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Science Partners:	IACR-Rothamsted HRI Wellesbourne IACR-Broom's Barn
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PRACTICAL SECTION FOR GROWERS

Background

Why do we need models? A significant barrier to more efficient use of nitrogen fertiliser by arable farmers and horticultural growers is the lack of information on seasonal, soil-related and cultural variations in the supply of mineral nitrogen by the soil and the requirements for nutrients by the crop. Researchers have identified many processes of nitrogen transformation and the controls exerted by climate and soil conditions. Models provide a tool for making practical use of this huge body of information and could be of enormous value in providing fertiliser recommendations and planning crop rotations on working farms.

Which model? There are essentially two types of model: static and dynamic. Static models are a one stage calculation which takes no account of progress of the soil/crop system with time. By contrast, dynamic models recalculate the state of the soil/crop system throughout the simulation, according to specific climate and soil conditions. Most currently available fertiliser recommendation systems use static models: These include MAFF Reference Book 209; the ADAS system, FERTIPLAN; and NCYCLE, the system developed at IGER-North Wyke for grassland. Because a dynamic model is able to respond to changes in climatic and soil conditions, the new generation of fertiliser recommendation systems may be based on dynamic models: WELL_N, developed at HRI-Wellesbourne, and SUNDIAL-FRS, developed at IACR Rothamsted are two such models.

How do dynamic fertiliser recommendation systems work? The calculated crop nitrogen offtake and nitrate leaching are used by the fertiliser recommendation system to determine a fertiliser recommendation that minimises nitrate losses whilst maintaining crop productivity. The WELL_N and SUNDIAL-FRS models use different approaches to calculate the values needed according to specified crop management, soil and weather conditions. Both models include a description of all major processes of nitrogen turnover in the soil/crop system. Inputs are by fertiliser applications and atmospheric deposition. Available soil nitrogen is taken up by the growing crop, and returned to the soil as crop debris. Crop debris decomposes and either releases or uses up available nitrogen. Nitrogen may be lost from the soil by leaching, denitrification or volatilisation. SUNDIAL-FRS includes a detailed description of soil organic matter decomposition and allows inputs by organic manures. The WELL_N model incorporates a more concise description of the soil, but a more detailed simulation of crop growth. It includes many simple widely applicable relationships for calculating N demand of the crop, amount of N taken up and its partitioning within the plant, automatically adjusting the results for changes in the amount and distribution of mineral N available to a crop.

Because the 2 models have been developed along separate, but parallel lines, there are great potential benefits from combining the models into a single package. The objectives of this project were

- to develop a fertiliser recommendation system based on the SUNDIAL-FRS and WELL_N models; and
- to establish field trials on working farms across the UK to test how well the fertiliser recommendation system works.

Development of Nitrogen-FRS

Nitrogen-FRS - Two dynamic N turnover models, SUNDIAL-FRS and WELL_N have been combined in a single package with a static model based on MAFF Reference Book 209 (MAFF, 1994). The package, referred to in this report as “Nitrogen-FRS”, allows the user to manually select the model, but also has the potential to automatically set the optimum model for use under particular field conditions. The system is Windows based and fully supported by default values, allowing simulations to be run quickly and easily with minimum requirement for user inputs. If more season and site specific data on crop management, soil description, weather data or manure inputs are entered, the dynamic models have the potential to provide season and site specific N fertiliser recommendations. The system provides further support for planning N use by presenting balance sheets, graphical plots and flow charts showing changes in the N status of the soil/crop system over time. Weather data can be entered manually or default weather is provided for SUNDIAL-FRS by an in-built weather generator. Development of a weather generator to provide default weather data for WELL_N requires further funding. It is envisaged that the system will be made available both as a standalone and a DESSAC compatible version. This is essential if the system is to make use of the additional functionality of DESSAC, while remaining accessible to DESSAC and non-DESSAC users.

Database of Measurements - In order to evaluate the likely accuracy of the fertiliser recommendations and simulations of N turnover on working farms, and to identify which model should be used to simulate a particular crop, field trials were run over 2 seasons on 37 sites across the UK with a range of arable and horticultural crops. Spring and harvest soil mineral N was measured at 0-30cm, 30-60cm and 60-90cm. Whole crops were sampled at harvest and analysed for N content. A database was constructed to store the descriptions and results of the field trials, and make it readily available for future use. This was designed with a hierarchical structure, starting with site identifiers (name of farmer etc.) expanding to general site data (e.g. location, soil type and previous husbandry details), and further to incorporate data which varies over time, and finally to data collected from each experimental plot.

Nitrogen Response -These trials were planned to evaluate the performance of the SUNDIAL-FRS and WELL_N fertiliser recommendation systems. In practice, they have told us more about nitrogen response on working farms than about the functioning of the models. No response to nitrogen application was observed in 14 trials out of a total of 64. This was partly because inappropriate sites were not excluded in advance, despite laying down clear site selection criteria. At sites 9/99, 15/98 and 15/99 this was due to applications of manure, in which case an optimum of zero is quite reasonable. Other sites (19/99 and 2/98) received inadvertent applications of fertiliser N. Nitrogen uptake, where no fertiliser was applied, varied from 21 to 266 kg N ha^{-1}, reflecting inherent differences in the fertility of the soil and the period and duration of crop growth. Surprisingly there was no significant relationship between spring soil mineral nitrogen and crop nitrogen uptake on zero plots, even when only the combinable crops or winter wheat alone were included. This suggests that soil characteristics more closely related to soil nitrogen supply, such as soil organic nitrogen, may be important input data. The optimum nitrogen fertiliser application (with an estimate of its 95% confidence interval) could be determined from a linear plus exponential relationship, for only 36% (23) of the trials. In nine trials no optimum could be fitted, possibly because the optimum was below the range of N rates used. In some cases, this may be due to high levels of fertiliser N and manure being used on commercial farms in previous years, where maximum productivity is paramount. It indicates an inefficient system that may be detrimental to the environment. It is particularly difficult to evaluate the performance of the models on these sites where an optimum N rate cannot be established (the optimum is zero if there is no response to N).

Shortage of Data - The models have been run assuming default soil conditions and using a maximum of five years of cropping history at the arable sites, and often only one or two years of cropping history at the horticultural sites. These limited data inputs cannot account for the changes in soil nitrogen supply that occur under a long-term high nitrogen input regime. This problem affects dynamic fertiliser recommendation systems using minimal input data in the same way as it affects static systems such as RB209. The effect is likely to be experienced by a large proportion of farmers attempting to achieve maximum productivity. High nitrogen input regimes can only be adequately described using a dynamic simulation model, driven by a suite of field diagnostics or using field records of more than 10 years. Where farmers do not have adequate long-term records, further work to develop field diagnostic measurements that can be used to drive models will be essential for future improvements in precision.

Spatial Variability – In some trials, the difficulty in determining an optimum nitrogen application rate appears to be due to spatial variability in the field. Spatial variability is an inevitable feature at some sites due to factors such as field history, underlying soil type, drainage conditions and field gradient. Methods for accounting for spatial variability in fertiliser recommendation are urgently needed. This could be done by driving the model using measures of the previous years yield combined with remotely sensed field diagnostics. In the longer term, a model including lateral movement of nitrogen due to the gradient may be beneficial. At some sites, increased precision in fertiliser applications will only be possible by developing advanced methods to describe the spatial variability of the soil.

Evaluation of Models - Evaluation at both the vegetable and arable sites indicated that the fertiliser recommendations from SUNDIAL-FRS, WELL_N and RB209 resulted in similar crop yields. However, both WELL_N and SUNDIAL-FRS gave more accurate recommendations than RB209 or farm practice, thereby reducing fertiliser costs and wastage to the potential benefit of the environment. Using spring SMN measurements as diagnostics did not generally improve the recommendations in SUNDIAL-FRS, and was of little benefit in terms of yield. Further work is needed to develop the use of SMN as a field diagnostic. Overall, using actual weather and yield was of only small benefit.

Evaluation of Nitrogen-FRS -When all 3 models were combined into the single package, Nitrogen-FRS, the fertiliser recommendations were significantly better than farm practice. It should be emphasised that the farmers participating in the trials were highly skilled at selecting optimum application rates. They were very familiar with the conditions on their farms and had years of experience in determining the nitrogen fertiliser rate that should be applied. As a result, farm practice was highly correlated with the observed optimum N rate. However, Nitrogen-FRS consistently provided improved recommendations over farm practice. This indicates the success of combining the 3 nitrogen recommendation systems into a single package. Different approaches to fertiliser recommendation no longer need to compete: instead each helps the overall system to provide better recommendations. Since the initiation of this project the 7th edition of RB209 has been published (MAFF, 2000). This should also be incorporated into Nitrogen-FRS, to provide a single source of the latest information for both arable and vegetable crops. This system allows diverse recommendation systems to be combined into one decision support system and used together to improve the overall result.

Action Points for Growers

In order to make full use of dynamic simulation models, farmers and growers should (1) maintain accurate, long-term field records; (2) improve uniformity of fertiliser applications; (3) calibrate fertiliser spreaders; (4) measure yield; (5) record applications of organic wastes.

Anticipated Practical and Financial Benefits

Accurate fertiliser recommendations are of clear benefit to:

- the farmer and grower - reducing costs of fertiliser, fuel and time
- the industry - maintaining yield and quality
- the environment - reducing leaching of nitrate to groundwater

Though a little more complex to operate than static systems, dynamic models are able to provide recommendations accounting for changes in weather conditions and management practices for specific fields or farms. Because a dynamic model includes a description of all major processes, the system provides access to the science underlying any recommendation, and may be used to assess associated risks.

SCIENTIFIC SECTION

1. Introduction

1.1. Background

A significant barrier to more efficient use of nitrogen (N) fertiliser by arable farmers and horticultural growers is the lack of information on the seasonal, soil-related and cultural variations in the supply of mineral N by the soil and the requirements for nutrients by the crop. Much of the necessary information can already be provided in a clear and flexible way for mainly arable crops by SUNDIAL (the Rothamsted model for SimUlation of Nitrogen Dynamics In Arable Land - Bradbury *et al.,* 1993.) and for mainly horticultural crops by WELL_N (based on the HRI N turnover model - Greenwood *et al.*, 1992). SUNDIAL has been constructed into a decision support system for fertiliser recommendation in previous work, funded by MAFF (NT1202 and NT2306), termed SUNDIAL-FRS (Fertilizer Recommendation System). In this project, the WELL_N model has been incorporated into the existing decision support system, and field trials have been run to evaluate the performance of both models on working farms. This pilot project should facilitate the release of the decision support system to the farming community, so ensuring that the potential benefits of 150 years of research on N, crops and soil organic matter are passed directly to the farmer. In addition, an ACCESS database of the results of the field trials has been created for use in the current project as well as by future researchers. The database provides a unique and invaluable resource for evaluating the performance of fertiliser recommendation systems.

There are essentially two types of model: static models and dynamic models. A static model is a one-stage calculation that takes no account of progress of the soil/crop system with time. In contrast, a dynamic model recalculates the state of the soil/crop system throughout the simulation, according to specific climate and soil conditions. Most currently available fertiliser recommendation systems use static models: these include MAFF Reference Book 209 (MAFF, 1994); the ADAS system, FERTIPLAN; and NCYCLE, the system developed at IGER-North Wyke for grassland. Because a dynamic model is able to respond to changes in climatic and soil conditions, the new generation of fertiliser recommendation systems may be based on dynamic models: WELL_N, developed at HRI-Wellesbourne, and SUNDIAL-FRS, developed at IACR Rothamsted are two such models.

WELL_N is a computer program that provides improved recommendations and management advice for the use of N on a wide range of vegetable and some arable crops. The software was developed under MAFF and HDC funding and uses the HRI N response model to tailor the recommendations to the different weather, soil and cultural practices at each site. The model incorporates many simple widely applicable relationships for calculating the N demand of each crop, the amount of N taken up and its partitioning within the plant, automatically adjusting the results for changes in the amount and distribution of mineral N available to a crop. Inputs to the model include information about the crop, the soil, management practices and weather: most of these are readily available or can be estimated for individual sites. Options are available to run the model either using regional long-term average weather data to provide an initial recommendation before the crop is grown or using actual weather data recorded during crop growth to provide management advice on top dressing or irrigation requirements.

SUNDIAL-FRS was originally developed under funding from HGCA and has been developed through subsequent MAFF funding. It is a fully functional dynamic model of the N cycle under a range of different arable and some horticultural crops. Management scenarios may be described through a user-friendly interface using measurements that are available to the farmer or advisor. The model is designed to use weekly weather data. In predicting fertiliser requirements a weekly time step introduces fewer problems associated with predicting weather data due to temporal and spatial variability than a model with a short time step. The model can be used to predict the fertiliser requirements of a given crop with a specified yield. Alternatively the model may be tested by running the simulation retrospectively and comparing the results to measurements of soil mineral N or N offtake in the crop.

Although both SUNDIAL-FRS and WELL_N models have undergone extensive retrospective testing using data from controlled experiments, few trials have been undertaken to test their reliability under *real* farm conditions. There is, therefore a pressing need to test both models on working farms to check that proper account is taken of management practices which are not always replicated in experiments.

SUNDIAL-FRS and WELL_N have been developed along separate, but parallel lines, and so there are large benefits from combining both models into a single package. The package is referred as "Nitrogen-FRS" in this report. However, it should be noted that the name of the combined fertiliser recommendation system is still under discussion.

1.2. Aims and Work Plan

In this project, we aimed to incorporate WELL_N and SUNDIAL-FRS into a flexible decision support system for designing whole farm rotations to optimise the use of available N in mixed arable and horticultural systems. The system has been taken to working farms and horticultural enterprises across the UK and used to provide recommendations for selected crops using projected weather data. The accuracy of the recommendations has been assessed by comparison with the results of field trials at each site. The model performance was further evaluated by retrospective simulation using actual weather data recorded during the experiments.

The overall objectives of this 3 year project are summarised as:

(1) Devise a decision support system to optimise the use of available N.
(2) Establish field trials including mixed arable/horticultural rotations.
(3) Evaluate *on-farm* performance by simulating N turnover in the field trials.
(4) Use the evaluated system to design improved rotations.

The work plan for the project is given below:

1997

	APR	JUL	SEP	
IACR		Devise decision support system for designing whole farm rotations	Establish AICC field sites	Set up trials for winter crops
HRI		Set up a database to hold details of rotations & results of analyses	Establish field sites identified by HDC	Provide fertiliser recommendations for specified rotation

1998

JAN	MAY	JUL	
IACR &	Take Soil Samples Set up trials for spring crops	Enter results into database	Take Soil and Crop Samples at Harvest
HRI	Provide fertiliser recommendations for specified rotation	Predict results of harvest sampling	Set up trials for winter crops & provide fertiliser recommendations for specified rotation

1999

JAN	MAY	JUL	
IACR &	Take Soil Samples Set up trials for spring crops	Enter results into database	Take Soil and Crop Samples at Harvest
HRI	Provide fertiliser recommendations for specified rotation	Predict results of harvest sampling	Start model evaluation

2000

JAN	APR	JUL	NOV
IACR &	Evaluation of model performance	Evaluation of model performance (Supplementary)	
HRI	Retrospective design of improved rotation & Report Writing	Retrospective design of improved rotation & Report Writing (Supplementary)	

2. Materials and Methods

2.1. Decision Support System

The decision support system has been written in Microsoft Visual C++, version 6.0. Microsoft Visual C++ was chosen because:

- it is an object-oriented language which can improve the efficiency of programming and memory management, and reduce running times;
- it provides a flexible Windows based graphical user interface, which is familiar to users; and
- it can avoid installation problems associated with use of Dynamically Linked Libraries as often experienced with languages such as Visual Basic.

To improve the memory management in SUNDIAL-FRS, the model was translated into C++ and incorporated into the decision support system as an object-oriented class. No memory problems were encountered with WELL_N, so the model was incorporated directly from Fortran code as local dynamically linked libraries. New grower interfaces were developed for WELL_N.

2.2. Database of Field Trials

The database was designed using Microsoft Access. This software was selected because:

- it is fully integrated into the Microsoft Office environment;

- it allows data to be stored and retrieved efficiently using a range of interchangeable formats for input into other software;
- it is a highly flexible system which allows future expansion of any database to include additional measurements (i.e. extra fields) and new data sets as they become available;
- it is well established and widely available to the scientific community; and
- it provides in-built design procedures to allow the creation of a compact clean storage system with visually attractive screens and automated functions.

2.3. On-Farm Nitrogen Response Trials

2.3.1. Site Selection

In selecting sites for the two years of the trials, the aim was to cover the principal vegetable and arable crops in their main growing areas. Selection was carried out with the assistance of consultants (from AICC or nominated by HDC). These consultants proposed farmers and growers who managed sites which had level or gently sloping topography and uniform soils. From the proposed shortlist, sites were chosen which gave a balance of crops and soil types. Ideal sites also had a known cropping history, mixed arable and horticultural rotations, easy access and had not used organic manures recently or been grassland in the previous ten years. Full details of the location of the trials are given in Table 1 and Figure 1. Four additional sites used in 1998, but lost when growers inadvertently harvested the trials before measurements were taken are omitted. The previous cropping and the cropping of the sites during the trials are given in Figure 2. Although it was planned to grow two crops in rotation, trials at six sites were discontinued in 1999 due to operational changes by the grower or, in one case, to the loss of a Brassica crop to clubroot. In total 65 crop trials were completed at 37 sites.

2.3.2. Trial Design and Management

Replicated N response plots were established at all sites. These comprised 6 rates of N, including a zero rate, in three randomised blocks. The overall size of the experiment was designed to minimise disruption to normal farming practice and was generally fitted within a half or full width of the on-site fertiliser spreader. Apart from fertiliser application and harvesting, the growers carried out all other crop husbandry according to farm (best commercial) practice. Where NPK compound was used by the grower in the remainder of the field, equivalent rates of P (as triple superphosphate) and K (as sulphate of potash) were applied by hand to the response plots. In the second year of a trial in the same field, trials were moved slightly so that subsequent trial plots were not affected by the management of the earlier trial. In two cases it was necessary to move the trial to a different field between seasons. These are indicated in Figure 2 as sites 3a & b and 6a & b.

Arable crops

In 1998, N application rates were selected to span the SUNDIAL-FRS predicted optimum application, with rates generally 15% and 30 % above and below. N was applied as ammonium nitrate by hand in one application (GS31 in cereals, before rapid stem elongation on oilseed rape and after emergence in potatoes and sugar beet). Following discussion of the results at a meeting of the farmers at IACR-Rothamsted in December 1998, trial designs for 1999 were modified slightly. The N rates used in the trial increased in regular increments from zero to a rate about 30% above the predicted optimum allowing response curves to be plotted more easily. Application of N was made in two applications in 1999: winter crops receiving a total N application greater than 100 kg N ha^{-1} had 50 kg N ha^{-1} applied by hand in February (GS30 in cereals). The remaining N was applied to each plot at the beginning of April (GS31/32 in cereals). Plots in cereals and oilseed rape ranged from 18 to 36 m^2 depending on the tramline width; smaller plots 5-12 m^2 were used in potatoes and sugar beet.

In 1998 some farmers also tested large unreplicated strips (often complete tramlines) of the SUNDIAL-FRS and WELL_N predicted optimum N application applied with farm machinery to compare to farm practice yields. However, few farms were able to maintain these trials through to the determination of final yields accurately. The most common problem was failure or inaccuracies of the yield meter on the combine. In 1999 separate estimates of farm practice yield were made at harvest on small hand-harvested plots.

Table 1. Site location and soil type.

Site Code	County	Soil Series	Topsoil Texture
1	East Yorkshire	Burlingham	Clay loam
2	Yorkshire	Escrick	Sandy clay loam
3	Kent	Hamble	Silt loam
4	Kent	Hamble	Silt loam
5	Bedfordshire	Bearsted	Sandy loam
6	Norfolk	Elmton	Clay loam
7	Lancashire	Downholland	Clay loam
8	Lancashire	Downholland	Clay loam
9	Shropshire	Hodnet	Sandy clay loam
10	Norfolk	Elmton	Clay loam
11	Hertfordshire	Hanslope	Clay
12	Hertfordshire	Hanslope	Clay
13	Cambridgeshire	Hanslope	Clay
14	Suffolk	Burlingham	Sandy clay loam
15	Suffolk	Burlingham	Sandy clay loam
16	Norfolk	Romney	Silt loam
17	Oxfordshire	Denchworth	Clay
18	West Sussex	Hook	Silty clay loam
19	Warwickshire	Bromsgrove	Sandy loam
20	Suffolk	Barrow	Sandy clay loam
21	Oxfordshire	Dullingham	Sandy clay loam
22	Suffolk	Swaffham Prior	Sandy loam
23	Lincolnshire	Wisbech	Silt loam
24	Lincolnshire	Tanvats	Silt loam
25	Norfolk	Newport	Loamy sand
26	Lancashire	Sollom	Loamy sand
27	Lancashire	Sollom	Humose loamy sand
28	Lancashire	Wisbech	Silt loam
29	Lancashire	Rufford	Sandy loam
30	South Yorkshire	Romney	Silt loam
31	Lincolnshire	Wisbech	Silt loam
32	Lincolnshire	Tanvats	Silt loam
33	Warwickshire	Wick	Sandy loam
34	Kent	Coombe	Silty clay loam
35	West Sussex	Hamble	Silt loam
36	Greater Manchester	Longmoss	Peat
37	Warwickshire	Whimple	Clay loam

Figure 1 Map showing location of trial sites

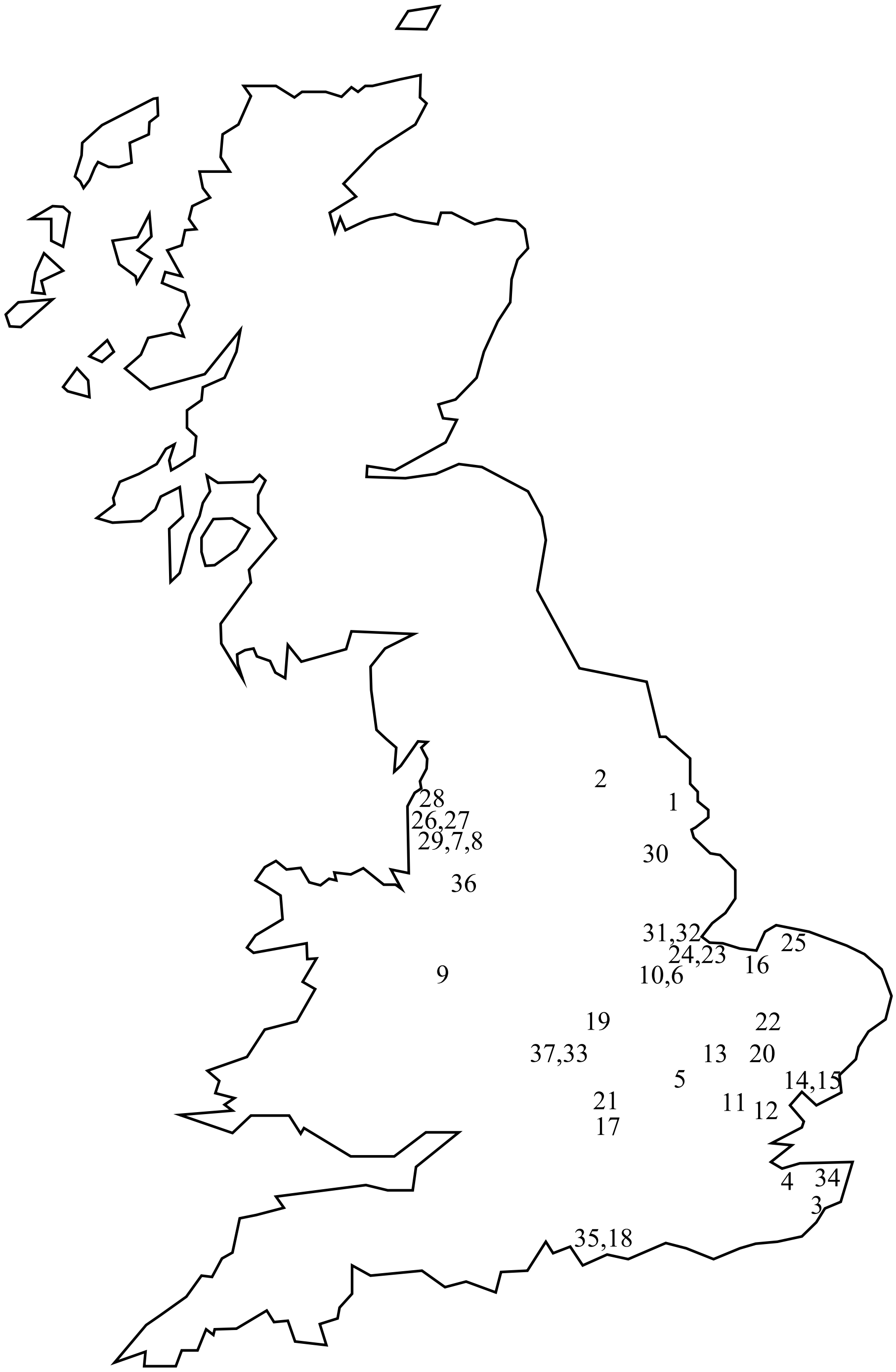
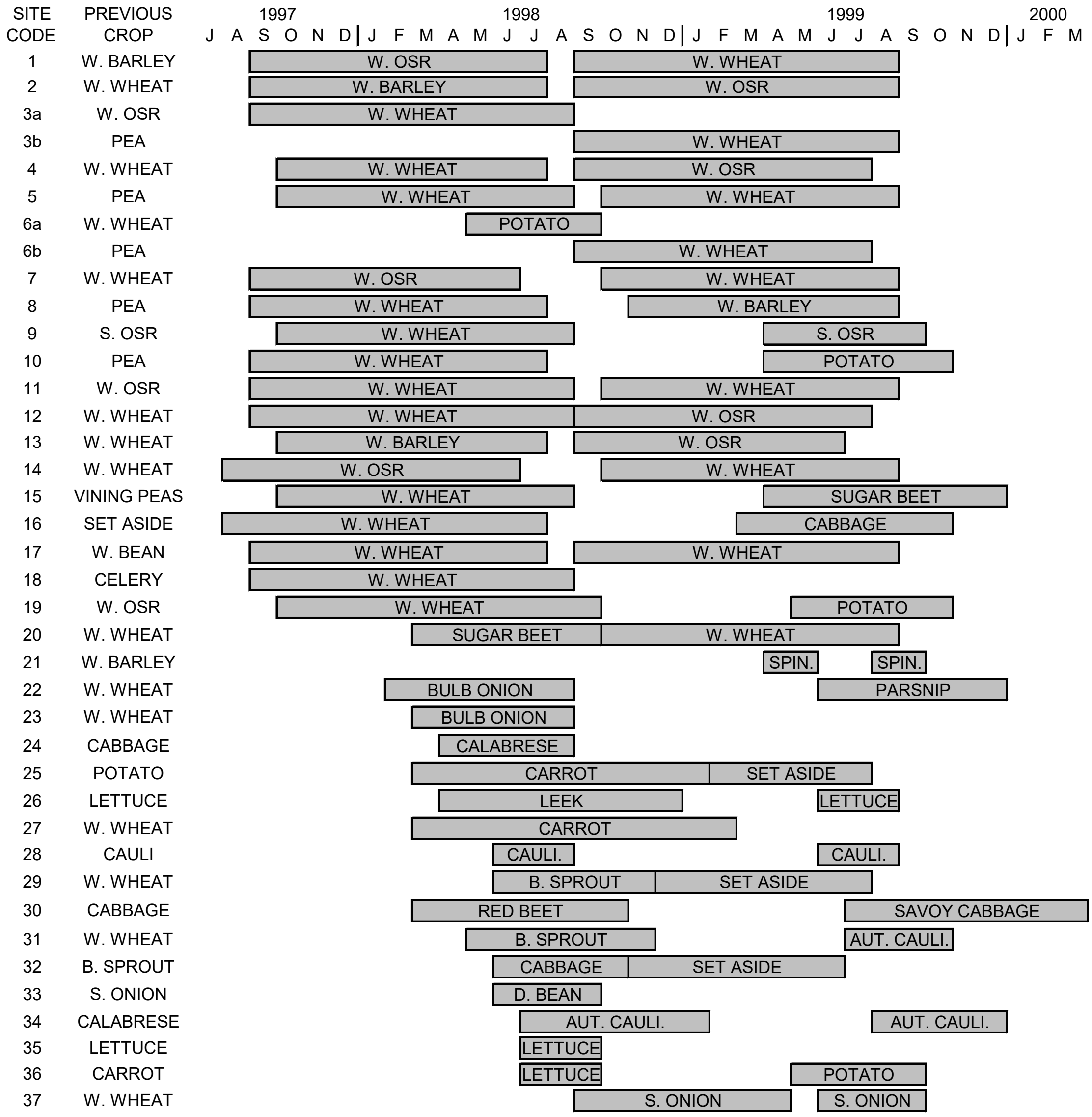


Figure 2. Trial crops at sites used for evaluation of fertiliser recommendation systems.



Crop abbreviations:

B. SPROUT	Brussel sprouts
CAULI	Cauliflower
D. BEAN	Dwarf bean
PEA	Field peas
S. ONION	Salad onion
S. OSR	Spring oilseed rape
SPIN	Spinach
W. BARLEY	Winter barley
W. BEAN	Winter field bean
W. OSR	Winter oilseed rape
W. WHEAT	Winter wheat

Horticultural crops

In both years the N rates were selected to span evenly between zero and the maximum used, as shown in Table 2, and included the WELL_N predicted optimum. Plot area varied between 7 and 40 m^2, depending on crop density and number of harvests. Nitrogen was applied by hand to each plot, as ammonium nitrate, or ammonium nitrate/ammonium sulphate mixture. At most sites, up to 75 or 100 kg N ha^{-1} was applied just before or just after drilling or planting, with any remainder applied after establishment. With the over-wintered salad onion crop (site 37 in 1998), the entire N was applied in the early spring. Where set-aside followed a vegetable crop (sites 25, 29 and 32 in 1999), no response trial was established but soil samples were taken (section 2.3.3).

Table 2. Horticultural sites – N application rates

Site code	Year	Crop	Response trial N applied[1] kg/ha				
21	1999a	Spinach	50	100	150	200	250
21	1999b	Spinach	50	100	150	200	250
22	1998	Onion	40	80	115	165	215
22	1999	Parsnip	40	80	120	160	200
23	1998	Onion	50	90	125	175	225
24	1998	Calabrese	50	100	150	200	275
25	1998	Carrot	25	50	75	100	125
26	1998	Leek	50	100	175	275	375
26	1999	Lettuce	50	100	150	200	250
27	1998	Carrot	25	50	75	100	125
28	1998	Cauliflower	75	150	225	300	375
28	1999	Cauliflower	75	150	225	300	375
29	1998	Brussels sprout	125	200	275	350	425
30	1998	Red beet	50	100	150	200	250
30	1999	Savoy cabbage	100	175	250	325	400
31	1998	Brussels sprout	100	175	250	325	400
31	1999	Autumn cauliflower	70	140	210	280	350
32	1998	Dutch white cabbage	50	125	200	275	350
33	1998	Dwarf bean	50	100	150	200	250
34	1998	Autumn cauliflower	75	150	225	300	375
34	1999	Autumn cauliflower	50	100	150	225	300
35	1998	Lettuce	75	125	175	225	275
36	1998	Lettuce	50	100	150	200	250
36	1999	Potato	50	100	150	200	250
37	1998	Salad onion	40	80	120	160	200
37	1999	Salad onion	40	80	120	160	200

[1] All experiments include a zero N treatment

Most growers were keen on locating a large, unreplicated area alongside the response plots on which the WELL_N rate of N would be spread using farm equipment, for comparison of yield with their normal field rates. As with the arable trials, this proved difficult to achieve in practice. In 1998 at several sites, N could not be varied independently of P and K as the grower applied the base application of N as a compound. At others, either no top dressing was planned or it was too wet to apply it, or model and farm rates were within 25 kg N ha^{-1} of each other or the plots were lost through application errors. Five sites were established in 1998. One of these (onion, site 22) was discarded because of soil variability, one (carrot, site 27) because of a lack of response to N and one (leek, uncoded) because of a harvesting error, leaving just two sites, leek (site 26) and red beet (site 30). This approach was not therefore pursued in 1999.

It was planned to monitor the grower application rate of granular N at as many sites as possible using IMATS (Independent Machinery Advisory & Technical Services) catch trays placed across the width of the spreader bout. Timing of site visits to coincide with applications proved difficult to organise and was achieved at only three sites. At two of these, which were using a single disc spreader, the measured rate was either 40% less or 50% more than the target. At the other site the rate, using a twin disc broadcaster and double overlap spreading, was within 15% of the desired amount. This suggests that growers need to ensure that they are getting the best from their machinery in order to maximise the benefits from sophisticated recommendation systems.

2.3.3. Soil and Crop Sampling

In spring, soil mineral N was measured on the response plots before fertiliser was applied. Six cores per block were bulked in increments of 30 cm to a depth of 90 cm or to rock. Between crop harvest and post-harvest cultivations, topsoil samples (0-30 cm) were taken in each plot of the N response trial with six cores taken per plot. In addition cores were taken to a depth of 90 cm (in increments of 30 cm) in plots which had received no N fertiliser and in the plots with the largest N application. Core samples were taken at each sampling to measure the topsoil bulk density.

All the plot trials in arable crops were harvested ahead of the farm fields, usually in the week immediately preceding combining. At harvest the central strip of each plot was cut using an Allen scythe for oilseed rape and cereal crops allowing the recovery of both grain and straw samples. On average a yield area of 8 m^2 was cut in each plot. The total biomass was weighed in the field and a sub-sample brought back for processing. Oilseed rape was cut just before the main crop was swathed and allowed to mature at Rothamsted to minimise seed loss. Cereals and oilseeds were threshed and sub-samples of grain, chaff and straw kept for analysis. Potatoes and sugar beet were lifted by hand from a minimum length of 2 m of paired yield rows. For all the potato crops sampled, the tops had been desiccated before sampling. However, for sugar beet the whole crop was sampled. Beet and tops were separated, washed and weighed, and a sub-sample kept for analysis. Potatoes were graded by size and a sub-sample of the ware grades was kept for analysis.

In the horticultural trials, yields were assessed from a minimum harvest area of 2 m of bed length (close-row crops) or 30 plants (wide-spaced Brassicae) on each response plot. All trials were hand harvested and timed to coincide closely with the commercial harvest, although we were required to clear one lettuce trial (site 35) a week early when the crop was slightly immature. In line with commercial practice, summer and early autumn cauliflower and calabrese were cut over on three occasions. Maturity of the late autumn cauliflower, grown on the Isle of Thanet (site 34), was delayed by low autumn temperatures and due to the risk of frost damage, in contrast to the commercial crop, were harvested as a single cut. Late maincrop carrots were lifted prior to strawing in October when the foliage was still present and also following dieback during the commercial harvest period. Total, marketable and residue fresh and dry weights were recorded for all crops. Where applicable, assessments of quality and size grading were made, as listed in Table 3, in order to provide data on the relationship between these parameters and N application rate.

Table 3. Horticultural sites - measured yield parameters

• All crops	Total, marketable and residue fresh and dry weights Plant population and % dry matter
• Brussels sprout	Size grades: 10-25, 25-30, 30-35, 35-40 mm
• Bulb onion	Size grades: <40, 40-50, 50-60, 60-80 and >80 mm
• Cabbage	Individual head weights
• Calabrese	Individual head weights and diameters
• Carrot	Size grades: <20, 20-25, 25-30, 30-35, 35-40, 40-55 mm and misshapen
• Cauliflower	Individual curd weights, diameters, quality class and defects
• Leek	Size grades: <15, 15-50, >50 mm
• Lettuce	Individual head weights and iceberg quality heads
• Parsnip	Size grades: <30, 30-35, 35-65, 65-75, 75-130 mm and misshapen
• Potato	Size grades: 25-45, 45-65, 65-85, >85 mm and outgrades
• Red beet	Size grades: <25, 25-45, 45-65, 65-75, > 75 mm and misshapen
• Salad onion	Size grades: <8, 8-18, >18 mm

2.3.4. Sample Analysis

Soil samples were sieved to remove stones and stored for no longer than one week at 4ºC before extraction. Where a delay was unavoidable, the soils were stored frozen. Soil mineral-N (nitrate plus ammonium-N extracted with saturated potassium sulphate solution) was measured by HPLC and colorimetry, respectively. Topsoil samples were also characterised for bicarbonate extractable P, ammonium nitrate extractable K, pH and total N (MAFF, 1986)

Crop samples were dried at 100°C and milled to fine flour before measuring total N content by thermal conductivity using a LECO® CN2000 combustion analyser.

2.3.5. Statistical Methods

Analysis of variance was used to test for significant effects of N application. The yield response to applied N was examined and described by a 'linear plus exponential function' (George, 1984), where appropriate:

$$Yield = a + br^N + cN$$

where N is the total amount of N applied (kg ha^{-1}); a, b, and c are linear coefficients and r is a non-linear parameter. Genstat was used for preliminary curve fitting with floating r.

The economic optimum N application was defined for all crops as the N application rate after which a 1 kg increase in N applied increased marketable yield by less than 1%, and was identified from the gradient of the fitted relationship. This is not the same definition of economic optimum commonly used (eg. Sylvester–Bradley *et al*., 1984), but allows one method to be used for all crops, including vegetables, whose price can fluctuate widely and are dependent on quality. After preliminary curve fitting in Genstat, data were imported into MLP, which was used to estimate the optimum and the precision of this estimate. The parameters of the linear plus exponential model were usually highly correlated and their dispersion matrix was often nearly singular. Therefore, except where the optimum was fairly well determined with data values falling away clearly on either side, it was difficult to assign a standard error to the estimate of the optimum. Confidence limits were usually very skew and possibly unlimited at the upper end. The lower 95% confidence limit was therefore used to give an indication of the precision of the estimate of the optimum.

Yields were calculated for all the recommended rates, from the linear plus exponential curve fitted to the trial data. In trials where there was no significant response to applied N, the optimum was taken as zero and the yield at optimum as the mean trial yield.

2.4. Evaluation of Decision Support System

WELL_N and SUNDIAL-FRS were used independently to predict the optimum N application for each crop. The simulations were carried out separately for the first year crops, with the second crop run in rotation with the first year farm crop. The data used was extracted from the database of field trials.

The WELL_N model is the same version as that included within the commercially used HRI MORPH decision support system (Draycott *et al*, 1999). However, within the project the model was extended to allow it to be run rotationally. For crisp lettuce, the parameter WLRT (the dry weight in t ha $^{-1}$ when roots reach the mid-point between rows), was updated to take account of recent work with glasshouse lettuce (Burns *et al*, 2001). WELL_N was run automatically within the database system using specially prepared procedures (Section 3.2). As in MORPH, estimates of the optimum were made to the nearest 25 kg N ha^{-1}. WELL_N predictions were not made for sites receiving large amounts of organic manures, or for oilseed rape for which crop parameters are not included in the currently available version. Two other trial crops, savoy cabbage and salad onion are not specifically parameterised in WELL_N but were run as Dutch white cabbage and bulb onion respectively, albeit with a lower yield. Default values for soil mineralisation rates (0.70 kg N ha^{-1} day^{-1} at 15.9°C) were used for all soils apart from peat (site 36). WELL_N has not previously been used on peat soils due to uncertainties in mineralisation rates. Opportunity was therefore taken to estimate mineralisation rate at the peat site from the measured changes in spring and post harvest soil mineral N and plant N uptake on the zero N plots. Since these mineralisation values were not independent of the field data, however, the simulations from the peat site were not used in the evaluation of the model.

The SUNDIAL-FRS recommendations and simulations were run with SUNDIAL-FRS V3.0. SUNDIAL-FRS was run separately to the database system after extracting the data for set-up files. Sites were run with as much previous cropping information as was available, up to 5 years for some sites. Recommendations were obtained for all the arable crops (sites 1-20) but not all the horticultural crops. No recommendations were derived for spinach (Site 21), parsnip (Site 22/99), calabrese (Site 24/98), lettuce (Sites 26/99 and 35/98), red beet (Site 30/98) or dwarf bean (Site 33/98) as SUNDIAL-FRS is not parameterised for these crops. Neither was it possible to run simulations for the peat soil (Site 36), as SUNDIAL-FRS is not parameterised for organic soils. SUNDIAL-FRS is not specifically parameterised for salad onion (Site 37), so it was run as bulb onion, with adjustments for the different dry matter contents, as this in physiologically very similar.

The initial SUNDIAL-FRS recommendations and simulations for **cauliflower** were very poor. The crop was often unable to take up the full N requirement, resulting in very low calculated yields and recommendations. The parameters were modified, with much improved results. The presented recommendations are for the new parameters, but the results are not used in the final evaluation of the SUNDIAL-FRS recommendations.

For each model, an initial, **predictive** optimum was obtained. This was based on grower estimates of potential marketable yield, using actual weather (obtained from the nearest Meteorological Office site) prior to the first N application and default weather for the remainder of the season. WELL_N also included the spring SMN measurements where available. To compare the effect of default and actual weather at the same potential yield, a second WELL_N predictive recommendation used actual weather for the whole season. A second SUNDIAL-FRS predictive recommendation was carried out, which included spring SMN measurements as diagnostics.

A **retrospective** optimum was subsequently obtained using actual weather for the whole of the season and 'actual' yields. WELL_N used the maximum total dry weight yield from the trial, SUNDIAL-FRS used the calculated marketable yield at the optimum N rate. The SUNDIAL-FRS retrospective recommendation was obtained both with and without the use of spring SMN measurements. . These predictions were compared with the optimum N application determined from the field trials (Section 2.3.5).

Retrospective simulations of the response trial plots (where no N had been applied and at the highest rate) were also carried out with each model to predict the mineral N remaining in the soil at harvest and crop N uptake. SUNDIAL-FRS also provided a retrospective simulation at the farm rate for the arable sites. The simulations used the actual weather, crop yields and N application rates, and spring SMN values, if available. These predictions were compared with the replicate measurements made in the field trials.

Measurements and simulated values were compared using the statistical methods outlined by Smith *et al*. (1997), across all sites and using groups of crop or soil types where at least 8 comparisons were possible.

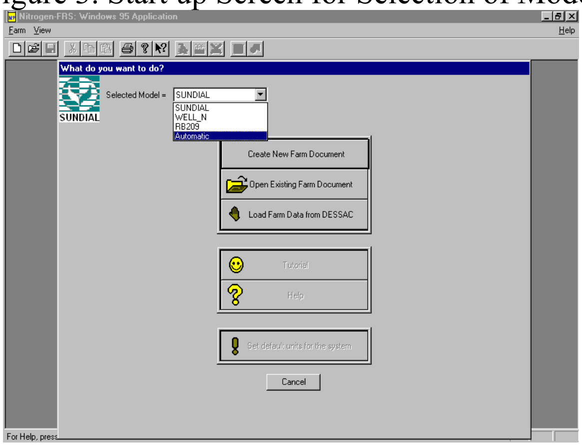
3. Results and Discussion

3.1. Decision Support System

3.1.1. Selection of Model

The selection of models can be either manual or automatic. On entering the system, a *Start Up Screen* is displayed, that allows the user to select the model and choose the source of input data (Figure 3).

Figure 3. Start up Screen for Selection of Model and Source of Input Data



If automatic model selection is chosen, the system will select the most appropriate model, based on the results of the model evaluation completed for this project.

The models currently available in the system are SUNDIAL-FRS, WELL_N and the MAFF Reference Book 209 (1994). On manually selecting the model, the model *Title Screen* is displayed and the icon in the top left corner of the screen changes to indicate the new model selection. The title screens for SUNDIAL-FRS and WELL_N are shown in Figure 4.

Figure 4a. Title Screen for SUNDIAL-FRS

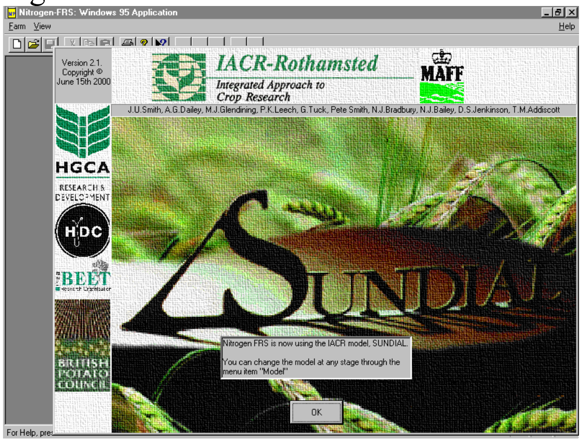


Figure 4b. Title Screen for WELL_N

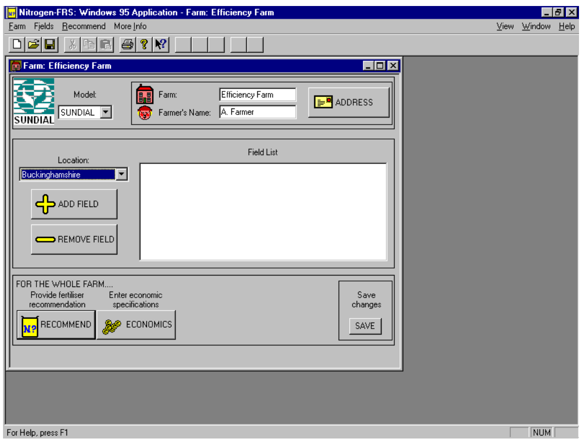
The model *Title Screen* acknowledges sponsorship by the project partners, the organisations responsible for the development of the model and the contributions from individual researchers. The icon associated with the selected model is given in the top left corner of all the main windows and a drop-down list is provided to allow the model selection to be easily changed at any stage.

3.1.2. Input of Data

The input screens are equivalent for all models. This is essential if the system is to move seamlessly between models.

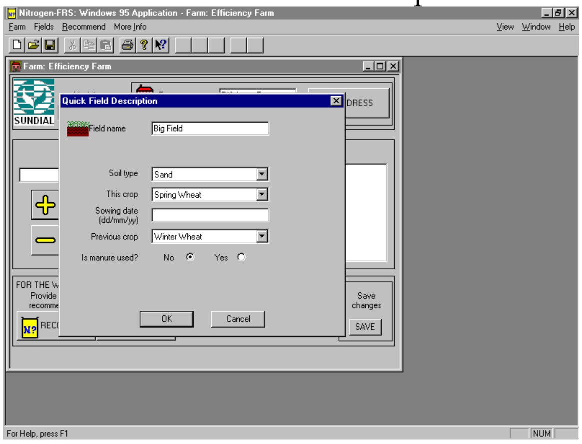
The first data input screen displayed is the *Farm Screen* (Figure 5). This screen displays the farm identity, and contains controls that allow the user to change the address, location, and economic settings, and to add and remove fields. The location of the farm is selected from a drop-down menu. This information is used to select default values and the statistics selected to run the weather generator.

Figure 5. Farm Screen, Showing Selection of Farm Location



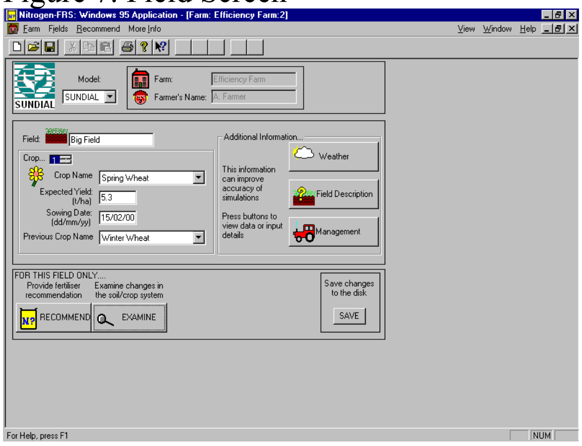
On pressing the *Add Field* button, a *Quick Field Screen* is displayed to allow the user to obtain a default description of the field with minimum requirement for input data. Here the soil type, current crop, sowing date, previous crop and manure use may be specified (Figure 6). Missing values are filled in by an underlying database of regional defaults. Selecting OK takes the user to the field screen with all data input controls completed. Clearly, a more accurate recommendation will be obtained if more field specific data is entered. Upon running the simulation, the user is provided with a screen detailing the default values used.

Figure 6 Quick Field Description Screen used by SUNDIAL-FRS and WELL_N to define field data with minimum user input



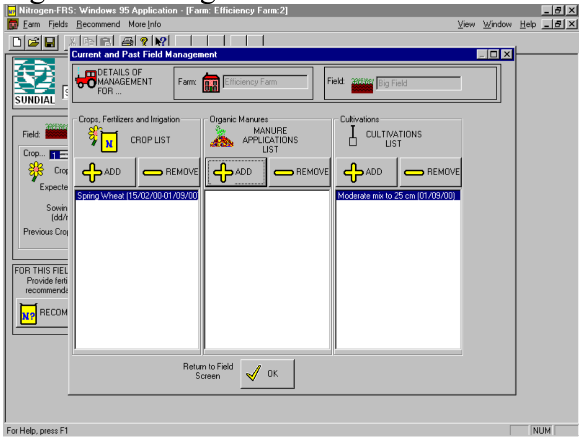
The *Field Screen* summarises the entered data. It also includes buttons that allow more field specific information to be entered and model simulations to be run (Figure 7).

Figure 7. Field Screen



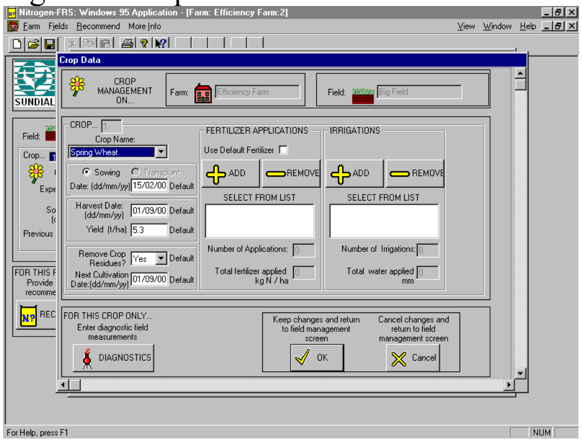
Selecting the *Management Button* (Figure 8) brings up lists of the crops, manure applications and cultivations already specified in the field management. From this screen, cropping, manure and cultivation details can be viewed, added or removed.

Figure 8: Management Screen



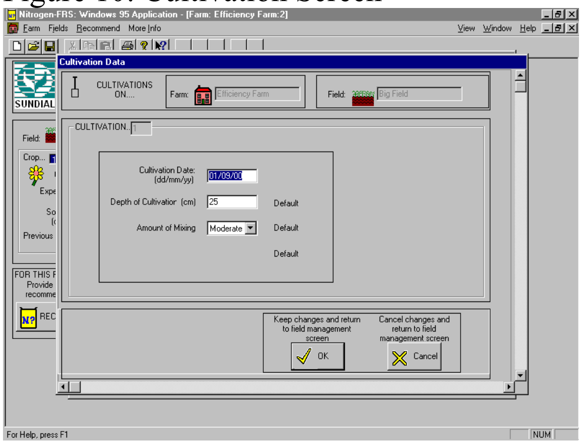
Selecting to add or view crop data brings up the *Crop Screen* (Figure 9). From this screen details crop management, fertiliser applications and irrigations can be added. In addition, diagnostic field measurements can be included that will be used by the models to modify the simulations.

Figure 9. Crop Screen



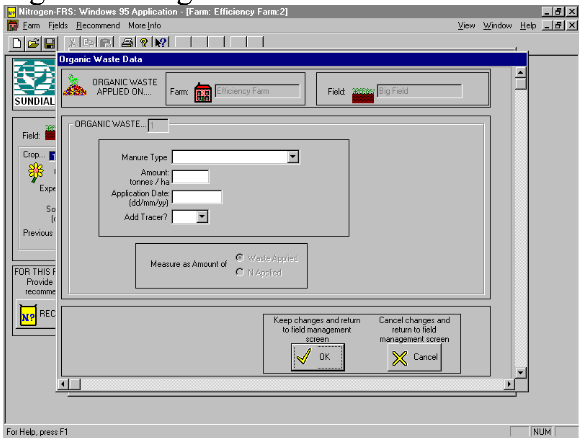
Similarly, selecting to add or view cultivations brings up the *Cultivation Screen* shown in Figure 10.

Figure 10: Cultivation Screen



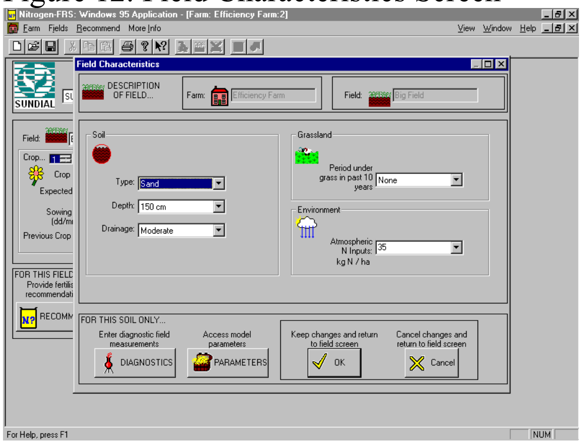
Selecting to add or view organic waste brings up the *Organic Waste Screen* (Figure 11). Application of organic waste is not included in WELL_N.

Figure 11: Organic Waste Screen



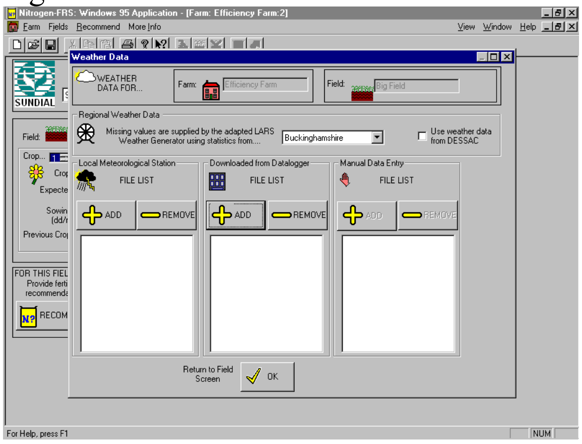
Selecting the *Field Description Button* from the *Field Screen* (Figure 7) brings up the *Field Characteristics Screen* (Figure 12) which displays and allows the user to make changes to the soil type, depth, drainage, period under grass in the past 10 years and atmospheric N inputs. The screen also includes two buttons: the *Diagnostics Button* and the *Parameters Button*. The *Diagnostics Button* allows diagnostic field measurements to be entered to improve the site specificity of the model simulations. The *Parameters Button* allows the user to view and change soil parameters, and to create new soil types for future use.

Figure 12. Field Characteristics Screen



Selecting the *Weather Button* from the *Field Screen* (Figure 7) brings up the *Weather Screen* (Figure 13). From here, weather data can be loaded from a local meteorological station, downloaded from a datalogging meteorological station on the farm, or entered manually.

