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Review of evidence on the principles of crop nutrient management and nutrition for horticultural crops

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1. Abstract

The Crop Nutrient Management Partnership was set up by AHDB to review and revise the “Fertiliser Manual (RB209)” (8th edition) and produce a new “Nutrient management Guide (RB209)” for release in May 2017. The main aim of the overall project was to review research since 2009 on crop nutrition for the main arable, horticulture and grassland crops of England, Wales and Northern Ireland (N.I.) and based on the findings, and where appropriate, to revise and amalgamate sections to inform revisions of RB209. The specific objectives of this work package were to review research on horticulture crop nutrition undertaken since the publication of the 8th edition of RB209 and to propose revisions to RB209 based on this evidence, and highlight remaining knowledge gaps.

Since the last revision of RB209 (2010) there has been new research on baby leaf lettuce, wild rocket and herbs (coriander and mint) and fertiliser recommendations for these crops can now be included in RB209. Nitrogen (N) fertiliser recommendations for sweetcorn have been revised based on the results of AHDB Horticulture project FV 409. The text guidance on N fertiliser applications to leeks (N application in the seedbed and overwinter ‘supplementary’ N) has been revised based on the findings from AHDB Horticulture projects FV 350 and FV 350a.

The review includes information from recent projects that have looked at assessing soil nitrogen supply (SNS) for field vegetables and proposes revised guidance on when SMN sampling can be most useful and on interpretation of SMN analysis results. Typical crop phosphate and potash offtakes have been compared against recommended fertiliser rates at the target soil Indices; this has highlighted the importance of replacing crop offtake, particularly for high yielding crops.

Information on sulphur (S) response and S requirements of field vegetables has been reviewed; we recommend increasing the S recommendation for vegetable brassica crops (Brussels sprouts, cabbage, cauliflower and calabrese) to 50-75 kg SO_3/ha (the same as for oilseed rape). Although there is a lack of evidence on which to base S recommendations for the other field vegetable crops, against a back drop of declining atmospheric S emissions and in view of crop S uptake values similar/greater than that of wheat, we recommend guidance to apply S fertiliser to all other field vegetable crops (at 25 kg SO_3/ha) where deficiencies are thought likely. The guidance on S at the start of the Field vegetables section has been revised.

Fertiliser recommendations for fruit have changed little since the first edition of RB209 in 1973. Recent UK research on fruit has focussed on irrigation/fertigation and does not provide information suitable to revise current RB209 recommended fertiliser rates.

The current guidance to pro-rata N applications to established top fruit where fertiliser is applied to the herbicide strip area only is discussed. Typical crop phosphate and potash offtakes have been compared against recommended fertiliser rates at the target soil Indices; recommended rates are sufficient to replace typical crop offtake for all fruit crops. The potential response of fruit crops to applied S is discussed and information text on S is proposed for inclusion in the fruit section.

2. Introduction

2.1. Aims and objectives

The overall aim of the project was to review research since 2009 on crop nutrition for the main arable and grassland crops of England, Wales and Northern Ireland (N.I.) and based on the findings, and where appropriate, to revise and amalgamate sections in the "Fertiliser Manual (RB209)" to produce new, clear, coherent, up to date, standalone and scientifically robust recommendations for each sector. The specific objectives for this work package (WP6 – Horticulture) were to:

i. Review the list of horticultural crops for inclusion within this review and revision of RB209.
ii. Review research on horticulture crop nutrition undertaken since the publication of the 8th edition of RB209.
iii. Identify knowledge gaps within current best practice and prioritise requirements for future research.
iv. Produce an AHDB Research Review report for horticulture.
v. Update the RB209 horticulture section including amalgamation of current RB209 sections 3 and relevant appendices.

3. Methodology

A review of both published and unpublished research on crop nutrition for horticultural crops was carried out. The review considered evidence from the following AHDB and Defra funded research projects and other relevant research reports from the UK:

- FV 345a. Establishing best practice for determining soil nitrogen supply.
- FV 350. Nitrogen requirements of leeks.
- FV 350a. Quantifying the over-winter nitrogen requirements of the leek crop.
- FV 359. Nutrient requirements for field grown herbs.
- FV 370a and 370b. Wild rocket and spinach: the impact of nitrogen and phosphorus fertiliser application on field grown crops.
- FV 380. Identification of critical soil phosphate levels in vining pea crops.
- FV 409. Sweetcorn: responses to nitrogen and phosphorus.
- FV 418. Baby leaf lettuce: N response studies to maximise yield and manage nitrate levels.
- FV 428. Vining peas: the effects of soil phosphate levels on rhizobial population.
- SF 107. Managing water nitrogen and calcium inputs to optimise flavour and shelf-life in soil less strawberry production.
- SF 136. Improving water and fertiliser use efficiencies and fruit quality in commercial substrate strawberry production.

- SF 137. Timing of nitrogen applications to optimise growth and yield without adversely affecting fruit storability and frost sensitivity.
- SV 137 Blueberry Timing of nitrogen applications to optimise growth and yield without adversely affecting fruit storability and frost sensitivity.
- SF 12 (221a) Blackcurrants: Evaluation of soil nitrogen assessments and the use of controlled release nitrogen fertilisers (2010).
- SF 12 (221b) Blackcurrants: Evaluation of controlled release nitrogen fertilisers.
- TF 198. Developing water and fertiliser saving strategies to improve fruit quality and sustainability of integrated high-intensity, modern and traditional pear production.
- TF 214. Improving nitrogen use efficiency, sustainability and fruit quality in high density apple orchards.
- CP 103. The application of precision agronomy to UK production of Narcissus.
- H-UK/HONE More sustainable orchards trials. Determine optimum nitrogen rates on apple trees and effect of twin N nitrifying bacteria on yields.
- Defra project SCF0308. Trends in atmospheric sulphur and potential impacts on crop yields.
- AHDB Cereals & Oilseeds RR78: A review of non-NPKS nutrient requirements of UK cereals and oilseed rape.

Web of Science was used to identify relevant recent (2009-2016) published scientific papers using the following search criteria:

Crop AND fertili* AND nutrients

Search terms used for ‘crop’ included all horticultural crop names included within RB209 and any new crops identified for inclusion (including Latin names). Search terms used for ‘nutrients’ included nitrogen, phosp*, potash, potassium, calcium, magnesium, sulphur, sulphur, sodium, lime, pH, micro-nutrients, manganese, boron, copper, molybdenum, zinc, iron.

In addition, a number of commercial organisations and individuals who provide advice and guidance on horticulture crop nutrition were invited to submit data for use in the review. A total of 24 organisations and all of the AHDB Horticulture grower associations were contacted specifically in relation to this work package (WP6 Horticulture). In addition, 18 individuals/organisations were contacted as part of the wider review to request data relevant to all work packages (including WP6 Horticulture). Details of all organisations and individuals contacted are given in Appendix 1.

