous Crop	W Barley	W Oats	W Oats
Fertiliser **Seedbed NPKS** **Spring NPKS (kg/ha)**	 0:8:8:3 kg/ha 17/10/2008 0:40:60 kg/ha 02/04/2009	 0:8:8:3 kg/ha 29/10/2008 0:40:60 kg/ha 01/04/2009	 0:8:8:3 kg/ha 16/10/2008 0:40:60 kg/ha 03/04/2009
Herbicides	Picona 2.0 l/ha Defy 2.0 l/ha 26/11/2008 Starane XL 1.0 l/ha 28/04/2009	Picona 2.0 l/ha Defy 2.0 l/ha 04/11/2008 Starane XL 1.0 l/ha 22/04/2009	Picona 2.0 l/ha Defy 2.0 l/ha 04/11/2008 Starane XL 1.0 l/ha 29/04/2009
Insecticides	Hallmark Zeon 25 ml/ha 26/11/2008	Hallmark Zeon 25 ml/ha 04/11/2008	Hallmark Zeon 50 ml/ha 04/11/2008
Trace Elements	Mn Liquid 1.0 l/ha 26/11/2008 Mn Liquid 3.0 l/ha 02/04/2009	Mn Liquid 1.0 l/ha 04/11/2008 Mn Liquid 3.0 l/ha 01/04/2009	Mn Liquid 1.0 l/ha 04/11/2008 Mn DF 2.0 l/ha 03/04/2009
Molluscicides	Jeckyll 7.5 kg/ha 22/10/2008 -	Karan 5.0 kg/ha 06/10/2008 Jeckyll 8.3 kg/ha 18/11/2008	Karan 5.0 kg/ha 03/10/2008 -
Desiccated	Hoedown 4.0 l/ha 16/07/2009	Gallup 360 3.0 l/ha 25/07/2009	Gallup 360 4.0 l/ha 27/07/2009
Harvested	28/07/2009	03 & 05/08/2009	06/08/2009
Trial Type	Randomised Small Plots		

Soil Sampling Details

Soil nitrogen Min Analysis 2007

Farm	Nearest Settlement	County	Soil Type	Previous Cropping	Spring 2007 Av nitrogen (0-60cm) (kg/ha)	Autumn 2007 Av nitrogen (0-60cm) (kg/ha)
Mawcarse	Milnathort	Kinrosshire	SL	WB	83.1	135.6
Mawcarse	Milnathort	Kinrosshire	SL	WW	67.6	85.0
Balado	Kinross	Kinrosshire	SL	SB	87.4	81.0
Kirkton	Culross	Fife	SL	WW	109.1	53.0
Skeddoway	Thornton	Fife	SCL	WW	54.6	40.6
Ferrymuir	Cupar	Fife	SL	SB	74.5	67.8
Westfield	Haddington	E Lothian	SCL	WW	30.3	28.4
Westfield	Haddington	E Lothian	SCL	WW	16.7	28.1
Manorhill	Kelso	Roxburghshire	SCL	Oats	22.9	42.2
Magdelane Hall	St Boswells	Roxburghshire	ZC	WB	24.0	24.7
Tipperty	Ellon	Aberdeenshire	SL	SB	89.0	58.9
Tipperty	Ellon	Aberdeenshire	SL	SB	62.5	100.7
Mains of Auchreddie	Ellon	Aberdeenshire	SL	WB	40.2	29.0
Balado	Kinross	Kinrosshire	ZL	WOSR	53.7	35.2
Balado	Kinross	Kinrosshire	ZL	WOSR	57.7	109.6
Skeddoway	Thornton	Fife	SL	WOSR	91.9	55.6
Skeddoway	Thornton	Fife	SCL	WOSR	22.6	23.0
Windywalls	Kelso	Roxburghshire	SL	WOSR	67.7	34.2
Roxburgh Newtown	Kelso	Roxburghshire	SCL	WOSR	91.8	66.1
Skeddoway	Thornton	Fife	SL	Potatoes	50.3	32.4
Ferrymuir	Cupar	Fife	SL	Potatoes	41.4	30.1
Windywalls	Kelso	Roxburghshire	SCL	Potatoes	23.9	24.7
Whitehouse	St Boswells	Roxburghshire	ZCL	Potatoes	38.9	37.0
Mawcarse	Milnathort	Kinrosshire	SL	Beans	71.0	44.0
Windywalls	Kelso	Roxburghshire	SCL	Vining Peas	38.4	14.2
Roxburgh Newtown	Kelso	Roxburghshire	SL	Peas	53.5	42.0