Figure 13. Weather Screen



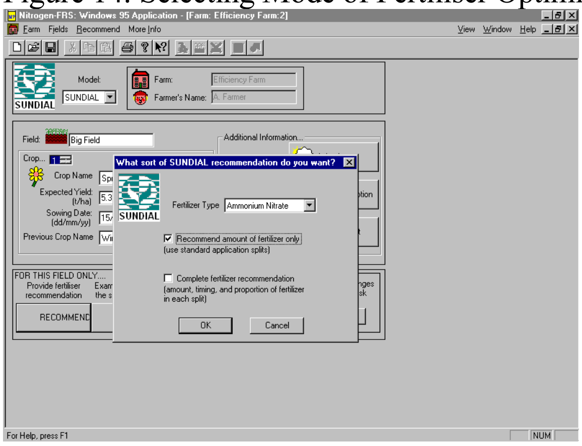
3.1.3. Calculation of Fertiliser Recommendation

The *Recommend Button* on the *Field Screen* (Figure 7) tells the system to run the selected model to provide a fertiliser recommendation. Whereas the input screens are equivalent for all models in the system, the screens associated with running simulations are necessarily different, because mode of operation and results from the models are different. Because the data used by each model is also different, the portion of the entered data that has been used in the simulation is echoed back to the user, indicating whether the information is derived from default values or user input.

SUNDIAL-FRS

The system allows the user to select *partial* or *full* optimisation for SUNDIAL-FRS (Figure 14). A partial optimisation includes only optimisation of the total amount of fertiliser applied. The full optimisation includes optimisation of all factors (i.e. amount, timing, number of splits and proportion in each split).

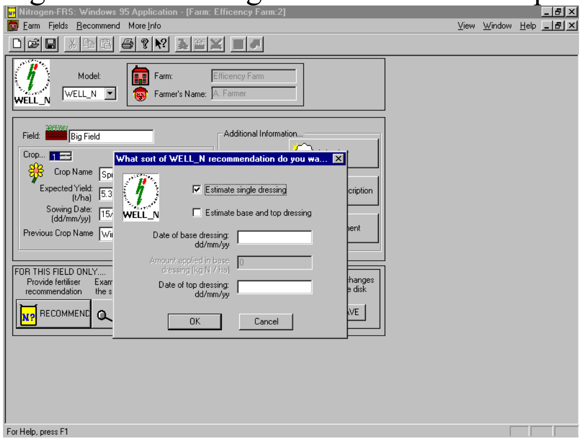
Figure 14: Selecting Mode of Fertiliser Optimisation for SUNDIAL-FRS



The fertiliser recommendation is calculated using a grid search that is initiated at the application rate given in MAFF reference book 209 (1994) and capped at a rate that achieves the required crop N offtake.

WELL_N
The system allows 2 modes of optimisation for WELL_N: estimate a single dressing only; or estimate base and top dressing (Figure 15). The dates of the fertiliser applications must be specified by the user. Before estimation of a single dressing, any previous applied dressings must be specified.

Figure 15: Selecting Mode of Fertiliser Optimisation for WELL_N



RB209
MAFF Reference Book 209 (1994) is included in the system, and provides recommendations via a series of look-up tables and rules within the computer code. No optimisation is possible for RB209.

3.1.4. Presentation of Results

Fertiliser Recommendations
Recommendations can either be presented for a single field (Figure 16) or for the whole farm (Figure 17). Applications listed in the whole farm recommendation can be sorted either in date or field order, depending on user preference.

Figure 16: Field Fertiliser Recommendations

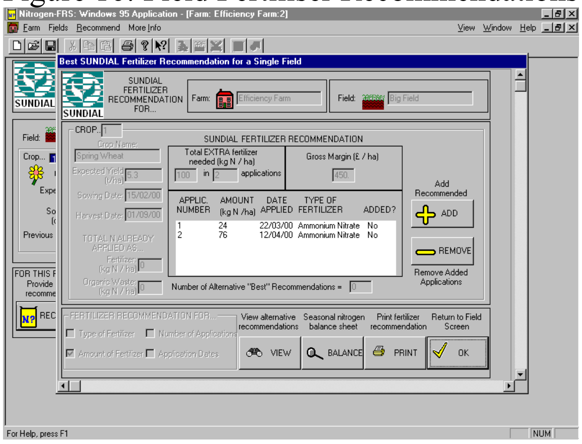
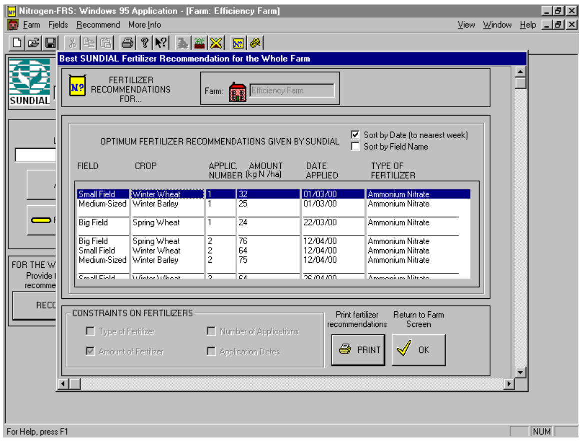


Figure 17: Farm Fertiliser Recommendations



A third type of recommendation screen, displaying the changes as the optimisation proceeds in the fresh weight, dry weight, crop N, soil mineral N and N leaching is currently under consideration

Examine Results

The *Examine Button* on the *Field Screen* allows the user to view balance sheets, graphical plots and flow diagrams displaying the simulated changes in N over time (Figures 18, 19 and 20).

Figure 18. Seasonal N Balance Sheet

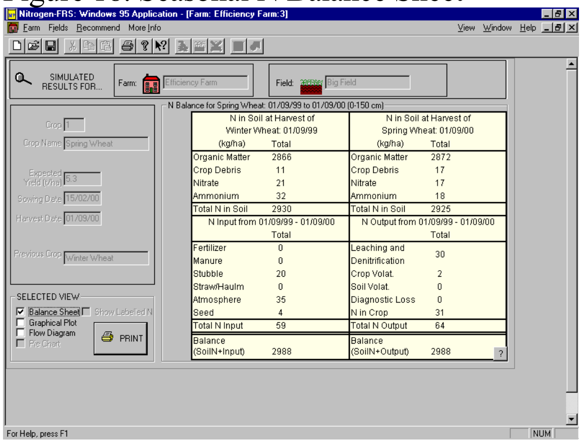


Figure 19. Graphical Plot of Changes in N throughout the Period of the Simulation

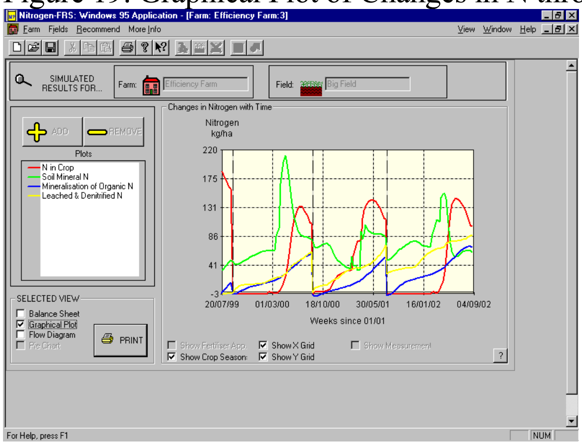
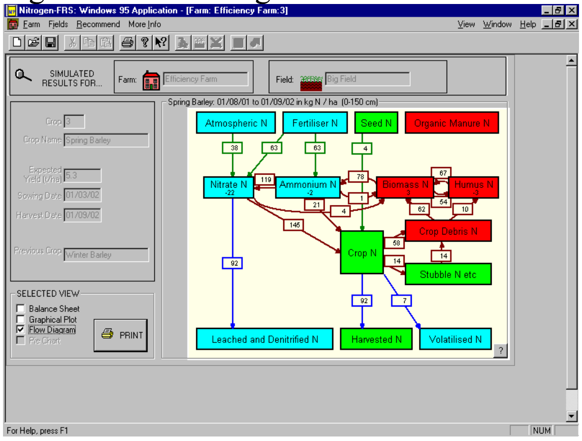


Figure 20. Flow Diagram of Seasonal N Fluxes



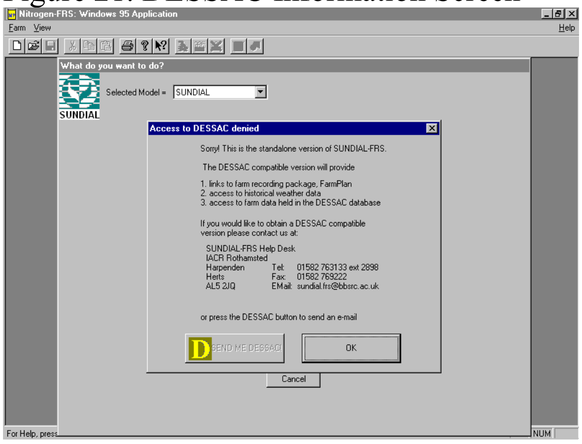
Detailed results are also output in ASCII files so that the more experienced user can analyse the results in any standard spreadsheet software.

3.1.5. DESSAC Compatibility

A DESSAC compatible version of the system is currently being developed under other funding (MAFF NT2306). It is envisaged that the system will be available both as a standalone and a DESSAC compatible version. This is essential if the system is to be accessible to DESSAC and non-DESSAC users alike. Buttons and screens have been included in the system to ensure that the user of the standalone version is fully aware of the additional functionality of the DESSAC compatible version.

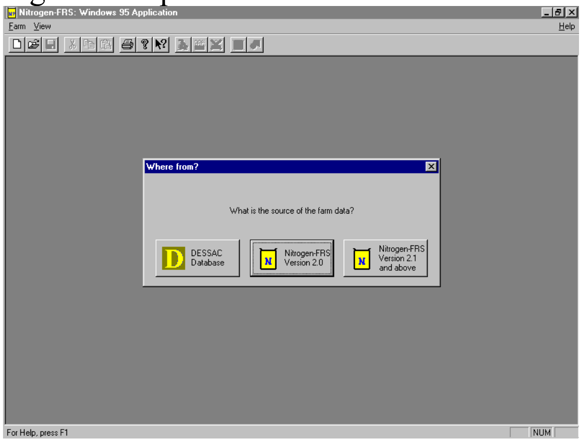
On entry to the system, the *Startup Screen* (Figure 3) includes a button to *Load Farm Data from DESSAC*. In the standalone version, selecting this button will bring up the *DESSAC Information Screen* (Figure 21). This informs the user that farm data cannot be loaded directly from DESSAC in the standalone version.

Figure 21. DESSAC Information Screen



On selecting the *Open Existing Farm Document Button* in the *Startup Screen* (Figure 3), the user is asked to specify the source of the data (Figure 22).

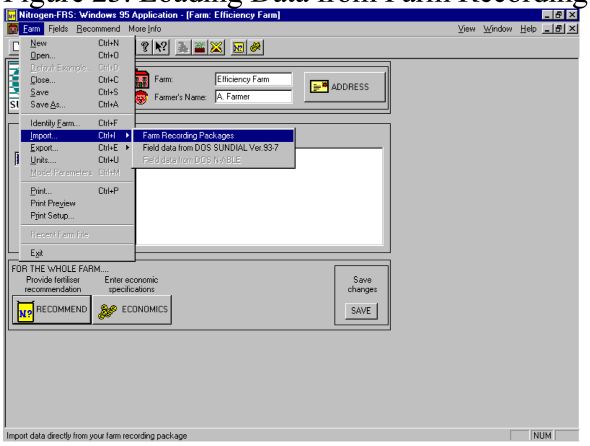
Figure 22. Specification of Data Source



On selecting the *DESSAC database Button* from the standalone version, the DESSAC Information Screen (Figure 21) is displayed to inform the user that the standalone version includes no direct access to the DESSAC database.

In the *Nitrogen-FRS Application Screen*, selection of the menu item *Farm – Import – Farm Recording Packages* (Figure 23) brings up the *DESSAC Information Screen* to inform the user that access to farm recording packages is only available via DESSAC.

Figure 23. Loading Data from Farm Recording Packages



The *Weather Screen* (Figure 13) includes a check box to select historical weather data from the DESSAC database. In the standalone version this is initially unchecked. If user selects this option, the *DESSAC Information Screen* (Figure 21) is displayed to inform the user that historical weather files from DESSAC are unavailable in the standalone version. Historical weather data must therefore be obtained either by the user from a datalogging meteorological station on the farm or the nearest meteorological office site, or automatically through the internal weather generator.

3.1.6. Continuing Development

Because users testing the interface are still providing suggestions for improvements, the layout of the system continues to develop. The above description relates to the status of Nitrogen-FRS, Version 2.1, on 21st July 2000.

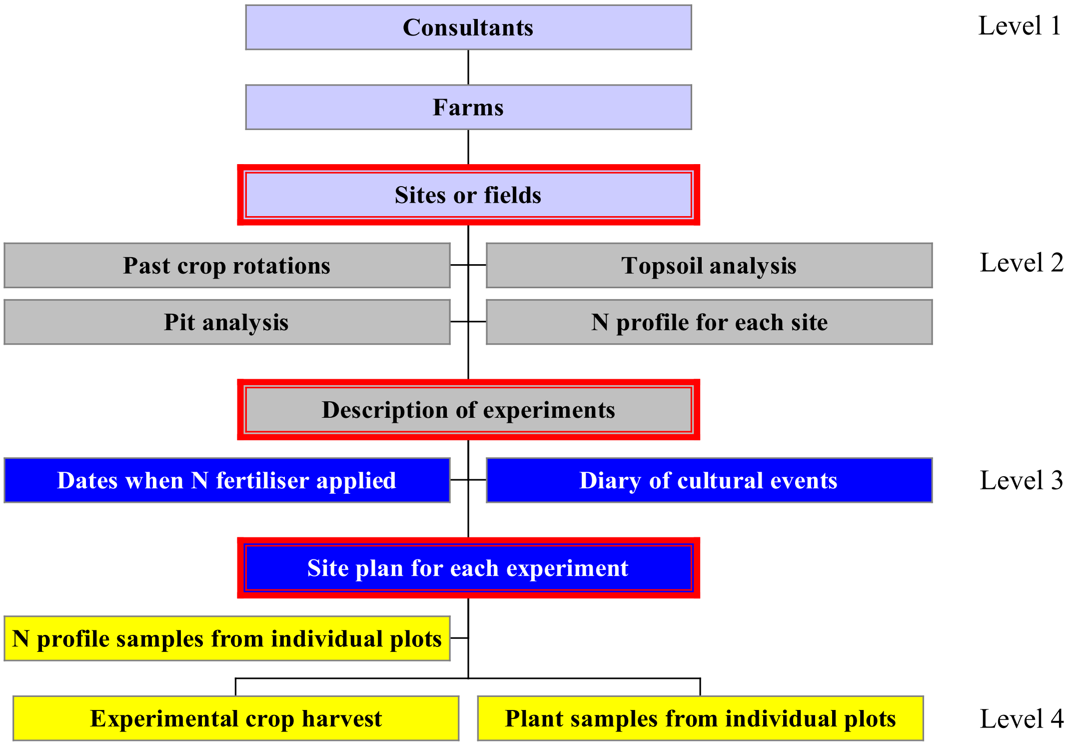
3.2. Database of Field Trials

The database has been designed with the flexibility to store all of the data from the field trials within a single structure. This has been achieved by storing the data within a hierarchical structure, starting with site identifiers (name of farmer etc.) expanding to general site data (e.g. location, soil type and previous husbandry details), and further to incorporate data from each crop and finally to data collected from each experimental plot:

- General data (Level 1) contains site identifiers.
- Site (Level 2) contains soil description and cultural history.
- Experiment (Level 3) contains details for each crop in rotation.
- Plot (Level 4) contains data recorded from individual plots.

Figure 24 below shows the four different levels each in a different colour. Tables which provide the link to the lower level are denoted by a red border.

Figure 24. Diagram showing hierarchical structure of data storage tables within the database.



The datafields are grouped into tables linked into the overall hierarchical structure, as shown below in Figures 25(a-d). This allows the relationships, which exist between the different tables to be recognised and used both during data entry and subsequent extractions. In addition to the main experimental data tables, memo tables have been included for supplementary unstructured information. These memo tables have been provided within hierarchical levels 2 to 4.

Figure 25(a). Relationships between Tables in the Database: Levels 1 and 2 (General Site Data).

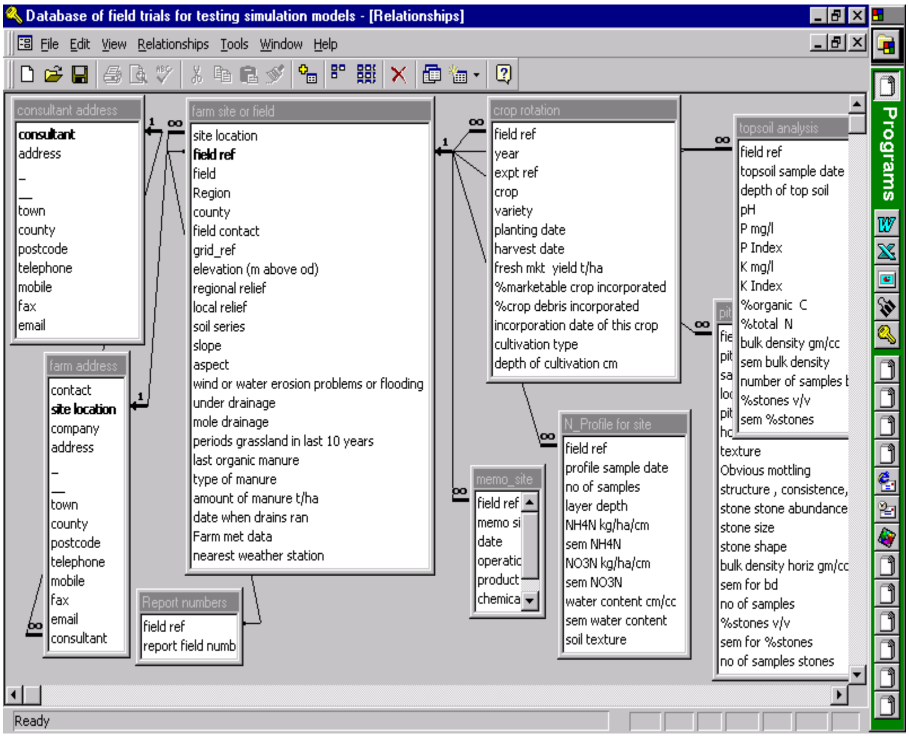


Figure 25(b). Relationships between Tables in the Database: Level 3 (Data from each crop in rotation).

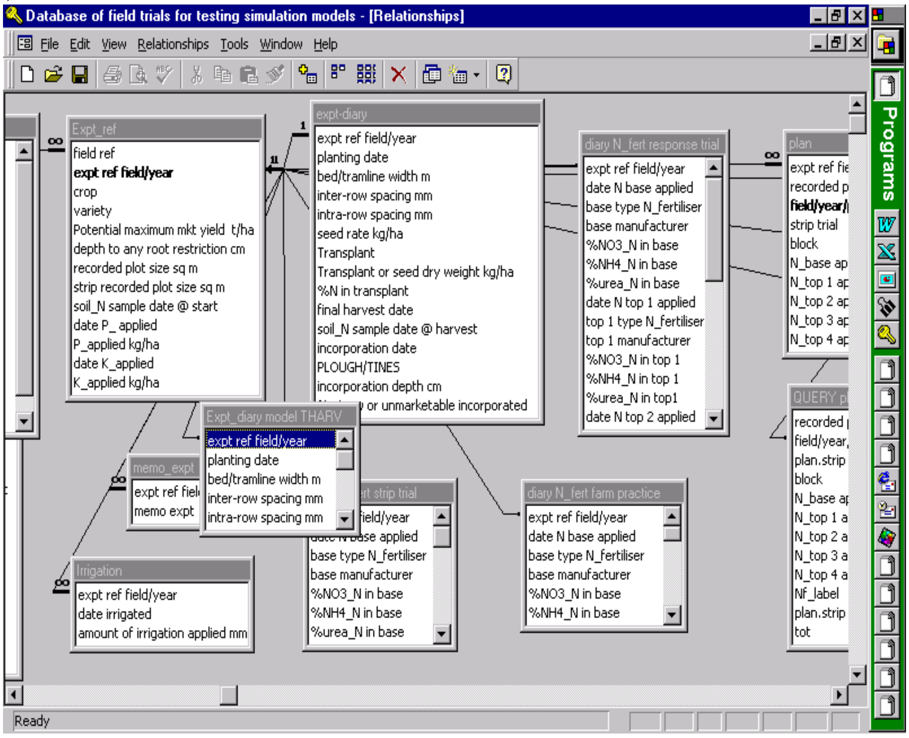


Figure 25(c). Relationships between Tables in the Database: Level 4 (Individual Plot Data).

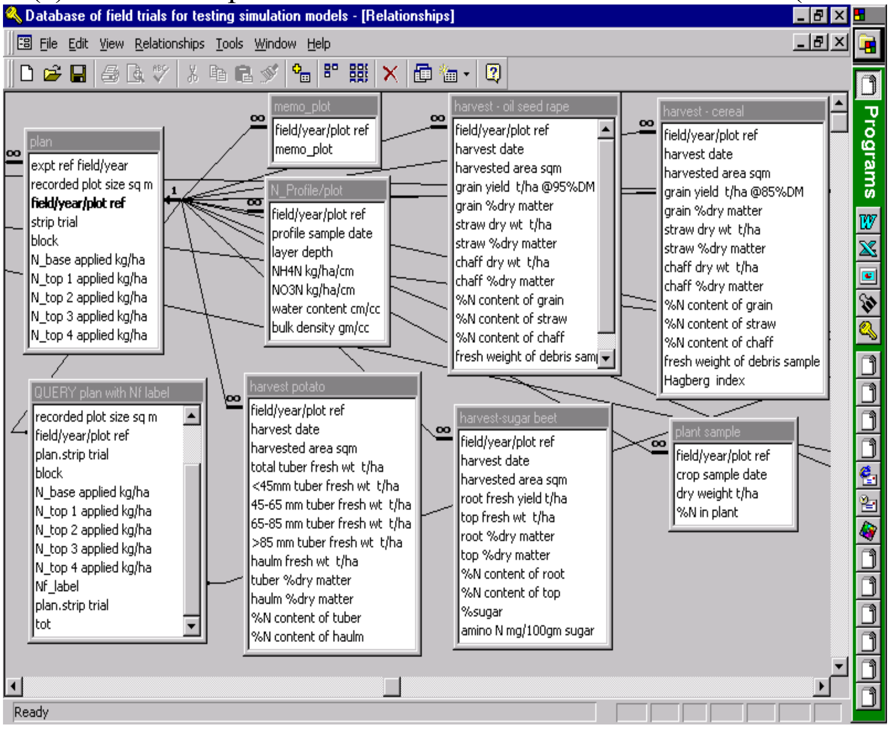
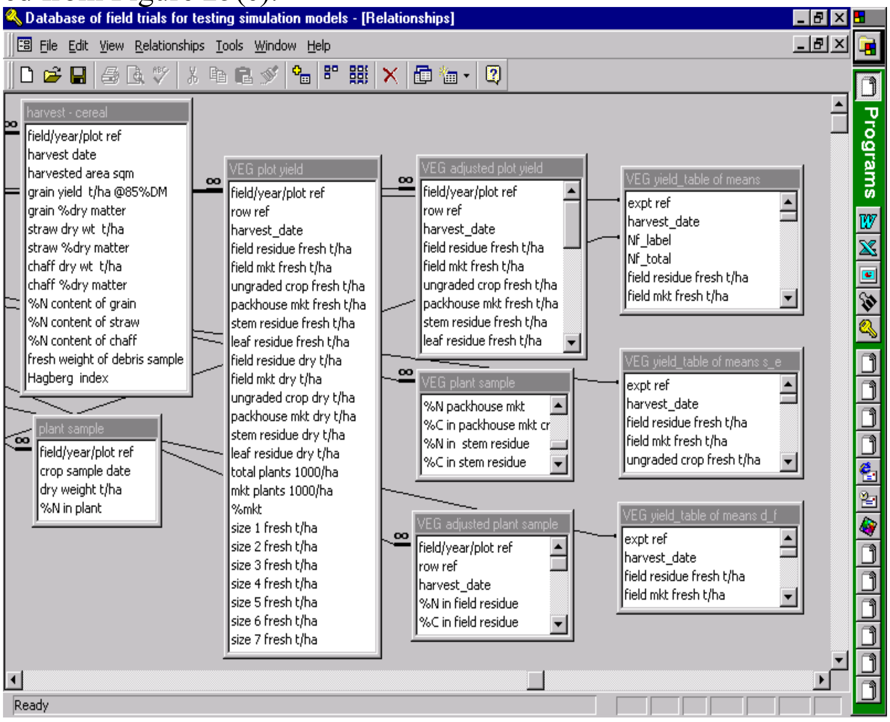
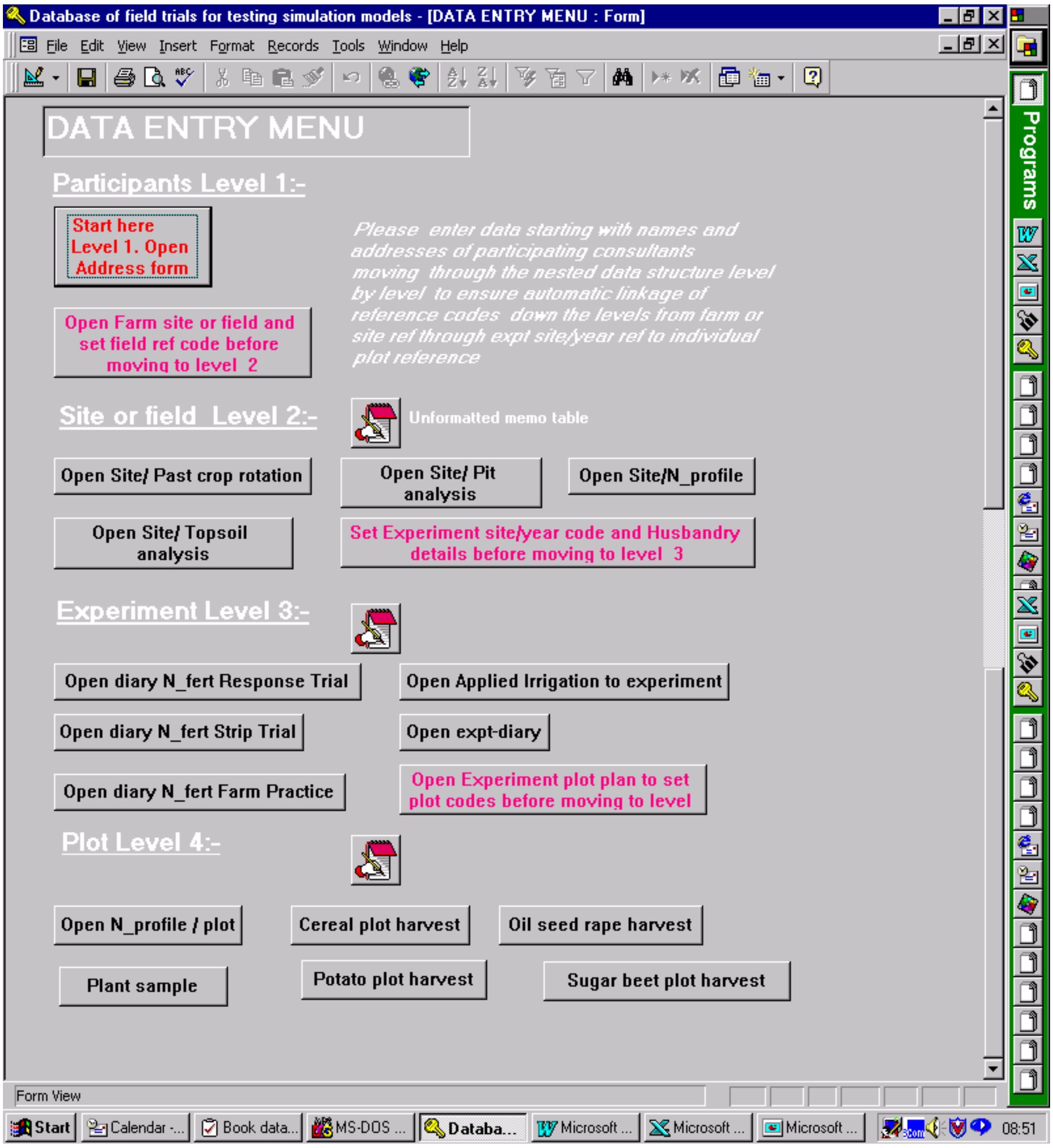


Figure 25(d). Relationships between Tables in the Database: Level 4 (Individual Plot Data) continued from Figure 25(c).



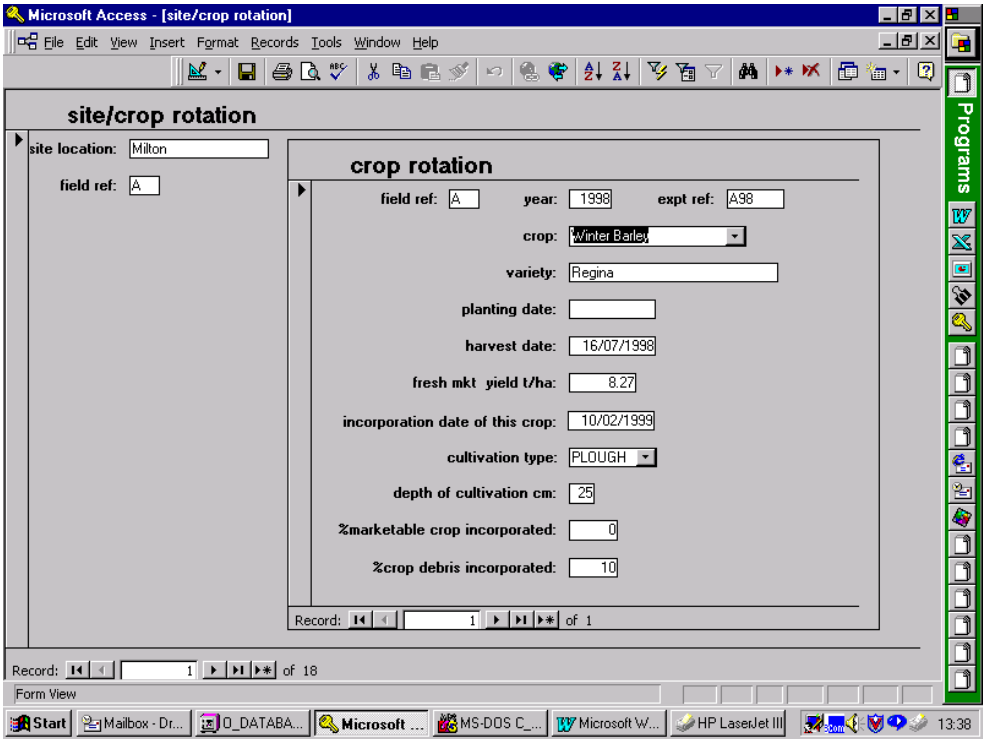
A push button menu shown in Figure 26 guides the user through the nested data entry forms provided for each table. Memo tables are provided at each level as described above. Pre-prepared data input forms were provided for the arable crops where the number of recorded data items at harvest was manageable. However, because of the diverse nature of the vegetable crop data, prepared input forms were not provided for these crops. Instead, the data was assembled in Excel Spreadsheets and pasted directly into the harvest tables.

Figure 26. Data Entry Menu.



One example of the prepared input forms is given in Figure 27. This shows data from two data tables displayed on a single input form. The field ref, entered with farm site or field description is linked through into the crop rotation table as a result of the relationship defined between the tables.

Figure 27. Example of an input form.



The database opens with sequenced title screens as shown in Figure 28. Command buttons direct the user to other screens such as that in Figure 29, which controls pre-defined data extraction procedures.

Figure 28. Database opening title screens.

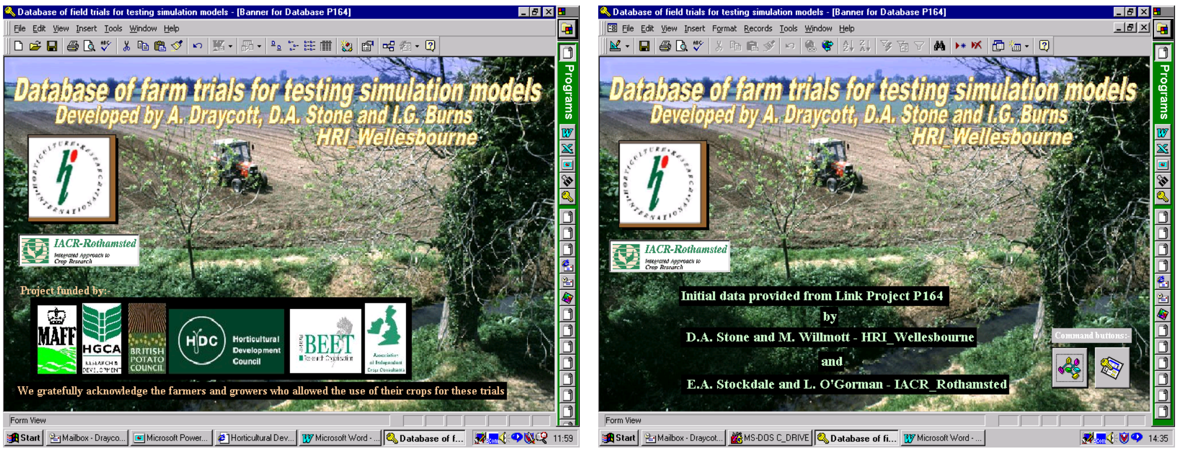
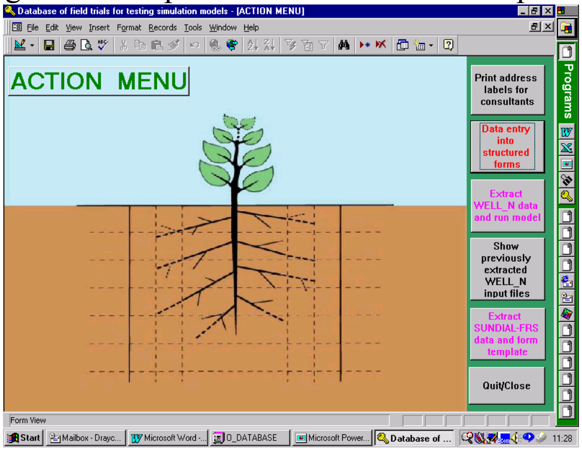


Figure 29. Controlling screen for pre-defined data extraction procedures.



Automatic data extraction for model testing was achieved by the use of procedures, specially written for this project. The system automatically extracts data from the database and formats it to enable the WELL_N and SUNDIAL-FRS models to be run rotationally for a selected site. Using queries, data is gathered together from the different storage tables to produce reports, which are exported to DOS text files. These files are automatically assembled by specialised utilities into input files for the simulation models. The operation is controlled by specialised Visual Basic for Applications (VBA) procedures within both modules and forms, together with DOS applications in the form of batch files and specialised utilities interacting with Access objects, tables, forms, queries, reports and macros. A single command button will, after selecting a site (Figure 30), extract data from the database, prepare input files and, for WELL_N, run a series of simulations. An extracted WELL_N input file is displayed in Figure 31.

Figure 30. A drop-down menu is provided to select required site.

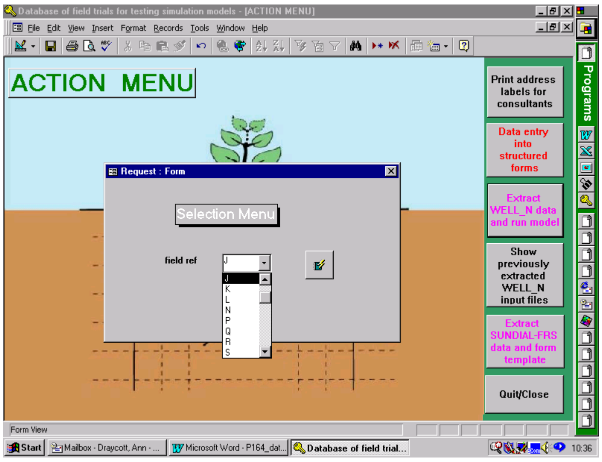
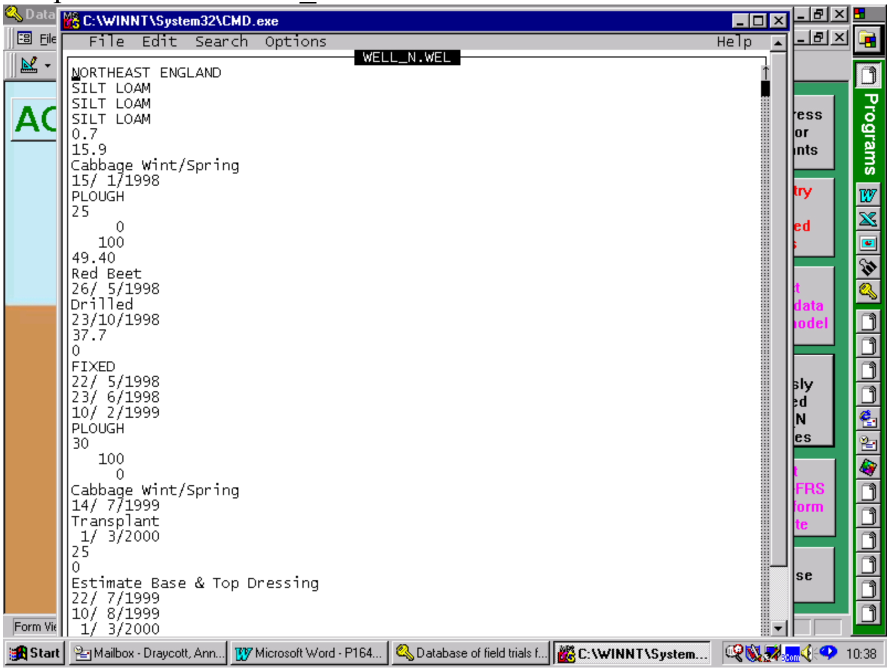
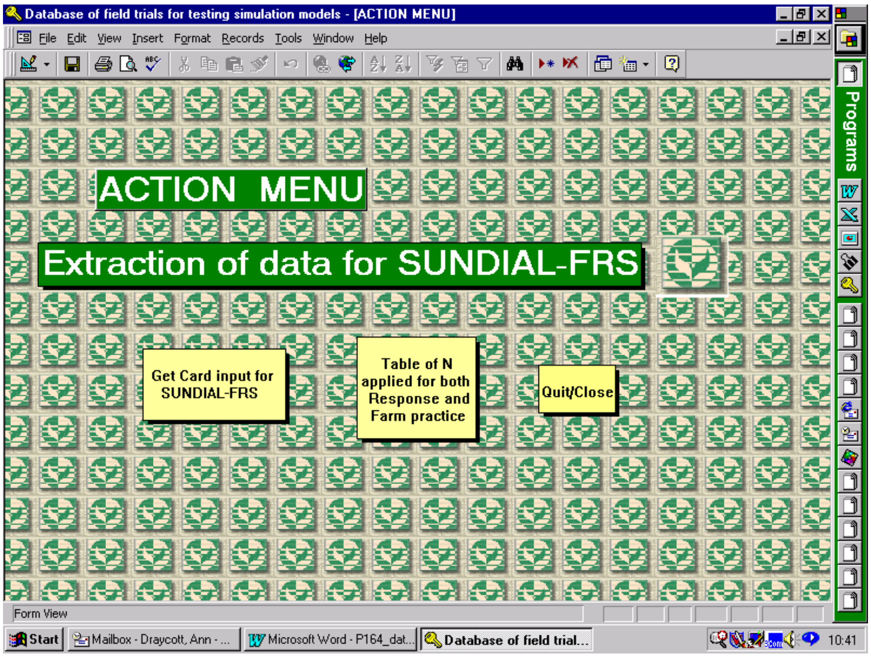


Figure 31. Input files for WELL_N.



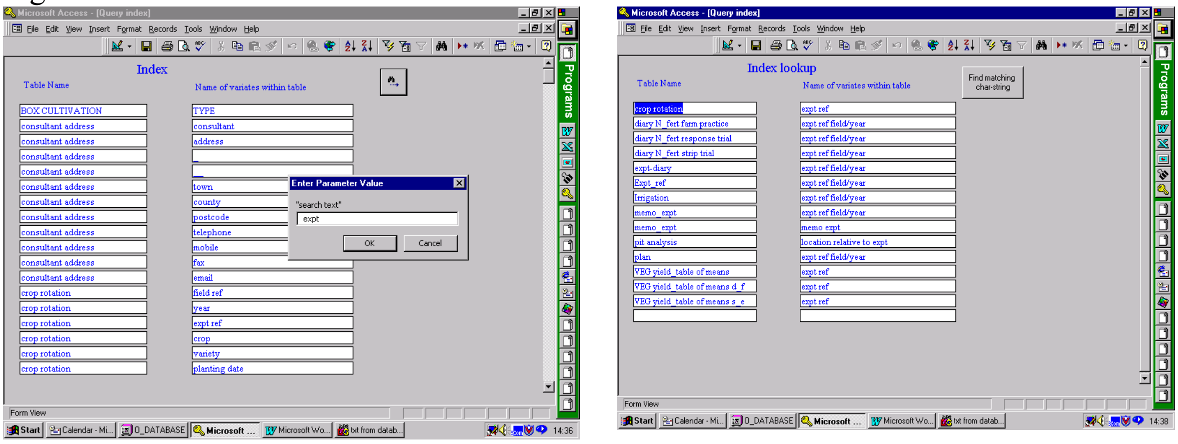
As SUNDIAL-FRS input is more complicated (e.g. names are coded) and was still being modified during final development of the database extractions a decision was taken to produce partially completed templates rather than complete input files (Figure 32). N fertiliser applications for both the response trial and farm practice are presented as reports.

Figure 32. Control Screen directs users in extraction of data to run SUNDIAL-FRS.



To allow data to be found quickly by users forming their own queries a computerised index has been developed to search all the datafields for those whose names contain a user supplied text string, as shown in Figure 33.

Figure 33. Datafield index screen with search button.



3.3. On–Farm Nitrogen Response Trials

Summaries of the results for each individual site are provided in Appendix A.

3.3.1. Weather

Annual rainfall amounts during the trials varied considerably between sites (565 - 930 mm; Table 4). In general, 1998 and 1999 were wetter than the 1992-1996 period. However, for some sites (Sites 11, 12, 18, 22, 30, 35), rainfall remained close to average in both years.

Table 4 Rainfall (mm) recorded at closest meteorological station to the field sites

Sites	1992-1996 average	1998	1999
1	559	706	642
2	611	733	648
3, 34	527	604	565
4	603	746	559
5	665	751	666
6, 10	635	701	639
7, 8, 26, 27, 28, 29	819	897	925
9	658	660	797
11, 12	617	622	617
13	589	744	615
14, 15, 20	591	603	677
16, 23, 24, 31, 32	534	681	715
17, 21	599	686	651
18, 35	768	785	789
19	678	930	914
22	685	701	736
25	647	751	663
30	599	644	643
33, 37	583	684	761
36	755	915	854

However, the patterns of rainfall and temperature are much more important than the total amounts. In 1998, March and April were cool and wet, and the wet soil conditions frequently delayed planting and drilling while heavy rain caused N top dressings to be late or missed altogether. In 1998, cool autumn temperatures slowed growth, and prolonged rainfall in autumn and winter led to slow establishment of autumn-sown arable crops and difficult conditions and soil structural damage during the harvest of some vegetable crops. As a result, some growers abandoned the planned cropping for 1999 in favour of set-aside at three sites (Sites 25, 29 and 32). In 1999, prolonged rainfall during August led to a delayed harvest and consequent poor quality for many cereals.

3.3.2. Field Work

For the arable sites work was focussed into an intensive period of spring soil sampling and fertiliser application (February-March) and a hectic and exhausting harvest period (July-September). Over 15,000 miles were travelled during each growing season, despite combining visits to sites as much as possible.

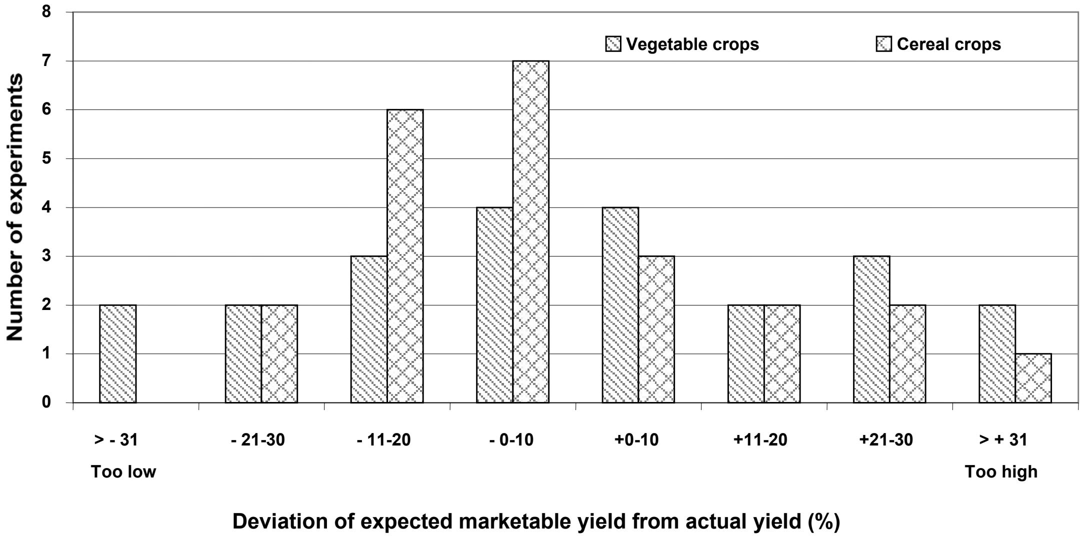
For horticultural crops the disrupted season in 1998 had a knock-on effect on the management of the trial sites, resulting in late changes to selections of both crops and sites. This led to periods of intensive work, particularly with multi-harvested crops, and during the short winter daylight hours. In the first cropping season, 17,000 miles were travelled from Wellesbourne involving 70 separate journeys, and in the second 12,250 miles in 55 trips.

3.3.3. Yields

The effect of inaccurate estimation of marketable yield was highlighted above with reference to site 24/98. Grower forecasts of yield were often inaccurate. Of 22 vegetable and 23 cereal trials, just 36% and 43% respectively gave estimates within ± 10% of the actual yield, as summarised in Figure 34.

With some vegetable crops there can be a discrepancy between the researcher's understanding of marketable yield in the field, as used to guide WELL_N and SUNDIAL-FRS, and the grower's information on saleable produce from the packhouse. However, cereal growers were little better at predicting grain yield and it is clear that there are genuine difficulties in making a realistic assessment of potential yield. Yields are affected by many factors during the growing season, which lie outside the control or prediction of the farmer. It is therefore important to update yield estimates during growth so that fertiliser recommendations can be adjusted.

Figure 34. Accuracy of farmer estimation of marketable yield



The maximum yields recorded in the arable trials were not significantly different to the farm-recorded field yields. These reflected the range of yields obtained on average across the UK *e.g.* 1st wheat 7-12 t ha^{-1}; 2nd wheat 4-11 t ha^{-1}; winter barley 6-9 t ha^{-1}; winter oilseed rape 1.5-6 t ha^{-1}.

Grower forecasts of marketable yield were often inaccurate. Of 22 vegetable and 23 cereal trials, just 36% and 43% respectively gave estimates within ± 10% of the actual yield. This can affect the N requirement of the crop by 25-50 kg N ha^{-1}. Yields are affected by many factors during the growing season, which lie outside the control or prediction of the grower. It is therefore important to update yield estimates during growth so that fertiliser recommendations, which are often guided by the yield estimate, can also be adjusted.

3.3.4. N Response

Over the two seasons, 14 trials showed no marketable yield response to added N fertiliser (Table 5). In some cases this reflected the use of manures (Sites 19 1999, 15 1998, 15 1999) or the use of basal fertiliser containing N (Site 19 1999) before the trial was established. High variability of bulb onions at site 22 in 1998 was caused by patchy recovery from severe hail damage early in the season. *Septoria* increased yield variability in wheat at high N rates at Site 3 in 1999. Lodging affected the winter barley at Site 2 in 1998. Both reduced the impact of increasing rates of N application on yield. The lack of response to N by potato at Site 6a 1998 is not unexpected with this potato variety. With other crops, there was no obvious reason for a lack of increase in yield with increasing N, for example the two carrot crops, at either the early or commercial harvest (Sites 25 and 27), or dwarf beans (Site 33). Only two of the seven winter oilseed rape crops in the trials (Sites 1 1998, 13 1999) showed a significant increase in yield in response to the addition of N fertiliser. However, in most of the winter oilseed rape trials, total dry matter yield and N uptake increased significantly with increasing N application. While the size of the crop canopy increases with increasing N application, this does not necessarily cause an increase in rape seed yield, due to shading of pods and increased disease susceptibility. In some cases yield may also have been restricted by sulphur availability, since farm applications of sulphur were made within the N fertiliser applications.

The optimum N fertiliser application could be determined from a linear plus exponential relationship for 37 trials. For 10 trials the optimum fertiliser application was not contained within the range of N applications tested, leading to an unbounded linear plus exponential curve or a straight line relationship between N applied and marketable yield (Table 5). Where responses were fitted to both the total dry matter and marketable yields for vegetable crops, the optimum N requirements were not significantly different.

In cereals the application of increasing amounts of N fertiliser generally increased the concentration of N in both grain and straw. With no additional N fertiliser the N content of wheat grain ranged from 1.2 – 2.3 %, with 1.5 % N as the most common value (6 sites). The critical N content of grain indicating N sufficiency is usually taken as 2%. At 3 sites (Site 15 1998, 17 1998 and 14 1999) the N content of the wheat grain was ≥ 2% in the absence of any additional N fertiliser; in these years sites 14 and 15 had received autumn manure applications. At the remainder of the sites, between 50 and 200 kg N ha^{-1} were required to increase the N content of the wheat grain to ≥ 2%, with 22 kg N ha^{-1} required on average to increase the %N in the grain by 0.1%. Following celery (Site 18 1998), set-aside (Site 16 1998) and sugar beet (Site 20 1999) even the maximum application of additional N fertiliser within the trial did not increase the grain N content above 2%. However, these circumstances were not replicated within the trials and it is unclear whether this is a true effect of the previous crop or due to a peculiarity of the site, timing of N application or season. The N content of cereal straw was typically 0.3 - 0.4 % in the absence of additional N fertiliser. However, at N applications above the optimum, the N content of straw increased to 0.7 – 1 % N.

In oilseed rape, the N content of the grain and straw generally increased with the addition of N fertiliser and the percentage of oils was generally reduced with increasing application of N fertiliser. The N content of sugar beet root also increased significantly with increasing N fertiliser application. However, with the exception of the peat soil, application of N did not significantly increase the N content of potato tubers.

N uptake where no fertiliser was applied varied from 21 to 267 kg N ha^{-1}; this reflects inherent differences in the fertility of the soil and the period and duration of crop growth. Salad onion and early spinach crops had the lowest N uptakes, where no fertiliser was applied. The largest N uptake in the absence of fertiliser was by a winter wheat crop after vining peas, which had also received 45 t ha^{-1} of pig manure in the previous autumn (Site 15, 1998). Even within the 20 winter wheat crops studied, N uptake in the absence of fertiliser ranged from 48.4 to 266.6 kg N ha^{-1} and showed no clear relationship with the N index determined from the previous cropping (MAFF, 1994). However, where two consecutive wheat crops were grown in the trials (Sites 5, 11, 17), the unfertilised N uptake of the first winter wheat was greater than that of the second winter wheat.

Table 5. Number of trials in various categories of model fit

Best-fit model	Optimum	Number of trials	Site & Year
No model could be fitted	-	3	14 98, 18 98, 31 99.
No response to applied N	0	14	2 98, 2 99, 4 99, 8 98, 9 99, 12 99, 15 98, 15 99, 19 99, 22 98, 25 98, 27 98, 33 98, 34 99.
Linear response to applied N	None	7	1 98, 1 99, 4 98, 6 98, 7 98, 26 98, 30 98
Linear plus exponential fit			
	> maximum level tested	3	7 99, 19 98, 31 98.
	Optimum within range, 95% confidence interval could not be estimated	14	5 98, 5 99, 8 99, 10 98, 11 98, 12 98, 13 99, 17 98, 22 99, 24 98, 34 98, 35 98, 36 99, 37 98.
	Optimum within range, 95% confidence interval estimated	23	3 98, 3 99, 6 99, 9 98, 10 99, 11 99, 13 98, 14 99, 16 98, 16 99, 17 99, 20 99, 21 99i, 21 99ii, 23 98, 26 99, 28 98, 28 99, 29 98, 30 99, 32 98, 36 98, 37 99.

3.3.5. Soil Mineral N

Spring mineral N to 90 cm varied from 19 to 180 kg N ha^{-1}, where no manure or fertiliser had been applied (Tables 6 and 7).

Table 6. Soil mineral N (NO_3 plus NH_4) measured in soil samples taken in early spring (winter crops) or pre-planting (spring and summer crops) in 1998.

Site	Crop	Previous crop	Date of sample	Soil mineral N (kg ha^{-1})		
				0-30 cm	30-60 cm	60-90 cm
1	W. OSR	W. barley	11/02/98	44	22	15
2	W. barley	W. wheat	12/02/98	42	26	41
3a	W. wheat	W. OSR	13/02/98	23	12	8
4	W. wheat	W. wheat	13/02/98	37	30	40
5	W. wheat	Field pea	18/02/98	43	37	35
6a	Potato	W. wheat	18/02/98	34	19	*
7	W. OSR	W. wheat	16/02/98	39	25	20
8	W. wheat	Field pea	16/02/98	56	33	40
9	W. wheat	S. OSR	17/02/98	42	28	34
10	W. wheat	Field pea	19/02/98	30	*	*
11	W. wheat	W. OSR	23/02/98	37	31	17
12	W. wheat	W. wheat	23/02/98	35	34	*
13	W. barley	W. wheat	24/02/98	30	34	30
14	W. OSR	W. wheat	25/02/98	25	22	27
15	W. wheat	Vining pea	25/02/98	54	53	109
16	W. wheat	Set-aside	27/02/98	23	26	53
17	W. wheat	W. bean	27/02/98	59	51	54
18	W. wheat	Celery	02/03/98	16	8	11
19	W. wheat	W. OSR	03/03/98	33	27	40
20	Sugar beet	W. wheat	14/04/98	40	31	18
22	Bulb onion	W. wheat	10/02/98	32	33	78
23	Bulb onion	W. wheat	16/02/98	29	20	19
24	Calabrese	Cabbage	06/03/98	39	46	95
25	Carrot	Potato	17/03/98	23	32	25
26	Leek	Lettuce	21/04/98	35	27	28
27	Carrot	W. wheat	21/04/98	23	25	18
28	Cauliflower	Cauliflower	29/04/98	27	20	20
29	Brussels sprout	W. wheat	28/04/98	19	20	20
30	Red beet	Cabbage	29/04/98	58	50	50
31	Brussels sprout	W. wheat	01/05/98	43	24	18
32	Cabbage	Brussels sprout	28/05/98	43	33	28
33	Dwarf bean	Salad onion	30/06/98	31	27	22
34	Cauliflower	Calabrese	22/07/98	8	6	5
35	Lettuce	Lettuce	18/08/98	103	41	35
36	Lettuce	Carrot	06/07/98	19	33	29
37	Salad onion	W. wheat	06/01/99	34	34	37

* No sample taken due to shallow soil

Table 7. Soil mineral N (NO_3 plus NH_4) measured in soil samples taken in early spring (winter crops) or pre-planting (spring and summer crops) in 1999.