4. Review of evidence to support RB209 recommendations for vegetables and bulbs

4.1. Industry consultation

There was very limited response following the initial industry consultation; only four individuals/companies responded to the consultation (for field vegetables and bulbs):

Two responses concerned the NVZ Nmax limit of zero for peas and bean. RB209 has a recommendation of 0 kg N/ha for field beans, broad beans and peas (dried, vining and market pick); although this is a recommendation, the NVZ Nmax rules prohibit the application of any N to peas or beans within a NVZ.

The first respondent noted that experience had shown them that a small amount of N (i.e. 30 kg N/ha) applied to vining peas which are drilled in agronomically suboptimal conditions was beneficial to help establishment of the crop. Current Nmax rules now prevent them from doing this and they are also not permitted to carry out trials to gather data on N applications to peas without specific permissions from the Environment Agency.

The second respondent also questioned the current Nmax rule of zero for legumes, specifically as it prohibits the application of many starter fertilisers which may be beneficial to growth, but which contain small amounts of N.

The third (ADAS) respondent identified fertiliser recommendations for field grown hardy nursery stock as a knowledge gap. The most recent fertiliser recommendations for hardy nursery stock are in the 1988 5th edition of RB209 and further work would be needed to update these recommendations.

The fourth respondent, British Herbs (formally known as the British Herb Trade Association), commented on nutrient research on herbs and identified their priority areas for future research. Additional comment on the proposed changes to RB209 was subsequently sought from a number of individual agronomists/consultants/ researchers.

4.2. Crops included

The current 8th edition of RB209 includes fertiliser recommendations for the main field vegetable crops. There are a number of more minority crops which are not included in RB209. Where new research is able to quantify the fertiliser requirements of other crops these crops can be included within future revisions of RB209. Since the last revision of RB209 (2010) there has been new research on baby leaf lettuce, wild rocket and herbs (coriander and mint) and fertiliser recommendations for these crops can now be included in RB209.

When RB209 was revised in 1990 (6th edition), fertiliser recommendations for rhubarb and glasshouse crops and nursery stock were removed. The 5th edition of RB209 is still used by some agronomists as the basis for fertiliser advice for these crops.

The 8th edition RB209 fertiliser recommendations were compared with fertiliser recommendations given in the Fresh Produce Crop Protocols[1] to (i) check that fertiliser recommendations were the same, and (ii) identify any crops which have a fertiliser recommendation in the Fresh Produce Crop Protocols but were not included within RB209 (8th edition).

Where a fertiliser recommendation was given for a crop in RB209 (8th edition), the Fresh Produce Crop Protocols generally use these recommendations, with the exception of cucurbits, swedes and turnips:

Cucurbits – RB209 (8th edition) provided recommendation for courgettes only, whereas the Fresh Produce Crop Protocol gives a single recommendation for all cucurbits (courgette, pumpkin, squash and marrow); this recommendation is the same as RB209 for P, K and Mg, but differs for N (**Table *1*** and **Table *2***)

Table 1. RB209 (8th edition) N recommendations – courgettes.

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
Seedbed	100	100	100	40	0[b]	0[b]	0[b]
Topdressing	Top-dressings of up to 75 kg N/ha in total may be required.						

b. A small amount of nitrogen may be needed if soil nitrogen levels are low in the 0-30 cm of soil

Table 2. Fresh Produce Crop Protocol N recommendations – cucurbits (courgette, pumpkin, squash and marrow).

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
Seedbed*	150	100	50	0[b]	0[b]	0[b]	0[b]

b. A small amount of nitrogen may be needed if soil nitrogen levels are low in the 0-30 cm of soil
*Apply no more than 100 kg N/ha in the seedbed. Apply the remainder as a top-dressing when the crop is fully established.

Swedes – RB209 (8th edition) provided a single set of N recommendations for ‘all soil types’ (of 135, 100, 70 and 30 kg N/ha at SNS indices 0-3 respectively). The Fresh Produce Crop Protocol gives separate N recommendations for ‘mineral soils’ (which are the same as in RB209) and ‘peat soils’ (which are lower at 60, 40 and 0 kg N/ha at SNS indices 0-2 respectively) (**Table *4***).

[1] Fresh Produce Crop Protocols available from http://assurance.redtractor.org.uk/standards/fresh-produce-crop-protocols

Turnips – RB209 (8th edition) provided different N recommendations for swedes and turnips, whereas the Fresh Produce Crop Protocol gives one set of N recommendations for both root crops. Nitrogen recommendations for turnips in the 8th edition of RB209 (**Table *3***) are higher than given in the Fresh Produce Crop Protocol (**Table *4***).

Table 3. RB209 (8th edition) N recommendation – turnips.

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
All soil types	170	130	100	70	20	0[b]	0[b]

b. A small amount of nitrogen may be needed if soil nitrogen levels are low in the 0-30 cm of soil (see ‘Techniques for Applying Fertiliser’).

Table 4. Fresh Produce Crop Protocol N recommendations for swedes and turnips.

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
Mineral soils	135	100	70	30	0[b]	0[b]	0[b]
Peat soils	60	40	0	0	0	0	0

b. A small amount of nitrogen may be needed if soil nitrogen levels are low in the 0-30 cm of soil
*Apply no more than 100 kg N/ha in the seedbed. Apply the remainder as a top-dressing when the crop is fully established.

The Fresh Produce Crop Protocols also give guidance on fertiliser applications for the following crops which were not included in the 8th edition of RB209: celeriac, chicory, Chinese cabbage, garlic, herbs (basil, chives, dill, marjoram, mint, oregano, parsley, rosemary, sage, tarragon and thyme), kale, rhubarb and spinach. The Fresh Produce Crop Protocol guidance on fertiliser rates for these crops is given in Appendix 2. Comparison with the Fresh Produce Crop Protocols is useful to highlight other horticultural crops that could be added, but we would need to explore the evidence base for these recommendations before they are included. Many of these are minor crops grown on small areas and area grown is not readily available with the exception of rhubarb which has a UK crop areas of 562 ha (Defra, 2014).

Rhubarb

Fertiliser recommendations for rhubarb are provided in the Fresh Produce Crop Protocol for Rhubarb, and these are based on the recommendations in the 5th edition of RB209 for crops in the year of establishment (Table 5). Whilst the Fresh Produce Crop Protocol gives a single set of recommendations, the 5th edition of RB209 gives separate recommendations for establishment and established crops (Table 5 and Table 6). These recommendations are understood to be based on research carried out at Stockbridge Technology Centre in the 1970’s and 1980’s, but the evidence to support these recommendations does not appear to be readily available. Due to the lack of available supporting data and changes to modern production systems growers do not wish these recommendations to be re-instated in RB209 without further research into the crop's nutrient requirements.