Soil nitrogen Min Analysis 2008

Farm	Nearest Settlement	County	Soil Type	Previous cropping	Spring 2008 Available nitrogen (kg/ha)	Autumn 2008 Available nitrogen (kg/ha)
Mawcarse	Milnathort	Kinrossshire	SCL	WW	55.5	81.2
Mawcarse	Milnathort	Kinrossshire	SCL	WW	39.9	62.4
Balado	Kinross	Kinrossshire	SCL	WW	24.9	81.3
Balado	Kinross	Kinrossshire	SL	WB	55.3	106
Balado	Kinross	Kinrossshire	SL	Set-Aside	43	84.2
Kirkton	Culross	Fife	SCL	Set-Aside	22	36
Skeddoway	Thornton	Fife	SCL	WW	17.7	30
Skeddoway	Thornton	Fife	SCL	SO	0	44.2
Skeddoway	Thornton	Fife	SCL	WOSR	37.5	100.2
Skeddoway	Thornton	Fife	SCL	WOSR	32.4	41.8
Perrymuir	Cupar	Fife	SCL	SB	32.8	24.1
Perrymuir	Cupar	Fife	SCL	Potatoes	51.3	33.2
Westfield	Haddington	East Lothian	SCL	WB	23.2	36.8
Westfield	Haddington	East Lothian	SCL	WB	24.3	22.2
Windywalls	Kelso	Roxburghshire	SCL	WW	18.6	38.4
Windywalls	Kelso	Roxburghshire	SCL	WW	23	38.5
Windywalls	Kelso	Roxburghshire	SCL	WW	12.6	42.1
Roxburgh Newton	Kelso	Roxburghshire	SCL	WW	42.4	63.2
Roxburgh Newton	Kelso	Roxburghshire	SL	WW	49.6	171
Ploughlands	St Boswells	Roxburghshire	ZCL	Potatoes	75	59.1
Magdalane Hall	St Boswells	Roxburghshire	SCL	WW	28.4	71.1
Tipperty	Ellon	Aberdeenshire	SCL	WB	49.8	80.8
Tipperty	Ellon	Aberdeenshire	SCL	WOSR	37.4	95.4
Mains of Auchreddie	Ellon	Aberdeenshire	SCL	WB	52.7	139.7
Mains of Auchreddie	Ellon	Aberdeenshire	SL	WW	29.7	184.6
Dunecht	Dunecht	Aberdeenshire	SL	SB	40.9	56.6
Dunecht	Dunecht	Aberdeenshire	SL	Potatoes	22.5	57
Gospetry	Kinross	Kinrossshire	SL	Peas	65.3	33.3

Soil nitrogen Min Analysis 2009

Farm	Nearest Settlement	County	Soil Type	Previous cropping	Spring 2009 Available nitrogen (kg/ha)	Autumn 2009 Available nitrogen (kg/ha)
Mawcarse	Milnathort	Kinrossshire	SL	WB	67.7	103.3
Mawcarse	Milnathort	Kinrossshire	SL	Potatoes	83.1	61.4
Mawcarse	Milnathort	Kinrossshire	SL	SB	50.4	124.1
Balado	Kinross	Kinrossshire	SCL	Potatoes	113.9	36.9
Balado	Kinross	Kinrossshire	SL	WOSR	42.1	120.7
Kirkton	Kincardine	Fife	SL	WW	28.9	37.2
Skeddoway	Thornton	Fife	SL	SO	47.9	100.4
South Parks	Coaltown of Balgonie	Fife	SCL	Potatoes	75.3	49.7
South Parks	Coaltown of Balgonie	Fife	SCL	WO	16.0	21.9
South Parks	Coaltown of Balgonie	Fife	SCL	WO	20.0	30.7
Ferrymuir	Cupar	Fife	SL	SB	22.2	50.5
Ferrymuir	Cupar	Fife	SL	SB	42.3	95.9
Westfield	Haddington	East Lothian	SL	WOSR	41.7	38.2
Westfield	Haddington	East Lothian	SCL	WOSR	30.3	39.5
Clintmains	St Boswells	Roxburghshire	SCL	WW	75.5	27.1
Windywalls	Kelso	Roxburghshire	SCL	WB	24.2	44.3
Windywalls	Kelso	Roxburghshire	SL	SB	24.0	45.2
Windywalls	Kelso	Roxburghshire	SCL	SB	18.0	75.4
Roxburgh Newton	Kelso	Roxburghshire	SL	SB	35.0	44.5
Roxburgh Newton	Kelso	Roxburghshire	SL	WB	23.2	44.1
Broomhall	St Boswells	Roxburghshire	SCL	Potatoes	30.7	21.4
Broomhall	St Boswells	Roxburghshire	SCL	WB	43.4	108.6
Coldstream	Laurencekirk	Kincardineshire	SCL	WO	25.9	44.8
Coldstream	Laurencekirk	Kincardineshire	SCL	WO	27.2	81.9
Coldstream	Laurencekirk	Kincardineshire	SCL	WO	107.9	33.6
Mains of Auchreddie	Ellon	Aberdeenshire	SL	WB	41.8	117
Mains of Auchreddie	Ellon	Aberdeenshire	SL	WOSR	148.5	81.8
Dunecht	Dunecht	Aberdeenshire	LS	WB	126.0	133.6
Dunecht	Dunecht	Aberdeenshire	SL	Potatoes	35.8	12.7
Dunecht	Dunecht	Aberdeenshire	LS	WB	48.5	97.1
South Parks	Coaltown of Balgonie	Fife	SCL	WW	73.2	63.1