Site	Crop	Previous crop	Date of sample	Soil mineral N (kg ha^{-1})		
				0-30 cm	30-60 cm	60-90 cm
1	W. wheat	W. OSR	05/03/99	39	39	35
2	W. OSR	W. barley	11/02/99	36	18	25
3b	W. wheat	Field pea	16/02/99	42	22	21
4	W. OSR	W. wheat	16/02/99	47	28	18
5	W. wheat	W. wheat	04/03/99	34	39	32
6b	W. wheat	Field pea	19/02/99	29	21	*
7	W. wheat	W. OSR	18/02/99	64	43	34
8	W. barley	W. wheat	18/02/99	37	38	36
9	S. OSR	W. wheat	10/04/99	285	105	45
10	Potato	W. wheat	31/03/99	52	*	*
11	W. wheat	W. wheat	04/03/99	74	43	25
12	W. OSR	W. wheat	15/02/99	45	35	*
13	W. OSR	W. wheat	15/02/99	30	30	18
14	W. wheat	W. OSR	02/03/99	30	41	59
15	Sugar beet	W. wheat	09/04/99	137	82	94
16	Cabbage	W. wheat	07/04/99	35	15	17
17	W. wheat	W. wheat	26/02/99	42	58	41
19	Potato	W. wheat	19/04/99	Sampled after top-dressing		
20	W. wheat	Sugar beet	02/03/99	23	27	25
21	Spinach	W. barley	13/04/99	56	54	50
21	Spinach	Spinach	04/08/99	96	71	35
22	Parsnip	Bulb onion	12/05/99	53	39	21
25	Set-aside	Carrot	25/05/99	11	7	15
26	Lettuce	Leek	08/04/99	27	15	10
28	Cauliflower	Cauliflower	11/05/99	40	43	42
29	Set-aside	Brussels sprout	11/05/99	65	42	21
30	Cabbage	Red beet	26/05/99	23	29	17
31	Cauliflower	Brussels sprout	26/05/99	57	27	18
32	Set-aside	Cabbage	19/05/99	56	23	28
34	Cauliflower	Cauliflower	22/06/99	84	23	16
36	Potato	Lettuce	08/04/99	19	55	41
37	Salad onion	Salad onion	07/07/99	105	50	31

* No sample taken due to shallow soil

Where manures (Site 15 1998, 15 1999, 9 1999) or fertiliser (Site 19, 1999) had been applied before soil sampling, mineral N levels were increased significantly. Any relationship between spring mineral N and previous cropping was obscured by the varied soil types and climates *e.g.* both the extremes quoted above followed calabrese (Sites 34, 1998 and 24 1998).

Surprisingly there was no significant relationship between spring mineral N and crop N uptake on zero plots, even when only the combinable crops or winter wheat alone were included. This relationship may have been improved if crop N uptake in spring had also been measured, which normally ranges between 15 and 50 kg N ha^{-1}, so that soil N supply rather than solely mineral N could have been considered.

Residual soil mineral N measured at harvest in the fertilised plots increased significantly above the level measured in the plots which had received no fertiliser in 24 of the 65 trials. An increase in residual mineral N was more common following oilseed rape than the other combinable crops and also occurred where lodging restricted the yield of winter barley (Site 2 1998). In addition, an increase in residual mineral N was seen at high rates of N application in potatoes. Both potatoes and oilseed rape return significant amounts of N to the soil in leaf litter during the growing season and this may contribute to the increase in soil mineral N at harvest in these crops. Many of the increases in soil mineral N where high rates of application were used on the vegetable crops were likely to be due to unused fertiliser.

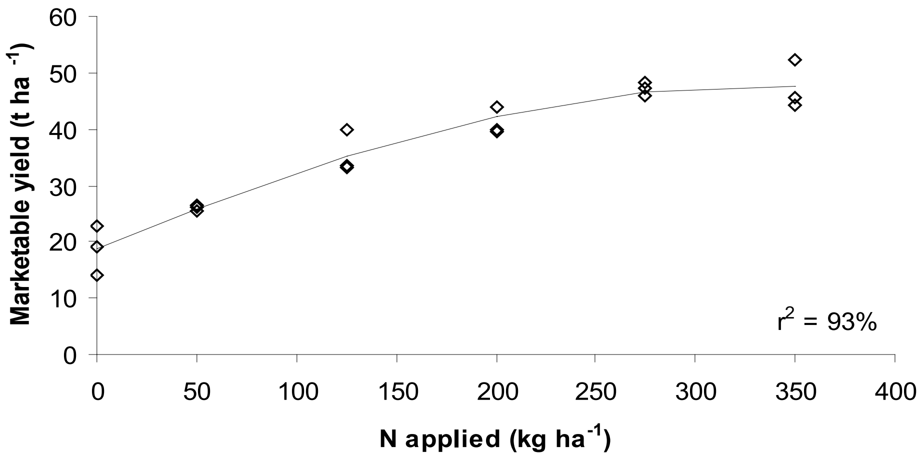
3.4. Evaluation of Decision Support System

The objectives of the evaluation of the decision support system were to determine the likely accuracy of the fertiliser recommendations, to assess the simulations of N turnover on working farms, and to identify which model should be used to simulate a particular crop. The decision support system was evaluated in 2 ways:

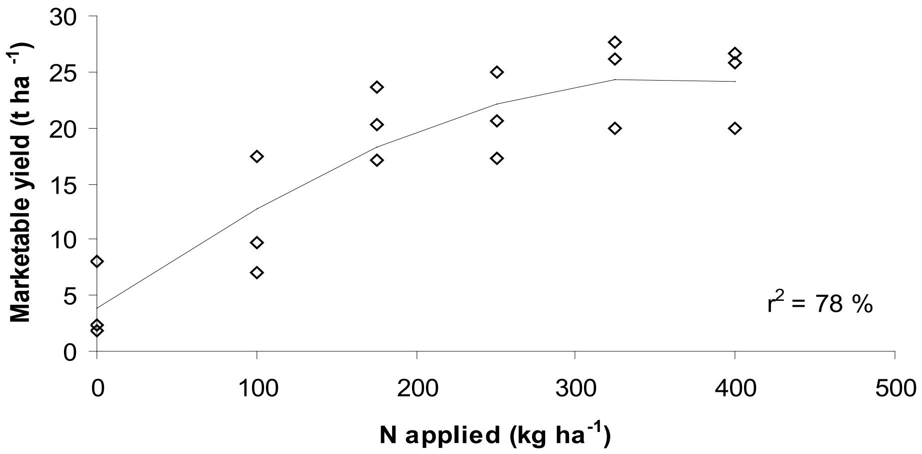
1. Comparison of the predicted optimum N application with the optimum N rate calculated from the N response trials; and
2. Comparison of the simulated N turnover with the soil mineral N and crop N offtake measured in the trial plots.

However, both types of evaluation were subject to difficulties in analysis associated with the complexity and variability of the experimental results, similar to those discussed by Sutherland (1986) and Goodlass (1997). The results from these trials show higher spatial variability than would be anticipated in a similar trial run on an experimental station, making it difficult to obtain reliable estimates of the optimum fertiliser dressing. This may be attributable to the differences in previous crop management and site history that inevitably occur on working farms. The spatial variability measured in yield is illustrated in figure 35. Where soils were known to be very uniform, e.g. Site 16, variation in yield between replicates was often very low (Figure 35a). However, at many other sites even where linear plus exponential yield response curves could be fitted (with highly significant correlation) the variation in yield between replicates was high, with a coefficient of variation of 10-20%. At some sites the coefficient of variation reached 29% between replicates in wheat (Figure 35b) and 47% between replicates in cabbage (Figure 35c).

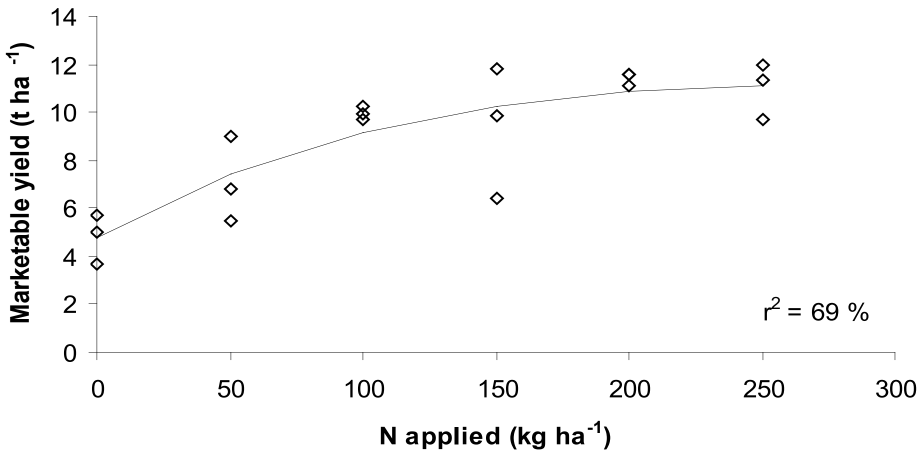
Figure 35. Variation in Yield on Replicated Plots
a) Site 16 1999, cabbage



b) Site 11 1999, winter wheat



c) Site 30 1999, Savoy cabbage



The advantage of process based simulation models, such as SUNDIAL and WELL_N, over statistical models, such as RB209 (MAFF, 1994) is the greater potential for simulating season and site specific variation in N turnover. However, despite high variation between replicate plots within a field, the data entered for the replicates were identical in SUNDIAL-FRS, and differed by only the spring soil mineral N values used in WELL_N. Soil measurements taken at the start of the trial indicated the inherent spatial variability of the sites. Plot specific measurements such as initial soil organic N and spring soil mineral N should help to capture the variability, and improve the accuracy of predicted optimum N rates and N turnover.

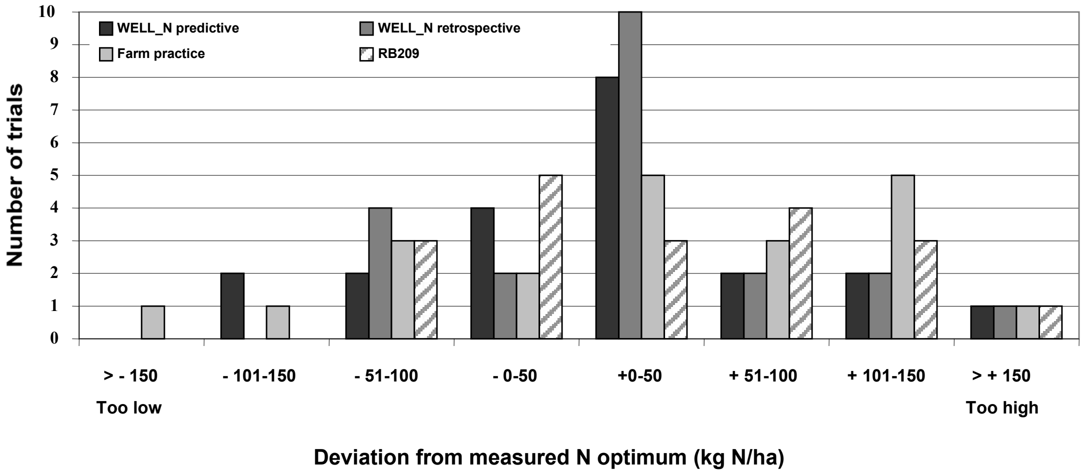
In the next 2 sections (3.4.1 and 3.4.2), the evaluations of WELL_N and SUNDIAL-FRS are described separately because different crops and soils are simulated by the 2 models. In the final section (3.4.3), the performance of the integrated system, Nitrogen-FRS, is evaluated against farm practice.

3.4.1. WELL_N Evaluation

Recommended Rates of N: Vegetables

Predictive and retrospective recommendations from WELL_N, RB 209 (6th edn.) and farm practice are compared in Figure 36 with the calculated N optima for the vegetable trials (including sugar beet and potatoes). Trials where it was not possible to calculate optima are excluded. A bandwidth of 50 kg N ha^{-1} was considered appropriate given the large errors associated with the calculation of the optima (Section 2.3.5), the variable recommendation interval between different recommendation systems and the errors in farm application rate.

Figure 36. Vegetable crops: Comparison of WELL_N and RB209 recommendations and farm practice with measured N optima.



Predictive and/or retrospective WELL_N recommendations were within ± 50 kg N ha^{-1} of the measured optima in 57% of the trials compared to 42% for RB209 and 33% for farm practice. Overall, WELL_N was superior to both RB209 and farm practice, but two trials (24/98, 22/99) underestimated and three (32/98, 33/98, 37/98) overestimated N requirement by more than 101 kg N ha^{-1}. Detailed results for all trials are given in Appendix B, but these five trials are also examined here.

In 24/98 the predictive underestimation of requirement was due to the marketable yield of calabrese being 30% higher than expected (retrospectively, with achieved yields, the recommendation was within 50 kg N ha^{-1}). Underestimation in 22/99, parsnip, was possibly due to weed competition which would have increased overall N requirement in the field, but also to the uncertainties in estimating the date of maximum potential yield for this overwintered crop, where foliage had died back before the commercial harvest. Apart from winter cereals, WELL_N is not fully parameterised for overwintered crops. Further work is required to determine parameters for the overwinter growth phase of vegetable crops.

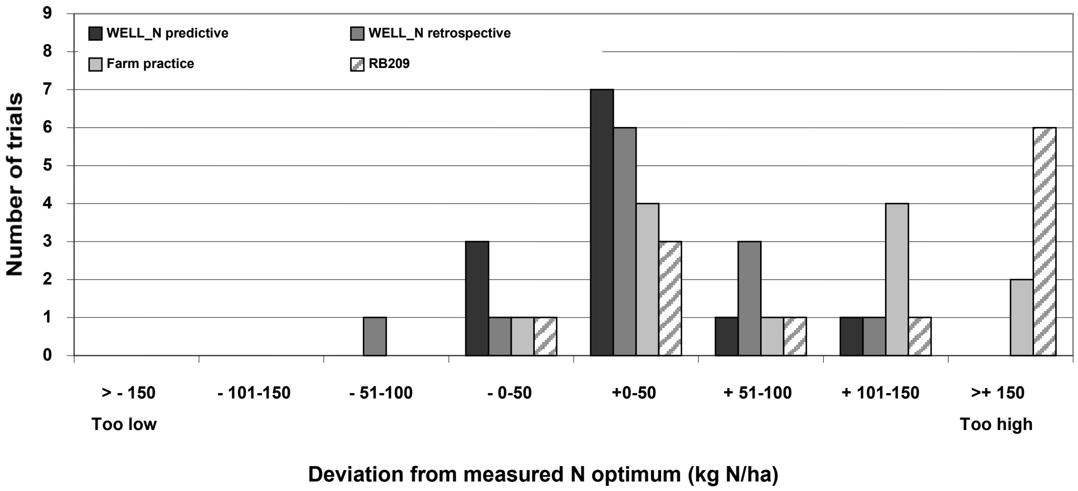
In the three trials where WELL_N overestimated N requirement, this occurred both predictively and retrospectively. In the Dutch white cabbage trial, 32/98, on a silt soil, both the SUNDIAL-FRS recommendation and farm practice were also above the calculated optimum. It is noticeable (see Appendix B) that both models underestimated crop N uptake and soil mineral N content when compared to the field data, suggesting that mineralisation rate was higher than expected. Indeed, estimating mineralisation from changes in spring and post harvest soil mineral N and plant N uptake on the zero N plots at this site indicated a rate more than double the default used in WELL_N. The rate was also higher than that estimated for other local marine silts used in the project, suggestive of unrecorded past applications of organic manures. At site 33/98, dwarf bean, it is likely that in the warm summer conditions prevailing, the model underestimated the speed of residue breakdown following the ploughing in of an unharvested salad onion crop five days prior to drilling the beans. For the overwintered salad onion crop (37/98), RB209, farm practice and WELL_N application rates agreed closely and out-yielded the low calculated optimum by 16%. There were no obvious reasons for the WELL_N overestimation as estimates of crop N uptake and soil mineral N were good and, although the crop was overwintered, the model run was updated with a spring measurement of plant size. WELL_N is not specifically parameterised for salad onions and was run as bulb onions, albeit with a lower expected yield. Dynamic models will only be of value in giving a broad indication of N requirement for salad onions, since farm practice is dominated by the use of N to control timing of crop maturity and leaf colour.

At the peat site (36), using mineralisation rates calculated from site data for lettuce and potato (Section 2.4), WELL_N gave predictive recommendations within 50 kg N ha^{-1}, and yields within 5% of the optimum. However, the calculated rates varied markedly between the two crops, 2.11 and 0.72 kg N ha^{-1} day^{-1} at 15.9ºC for lettuce and potato respectively. Further work is needed to enable the model to be reliably used on peat soils.

Recommended Rates of N: Cereals

Recommendations for the cereal trials are summarised in Figure 37. The predictive recommendations for WELL_N were within ± 50 kg N ha^{-1} of the measured optima in 83% of the trials. This compared with 50% of the trials for the retrospective recommendation, 42% for farm practice and 33% for RB209.

Figure 37. Cereal crops: Comparison of WELL_N and RB209 recommendations and farm practice with measured N optima.



In contrast to the vegetable trials, there was a tendency for each recommendation method to overestimate N requirement. This was particularly marked for RB209 and farm practice where rates deviated by more than 101 kg N ha^{-1} from the measured optima in 58 and 50% of the trials, respectively. WELL_N overestimated by the same amount in just one trial, 2/98, representing just 8% of its recommendations. At this site, lodging at high rates of N had reduced grain yields and lowered the optimum.

This summary is based on the 10 winter wheat and 2 winter barley trials which had detectable optima and excluded trials where organic manures had been applied. Also excluded are the 6 cereal trials on the structured clay soils of the Hanslope and Denchworth series. WELL_N was not specifically developed for highly structured soils and does not differentiate the leaching function and default mineralisation rate from those used with unstructured soils.

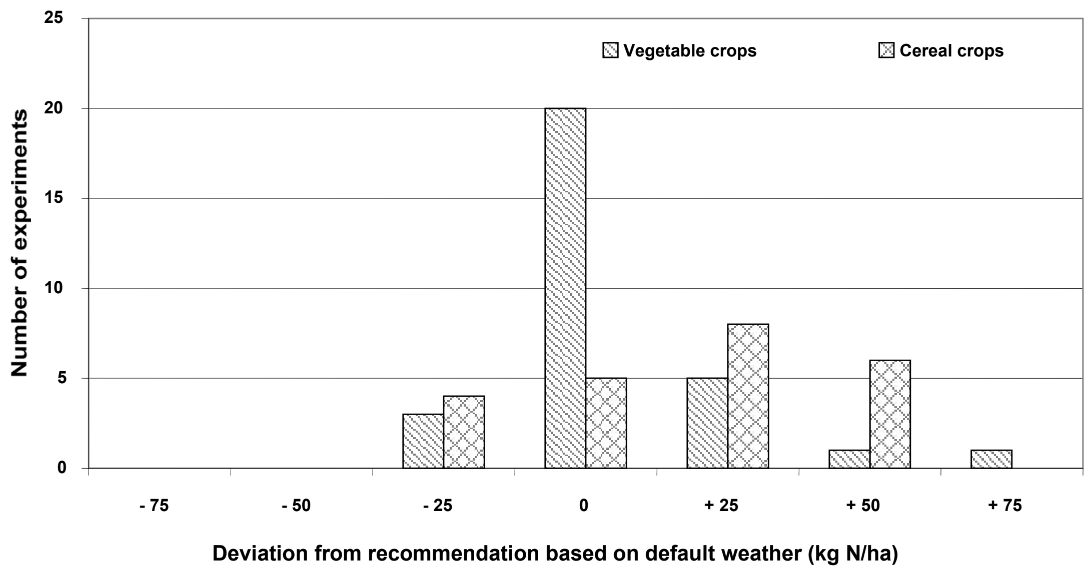
Thus no account is taken of preferential water flow between aggregates and in cracks in the soil profile, nor of adsorption/fixing of N by clay minerals. Nevertheless, WELL_N, with 2 of the 6 trials within 50 kg N ha^{-1} of the calculated optima, performed no worse than SUNDIAL-FRS. RB209 and farm practice did slightly better, with 3 out of the 6 trials meeting the criteria used.

Effect of Weather on Recommendations

It was noted in Section 3.3.1 that, during the two years of the field trials, most sites experienced higher than average rainfall, particularly in the spring. To investigate the impact of this on WELL_N, a comparison was made between recommendations obtained by using either default or actual weather throughout the growing season. The results are presented in Figure 38, which shows the change in recommended rate of N when actual weather was used.

As expected, given the two wet seasons, there was a tendency for recommendations to be higher when actual weather was compared to default weather. This was least marked with the vegetable crops, where 67% of the trials showed no change. Three sites, 26/98 (Lancashire) 28/98 (Lancashire), and 35/98 (Sussex) showed a decrease of 25 kg N ha^{-1} and one 22/98 (Suffolk) a 75 kg N ha^{-1} increase when actual weather was used. In contrast to the vegetable sites, only 21% of cereal trial recommendations were unaffected by the weather data used, but 63% showed increases of 25-50 kg N ha^{-1}. There are two possible explanations for this. First, the N applications to the winter cereal trials were made earlier in the year than on most of the vegetable trials and were consequently more at risk from leaching in the early spring. Second, the trial applications of N to the cereals in the first year were applied as a single dressing, again increasing the risk of leaching. For the purposes of comparison with trial results, the model was run with the N application dates used in the trial. In practice it would be advisable to run the model with updated actual weather immediately prior to each top-dressing.

Figure 38. Effect of using actual weather on WELL_N recommendations

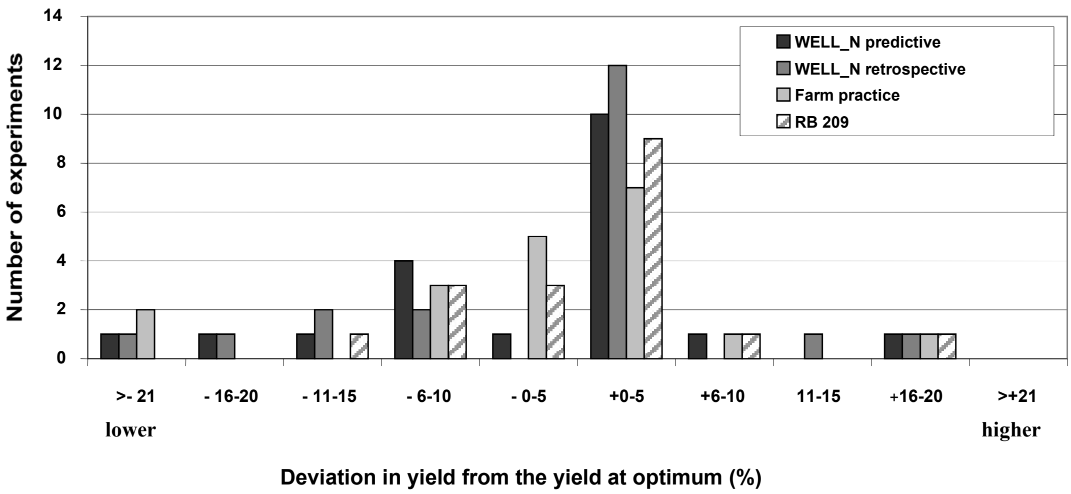


Although reference is made to 'actual' weather it should be realised that this was obtained from meteorological stations sited between 2 and 62 km from the trial and therefore may not closely reflect the weather experienced at the site. In particular, heavy localised showers, which can be important in determining leaching shortly after fertiliser applications, may have been missed. It is advisable whenever possible to use meteorological data, particularly rainfall, recorded on site.

Effect of recommendations on marketable yield
To estimate the potential effect of the recommended rates on marketable yield, yield at the recommended rate was expressed as a percentage of the yield at the optimum. For vegetable crops this is shown in Figure 39.

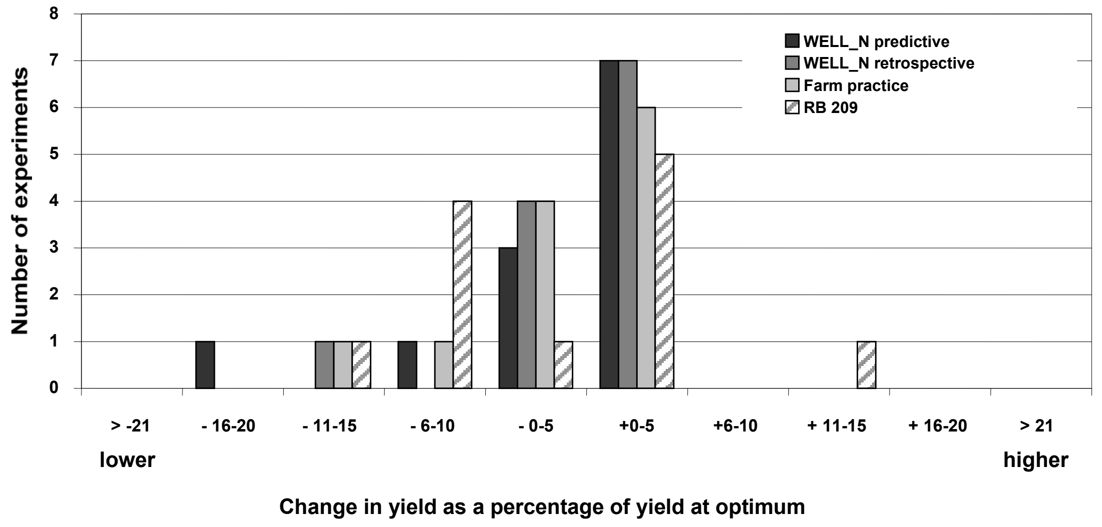
Using RB 209 or WELL_N predictively and retrospectively provided recommended rates which gave the same or higher marketable yields than those calculated for the optima in 60-70% of the trials. With farm practice this was achieved in just 47%. In trials 24/98 and 22/99, where WELL_N grossly underestimated N requirement for the reasons explained, the recommendations also led to large reductions in yield. Yield losses greater than 15% also occurred at sites 21/99(1), spinach (predictive and retrospective) and 37/99, salad onion (retrospective). Spinach is a fast growing crop, making it difficult to estimate the optimum from a single harvest. The crop grown with the WELL_N recommendation of 125 kg N ha^{-1} was judged by the farmer on the day of harvest to be of marketable quality, while with the 200 kg N ha^{-1} rate (close to the calculated optimum of 201 kg N ha^{-1}) was judged overmature. The salad onion crop, as noted in Appendix B, was very low yielding due to an uneven stand resulting from a cloddy seedbed. Using the low achieved dry weight in the retrospective analysis gave a low recommendation and a 24% lower marketable yield than at optimum. Yield per unit area under these conditions is an average of good and bad areas. To grow the good areas needs a higher N requirement than that given by a recommendation based on a low average yield. It is clearly wrong to compensate for patchy growth by reducing estimated potential yield.

Figure 39. Vegetable crops: Effect of WELL_N and RB 209 recommendations and farm practice on marketable yield.



The affect of recommendations on yield of cereals (excluding heavy clays) is given in Figure 40. Given a generally flat response to N at many sites, the yields obtained with the recommended rates and farm practice did not generally deviate by much from that calculated for the optima. WELL_N recommendations and farm practice gave yields within ±5% of the optimum in 83-92% of the trials, with RB 209 achieving considerably less at 50%. At only one site, 20/99, did a WELL_N recommendation reduce yield by more than 11%. Here, a winter wheat crop followed sugar beet for which details of residue incorporation were unavailable. Default values of residue appear to have overestimated N supply leading to an underestimate of N requirement and loss of yield.

Figure 40. Cereal crops: Effect of WELL_N and RB 209 recommendations and farm practice on marketable yield.



Crop N Uptake and Soil Mineral N

In comparison with measured values, WELL_N showed a tendency, with both vegetables and cereals, to overestimate crop N uptake and to underestimate mineral N remaining in the soil at harvest. Data for individual trials are shown in the appendices. Simulated values of crop N plus soil mineral N are shown plotted against measured values for all trials: vegetables in Figure 41 and cereals in Figure 42 (excluding clay soils). These XY plots show data points scattered about the lines of perfect agreement.

Figure 41. Vegetables: Simulated crop N + soil mineral N plotted against measured values. The line shown is the line of perfect agreement.

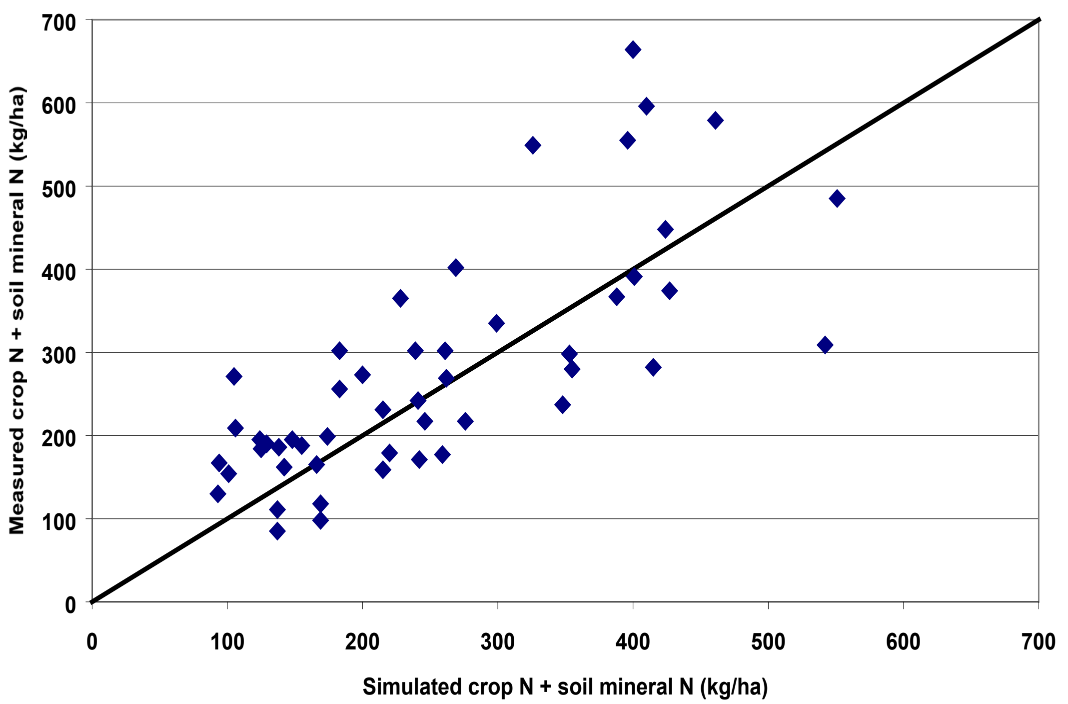
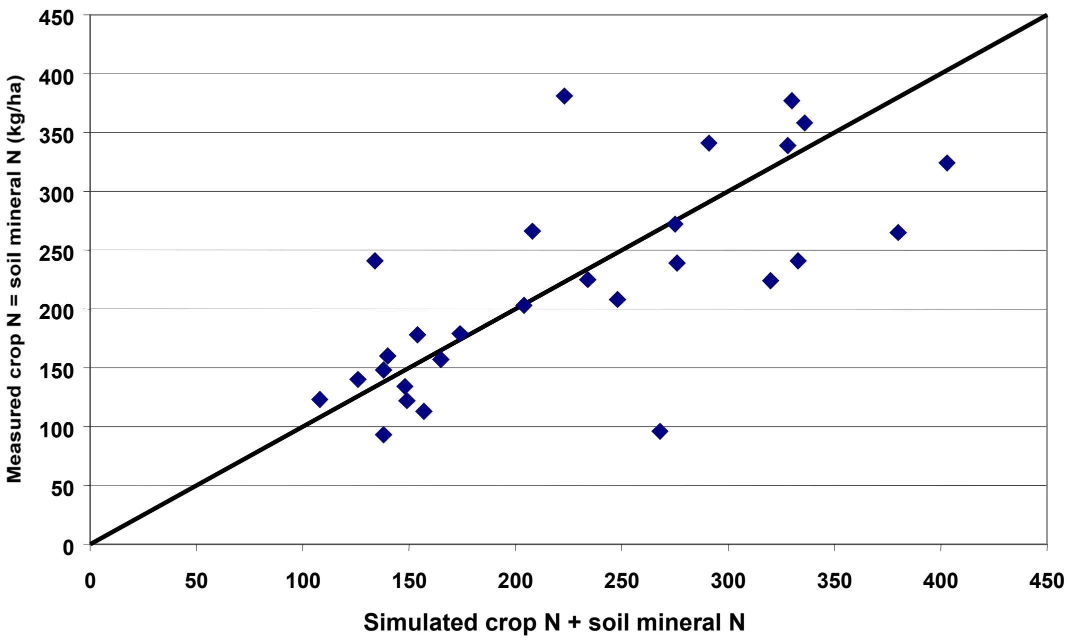


Figure 42. Cereals: Simulated crop N + soil mineral N plotted against measured values. The line shown is the line of perfect agreement.



Conclusion

The overall conclusion from both the vegetable and cereal sites is that, in the majority of circumstances, the use of WELL_N gives much the same yield as following RB209 or farm practice. WELL_N, however, is more likely to recommend the correct rate of N, thereby reducing fertiliser costs and wastage to the potential benefit of the environment.

3.4.2. SUNDIAL-FRS Evaluation

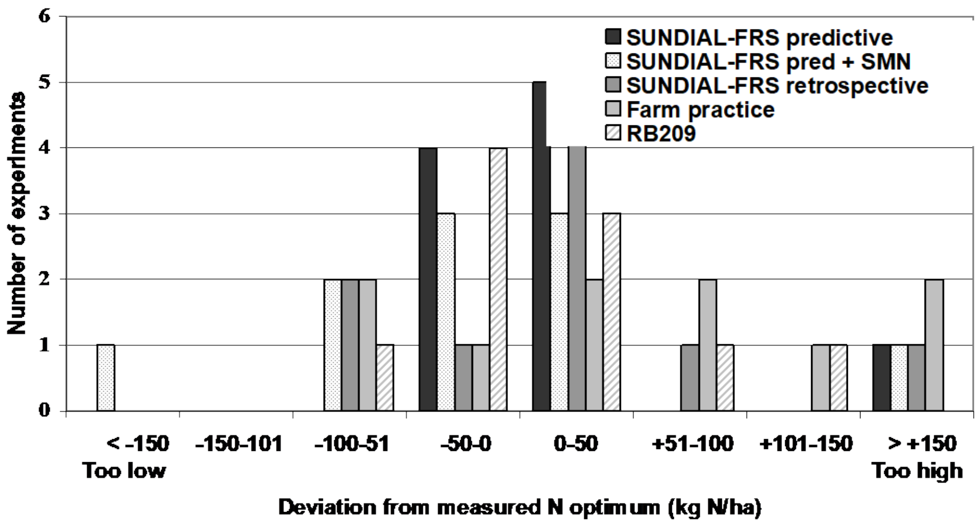
Recommended Rates of N: Vegetables

Predictive and retrospective recommendations from SUNDIAL-FRS, RB 209 (6th edn.) and farm practice are compared in Table 8 and Figure 43 with the calculated N optima for the vegetable trials (including sugar beet and potatoes). The SUNDIAL-FRS predictive recommendations use the expected marketable yield and default weather data from fertiliser application to harvest. The predictive + SMN recommendation uses spring SMN measurements (0-90cm) as an input, but relies on default weather and the predicted yield. A farmer might use this method to improve site specificity. The retrospective recommendations are based on actual yields and weather, and include spring SMN measurements. Comparisons were only possible at 10 sites, as trials where it was not possible to calculate optima are excluded, as are trials where there was no response to N (i.e. the optimum was zero). Similarly, trials with crops that are not parameterised in SUNDIAL-FRS were excluded. All sites where cauliflower was grown were also excluded, as the crop parameters were revised using the data from the trials. As in the WELL_N evaluation, a bandwidth of 50 kg N ha^{-1} was considered appropriate given the large errors associated with the calculation of the optima (Section 2.3.5), the variable recommendation interval between different recommendation systems and the errors in farm application rate.

Table 8. Vegetable crops. Summary of deviation of farm practice, SUNDIAL-FRS and RB209 recommendations from measured N optima. Expressed as percentage of trials.

Difference from optima	SUNDIAL Predictive	SUNDIAL Predictive + SMN	SUNDIAL Retrospec-tive	Farm practice	RB209
% within 50 kg N	90	60	60	30	70
% within 100 kg N	90	80	90	70	90
% over 100 kg N	10	20	10	30	10
Number of trials	10	10	10	10	10

Figure 43. Vegetable crops: Comparison of SUNDIAL-FRS and RB209 recommendations and farm practice with measured N optima.



90% of predictive SUNDIAL-FRS recommendations were within ± 50 kg N ha^{-1} of the measured optima compared to 70% for RB209 and 30% for farm practice (Table 8). At only one of the trials was the SUNDIAL-FRS predictive recommendations outside this range, at 32/98 (Dutch white cabbage).

Detailed results for all trials are given in Appendix B, but these two trials are also examined here. At site 32/98 the SUNDIAL-FRS recommendation was 220 kg N ha^{-1} above the optimum. WELL_N also over-estimated the optimum at this site. See discussion in the WELL_N section for further details.

Including spring SMN measurements tended to reduce the recommendations, so that fewer of the predictive recommendations were within ± 50 kg N ha^{-1} of the measured optima (60%). The methodology for using simple measurements such as SMN to improve site specificity requires further development. The SMN measurement has been used to adjust the modelled value, so resetting the model to correct the size of any loss or transformation processes.

However, if the model accurately simulates the *size* of processes but there is a slight discrepancy in *timing*, a simple adjustment of modelled SMN will introduce additional error as observed in these trials. A SMN measurement is easy to take and has potential to greatly improve recommendations. However, a simple adjustment of SMN is inadequate: development of a more complex methodology is needed.

Including actual weather and yield had no overall effect on the number of recommendations within 50 kg N ha^{-1} of the optima, but reduced the number of recommendations which were more than 100kgN/ha outside this range to one (10/99). At this site, the predictive recommendation for the potatoes was reasonable, being within 20 kg N/ha of the optimum. However, it was based on an expected yield which was much lower than that actually achieved (60 t/ha compared to a maximum yield of 82 t/ha). This suggests that SUNDIAL-FRS may need further work refining potato parameters under conditions of high yields.

Recommended Rates of N: Arable

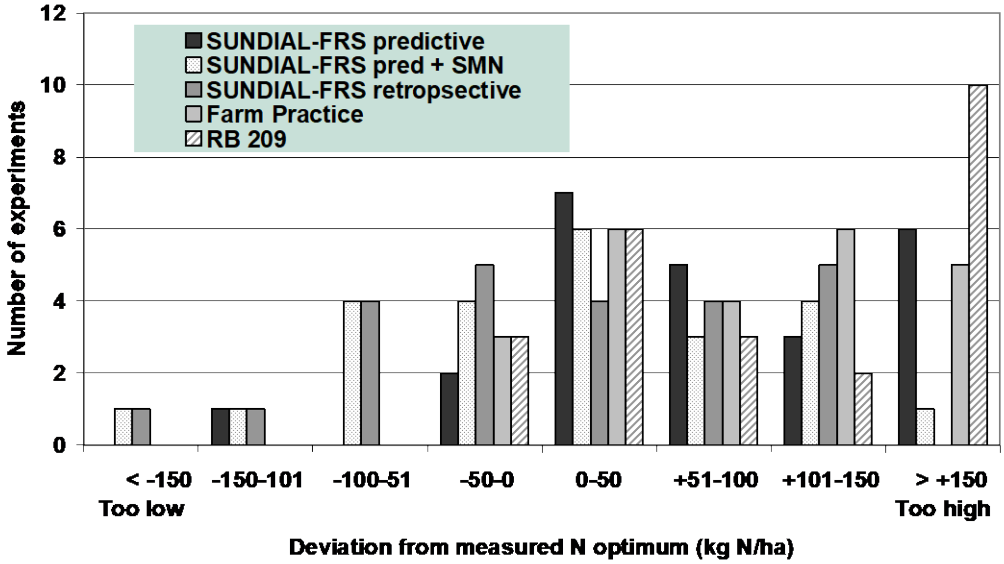
Predictive, predictive plus spring SMN and retrospective recommendations from SUNDIAL-FRS, RB 209 (6th edn.) and farm practice are compared in Table 9 and Figure 44 with the calculated N optima for the 24 arable trials which had detectable optima. Trials where it was not possible to calculate optima are excluded. Trials where there was no response to N (i.e. the optimum was zero) are included. There were 17 winter wheat, 3 winter barley and 4 oilseed trials. Unlike the WELL_N comparison, oilseed rape and trials where organic manures had been applied were included.

The predictive recommendations for SUNDIAL-FRS were within ± 50 kg N ha^{-1} of the measured optima in 38% of the trials (Table 9). This compared with 38% of the trials for farm practice and RB209. Including spring SMN measurements increased this to 42%, with fewer recommendations more than 100 kg N ha^{-1} out. There was no further benefit from using real weather and yields.

Table 9. Arable crops. Summary of deviation of SUNDIAL-FRS and RB209 recommendations and farm practice from measured N optima. Expressed as percentage of trials.

Difference from optima	SUNDIAL Predictive	SUNDIAL Predictive + SMN	SUNDIAL Retrospec-tive	Farm practice	RB209
% within 50 kg N	38	42	38	38	38
% within 100 kg N	58	71	71	54	50
% over 100 kg N	42	29	29	46	50
Number of trials	24	24	24	24	24

Figure 44. Arable crops. Comparison of SUNDIAL-FRS and RB209 recommendations and farm practice with measured N optima.



In contrast to the vegetable trials, there was a tendency for each recommendation method to overestimate N requirement. This was particularly marked for RB209 and farm practice where rates were overestimated by more than 101 kg N ha^{-1} from the measured optima in 50% and 46% of the trials respectively. SUNDIAL-FRS predictive recommendations overestimated by the same amount in 38% of the trails, and by 21% in the retrospective recommendations. At nine sites the SUNDIAL-FRS predictive recommendations was over 100 kg N ha^{-1} more than the optimum. Using spring SMN measurements improved most of these recommendations, although five still overestimated by more than 100 kg N ha^{-1} (2/99, 3/98, 3/99, 12/99, 16/98). At two sites the recommendation was more than 100 kg N ha^{-1} less than the optimum (13/99 and 17/99). Detailed results for all trials are given in Appendix B, and these trails are discussed in more detail below.

At 2/99, 3/99 and 12/99 there was no response to applied fertiliser N, i.e. the optimum was 0 kg N ha^{-1}. Two of these sites were winter OSR, which often shows little response to fertiliser N. The RB209 and farm rates at these sites were also far too high. At 3/98 and 16/98, where high yielding winter wheats followed OSR and set-aside respectively, the SUNDIAL-FRS recommendations were far too high. These results suggest that the OSR parameters may need further development, both as a current and as a previous crop. Set-aside as a previous crop may also require further development.

At 13/99, another OSR site, the SUNDIAL-FRS retrospective recommendation was much too low. Including the spring SMN values reduced the recommendation substantially. At 17/99, winter wheat on clay, again including the spring SMN values reduced the recommendation substantially, to 208 kg N ha^{-1} less than the optimum. There was no obvious reason for this poor recommendation.

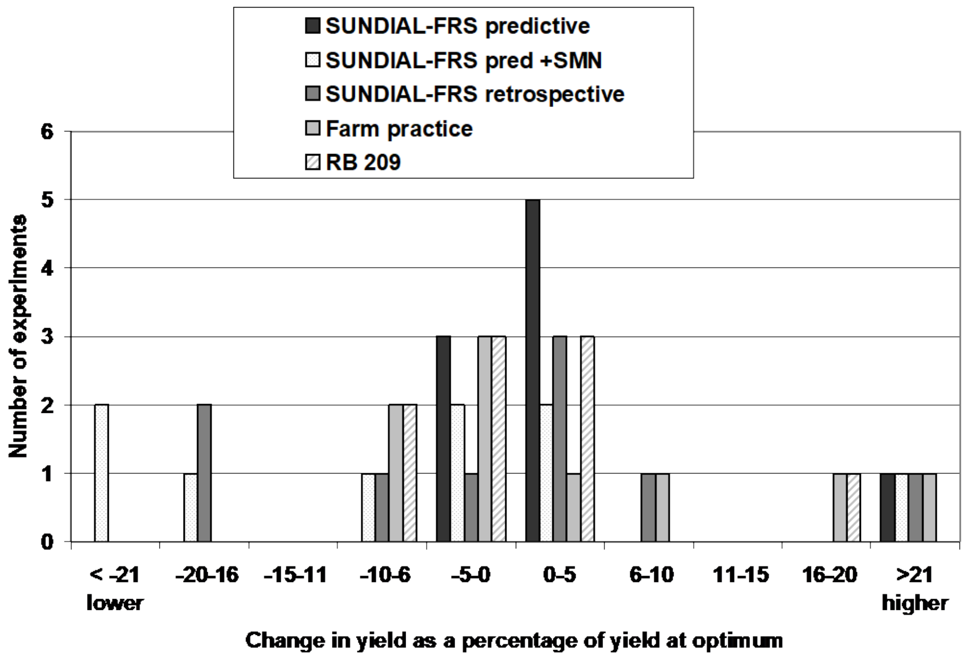
Effect of Recommendations on Marketable Yield
To estimate the potential effect of the recommended rates on marketable yield, yield at the recommended rate was expressed as a percentage of the calculated yield at the optimum (Table 10, Figure 45). For vegetable crops it was only possible to calculate yields at the SUNDIAL-FRS recommended rates at 9 sites. Sites where cauliflower was grown are excluded from the results.

If SUNDIAL-FRS is used predictively, the calculated yields were within 5% of the yield calculated at the optimum rate at all but one site (32/98). With RB209 and farm practice this was achieved in 67 and 44% of the trials, respectively. When spring SMN measurements were used to adjust the SUNDIAL-FRS recommendation, yields were generally reduced, and only 44% of the SUNDIAL-FRS recommendations gave calculated yields within 5% of the optimum. Again, this indicates the need for further development in the use of SMN measurements. Using actual weather and yields was of little benefit.

Table 10. Vegetable crops. Deviation of SUNDIAL-FRS, RB209 and farm practice calculated marketable yield from yield at optima. Expressed as percentage of trials.

Difference from yield at optima	SUNDIAL Predictive	SUNDIAL Predictive + SMN	SUNDIAL Retrospec-tive	Farm practice	RB209
within 5% of yield	89	44	44	44	67
within 10% of yield	89	55	66	77	89
Number of trials	9	9	9	9	9

Figure 45. Vegetable crops: Effect of SUNDIAL-FRS and RB 209 recommendations and farm practice on marketable yield.

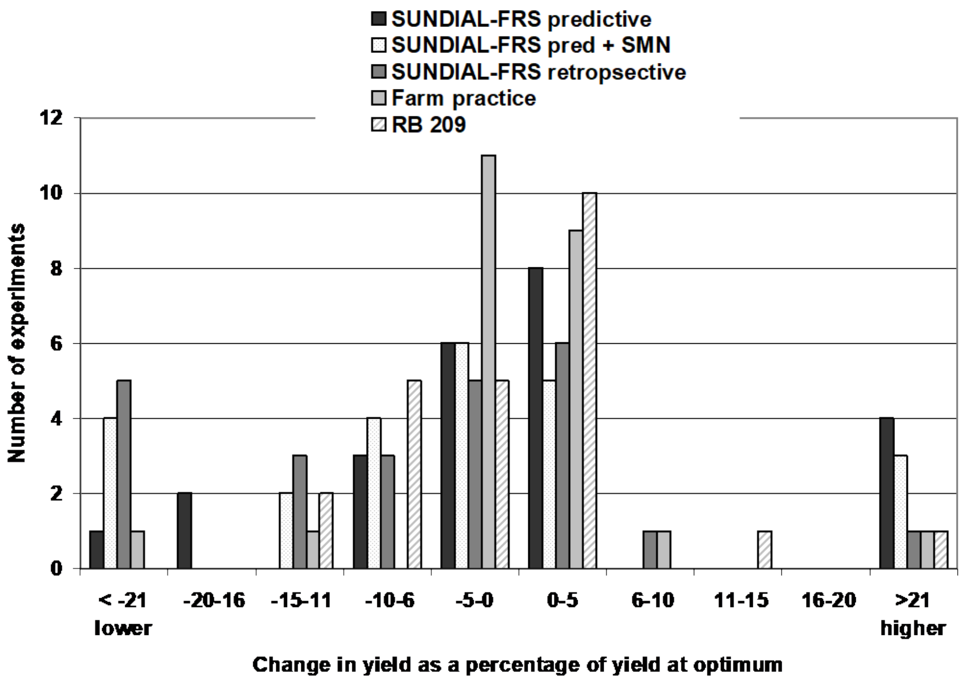


The effect of recommendations on yield of arable crops (cereals and OSR) is given in Table 11 and Figure 46. Yields could be calculated at 24 sites. Given a generally flat response to N at many sites, the yields obtained with the recommended rates and farm practice did not generally deviate by much from that calculated for the optima. Farm practice gave yields within ±5% of the optimum in 83% of the trials, with SUNDIAL-FRS used predictively and RB 209 achieving 58 and 63% respectively. When the spring SMN measurements were included, many of the SUNDIAL-FRS recommendations were reduced, and only 46% gave yields within ±5% of the optimum. Including actual weather and yields gave no further improvement.

Table 11. Arable crops. Deviation of SUNDIAL-FRS, RB209 and farm practice calculated marketable yield from yield at optima. Expressed as percentage of trials.

Difference from yield at optima	SUNDIAL Predictive	SUNDIAL Predictive + SMN	SUNDIAL Retrospec-tive	Farm practice	RB209
within 5% of yield	58	46	46	83	63
Within 10% of yield	71	63	65	87	84
Number of trials	24	24	24	24	24

Figure 46. Arable crops: Effect of SUNDIAL-FRS and RB 209 recommendations and farm practice on marketable yield.



Crop N Uptake and Soil Mineral N

Simulated and measured values were compared at each site, for the zero and maximum N rates (see Appendix B). The SUNDIAL-FRS simulations used actual weather, yields and applied, plus spring SMN measurements where available. Figures 47 and 48 show the plots of simulated vs measured crop N plus SMN at harvest for all the horticultural and arable sites respectively.

Figure 47. Horticultural Crops: SUNDIAL-FRS simulated crop N + soil mineral N plotted against measured values. The line shown is the line of perfect agreement.

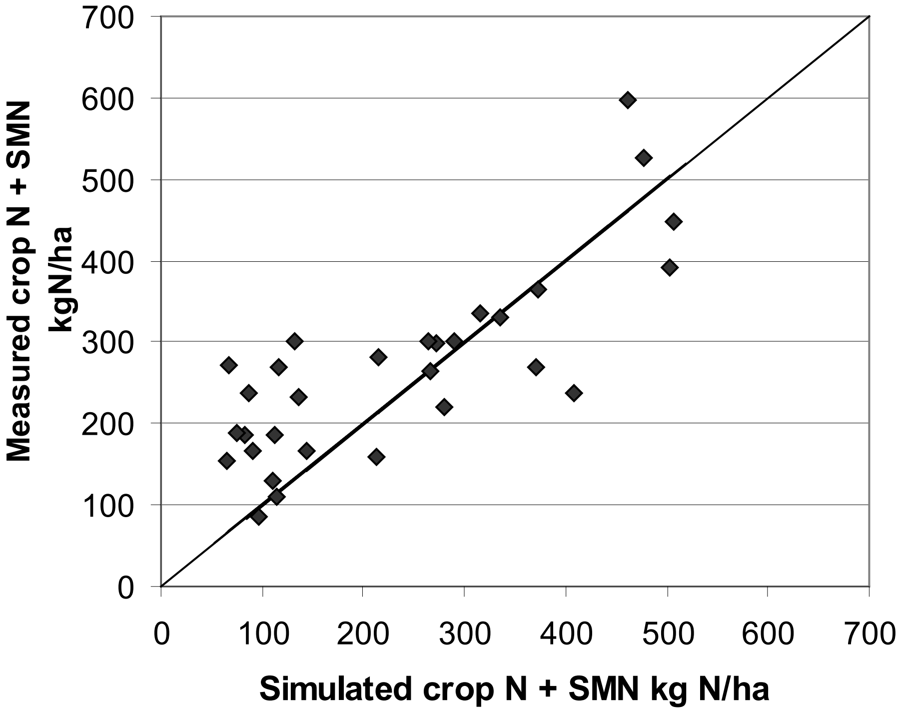


Figure 48. Arable Crops: SUNDIAL-FRS simulated crop N + soil mineral N plotted against measured values. The line shown is the line of perfect agreement.