With regard to changes to production, the fertiliser guidance in the Fresh Produce Crop Protocol is believed to be for crops harvested only once in a season (traditionally from March to May). To achieve an extended season supply to meet retailer's demands, growers now harvest up to 3 crops from the same crowns within a single season. As rhubarb is a perennial crop these multiple harvests can occur year on year from the same crowns, placing increased demand on the plants. The Fresh Produce Crop Protocol does include a footnote that extra N can be applied based on previous crop vigour and growth, but little further information is available to the grower, and there is no guidance on the timing of N applications for crops pulled more than once in a season. In addition, newer perpetual varieties have been developed which do not have a period of dormancy, and these may not have the inherent vigour of the older varieties. Therefore research is required on the nutrient requirements of these perpetual varieties before recommendations for these can be included.

In the absence of recommendations in the 8th edition of RB209, growers and consultants use a combination of expert opinion and the recommendations for established crops from the 5th edition of RB209 and the Fresh Produce Crop Protocol. Typical annual applications of N for established outdoor crops range from 70 to 300 kg N/ha depending on whether the crop is being pulled once or several times in a season, as well as factors such as soil type. Higher applications are usually split. Despite using this advice and recommendations, growers and consultants are concerned that the crop may not be reaching its maximum potential due to the lack of available data to support these practices.

Table 5. 5th edition RB209 recommendation for rhubarb crops at establishment (used in Fresh Produce Crop Protocol.

Soil Index	0	1	2	3	4	5	6
	kg/ha						
N	175	125	75	0	0	0	0
P_2O_5	175	150	120	100	50	0	0
K_2O	250	225	200	150	125	0	0
Mg - light soils	90	60	0	0	0	0	0
Mg - other soils	60	30	0	0	0	0	0

Notes: Additional applications of N will be required each year but should be targeted to previous crop growth and vigour of the plantation. In the spring prior to forcing up to 400 kg N/ha may be required, split as two or more top dressings.

Table 6. 5th edition RB209 recommendation for established rhubarb crops (in cropping years).

Soil Index	0	1	2	3	4	5	6
	kg/ha						
N	250	250	250	0	0	0	0
P_2O_5	100	100	75	75	0	0	0
K_2O	300	250	175	150	100	0	0
Mg - light soils	90	60	0	0	0	0	0
Mg - other soils	60	30	0	0	0	0	0

Recommendations:

- Revised RB209 to include recommendations for the following new crops: baby leaf lettuce, wild rocket, coriander and mint.
- We recommend that AHDB consider inclusion of nutrient recommendations for rhubarb in a future revision of RB209 (i.e. 10th edition in 2019 or later). Recommendations would need to be based on new research.

4.3. Principles of nutrient use for vegetables and bulbs

4.3.1. Nitrogen

Crop nitrogen requirements

The 8th edition RB209 N recommendations for field vegetables were based on a three-step framework taking into account:

- *Size of the crop* – the size, frame, or weight of the crop needed to provide optimal economic production.
- *Nitrogen uptake* – the optimum N uptake associated with a crop of that size.
- *Supply of N* – based on the N supply from the soil within rooting depth including the potential N mineralised from soil organic matter.

This framework was used to calculate 8th edition RB209 N recommendations for all field vegetable crops apart from asparagus, celery, peas and beans, sweetcorn, courgettes and bulb/bulb flowers where insufficient data was available to include these crops in the framework.

A description of the calculation of crop N requirement is included in 8th edition RB209 Appendix 9 and the values used to derive the crop N requirements are given in Appendix 10. This information is also included within the revised RB209. The Horticulture Technical Working Group agreed that the description of the calculation of crop N requirement should specify that it can be used *by FACTS Qualified Advisers* to derive N recommendations; the inclusion of FACTS advice is recommended to reflect the complexity of the calculations.

A full description of the calculations and validation of the 8th edition RB209 recommendations is given in Appendix 3 (unpublished supporting documentation produced for the 8th edition revision).

The existing values in the framework have not be updated as part of the current revision, however data for coriander and mint have been added. The new recommendations for sweetcorn, baby leaf lettuce and wild rocket are based on the principles of the framework (i.e. N uptake and supply of N from the soil), however values for crop N uptake are taken from measured values rather than derived from calculation of critical N, and therefore these crops have not been added to the framework.

Assessing soil nitrogen supply

AHDB Cereals & Oilseeds Project Report 490 aimed to establish best practice for the estimation of SNS and included measurements of SNS in more than 160 winter cereal crops between 2008 and 2010. AHDB Horticulture project FV345a 'Establishing best practice for determining soil nitrogen supply', was an extension to this project to include an additional ten field sites following Brassica crops (four field following both calabrese and cauliflower and two fields following cabbage).

Soil N supply measured following the four cauliflower crops was variable (measured SNS Index 1-4, mean SNS Index 2) and lower than predicted by the Field Assessment Method (FAM) (SNS Index 3-4) at three of the sites, which was attributed to relatively low fertiliser N applications to the cauliflower crops. Soil N supply was very low after the two cabbage crops (measured SNS Index 0) and less than predicted by the FAM (SNS Index 3). However, SMN levels were very high after the four calabrese crops (measured SNS Index 4-6, compared to FAM predicted SNS of 4-5). Soil mineral N measurements at these sites showed that assessments of SNS Index following brassica crops using the FAM can be in error and measurements of SMN would help to avoid errors in under or over fertilisation of the following crops. Furthermore, where the next crop grown is shallow rooted, measurement of SMN would provide information on SMN in the root zone.

AHDB Horticulture published Factsheet 09/12 '*Soil Nitrogen Supply for field vegetables*' to incorporate guidance on best management practices for SMN sampling. The main conclusions of FV 345 and recommendations given in Factsheet 09/12 which should be incorporated into the revised RB209 are:

- Soil N supply following vegetable crops can be variable and difficult to predict using the FAM. Consider sampling SMN in fields with high or uncertain amounts of residues such as intensively cropped Brassica rotations.
- Take SMN samples as close to planting date as possible after N has mineralised from previously incorporated residues.
- Take samples to 90cm or to rooting depth (for shallow rooted crops).
- The appropriate fertiliser recommendation will be affected by the distribution of N within the profile. For field vegetables crops it is important to ensure that N is available to rooting depth, especially with young or shallow rooted crops. Even if the SNS Index is high, if limited N is

available in the topsoil, fertiliser may still be required. SMN sampling will show the availability of SMN within the rooting depth of the crop.