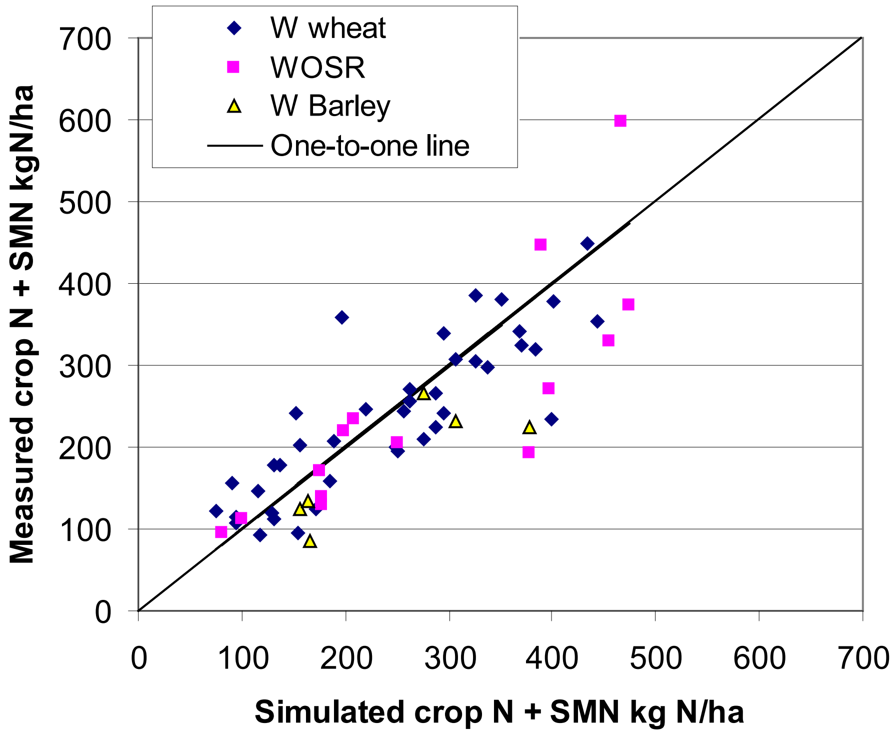


Table 12 summarises the statistical evaluation of the SUNDIAL-FRS simulations of soil mineral N + crop N uptake against measured values. The correlation between simulated and measured values is highly significant ($P<0.05$) in both horticultural and arable sites, at r=0.79 and r=0.82 respectively. The mean difference, M, indicates the level of bias in the simulations. Comparison of the Student's *t* value associated with *M* with the critical *t* value ($P<0.05$) indicates that the bias, *M*, is non-significant at arable sites (t=1.7, t_{crit}=2.0). At horticultural sites, the bias is very close to the non-significant level. The root mean squared error, *RMSE*, gives an indication of total error between simulated and measured values. $RMSE_{95}$ is the value of the *RMSE* statistic that would correspond to the 95% confidence interval in the measurements. At the horticultural sites, *RMSE* is greater than $RMSE_{95}$ (*RMSE*=35; $RMSE_{95}$=17)and so the total error is significant at $P<0.05$. At the arable sites, *RMSE* is very close to the $RMSE_{95}$ value (*RMSE*=25; $RMSE_{95}$=23) and so the total error can be considered to be non-significant at $P<0.05$. The average difference between simulated and measured values, indicated by the root mean squared value, *RMS*, is 92 kg N / ha at horticultural sites and 68 kg N / ha at arable sites. These values are surprisingly high, given the high correlation between simulated and measured values. The average difference is increased by large errors in a small number of values. This is reflected in the maximum error between measured and simulated values: 202 kg N / ha at horticultural sites and 153 kg N / ha at arable sites. Future work should focus on the sites at which high errors occur to determine whether there is some real process not included in the models or whether the measurements at these sites were erroneous.

Table 12. Measured Soil Mineral N + Crop N Uptake vs Value Simulated by SUNDIAL-FRS (statistics as described by Smith *et al*, 1996).

	Horticultural	Arable
r = Correlation coefficient	0.79	0.82
Student's *t* associated with *r*	6.91	11.11
Critical *t* value (at 5%)	2.04	2.00
M = Mean Difference (kg N / ha)	34	14
Student's *t* associated with *M*	2.1	1.7
Critical *t* value (at 5%)	2.0	2.0
RMSE = Root Mean Squared Error	35	25
$RMSE_{95}$	17	23
RMS = Root Mean Squared Deviation (kg N / ha)	92	68
Maximum Error (kg N / ha)	202	153
Number of Values	30	60

Conclusion
The overall conclusion from both the vegetable and arable sites is that, in the majority of circumstances, the use of SUNDIAL-FRS gives much the same yield as following RB209. However, SUNDIAL-FRS is more likely to recommend the correct rate of N, than RB209 or farm practice, thereby reducing fertiliser costs and wastage to the potential benefit of the environment. Using spring SMN measurements as diagnostics did not generally improve the recommendations, and was of little benefit in terms of yield. Further work is needed to develop the use of SMN as a field diagnostic. Overall, using actual weather and yield was of only small benefit. However, any potential improvements will have been hidden by the detrimental effect of using the spring SMN measurement.

3.4.3. Nitrogen-FRS Evaluation
The decision support system requires the evaluation to indicate which model should be used for each crop and on each soil type. Due to lack of response to nitrogen or the absence of a clear optimum nitrogen rate, it is not possible to use normal methods of model evaluation (such as given by Smith, *et al*, 1996) to provide this information. In a simple ranking test, the models were ranked in order of closest estimate of optimum nitrogen rate. Results were excluded from the trials where there was no clear optimum N rate. Trials showing no response to N were included, as this is a positive result, indicating no fertiliser N should be applied. The model giving the closest estimate of the optimum scored 1 point. Where the optimum was above the maximum rate included in the trial, the model recommending the highest nitrogen rate scored 1 point. Where 2 or more models gave the same result, the point was divided between them. The model was excluded from the ranking if it had been parameterised using data from the trial (e.g. SUNDIAL-FRS recommendations for cauliflowers), if it was unable to provide recommendations for that crop (e.g. there are no WELL_N recommendations for oilseed rape and no SUNDIAL-FRS recommendations for several vegetable crops) or if the simulation was under conditions for which it had not been developed (e.g. WELL_N on heavy clay soils). The total points were expressed as a percentage. Note that this test gives no indication of how good the estimate of optimum nitrogen rate is. The purpose of the test is to determine which model should be used to provide the recommendation. It does not constitute a statistical comparison of model performance. This simple test suggests SUNDIAL-FRS performs best overall in the arable sites and WELL_N performs best overall in the horticultural sites (see Table 13). This result is not a comparison of model performance, but provides a basis on which to select the default model: in the absence of further information, SUNDIAL-FRS will be used as the default model in arable sites; and WELL_N will be used as the default model in horticultural sites.

Table 13: Frequency of model showing closest match to optimum N rate

Model	Arable Crops	Horticultural Crops	Overall
SUNDIAL-FRS	33%	24%	30%
WELL_N	26%	32%	28%
RB209	15%	20%	17%
Farm Practice	26%	24%	25%

Further subdivision of the simple ranking test was used to indicate which model should be used for a particular crop or soil type (Table 14). For some crops and some soil types, this comparison was done using data at only one site, and so in no way should this be taken to be a statistical comparison. However, the comparison is useful because it provides a look-up table that can be coded into the decision support system to guide automatic model selection. As future field trials in other projects are completed, further data for evaluation will become available. Therefore, a user interface is included that allows the look-up table for automatic model selection to be altered according to future results. In addition, the user can select to manually override the automatic model selection at any time.

Table 14a: Model showing closest match to optimum N rate for a range of crops

Crop	Optimum Model
Winter Wheat	SUNDIAL / WELL_N
Winter Barley	SUNDIAL
Winter Oilseed Rape	SUNDIAL / RB209
Spring Oilseed Rape	SUNDIAL
Potatoes	SUNDIAL / RB209
Sugar Beet	SUNDIAL
Dutch White Cabbage	RB209
Savoy Cabbage	RB209
Brussels Sprouts	SUNDIAL
Cauliflower	WELL_N
Spinach	WELL_N
Red Beet	WELL_N / SUNDIAL / RB209
Calabrese	RB209
Crisp Lettuce	WELL_N
Carrot	WELL_N / SUNDIAL
Parsnip	RB209
Red Bulb Onion	RB209
Bulb Onion (sets)	WELL_N
Salad Onion	SUNDIAL
Leek	SUNDIAL
Dwarf Bean	RB209

Table 14b: Model showing closest match to optimum N rate for a range of soils

Soil	Optimum Model
Loamy Sand	SUNDIAL
Sandy Loam	SUNDIAL
Silt Loam	WELL_N
Sandy Clay Loam	SUNDIAL
Silty Clay Loam	RB209
Clay Loam	SUNDIAL
Clay	RB209
Peat	RB209

The automatic model selection is initially based on crop-type: the optimum model scoring 1, and all other models scoring 0. Where 2 models are ranked equally as the optimum, the automatic model selection passes to model preference according to soil type, again the optimum model for a given soil type scoring 1, and all other models scoring 0. Multiplication of the crop and soil score allows the optimum model with a final score of 1 to be determined.

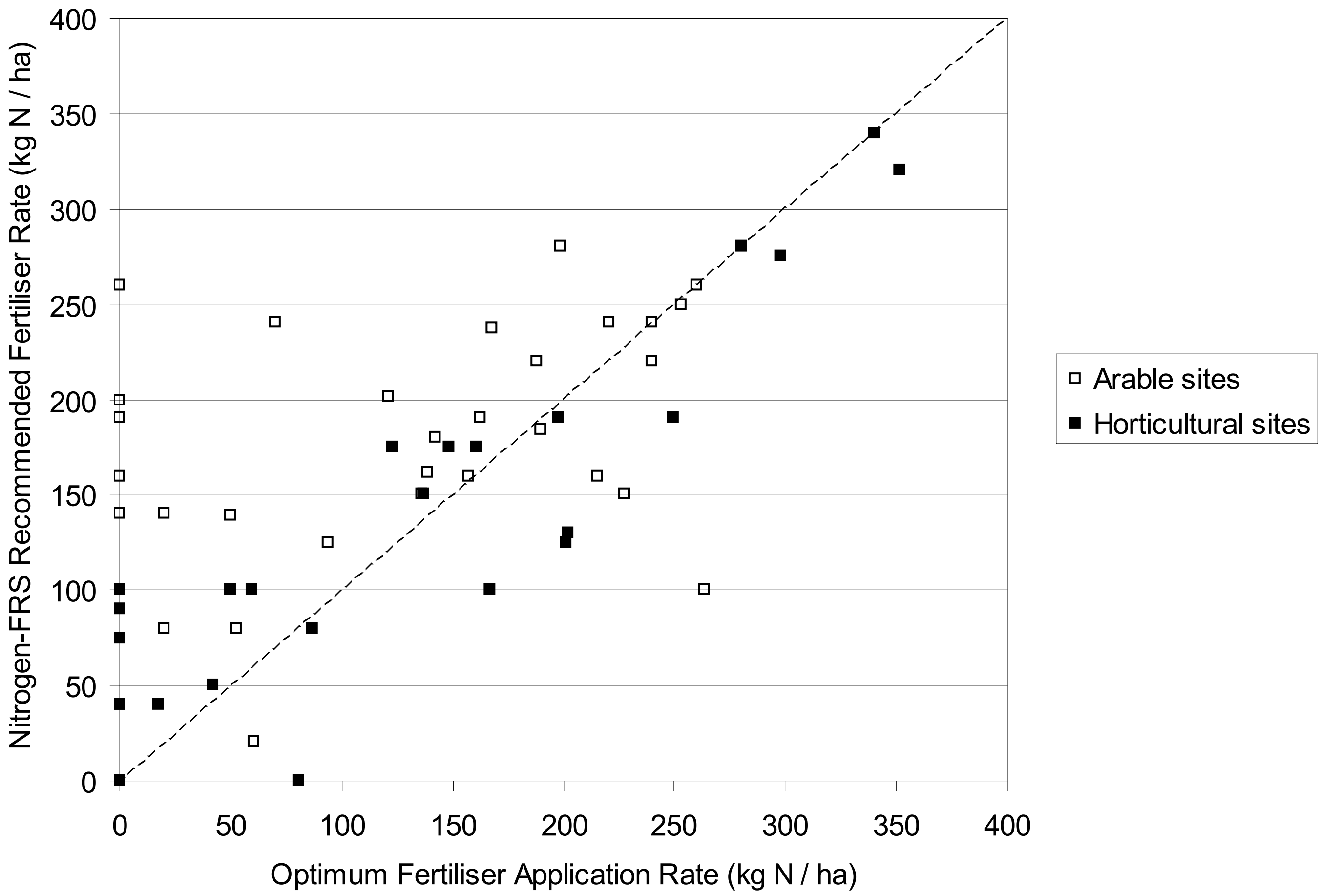
The automatic model selection procedure was used to obtain fertiliser recommendations from the combined Nitrogen–FRS. The ability of Nitrogen-FRS to predict the optimum nitrogen rate was compared to farm practice (Table 15).

Table 15. Evaluation against Optimum N Rate of Recommendations provided by Nitrogen-FRS and Farm Practice (statistics as described by Smith *et al*, 1996).

	Arable Sites		Horticultural Sites		Overall	
	Farm Practice	Nitrogen-FRS	Farm Practice	Nitrogen-FRS	Farm Practice	Nitrogen-FRS
r = Correlation coefficient	0.40	0.55	0.57	0.89	0.47	0.70
Student's *t* associated with *r*	2.58	3.83	3.22	9.38	4.08	7.39
Critical *t* value (at 5%)	2.03	2.03	2.07	2.07	2.00	2.00
M = Mean Difference (kg N / ha)	-67	-47	-35	-4	-54	-30
Student's *t* associated with *M*	-4.5	-3.4	-1.8	-0.4	-4.6	-3.1
Critical *t* value (at 5%)	2.0	2.0	2.0	2.0	2.0	2.0
RMS = Root Mean Squared Deviation (kg N / ha)	109	95	98	50	105	80
Maximum Error (kg N / ha)	255	260	215	100	255	260
Number of Values	36	36	24	24	60	60

In arable and horticultural sites, both farm practice and Nitrogen-FRS recommendations are significantly correlated to the optimum N rate, as shown by the correlation coefficient, *r* ($P < 0.05$). Nitrogen-FRS is more highly correlated to the optimum N rate than farm practice. The mean difference, *M*, indicates the bias in the error between the recommendation and the optimum N rate, and is significantly higher for farm practice than for Nitrogen-FRS. The root mean squared deviation, *RMS*, calculates the average deviation in the recommendation from the optimum N rate, and again is significantly higher for farm practice than for Nitrogen-FRS. These statistics indicate that the performance of Nitrogen-FRS is significantly better than farm practice, and show greater improvement for horticultural than arable sites. However, even for Nitrogen-FRS recommendations, the values of *RMS* range from 50 to 95 kg N / ha. The plot of recommended values against the optimum N rate (figure 49) illustrates that the high RMS values are attributable to the failure to reproduce a small number of values where the optimum N rates that occurred at 0. This is supported by the high maximum error between recommendations and the optimum N rate, suggesting that a small number of poor recommendations are increasing the apparent error. Further work is needed to simulate the processes that caused the optimum N rates to be 0.

Figure 49. Recommendations Provided by Nitrogen-FRS compared to Optimum N Rate



This novel approach has allowed us to combine all 3 recommendation systems, SUNDIAL-FRS, WELL_N and RB209 into a single fertiliser recommendation system. Different approaches are no longer competing: instead each helps the overall system to provide better recommendations. Under MAFF funding, an evaluation is currently underway of the performance of the revised RB209. If the evaluation indicates improved recommendations using revised RB209, this could also be incorporated into Nitrogen-FRS. This system allows diverse recommendation systems to be combined into one decision support system and used together to improve the overall result.

4. Conclusions

Nitrogen-FRS - Two dynamic N turnover models, SUNDIAL-FRS and WELL_N have been combined in a single package with a static model based on MAFF Reference Book 209 (MAFF, 1994). The package, referred to in this report as “Nitrogen-FRS”, allows the user to manually select the model, but also has the potential to automatically set the optimum model for use under particular field conditions. The system is Windows based and fully supported by default values, allowing simulations to be run quickly and easily with minimum requirement for user inputs. If more season and site specific data on crop management, soil description, weather data or manure inputs are entered, the dynamic models have the potential to provide season and site specific N fertiliser recommendations. The system provides further support for planning N use by presenting balance sheets, graphical plots and flow charts showing changes in the N status of the soil / crop system over time. It is envisaged that the system will be made available both as a standalone and a DESSAC compatible version. This is essential if the system is to make use of the additional functionality of DESSAC, while remaining accessible to DESSAC and non-DESSAC users alike.

Database of Measurements - In order to evaluate the likely accuracy of the fertiliser recommendations and simulations of N turnover on working farms, and to identify which model should be used to simulate a particular crop, field trials were run over 2 seasons on 37 sites across the UK including a range of arable and horticultural crops. Spring and harvest soil mineral N was measured at 0-30cm, 30-60cm and 60-90cm. Whole crops were sampled at harvest and analysed for N content. A database was constructed to store the descriptions and results of the field trials, and make it readily available for future use. This was designed with a hierarchical structure, starting with site identifiers (name of farmer etc.) expanding to general site data (e.g. location, soil type and previous husbandry details), and further to incorporate data which varies over time, and finally to data collected from each experimental plot.

Nitrogen Response -These trials were planned to evaluate the performance of the SUNDIAL-FRS and WELL_N fertiliser recommendation systems. In practice, they have told us more about response to nitrogen on working farms than about the functioning of the models themselves. No response to nitrogen application was observed in 14 of the trials out of a total of 64. Several of these are due to applications of manure – sites 9/99, 15/98 and 15/99, in which case an optimum of zero is quite reasonable. At other sites there were inadvertent applications of fertiliser N to the trial (sites 19/99 and 2/98). Nitrogen uptake, where no fertiliser was applied, varied from 21 to 266 kg N ha^{-1}. This reflects inherent differences in the fertility of the soil and the period and duration of crop growth. Surprisingly there was no significant relationship between spring soil mineral nitrogen and crop nitrogen uptake on zero plots, even when only the combinable crops, or winter wheat, alone were included. This suggests that soil characteristics more closely related to soil nitrogen supply, such as the soil organic nitrogen, may also be important input data. The optimum nitrogen fertiliser application (with an estimate of its 95% confidence interval) could be determined from a linear plus exponential relationship, for only 36% (23) of the trials. There were 9 trials where no optimum could be fitted, possibly because the optimum was below the range of N rates used. In some cases, this may be due to high levels of fertiliser N and manure being used on commercial farms in previous years, where maximum productivity is paramount. It indicates an inefficient system that may be detrimental to the environment. It is particularly difficult to evaluate the performance of the models on these sites where an optimum N rate cannot be established (the optimum is zero if there is no response to N).

Shortage of Data - The models have been run assuming default soil conditions and using a maximum of five years of cropping history at the arable sites, and often only one or two years of cropping history at the horticultural sites. These limited data inputs cannot account for the changes in soil nitrogen supply that occur under a long-term high nitrogen input regime. This problem affects dynamic fertiliser recommendation systems using minimal input data in the same way as it affects static systems such as RB209. The effect is likely to be experienced by a large proportion of farmers attempting to achieve maximum productivity. High nitrogen input regimes can only be adequately described using a dynamic simulation model, driven by a suite of field diagnostics or using field records of more than 10 years. Where farmers do not have adequate long-term records, further work to develop field diagnostic measurements that can be used to drive models will be essential for future improvements in precision.

Spatial Variability – In some trials, the difficulty in determining an optimum nitrogen application rate appears to be due to spatial variability in the field. Spatial variability is an inevitable feature at some sites due to factors such as field history, underlying soil type, drainage conditions and field gradient. Methods for accounting for spatial variability in fertiliser recommendation are urgently needed. This could be done by driving the model using measures of the previous years yield combined with remotely sensed field diagnostics. In the longer term, a model including lateral movement of nitrogen due to the gradient may be beneficial. At some sites, increased precision in fertiliser applications will only be possible by developing advanced methods to describe the spatial variability of the soil.

Evaluation of Models - Evaluation at both the vegetable and arable sites indicated that the fertiliser recommendations from SUNDIAL-FRS, WELL_N and RB209 resulted in similar crop yields. However, both WELL_N and SUNDIAL-FRS gave more accurate recommendations than RB209 or farm practice, thereby reducing fertiliser costs and wastage to the potential benefit of the environment. Using spring SMN measurements as diagnostics did not generally improve the recommendations in SUNDIAL-FRS, and was of little benefit in terms of yield. Further work is needed to develop the use of SMN as a field diagnostic. Overall, using actual weather and yield was of only small benefit.

Model Improvements - The need for a number of model developments was highlighted in the evaluation process. (1) The precision with which soil nitrogen supply can be simulated would be improved by the development of links to field diagnostic measurements describing the quality and quantity of organic matter in the soil profile. A promising method is the hot KCl extraction procedure currently being investigated at IACR Rothamsted, IGER North Wyke and ADAS Gleadthorpe. (2) A module describing variable crop N uptake has been developed for SUNDIAL-FRS in earlier work. It was not implemented in the evaluated model as previous evaluations on experimental farms had not indicated the need for this extra level of complexity. However, on working farms, where fertiliser has been applied to achieve maximum possible yield for a number of years, variable uptake is a more important factor and so this module should be implemented. (3) Description of nitrogen sequestration from porous bedrock may be important in shallow soils. A new module to describe this could use the porosity of bedrock and the history of nitrogen leaching from the profile to determine the potential for nitrogen sequestration during periods of drought. (4) Where farmyard manures were applied, errors are observed associated with the timing of nitrogen mineralisation from the manure. Farmyard manures are inherently variable in nature. The farmyard manure parameters used in SUNDIAL-FRS are based on an average standard for each manure type. There is a need to develop a manure module that will allow improved description of a specific manure according to diagnostic manure measurements and information that is available to the farmer.

Evaluation of Nitrogen-FRS -When all 3 models were combined into the single package, Nitrogen-FRS, the fertiliser recommendations were significantly better than farm practice. It should be emphasised that the farmers participating in the trials were highly skilled at selecting optimum application rates. They were very familiar with the conditions on their farms and had years of experience in determining the nitrogen fertiliser rate that should be applied. As a result, farm practice was highly correlated with the observed optimum N rate. However, Nitrogen-FRS consistently provided improved recommendations over farm practice. This indicates the success of combining the 3 nitrogen recommendation systems into a single package. Different approaches to fertiliser recommendation no longer need to compete: instead each helps the overall system to provide better recommendations. Since the initiation of this project the 7th edition of RB209 has been published (MAFF, 2000). This should also be incorporated into Nitrogen-FRS, to provide a single source of the latest information for both arable and vegetable crops. This system allows diverse recommendation systems to be combined into one decision support system and used together to improve the overall result.

5. Exploitation of Results

5.1 Decision Support System

Nitrogen-FRS is due to be released during 2001. It will be distributed under licence or by subscription to pay for continued product support. The system will be available on CD or over the Internet. The Internet has the advantage of low cost distribution and rapid product upgrade. A business plan is currently being negotiated between IACR, HRI, MAFF and the partners of this project.

5.2 Database

Researchers may apply to HRI for a copy of the database and guide.

5.3 Further work

The overall objective of the work was to develop a combined fertiliser recommendation system using the existing models, SUNDIAL-FRS, WELL_N and RB209, and to demonstrate the effectiveness of the system using the results of field trials on working farms. This has been achieved, and the evaluation of the recommendations provided by the combined system, Nitrogen-FRS, show a significant improvement in accuracy over the recommendations provided by the individual models. In parallel with these developments, SUNDIAL-FRS has received 3 years additional funding from MAFF since the start of this project, and so its interfaces and facilities have advanced since this project was planned. These developments have already been incorporated in Nitrogen-FRS but corresponding upgrades to the interfaces for WELL_N have yet to be made. As a result the consistency and effectiveness of the system would be improved if the interfaces to WELL_N were updated to match the developments already made for SUNDIAL-FRS. Potential areas for improvement are outlined below:

1. *Weather Generation*. SUNDIAL-FRS can obtain default weather data for any given region using the internal weather generator, ETCETERA. The weather data needed to run WELL_N is different to that needed to run SUNDIAL-FRS. Recommendations from Nitrogen-FRS would be made more consistent by extending the weather generator used by SUNDIAL-FRS to provide data for WELL_N.

2. *Presentation of Results*. The recommended fertiliser application rate is clearly presented by the system for SUNDIAL-FRS, WELL_N and RB209. However, both SUNDIAL-FRS and WELL_N produce additional data relating to the soil nitrogen and carbon status, nitrogen losses from the soil, plant growth, soil water contents, etc. Because the theoretical basis of SUNDIAL-FRS and WELL_N is not the same, the types of results produced by the two models differ. Work has been completed to create graphical interfaces to present the results produced by SUNDIAL-FRS but the results produced by WELL_N have yet to be fully exploited. The range of information provided by Nitrogen-FRS would be increased by further development of the result screens for WELL_N.

3. *Access to Model Parameters*. Work has been completed to provide access to the parameters used to drive SUNDIAL-FRS through the graphical user interface. This helps users to understand what information is being used to generate a particular recommendation, and allows the user to enter more site specific input parameters. For instance, if the farmer uses a fertiliser blend that is not included in the list of fertiliser types, alterations can be made to the proportions of nitrogen compounds in the fertiliser used. The model parameters used by WELL_N differ from those used by SUNDIAL-FRS. The site specificity of Nitrogen-FRS would therefore be improved by developing similar parameter screens for WELL_N.

4. *Extending the system to include the latest version of RB209.* Since the initiation of this project a new version of MAFF Reference Book 209 (UK National Fertiliser Recommendations) has been published (MAFF, 2000). Incorporation of these recommendations within Nitrogen-FRS would provide a single source of the latest information for both arable and vegetable crops.

6. Glossary

Crop Nitrogen Offtake: Nitrogen removed from the field in the crop.

Crop Nitrogen Uptake: Total nitrogen taken up by the growing plant, including that recycled to the soil before harvest.

Decision Support System: a computerised system to provide information to support complex decision making processes.

Dynamic Simulation Model: A computer based model that recalculates the state of the system throughout the simulation, according to specific climate and soil conditions.

Denitrification: loss of nitrogen containing gas (N_2 and N_2O) by reduction of ionic oxides nitrate (NO_3^-) and nitrite (NO_2^-)

Immobilisation: the transformation of nitrogen from plant available forms in the soil to plant unavailable soil organic matter by biological and chemical processes.

Leaching: loss of nitrogen as soluble nitrate in drainage water.

Mineralisation: the transformation of nitrogen from soil organic matter to plant available forms by biological and chemical degradation processes.

Nitrification: the transformation of ammonium (NH_4^+) to nitrate (NO_3) by micro-organisms within the soil

Senescence: the loss of nitrogen from the plant after anthesis by leaf fall.

Static Simulation Model: a one-stage calculation that takes no account of progress of the soil/crop system with time.

Strawing: the covering of carrots with straw (c.40 t/ha) to protect the crop from frost during overwinter storage in the ground.

Volatilisation: the loss of ammonium nitrogen (NH_4^+-N) from the plant or soil as gaseous ammonia (NH_3).

7. References

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Site reference: 01 **Year: 1998**

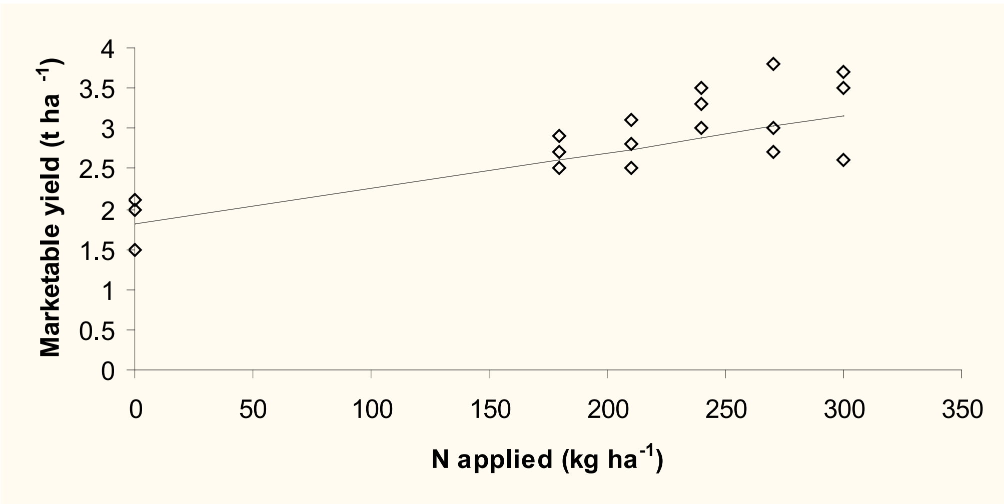
County:	**East Yorkshire**	**Soil series:**	**Burlingham**
Grid reference:	**TA 025562**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**6.1**
Previous crop:	**Winter barley**	**Available P:**	**11 mg/l (Index 1)**
Current crop:	**Winter oilseed rape** *cv.* **Apex**	**Available K:**	**119 mg/l (Index 1)**
		Total N:	**0.12 %**
Sowing date:	**11/09/97**		
Harvest date:	**24/07/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate *	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	2.1	4.0	76.3	5.3	67.1	23.3	17.5
180	2.7	5.5	108.4	24.4	91.3		
210	3.1	5.7	113.5	27.5	103.4		
240	3.1	5.3	117.9	21.1	119.7		
270	3.4	5.8	114.3	19.8	108.0		
300	3.1	5.9	130.3	23.8	183.9	33.3	16.4
Farm	3.1				74.9	31.7	12.1

*** Basal application of 10 kgN/ha applied to all plots and farm area 7/8/97.**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted.

APPENDIX A

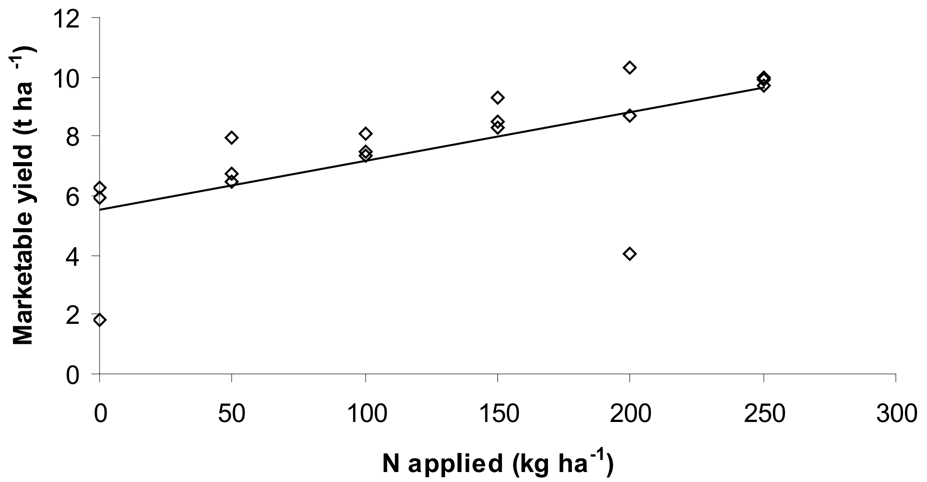
Site reference: 01 **Year: 1999**

County:	**East Yorkshire**	**Soil series:**	**Burlingham**
Grid reference:	**TA 025562**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**6.1**
Previous crop:	**Winter oilseed rape**	**Available P:**	**11 mg/l (Index 1)**
Current crop:	**Winter wheat**	**Available K:**	**119 mg/l (Index 1)**
	***cv.* Madrigal**	**Total N:**	**0.12 %**
Sowing date:	**15/09/98**		
Harvest date:	**22/08/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.7	9.2	68.6	20.6	51.6	25.2	13.9
50	7.0	11.6	111.7	29.0	43.9		
100	7.6	12.7	132.1	33.7	43.5		
150	8.7	13.5	153.5	34.9	42.1		
200	7.7	15.1	195.0	67.6	47.7		
250	9.9	16.1	243.9	57.7	60.0	25.0	12.0
Farm	11.8		217.4	41.9	35.6	13.7	11.5

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted.

Site reference: 02 Year: 1998

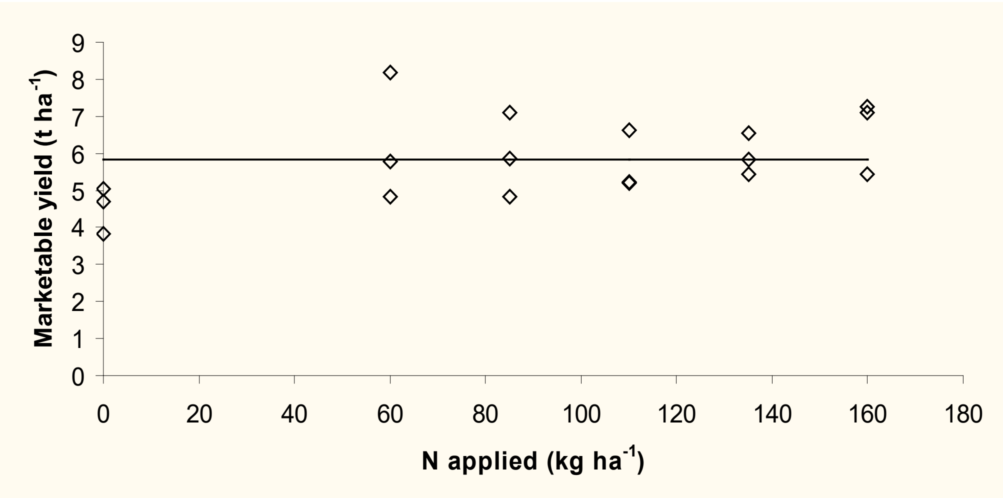
County:	**North Yorkshire**	**Soil series:**	**Escrick**
Grid reference:	**SE 373739**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**6.7**
Previous crop:	**Winter wheat**	**Available P:**	**87 mg/l (Index 5)**
Current crop:	**Winter barley**	**Available K:**	**249 mg/l (Index 3)**
	***cv.* Regina**	**Total N:**	**0.06 %**
Sowing date:	**21/09/97**		
Harvest date:	**01/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate *	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.5	8.7	82.4	3.7	53.6	31.2	21.3
60	5.9	9.9	114.9	4.0	86.9		
85	5.9	11.7	162.6	7.4	95.4		
110	5.7	11.4	171.5	8.3	77.1		
135	5.9	10.2	172.4	6.2	114.0		
160	6.6	12.1	207.7	8.8	116.5	33.0	26.9
Farm					96.0	37.5	19.1

*** Basal application of 10 kgN/ha applied to all plots and farm area 14/9/97.**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N application.

Site reference: 02 Year: 1999

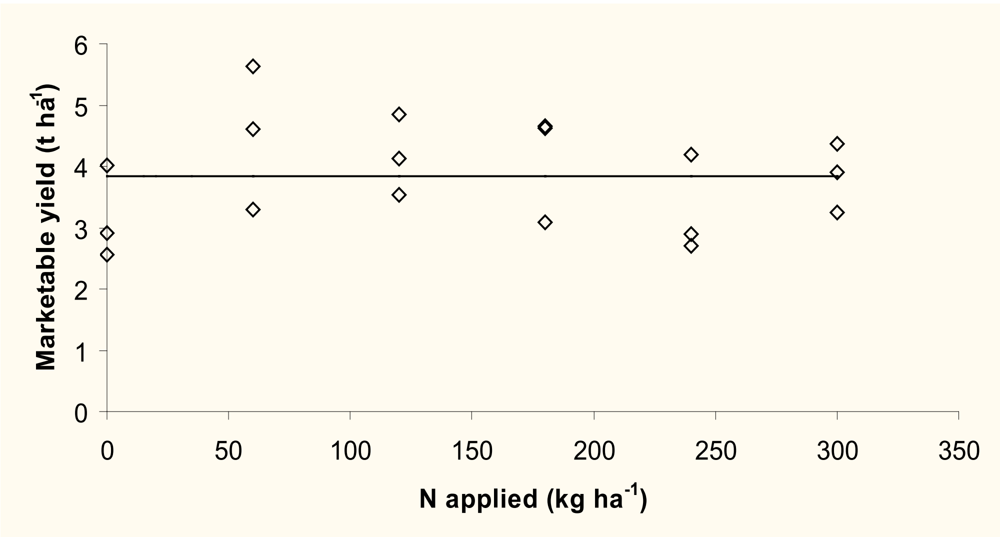
County:	**North Yorkshire**	**Soil series:**	**Escrick**	
Grid reference:	**SE 373739**	**Topsoil texture:**	**Sandy clay loam**	
		pH:		**6.7**
Previous crop:	**Winter barley**	**Available P:**		**87 mg/l (Index 5)**
Current crop:	**Winter oilseed rape**	**Available K:**		**249 mg/l (Index 3)**
	***cv.* Pronto**	**Total N:**	**0.06 %**	
Sowing date:	**27/08/98**			
Harvest date:	**31/08/99**			

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate *	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	3.2	8.6	124.4	37.3	65.6	14.5	14.8
60	4.5	10.6	181.3	50.9	56.5		
120	4.1	10.2	191.6	70.8	63.1		
180	4.1	10.9	199.7	78.2	89.3		
240	3.3	10.4	183.3	90.4	145.6		
300	3.9	11.0	211.5	88.7	147.2	50.6	37.0
Farm	4.8		261.7		5.5	12.4	13.0

*** Basal application of 45 kgN/ha applied 13/9/98 to all plots and farm area.**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N

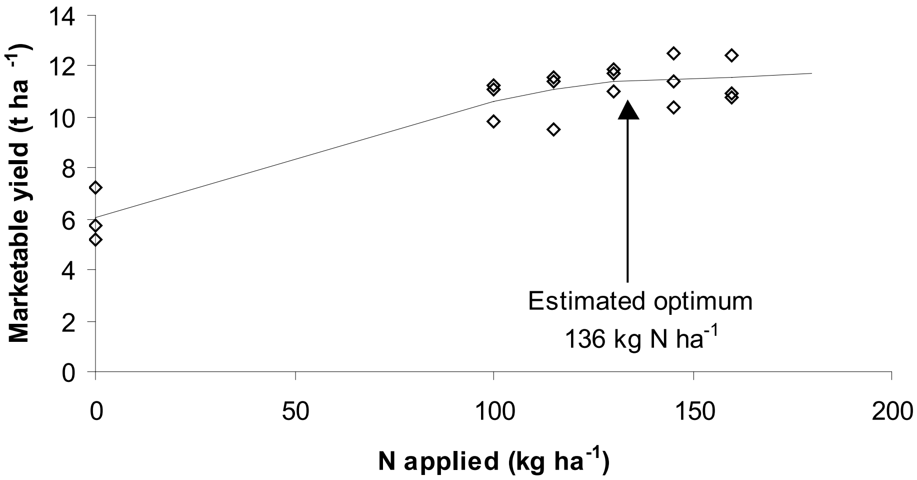
Site reference: 03a Year: 1998

County:	**Kent**	**Soil series:**	**Hamble**
Grid reference:	**TR 317525**	**Topsoil texture:**	**Silt loam**
		pH:	**6.9**
Previous crop:	**Winter oilseed rape**	**Available P:**	**65 mg/l (Index 4)**
Current crop:	**Winter wheat *cv.* Consort**	**Available K:**	**180 mg/l (Index 2)**
		Total N:	**0.07 %**
Sowing date:	**18/09/97**		
Harvest date:	**10/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	6.1	8.5	73.3	9.6	27.8	7.9	7.0
100	10.7	14.8	167.5	22.8	18.8		
115	10.8	15.8	189.3	29.6	24.6		
130	11.5	15.4	190.7	22.4	21.3		
145	11.5	16.3	220.7	33.2	19.2		
160	11.4	15.3	206.9	26.6	27.3	8.8	6.4
Farm	10.4				6.4	6.2	7.9

Response of marketable yield (t ha-1) to N applied (kg ha-1)



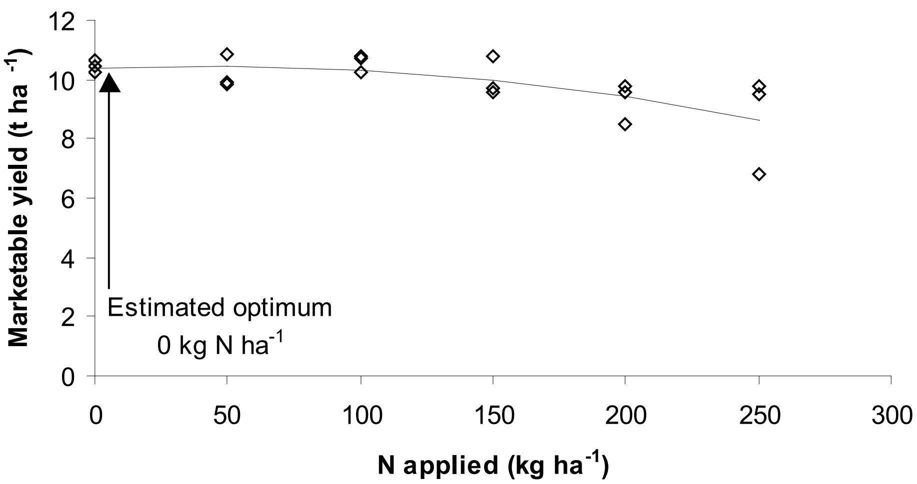
Site reference: 03b Year: 1999

County:	**Kent**	**Soil series:**	**Hamble**
Grid reference:	**TR 317525**	**Topsoil texture:**	**Silt loam**
		pH:	**6.9**
Previous crop:	**Field peas**	**Available P:**	**mg/l (Index 3)**
Current crop:	**Winter wheat**	**Available K:**	**mg/l (Index 2)**
	***cv.* Chaucer**	**Total N:**	**0.07 %**
Sowing date:	**17/09/98**		
Harvest date:	**09/08/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	10.4	14.7	162.1	32.9	19.7	14.3	6.6
50	10.2	13.9	187.6	37.7	22.1		
100	10.6	15.5	225.8	53.5	44.9		
150	10.0	13.7	230.1	50.2	27.6		
200	9.3	14.1	232.8	68.2	24.1		
250	8.7	13.3	244.3	74.4	47.8	23.3	8.8
Farm	10.2		195.9		31.4	17.9	10.5

Response of marketable yield (t ha-1) to N applied (kg ha-1)



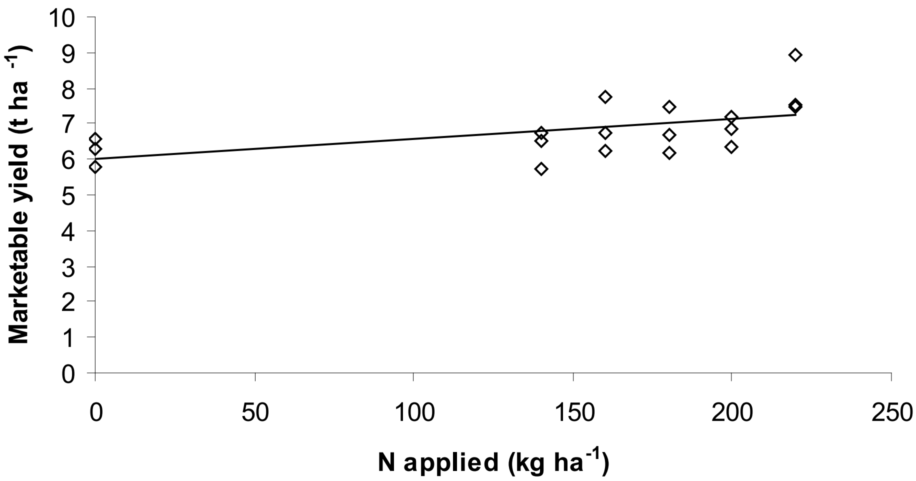
Site reference: 04 Year: 1998

County:	**Kent**	**Soil series:**	**Hamble**
Grid reference:	**TQ 883625**	**Topsoil texture:**	**Silt loam**
		pH:	**5.2**
Previous crop:	**Winter wheat**	**Available P:**	**53 mg/l (Index 4)**
Current crop:	**Winter wheat**	**Available K:**	**334 mg/l (Index 3)**
	***cv.* Soissons**	**Total N:**	**0.14 %**
Sowing date:	**10/10/97**		
Harvest date:	**27/07/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	Kg N ha-1	kg N ha-1
0	6.2	9.6	106.5	18.6	65.5	21.3	13.4
140	6.3	10.7	132.3	25.7	91.8		
160	6.9	10.3	136.8	21.7	85.8		
180	6.8	11.4	163.7	36.9	96.5		
200	6.8	9.8	142.2	20.0	92.6		
220	8.0	11.5	173.5	24.6	147.2	38.3	27.5
Farm 264	8.4				70.3	65.4	76.5

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted

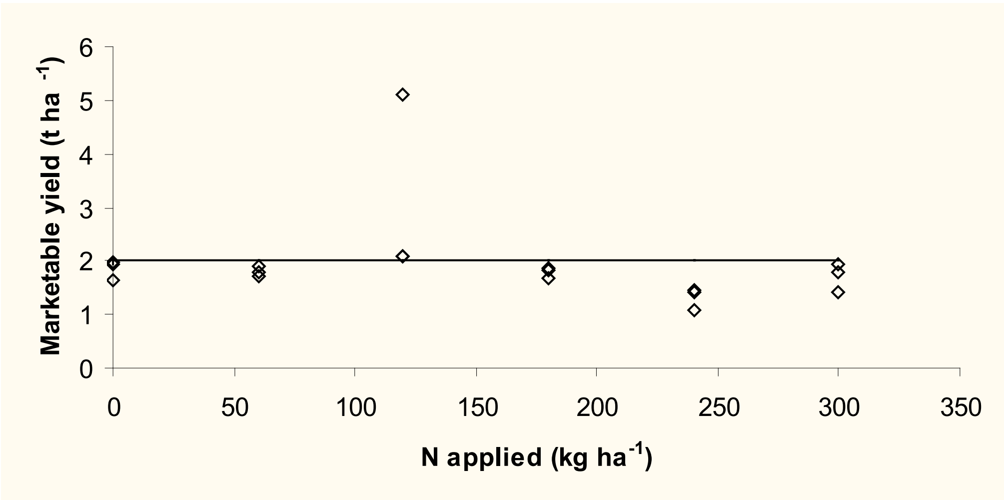
Site reference: 04 Year: 1999

County:	**Kent**	**Soil series:**	**Hamble**
Grid reference:	**TQ 883625**	**Topsoil texture:**	**Silt loam**
		pH:	**5.2**
Previous crop:	**Winter wheat**	**Available P:**	**53 mg/l (Index 4)**
Current crop:	**Winter oilseed rape**	**Available K:**	**334 mg/l (Index 3)**
	***cv.* Apex**	**Total N:**	**0.14 %**
Sowing date:	**02/09/98**		
Harvest date:	**15/07/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	**Marketable yield**	**Total dry weight yield**	**N uptake**	**N returned in crop residues**	**Soil mineral N after harvest**		
					0-30 cm	**30-60 cm**	**60-90 cm**
kg N ha-1	**t ha-1**	**t ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**
0	**1.9**	**9.7**	**102.0**	**43.2**	**39.8**	**16.5**	**11.3**
60	**1.8**	**8.3**	**107.1**	**43.9**	**48.2**		
120	**3.1**	**10.6**	**153.8**	**42.2**	**46.3**		
180	**1.8**	**9.1**	**112.3**	**46.4**	**106.2**		
240	**1.3**	**7.9**	**121.9**	**76.7**	**125.5**		
300	**1.7**	**10.0**	**121.0**	**56.8**	**170.8**	**23.9**	**13.7**
Farm 110	**1.6**		**101.1**		**129.8**	**73.6**	**73.1**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N

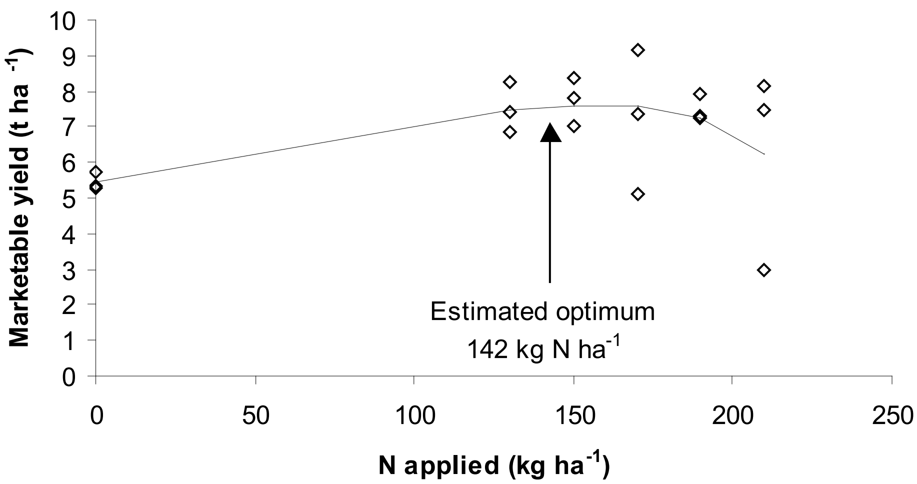
Site reference: 05 **Year: 1998**

County:	**Bedfordshire**	**Soil series:**	**Bearsted**
Grid reference:	**SP 955248**	**Topsoil texture:**	**Sandy loam**
		pH:	**6.9**
Previous crop:	**Field peas**	**Available P:**	**28 mg/l (Index 3)**
Current crop:	**Winter wheat** *cv.* **Hereward**	**Available K:**	**124 mg/l (Index 2)**
		Total N:	**0.24 %**
Sowing date:	**05/10/97**		
Harvest date:	**15/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	5.5	10.7	99.9	24.6	96.7	32.5	18.2
130	8.0	15.2	224.8	79.8	105.0		
150	7.7	13.0	193.0	47.2	125.1		
170	7.2	14.7	242.8	86.3	124.1		
190	7.5	13.9	227.2	76.7	135.1		
210	6.2	11.7	213.9	85.7	153.8	81.2	50.2
Farm 222	8.3				131.7	59.2	29.2

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 05 **Year: 1999**

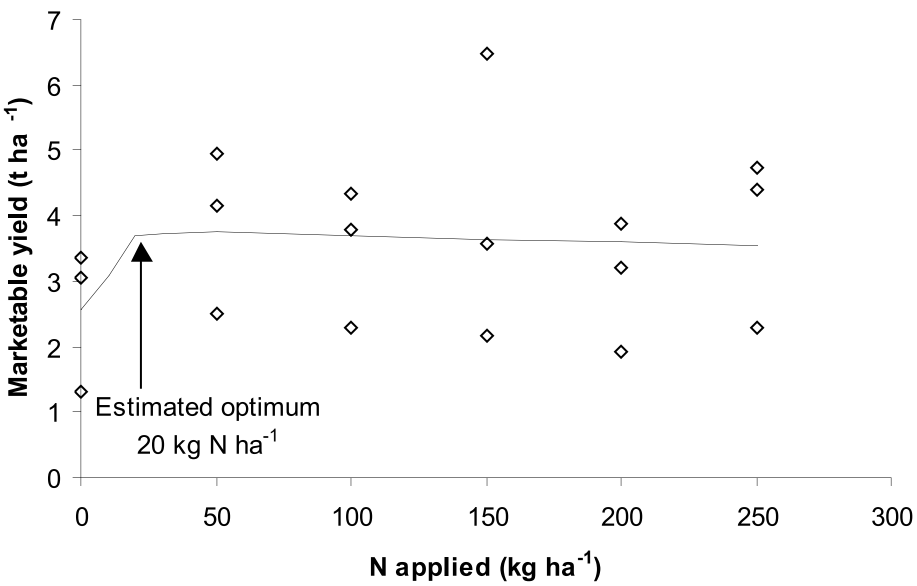
County: **Bedfordshire** **Soil series:** **Bearsted**
Grid reference: **SP 955248** **Topsoil texture:** **Sandy loam**
pH: **6.9**
Previous crop: **Winter wheat** **Available P:** **28 mg/l (Index 3)**
Current crop: **Winter wheat** **Available K:** **124 mg/l (Index 2)**
***cv.* Rialto** **Total N:** **0.24 %**
Sowing date: **19/10/98**
Harvest date: **22/08/99**

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	2.6	6.3	45.4	13.8	45.5	33.8	22.5
50	3.9	7.8	71.2	18.6	40.9		
100	3.5	8.6	75.1	26.3	38.7		
150	4.1	9.0	107.4	38.1	49.4		
200	3.0	8.3	100.5	48.8	53.6		
250	3.8	8.6	116.3	43.7	75.0	77.6	69.6
Farm 125	3.7		106.3		43.6	25.8	24.3

Comments: Yields reduced by blackgrass infestation

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 06a Year: 1998

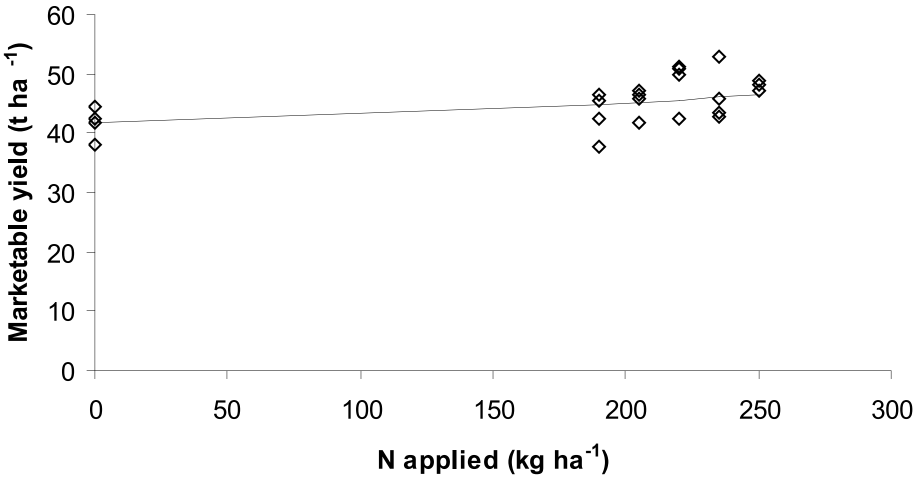
County:	**Cambridgeshire**	**Soil series:**	**Elmton**
Grid reference:	**TF 074009**	**Topsoil texture:**	**Clay loam**
		pH:	**7.7**
Previous crop:	**Winter wheat**	**Available P:**	**65 mg/l (Index 4)**
Current crop:	**Potatoes**	**Available K:**	**279 mg/l (Index 3)**
	***cv.* Maris Piper**	**Total N:**	**0.16 %**
Sowing date:	**05/05/98**		
Harvest date:	**28/09/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**39.1**	**10.5**	**96.2**	**4.8**	**41.7**	**56.5**	
190	**40.1**	**10.8**	**100.1**	**5.0**	**31.9**		
205	**42.7**	**11.5**	**106.6**	**5.3**	**45.1**		
220	**46.8**	**12.0**	**118.3**	**6.0**	**45.4**		
235	**44.3**	**11.6**	**112.3**	**5.6**	**47.7**		
250	**41.9**	**11.0**	**112.3**	**5.7**	**48.8**	**56.1**	
Farm 240	**31.1**						

Comments: Soil reaches limestone at 60 cm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted

Site reference: 06b Year: 1999

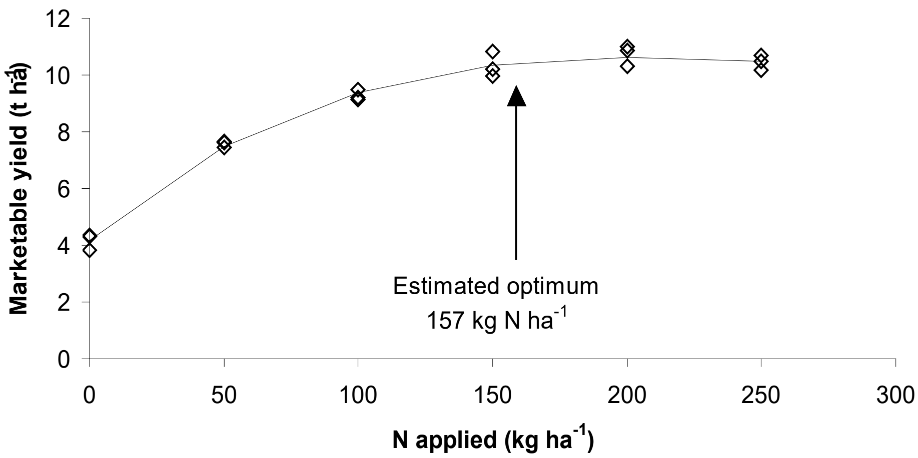
County: Cambridgeshire **Soil series:** Elmton
Grid reference: TF 074009 **Topsoil texture:** Clay loam
pH: 7.6
Previous crop: Field peas **Available P:** mg/l (Index 3)
Current crop: Winter wheat *cv.* Riband **Available K:** mg/l (Index 3)
Total N: 0.16 %
Sowing date: 03/09/98
Harvest date: 04/08/99

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.2	8.4	58.5		55.0		
50	7.6	15.1	124.9		56.7		
100	9.3	17.7	169.1		52.5		
150	10.3	19.4	182.2		44.4		
200	10.7	21.5	255.5		55.4		
250	10.5	20.5	281.9		56.6		
Farm 190	10.5		254.1		45.0		

Comments: Soil sampled only to 30 cm.
% N determined for whole plant sample, therefore it was not possible to calculate N return in residues.

Response of marketable yield (t ha-1) to N applied (kg ha-1)



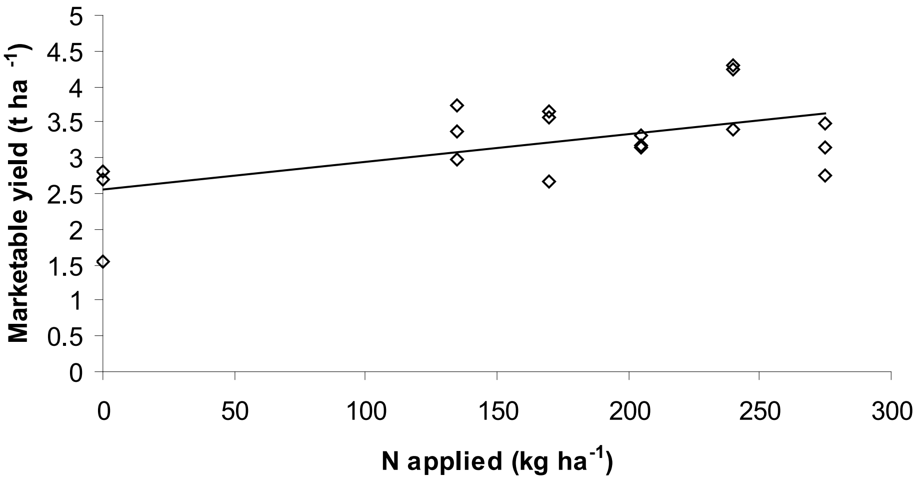
Site reference: 07 Year: 1998

County:	**Lancashire**	**Soil series:**	**Downholland**
Grid reference:	**SD 304059**	**Topsoil texture:**	**Clay loam**
		pH:	**7.5**
Previous crop:	**Winter wheat**	**Available P:**	**15 mg/l (Index 1)**
Current crop:	**Winter oilseed rape**	**Available K:**	**190 mg/l (Index 2)**
	***cv.* Apex**	**Total N:**	**0.10 %**
Sowing date:	**27/08/97**		
Harvest date:	**03/08/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	30-60 cm kg N ha-1	60-90 cm kg N ha-1
0	**2.3**	**4.1**	**65.3**	**9.0**	**38.1**	**20.5**	**9.5**
135	**3.4**	**6.6**	**128.2**	**26.3**	**50.4**		
170	**3.3**	**7.0**	**144.5**	**39.5**	**82.8**		
205	**3.2**	**6.7**	**144.9**	**39.4**	**112.5**		
240	**4.0**	**6.5**	**159.5**	**29.1**	**148.4**		
275	**3.2**	**6.8**	**154.3**	**46.9**	**97.8**	**32.0**	**15.7**
Farm 174	**2.9**				**45.7**	**15.2**	**36.8**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted

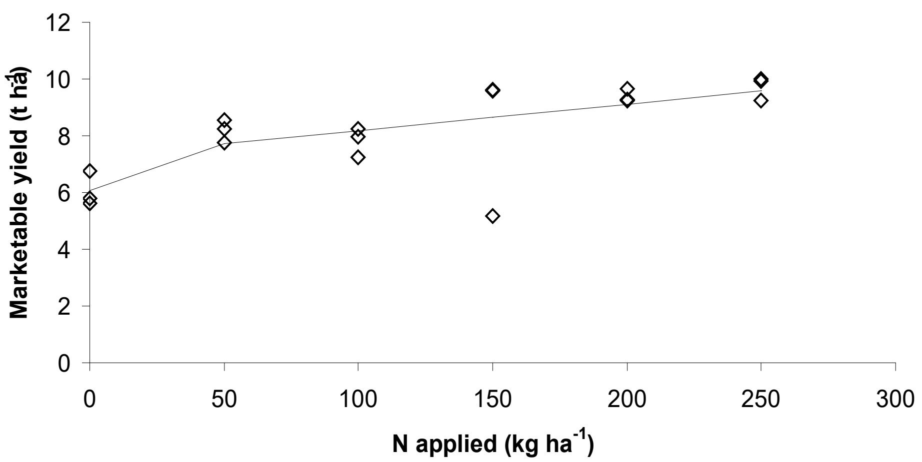
Site reference: 07 Year: 1999

County:	**Lancashire**	**Soil series:**	**Downholland**
Grid reference:	**SD 304059**	**Topsoil texture:**	**Clay loam**
		pH:	**7.5**
Previous crop:	**Winter oilseed rape**	**Available P:**	**15 mg/l (Index 1)**
Current crop:	**Winter wheat**	**Available K:**	**190 mg/l (Index 2)**
	***cv.* Rialto**	**Total N:**	**0.10 %**
Sowing date:	**04/10/98**		
Harvest date:	**12/08/99 (trial)**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**6.1**	**10.6**	**97.7**	**20.0**	**40.5**	**23.6**	**16.1**
50	**8.2**	**13.0**	**148.8**	**28.1**	**34.3**		
100	**7.8**	**13.4**	**148.3**	**34.2**	**39.9**		
150	**8.1**	**13.7**	**186.5**	**40.8**	**40.3**		
200	**9.4**	**16.9**	**269.4**	**83.3**	**54.4**		
250	**9.7**	**16.1**	**286.0**	**83.7**	**35.8**	**36.4**	**18.7**
Farm 215	**8.7**		**181.6**		**48.8**	**26.7**	**12.2**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: Optimum above maximum N rate used

Site reference: 08 Year: 1998

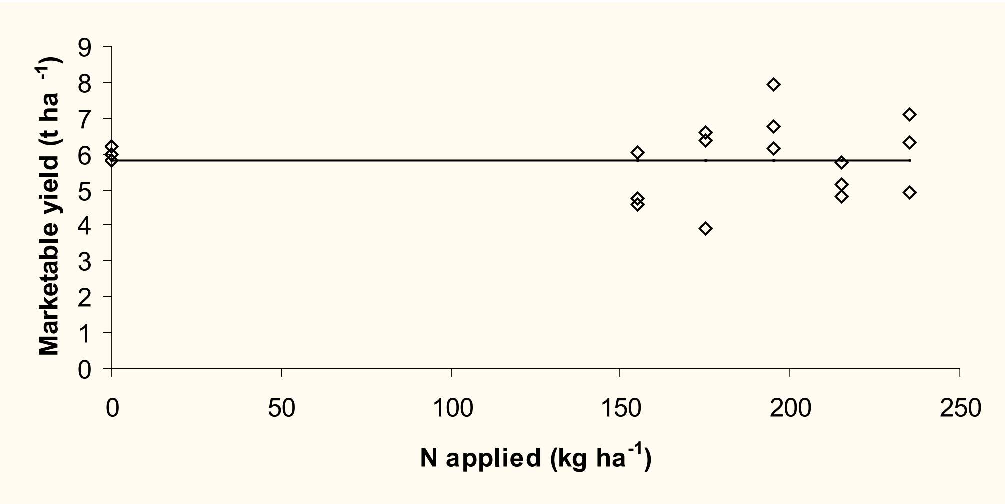
County: Lancashire
Grid reference: SD 306053
Previous crop: Field peas
Current crop: Winter wheat *cv.* Hussar
Sowing date: 09/09/97
Harvest date: 14/08/98

Soil series: Downholland
Topsoil texture: Clay loam
pH: 7.6
Available P: 20 mg/l (Index 2)
Available K: 237 mg/l (Index 2)
Total N: 0.16 %

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	6.2	12.5	106.2	52.1	34.5	12.5	10.9
155	5.2	11.8	157.2	95.1	151.9		
175	6.4	13.5	191.9	107.7	148.5		
195	6.2	13.8	176.6	117.7	93.7		
215	6.0	12.5	190.6	123.5	104.8		
235	5.5	11.5	167.3	105.3	138.1	22.9	11.9
Farm 174	9.0						

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N

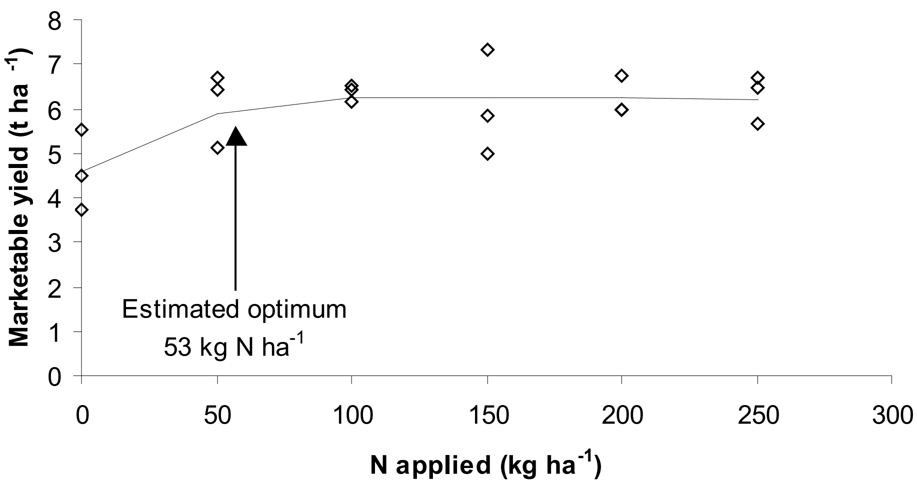
Site reference: 08 **Year: 1999**

County:	**Lancashire**	**Soil series:**	**Downholland**
Grid reference:	**SD 306053**	**Topsoil texture:**	**Clay loam**
		pH:	**7.6**
Previous crop:	**Winter wheat**	**Available P:**	**20 mg/l (Index 2)**
Current crop:	**Winter barley**	**Available K:**	**237 mg/l (Index 2)**
	***cv.* Regina**	**Total N:**	**0.16 %**
Sowing date:	**10/10/98**		
Harvest date:	**28/07/99 (trial)**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.6	6.4	65.5	11.3	38.6	14.1	15.4
50	6.3	9.1	114.7	25.9	32.5		
100	6.4	9.1	115.8	27.3	30.1		
150	6.3	9.4	137.2	34.1	40.9		
200	6.1	8.1	131.6	27.8	43.8		
250	6.2	9.3	136.1	36.5	47.4	18.8	22.4
Farm 160	5.8		124.1		30.2	18.0	15.5

Response of marketable yield (t ha-1) to N applied (kg ha-1)



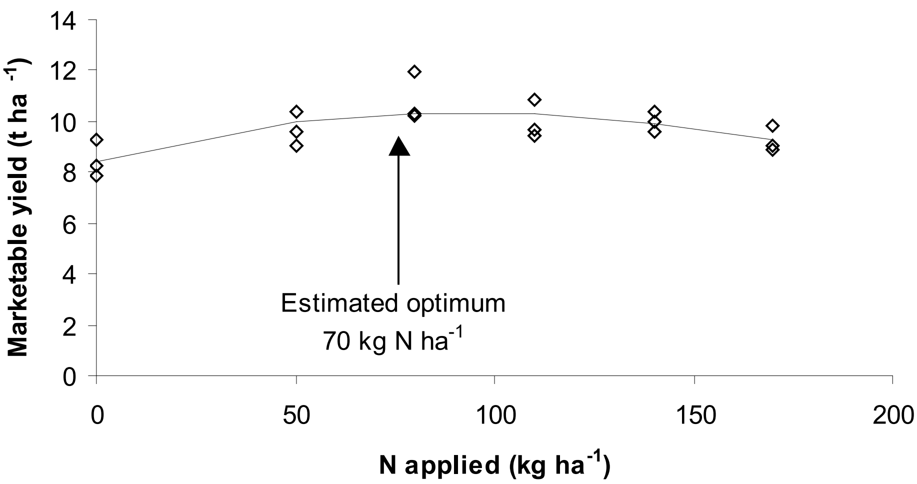
Site reference: 09 Year: 1998

County:	**Cheshire**	**Soil series:**	**Hodnet**
Grid reference:	**SJ 492461**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**5.9**
Previous crop:	**Spring oilseed rape**	**Available P:**	**50 mg/l (Index 4)**
Current crop:	**Winter wheat**	**Available K:**	**132 mg/l (Index 2)**
	***cv.* Equinox**	**Total N:**	**0.17 %**
Sowing date:	**26/09/97**		
Harvest date:	**25/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	 30-60 cm kg N ha-1	 60-90 cm kg N ha-1
0	**8.5**	**11.9**	**126.3**	**2.8**	**66.1**	**15.1**	**16.1**
50	**9.7**	**13.8**	**176.3**	**4.4**	**41.8**		
80	**10.8**	**15.5**	**219.1**	**6.1**	**39.9**		
110	**10.0**	**14.7**	**218.4**	**6.8**	**83.6**		
140	**10.0**	**14.1**	**218.2**	**6.4**	**71.1**		
170	**9.3**	**13.9**	**223.1**	**7.8**	**91.9**	**20.8**	**15.3**
Farm 122	**8.0**				**22.4**	**31.2**	**30.4**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 09 Year: 1999

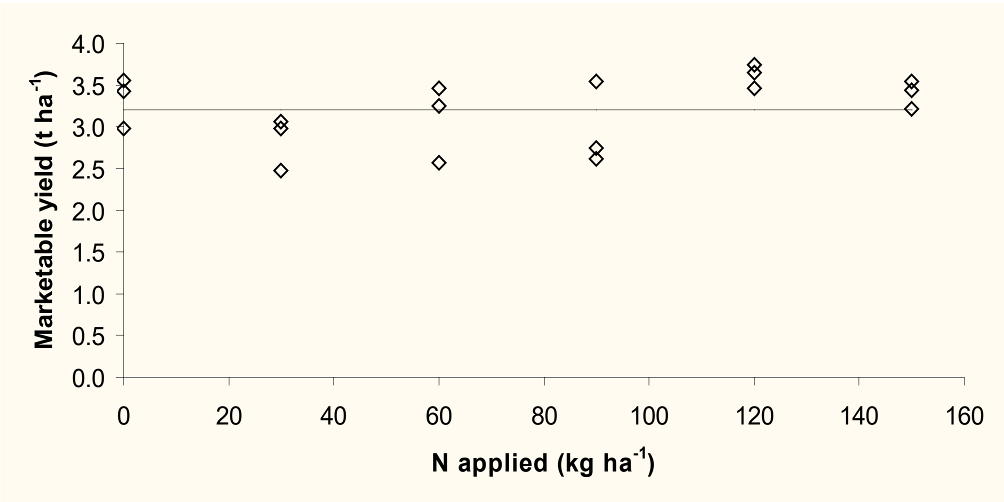
County:	**Cheshire**	**Soil series:**	**Hodnet**
Grid reference:	**SJ 492461**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**5.9**
Previous crop:	**Winter wheat**	**Available P:**	**50 mg/l (Index 4)**
Current crop:	**Spring oilseed rape**	**Available K:**	**132 mg/l (Index 2)**
	***cv.* Sprinter**	**Total N:**	**0.17 %**
Sowing date:	**02/04/99**		
Harvest date:	**10/09/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**3.2**	**8.3**	**145.8**	**33.0**	**61.3**	**29.6**	**14.9**
30	**3.3**	**8.5**	**156.2**	**38.7**	**67.8**		
60	**3.4**	**8.9**	**164.3**	**47.1**	**70.1**		
90	**2.9**	**8.2**	**148.1**	**44.1**	**102.5**		
120	**3.3**	**9.8**	**179.2**	**58.5**	**61.4**		
150	**3.1**	**9.8**	**171.2**	**59.7**	**62.4**	**51.5**	**21.3**
Farm 115	**2.3**		**121.5**	**40.5**	**52.7**	**37.8**	**15.5**

Comments: Field received an application of slurry by a neighbouring farmer in January 1999, the quantity was not known.

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N

Site reference: 10 Year: 1998

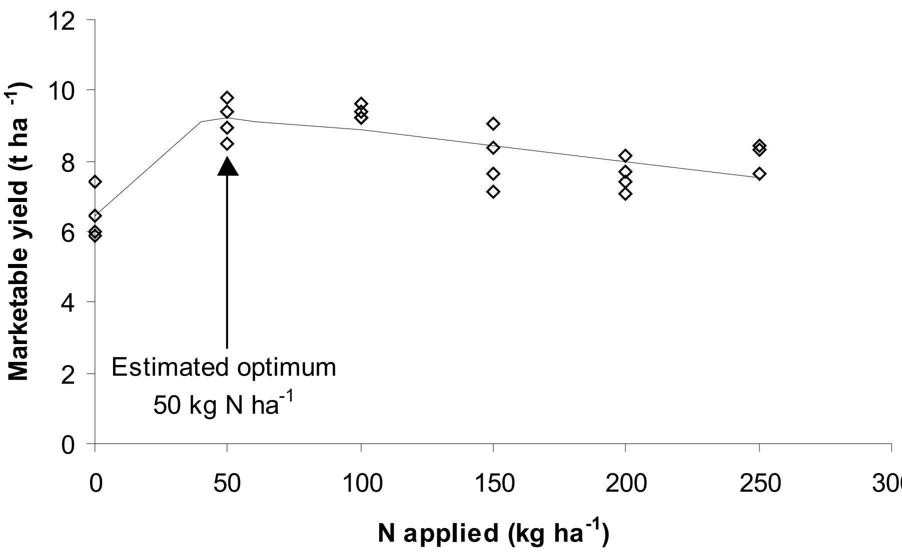
County:	**Cambridgeshire**	**Soil series:**	**Elmton**
Grid reference:	**TF 074009**	**Topsoil texture:**	**Clay loam**
		pH:	**7.7**
Previous crop:	**Field peas**	**Available P:**	**49 mg/l (Index 4)**
Current crop:	**Winter wheat** *cv.* **Riband**	**Available K:**	**126 mg/l (Index 2)**
		Total N:	**0.17 %**
Sowing date:	**03/09/97**		
Harvest date:	**06/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	Soil mineral N after harvest 30-60 cm kg N ha-1	Soil mineral N after harvest 60-90 cm kg N ha-1
0	**6.5**				**21.4**		
50	**9.2**				**15.7**		
100	**9.3**				**14.6**		
150	**8.3**				**14.9**		
200	**7.8**				**20.7**		
250	**7.9**				**14.2**		
Farm 190	**7.6**				**17.2**		

Comments: Crop samples not kept from combine. No determinations of %N possible.
Soil only 30 cm depth to limestone.

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 10 Year: 1999

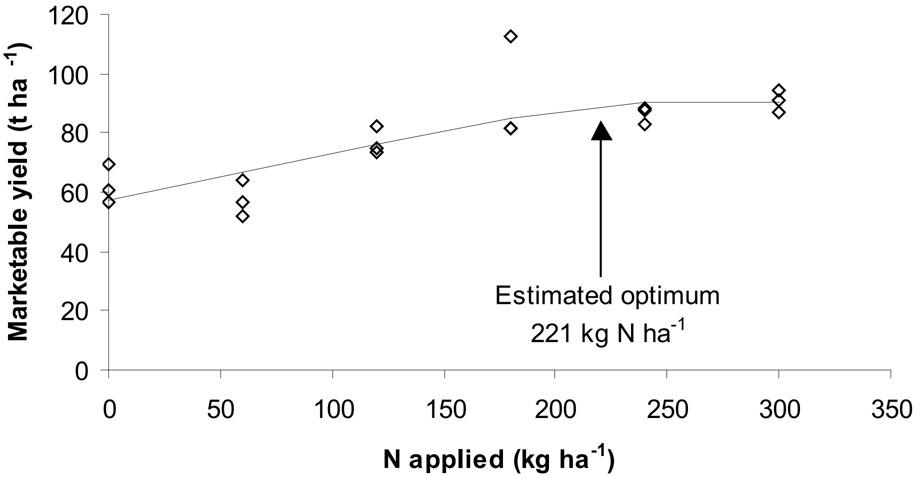
County:	**Cambridgeshire**	**Soil series:**	**Elmton**
Grid reference:	**TF 074009**	**Topsoil texture:**	**Clay loam**
		pH:	**7.7**
Previous crop:	**Winter wheat**	**Available P:**	**49 mg/l (Index 4)**
Current crop:	**Potatoes**	**Available K:**	**136 mg/l (Index 2)**
	***cv.* Cara**	**Total N:**	**0.17 %**
Sowing date:	**03/04/99**		
Harvest date:	**16/10/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	**Marketable yield**	**Total dry weight yield**	**N uptake**	**N returned in crop residues**	**Soil mineral N after harvest**		
					0-30 cm	**30-60 cm**	**60-90 cm**
kg N ha-1	**t ha-1**	**t ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**
0	**53.6**	**14.1**	**157.4**	**7.9**	**28.3**		
60	**51.6**	**13.1**	**156.3**	**7.8**	**32.2**		
120	**64.6**	**17.7**	**168.2**	**8.4**	**29.9**		
180	**71.9**	**19.2**	**231.9**	**13.6**	**28.2**		
240	**82.1**	**22.3**	**172.6**	**11.1**	**37.1**		
300	**76.1**	**20.8**	**219.5**	**11.0**	**49.0**		
Farm 213	**73.9**						

Comments: Soil only 30 cm depth to rock.

Response of total tuber yield (t ha-1) to N applied (kg ha-1)



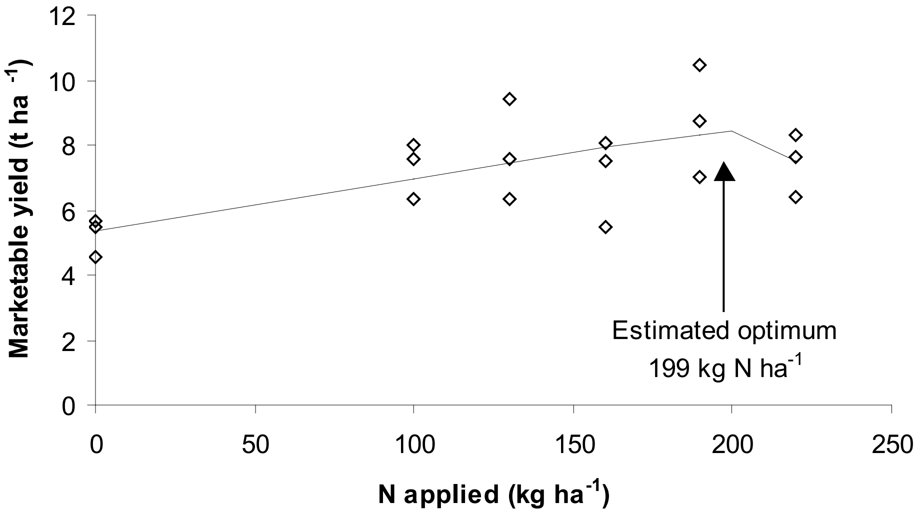
Site reference: 11 Year: 1998

County:	**Hertfordshire**	**Soil series:**	**Hanslope**
Grid reference:	**TL 401350**	**Topsoil texture:**	**Clay**
		pH:	**7.8**
Previous crop:	**Winter oilseed rape**	**Available P:**	**24 mg/l (Index 2)**
Current crop:	**Winter wheat**	**Available K:**	**196 mg/l (Index 2)**
	***cv.* Martina**	**Total N:**	**0.17 %**
Sowing date:	**15/09/97**		
Harvest date:	**19/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	 30-60 cm kg N ha-1	 60-90 cm kg N ha-1
0	**5.3**	**10.3**	**80.2**	**23.1**	**35.3**	**20.3**	**9.6**
100	**7.3**	**14.1**	**157.0**	**47.8**	**55.9**		
130	**7.8**	**15.0**	**169.0**	**52.6**	**35.7**		
160	**7.0**	**13.5**	**199.6**	**68.5**	**46.0**		
190	**8.8**	**15.5**	**218.9**	**68.3**	**39.1**		
220	**7.5**	**13.9**	**218.0**	**76.6**	**64.9**	**22.8**	**13.0**
Farm 200	**9.5**				**39.0**	**17.7**	**15.3**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 11 Year: 1999

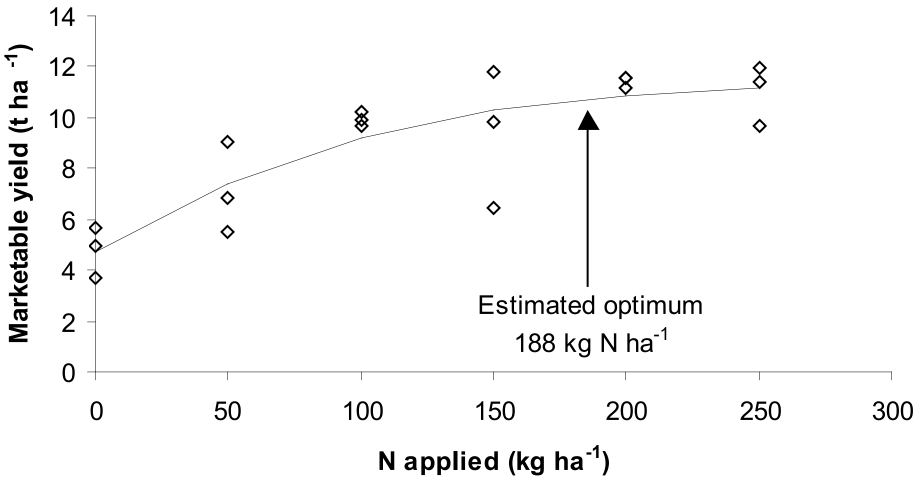
County: Hertfordshire
Grid reference: TL 401350
Previous crop: Winter wheat
Current crop: Winter wheat *cv.* Madrigal
Sowing date: 22/09/98
Harvest date: 12/08/99

Soil series: Hanslope
Topsoil texture: Clay
pH: 7.8
Available P: 24 mg/l (Index 2)
Available K: 196 mg/l (Index 2)
Total N: 0.17 %

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.8	6.6	59.0	8.8	45.1	20.8	3.9
50	7.1	9.7	117.4	18.0	47.5		
100	9.9	14.1	151.6	25.3	61.4		
150	9.4	13.8	170.1	30.6	61.7		
200	11.4	15.2	236.7	39.6	61.5		
250	11.0	15.0	231.3	39.2	59.6	28.8	2.1
Farm 236	10.8		191.8		41.1	17.9	15.5

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 12 Year: 1998

County: Essex
Grid reference: TL 465342
Previous crop: Winter wheat
Current crop: Winter wheat *cv.* Reaper
Sowing date: 17/09/97
Harvest date: 10/08/98

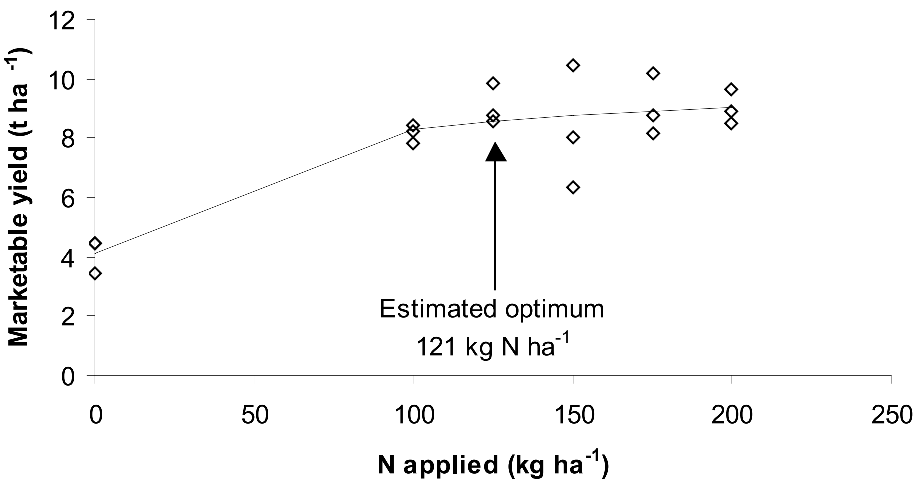
Soil series: Hanslope
Topsoil texture: Clay
pH: 7.4
Available P: 37 mg/l (Index 3)
Available K: 171 mg/l (Index 2)
Total N: 0.16 %

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.1	7.2	56.1	12.0	146.7	44.4	
100	8.1	13.5	134.1	26.6	103.8		
125	9.5	13.5	150.3	23.6	120.8		
150	8.2	14.1	155.8	35.8	97.3		
175	9.0	13.5	177.9	32.6	129.7		
200	9.0	14.7	197.9	43.3	117.8	37.7	
Farm 223					72.4	36.8	

Comments: Soil reaches chalk at 60 cm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 12 Year: 1999

County:	**Essex**	**Soil series:**	**Hanslope**
Grid reference:	**TL 465342**	**Topsoil texture:**	**Clay**
		pH:	**7.4**
Previous crop:	**Winter wheat**	**Available P:**	**37 mg/l (Index 3)**
Current crop:	**Winter oilseed rape** *cv.* **Apex**	**Available K:**	**171 mg/l (Index 2)**
		Total N:	**0.16 %**
Sowing date:	**11/08/98**		
Harvest date:	**18/07/99**		

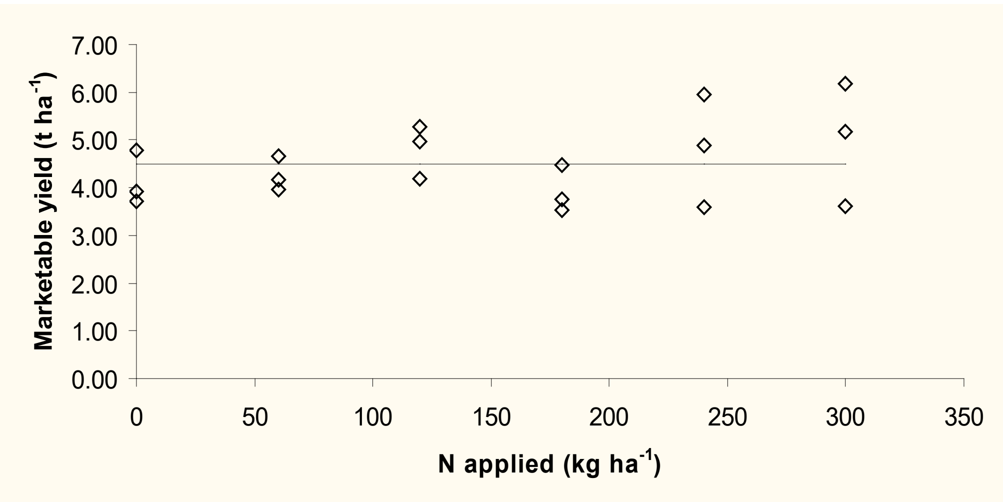
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate *	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.0	9.7	155.4	53.3	45.8	32.7	
60	4.3	9.7	175.6	47.6	71.5		
120	4.8	11.3	208.0	62.2	85.6		
180	3.9	8.5	182.3	56.4	116.7		
240	4.8	11.4	219.4	67.7	212.4		
300	5.0	11.3	213.8	54.6	304.4	79.7	
Farm 255	4.3		158.0		58.9	37.9	

Comments: Soil reaches chalk at 60 cm. Oilseed rape autocast

* **Basal application of 36 kgN/ha August 1998 to all plots and farm area.**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to applied N

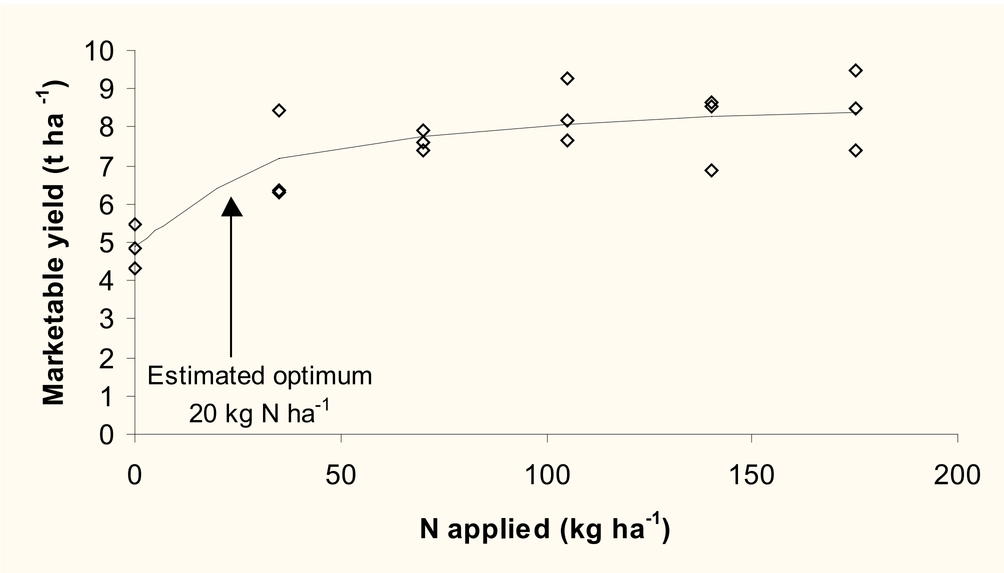
Site reference: 13 Year: 1998

County:	**Cambridgeshire**	**Soil series:**	**Hanslope**
Grid reference:	**TL 399607**	**Topsoil texture:**	**Clay**
		pH:	**7.8**
Previous crop:	**Winter wheat**	**Available P:**	**24 mg/l (Index 2)**
Current crop:	**Winter barley** *cv.* **Regina**	**Available K:**	**244 mg/l (Index 3)**
		Total N:	**0.16 %**
Sowing date:	**02/10/97**		
Harvest date:	**08/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.9	7.1	64.1	8.0	30.4	24.6	14.1
35	7.0	9.4	98.3	11.0	51.6		
70	7.6	10.5	121.9	16.1	66.0		
105	8.4	10.9	140.4	16.3	49.2		
140	8.0	11.6	173.8	33.6	33.3		
175	8.5	11.9	200.8	42.8	39.4	36.2	24.4
Farm 188	7.4				54.0	25.5	16.9

Response of marketable yield (t ha-1) to N applied (kg ha-1)



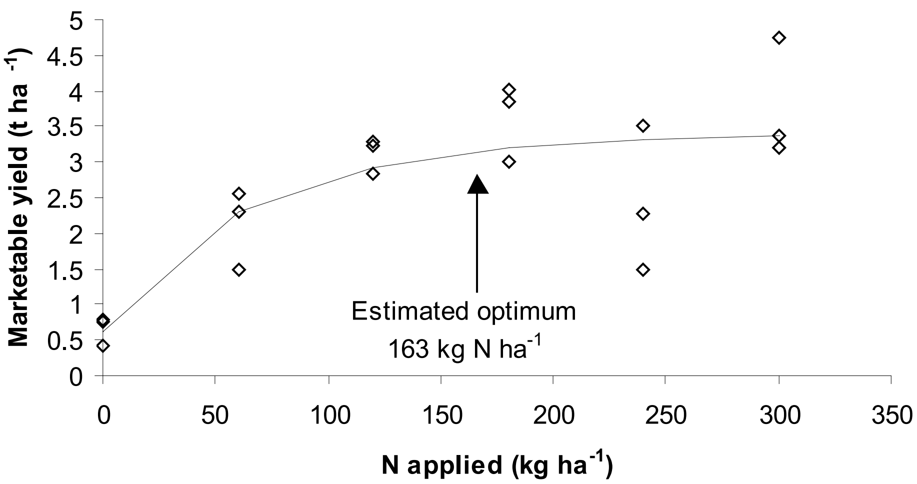
Site reference: 13 Year: 1999

County:	**Cambridgeshire**	**Soil series:**	**Hanslope**
Grid reference:	**TL 399607**	**Topsoil texture:**	**Clay**
		pH:	**7.8**
Previous crop:	**Winter barley**	**Available P:**	**24 mg/l (Index 2)**
Current crop:	**Winter oilseed rape**	**Available K:**	**244 mg/l (Index 3)**
	***cv.* Lipton**	**Total N:**	**0.16 %**
Sowing date:	**04/09/98**		
Harvest date:	**20/07/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	0.7	4.5	42.4	30.6	51.5	30.6	14.6
60	2.1	7.9	108.9	53.3	57.6		
120	3.1	9.0	142.8	47.7	67.5		
180	3.6	9.7	180.8	67.9	62.6		
240	2.4	8.1	158.5	78.5	62.8		
300	3.8	11.0	222.0	100.6	77.1	42.3	30.8
Farm 232	4.5		205.7		62.1	29.6	13.4

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 14 Year: 1998

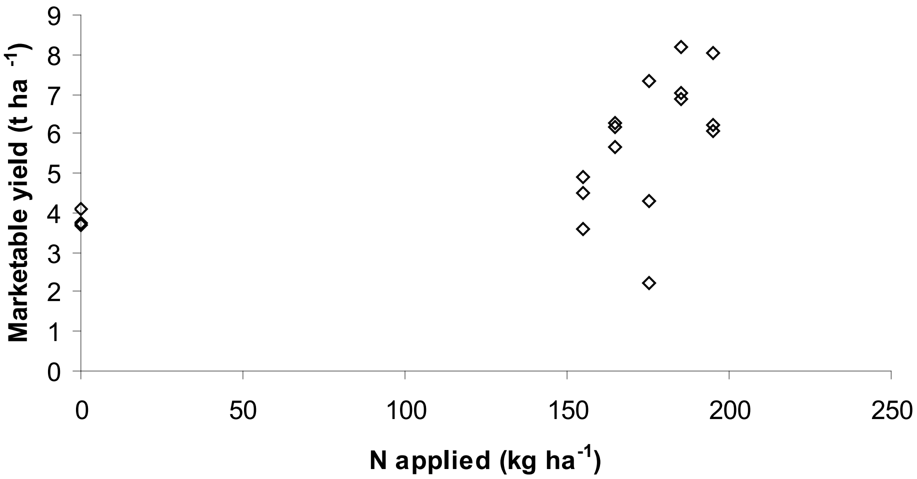
County:	**Suffolk**	**Soil series:**	**Burlingham**
Grid reference:	**TM 247672**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**7.9**
Previous crop:	**Winter wheat**	**Available P:**	**76 mg/l (Index 5)**
Current crop:	**Winter oilseed rape** *cv.* **Navajo**	**Available K:**	**264 mg/l (Index 3)**
		Total N:	**0.14 %**
Sowing date:	**11/09/97**		
Harvest date:	**25/07/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate *	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**3.8**	**6.1**	**102.4**	**6.9**	**44.1**	**19.8**	**16.5**
155	**4.3**	**9.5**	**175.1**	**46.8**	**65.4**		
165	**6.0**	**10.5**	**222.9**	**43.8**	**75.3**		
175	**4.6**	**7.7**	**169.4**	**38.9**	**88.2**		
185	**7.4**	**12.8**	**262.4**	**55.0**	**86.0**		
195	**6.8**	**10.5**	**234.3**	**31.1**	**81.7**	**25.8**	**15.9**
Farm 238	**4.3**				**62.2**	**16.4**	**16.5**

*** Basal application of 40 kgN/ha applied 27/10/97 to all plots and to farm area.**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comment: Response curve could not be fitted

Site reference: 14 Year: 1999

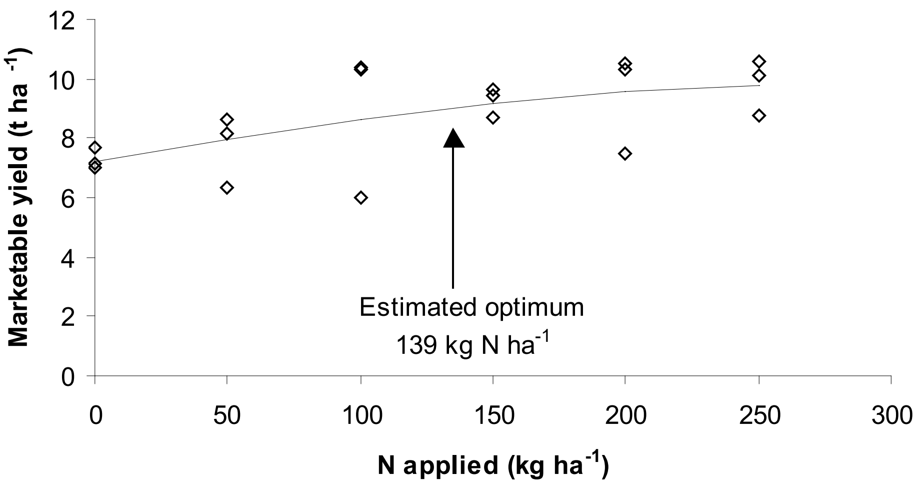
County:	**Suffolk**	**Soil series:**	**Burlingham**
Grid reference:	**TM 247672**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**7.9**
Previous crop:	**Winter oilseed rape**	**Available P:**	**76 mg/l (Index 5)**
Current crop:	**Winter wheat**	**Available K:**	**264 mg/l (Index 3)**
	***cv.* Equinox**	**Total N:**	**0.14 %**
Sowing date:	**03/10/98**		
Harvest date:	**18/08/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	7.3	8.6	132.1	1.3	27.9	20.9	18.9
50	7.7	10.1	146.1	2.0	40.1		
100	8.9	11.3	198.6	2.8	22.1		
150	9.2	11.1	196.2	3.0	32.9		
200	9.4	11.0	163.5	3.2	42.8		
250	9.8	11.3	201.2	3.4	35.2	41.5	25.9
Farm 124	10.0		185.0		15.6	39.2	17.0

Comments: Field received 40 t ha-1 of pig FYM in autumn

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 15 Year: 1998

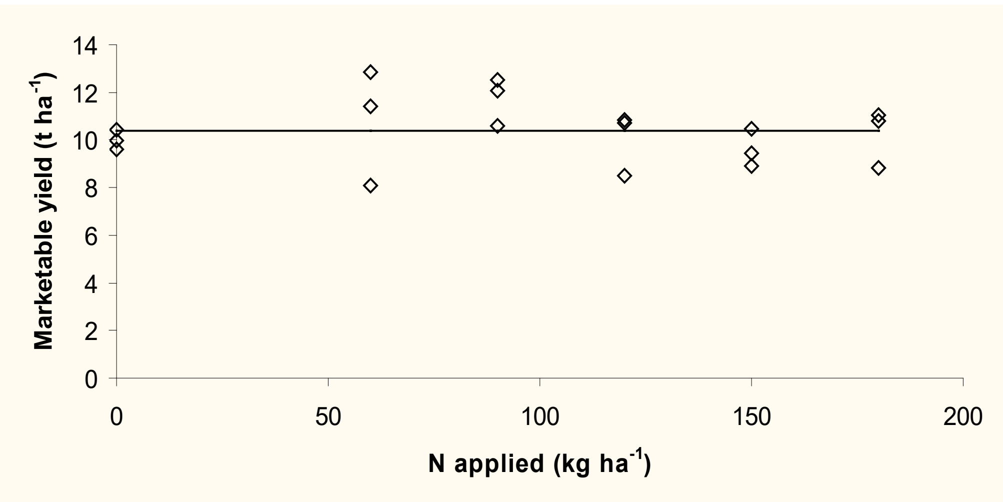
County:	**Suffolk**	**Soil series:**	**Burlingham**
Grid reference:	**TM 251167**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**6.6**
Previous crop:	**Vining peas**	**Available P:**	**119 mg/l (Index 6)**
Current crop:	**Winter wheat**	**Available K:**	**483 mg/l (Index 4)**
	***cv.* Equinox**	**Total N:**	**0.22 %**
Sowing date:	**13/10/97**		
Harvest date:	**20/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**10.0**	**18.3**	**266.6**	**10.1**	**87.1**	**52.9**	**36.2**
60	**10.8**	**18.2**	**280.0**	**9.0**	**80.5**		
90	**11.7**	**20.5**	**351.6**	**15.9**	**93.3**		
120	**10.0**	**18.6**	**306.5**	**14.3**	**85.6**		
150	**9.6**	**17.4**	**288.3**	**13.0**	**91.2**		
180	**10.2**	**18.0**	**304.6**	**13.4**	**122.2**	**59.9**	**50.4**
Farm 84	**11.7**				**85.6**	**64.2**	**53.9**

Comments: Field received 45 t ha–1 of pig FYM in autumn

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N applied

Site reference: 15 Year: 1999

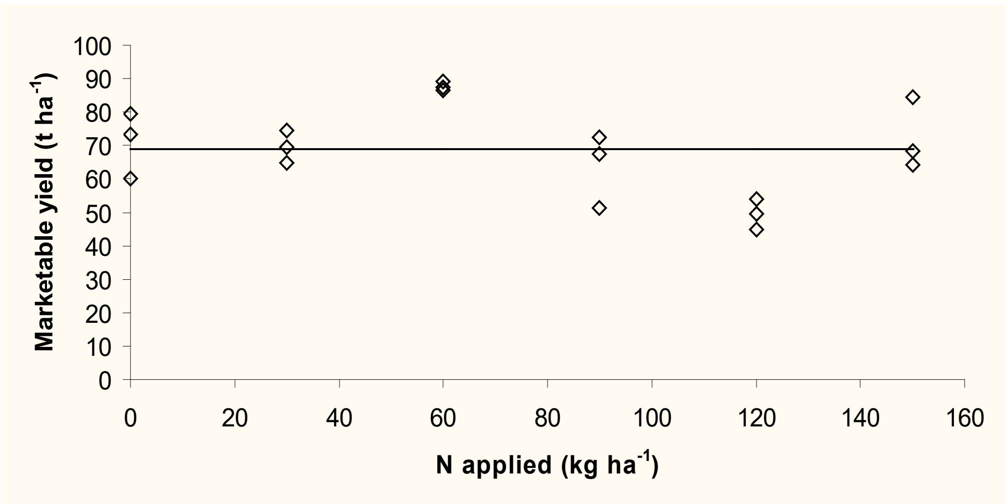
County:	**Suffolk**	**Soil series:**	**Burlingham**
Grid reference:	**TM 251167**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**6.6**
Previous crop:	**Winter wheat**	**Available P:**	**119 mg/l (Index 6)**
Current crop:	**Sugar beet**	**Available K:**	**483 mg/l (Index 4)**
	***cv.* Madison**	**Total N:**	**0.22 %**
Sowing date:	**03/04/99**		
Harvest date:	**13/12/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**70.9**	**20.8**	**208.7**	**78.4**	**29.3**	**14.6**	**12.3**
30	**69.5**	**20.5**	**216.5**	**83.3**	**48.4**		
60	**87.7**	**25.0**	**255.8**	**78.5**	**54.9**		
90	**63.7**	**18.2**	**204.5**	**66.4**	**42.4**		
120	**49.5**	**14.1**	**178.8**	**72.1**	**51.9**		
150	**72.3**	**19.0**	**234.3**	**78.2**	**31.8**	**19.0**	**14.4**
Farm 192	**92.6**						

Comments: Field received 35 t ha-1 of duck FYM in autumn

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to N applied

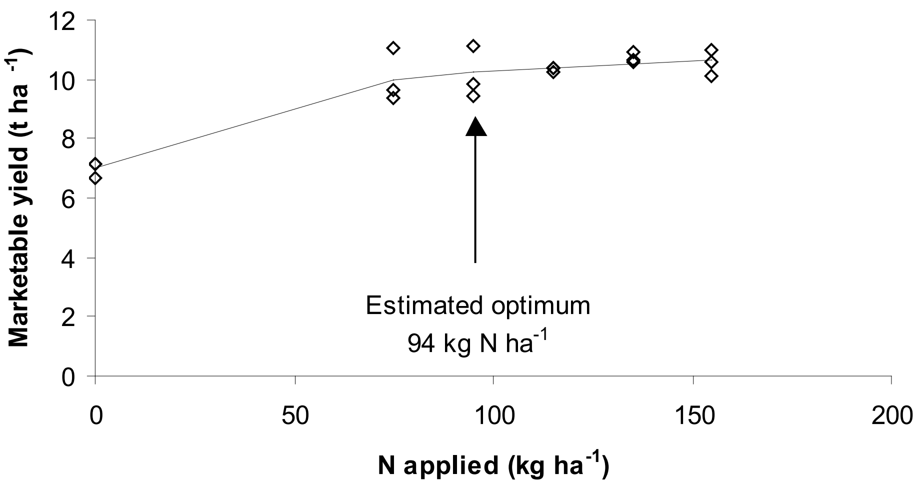
Site reference: 16 — Year: 1998

County:	**Norfolk**	**Soil series:**	**Romney**
Grid reference:	**TF 577245**	**Topsoil texture:**	**Silt loam**
		pH:	**7.9**
Previous crop:	**Set-aside**	**Available P:**	**28 mg/l (Index 3)**
Current crop:	**Winter wheat** *cv.* **Consort**	**Available K:**	**292 mg/l (Index 3)**
		Total N:	**0.07 %**
Sowing date:	**17/09/97**		
Harvest date:	**15/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest 0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	7.0	10.1	97.2	9.3	16.9	11.3	8.2
75	10.0	14.1	158.7	19.1	22.6		
95	10.1	14.6	172.0	23.1	26.6		
115	10.3	15.5	189.4	28.1	23.9		
135	10.7	15.0	176.5	20.1	27.6		
155	10.6	16.2	190.6	35.3	20.9	9.7	7.8
Farm 130	11.0				27.2	9.3	9.0

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 16 Year: 1999

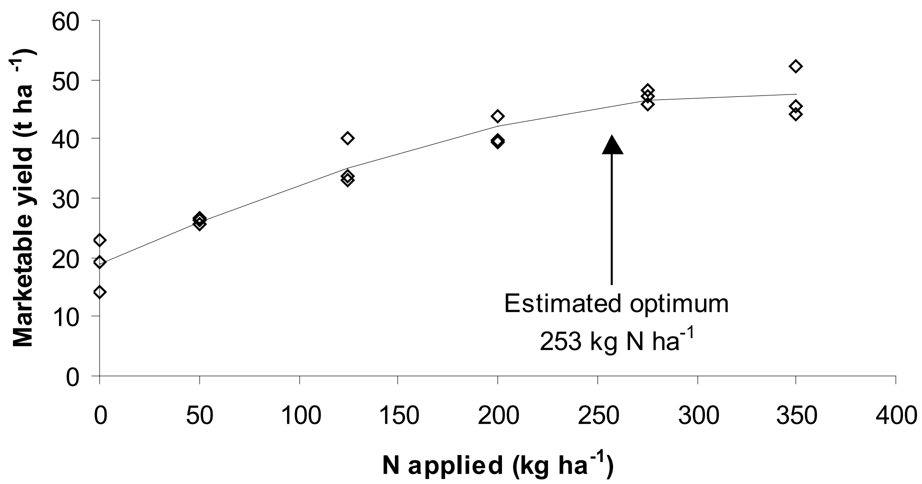
County:	**Norfolk**	**Soil series:**	**Romney**
Grid reference:	**TF 570246**	**Topsoil texture:**	**Silt loam**
		pH:	**7.9**
Previous crop:	**Winter wheat**	**Available P:**	**28 mg/l (Index 3)**
Current crop:	**Dutch white cabbage *cv.* Quisto**	**Available K:**	**292 mg/l (Index 3)**
		Total N:	**0.07%**
Sowing date:	**17/05/99**		
Harvest date:	**07/09/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	30-60 cm kg N ha-1	60-90 cm kg N ha-1
0	**18.7**	**4.86**	**50.8**	**28.3**	**18.5**	**9.5**	**5.9**
50	**26.1**	**6.17**	**62.9**	**31.5**	**22.1**		
125	**35.6**	**7.42**	**88.5**	**43.1**	**21.4**		
200	**41.1**	**8.26**	**124.9**	**57.5**	**23.1**	**8.8**	**6.8**
275	**47.1**	**8.42**	**150.9**	**67.6**	**22.6**		
350	**47.4**	**9.01**	**184.0**	**87.2**	**34.4**	**11.2**	**8.2**
Farm 200	**N/A**						

Comments: Single cut, marketable heads > 450 g.