The current RB209 and AHDB Horticulture Factsheet 09/12 both suggest the use of the WELL_N decision support tool to help interpret the results of SMN analysis. WELL_N provides field specific N recommendations taking into account field specific information and takes into account the rooting depth of the crop and the distribution of SMN through the soil profile to give a N recommendation based on the SMN available within the rooting depth of the crop (Burns *et al.,* 1996; Rahn *et al.,* 1996). In the late 1980's and early 1990's the WELL_N tool was used by many growers and their consultants, however it is no longer available and therefore now not widely used. Therefore, we recommend that reference to WELL_N is removed from RB209. However, this functionality of WELL_N is very useful and could be incorporated into future fertiliser management decision support tools.

The FAM estimates SNS Index based on previous cropping, soil type and excess winter rainfall. In vegetable rotations, type and management of crop residues from the previous crop has a large influence on the SNS Index. RB209 (8th edition) and AHDB Horticulture Factsheet 09/12 describe the three categories of vegetable crop residues as follows:

- High N vegetables are leafy, N rich Brassica crops such as calabrese, Brussels sprouts and some crops of cauliflower, where significant amounts of crop debris are returned to the soil, especially in rotations where an earlier Brassica crop has been grown within the previous 12 months.
- Medium residual N vegetables are crops such as lettuce, leeks and long season Brassicas such as Dutch white cabbage where a moderate amount of crop debris is returned to the soil.
- Low residual N vegetables are crops such as carrots, onions, radish, swedes or turnips where the amount of crop residue is relatively small.

Recent work has highlighted the importance of N fertilisation of the previous crop in addition to crop residues in determining SNS to the following crop. FV 345a measured lower than expected SNS following two cabbage crops (described above) which was attributed to conservative amounts of N applied to the cabbage crop. FV 350a '*Quantifying the over-winter nitrogen requirements of the leek crop'* showed that supplementary N applied in the autumn to leeks may leave more crop residues and SMN after harvest which need to be considered for the following crop.

AHDB Horticulture Projects FV 370a '*Wild rocket: N response studies to manage and reduce nitrate levels'* included measurements to assess the effect of incorporating wild rocket crop residues on the SNS to subsequent wild rocket crops sown in the same season. This work showed that late-season rocket crops which have had previous crop residues incorporated and a previous application of N within the same season will have large amounts of readily available N in the soil for rapid crop uptake. FV 370a concluded that for first sown crops, SNS can be estimated using the FAM. However, for crops sown in the second or third position within a season, the FAM is not appropriate; SNS indices estimated using the FAM, are likely to need adjusting by at least 1 and up to 4 indices compared to the first crop within the season (if for instance a preceding crop has been abandoned and ploughed in) and in such cases SNS is best estimated by measuring SMN close to and prior to planting. In addition, where the first sowing is late in the season, SMN may still be higher than estimated using the FAM due to continued mineralisation of N and SMN sampling is recommended for late sown crops.

Recommendations:

Within the 8th edition of RB209, guidance on assessing SNS was given in Section 3 and guidance on SMN sampling was given in Appendix 2. In addition, guidance on assessing SNS specific to field vegetables was given in Section 5 (Field vegetables and bulbs). As part of the current RB209 revision the guidance on assessing SNS has been combined within the Field vegetable and bulbs section. The main changes are:

- SNS Indices are given based on SMN measured to 30, 60 and 90 cm. The 8th edition of RB209 only identified SNS Index based on SMN measured to 90 cm, which required SMN measured to shallower depths (for shallow rooted crops) to be 'scaled up' to 90 cm.
- The map of average annual rainfall used to identify areas of low, moderate or high rainfall as part of the Field Assessment Method has been updated to a more recent map of long term average (1981-2010) excess winter rainfall.
- Remove reference to the WELL_N decision support tool.
- Include reference to the importance of fertilisation of the previous crop to SNS:
  "Nitrogen fertilisation and management of the previous vegetable crop can also have a large impact on SNS. Where N fertiliser recovery is expected to be higher or lower than normal, the Index may need to be adjusted to account for greater or lower than normal nitrogen residues remaining in the soil."
- Include a recommendation to use the Measurement method to assess SNS for second or third crops grown within the same season, and for late sown/planted crops:
  "Where there are repeated crops in the same season (i.e. multiple salad crops), either the field assessment method or the measurement method can be used to determine the SNS Index for the first crop, but the measurement method is recommended to determine the SNS Index of subsequent crops."
  "The measurement method is also recommended where planting or sowing is late as soil mineral nitrogen may be higher than expected due to mineralisation."
- Update guidance on SMN sampling (see WP1 report) to include:
  - Recommendation to sample as close to planting as possible and to 90 cm or rooting depth for shallower rooting crops.
  - Guidance on number of samples revised to recommend a minimum of 10-15 cores per field (based on a 10 ha field), or 15-20 cores for larger fields (10-20 ha).

    - Recommendation for samples to be analysed by the laboratory within 3 days of sampling.
    - Guidance on converting laboratory analysis in mg N/kg to kg N/ha based on the dry bulk density of the soil.
- The examples of SNS calculation have been updated from arable to field vegetable examples.

Nitrification inhibitors

The 8th edition RB209 included a description of Nitrification Inhibitors under the background information on fertiliser use for vegetables. FV 350a *'Quantifying over-winter nitrogen requirements of the leek crop'* included a treatment to examine the effect of the Nitrification Inhibitor EnTec26 for 'supplementary' autumn N for leeks. The project concluded that there appeared to be little benefit in using a N fertiliser product containing a nitrification inhibitor to provide 'supplementary' autumn N, as it may not release the N quickly enough to benefit the crop. The revised Principles section of RB209 includes information on the use of nitrification inhibitors.

Recommendation:

- Remove text on nitrification inhibitors and include in the Principles section of RB209.

4.3.2. Phosphate and potash

Phosphate and potash fertiliser recommendations for field vegetables in the 8th edition of RB209 were based on work conducted by Duncan Greenwood in 1960s and 1970s with vegetable crops grown at Wellesbourne and include an Index adjustment where the soil is below/above the target soil Index. The target soil Indices for vegetable rotations were P Index 3 and K Index 2+. When RB209 was last reviewed in 2010, P and K recommendations were checked to ensure they were sufficient to replace crop offtake at target soil indices.

Phosphate

Table *7* lists the phosphate recommendations for field vegetables and bulbs (8th edition RB209 recommendations and new recommendations for baby leaf lettuce, wild rocket, coriander and mint – see Section 4.4). All crops, except vining peas, have a phosphate recommendation at the target Index of 3, and all crops except vining peas and asparagus use the following Index adjustments:

+ 50 kg P_2O_5/ha at Index 2

+ 100 kg P_2O_5/ha at Index 1

+ 150 kg P_2O_5/ha at Index 0

Although vining peas are included as part of this review, recommendations for vining peas were given within the 'Arable and forage crops' section of RB209 (8th edition) where the target P Index was 2 with Index adjustments of + 30 kg P_2O_5/ha at Index 1 and + 60 kg P_2O_5/ha at Index 0.