Response of marketable yield (t ha-1) to N applied (kg ha-1)



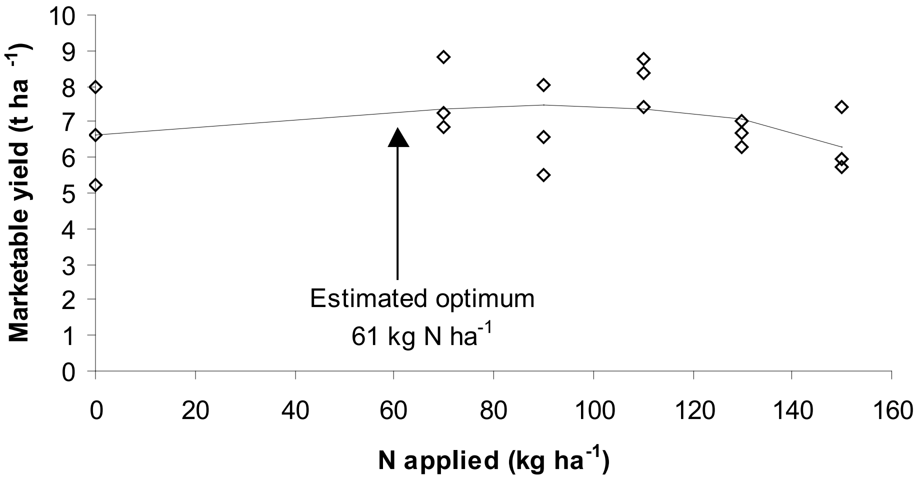
Site reference: 17 Year: 1998

County:	**Oxfordshire**	**Soil series:**	**Denchworth**
Grid reference:	**SP 429957**	**Topsoil texture:**	**Clay**
		pH:	**7.0**
Previous crop:	**Winter beans**	**Available P:**	**49 mg/l (Index 4)**
Current crop:	**Winter wheat** *cv.* **Hereward**	**Available K:**	**328 mg/l (Index 3)**
		Total N:	**0.33 %**
Sowing date:	**27/09/97**		
Harvest date:	**15/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	6.6	11.8	151.8	24.3	56.6	27.5	10.0
70	7.6	13.4	192.1	36.9	32.4		
90	6.7	11.8	194.3	46.5	44.7		
110	8.2	14.0	235.5	51.7	30.1		
130	6.7	12.0	194.8	46.0	30.7		
150	6.4	12.3	209.4	62.0	32.2	17.0	9.5
Farm 160	8.5				20.6	12.6	13.7

Response of marketable yield (t ha-1) to N applied (kg ha-1)



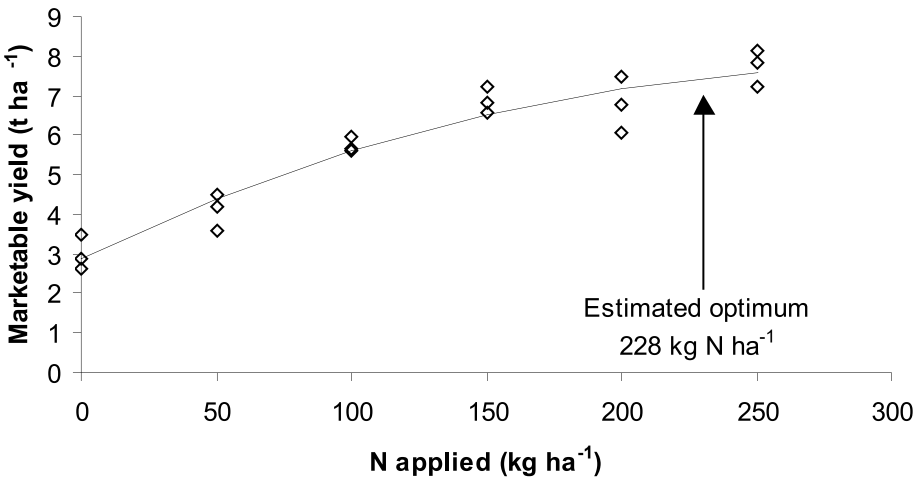
Site reference: 17 Year: 1999

County:	**Oxfordshire**	**Soil series:**	**Denchworth**
Grid reference:	**SP 429957**	**Topsoil texture:**	**Clay**
		pH:	**7.0**
Previous crop:	**Winter wheat**	**Available P:**	**49 mg/l (Index 4)**
Current crop:	**Winter wheat**	**Available K:**	**328 mg/l (Index 3)**
	***cv.* Equinox**	**Total N:**	**0.33 %**
Sowing date:	**19/10/98**		
Harvest date:	**13/08/99 (trial)**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**3.0**	**4.5**	**42.1**	**7.4**	**122.2**	**35.4**	**46.2**
50	**4.1**	**6.1**	**70.4**	**11.9**	**139.8**		
100	**5.8**	**8.2**	**87.6**	**14.7**	**128.2**		
150	**6.9**	**10.2**	**132.9**	**25.3**	**111.5**		
200	**6.8**	**9.6**	**137.1**	**15.3**	**213.8**		
250	**7.7**	**10.7**	**136.4**	**19.4**	**212.1**	**55.1**	**46.2**
Farm 220	**8.3**		**154.0**		**75.6**	**36.9**	**27.2**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



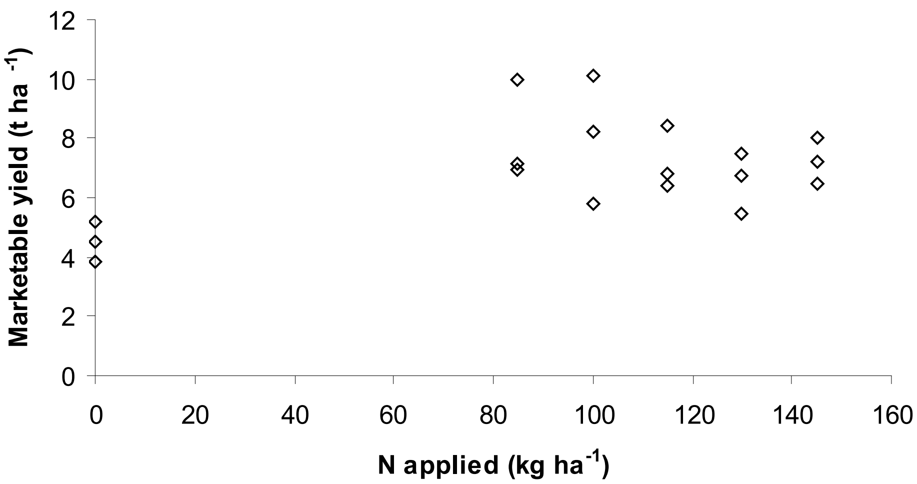
Site reference: 18 Year: 1998

County:	**West Sussex**	**Soil series:**	**Hook**
Grid reference:	**TQ 872025**	**Topsoil texture:**	**Silty clay loam**
		pH:	**6.9**
Previous crop:	**Celery**	**Available P:**	**48 mg/l (Index 4)**
Current crop:	**Winter wheat**	**Available K:**	**187 mg/l (Index 2)**
	***cv.* Brigadier**	**Total N:**	**0.12 %**
Sowing date:	**03/10/97**		
Harvest date:	**01/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**4.5**	**7.5**	**53.2**	**7.0**	**22.4**	**13.9**	**11.5**
85	**7.5**	**12.7**	**125.8**	**23.2**	**20.7**		
100	**8.6**	**13.4**	**137.9**	**22.4**	**22.9**		
115	**7.2**	**14.2**	**133.7**	**32.3**	**18.1**		
130	**6.6**	**11.8**	**118.5**	**25.4**	**18.5**		
145	**7.2**	**14.5**	**151.2**	**46.2**	**29.8**	**16.5**	**12.5**
Farm N/A	**N/A**				**21.1**	**13.1**	**9.9**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: Response curve could not be fitted

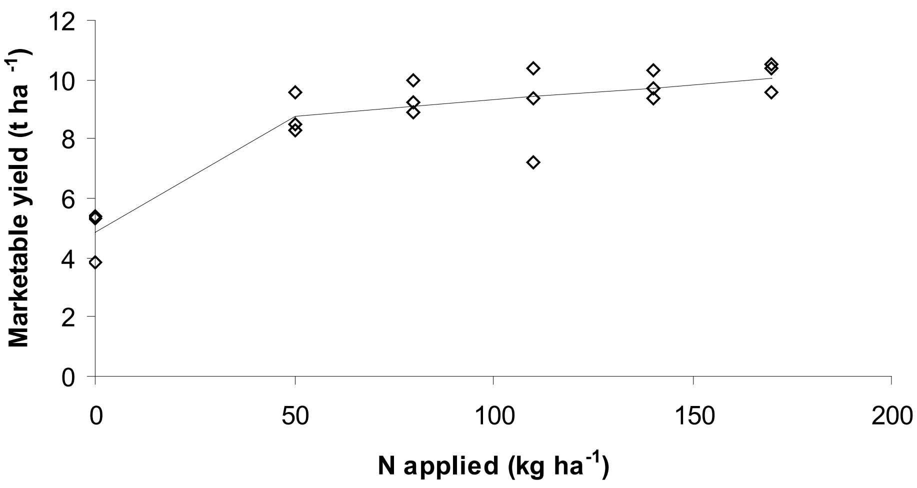
Site reference: 19 Year: 1998

County:	**Warwickshire**	**Soil series:**	**Bromsgrove**
Grid reference:	**SE 311709**	**Topsoil texture:**	**Sandy loam**
		pH:	**6.3**
Previous crop:	**Winter oilseed rape**	**Available P:**	**35 mg/l (Index 3)**
Current crop:	**Winter wheat**	**Available K:**	**87 mg/l (Index 1)**
	***cv.* Caxton**	**Total N:**	**0.06 %**
Sowing date:	**06/10/97**		
Harvest date:	**15/08/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.9	7.9	73.4	1.8	25.1	11.0	11.3
50	8.8	13.8	144.6	3.4	19.5		
80	9.4	15.0	185.7	4.8	21.8		
110	9.0	13.8	170.1	4.4	21.1		
140	9.8	14.8	208.6	5.4	20.8		
170	10.2	15.0	239.8	7.1	40.0	15.1	11.1
Farm 210	10.4				28.7	13.8	12.1

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: Optimum above maximum N rate used.

Site reference: 19 Year: 1999

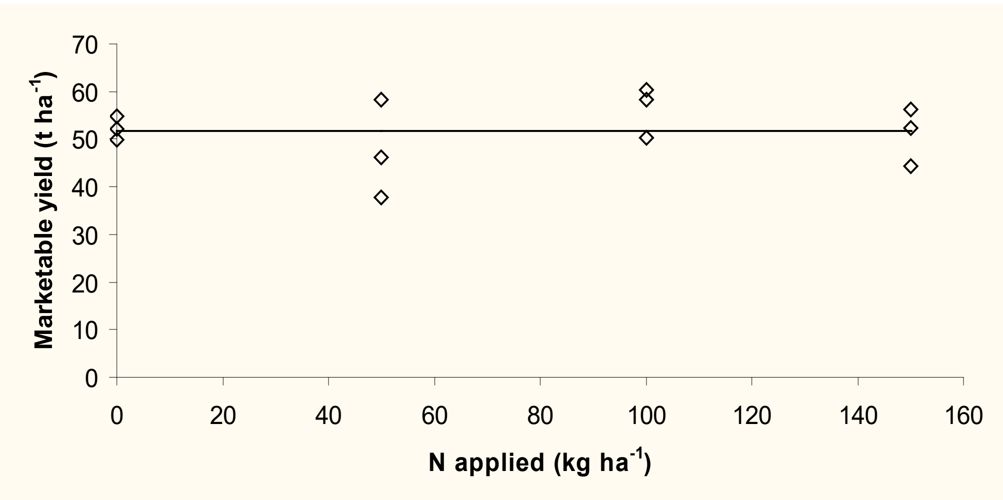
County:	**Warwickshire**	**Soil series:**	**Bromsgrove**
Grid reference:	**SE 311709**	**Topsoil texture:**	**Sandy loam**
		pH:	**6.3**
Previous crop:	**Winter wheat**	**Available P:**	**35 mg/l (Index 3)**
Current crop:	**Potatoes**	**Available K:**	**87 mg/l (Index 1)**
	***cv.* Romano**	**Total N:**	**0.06 %**
Sowing date:	**04/05/99**		
Harvest date:	**19/10/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0 (212)	48.5	10.6	196.5	9.8	51.2	35.5	47.9
50 (262)	43.5	9.7	186.3	9.3	55.4		
100 (312)	52.9	11.6	232.1	11.6	77.7		
150 (362)	47.5	10.8	213.4	10.7	111.0	129.2	72.2
Farm 212	50.0						

Comments: Basal N (212 kg N ha-1)had been uniformly applied to the site before N rates were imposed. Originally this had been planned to be only 100 kg N ha-1

Response of total tuber yield (t ha-1) to N applied (kg ha-1)



Comments: No response to additional N application

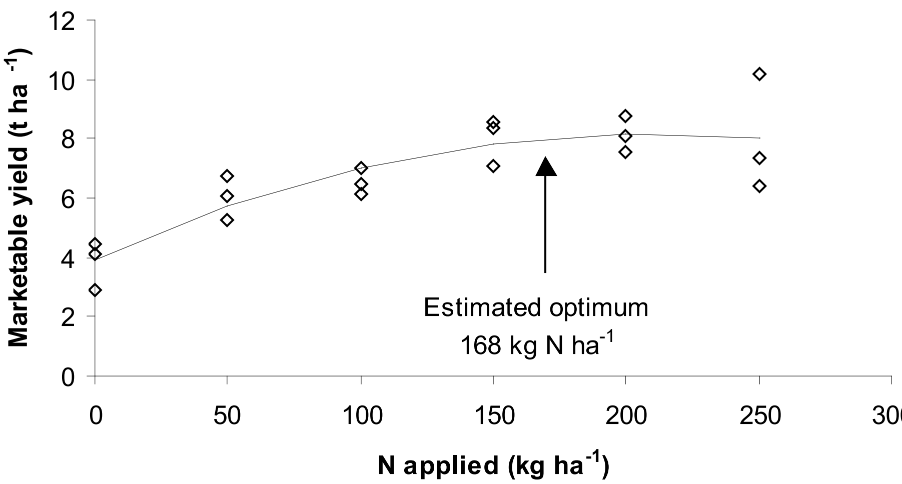
Site reference: 20 Year: 1999

County:	**Suffolk**	**Soil series:**	**Barrow**
Grid reference:	**TL 944735**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**7.9**
Previous crop:	**Sugar beet**	**Available P:**	**25 mg/l (Index 2)**
Current crop:	**Winter wheat**	**Available K:**	**137 mg/l (Index 2)**
	***cv.* Consort**	**Total N:**	**0.07 %**
Sowing date:	**03/10/98**		
Harvest date:	**23/08/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	<u>N uptake</u>	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**3.6**	**4.6**	**55.5**	**5.6**	**28.5**	**21.8**	**15.0**
50	**6.0**	**8.5**	**85.0**	**12.4**	**35.6**		
100	**6.6**	**9.7**	**105.4**	**18.7**	**27.4**		
150	**8.0**	**11.1**	**123.8**	**23.3**	**30.9**		
200	**8.1**	**10.5**	**130.8**	**23.1**	**34.5**		
250	**8.0**	**10.7**	**132.1**	**24.2**	**61.4**	**35.6**	**12.0**
Farm 166	**6.8**		**113.3**		**32.3**	**22.7**	**15.1**

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 21 **Year: 1999 (1)**

County:	**Oxfordshire**	**Soil series:**	**Dullingham**
Grid reference:	**SP 613010**	**Topsoil texture:**	**Sandy clay loam**
		pH:	**7.6**
Previous crop:	**Winter barley**	**Available P:**	**109 mg/l (Index 6)**
Current crop:	**Spinach**	**Available K:**	**363 mg/l (Index 3)**
	***cv.* Calata**	**Total N:**	**0.18%**
Sowing date:	**15/04/99**		
Harvest date:	**28/05/99**		

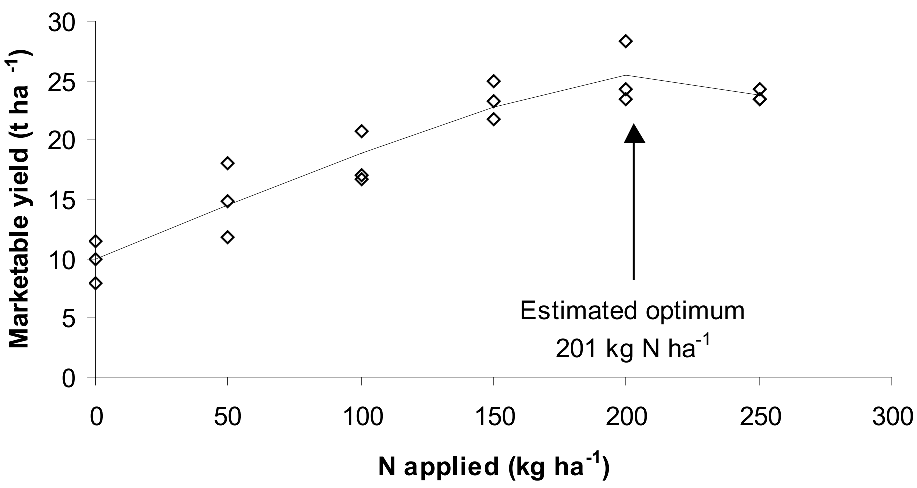
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	**Marketable yield**	**Total dry weight yield**	**N uptake**	**N returned in crop residues**	**Soil mineral N after harvest**		
					0-30 cm	**30-60 cm**	**60-90 cm**
kg N ha-1	**t ha-1**	**t ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**
0	**9.8**	**1.23**	**37.5**	**8.6**	**27.9**	**29.8**	**22.8**
50	**14.8**	**1.68**	**62.0**	**15.7**	**31.9**		
100	**18.2**	**1.89**	**78.0**	**21.9**	**44.5**		
150	**23.3**	**2.19**	**112.7**	**30.1**	**82.5**	**43.3**	**22.7**
200	**25.3**	**2.31**	**127.9**	**35.1**	**82.1**		
250	**23.8**	**2.23**	**128.7**	**36.9**	**151.9**	**59.3**	**26.9**

Comments:

Commercial crop ploughed in. Single cut c. 75 mm above ground level.

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 21 Year: 1999 (2)

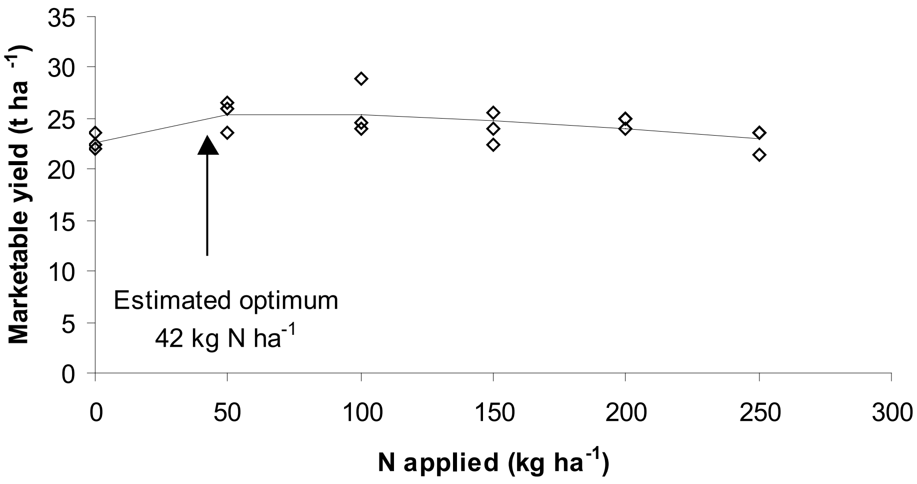
County: Oxfordshire **Soil series:** Dullingham
Grid reference: SP 613010 **Topsoil texture:** Sandy clay loam
pH: 7.6
Previous crop: Spinach **Available P:** 109 mg/l (Index 6)
Current crop: Spinach *cv.* RX940284 **Available K:** 363 mg/l (Index 3)
Total N: 0.18%
Sowing date: 18/08/99
Harvest date: 23/09/99

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	22.7	1.91	96.5	25.8	53.9	70.3	54.5
50	25.3	2.06	112.7	29.7	51.1	83.9	
100	25.8	2.10	116.0	30.3	86.6	120.8	
150	24.0	2.07	115.8	32.3	102.0	126.9	61.4
200	24.7	2.07	114.6	30.0	134.3	179.3	
250	22.8	1.99	111.9	31.6	181.6	204.2	80.5

Comments:
Single cut c. 75 mm above ground level.

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 22 Year: 1998

County:	**Suffolk**	**Soil series:**	**Swaffham Prior**
Grid reference:	**TL 714720**	**Topsoil texture:**	**Sandy loam**
		pH:	**7.7**
Previous crop:	**Winter wheat**	**Available P:**	**27 mg/l (Index 3)**
Current crop:	**Red bulb onion**	**Available K:**	**131 mg/l (Index 2)**
	***cv.* Red Baron**	**Total N:**	**0.09%**
Sowing date:	**27/02/98**		
Harvest date:	**27/08/98**		

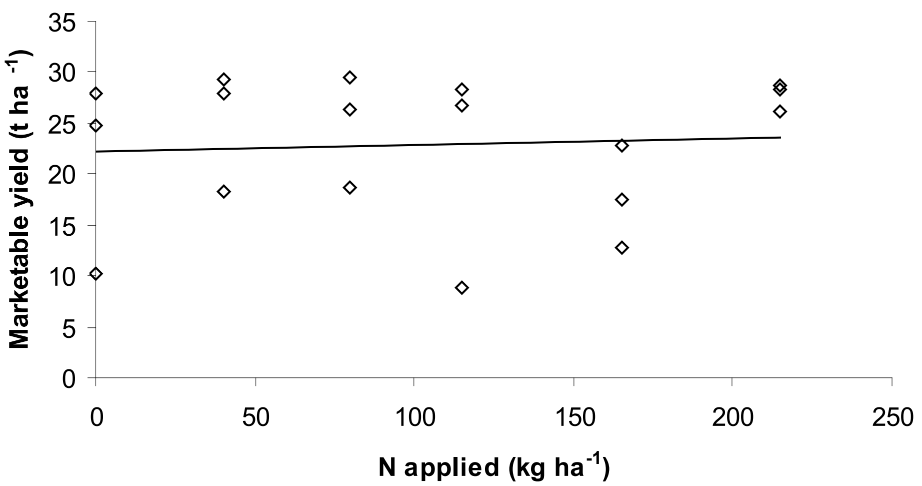
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	Soil mineral N after harvest 30-60 cm kg N ha-1	Soil mineral N after harvest 60-90 cm kg N ha-1
0	20.9	5.48	102.7	42.8	139.7	59.5	52.3
40	25.1	6.10	108.7	39.7	62.9		
80	24.9	5.97	113.2	39.8	68.8		
115	21.3	5.79	112.7	41.1	91.6	66.8	86.1
165	17.7	5.43	107.1	40.8	127.2		
215	27.7	6.12	120.9	37.7	132.4	91.1	61.3

Comments:

Crop severely damaged by hail 09/04/98. Marketable bulbs 50-80 mm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to applied N.

Site reference: 22 **Year: 1999**

County:	**Suffolk**	**Soil series:**	**Swaffham Prior**
Grid reference:	**TL 714720**	**Topsoil texture:**	**Sandy loam**
		pH:	**7.7**
Previous crop:	**Red bulb onion**	**Available P:**	**27 mg/l (Index 3)**
Current crop:	**Parsnip** *cv.* **Arrow**	**Available K:**	**131 mg/l (Index 2)**
		Total N:	**0.09%**
Sowing date:	**22/05/99**		
Harvest date:	**12/01/00**		

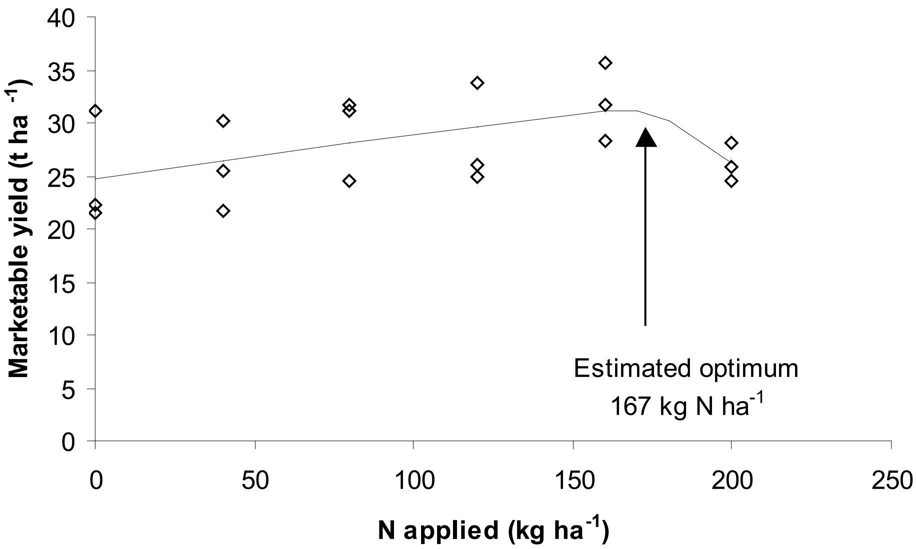
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	25.0	8.34	74.6		12.0	5.9	5.3
40	25.8	7.71	81.8		12.4		
80	29.2	8.60	99.6		12.4		
120	28.2	8.61	98.7		14.3		
160	31.9	8.54	110.4		13.2	13.0	29.4
200	26.2	8.46	111.3		11.7	14.4	40.5

Comments:

Marketable roots 30-65 mm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 23 Year: 1998

County:	**Lincolnshire**	**Soil series:**	**Wisbech**
Grid reference:	**TF 305306**	**Topsoil texture:**	**Silt loam**
		pH:	**7.7**
Previous crop:	**Winter wheat**	**Available P:**	**49 mg/l (Index 4)**
Current crop:	**Bulb onion (sets)**	**Available K:**	**213 mg/l (Index 2)**
	***cv.* Sturon**	**Total N:**	**0.12%**
Planting date	**24/02/98**		
Harvest date:	**11/08/98**		

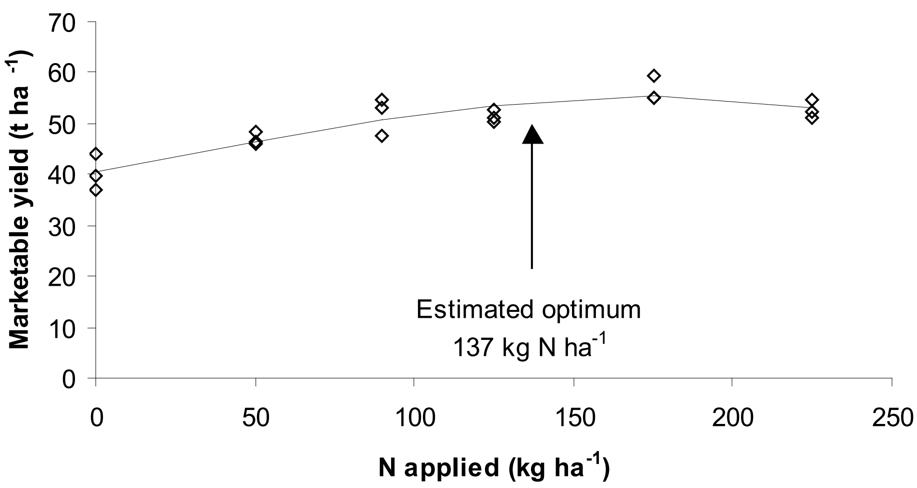
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	40.2	8.24	81.1	15.0	35.9	22.5	27.0
50	47.1	9.46	100.0	18.3	38.0		
90	51.8	9.94	122.6	23.9	36.2		
125	51.4	9.80	142.7	22.2	43.4	25.7	29.3
175	56.4	10.57	157.7	27.0	63.7		
225	52.7	10.12	163.1	28.4	69.1	36.8	33.2

Comments:

Marketable bulbs 50-80 mm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 24 Year: 1998

County:	**Lincolnshire**	**Soil series:**	**Tanvats**
Grid reference:	**TF 279356**	**Topsoil texture:**	**Silt loam**
		pH:	**7.7**
Previous crop:	**Summer cabbage**	**Available P:**	**55 mg/l (Index 4)**
Current crop:	**Calabrese**	**Available K:**	**319 mg/l (Index 3)**
	***cv.* Marathon**	**Total N:**	**0.06%**
Planting date	**23/04/98**		
Harvest date:	**27/07/98**		

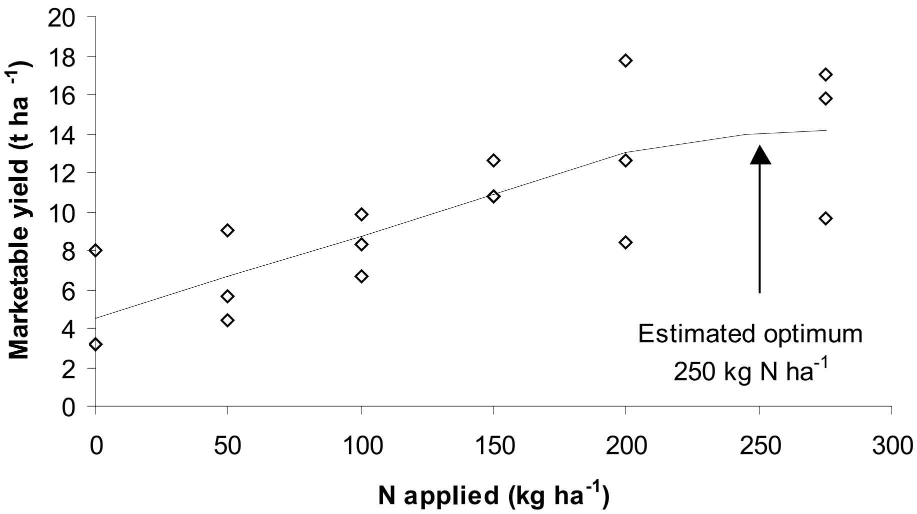
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.8	2.26	60.9	42.0	64.1	32.7	40.8
50	6.4	2.83	65.0	42.2	28.8		
100	8.3	3.16	84.1	50.9	31.2		
150	11.4	3.75	106.2	59.1	32.8	32.0	65.7
200	12.9	4.41	129.7	70.7	34.0		
275	14.2	4.55	146.9	84.1	39.4	39.3	54.9

Comments:

Marketable heads class I >75 mm diameter, trimmed to 150 mm head plus stem length

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 25 Year: 1998

County:	**Norfolk**	**Soil series:**	**Newport**
Grid reference:	**TF 782362**	**Topsoil texture:**	**Loamy sand**
		pH:	**8.0**
Previous crop:	**Maincrop potato**	**Available P:**	**45 mg/l (Index 3)**
Current crop:	**Carrot**	**Available K:**	**318 mg/l (Index 3)**
	***cv.* Bergen**	**Total N:**	**0.03%**
Sowing date	**08/05/98**		

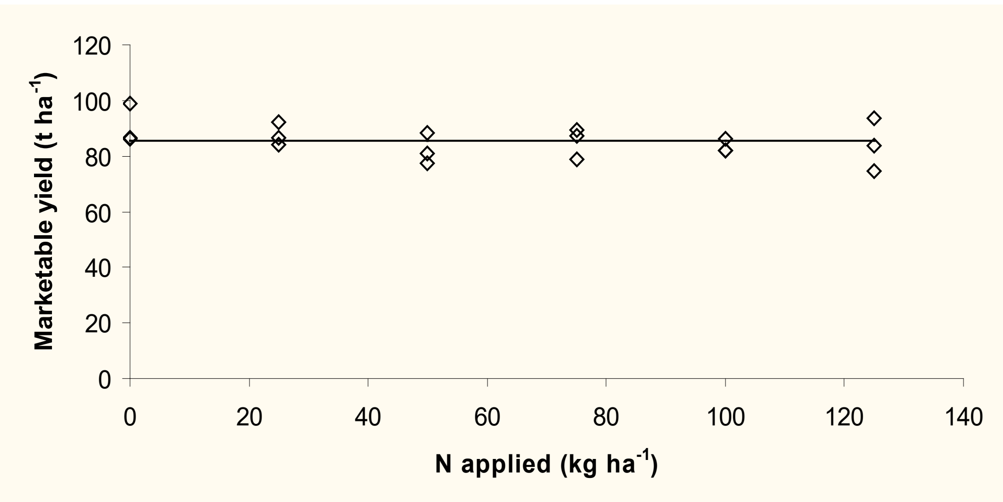
Harvest date: 15/10/98 (pre-strawing) 20/01/00 (commercial)

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	90.6	9.64	108.2		30.1	15.7	11.8
25	87.6	9.81	100.9		22.5		
50	82.3	9.63	110.0		19.6		
75	85.0	9.55	107.1		19.6	15.6	11.0
100	83.5	9.68	108.0		20.5		
125	83.9	9.81	114.9		21.0	20.9	15.7

Comments:
Marketable roots at commercial harvest 25-40 mm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to applied N.

Site reference: 26 Year: 1998

County:	**Lancashire**	**Soil series:**	**Sollom**
Grid reference:	**SD 372122**	**Topsoil texture:**	**Loamy sand**
		pH:	**7.1**
Previous crop:	**Crisp lettuce**	**Available P:**	**80 mg/l (Index 5)**
Current crop:	**Leek**	**Available K:**	**71 mg/l (Index 1)**
	***cv.* Farinto**	**Total N:**	**0.17%**
Sowing date	**17/04/98**		
Harvest date:	**19/01/99**		

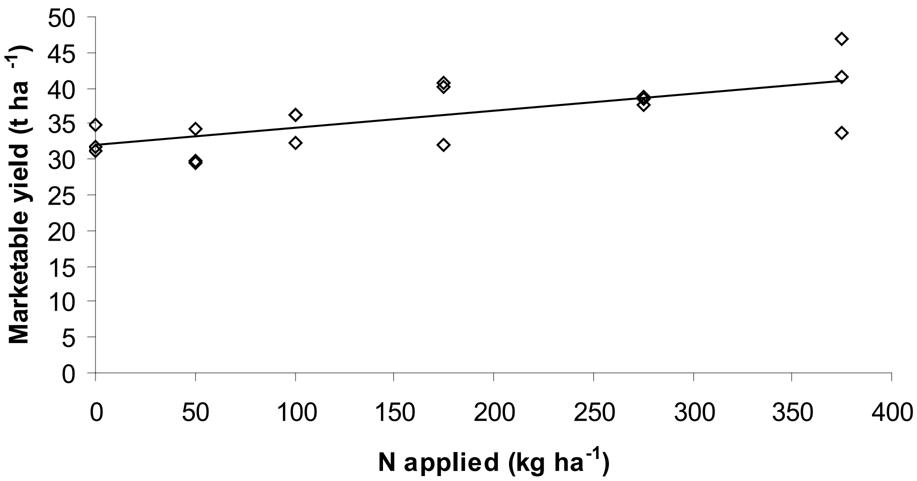
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	32.6	5.49	138.5	39.0	61.2	51.4	19.8
50	31.1	6.08	137.6	48.5	47.5		
100	34.9	6.17	160.9	57.6	35.1	25.6	14.9
175	37.6	6.65	186.1	68.6	24.2		
275	38.5	6.31	247.3	96.3	26.8		
375	40.8	7.20	272.1	120.4	42.9	38.5	10.6

Comments:

Marketable - 15-50 mm shank diameter, trimmed to 350 mm length

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted

Site reference: 26 Year: 1999

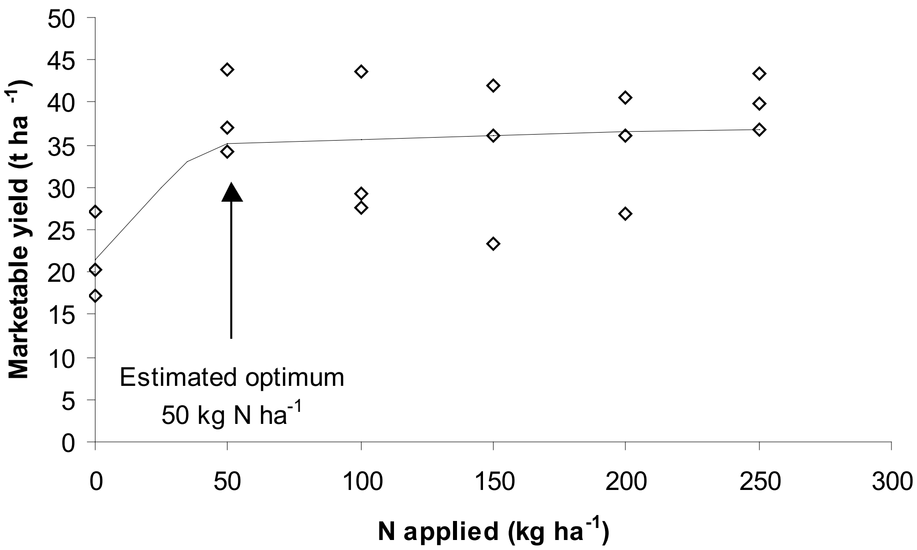
County:	**Lancashire**	**Soil series:**	**Sollom**
Grid reference:	**SD 372122**	**Topsoil texture:**	**Loamy sand**
		pH:	**7.1**
Previous crop:	**Leek**	**Available P:**	**80 mg/l (Index 5)**
Current crop:	**Crisp lettuce** *cv.* **Calgary**	**Available K:**	**71 mg/l (Index 1)**
		Total N:	**0.17%**
Planting date	**27/06/99**		
Harvest date:	**05/08/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	30-60 cm kg N ha-1	60-90 cm kg N ha-1
0	21.5	2.45	83.5	57.9	24.6	22.4	24.3
50	38.4	2.59	104.2	56.6	83.1		
100	33.5	2.57	101.2	55.4	187.9		
150	33.8	2.39	98.5	53.1	137.8	24.7	21.8
200	34.4	2.48	99.1	50.7	227.1		
250	40.0	2.36	106.3	50.3	156.5	45.0	27.0

Comments:
Marketable - trimmed heads > 450 g

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 27 Year: 1998

County:	**Lancashire**	**Soil series:**	**Sollom**
Grid reference:	**SD 448137**	**Topsoil texture:**	**Humose loamy sand**
		pH:	**5.3**
Previous crop:	**Winter wheat**	**Available P:**	**42 mg/l (Index 3)**
Current crop:	**Carrot**	**Available K:**	**163 mg/l (Index 2)**
	***cv.* Nerac**	**Total N:**	**0.39%**
Sowing date	**27/04/98**		
Harvest date:	**10/03/99**		

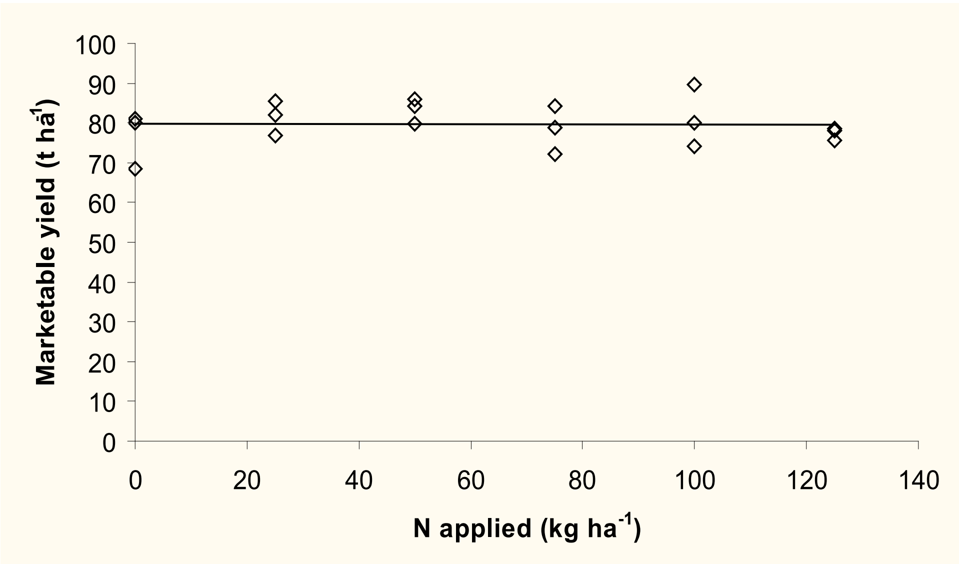
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	76.5	8.29	95.8		39.4	35.9	16.9
25	81.5	8.83	109.8		40.1		
50	83.4	8.73	111.8		38.6		
75	78.4	8.83	121.9		48.1	37.7	20.6
100	81.2	8.80	133.6		43.4		
125	77.4	8.62	131.9		49.0	45.1	16.0

Comments:

Marketable roots at commercial harvest 25-40 mm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No significant response to applied N

Site reference: 28 Year: 1998

County:	**Lancashire**	**Soil series:**	**Wisbech**
Grid reference:	**SD 432248**	**Topsoil texture:**	**Silt loam**
		pH:	**7.8**
Previous crop:	**Late summer cauliflower**	**Available P:**	**22 mg/l (Index 2)**
Current crop:	**Late summer cauliflower** *cv.* **Nautilis**	**Available K:**	**149 mg/l (Index 2)**
		Total N:	**0.07%**
Planting date	**29/05/98**		
Harvest date:	**02/09/98**		

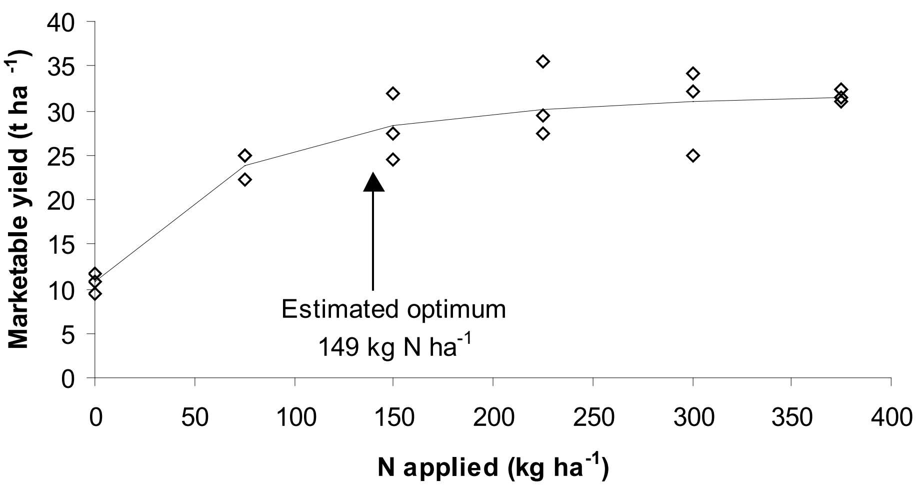
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	Soil mineral N after harvest 30-60 cm kg N ha-1	Soil mineral N after harvest 60-90 cm kg N ha-1
0	10.7	4.02	44.4	57.8	28.3	20.7	31.1
75	24.0	4.77	44.7	82.5	31.6		
150	27.9	4.99	44.9	90.3	31.2	21.9	32.6
225	30.8	5.54	44.8	116.0	100.3		
300	30.5	5.35	45.1	121.2	104.8		
375	31.6	5.73	44.9	141.8	78.8	40.6	30.7

Comments:

Marketable – Class I > 110 mm curd diameter, 3 cuts

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 28 Year: 1999

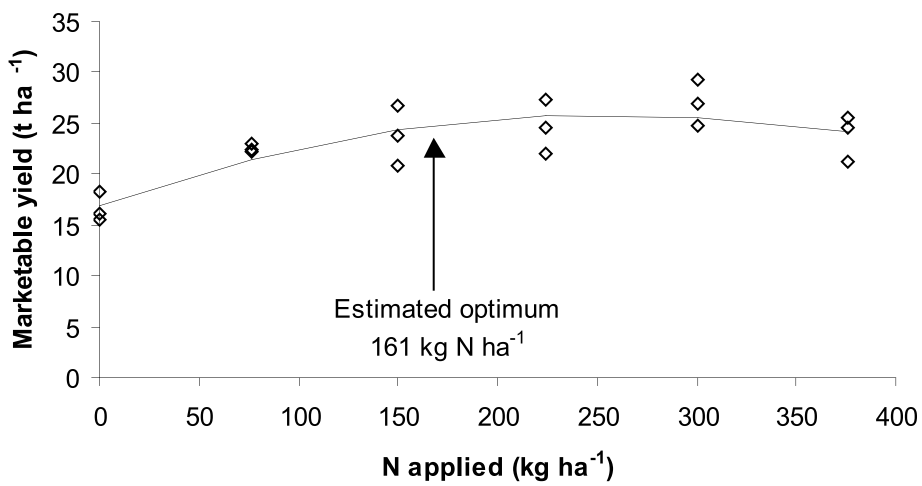
County: Lancashire
Soil series: Wisbech
Grid reference: SD 432248
Topsoil texture: Silt loam
pH: 7.8
Previous crop: Late summer cauliflower
Available P: 22 mg/l (Index 2)
Current crop: Late summer cauliflower *cv.* Amsterdam
Available K: 149 mg/l (Index 2)
Total N: 0.07%
Planting date 02/06/98
Harvest date: 26/08/98

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate kg N ha-1	Marketable yield t ha-1	Total dry weight yield t ha-1	N uptake kg N ha-1	N returned in crop residues kg N ha-1	Soil mineral N after harvest 0-30 cm kg N ha-1	30-60 cm kg N ha-1	60-90 cm kg N ha-1
0	16.7	5.31	118.0	77.0	26.9	14.5	19.2
75	22.5	5.98	166.6	106.8	60.7		
150	23.8	5.81	179.8	107.8	106.3		
225	24.6	6.22	208.6	127.4	139.6	27.9	27.8
300	27.0	6.35	226.3	140.1	293.0		
375	23.8	5.90	208.3	139.7	235.6	15.8	24.8

Comments:
Marketable – Class I > 110 mm curd diameter, 2 cuts

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 29 Year: 1998

County:	**Lancashire**	**Soil series:**	**Rufford**
Grid reference:	**SD 392088**	**Topsoil texture:**	**Sandy loam**
		pH:	**6.0**
Previous crop:	**Winter wheat**	**Available P:**	**31 mg/l (Index 2)**
Current crop:	**Brussels sprout**	**Available K:**	**148 mg/l (Index 2)**
	***cv.* Adonis**	**Total N:**	**0.06%**
Planting date	**16/06/98**		
Harvest date:	**09/12/98**		

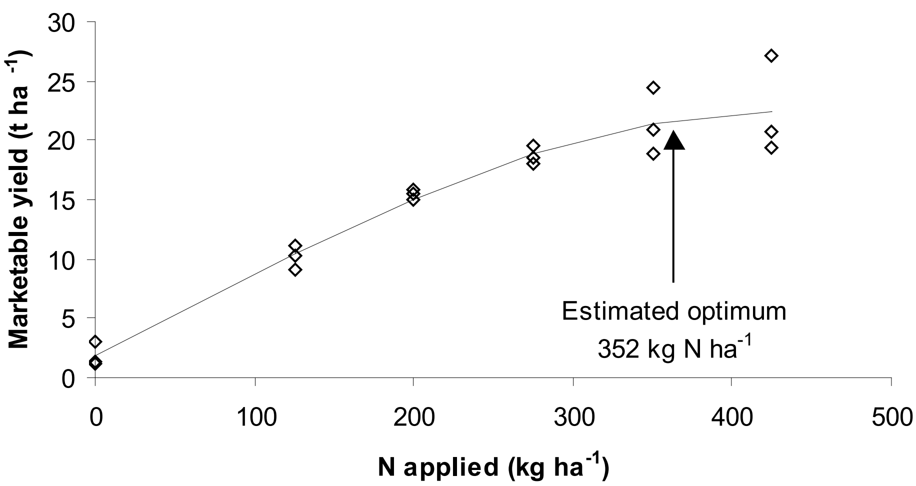
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	**Marketable yield**	**Total dry weight yield**	**N uptake**	**N returned in crop residues**	**Soil mineral N after harvest**		
					0-30 cm	**30-60 cm**	**60-90 cm**
kg N ha-1	**t ha-1**	**t ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**	**kg N ha-1**
0	**1.9**	**2.73**	**49.9**	**36.7**	**21.5**	**20.1**	**20.1**
125	**10.2**	**5.36**	**111.0**	**53.3**	**22.6**		
200	**15.5**	**7.24**	**174.1**	**84.4**	**20.3**		
275	**18.7**	**8.41**	**222.2**	**107.9**	**20.1**	**18.5**	**20.9**
350	**21.5**	**9.86**	**296.0**	**150.3**	**21.9**		
425	**22.5**	**9.87**	**331.9**	**160.1**	**24.3**	**19.3**	**16.3**

Comments:

Marketable – 10-40 mm diameter sprouts

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 30 Year: 1998

County:	**South Yorkshire**	**Soil series:**	**Romney**
Grid reference:	**SE 821023**	**Topsoil texture:**	**Silt loam**
		pH:	**7.8**
Previous crop:	**Cabbage**	**Available P:**	**5 mg/l (Index 0)**
Current crop:	**Red beet** *cv.* **Crimson Glow**	**Available K:**	**50 mg/l (Index 0)**
		Total N:	**0.13%**
Sowing date	**26/05/98**		
Harvest date:	**23/10/98**		

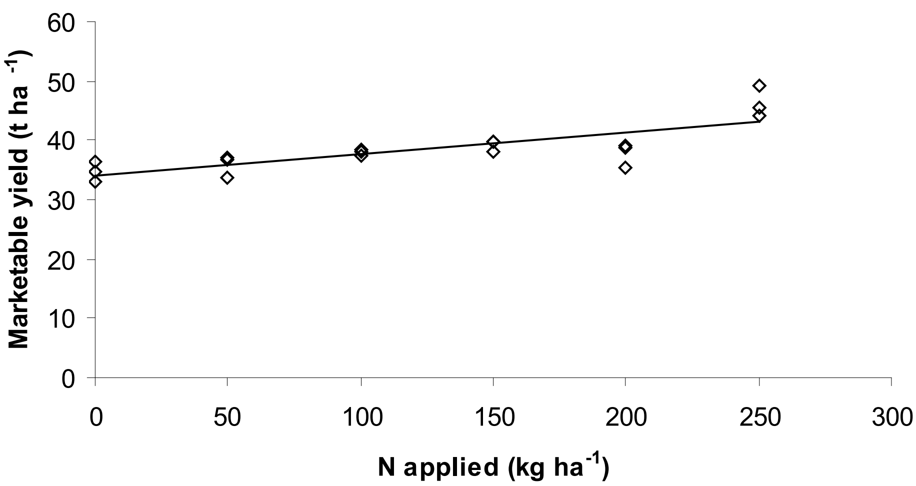
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	34.7	8.54	216.7	99.6	26.5	15.7	12.9
50	35.9	9.20	300.5	137.3	34.6		
100	37.8	9.61	303.0	147.9	27.6		
150	39.2	9.85	300.4	145.4	61.5	23.9	21.3
200	37.8	10.22	302.2	160.0	73.9		
250	46.3	10.89	344.8	170.0	153.8	27.81	21.7

Comments:

Marketable – 25-75 mm diameter beet

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: No optimum could be fitted

Site reference: 30 **Year: 1999**

County:	**South Yorkshire**	**Soil series:**	**Romney**
Grid reference:	**SE 821023**	**Topsoil texture:**	**Silt loam**
		pH:	**7.8**
Previous crop:	**Red beet**	**Available P:**	**5 mg/l (Index 0)**
Current crop:	**Savoy cabbage**	**Available K:**	**50 mg/l (Index 0)**
	***cv.* Siberia**	**Total N:**	**0.13%**
Planting date	**14/07/99**		
Harvest date:	**01/03/00**		

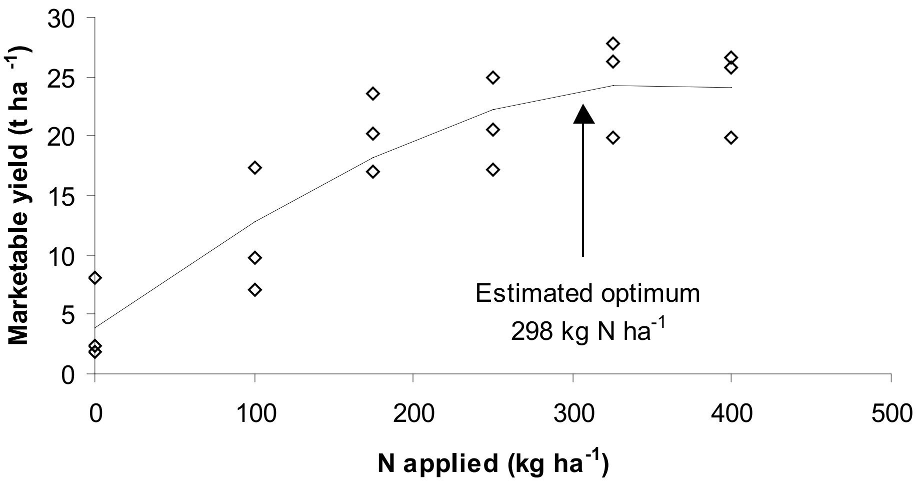
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	4.1	8.00	186.1	162.7	35.3	20.2	14.7
100	11.4	8.96	259.1	189.3	30.3		
175	20.3	9.59	336.3	207.8	32.8		
250	20.9	9.49	343.7	209.0	38.9	20.5	20.1
325	24.6	10.15	410.3	250.7	38.6		
400	24.1	9.98	411.4	257.8	54.8	57.3	31.7

Comments:

Marketable – close trimmed head weight >500 g, single cut

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 31 Year: 1998

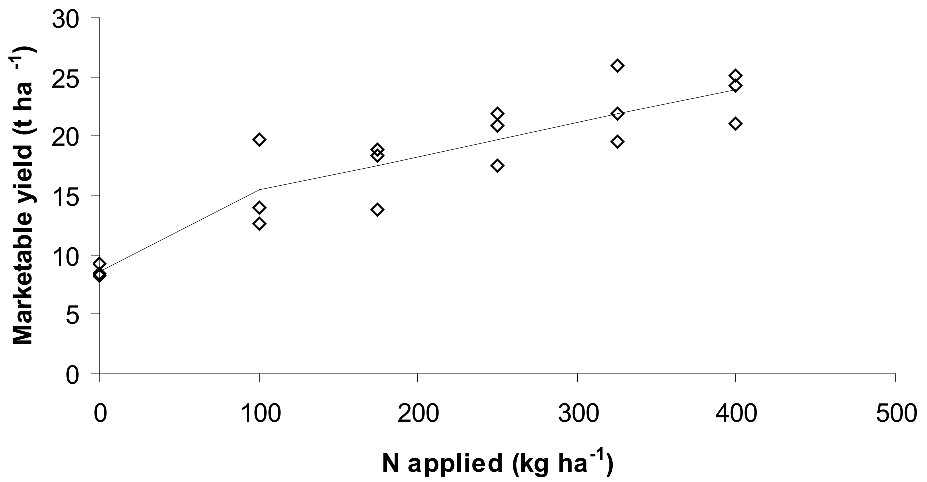
County:	**Lincolnshire**	**Soil series:**	**Wisbech**
Grid reference:	**TF 208372**	**Topsoil texture:**	**Silt loam**
		pH:	**7.5**
Previous crop:	**Winter wheat**	**Available P:**	**25 mg/l (Index 2)**
Current crop:	**Brussels sprout**	**Available K:**	**154 mg/l (Index 2)**
	***cv.* Adonis**	**Total N:**	**0.10%**
Planting date	**19/05/98**		
Harvest date:	**14/12/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	8.6	5.76	111.4	68.5	27.0	16.6	10.1
100	15.5	8.77	186.7	108.7	20.9		
175	17.1	9.27	208.4	120.7	24.6		
250	20.1	10.86	270.7	159.7	26.3	17.9	9.2
325	22.5	11.99	325.4	188.8	30.4		
400	23.5	13.20	384.1	229.5	31.7	19.4	12.5

Comments:
Marketable – 10-40 mm diameter sprouts

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comments: Optimum above maximum N rate used.

Site reference: 31 Year: 1999

County:	**Lincolnshire**	**Soil series:**	**Wisbech**
Grid reference:	**TF 208372**	**Topsoil texture:**	**Silt loam**
		pH:	**7.5**
Previous crop:	**Brussels sprout**	**Available P:**	**25 mg/l (Index 2)**
Current crop:	**Autumn cauliflower**	**Available K:**	**154 mg/l (Index 2)**
	***cv.* Stanley**	**Total N:**	**0.10%**
Planting date	**07/07/99**		
Harvest date:	**22/10/99**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate (see comments)**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	**3.4**	**3.90**	**72.7**	**64.5**	**24.3**	**11.7**	**13.8**
70	**9.8**	**5.17**	**129.0**	**101.2**	**33.3**		
140	**12.0**	**5.34**	**152.0**	**114.0**	**35.3**		
210	**17.0**	**6.30**	**233.1**	**178.0**	**52.5**	**19.2**	**12.0**
280	**13.6**	**7.03**	**237.7**	**192.7**	**26.7**		
350	**16.0**	**7.19**	**294.7**	**243.7**	**117.6**	**27.6**	**16.2**

Comments:

Marketable – Class I > 110 mm curd diameter, 2 cuts.