The only crops with phosphate recommendations at Index 4 were asparagus and celery, although footnotes to the tables in RB209 (8th edition) for lettuce, onions and leeks stated that at P Index 4 and 5 '*up to 60 kg P_2O_5/ha as a starter fertiliser may be justified'.*

Data on typical crop yields and crop phosphate content has been collated (where available) to calculate typical crop phosphate offtake (**Table *7***). In order to maintain a target P Index of 3, the amount of phosphate applied should match crop offtake at Index 3. A comparison of RB209 (8th edition) phosphate recommendations at Index 3 with typical crop phosphate offtakes (**Table *7***) shows that for most crops, crop removal is approximately balanced by phosphate recommendations at Index 3 (i.e. within +/- 50 kg P_2O_5/ha of crop removal) with the exception of:

- High yields of storage cabbage will remove more phosphate than recommended at Index 3.
- Fertiliser recommendations for leafy salads were *c.*70-90 kg P_2O_5/ha greater than the amount typically removed by a single crop. However, recommendations for leafy salads were for the entire season and where (more typically) two or three leafy salad crops are grown within a season, the crop offtake will more closely match the fertiliser recommendation.

Potash

Table *8* lists the potash recommendations for field vegetables and bulbs (8th edition RB209 recommendations and new recommendations for baby leaf lettuce, wild rocket, coriander and mint – see Section 4.4). All crops have a potash recommendation at the target Index of 2+ and all crops, except vining peas and asparagus, use the following Index adjustments:

+ 50 kg K_2O/ha at Index 2-
+ 100 kg K_2O/ha at Index 1
+ 150 kg K_2O/ha at Index 0

As noted above, recommendations for vining peas were given within the 'Arable and forage crops' section of RB209 (8th edition) where the target K Index is 2- with Index adjustments of + 30 kg K_2O/ha at Index 1 and + 60 kg K_2O/ha at Index 0.

Crops take up a lot of potash and crop potash offtake is typically 2-4 times greater than the phosphate offtake. All crops have a potash recommendation at the target Index of 2+. In addition, to ensure a managed run down of soli K Index, where the soil K Index is above target, crops with a high potash demand also have a recommendation at Index 3; where the potash recommendation at the target Index of 2+ is greater than 100 kg K_2O/ha, there is a potash recommendation for Index 3 equivalent to the Index 2+ recommendation minus 90 kg K_2O/ha. In order to be consistent with this principle the 8th edition recommendations for turnips and parsnip at Index 3 should be increased from 0 to 60 kg K_2O/ha. The only crops with a potash recommendation at Index 4 are asparagus and celery.

Data on typical crop yields and crop potash content has been collated (where available) to calculate typical crop potash offtake (**Table *8***). In order to maintain a target K Index of 2+, the amount of potash applied should match crop offtake at Index 2+. A comparison of RB209 (8th edition) potash recommendations at Index 2+ with typical crop potash offtakes highlights the following anomalies:

- The large differences in yields between the different types of cabbage (from 20 t/ha for collards – pre-December 31st to 110 t/ha for storage cabbage) results in large differences in potash offtake (from *c*.70 to 400 kg K_2O/ha). The 8th edition of RB209 included the following footnote to the recommendations *'Phosphate and potash requirements are for average crops and it is important to calculate specific phosphate and potash removals based on yields especially for the larger yielding cabbage crops*'. We recommend this footnote is amended to include '*As a general rule, for cabbage crops increase potash application by 40 kg K_2O/ha for every 10 t/ha fresh weight yield over 40 t/ha'.'*
- Potash recommendations for root vegetables were less than crop offtake at Index 2+ and may need increasing.

However, field vegetables are often grown on light textured soils which have a limited capacity to hold potash. The Principles section of RB209 (8th edition) included the following guidance re potash use on sandy and sandy loam soils:

Sandy and sandy loam soils together with other soils containing very little clay, have a limited capacity to hold potash. On such soils it is almost impossible to achieve the appropriate soil K Index. For sandy loams it is generally possible to maintain soil at 150 mg K/litre (Index 2-) but for sands and loamy sands, the realistic upper limit is 100 mg K/litre (upper Index 1). Adding potash fertilisers to try to exceed these values will result in movement of potash into the subsoil where it may only be available to deep-rooted crops. On sands, it is preferable to apply and cultivate into the topsoil an amount of potash fertiliser each year to meet the potash requirements of the crop to be grown.

If the target K Index of 2+ is not attainable on sandy and sandy loam soils, it would be more appropriate to select a lower target Index and aim to replace crop offtake at this target Index.

Accurate information on crop phosphate and potash removal for a wider range of field vegetable crops would enable growers to calculate crop offtake to inform fertiliser use. The 8th edition of RB209 Appendix 5 only included crop phosphate and potash removal figures for a limited number of field vegetable crops and it was not clear how robust the evidence base for these crop offtake figures were.

Recommendations:

- There has been no recent research on the potash response of field vegetable crops. Research is needed to quantify the optimum potash application rates for a range of field vegetables (i.e. brassica, legume and root crops) and to confirm whether the current target K Index of 2+ is appropriate/attainable on light textured soils.

- Collate more recent phosphate and potash crop removal figures for all field vegetable crops to provide accurate information on crop offtake on which growers can base their fertiliser decisions and to inform future revisions of RB209.
- Increase the potash recommendation for turnips and parsnip at Index 3 from 0 to 60 kg K_2O/ha (to be consistent with other crops).
- Amend the footnote on phosphate and potash for Brussels sprouts and cabbage to include: ***"As a general rule, for cabbage crops increase potash application by 40 kg K_2O/ha for every 10 t/ha fresh weight yield over 40 t/ha."***

Table 7. Field vegetables and bulbs phosphate recommendations (RB209 8th edition) and crop phosphate offtake.

Crop	P recommendation (kg P_2O_5/ha)						Yield (t/ha FW)	P_2O_5 (kg/t FW)	P_2O_5 offtake (kg/ha)	Index 3 Rec –offtake
	Index 0	Index 1	Index 2	Index 3	Index 4	Index 5				
Asparagus, establishment	175	150	125	**100**	75	0	*	1.3[e]	*	*
Asparagus, later years	75	75	50	**50**	25	0	*	1.3[e]	*	*
Brussels sprouts	200	150	100	**50**	0	0	20[a]	2.6[d]	52	-2
Cabbage, storage	200	150	100	**50**	0	0	110[a]	0.9[d]	99	-49
Cabbage, head pre-Dec 31st							60[a]	0.9[d]	54	-4
Cabbage, head post-Dec 31st							53[a]	0.9[d]	48	+2
Cabbage, collards pre-Dec 31st							20[a]	0.9[d]	18	+32
Cabbage, collards post-Dec 31st							30[a]	0.9[d]	27	+23
Cauliflower, summer/autumn	200	150	100	**50**	0	0	31[a]	1.4[d]	43	+7
Cauliflower, winter hardy/roscoff							*	1.4[d]	*	*
Calabrese	200	150	100	**50**	0	0	16[a]	1.4[d]	23	+28
Celery	250	200	150	**100**	50	0	*	0.6[e]	*	*
Peas, vining	95	65	35	**0**	0	0	4.5[c]	1.7[d]	8	-8
Peas, market pick	185	135	85	**35**	0	0	*	0.7[e]	*	*
Beans, broad	200	150	100	**50**	0	0	*	1.6[d]	*	*
Beans, dwarf	200	150	100	**50**	0	0	*	1.0[d]	*	*
Beans, runner	200	150	100	**50**	0	0	*	*	*	*
Radish	175	125	75	**25**	0	0	50[a]	0.6[e]	30	-5
Sweetcorn	175	125	75	**25**	0	0	11[b]	1.3[f]	14	+11
Courgettes	175	125	75	**25**	0	0	*	*	*	*
Lettuce – whole head	250	200	150	**100**	0	0	45[a]	0.6[e]	27	+73
Lettuce – baby leaf							23[b]	*	*	*
Wild rocket							20[b]	0.6[f]	12	+88
Onions, bulb	200	150	100	**50**	0	0	60[a]	0.7[d]	42	+8
Onions, salad							30[a]	0.7[d]	21	+29
Leeks	200	150	100	**50**	0	0	47[a]	0.8[e]	38	+12
Beetroot	200	150	100	**50**	0	0	60[a]	1.0[d]	60	-10
Swedes	200	150	100	**50**	0	0	85[a]	0.7[d]	60	-9
Turnips	200	150	100	**50**	0	0	48[a]	1.3[e]	62	-12
Parsnips	200	150	100	**50**	0	0	48[a]	1.6[e]	77	-27
Carrots	200	150	100	**50**	0	0	150[a]	0.7[d]	105	-55
Bulbs and bulb flowers	200	150	100	**50**	0	0	*	2.4[d]	*	*
Coriander	175	125	75	**25**	0	0	31[b]	0.8[f]	25	0
Mint	175	125	75	**25**	0	0	25[b]	1.0[f]	25	0

- Source of yield data: [a] RB209 8th edition Appendix 10; [b] Trial data; [c] Provided by industry; * No data
- Source of P_2O_5 offtake data: [d] RB209 8th edition Appendix 5; [e] USDA crop offtake database (www.plants.usda.gov/npk/main); [f] Trail data; * No data

Table 8. Field vegetables and bulbs potash recommendations (RB209 8th edition) and crop potash offtake.