Only one plot replicate harvested because of waterlogging, response curve therefore not fitted.

Site reference: 32 Year: 1998

County:	**Lincolnshire**	**Soil series:**	**Tanvats**
Grid reference:	**TF 299354**	**Topsoil texture:**	**Silt loam**
		pH:	**7.7**
Previous crop:	**Brussels sprout**	**Available P:**	**41 mg/l (Index 3)**
Current crop:	**Dutch white cabbage** *cv.* **Delus**	**Available K:**	**296 mg/l (Index 3)**
		Total N:	**0.11%**
Planting date	**29/05/98**		
Harvest date:	**14/10/98**		

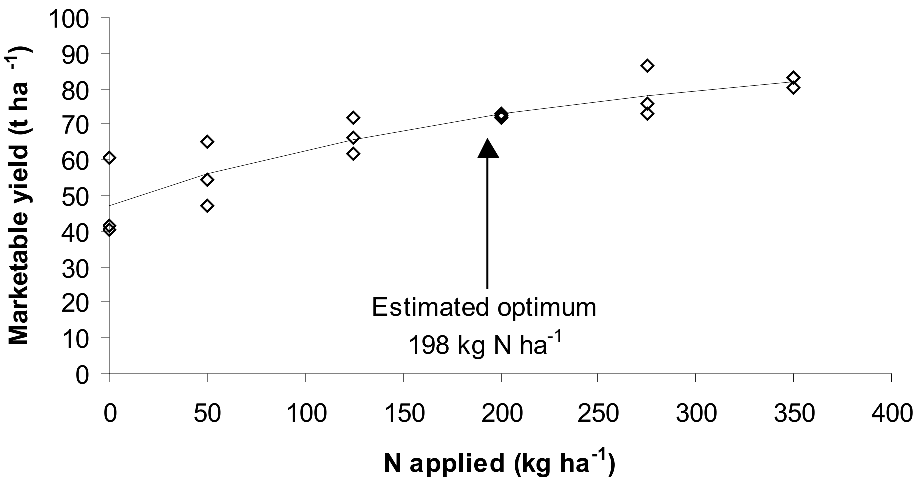
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	47.5	13.32	231.3	136.7	30.6	23.5	17.0
50	55.7	13.65	265.0	146.3	33.8		
125	66.6	14.32	299.6	155.5	50.3		
200	72.4	14.26	368.8	196.8	51.5	28.9	16.6
275	78.3	15.29	395.4	206.0	83.7		
350	82.2	15.39	431.4	227.4	98.8	47.0	18.8

Comments:

Marketable – close trimmed head weight >500 g, single cut

Response of marketable yield (t ha-1) to N applied (kg ha-1)



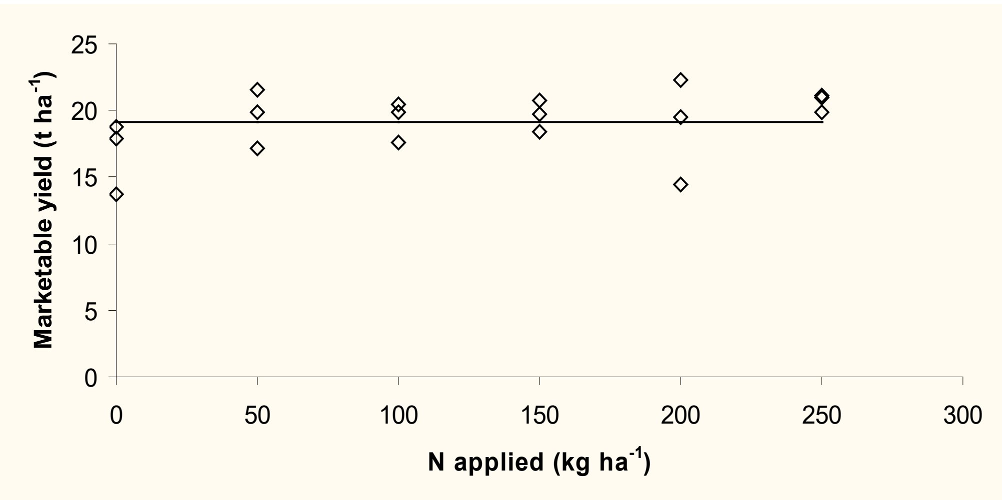
Site reference: 33 Year: 1998

County:	**Warwickshire**	**Soil series:**	**Wick**
Grid reference:	**SP 241574**	**Topsoil texture:**	**Sandy loam**
		pH:	**6.4**
Previous crop:	**Salad onion (ploughed in)**	**Available P:**	**13 mg/l (Index 1)**
Current crop:	**Dwarf bean**	**Available K:**	**132 mg/l (Index 2)**
	***cv.* Nerina**	**Total N:**	**0.07%**
Sowing date	**23/06/98**		
Harvest date:	**09/09/98**		

Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	16.8	4.89	117.6	70.2	41.4	22.3	27.6
50	19.5	5.25	152.6	90.1	47.3		
100	19.3	5.13	161.2	97.2	94.5		
150	19.6	5.25	172.6	105.0	79.1	25.5	30.9
200	18.7	5.09	172.0	106.3	143.8		
250	20.7	5.45	189.0	114.6	149.4	35.0	29.3

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comment: No significant response to applied N

Site reference: 34 Year: 1998

County:	**Kent**	**Soil series:**	**Coombe**
Grid reference:	**TQ 286655**	**Topsoil texture:**	**Silty clay loam**
		pH:	**8.1**
Previous crop:	**Calabrese**	**Available P:**	**32 mg/l (Index 3)**
Current crop:	**Autumn cauliflower**	**Available K:**	**447 mg/l (Index 4)**
	***cv.* Dova**	**Total N:**	**0.08%**
Planting date	**08/08/98**		
Harvest date:	**28/01/99**		

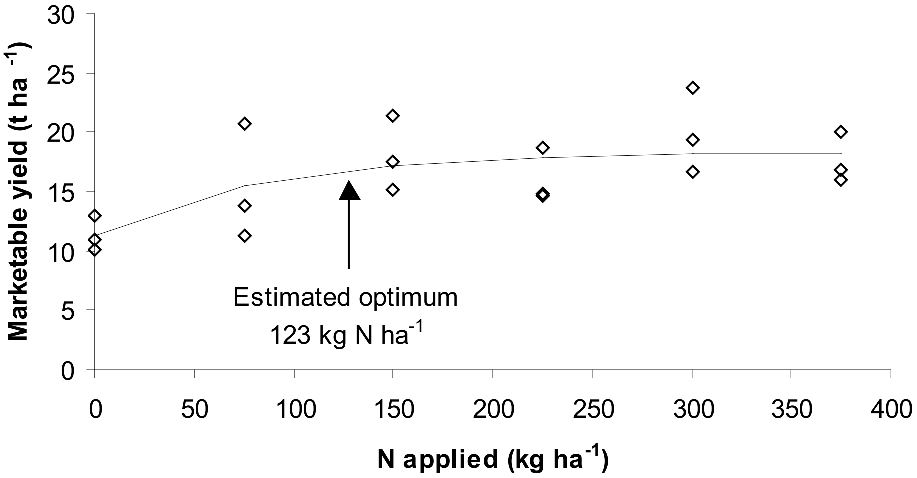
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	11.4	3.17	116.2	76.0	34.3	23.4	11.2
75	15.3	3.42	138.0	82.3	29.6		
150	18.0	3.81	164.5	93.3	35.3		
225	16.1	4.00	171.2	109.3	42.3	31.0	36.4
300	19.9	4.24	194.7	117.2	38.6		
375	17.7	4.09	184.0	114.8	41.5	23.9	49.1

Comments:

Marketable – Class I > 110 mm curd diameter, including frost damaged curds, single cut

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 34 Year: 1999

County:	**Kent**	**Soil series:**	**Coombe**
Grid reference:	**TQ 286655**	**Topsoil texture:**	**Silty clay loam**
		pH:	**8.1**
Previous crop:	**Calabrese**	**Available P:**	**32 mg/l (Index 3)**
Current crop:	**Autumn cauliflower *cv.* Tucson**	**Available K:**	**447 mg/l (Index 4)**
		Total N:	**0.08%**
Planting date	**27/07/99**		
Harvest date:	**10/12/99**		

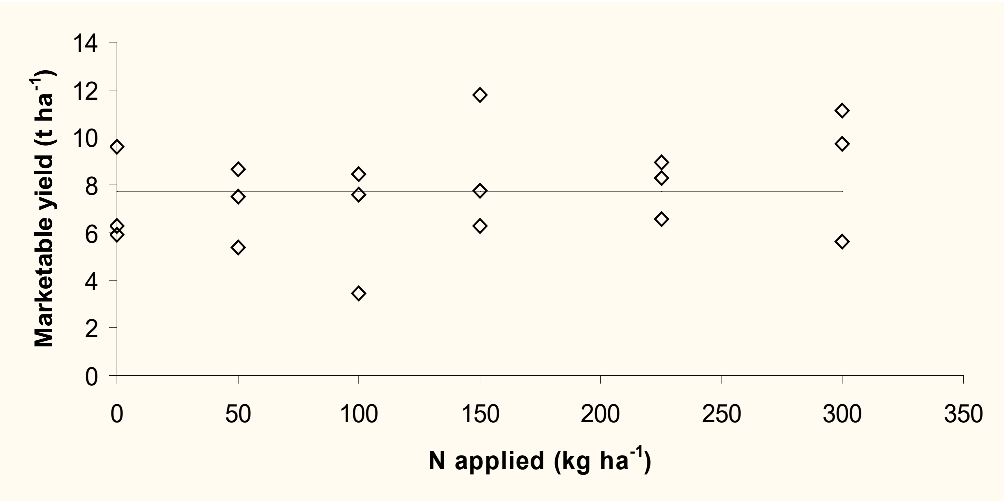
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	7.3	4.26	147.0	120.1	11.7	8.3	4.4
50	7.2	4.79	170.4	141.6	10.1		
100	6.5	4.50	156.4	130.4	12.0		
150	8.6	4.74	191.5	155.5	20.0	18.4	6.6
225	7.9	4.13	187.8	159.5	29.3		
300	8.8	4.59	217.3	183.0	49.8	34.6	7.5

Comments:

Marketable – Class I > 110 mm curd diameter, single cut, slightly immature to avoid frost damage

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Comment: No significant response to added N

Site reference: 35 Year: 1998

County:	**West Sussex**	**Soil series:**	**Hamble**
Grid reference:	**SZ 841027**	**Topsoil texture:**	**Silt loam**
		pH:	**6.6**
Previous crop:	**Crisp lettuce**	**Available P:**	**15 mg/l (Index 1)**
Current crop:	**Crisp lettuce**	**Available K:**	**116 mg/l (Index 1)**
	***cv.* Calgary**	**Total N:**	**0.10%**
Planting date	**16/08/98**		
Harvest date:	**07/10/98**		

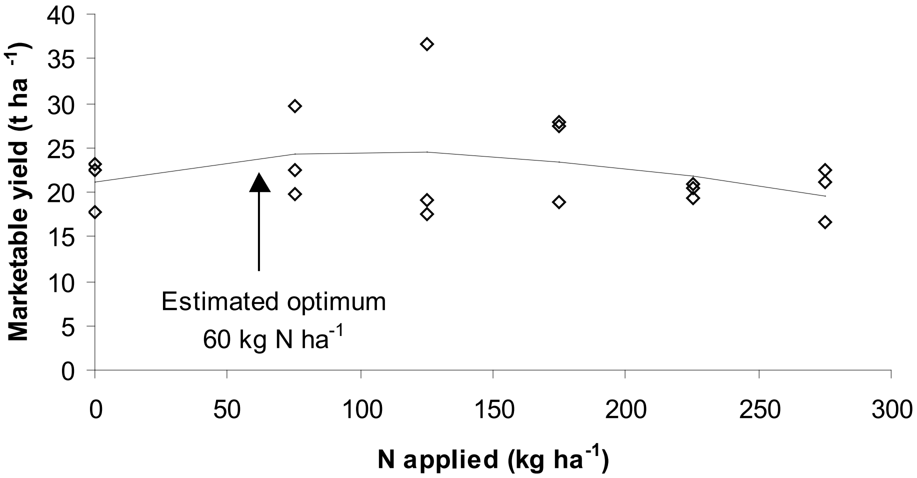
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	21.2	2.10	86.4	57.3	36.0	36.9	36.1
75	24.0	2.26	103.6	66.1	73.2		
125	24.4	2.35	112.3	74.6	95.0		
175	24.7	2.26	105.4	66.9	142.7	80.0	42.7
225	20.2	2.12	102.4	70.5	246.5		
275	20.1	2.22	107.1	74.6	292.0	146.4	119.1

Comments:

Marketable - trimmed heads > 350 g, harvested slightly immature to clear trial area before commercial harvest

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 36 Year: 1998

County:	**Greater Manchester**	**Soil series:**		**Longmoss**
Grid reference:	**SJ 914944**	**Topsoil texture:**	**Peat**	
			pH:	**6.0**
Previous crop:	**Carrot**	**Available P:**		**127 mg/l (Index 6)**
Current crop:	**Crisp lettuce**	**Available K:**		**163 mg/l (Index 2)**
	***cv.* Brandon**	**Total N:**		**1.48%**
Planting date	**17/07/98**			
Harvest date:	**10/09/98**			

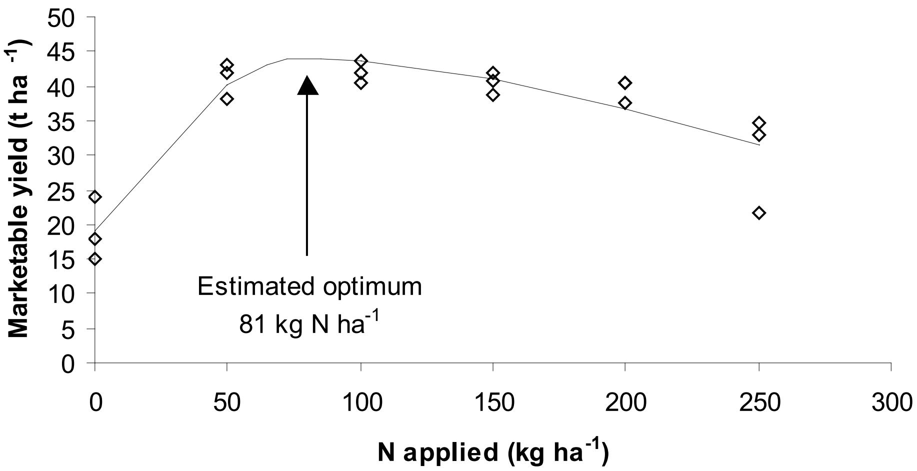
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	19.0	2.52	66.9	48.2	37.5	35.8	107.9
50	41.0	3.01	106.5	59.1	47.7		
100	42.0	2.91	126.4	70.1	99.8		
150	40.4	2.98	132.2	77.8	115.3	27.1	117.7
200	39.6	2.81	125.2	70.7	141.5		
250	29.8	2.39	109.2	68.8	281.1	80.1	481.3

Comments:

Marketable - trimmed heads > 450 g

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 36 Year: 1999

County:	**Greater Manchester**	**Soil series:**	**Longmoss**
Grid reference:	**SJ 914944**	**Topsoil texture:**	**Peat**
		pH:	**6.0**
Previous crop:	**Crisp lettuce**	**Available P:**	**127 mg/l (Index 6)**
Current crop:	**2nd early potato *cv.* Nadine**	**Available K:**	**163 mg/l (Index 2)**
		Total N:	**1.48%**
Planting date	**03/05/99**		
Harvest date:	**05/10/99**		

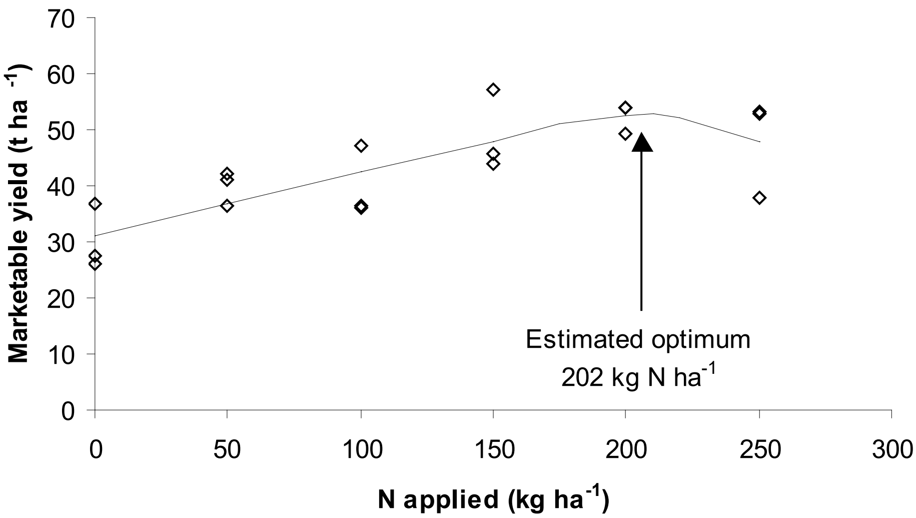
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	30.0	6.07	61.1		56.5	24.0	75.0
50	39.9	7.41	93.3		55.0		
100	39.8	7.89	94.4		51.0		
150	49.0	9.34	130.3		49.1	40.1	50.6
200	52.4	10.74	158.5		48.5		
250	48.0	9.51	147.9		68.2	52.7	68.3

Comments:

Harvested after haulm senescence. Marketable – 45-85 mm

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 37 Year: 1998

County:	**Warwickshire**	**Soil series:**	**Whimple**
Grid reference:	**SP 207531**	**Topsoil texture:**	**Clay loam**
		pH:	**6.6**
Previous crop:	**Winter wheat**	**Available P:**	**11 mg/l (Index 1)**
Current crop:	**Overwintered salad onion**	**Available K:**	**206 mg/l (Index 2)**
	***cv.* White Lisbon**	**Total N:**	**0.09%**
Sowing date	**30/08/98**		
Harvest date:	**28/04/99**		

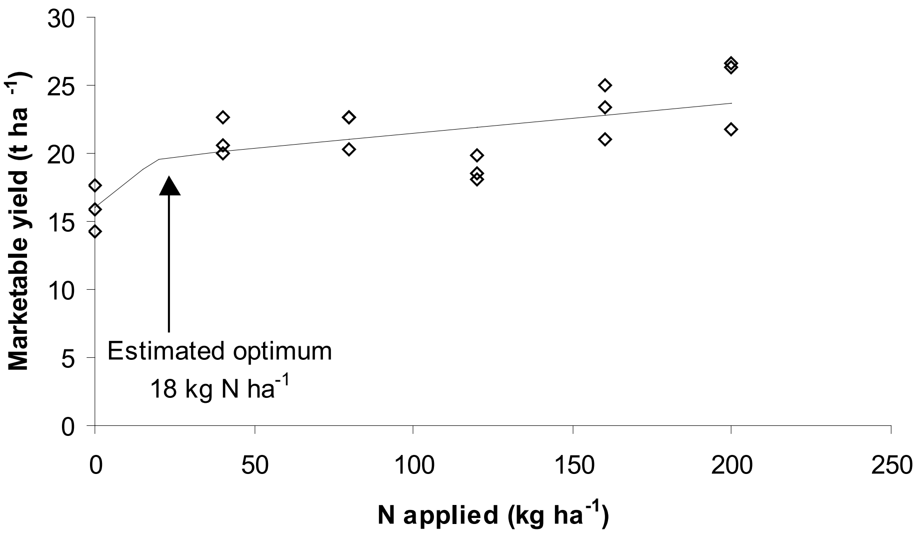
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	16.0	1.83	27.1	4.6	40.0	39.6	23.4
40	21.1	1.95	45.0	10.5	39.7		
80	21.9	1.84	49.8	13.4	60.4		
120	18.9	1.70	66.6	20.9	79.0	44.9	31.3
160	23.1	1.97	85.4	24.8	122.6		
200	24.9	1.93	93.7	24.1	132.6	46.6	28.0

Comments:

Marketable - 8-18 mm diameter, trimmed to 280 mm length

Response of marketable yield (t ha-1) to N applied (kg ha-1)



Site reference: 37 Year: 1999

County:	**Warwickshire**	**Soil series:**	**Whimple**
Grid reference:	**SP 207531**	**Topsoil texture:**	**Clay loam**
		pH:	**6.6**
Previous crop:	**Overwintered salad onion**	**Available P:**	**11 mg/l (Index 1)**
Current crop:	**Salad onion**	**Available K:**	**206 mg/l (Index 2)**
	***cv.* Laser**	**Total N:**	**0.09%**
Sowing date	**24/06/99**		
Harvest date:	**16/09/99**		

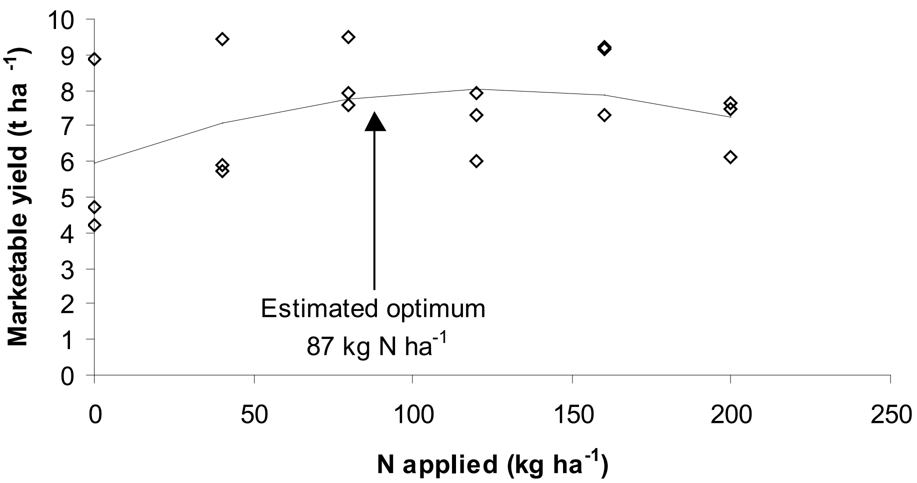
Summary of N response trial results, **Mean of 3 replicate plots for each rate**:

Rate	Marketable yield	Total dry weight yield	N uptake	N returned in crop residues	Soil mineral N after harvest		
					0-30 cm	30-60 cm	60-90 cm
kg N ha-1	t ha-1	t ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1	kg N ha-1
0	5.9	0.83	21.0	6.3	68.4	47.9	22.0
40	7.0	0.95	23.6	7.5	83.3		
80	8.3	1.02	30.8	9.9	83.2		
120	7.1	1.00	28.3	10.0	76.8	52.6	25.9
160	8.6	1.07	36.9	12.3	138.1		
200	7.1	0.93	29.2	9.5	136.7	73.1	42.9

Comments:

Marketable - 8-18 mm diameter, trimmed to 280 mm length. Yield low due to cloddy seedbed reducing plant stand

Response of marketable yield (t ha-1) to N applied (kg ha-1)



APPENDIX B

Site reference: 01 Year: 1998

Topsoil texture: Sandy clay loam **Previous crop:** Winter barley

Current crop: Winter OSR **Expected mkt yield t/ha:** 4.0

Maximum mkt yield t/ha: 3.4 **Maximum total DW t/ha:** 5.9

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	190	188	N/A	N/A	N/A	N/A	200	159	120	89
Calculated yield *	N/A	3.1	3.1					3.2	2.9	2.7	2.6
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was a linear response to applied N and no optimum could be fitted. Yield variability increased significantly above applications of 250 kgN/ha. The SUNDIAL-FRS predictive recommendation (default weather) was very close to the farm yield. Using actual weather and spring SMN reduced the recommendation. The SUNDIAL-FRS recommendation is probably too low for this expected yield at this site. The recommendation given by RB209 was also too low.**

WELL_N is not parameterised for oil seed rape.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	76	67	23	18	184
300	130	184	33	16	363
188 (farm)$	N/A	75	32	12	N/A
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
300	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	62	13	13	12	100
300	199	15	130	34	378
188 (farm)$	164	15	81	22	282

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL simulated crop N well at the zero N rate, but underestimated SMN. Where fertiliser N had been applied, SUNDIAL overestimated crop N, but simulated total SMN reasonably well, although the distribution of SMN in the profile was not correct.

Site reference: 01 Year: 1999

Topsoil texture: Sandy clay loam **Previous crop:** Winter OSR
Current crop: Winter wheat **Expected mkt yield t/ha:** 10.5
Maximum mkt yield t/ha: 9.9 **Maximum total DW t/ha:** 16.1

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	200	136	175	150	175	150	240	160	280	200
Calculated yield *	N/A	8.8	8.0	8.5	8.2	8.5	8.2	9.2	8.3	9.7	8.8
% difference from optimum yield											

* Calculated from linear plus exponential curve fitted to trial data.
$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was a linear response to applied N and no optimum could be fitted. The expected yield was not achieved on the trial, yet the farm rate of 136 kgN/ha used in the remainder of the field gave a measured yield of 11.8 t/ha. The farm N was applied 2 weeks later than the trial N (20/4/99 compared to 5/4/99) and appears to have been used much more efficiently. This illustrates the importance of timing, and indicates that there was considerable yield variability across the field.**

The SUNDIAL-FRS retrospective recommendation (without spring SMN) was the greatest for this site. The use of the spring SMN measurements reduced the recommendation, and would have resulted in reduced yields. WELL_N gave recommendations close to RB209 and farm practice and were reduced by 25 kgN/ha by actual weather.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	69	52	25	14	160
250	244	60	25	12	341
136 (farm)$	217	36	14	12	279
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	109	18	7	6	140
250	260	18	7	6	291
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	94	34	46	12	186
250	240	39	77	12	368
136 (farm)$	215	32	20	12	279

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL simulated crop N and SMN well for all the N rates. WELL_N simulated crop + soil N well at both zero and maximum rates, but underestimated SMN, particularly in the 0-

30cm layer.

Site reference: **02** Year: **1998**

Topsoil texture: Sandy clay loam **Previous crop:** Winter wheat

Current crop: Winter barley **Expected mkt yield t/ha:** 7.5

Maximum mkt yield t/ha: 6.6 **Maximum total DW t/ha:** 12.1

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	160	202	125	150	125	150	40	0	60	0
Calculated yield *	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was no significant response to applied N, with very variable results in the field trial caused by lodging. SUNDIAL correctly recommended that no fertiliser N should be applied, when spring SMN measurements were included. All other recommendations were too high. The interactive effects of increased N applications, increased grain fill and lodging make it difficult to draw any conclusions from this data set.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	82	54	31	21	188
160	208	116	33	27	384
202 (farm)$	N/A	96	38	19	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	90	7	6	5	108
160	190	7	6	5	208
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	81	19	37	19	157
160	128	23	92	32	275
202 (farm)$	135	23	71	58	287

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS simulated crop N and SMN well in the zero N treatment, but underestimated crop N at the maximum N rate. Total SMN at the maximum N rate was reasonably well simulated, but the distribution within the profile was again wrong (as in Site 1/98). Total crop N uptake at the maximum N rate was high, suggesting that SUNDIAL-FRS was unable to simulate luxury N uptake. A variable nitrogen uptake module for SUNDIAL has been developed in earlier work and could be implemented in this version of the model if the results suggest that this is necessary. WELL_N simulated crop N uptake very well, but considerably underestimated SMN.

APPENDIX B

Site reference: 02 Year: 1999

Topsoil texture:	Sandy clay loam	**Previous crop:**	Winter barley
Current crop:	Winter OSR	**Expected mkt yield t/ha:**	4.5
Maximum mkt yield t/ha:	4.5	**Maximum total DW t/ha:**	11.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**0 (see below)**	**190**	**225**	**N/A**	**N/A**	**N/A**	**N/A**	**160**	**141**	**180**	**140**
Calculated yield *	**3.9**	**3.9**	**3.9**					**3.9**	**3.9**	**3.9**	**3.9**
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **A basal application of 45 kgN/ha was applied to all plots and the farm area in September 1998. There was no significant response to additional N at this site, and very high variability between the field replicates. The farm rate of 225 kgN/ha used in the remainder of the field produced a higher yield (4.8 t/ha) than the trial area, and left very little SMN at harvest. This implies that the timing of the N applications was very important. The farm N was applied 2 weeks earlier than the trial N. The SUNDIAL-FRS and RB209 recommendations were all too high, although the SUNDIAL recommendation was reduced when spring SMN measurements were used. The difficulty in determining an optimum N rate may be due to spatial variability in the field. High spatial variability will also make accurate fertiliser recommendation difficult. Where spatial variability is high, the variation should be accounted for in the recommendations.**

WELL_N is not parameterised for oil seed rape.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	124	66	15	15	220
300	212	147	51	37	447
225 (farm)$	270	6	12	13	301
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
300	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	163	12	12	12	199
300	205	17	144	24	390
225 (farm)$	267	15	14	12	308

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments:

SUNDIAL-FRS simulated crop N uptake and SMN very well under the farm conditions, and reasonably well in the trial.

APPENDIX B

Site reference: 03a Year: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Winter OSR
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	11.0
Maximum mkt yield t/ha:	11.5	**Maximum total DW t/ha:**	16.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	136 (±7.6)	90	175	150	125	125	125	280	260	280	260
Calculated yield *	11.4	10.3	10.9	11.5	11.3	11.3	11.3	N/A	N/A	N/A	N/A
% difference from optimum yield		-10	-5	0	-1	-1	-1				

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The SUNDIAL-FRS recommendations were outside the range of N rates applied in the trial, thus it was not possible to calculate yields for these N rates. The SUNDIAL-FRS recommendations were much too high, and only reduced by 20kg N/ha with the spring SMN measurements. WELL_N accurately predicted the optimum. The RB209 recommendation was too low.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	73	28	8	7	116
160	207	27	9	6	249
175 (farm)$	N/A	6	6	8	N/A
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	123	5	5	5	138
160	219	5	5	5	234
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	46	48	14	9	117
160	183	66	30	9	288
175 (farm)$	201	57	23	9	289

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS underestimated crop N at zero and overestimated SMN at all N rates. This suggests that the simulated crop could not take up nitrogen as quickly as observed in the field. Implementing the existing variable uptake module of SUNDIAL could solve this problem. WELL_N gave reasonable estimates of SMN but overestimated crop uptake at the zero rate.

APPENDIX B

Site reference: 03b Year: 1999

Topsoil texture:	Silt loam	**Previous crop:**	Field peas
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	11.5
Maximum mkt yield t/ha:	10.6	**Maximum total DW t/ha:**	15.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0 (±6.1)	205	118	75	75	50	75	240	179	200	140
Calculated yield *	10.0	9.0	9.9	10.0	10.0	10.0	10.0	8.4	9.3	9.0	9.7
% difference from optimum yield		-10	-1	0	0	0	0	-16	-7	-10	-3

* Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **Marketable yields declined with increasing levels of applied N above 150 kgN/ha. WELL_N gave good predictive and retrospective recommendations that, although higher than required, did not affect yield. The SUNDIAL-FRS predictive recommendations (based on an expected yield of 11.5 t/ha that was not achieved in the trial) were too high, and gave a yield penalty. The use of spring SMN measurements improved the SUNDIAL recommendations. The SUNDIAL retrospective run with actual weather, a reduced yield (10.0 t/ha) and spring SMN, reduced the recommendation further to 140 kg N/ha. This was still too high, but did not incur a yield penalty. The RB209 recommendation was also too high.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	162	20	14	7	203
250	244	48	23	9	324
118$	196	31	18	11	256
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	174	17	7	6	204
250	265	42	56	40	403
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	116	20	11	9	157
250	202	142	18	9	371
118$	227	21	11	9	268

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N gave a good estimate of crop N at both zero and maximum rates, but overestimated SMN at the maximum N rate. SUNDIAL underestimated crop N at both zero and maximum rates, resulting in an accumulation of SMN at the maximum N rate. Again, these results suggest implementation of the variable uptake module in SUNDIAL-FRS would improve the simulations.

Site reference: 04 Year: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Winter wheat
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	9.0
Maximum mkt yield t/ha:	8.0	**Maximum total DW t/ha:**	11.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	180	264	100	150	75	125	230	230	210	210
Calculated yield *	N/A										
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was a linear response to applied N and no optimum could be fitted. It was not possible to derive yields. The expected yield of 9 t/ha was not achieved, even by the farm rate, which was adjusted to increase grain protein. The expected yield may have been unrealistic for this site in this year. However, the trial received only a single dose of N in contrast to farm practice (3 applications) and timing may have been crucial for this variety.**

The SUNDIAL-FRS predictive recommendation was unaffected by SMN measurements. The retrospective recommendation used the maximum yield of 8.0 t/ha, which reduced the recommendation a little. WELL_N recommendations appear to be low and affected by both the high yield expectation and actual weather.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	106	66	21	13	206
220	174	147	38	28	387
264 (farm)$	N/A	70	65	77	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	93	4	22	7	126
220	211	22	15	28	276
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	131	33	16	9	189
220	149	28	140	9	326
264 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: The SUNDIAL-FRS simulations were reasonable, although the distribution within the 0-60 cm soil layers was not well simulated at the maximum N rate (compare sites 1/99 and 2/98). WELL_N considerably underestimated SMN.

Site reference: 04 Year: 1999

Topsoil texture:	Silt loam	**Previous crop:**	Winter wheat
Current crop:	Winter OSR	**Expected mkt yield t/ha:**	4.0
Maximum mkt yield t/ha:	3.1	**Maximum total DW t/ha:**	10.6

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	250	110	N/A	N/A	N/A	N/A	0	0	0	0
Calculated yield *	1.9	1.9	1.9					1.9	1.9	1.9	1.9
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was no significant response to applied N at this site. SUNDIAL-FRS correctly recommends that no fertiliser N should be applied. The expected yield is not achieved; the maximum yield of 3.1 t/ha is due to one very high yielding plot, all other plots yielding around 2 t/ha. The SUNDIAL-FRS recommendation would not have achieved the expected yield. The RB209 recommendation (which included 30 kgN/ha in the autumn) was too high.**

WELL_N is not parameterised for winter OSR.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	102	40	17	11	170
300	121	171	24	14	330
110 (farm)$	101	130	74	73	378
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
300	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	95	45	26	9	175
300	85	66	291	13	455
110 (farm)$	76	43	123	15	257

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Note the very large SMN values when fertiliser N was applied. SUNDIAL-FRS overestimates this at the maximum N rate. SUNDIAL-FRS does not simulate the slight increase in crop N uptake due to luxury uptake.

APPENDIX B

Site reference: 05 Year: 1998

Topsoil texture:	Sandy loam	**Previous crop:**	Field peas
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	8.5
Maximum mkt yield t/ha:	8.0	**Maximum total DW t/ha:**	15.2

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	142	180	180	100	150	100	150	180	100	160	60
Calculated yield *	7.6	7.5	7.5	7.1	7.6	7.1	7.6	7.5	7.1	7.6	6.5
% difference from optimum yield		-1	-1	-6	1	-6	1	-1	-6	0	-15

* Calculated from linear plus exponential curve fitted to trial data.

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **SUNDIAL-FRS gave good predictive recommendations, within 6% of the calculated yield of the optimum. The retrospective simulation was run with the lower expected yield of 7.6 t/ha, which improved the recommendation further. However, including spring SMN reduced the retrospective recommendation by 100 kgN/ha, with a dramatic effect on yields. WELL_N predictions were slightly low but corrected by using actual weather.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	100	97	33	18	241
210	214	154	81	50	482
222 (farm)$	N/A	132	59	29	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	103	11	6	14	134
210	223	11	6	17	223
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	114	18	12	9	153
210	132	68	126	24	350
222 (farm)$	196	66	100	9	370

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS simulated crop N well at the zero N rate but underestimated SMN. Crop N uptake was underestimated at the maximum N rate, and again too much SMN was present in the 30-60cm soil layer, although total SMN was reasonable. WELL_N simulated crop N well but considerably underestimated SMN.

APPENDIX B

Site reference: 05 Year: 1999

Topsoil texture:	Sandy loam	**Previous crop:**	Winter wheat
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	5.5
Maximum mkt yield t/ha:	4.1	**Maximum total DW t/ha:**	9.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	20	210	125	50	100	50	100	140	60	80	0
Calculated yield *	3.8	3.6	3.7	3.8	3.8	3.8	3.7	3.7	3.8	3.7	2.6
% difference from optimum yield		-6	-3	0	-2	0	-2	-4	-1	-2	-32

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **Yields were reduced and variable due to blackgrass infestation. This was partially allowed for in the low expected yield so that SUNDIAL-FRS and WELL_N recommendations were closer to the optimum than the RB209 or farm rate. The SUNDIAL retrospective recommendation used a yield of 3.8 t/ha. The use of SMN improved the SUNDIAL retrospective recommendation, to within 20 kgN/ha of the field optimum, but was calculated to reduce yield substantially.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	45	46	34	23	148
250	116	75	78	70	339
125 (farm)$	106	44	26	24	200
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	109	5	5	19	138
250	188	42	59	39	328
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	49	36	17	13	114
250(max)	75	87	154	9	325
125(farm)$	73	64	54	9	200

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS underestimated crop N at the higher N rates, and accumulated SMN. WELL_N overestimated N uptake but underestimated soil N content so that crop + soil N estimates were reasonable.

Site reference: 06a Year: 1998

Topsoil texture: Clay loam **Previous crop:** Winter wheat

Current crop: Potatoes **Expected mkt yield t/ha:** 40

Maximum mkt yield t/ha: 46.8 **Maximum total DW t/ha:** 12.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	220	240	150	150	175	175	220	220	220	220
Calculated yield *	N/A	45.7	46.3	43.5	43.5	44.3	44.3	45.7	45.7	45.7	45.7
% difference from optimum yield											

* Calculated from linear plus exponential curve fitted to trial data.

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **No optimum could be fitted. Note the very similar crop N uptakes and SMN values at the zero and maximum N rates. The low response to N is not unexpected in this potato variety. Potato responses to N depend heavily on the variety with determinate and indeterminate varieties showing different responses. The SUNDIAL-FRS recommendation was very close to the farm and RB209 recommendations, and was not affected by spring SMN or actual weather. Simulated leaching losses were very high (148kg N/ha) before the 1998 fertiliser was applied. Simulated spring SMN (mid February) values were within 5 kg N/ha of the measured values. The distribution of N rates used in the trial make it difficult to judge the accuracy of the WELL_N recommendation. Used predictively, WELL_N was affected by the higher than expected marketable yield.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	96	42	56	N/A	194
250	112	49	62	N/A	223
240 (farm)$	N/A	N/A	N/A		
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	96	14	14	N/A	124
250	218	14	14	N/A	246
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	60	11	12	N/A	83
250	178	16	86	N/A	280
240 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: The soil reaches limestone at 60cm, so no samples were taken below this depth.
SUNDIAL-FRS gave a poor simulation of crop N and SMN at harvest at this site. Refer to comments above concerning variation in potato response to N according to variety. WELL_N underestimated SMN at both rates and overestimated uptake at the maximum rate.

APPENDIX B

Site reference: 06b Year: 1999

Topsoil texture:	Clay loam	**Previous crop:**	Field peas
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	7.5
Maximum mkt yield t/ha:	10.7	**Maximum total DW t/ha:**	21.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**157 (±4.3)**	**207**	**190**	**125**	**100**	**175**	**175**	**160**	**141**	**200**	**181**
Calculated yield *	**10.4**	**10.6**	**10.6**	**10.0**	**9.4**	**10.6**	**10.6**	**10.4**	**10.2**	**10.6**	**10.6**
% difference from optimum yield		**2**	**2**	**-4**	**-10**	**2**	**2**	**0**	**-2**	**2**	**2**

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **Predictive SUNDIAL-FRS recommendations were within 20 kg N/ha of the optimum. Used retrospectively, with a revised yield of 10.4 t/ha, the recommendations were increased, but with SMN within 25 kgN/ha of the optimum. WELL_N used predictively underestimated N requirement because the expected marketable yield on which it was based was 40% less than the achieved yield. Used retrospectively WELL_N gave a good recommendation without loss of yield. The RB209 recommendation was too high.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
		Measured values			
0	59	55	N/A	N/A	
250	282	57	N/A	N/A	
190 (farm)$	254	45	N/A	N/A	
		WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**			
0	123	11			
250	275	11			
		SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)			
0	68	26			
250	268	27			
190 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: There was good agreement between measured and simulated crop N values at harvest with SUNDIAL-FRS. WELL_N overestimated crop N uptake at zero. Due to soil samples being taken only to 30 cm, SMN data was insufficient to make other comparisons.

Site reference: 07 Year: 1998

Topsoil texture:	Clay loam	**Previous crop:**	Winter wheat
Current crop:	Winter OSR	**Expected mkt yield t/ha:**	2.9
Maximum mkt yield t/ha:	4.0	**Maximum total DW t/ha:**	6.8

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	190	140	N/A	N/A	N/A	N/A	184	184	184	184
Calculated yield *	N/A										
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was a linear response to applied N and no optimum could be fitted. The trial data was very variable. No yields could be calculated. The maximum marketable yield was much higher than the expected yield of 2.9 t/ha. The SUNDIAL-FRS recommendation, based on the expected yield, was within 50kgN/ha of the farm rate, which gave a yield of 2.9t/ha in the remainder of the field, suggesting that SUNDIAL-FRS gave a reasonable recommendation for this yield**

WELL_N is not parameterised for winter OSR.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	65	38	21	10	134
275	154	98	32	16	300
140 (farm)$	N/A	N/A	N/A	N/A	N/A
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
275	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	44	13	13	11	81
275	146	43	51	11	251
140 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS gave a reasonable estimation of crop N uptake and slightly underestimated SMN at the maximum N rate.

APPENDIX B

Site reference: 07 Year: 1999

Topsoil texture:	Clay loam	**Previous crop:**	Winter OSR
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	10.5
Maximum mkt yield t/ha:	9.7	**Maximum total DW t/ha:**	16.9

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	160	215	100	100	100	100	160	180	160	180
Calculated yield *	N/A	8.7	9.3	8.2	8.2	8.2	8.2	8.7	8.9	8.7	8.9
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **It was not possible to derive an optimum or to calculate yields at the optimum, as the optimum was above the maximum N rate used. The SUNDIAL-FRS, WELL_N and RB209 recommendations were probably too low, and were unlikely to have achieved the expected yield.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	98	41	24	16	179
250	286	36	36	19	377
215 (farm)$	182	49	27	12	270
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	145	16	7	6	174
250	284	14	6	26	330
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	95	12	19	11	137
250	233	28	130	11	402
215 (farm)$	201	28	127	11	367

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS overestimated SMN in the 30-60 cm layer at the high N rates. This may be due to immobilization of nitrogen by organic residues in the soil. Simulations of immobilization in this soil would be improved by the development of field diagnostics to describe the quantity and quality of soil organic matter in the soil profile. WELL_N tended to underestimate N in the soil.

Site reference: 08 Year: 1998

Topsoil texture:	Clay loam	**Previous crop:**	Field pea
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	9.5
Maximum mkt yield t/ha:	6.4	**Maximum total DW t/ha:**	13.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	180	160	50	75	50	75	200	100	160	60
Calculated yield *	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was no significant response to applied N in the field trials. The maximum trial yield was well below the expected yield, but the yield achieved with the farm rate in the remainder of the field (9.0 t/ha) was close to the expected yield. This implies that the timing of the N applications was very important. The SUNDIAL predictive rates were well above the optimum, but when run with a revised yield of 6.9 t/ha, actual weather and spring SMN, the rate was reduced substantially. WELL_N gave slightly high predictive and retrospective recommendations, which increased using actual weather data.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	106	34	12	11	163
235	167	138	23	12	340
160$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	146	8	6	5	165
235	247	27	46	16	336
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	39	17	24	11	91
235	129	29	28	11	196
160$	193	15	20	11	239

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS underestimated both crop N and SMN. WELL_N overestimated crop N and underestimated soil N 0-30 cm at the maximum rate.

Site reference: 08 Year: 1999

Topsoil texture: Clay loam **Previous crop:** Winter wheat

Current crop: Winter barley **Expected mkt yield t/ha:** 7.5

Maximum mkt yield t/ha: 6.4 **Maximum total DW t/ha:** 9.4

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**53**	**160**	**160**	**100**	**125**	**50**	**100**	**80**	**0**	**60**	**0**
Calculated yield *	**6.1**	**6.2**	**6.2**	**6.2**	**6.2**	**6.1**	**6.2**	**6.2**	**4.6**	**6.2**	**4.6**
% difference from optimum yield		**1**	**1**	**1**	**1**	**0**	**1**	**1**	**-25**	**1**	**-25**

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **SUNDIAL-FRS gave a good predictive recommendation. Including spring SMN values gave a slightly worse recommendation, which resulted in a big yield penalty. WELL_N tended to overestimate the requirement, but without effecting yield.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	**Crop N uptake**	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	**Crop N + SMN**
Measured values					
0	**66**	**39**	**14**	**15**	**134**
250	**136**	**47**	**19**	**22**	**224**
160 (farm)$	**124**	**30**	**18**	**16**	**224**
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	**114**	**16**	**7**	**11**	**148**
250	**192**	**73**	**38**	**37**	**320**
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	**84**	**17**	**32**	**31**	**164**
250	**121**	**17**	**160**	**80**	**378**
160 (farm)$	**105**	**18**	**119**	**73**	**315**

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS simulated crop N uptake well at both N rates, and SMN at harvest well, when no fertilizer N was applied, but over estimated SMN where N was applied by over 150 kgN/ha. WELL_N simulated crop + soil N well at zero N, but overestimated crop N and soil N in the 0-60cm layer at the maximum N rate.

APPENDIX B

Site reference: 09 Year: 1998

Topsoil texture:	Sandy clay loam	**Previous crop:**	Spring OSR
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	9.0
Maximum mkt yield t/ha:	10.8	**Maximum total DW t/ha:**	15.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**70 (±6.8)**	**170**	**122**	**75**	**125**	**75**	**125**	**240**	**160**	**280**	**180**
Calculated yield *	**10.3**	**9.3**	**10.2**	**10.3**	**10.2**	**10.3**	**10.2**	**6.5**	**9.5**	**4.3**	**9.0**
% difference from optimum yield		**-10**	**-1**	**0**	**-1**	**0**	**-1**	**-36**	**-7**	**-58**	**-13**

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **SUNDIAL-FRS overestimated the recommendation. Including spring SMN measurements improved the recommendation, with estimated yields within 7% of those calculated for the optimum. The retrospective recommendations, based on a yield of 10.3 t/ha, were higher.**
WELL_N gave good predictive and retrospective recommendations with default weather but were slightly higher with actual weather although on a par with RB209 and farm practice.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	126	66	15	16	223
170	223	92	21	15	351
122(farm)$	N/A	22	31	30	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	131	11	6	6	154
170	233	11	6	6	275
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	94	18	11	9	132
170	221	22	11	9	263
122 (farm)$		18	12	9	

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Both WELL_N and SUNDIAL underestimated SMN at 0-30cm, but simulated crop N uptake well.

APPENDIX B

Site reference: 09 Year: 1999

Topsoil texture: Sandy clay loam **Previous crop:** Winter wheat

Current crop: Spring OSR **Expected mkt yield t/ha:** 2.8

Maximum mkt yield t/ha: 3.4 **Maximum total DW t/ha:** 9.8

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**0**	**120**	**115**	**N/A**	**N/A**	**N/A**	**N/A**	**100**	**0**	**100**	**0**
Calculated yield *	**3.2**	**3.2**	**3.2**					**3.2**	**3.2**	**3.2**	**3.2**
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was no significant response to N in this trial. The trial area received an application of slurry by a neighbouring farmer in January 1999, the quantity was unknown. The spring SMN values, consequently, were extremely high. The initial SUNDIAL-FRS recommendation was correctly reduced to 0 when spring SMN measurements were included.**

WELL_N is not parameterised for oil seed rape.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	**Crop N uptake**	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	**Crop N + SMN**
Measured values					
0	**146**	**61**	**30**	**15**	**252**
(max)	**171**	**62**	**52**	**21**	**306**
(farm)$	**122**	**53**	**38**	**16**	**229**
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	**N/A**	**N/A**	**N/A**	**N/A**	
(max)	**N/A**	**N/A**	**N/A**	**N/A**	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	**N/A**	**N/A**	**N/A**	**N/A**	
(max)	**N/A**	**N/A**	**N/A**	**N/A**	
(farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: It was not possible to simulate crop N uptake and SMN, as the amount of slurry applied in the winter was unknown.

Site reference: 10 Year: 1998

Topsoil texture: Clay loam **Previous crop:** Field peas
Current crop: Winter wheat **Expected mkt yield t/ha:** 7.5
Maximum mkt yield t/ha: 9.3 **Maximum total DW t/ha:** 15.4

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	50	207	190	75	100	100	100	139	119	162	141
Calculated yield *	9.2	7.9	8.1	9.1	8.9	8.9	8.9	8.5	8.7	8.4	8.5
% difference from optimum yield		-14	-12	-1	-3	-3	-3	-7	-5	-9	-7

* Calculated from linear plus exponential curve fitted to trial data.

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **RB209 and farm practice overestimated the requirement, leading to >10% loss in yield. SUNDIAL also gave rather high recommendations, although the calculated yield of the best was within 5% of the calculated yield at the optimum N rate. Spring SMN values slightly reduced the SUNDIAL-FRS recommendations. The retrospective recommendation, using a yield of 9.2 t/ha, gave higher recommendations. WELL_N gave slightly high recommendations but within 3% of the optimum yield. Both models were considerably better than RB209 and farm practice.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	N/A	21	N/A	N/A	
250	N/A	14	N/A	N/A	
190 (farm)$	N/A	17	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	124	20			
250	250	20			
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	99	14			
250	179	33			
190 (farm)$	170	33			

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: It is not possible to draw any conclusions about the simulated crop and SMN values at harvest as insufficient measurements were made.

Site reference: 10 Year: 1999

Topsoil texture: Clay loam **Previous crop:** Winter wheat

Current crop: Potatoes **Expected mkt yield t/ha:** 60

Maximum mkt yield t/ha: 82 **Maximum total DW t/ha:** 22.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	221 (±12)	240	213	175	200	250	275	240	200	520	480
Calculated yield *	76	77	75	71	74	77	75	77	74	N/A	N/A
% difference from optimum yield		1	-1	-7	-3	2	3	2	-2		

* Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The SUNDIAL-FRS predictive recommendation agreed with the optimum obtained from the field trial, although it was using an expected yield of only 60 t/ha. The retrospective recommendation, using an expected yield of 89 t/ha, gave recommendations that were far too high and outside the range of the trial. WELL_N gave a low recommendation when used predictively due to the expected yield being 27% less than the actual maximum.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	157	28	N/A	N/A	186
300	220	49	N/A	N/A	269
213 (farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	124	14			138
300	232	30			262
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	102	11			112
300	360	11			371
213 (farm)$	219	11			229

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS did not simulate crop N or SMN at harvest well. WELL_N gave a good simulation at the maximum N rate.

Site reference: 11 Year: 1998

Topsoil texture:	Clay	**Previous crop:**	Winter OSR
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	10.0
Maximum mkt yield t/ha:	8.8	**Maximum total DW t/ha:**	15.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**199**	**150**	**200**	**75**	**100**	**50**	**100**	**280**	**240**	**118**	**180**
Calculated yield *	**8.4**	**7.8**	**8.4**	**6.6**	**7.0**	**6.2**	**7.0**	**N/A**	**N/A**	**7.3**	**8.2**
% difference from optimum yield		**-7**	**0**	**-21**	**-16**	**-26**	**-16**			**-12.6**	**-1.6**

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The predictive SUNDIAL-FRS recommendation was much higher than the optimum, although improved slightly by including spring SMN. Yields were not calculated for the SUNDIAL-FRS predictive recommendations, as they were outside the range of N rates applied in the trial. The SUNDIAL retrospective recommendations, based on a yield of 8.4 t/ha, were reduced to 180 kg N/ha (with actual weather and spring SMN), within 20 kg N/ha of the optimum. Without spring SMN, simulated crop uptake was only 49% of the N requirement, which reduced the recommendation and the yield.**

WELL_N is not parameterised for heavy clay soils. The recommended rates and yields were below the calculated optimum.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	80	35	20	10	145
220	218	65	23	13	308
200 (farm)$	N/A	39	18	15	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	145	14	6	11	176
220	265	14	19	25	298
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	46	21	17	11	95
220	166	24	56	11	252
200 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS underestimated crop N at both N rates, but gave a reasonable estimation of total SMN, except for the distribution of N within the profile at the maximum N rate. WELL_N overestimated crop N at both N rates and underestimated SMN, but total crop N + SMN were well simulated.

Site reference: 11 Year: 1999

Topsoil texture:	Clay	**Previous crop:**	Winter wheat
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	9.3
Maximum mkt yield t/ha:	11.4	**Maximum total DW t/ha:**	15.2

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	188 (±25.2)	210	236	75	75	125	100	220	100	260	140
Calculated yield *	10.8	11.0	11.1	8.4	8.4	9.8	9.2	11.0	9.2	11.2	10.1
% difference from optimum yield		2	3	-22	-22	-9	-15	2	-15	3	-6

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The predictive SUNDIAL-FRS recommendation was within 40 kg N/ha of the optimum. The retrospective SUNDIAL-FRS recommendation, based on a higher yield of 10.8 t/ha, was 40 kgN/ha more. Including spring SMN measurements reduced the recommendation by 120 kgN/ha, resulting in a yield penalty.**

WELL_N is not parameterised for heavy clay soils. Recommended rates and yields were lower than for the calculated optimum, especially when used predictively with the low expected yield.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	59	45	21	4	129
250	231	60	29	2	322
236 (farm)$	192	41	18	16	267
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	145	14	6	11	176
250	265	14	19	25	323
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	97	26	48	22	193
250	278	31	74	20	403
236 (farm)$	271	30	54	16	371

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS and WELL_N overestimated crop N and SMN at harvest. The variable N uptake module should be implemented in SUNDIAL-FRS. WELL_N overestimated crop N uptake at the zero N rate.

Site reference: 12 Year: 1998

Topsoil texture:	Clay	**Previous crop:**	Winter wheat
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	8.55
Maximum mkt yield t/ha:	9.5	**Maximum total DW t/ha:**	14.7

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	121	200	223	100	125	100	125	202	160	202	202
Calculated yield *	8.5	9.0	9.1	8.3	8.6	8.3	8.6	9.0	8.8	9.0	9.0
% difference from optimum yield		5	7	-3	0	-3	0	5	3	5	5

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The recommendations given by both SUNDIAL-FRS and RB209 are too high. SUNDIAL-FRS recommended 80 kgN/ha more than the optimum, yet the calculated yield was within 6% of the optimum, due to the relatively small response of yield to N. The use of spring SMN measurements improved the recommendation to within 40 kg of the optimum, for the predictive recommendation only.**

WELL_N is not parameterised for heavy clay soils, but nevertheless gave recommendations within 25 kg of the optimum.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	56	147	44	N/A	247
200	198	118	38	N/A	354
223 (farm)$	N/A	72	37	N/A	N/A
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	111	14	7	N/A	153
200	232	14	7	N/A	276
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	76	37	17	N/A	141
200	180	29	54	N/A	273
223 (farm)$	163	32	23	N/A	229

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: The soil reaches chalk at 60cm so no SMN measurements were available below this depth. Both models considerably underestimated SMN in the 0-30cm layer. SUNDIAL-FRS showed reasonable agreement between measured and simulated crop N uptake at both N rates. WELL_N overestimated crop N at the zero rate.