<table>
<tr><th rowspan="2">Crop</th><th colspan="6">K recommendation (kg K_2O/ha)</th><th rowspan="2">Yield (t/ha FW)</th><th rowspan="2">K_2O (kg/t FW)</th><th rowspan="2">K_2O offtake (kg/ha)</th><th rowspan="2">Index 2+ Rec –offtake</th></tr>
<tr><th>Index 0</th><th>Index 1</th><th>Index 2-</th><th>Index 2+</th><th>Index 3</th><th>Index 4</th></tr>
<tr><td>Asparagus, establishment</td><td>250</td><td>225</td><td>200</td><td>**200**</td><td>150</td><td>125</td><td>*</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Asparagus, later years</td><td>100</td><td>50</td><td>50</td><td>**50**</td><td>50</td><td>0</td><td>*</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Brussels sprouts</td><td>300</td><td>250</td><td>200</td><td>**150**</td><td>60</td><td>0</td><td>20[a]</td><td>6.3[d]</td><td>126</td><td>+24</td></tr>
<tr><td>Cabbage, storage</td><td rowspan="5">300</td><td rowspan="5">250</td><td rowspan="5">200</td><td rowspan="5">**150**</td><td rowspan="5">60</td><td rowspan="5">0</td><td>110[a]</td><td>3.6[d]</td><td>396</td><td>-246</td></tr>
<tr><td>Cabbage, head pre-Dec 31st</td><td>60[a]</td><td>3.6[d]</td><td>216</td><td>-66</td></tr>
<tr><td>Cabbage, head post-Dec 31st</td><td>53[a]</td><td>3.6[d]</td><td>191</td><td>-41</td></tr>
<tr><td>Cabbage, collards pre-Dec 31st</td><td>20[a]</td><td>3.6[d]</td><td>72</td><td>+78</td></tr>
<tr><td>Cabbage, collards post-Dec 31st</td><td>30[a]</td><td>3.6[d]</td><td>108</td><td>+42</td></tr>
<tr><td>Cauliflower, summer/autumn</td><td rowspan="2">275</td><td rowspan="2">225</td><td rowspan="2">175</td><td rowspan="2">**125**</td><td rowspan="2">35</td><td rowspan="2">0</td><td>31[a]</td><td>4.8[d]</td><td>149</td><td>-24</td></tr>
<tr><td>Cauliflower, winter hardy/roscoff</td><td>*</td><td>4.8[d]</td><td>*</td><td>*</td></tr>
<tr><td>Calabrese</td><td>275</td><td>225</td><td>175</td><td>**125**</td><td>35</td><td>0</td><td>16[a]</td><td>4.8[d]</td><td>77</td><td>+48</td></tr>
<tr><td>Celery</td><td>450</td><td>400</td><td>30</td><td>**300**</td><td>210</td><td>50</td><td>*</td><td>1.9[e]</td><td>*</td><td>*</td></tr>
<tr><td>Peas, vining</td><td>100</td><td>70</td><td>40</td><td>**20**</td><td>0</td><td>0</td><td>4.5[c]</td><td>3.2[d]</td><td>14</td><td>+6</td></tr>
<tr><td>Peas, market pick</td><td>190</td><td>140</td><td>90</td><td>**40**</td><td>0</td><td>0</td><td>*</td><td>2.2[e]</td><td>*</td><td>*</td></tr>
<tr><td>Beans, broad</td><td>200</td><td>150</td><td>100</td><td>**50**</td><td>0</td><td>0</td><td>*</td><td>3.6[d]</td><td>*</td><td>*</td></tr>
<tr><td>Beans, dwarf</td><td>200</td><td>150</td><td>100</td><td>**50**</td><td>0</td><td>0</td><td>*</td><td>2.4[d]</td><td>*</td><td>*</td></tr>
<tr><td>Beans, runner</td><td>200</td><td>150</td><td>100</td><td>**50**</td><td>0</td><td>0</td><td>*</td><td></td><td>*</td><td>*</td></tr>
<tr><td>Radish</td><td>250</td><td>200</td><td>150</td><td>**100**</td><td>0</td><td>0</td><td>50[a]</td><td>2.3[e]</td><td>115</td><td>-15</td></tr>
<tr><td>Sweetcorn</td><td>250</td><td>200</td><td>150</td><td>**100**</td><td>0</td><td>0</td><td>11[b]</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Courgettes</td><td>250</td><td>200</td><td>150</td><td>**100**</td><td>0</td><td>0</td><td>*</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Lettuce – whole head</td><td rowspan="3">250</td><td rowspan="3">200</td><td rowspan="3">150</td><td rowspan="3">**100**</td><td rowspan="3">0</td><td rowspan="3">0</td><td>45[a]</td><td>2.8[e]</td><td>126</td><td>-26</td></tr>
<tr><td>Lettuce – baby leaf</td><td>23[b]</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Wild rocket</td><td>20[b]</td><td>*</td><td>*</td><td>*</td></tr>
<tr><td>Onions, bulb</td><td rowspan="2">275</td><td rowspan="2">225</td><td rowspan="2">175</td><td rowspan="2">**125**</td><td rowspan="2">35</td><td rowspan="2">0</td><td>60[a]</td><td>1.8[d]</td><td>108</td><td>+17</td></tr>
<tr><td>Onions, salad</td><td>30[a]</td><td>1.8[d]</td><td>54</td><td>+71</td></tr>
<tr><td>Leeks</td><td>275</td><td>225</td><td>175</td><td>**125**</td><td>35</td><td>0</td><td>47[a]</td><td>2.2[e]</td><td>103</td><td>+22</td></tr>
<tr><td>Beetroot</td><td>300</td><td>20</td><td>200</td><td>**150**</td><td>60</td><td>0</td><td>60[a]</td><td>4.5[d]</td><td>270</td><td>-120</td></tr>
<tr><td>Swedes</td><td>300</td><td>250</td><td>200</td><td>**150**</td><td>60</td><td>0</td><td>85[a]</td><td>2.4[d]</td><td>204</td><td>-54</td></tr>
<tr><td>Turnips</td><td>300</td><td>250</td><td>200</td><td>**150**</td><td>0</td><td>0</td><td>48[a]</td><td>4.9[e]</td><td>235</td><td>-85</td></tr>
<tr><td>Parsnips</td><td>300</td><td>250</td><td>200</td><td>**150**</td><td>0</td><td>0</td><td>48[a]</td><td>4.0[e]</td><td>192</td><td>-42</td></tr>
<tr><td>Carrots</td><td>275</td><td>225</td><td>175</td><td>**125**</td><td>35</td><td>0</td><td>150[a]</td><td>3.0[d]</td><td>450</td><td>-325</td></tr>
<tr><td>Bulbs and bulb flowers</td><td>300</td><td>250</td><td>200</td><td>**150**</td><td>60</td><td>0</td><td>*</td><td>6.3[d]</td><td>*</td><td>*</td></tr>
<tr><td>Coriander</td><td>315</td><td>265</td><td>215</td><td>**165**</td><td>75</td><td>0</td><td>31[b]</td><td>5.5[f]</td><td>170</td><td>-6</td></tr>
<tr><td>Mint</td><td>280</td><td>230</td><td>180</td><td>**130**</td><td>40</td><td>0</td><td>25[b]</td><td>3.9[f]</td><td>98</td><td>+33</td></tr>
</table>

- Source of yield data: [a] RB209 8th edition Appendix 10; [b] Trial data; [c] Provided by industry; * No data
- Source of K_2O offtake data: [d] RB209 8th edition Appendix 5; [e] USDA crop offtake database (www.plants.usda.gov/npk/main); [f] Trail data; * No data

4.3.3. Magnesium

The 8th edition RB209 recommendations for magnesium are for 150 kg MgO/ha at Index 0 and 100 kg MgO/ha at Index 1 for all field vegetable crops apart from peas and beans, which have recommendations of 100 kg MgO/ha at Index 0 and 50 kg MgO/ha at Index 1. The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of field vegetables to magnesium.

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4.3.4. Sulphur

Sulphur is an essential plant nutrient and as such has an important influence on the yield and quality of crops. The risk of S deficiency and likely yield responsiveness to S will depend on the crop requirement for S (i.e. crop S uptake) and the S supply from the environment from both the mineralisation of soil organic S and the input of S from atmospheric deposition. Sulphur deficiency in crops has become more widespread since the 1990's due to the substantial decrease in atmospheric S deposition.

A recent Defra funded review of crop sulphur requirements (Webb *et al.,* 2015) estimated that sulphur dioxide (SO_2) emissions in the UK declined by 94% between 1970 and 2010 and are expected to decrease by a further 50% from 2011 to 2020 as more coal fired power stations are decommissioned. The review found that there is currently little variation among UK regions in net S deposition, which is greatest in Yorkshire and Humberside (*c.*12-15 kg SO_3/ha) and least in Wales (*c*.7-10 kg SO_3/ha).

Although there has been more recent research on the S response of cereals and oilseed rape on which to base S recommendations (25-50 kg SO_3/ha for cereals and 50-75 kg SO_3/ha for oilseed rape), there has been very limited work on the S response of field vegetable crops. The 8th edition of RB209 included a recommendation of 50 kg SO_3/ha for the vegetable brassica crops (Brussels sprouts, cabbage, cauliflower and calabrese) and 25 kg SO_3/ha for peas where S deficiency is possible. There were no S recommendations for any of the other vegetable crops (asparagus, celery, lettuce, radish, sweetcorn, courgettes, onions, leeks, root vegetables, broad/dwarf/runner beans or bulb/bulb flowers). Sulphur can also impact on crop quality and has been shown to increase the glucosinolate content of brassicas, increase the pungency of onions and the alliin content of both onions and garlic.

AHDB Horticulture project FV 216 (Paterson, 1999) measured the yield response of Brussels sprouts to S fertiliser in a single trial at HRI-Kirton in 1998. Although, a yield response to the applied S treatments was not measured, it should be noted that the entire trial site received an application of 45 kg SO_3/ha as part of routine P and K fertiliser applications, and this is very likely to have obscured any yield response to the applied S treatments.