Site reference: 12 Year: 1999

Topsoil texture: Clay **Previous crop:** Winter wheat

Current crop: Winter OSR **Expected mkt yield t/ha:** 3.97

Maximum mkt yield t/ha: 5.0 **Maximum total DW t/ha:** 11.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	190	255	N/A	N/A	N/A	N/A	248	120	248	120
Calculated yield *	4.5	4.5	4.5					4.5	4.5	4.5	4.5
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was no significant response to applied N at this site. The SUNDIAL-FRS recommendations were too high, although substantially improved by the use of spring SMN measurements. The RB209 and Farm recommendations were also too high.**

WELL_N is not parameterised for oil seed rape.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	155	46	33	N/A	234
300	214	304	80	N/A	598
255 (farm)$	158	59	38	N/A	255
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	N/A
300	N/A	N/A	N/A	N/A	N/A
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	145	38	26	N/A	209
300	211	38	217	N/A	466
255 (farm)$	212	41	168	N/A	421

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Soil reaches chalk at 60cm. SUNDIAL-FRS showed good agreement between measured and simulated crop N at both N rates, and was also able to simulate the very high SMN values reasonably under the maximum N rate, although in a deeper soil layer. The good agreement between simulated and measured values, but poor agreement between recommended and optimum N rates suggests that N may be being obtained by other processes. Under some conditions N may be obtained from the porous chalk bedrock, and there is no description of this process in SUNDIAL. Some description of the sequestration of N from porous bedrock could be included in the model.

APPENDIX B

Site reference: 13 Year: 1998

Topsoil texture: Clay **Previous crop:** Winter wheat

Current crop: Winter barley **Expected mkt yield t/ha:** 7.5

Maximum mkt yield t/ha: 8.5 **Maximum total DW t/ha:** 11.9

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**20 (±16.2)**	**160**	**188**	**125**	**150**	**125**	**125**	**80**	**0**	**80**	**0**
Calculated yield *	**6.4**	**8.3**	**8.4**	**8.2**	**8.3**	**8.2**	**8.2**	**7.9**	**4.9**	**7.9**	**4.9**
% difference from optimum yield		**30**	**31**	**28**	**30**	**28**	**28**	**23**	**-23**	**23**	**-23**

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **This was a poor data set, with large errors on the fitted curve parameters, and the calculated optimum should be treated with some caution, although it does lie below 35 kgN/ha. Including the spring SMN values as diagnostics improved the SUNDIAL-FRS recommendation. Using actual weather over the spring in the retrospective simulations had no effect on either WELL_N or SUNDIAL-FRS recommendations. RB209 greatly over-estimated the optimum.**

WELL_N is not parameterised for heavy clay soils. Recommended rates and yields were higher than the calculated optimum.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	64	30	25	14	133
175	201	39	36	24	300
188 (farm)$	N/A	54	25	17	-
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	96	5	5	13	119
175	201	5	5	17	228
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	90	45	20	11	166
175	176	44	76	11	307
188 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS overestimated the harvest SMN at the maximum N rate. WELL_N simulated crop N uptake well, but underestimated SMN.

Site reference: 13 Year: 1999

Topsoil texture:	Clay	**Previous crop:**	Winter barley
Current crop:	Winter OSR	**Expected mkt yield t/ha:**	3.9
Maximum mkt yield t/ha:	3.8	**Maximum total DW t/ha:**	11.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	163	190	232	N/A	N/A	N/A	N/A	120	59	120	59
Calculated yield *	3.1	3.2	3.3					2.9	2.3	2.9	2.3
% difference from optimum yield		3	5					-7	-27	-7	-27

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **WELL_N is not parameterised for OSR.**

The SUNDIAL-FRS recommendation was a little low, with the calculated yield 7% less than that achieved by the optimum N rate. Including spring SMN values as diagnostics reduced the recommendation, with a yield reduction of 27%. Using the actual weather in the spring was of no benefit in this simulation.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	42	52	31	15	139
300	222	77	42	31	372
232 (farm)$	206	62	30	13	311
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
300	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	30	41	79	28	179
300	183	48	230	13	474
232 (farm)$	188	48	221	12	469

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS substantially overestimated harvest SMN below 30cm when fertilizer N was applied.

Site reference: 14 Year: 1998

Topsoil texture: Sandy clay loam **Previous crop:** Winter wheat
Current crop: Winter OSR **Expected mkt yield t/ha:** 4.3
Maximum mkt yield t/ha: 7.4 **Maximum total DW t/ha:** 12.8

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	190	238	N/A	N/A	N/A	N/A	158	100	140	100
Calculated yield *	N/A										
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **A response curve could not be fitted to the trial data, as the data was too variable to fit, and no optimum could be derived. Some of the yields derived from the trial were very high for winter OSR, and much higher than the farm rate of 238 kgN/ha used in the remainder of the field (4.3 t/ha).**

WELL_N is not parameterised for Winter OSR.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	102	44	20	17	183
195	234	86	26	16	362
238 (farm)$	N/A	62	16	16	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
195	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	137	20	12	9	178
195	365	13	10	9	397
238 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS overestimated crop N at both N rates, but underestimated SMN, so that the total crop N + SMN was well simulated.

APPENDIX B

Site reference: 14 Year: 1999

Topsoil texture:	Sandy clay loam	**Previous crop:**	Winter OSR
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	11.3
Maximum mkt yield t/ha:	9.8	**Maximum total DW t/ha:**	11.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**139 (±17.4)**	**182**	**124**	**N/A**	**N/A**	**N/A**	**N/A**	**162**	**40**	**141**	**40**
Calculated yield *	**9.1**	**9.5**	**8.9**					**9.3**	**7.8**	**9.1**	**7.8**
% difference from optimum yield		**4**	**-2**					**2**	**-14**	**0**	**-14**

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The field received 40t/ha of pig FYM in the autumn. The farm and SUNDIAL-FRS without spring SMN values gave very good recommendations. Including spring SMN values substantially reduced the recommendations, and reduced the calculated yield well below the optimum. The reduction in the recommendation may be due to inaccurate parameters describing the quality of the pig FYM. If the simulation of N mineralisation from the applied FYM does not have the correct time profile, a simple addition of measured SMN would introduce an error. Farmyard manures are inherently variable in nature. The farmyard manure parameters are based on an average pig FYM type. There is a need to develop a manure module that will allow improved description of a specific manure according to diagnostic manure measurements and information that is available to farmers.**

WELL_N does not have routines for dealing with organic manures.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	132	28	21	19	200
250	201	35	42	26	304
124 (farm)$	185	16	39	17	257
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	161	28	51	9	249
250	237	28	64	9	338
124 (farm)$	244	28	97	11	380

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Note the very similar measured crop N uptake from the farm and maximum N rate field plots. The farm plots received half the N rate of the maximum trial plot, but gave the same yield (10 t/ha). The farm N was applied much later than the trial N (mid April and mid May, compared to early March and early April), demonstrating the importance of timing of N applications as well as the amount of N applied. SUNDIAL-FRS slightly overestimated crop N uptake at all N rates, and gave a high SMN simulation under the farm rate.

APPENDIX B

Site reference: 15 Year: 1998

Topsoil texture: Sandy clay loam **Previous crop:** Vining peas

Current crop: Winter wheat **Expected mkt yield t/ha:** 10.0

Maximum mkt yield t/ha: 11.7 **Maximum total DW t/ha:** 20.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**0**	**190**	**84**	**N/A**	**N/A**	**N/A**	**N/A**	**140**	**0**	**140**	**0**
Calculated yield *	**10.4**	**10.4**	**10.4**					**10.4**	**10.4**	**10.4**	**10.4**
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **45 t/ha of pig FYM was applied in the autumn of 1997, which precluded the use of WELL_N. There was no significant response to N applied in the trial. The initial SUNDIAL-FRS recommendation was too high; but once the spring SMN measurement was included, the recommendation was correctly reduced to 0 kg N/ha. Using real weather data from the date of fertiliser application had no effect on the recommendation. The recommendation given by RB209 was too high.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	**Crop N uptake**	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	**Crop N + SMN**
Measured values					
0	267	87	53	36	443
180	305	122	60	50	537
84 (farm)$	N/A	86	64	54	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
180	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	243	27	28	9	307
180	256	32	147	9	438
84 (farm)$	304	28	47	9	388

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS simulated crop N very well in the zero N plot. It was unable to simulate the luxury uptake of N by the crop in the plots given fertiliser N, which had very similar yields to the unfertilised plot, so tended to simulate too much mineral N in the soil. Including the variable N uptake module into SUNDIAL-FRS would improve this simulation. SUNDIAL underestimated SMN at both N rates.

Site reference: 15 Year: 1999

Topsoil texture: Sandy clay loam **Previous crop:** Winter wheat

Current crop: Sugar beet **Expected mkt yield t/ha:** 95

Maximum mkt yield t/ha: 88 **Maximum total DW t/ha:** 25.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**0**	**21**	**192**	**N/A**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**
Calculated yield *	**68.9**	**68.9**	**68.9**					**68.9**	**68.9**	**68.9**	**68.9**
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was no significant response to applied N. 35 t/ha of duck FYM was applied to the trial in autumn 1998; duck FYM is not parameterised in SUNDIAL-FRS so layer manure was used instead. SUNDIAL-FRS correctly recommended that no fertiliser N should be applied, with and without the spring SMN measurements. WELL_N does not included routines for handling organic manures. The farmer over-estimated the amount of fertiliser N needed.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	209	29	15	12	265
150	234	32	19	14	299
192 (farm)$	N/A	N/A	N/A	N/A	N/A
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	N/A	N/A	N/A	N/A	
150	N/A	N/A	N/A	N/A	
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	218	10	20	18	266
150	224	10	20	18	272
192 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS correctly simulated the crop N and SMN at harvest at both fertiliser rates.

Site reference: 16 Year: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Set-aside
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	12.0
Maximum mkt yield t/ha:	10.7	**Maximum total DW t/ha:**	16.2

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	94 (±2.6)	260	130	125	150	75	125	340	240	280	180
Calculated yield *	10.2	11.3	10.5	10.5	10.6	10.0	10.5	N/A	N/A	N/A	10.8
% difference from optimum yield		11	3	3	4	-2	3				6

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **SUNDIAL-FRS gave far too high a predictive recommendation. Using spring SMN values reduced the recommendation by 100 kgN/ha, but it was still too high. Yields were not calculated for the SUNDIAL predictive recommendations as they were well above the maximum trial N rate of 155 kg N/ha. The SUNDIAL-FRS retrospective recommendations used a yield of 10.2 t/ha. This reduced the recommendation to 180 kg N/ha (with actual weather and spring SMN measurements), still 86 kg N/ha more than the optimum, but within 6% of the calculated yield at the optimum rate. The RB209 recommendation was also too high.**

WELL_N gave a good recommendation, being within 50 kg N/ha of the optimum and 5% of the yield. Using actual weather the WELL_N recommendations were increased by 25-50 kg N/ha.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	97	17	11	8	133
155	191	21	10	8	230
130 (farm)$	N/A	27	9	9	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	129	15	7	6	157
155	220	15	7	6	248
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	91	17	15	9	132
155	240	14	12	9	275
130 (farm)$	220	14	10	9	253

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS and WELL_N simulated SMN at harvest well, but tended to overestimate crop N at the maximum N rates.

Site reference: 16 Year: 1999

Topsoil texture:	Silt loam	**Previous crop:**	Winter wheat
Current crop:	Dutch white cabbage	**Expected mkt yield t/ha:**	48.8
Maximum mkt yield t/ha:	47.4	**Maximum total DW t/ha:**	9.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	253 (±14.5)	250	200	225	225	275	275	300	0	300	300
Calculated yield *	45.5	45.3	42.1	43.9	43.9	46.4	46.4	47.2	18.8	47.2	47.2
% difference from optimum yield		0	-7	-3	-3	2	2	4	-58	4	4

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used.

Comments: **Farm rate limited to 200 kgN/ha by supermarket requirements. Good assessment of marketable yield based on stand and average marketable head weight. WELL_N recommendations were within 50 kgN/ha of optimum and unaffected by actual weather. Predictive recommendation 50 kgN/ha lower than retrospective since conversion of marketable fresh weight to dry weight 30% lower than expected from WELL_N defaults. SUNDIAL-FRS recommendations were also within 50 kgN/ha of optimum, except predictive with SMN, which gave a very unexpected result. This was due to poor simulation of crop N uptake.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	51	19	9	6	85
350	184	34	11	8	237
200 (farm)$					
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	81	22	16	18	137
350	305	15	14	14	348
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	4	20	50	22	95
350	15	26	346	22	409
200 (farm)$					

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS was unable to simulate N uptake by the crop, hence all the fertilizer N accumulated in the soil.   WELL_N overestimated crop N uptake at the maximum N rate.

Site reference: 17 Year: 1998

Topsoil texture:	Clay	**Previous crop:**	Winter beans
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	9.0
Maximum mkt yield t/ha:	8.2	**Maximum total DW t/ha:**	14

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	61	150	160	25	75	25	75	20	0	40	0
Calculated yield *	7.3	6.3	5.7	6.9	7.4	6.9	7.4	6.9	6.6	7.1	6.6
% difference from optimum yield		-14	-23	-5	1	-5	1	-6	-9	-3	-9

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **There was a decline in yield with N applications above 100 kgN/ha. Both RB209 and farm practice overestimated N requirement, leading to large reductions in yield. SUNDIAL-FRS recommendations were slightly low, and were not greatly affected by actual weather or spring SMN measurements. All model recommendations produced calculated yields within 10% of the optimum. WELL_N is not parameterised for heavy clay soils and gave slightly low recommendations with default weather. These were improved by using actual weather achieving yields within 1% of the optimum.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	152	57	28	10	247
150	209	32	17	9	267
160 (farm)$	N/A	21	13	14	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	146	12	6	6	170
150	235	12	6	6	259
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	142	38	36	34	250
150	137	39	176	48	400
160 (farm)$	196	38	153	23	410

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS considerably underestimated crop N uptake at the maximum N rate, and hence accumulated fertilizer N as SMN in the soil. Yields at the zero and maximum rates were almost the same, 6.6 and 6.4 t/ha respectively. SUNDIAL-FRS was unable to simulate the luxury uptake by the wheat when given fertiliser N. Including the variable N uptake module in SUNDIAL-FRS would improve these simulations. WELL_N simulated crop N well at both N rates, but underestimated SMN.

Site reference: 17 Year: 1999

Topsoil texture:	Clay	**Previous crop:**	Winter wheat
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	8.5
Maximum mkt yield t/ha:	7.7	**Maximum total DW t/ha:**	10.7

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	228 (±19.3)	190	220	150	125	125	125	120	20	120	20
Calculated yield *	7.5	7.1	7.4	6.5	6.1	6.1	6.1	6.0	3.5	6.0	3.5
% difference from optimum yield		-5	-1	-12	-18	-18	-18	-19	-53	-19	-53

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **SUNDIAL-FRS gave a poor recommendation, well below the optimum. Including spring SMN measurements resulted in a worse recommendation. WELL_N is not parameterised for heavy clay soils and underestimated the optimum. The farm rate of 220 kgN/ha used in the remainder of the field gave a higher yield (8.3 t/ha) than the trial maximum (7.7 t/ha), suggesting that timing of N applications was important.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	42	122	35	46	245
250	136	212	55	46	449
220(farm)$	154	76	37	27	294
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	141	13	6	6	166
250	205	53	63	46	367
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	58	34	90	38	220
250	164	34	197	38	433
220 (farm)$	209	34	165	11	419

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS simulated crop N uptake reasonably well, and also simulated the high SMN values, although not always in the correct soil layer. WELL_N overestimated crop N uptake at both rates and tended to underestimate SMN, particularly in the 0-30 cm layer. Note the very high SMN values at harvest, even in the unfertilised plot. Spring SMN was not especially high (141 kgN/ha 0-90cm), and no manure was applied. Inadvertent N application to the trial is unlikely, as N uptake at the zero N rate is low, and the response curve is one of the steepest. Measurements of gross mineralisation at this site (MAFF project NT 1520) showed the highest rates measured for 1999 due to over-compaction following drilling. In autumn these were balanced by high rates of immobilisation, however, this may not have occurred throughout the growing season.

Site reference: 18 Year: 1998

Topsoil texture: Silty clay loam **Previous crop:** Celery

Current crop: Winter wheat **Expected mkt yield t/ha:** 10

Maximum mkt yield t/ha: 8.6 **Maximum total DW t/ha:** 14.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	220	N/A	150	150	125	150	N/A	N/A	N/A	N/A
Calculated yield *	N/A										
% difference from optimum yield											

* Calculated from linear plus exponential curve fitted to trial data.

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **A response curve could not be fitted to the trial data, as it was too variable.**

The three previous crops were celery, for which SUNDIAL-FRS is not parameterised.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	53	22	14	12	101
145	151	30	17	13	211
(farm)$	N/A	21	13	10	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	95	14	6	6	121
145	183	14	6	6	209
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
145	N/A	N/A	N/A	N/A	
(farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N overestimated crop uptake but simulated soil N reasonably well.

Site reference: 19 Year: 1998

Topsoil texture:	Sandy loam	**Previous crop:**	Winter OSR
Current crop:	Winter wheat	**Expected mkt yield t/ha:**	10.4
Maximum mkt yield t/ha:	10.2	**Maximum total DW t/ha:**	15

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	190	212	100	150	75	150	260	180	260	180
Calculated yield *	N/A	10.3	10.5	9.3	9.9	9.0	9.9	11.0	10.2	11.0	10.2
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The optimum was above the maximum N rate used in the trial (170kgN/ha), but was probably around 180 kgN/ha as the farm rate achieved a yield of 10.4 t/ha on the remainder of the field, compared to 10.2 from the trial maximum. This suggests that the SUNDIAL recommendations with SMN were about right. WELL_N tended to recommend low, but was noticeably affected by actual weather at this site.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	73	25	11	11	120
170	240	40	15	11	306
210$	N/A	29	14	12	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	182	14	26	46	268
170	252	14	52	62	380
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	100	20	26	9	155
170	250	15	14	9	288
210$	258	30	30	9	327

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: **Both WELL_N and SUNDIAL overestimated crop N uptake at zero. WELL_N also overestimated SMN at the 30-90 cm depth. SUNDIAL gave good simulation at the maximum N rate.**

Site reference: 19 Year: 1999

Topsoil texture: Sandy loam **Previous crop:** Winter wheat

Current crop: Potatoes **Expected mkt yield t/ha:** 45

Maximum mkt yield t/ha: 53 **Maximum total DW t/ha:** 11.6

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0 (See below)	240	212	0	0	0	0	0	N/A	0	N/A
Calculated yield *	48.5	48.5	48.5	48.5	48.5	48.5	48.5	48.5	N/A	48.5	N/A
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **A basal N rate of 212 kgN/ha was inadvertently applied uniformly to the site before N rates were imposed. There was no response to additional N applied. The SUNDIAL-FRS and WELL_N recommendations made after the application of the basal N correctly recommended that no additional N should be applied. The spring SMN measurements were taken after the basal application so could not be used as a diagnostic for SUNDIAL-FRS.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0 (212)	196	51	36	48	331
362	213	110	129	72	524
212 (farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0 (212)	212	14	26	46	298
362	252	14	52	62	380
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0 (212)	240	12	34	49	335
362	261	11	149	57	478
212 (farm)$					

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: There was very good agreement between SUNDIAL-FRS and measured crop N and SMN at harvest. WELL_N underestimated SMN in the 0-60 cm layer.

Site reference: 20 Year: 1999

Topsoil texture: Sandy clay loam **Previous crop:** Sugar beet

Current crop: Winter wheat **Expected mkt yield t/ha:** 8

Maximum mkt yield t/ha: 8.1 **Maximum total DW t/ha:** 11.1

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	168 (±15.4)	210	166	125	125	100	100	237	180	237	180
Calculated yield *	8.0	8.1	8.0	7.4	7.4	7.0	7.0	8.1	8.1	8.1	8.1
% difference from optimum yield		2	0	-16	-16	-12	-12	1	1	1	1

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used by the farmer in the rest of the field.

Comments: **The SUNDIAL-FRS recommendation is improved with the use of spring SMN as a diagnostic measurement. The SUNDIAL, RB209 and farm recommendations were all within 2% of the optimum yield. The SUNDIAL recommendations with SMN were within the standard error of the optimum. WELL_N underestimated the optimum requirement, resulting in a yield loss of 12-16%.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	SMN 0-30cm	SMN 30-60cm	SMN 60-90cm	Crop N + SMN
Measured values					
0	56	29	22	15	122
250	132	61	36	12	241
166 (farm)$	113	32	23	15	183
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	121	15	7	6	149
250	210	31	65	27	333
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	46	12	9	9	76
250	182	25	79	9	295
166 (farm)$	145	17	27	9	198

* Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: There was good agreement between SUNDIAL-FRS and measured crop N harvest in the zero N rate. SUNDIAL-FRS and WELL_N overestimated N in the crop at the maximum N rate.

Site reference: 21 Year: 1999(1)

Topsoil texture:	Sandy clay loam	**Previous crop:**	Winter barley
Current crop:	Spinach	**Expected mkt yield t/ha:**	23.0
Maximum mkt yield t/ha:	23.0	**Maximum total DW t/ha:**	2.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	201 (±6.1)	N/A	100	125	125	125	125	N/A	N/A	N/A	N/A
Calculated yield *	25.5		18.8	20.9	20.9	20.9	20.9				
% difference from optimum yield			-26	-18	-18	-18	-18				

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used.

Comments: **No RB209 recommendation for this crop. A planned top-dressing by the farmer was omitted because of wet soil conditions. Spinach is a fast growing crop, making it difficult to estimate the optimum from a single harvest. Trial application of 200 kgN/ha, close to the calculated optimum, judged overmature by farmer on day of harvest - rate of 150 kgN/ha judged to be optimum quality. NO_3N in fresh weight marketable exceeded E.C. limit of 2500 ppm for N application rates greater than 150 kgN/ha. WELL_N gave good prediction and retrospective estimation of the N rate for optimum quality. The farm crop was in oversupply and was ploughed in.**

SUNDIAL-FRS is not parameterised for spinach.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	37	28	30	23	118
250	129	152	59	27	367
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	18	45	55	51	169
250	81	201	55	51	388
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake and tended to overestimated SMN

Site reference: 21 Year: 1999(2)

Topsoil texture:	Sandy clay loam	**Previous crop:**	Spinach
Current crop:	Spinach	**Expected mkt yield t/ha:**	23.0
Maximum mkt yield t/ha:	24.7	**Maximum total DW t/ha:**	2.1

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	42 (±9)	N/A	172	50	75	50	75	N/A	N/A	N/A	N/A
Calculated yield *	25.3		24.4	25.4	25.6	25.4	25.6				
% difference from optimum yield			-3	1	1	1	1				

* Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.

$ Farm recommendation is actual rate used.

Comments: **No RB209 recommendation for this crop. High residue situation, with previous crop entirely ploughed in, giving a low optimum requirement. Farmer did not allow for N in the crop residues, and overestimated requirement. In contrast to the first crop at this site, NO_3N in fresh weight marketable did not exceeded the E.C. limit of 2500 ppm at any of the N application rates. WELL_N predictive and retrospective recommendations were within 50 kgN/ha of the calculated optimum.**

SUNDIAL-FRS is not parameterised for spinach.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	97	54	70	55	276
250	112	182	204	81	579
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	69	28	63	57	217
250	88	216	97	60	461
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N tended to underestimate crop N uptake and poorly estimated the distribution of SMN, particularly at the maximum application rate.

APPENDIX B

Site reference: 22 Year: 1998

Topsoil texture:	Sandy loam	**Previous crop:**	Winter wheat
Current crop:	Red bulb onion	**Expected mkt yield t/ha:**	45.0
Maximum mkt yield t/ha:	30.0	**Maximum total DW t/ha:**	6.1

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	90	215	100	175	100	175	140	40	140	40
Calculated yield *											
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **The farm crop and trial were severely damaged by a storm on 9 April. To aid recovery of the farm crop, 3 top-dressings were applied by contractors during the season. From the lack of response to N on the trial and the high post-harvest SMN on the zero plots, it was assumed that at least one of the top-dressings had been accidentally applied to the trial. The results were therefore not used for model evaluations.**

With heavy rain falling shortly after fertiliser application on the trial, the WELL_N predictions with actual weather were 75 kgN/ha higher than with the default weather. Actual weather had no effect on the SUNDIAL-FRS recommendation. The use of SMN reduced the recommendations by 100 kgN/ha.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	103	140	52	59	354
215	121	132	61	91	405
215 (farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0					
215					
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0					
215					

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: **Due to the accidental application of N to the trial, crop and SMN simulations are not presented.**

Site reference: 22 Year: 1999

Topsoil texture:	Sandy loam	**Previous crop:**	Red bulb onion
Current crop:	Parsnip	**Expected mkt yield t/ha:**	40.0
Maximum mkt yield t/ha:	32.0	**Maximum total DW t/ha:**	8.6

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	167	100	110	50	75	75	75	N/A	N/A	N/A	N/A
Calculated yield *	31.4	28.9	29.3	26.8	27.8	27.8	27.8				
% difference from optimum yield		-8	-7	-14	-11	-11	-11				

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **The crop responded to levels of N considerably in excess of both the RB209 recommendation and farm practice. This was possibly because of poor weed control on the trial plots and commercial area for much of the season. WELL_N also underestimated N requirement, possibly for the same reason, but it also proved difficult to estimate the date of maximum potential dry matter of this overwintered crop where foliage had died back before harvest.**

SUNDIAL-FRS is not parameterised for parsnip.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	75	12	6	5	98
200	111	12	14	40	177
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	108	30	16	15	169
200	198	30	16	15	259
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
200	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N tended to overestimate crop N and SMN.

Site reference: 23 Year: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Winter wheat
Current crop:	Bulb onion (sets)	**Expected mkt yield t/ha:**	50.0
Maximum mkt yield t/ha:	55.0	**Maximum total DW t/ha:**	10.6

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	137 (±6.5)	90	140	150	175	175	200	180	180	180	180
Calculated yield *	54.2	50.7	54.4	54.9	55.4	55.4	54.9	55.4	55.4	55.4	55.4
% difference from optimum yield		-7	0	1	2	2	1	2	2	2	2

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used.

Comments: **The calculated optimum was very close to farm practice but RB209 underestimated N requirement. WELL_N predictions were good but increased by 25 kgN/ha for both actual weather and the higher than expected dry matter yield. SUNDIAL-FRS recommendations were too high, but the calculated yield was within 2% of the optimum.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	81	36	23	27	167
225	163	69	37	33	302
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	46	14	18	16	94
225	165	19	35	20	239
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	63	9	9	9	90
225	202	11	51	25	290

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Both WELL_N and SUNDIAL-FRS underestimated crop N uptake at zero, and underestimated SMN in the 0-30 cm layer at both rates. The high measured SMN near the surface could result from the breakdown of the onion tops, which had largely died back by harvest. The models do not take this into account.

Site reference: 24 Year: 1998

Topsoil texture: Silt loam **Previous crop:** Summer cabbage

Current crop: Calabrese **Expected mkt yield t/ha:** 11.1

Maximum mkt yield t/ha: 14.2 **Maximum total DW t/ha:** 4.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	250	190	275	100	100	200	200	N/A	N/A	N/A	N/A
Calculated yield *	14.5	12.6	14.2	8.8	8.8	13.0	13.0				
% difference from optimum yield		-13	-2	-40	-40	-11	-11				

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **RB209 and WELL_N used predictively both underestimated N requirement. The latter was due to a nearly 30% underestimate of the potential marketable yield.**

SUNDIAL-FRS is not parameterised for calabrese.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	61	64	33	41	199
275	147	39	39	55	280
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	40	51	31	52	174
275	198	72	33	52	355
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
275	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake at zero, but overestimated at the high rate.

Site reference: 25 Year: 1998

Topsoil texture:	Loamy sand	**Previous crop:**	Potato (main)
Current crop:	Carrot	**Expected mkt yield t/ha:**	67.0 (commercial)
Maximum mkt yield t/ha:	90.0 (pre-strawing)	**Maximum total DW t/ha:**	11.5(pre-strawing)

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	25	170	50	50	50	50	0	0	0	0
Calculated yield *	85.8	85.8	N/A	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8
% difference from optimum yield		0		0	0	0	0	0	0	0	0

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial.**

$ Farm recommendation is actual rate used.

Comments: **There was no response of marketable fresh weight or total dry weight yields to applied N at either the pre-strawing (15 October 1998) or commercial (20 January 1999) harvests. Due to the unknown effect of the straw covering on soil temperature, it was not feasible to make predictions beyond the pre-strawing harvest. Farm practice on this sandy soil was to use a high rate of N in an attempt to improve skin quality a characteristic not assessed in the trial. WELL_N recommendations were based on the expected yield at the pre-strawing harvest, when foliage and roots were present and were higher than required. SUNDIAL-FRS correctly recommended that no fertiliser N should be applied.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	134	39	17	N/A	190
125	147	40	45	N/A	231
170 (farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	101	14	14	N/A	129
125	184	14	17	N/A	215
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	70	3	2	N/A	75
125	85	15	37	N/A	137

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Measured and simulated values are for the pre-strawing harvest. WELL_N underestimated crop N uptake at zero but overestimated at the maximum rate. WELL_N tended to underestimate SMN. SUNDIAL underestimated crop N at harvest.

Site reference: 26 Year: 1998

Topsoil texture:	Loamy sand	**Previous crop:**	Crisp lettuce
Current crop:	Leek	**Expected mkt yield t/ha:**	33.6
Maximum mkt yield t/ha:	40.8	**Maximum total DW t/ha:**	7.2

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	150+	205	150	125	150	100	340	460	340	460
Calculated yield *			37.3	35.9	35.2	35.9	34.5	40.2	41.4	40.2	41.4
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **A linear response, with the optimum apparently above the maximum (375 kg N/ha) N rate used. With spring SMN measurements, the SUNDIAL-FRS recommendation was increased by 120 kgN/ha. From the response trial, WELL_N appeared to be underestimating requirement, but from a successful strip trial at this site, the WELL_N predictive rate yielded 41.7 t/ha, compared to 34.4 t/ha at the farm rate. This suggests considerable spatial variability cross the site.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	139	61	51	20	271
375	272	43	39	11	365
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	59	18	14	14	105
375	173	27	14	14	228
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	50	6	10	8	73
375	331	12	34	8	385

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS considerably underestimated crop N and SMN where no fertiliser N had been applied, but gave a good simulation at the maximum N rate, apart from SMN at 0-30cm. WELL_N underestimated at both rates.

Site reference: 26 Year: 1999

Topsoil texture:	Loamy sand	**Previous crop:**	Leek
Current crop:	Crisp lettuce	**Expected mkt yield t/ha:**	33.6
Maximum mkt yield t/ha:	38.0	**Maximum total DW t/ha:**	2.6

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	50 (±5)	160	195	100	100	100	100	N/A	N/A	N/A	N/A
Calculated yield *	35.2	36.1	36.4	35.6	35.6	35.6	35.6				
% difference from optimum yield		3	3	1	1	1	1				

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used.

Comments: **Farm practice and RB209 overestimated N requirement in the presence of leek residues. The WELL_N recommendation was within 1% of the optimum calculated yield.**

SUNDIAL-FRS was not able to provide a recommendation for this crop.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	83	25	22	24	154
250	106	157	45	27	335
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	53	16	17	15	101
250	109	154	21	15	299
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N gave reasonable estimates of crop and soil N.

APPENDIX B

Site reference: 27 Year: 1998

Topsoil texture:	Humose loamy sand	**Previous crop:**	Winter wheat
Current crop:	Carrot	**Expected mkt yield t/ha:**	97 (commercial)
Maximum mkt yield t/ha:	82.2 (pre-strawing)	**Maximum total DW t/ha:**	12.7 (pre-strawing)

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	60	30	25	25	25	25	40	0	40	0
Calculated yield *	79.7	79.7	79.7	79.7	79.7	79.7	79.7	79.7	79.7	79.7	79.7
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial**

$ Farm recommendation is actual rate used.

Comments: **There was no response of marketable fresh weight or total dry weight yields to applied N at either the pre-strawing (28 October 1998) or commercial (9 March 1999) harvests. Due to the unknown effect of the straw covering on soil temperature, it was not feasible to make predictions beyond the pre-strawing harvest. WELL_N recommendations based on dry weight yields at the pre-strawing harvest, when foliage and roots were present, were good. Using spring SMN measurements as a diagnostic improved the SUNDIAL-FRS recommendation.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	96	39	36	17	188
125	132	49	45	16	242
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	113	14	14	14	155
125	199	14	14	14	241
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	76	3	5	3	87
125	77	6	22	11	116

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Measured and simulated values are for the pre-strawing harvest. WELL_N correctly estimated crop N uptake at the zero rate but overestimated at the maximum rate. WELL_N underestimate SMN in the 0-60 cm layers. As in Site 25/98, SUNDIAL underestimates crop N at harvest.

Site reference: 28 Year: 1998

Topsoil texture: Silt loam **Previous crop:** Cauliflower

Current crop: Cauliflower **Expected mkt yield t/ha:** 29.7

Maximum mkt yield t/ha: 31.0 **Maximum total DW t/ha:** 5.7

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	149 (±24)	250	190	175	175	200	200	190	180	190	100
Calculated yield *	28.3	30.4	29.5	29.1	29.1	29.7	29.7	29.5	29.2	29.5	25.9
% difference from optimum yield		7	4	3	3	5	5	4	3	4	-9

*** Calculated from linear plus exponential curve fitted to trial data. Estimated standard error given in brackets.**

$ Farm recommendation is actual rate used.

Comments: **The estimate of the optimum had a high standard error (± 24). WELL_N and farm practice were close to one standard error from optimum, with RB209 overestimating. Retrospective recommendation from WELL_N were 25 kgN/ha higher than predictive since conversion of marketable fresh weight to dry weight 20% higher than expected from model default.**

With the original SUNDIAL-FRS cauliflower parameters, the crop was only able to take up 18% of the total N requirement, so the recommendation and calculated yields were far too low. The parameters have now been modified, with much improved results. The presented recommendations are for the new parameters, but the results are not used in the final evaluation of the SUNDIAL recommendations.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	82	28	21	31	162
375	223	79	41	31	374
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	58	38	25	21	142
375	239	136	31	21	427
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	20	13	29	22	84
375	198	193	29	22	443

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: The new SUNDIAL-FRS cauliflower parameters gave much improved simulation of crop N uptake, although it was still underestimated at the zero N rate. WELL_N gave reasonable agreement with crop and soil N.

Site reference: 28 Year: 1999

Topsoil texture: Silt loam **Previous crop:** Cauliflower

Current crop: Cauliflower **Expected mkt yield t/ha:** 29.7

Maximum mkt yield t/ha: 29.0 **Maximum total DW t/ha:** 6.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	161 (±9.9)	250	210	175	150	200	175	200	180	180	180
Calculated yield *	24.6	25.8	25.6	25.0	24.3	25.4	25.0	25.4	25.1	25.1	25.1
% difference from optimum yield		5	4	1	-1	3	1	3	2	2	2

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments**: WELL_N and farm practice were within 50 kgN/ha of the calculated optimum. As in the previous year, the retrospective recommendation from WELL_N was 25 kgN/ha higher than predictive due to the conversion of marketable fresh weight to dry weight being 20% higher than expected from model default.**

With the improved cauliflower parameters (see Site 28/98), the SUNDIAL-FRS recommendation with SMN was within 20 kgN/ha of the optimum. The presented recommendations are for the new parameters, but the results are not used in the final evaluation.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	118	27	15	19	179
375	208	236	16	25	485
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	142	21	14	43	220
375	258	199	51	43	551
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	35	19	55	45	154
375	159	260	55	45	519

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N overestimated crop N uptake. As in the previous year, the new SUNDIAL-FRS cauliflower parameters gave much improved simulation of crop N uptake, although it was still underestimated at the zero N rate.

Site reference: 29 **Y**ear: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Winter wheat
Current crop:	Brussels sprout	**Expected mkt yield t/ha:**	17.9
Maximum mkt yield t/ha:	25.0	**Maximum total DW t/ha:**	10.6

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	352	300	300	300	300	300	300	320	300	300	300
Calculated yield *	21.5	19.9	19.9	19.9	19.9	19.9	19.9	20.6	19.9	19.9	19.9
% difference from optimum yield		-8	-8	-8	-8	-8	-8	-4	-8	-8	-8

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **The maximum marketable yield was 40% greater than expected due to one high yielding replicate. WELL_N and SUNDIAL-FRS gave similar recommendations, 50kgN/ha less than the optimum, but closer to the expected yield than yield at the optimum N rate. Using actual yields and weather had no effect on the recommendations.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	50	21	20	20	111
425	332	24	19	16	391
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	89	17	15	16	137
425	351	22	14	14	401
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	40	12	41	22	115
425	449	9	21	24	502

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: SUNDIAL-FRS overestimated crop N uptake at the maximum rate, leading to the simulated crop N + SMN being over 100 kg N / ha higher than observed. SUNDIAL-FRS gave a good simulation of crop N and SMN at the zero N rate. WELL_N gave reasonable simulations at both rates.

Site reference: 30 **Y**ear: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Cabbage
Current crop:	Red beet	**Expected mkt yield t/ha:**	37.7
Maximum mkt yield t/ha:	46.3	**Maximum total DW t/ha:**	10.9

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	250	190	125	150	125	150	N/A	N/A	N/A	N/A
Calculated yield *		46.3	38.8	37.5	38.0	37.5	38.0				
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **There was a linear response to applied N and no optimum could be fitted. WELL_N recommended less than either RB209 or farm practice. In a successful strip trial at this site there was no difference in marketable yield between the WELL_N predicted rate and farm practice.**

SUNDIAL-FRS is not parameterised for red beet.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
		Measured values			
0	217	27	16	13	273
250	345	154	28	22	549
(farm)$					
		WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)			
0	133	14	14	39	200
250	284	14	14	14	326
		SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)			
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake at both rates and SMN at the high rate.

Site reference: 30 Year: 1999

Topsoil texture:	Silt loam	**Previous crop:**	Red beet
Current crop:	Savoy cabbage	**Expected mkt yield t/ha:**	25.0
Maximum mkt yield t/ha:	27.0	**Maximum total DW t/ha:**	10.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	298	275	130	250	250	250	250	N/A	N/A	N/A	N/A
Calculated yield *	23.8	23.1	15.1	22.2	22.2	22.2	22.2				
% difference from optimum yield		-3	-36	-7	-7	-7	-7				

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **Farm practice rate was particularly low - possibly a top-dressing went unrecorded on the non-trial area. Savoy cabbage is not specifically parameterised in WELL_N, but the crop was successfully simulated using Dutch white cabbage parameters.**

SUNDIAL-FRS is not parameterised for red beet (the previous crop) or Savoy cabbage.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	186	35	20	15	256
400	411	55	57	32	555
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	141	14	14	14	183
400	342	24	14	16	396
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
400	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake at both rates.

Site reference: 31 Year: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Winter wheat
Current crop:	Brussels sprout	**Expected mkt yield t/ha:**	17.0
Maximum mkt yield t/ha:	22.0	**Maximum total DW t/ha:**	13.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	210	265	250	250	300	300	280	240	300	300
Calculated yield *											
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **The optimum was above the maximum (400 kgN/ha) rate used. RB209, farm practice and both models underestimated N requirement. Underestimation by the models used predictively was due, at least in part, to an expected marketable yield 23% less than actually achieved. Used retrospectively, with the actual maximum yield, the SUNDIAL and WELL_N recommendations increased, but were still less than the maximum rate used. It is probable that peak dry matter production had occurred before harvest, prior to loss of mature leaves.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	111	27	17	10	165
400	384	32	19	13	448
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	124	14	14	14	166
400	375	21	14	14	424
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	116	9	9	9	143
400	466	11	12	17	505

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N simulated crop N and SMN well. SUNDIAL-FRS gave a good simulation at the zero N rate, but overestimated crop N at the maximum N rate.

Site reference: 31 **Y**ear: 1999

Topsoil texture:	Silt loam	**Previous crop:**	Brussels sprout
Current crop:	Autumn cauliflower	**Expected mkt yield t/ha:**	17.0
Maximum mkt yield t/ha:	17.0	**Maximum total DW t/ha:**	7.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	See below	210	265	250	250	300	300	100	80	120	120
Calculated yield *											
% difference from optimum yield											

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **No response curve was fitted as only one replicate was harvested because of soil waterlogging on part of the trial. The SUNDIAL-FRS recommendation is low compared to RB209, the farm and WELL_N, and is not used in the overall evaluation of SUNDIAL, as the cauliflower parameters were modified as a result of the initial poor simulation of crop N uptake (see Site 28/98).**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	73	24	12	14	123
350	295	118	28	16	457
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	148	14	14	14	190
350	277	47	95	33	452
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	20	37	73	21	151
350	109	173	54	21	357

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Measured values based on single replicate due to waterlogging. SUNDIAL underestimated crop N uptake, in spite of the improved crop parameters. It compensated by overestimating SMN, although crop N + SMN at the maximum N rate was still underestimated.

APPENDIX B

Site reference: 32 **Y**ear: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Brussels sprout
Current crop:	Dutch white cabbage	**Expected mkt yield t/ha:**	97.5
Maximum mkt yield t/ha:	82.2	**Maximum total DW t/ha:**	15.4

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**198**	**190**	**260**	**300**	**300**	**325**	**325**	**420**	**420**	**300**	**280**
Calculated yield *	**72.7**	**72.1**	**77.2**	**79.6**	**79.6**	**80.9**	**80.9**	**N/A**	**N/A**	**79.6**	**78.4**
% difference from optimum yield		**-1**	**6**	**9**	**9**	**11**	**11**			**9**	**8**

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **The calculated optimum had a high standard error (± 37). Both WELL_N and SUNDIAL-FRS recommendations were consistently above the optimum, but did result in high yields. It was not possible to calculate yields for the SUNDIAL predictive recommendation, as the recommendation was well above the trail maximum (350 kg N/ha). The SUNDIAL retrospective plus SMN, using the optimum yield, reduced the recommendation, but it was still 80 kgN/ha above the optimum.**

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	**Crop N uptake**	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	**Crop N + SMN**
Measured values					
0	231	31	23	17	302
350	431	99	47	19	596
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	134	19	14	16	183
350	363	19	14	14	410
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	58	11	37	26	132
350	372	22	41	26	461
(farm)$					

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Both WELL_N and SUNDIAL-FRS underestimated crop N and SMN at this site.

Site reference: 33 Year: 1998

Topsoil texture:	Sandy loam	**Previous crop:**	Salad onion
Current crop:	Dwarf bean	**Expected mkt yield t/ha:**	19.0
Maximum mkt yield t/ha:	20.7	**Maximum total DW t/ha:**	5.2

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	100	86	175	175	175	175	N/A	N/A	N/A	N/A
Calculated yield *	19.1	19.1	19.1	19.1	19.1	19.1	19.1				
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial**

$ Farm recommendation is actual rate used.

Comments: **There was no significant response to applied N in the trial. RB209, farm practice and, particularly WELL_N overestimated N requirement, but without loss of yield. The previous salad onion crop had been unharvested and ploughed in 5 days prior to drilling the beans. It is possible that the timing of breakdown of the onion residues had been incorrectly simulated.**

SUNDIAL-FRS is not parameterised for salad onion or dwarf beans.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	118	42	22	27	209
250	189	149	35	29	402
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	37	14	32	23	106
250	125	89	32	23	269
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	
(farm)$					

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake and SMN, leading to the overestimate of N requirement.

Site reference: 34 Year: 1998

Topsoil texture:	Silty clay loam	**Previous crop:**	Calabrese
Current crop:	Autumn cauliflower	**Expected mkt yield t/ha:**	31.0
Maximum mkt yield t/ha:	23.0	**Maximum total DW t/ha:**	4.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	123	130	112	175	175	175	175	160	180	80	100
Calculated yield *	16.7	16.9	16.5	17.5	17.5	17.5	17.5	17.3	17.6	15.6	16.2
% difference from optimum yield		1	-1	5	5	5	5	4	5	-7	-3

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **Maturity of this autumn cauliflower variety was delayed into the New Year by cool growing conditions. Not being frost hardy, the trial and commercial crop were both affected by frost damage. The calculated optimum and recommendations were made on the assumption that frosted heads had been marketable, nevertheless, yields were lower than expected and WELL_N overestimated N requirement. A planned top-dressing by the farmer was omitted because of wet soil conditions.**

SUNDIAL-FRS is not parameterised for calabrese (the previous crop), so cauliflower was used. Modified cauliflower parameters (see Site 28/98) resulted in much improved crop N uptake. The retrospective recommendation plus SMN was within 25 kgN/ha of the optimum.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	116	34	23	11	184
375	184	41	24	49	298
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	65	19	19	22	125
375	198	19	31	105	353
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	17	9	18	9	52
375	112	23	221	10	366

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake at zero, and overestimated SMN in the porous chalk 60-90 cm layer at the high rate of N. The SUNDIAL simulations with modified cauliflower parameters were much improved, although crop N uptake was still underestimated, leading to an accumulation of SMN in the 30-60cm soil layer.

Site reference: 34 **Y**ear: 1999

Topsoil texture:	Silt loam	**Previous crop:**	Aut. cauliflower
Current crop:	Autumn cauliflower	**Expected mkt yield t/ha:**	31.0
Maximum mkt yield t/ha:	11.0	**Maximum total DW t/ha:**	2.5

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	0	250	115	75	75	0	0	160	120	120	120
Calculated yield *	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
% difference from optimum yield											

*** Calculated as mean trial yield, as there was no significant response to N within the range of the trial**

$ Farm recommendation is actual rate used.

Comments: **As a consequence of a high spring soil mineral N content from the previous crop residue (Table 7), there was no significant response to applied N. The trial crop was harvested slightly immature to avoid frost damage, and as a result the expected yield was not achieved and the predictive recommendation of WELL_N, together with RB209 and farm practice, was too high. Retrospectively, with the low achieved yield, WELL_N correctly recommended a zero N application.**

The SUNDIAL recommendations were based on the improved cauliflower parameters (see Site 28/98). They were far too high, even with the spring SMN measurements and a reduced yield in the retrospective runs.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	147	12	8	4	171
300	217	50	35	7	309
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	119	47	49	27	242
300	119	209	179	35	542
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	1	112	35	15	162
300	64	270	35	15	384

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N underestimated crop N uptake but overestimated SMN. SUNDIAL was unable to simulate crop N uptake by cauliflower, even with the improved crop parameters, so large amounts of fertiliser N accumulated in the soil at the maximum N rate. Yields were rather low at this site (compare with site 28).

Site reference: 35 **Y**ear: 1998

Topsoil texture:	Silt loam	**Previous crop:**	Crisp lettuce
Current crop:	Crisp lettuce	**Expected mkt yield t/ha:**	43.7
Maximum mkt yield t/ha:	24.7	**Maximum total DW t/ha:**	2.4

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	60	120	125	100	75	100	75	N/A	N/A	N/A	N/A
Calculated yield *	24.0	24.4	24.4	24.5	24.3	24.5	24.3				
% difference from optimum yield		2	2	2	1	2	1				

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **Crop harvested about 1 week early at farmer's request in order to clear the trial area before the commercial harvest. Consequently the crop had not achieved its expected weight and the calculated optimum was lower than it might otherwise have been.**

SUNDIAL-FRS was unable to provide a recommendation for this crop.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	86	36	37	36	195
275	107	292	146	119	664
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	78	14	18	38	148
275	102	92	157	49	400
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
275	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N predicted crop uptake reasonably well but underestimated SMN

Site reference: 36 **Y**ear: 1998

Topsoil texture:	Peat	**Previous crop:**	Carrot
Current crop:	Crisp lettuce	**Expected mkt yield t/ha:**	43.7
Maximum mkt yield t/ha:	42.0	**Maximum total DW t/ha:**	3.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	**81**	**100**	**100**	**100**	**100**	**75**	**75**	**N/A**	**N/A**	**N/A**	**N/A**
Calculated yield *	**43.3**	**43.5**	**43.5**	**43.5**	**43.5**	**43.0**	**43.0**				
% difference from optimum yield		**1**	**1**	**1**	**1**	**-1**	**-1**				

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **WELL_N has not previously been used on peat soils due to uncertainties in mineralisation rate. Using an estimate of mineralisation based on measured changes in pre- and post-cropping soil mineral N on the zero N plots, good estimates of the calculated optimum were achieved both predictively and retrospectively. These results were not used in the evaluation of the model, however, as the mineralisation value was not independent of the data.**

SUNDIAL-FRS is not parameterised for peat soils.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	**Crop N uptake**	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	**Crop N + SMN**
Measured values					
0	**67**	**37**	**36**	**108**	**248**
250	**109**	**281**	**80**	**105**	**539**
(farm)$	**N/A**	**N/A**	**N/A**	**N/A**	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	**80**	**14**	**27**	**30**	**151**
250	**122**	**162**	**46**	**30**	**360**
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	**N/A**	**N/A**	**N/A**	**N/A**	
250	**N/A**	**N/A**	**N/A**	**N/A**	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N gave reasonable estimates of crop N uptake but underestimated SMN.

Site reference: 36 Year: 1999

Topsoil texture:	Peat	**Previous crop:**	Crisp lettuce
Current crop:	2nd early potato	**Expected mkt yield t/ha:**	62.8
Maximum mkt yield t/ha:	55.0	**Maximum total DW t/ha:**	11.0

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	202	130	230	175	175	100	100	N/A	N/A	N/A	N/A
Calculated yield *	52.6	45.9	52.4	50.6	50.6	42.5	42.5				
% difference from optimum yield		-13	-1	-4	-4	-19	-19				

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **Achieved marketable yields were lower than expected, due to a high percentage (up to 10%) of rejected green tubers. Using a calculated mineralisation rate (see site 36/98), WELL_N gave a reasonably good predictive estimate of the optimum. Total dry weight yield was also lower than expected and use of WELL_N retrospectivly gave an underestimate of optimum. These results were not used in the evaluation of the model, however, as the mineralisation value was not independent of the data.**

SUNDIAL-FRS is not parameterised for peat soils.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	61	57	24	75	217
250	148	68	53	68	337
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	123	14	14	33	184
250	254	14	14	36	318
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	N/A	N/A	N/A	N/A	
250	N/A	N/A	N/A	N/A	

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N overestimated crop N uptake and underestimated SMN.

Site reference: 37 **Y**ear: 1998

Topsoil texture:	Clay loam	**Previous crop:**	Winter wheat
Current crop:	Salad onion	**Expected mkt yield t/ha:**	23.0
Maximum mkt yield t/ha:	25.0	**Maximum total DW t/ha:**	2.1

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	18	125	129	125	125	125	125	40	0	20	0
Calculated yield *	19.1	22.1	22.2	22.1	22.1	22.1	22.1	20.1	16.0	19.2	16.0
% difference from optimum yield		16	16	16	16	16	16	5	-16	1	-16

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **Salad onions are not specifically parameterised in WELL_N and were run as bulb onions, albeit with a lower target yield. With this over-wintered crop, recommendations were made prior to spring top-dressing, following a measurement of plant size. RB209, farm practice and WELL_N recommended rates agreed closely and out-yielded the particularly low calculated optimum by 16%.**

SUNDIAL-FRS is not specifically parameterised for salad onions and was also run as bulb onions, with adjustments to the expected yield to take account of the different dry matter contents. The retrospective recommendations used an equivalent yield of 19 t/ha. Recommendations were close to the optimum, but gave a yield penalty in comparison with the WELL_N, RB209 and farm rates.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
		Measured values			
0	27	40	40	23	130
200	94	133	47	28	302
(farm)$					
		WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**			
0	18	26	19	30	93
200	67	137	26	31	261
		SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)			
0	40	21	24	25	110
200	57	73	111	24	265

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: Both WELL_N and SUNDIAL-FRS gave reasonable estimates of crop and soil N, considering that they are not parameterised for salad onion.

Site reference: 37 Year: 1999

Topsoil texture:	Clay loam	**Previous crop:**	Salad onion
Current crop:	Salad onion	**Expected mkt yield t/ha:**	29.0
Maximum mkt yield t/ha:	9.5	**Maximum total DW t/ha:**	1.3

Summary of N recommendations (kgN/ha) and calculated yields (t/ha):

Method	Optimum*	RB209	Farm $	WELL_N:				SUNDIAL-FRS:			
				Predictive		Retrospective		Predictive		Retrospective	
				Default weather	Actual weather	Default weather	Actual weather	Default weather	+ spring SMN	Actual weather	+ spring SMN
Recommendation	87	75	175	50	50	0	0	80	0	40	20
Calculated yield *	7.8	7.6	7.6	7.2	7.2	5.9	5.9	7.7	5.9	7.0	6.5
% difference from optimum yield		-2	-2	-7	-7	-24	-24	-1	-24	-10	-17

*** Calculated from linear plus exponential curve fitted to trial data.**

$ Farm recommendation is actual rate used.

Comments: **This Japanese bunching onion (*Allium fistulosum*) yielded considerably less than expected because of a low plant stand due to a cloddy seedbed. There was also considerable spatial variability in yield. This species is not parameterised for WELL_N and was run as bulb onion. Predictive recommendations were within 50 kgN/ha of the calculated optimum but the retrospective recommendations were too low.**

SUNDIAL-FRS is not parameterised for salad onions, and so the recommendations were run for bulb onions with adjustments to the expected yield to take account of the different dry matter contents. The SUNDIAL predictive recommendation was very close to the optimum, but the retrospective recommendations were well below the optimum and resulted in a yield penalty.

Crop N uptake and Soil Mineral N (SMN, nitrate plus ammonium) at harvest (kgN/ha)

N rate*	Crop N uptake	Soil 0-30cm	Soil 30-60cm	Soil 60-90cm	Crop N + SMN
Measured values					
0	21	68	48	22	159
200	29	137	73	43	282
(farm)$	N/A	N/A	N/A	N/A	
WELL_N Simulation **(retrospective with actual weather, actual yields and N rates and spring SMN)**					
0	48	87	48	32	215
200	48	287	48	32	415
SUNDIAL-FRS Simulation (retrospective with actual weather, actual yields and N rates and spring SMN)					
0	43	11	124	35	213
200	46	11	123	34	214

Zero and maximum rates used in trial, plus farm rate$ where available.

Comments: WELL_N overestimated crop N uptake and SMN in the 0-30 cm layer. SUNDIAL overestimated crop N, and gave a poor estimation of SMN.