Cleveland Potash Ltd have provided more recent unpublished data from a S response experiment on processing cabbage carried out in 2010 in Lincolnshire on a light textured soil. Cleveland Potash's Polysulphate fertiliser was used as the source of S, with the K, Mg and Ca inputs balanced by applications of calcined magnesite and muriate of potash to ensure S was the only variable. The Polysulphate was applied at five application rates equivalent to 0, 30, 60, 90 and 120 kg SO_3/ha, with each treatment replicated 5 times. Yields were measured as fresh weight of 25 head of cabbage. The application of S increased (P<0.05) yields by *c*.40% from 10.3 kg from the zero S control treatment to a mean of 14.3 kg where S fertiliser had been applied (**Table *9***). The application of S also increased (P<0.05) dry matter content from 7.5% on the zero S content to a mean of 10.2% where S fertiliser had been applied (**Table *9***); increased dry matter is associated with better storage quality in cabbage.

Table 9. Sulphur response of processing cabbage (data from Cleveland Potash).

Treatment	Fresh weight yield (kg per 25 head of cabbage)	Dry matter (%)	N:S ratio
0 kg SO_3/ha	10.3 (a)	7.5 (a)	12.0 (a)
30 kg SO_3/ha	14.9 (b)	10.6 (b)	9.6 (b)
60 kg SO_3/ha	13.8 (b)	10.5 (b)	8.1 (c)
90 kg SO_3/ha	15.6 (b)	10.2 (b)	7.5 (c)
120 kg SO_3/ha	13.0 (b)	9.6 (b)	7.4 (c)

*Letters in brackets indicate statistically significant differences between treatments at 5% probability level.

Skwierawska *et al.* (2008) carried out field experiments in Poland in 2000 (on head cabbage) and 2001 (on onions) where S was applied at 0, 40, 80 and 120 kg S/ha (equivalent to 0, 100, 200 and 300 kg SO_3/ha) as a sulphate containing fertiliser and as elemental S. Skwierawska *et al.* (2008) found a significant increase in both cabbage and onion yields from the application of both forms of S fertiliser; cabbage yields increased from 52 t/ha (on the zero S control) to *c*.60 t/ha, and onion yields increased from 23 t/ha (on the zero S control) to *c*.30 t/ha. Maximum yields of both cabbage and onion were achieved at the 40 kg S/ha application rate – there was no further increase in yields with increasing application rate and application of the sulphate containing fertiliser at the highest application (120 kg S/ha) resulted in a notable decrease in both cabbage and onion yields.

The S uptake of vegetable brassica crops is known to be high and comparable to the S uptake of oilseed rape. Zhao *et al*. (2002) gave S uptake figures of *c*.55 kg S/ha (*c*.138 kg SO_3/ha) for cabbage, *c*.60 kg S/ha (*c*.150 kg SO_3/ha) for broccoli and *c*.74 kg S/ha (*c*.185 kg SO_3/ha) for Brussels sprouts, compared to *c*.60 kg S/ha (*c*.150 kg SO_3/ha) for oilseed rape (**Figure *1***). Paterson (1999) gave mean S uptake values of 66 kg S/ha (165 kg SO_3/ha) for Brussels sprouts and 95 kg S/ha (238 kg SO_3/ha) for cauliflowers. Current AHDB Cereals & Oilseeds project 216-0007 (Sagoo *et al*., 2015) aims to quantify the S requirement of oilseed rape and results to date support the current RB209 recommendations of 50-75 kg SO_3/ha for oilseed rape (see WP4 report).

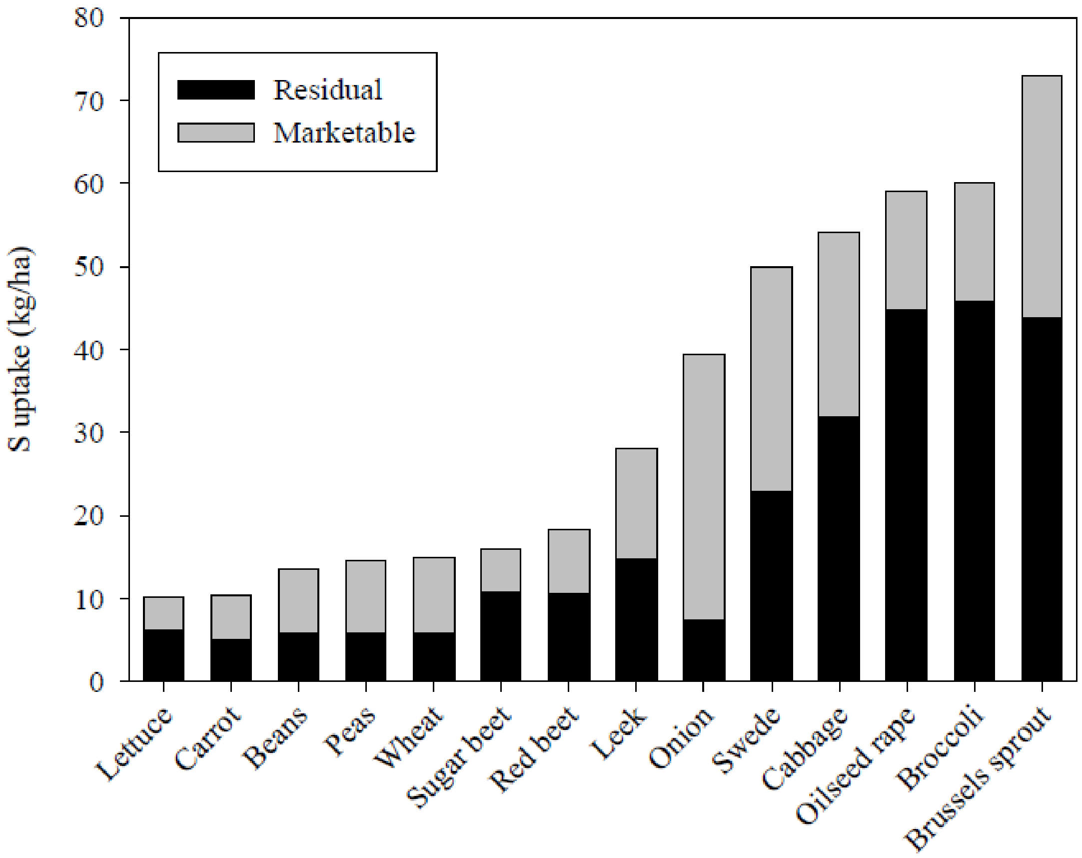

Figure 1. Sulphur uptake and distribution by different crops (Zhao et al., 2002).

Zhao *et al*. (2002) gave S uptake figures for lettuce, carrots, beans and peas of 10-15 kg S/ha (25-45 kg SO_3/ha), similar to that of wheat (15 kg S/ha; 45 kg SO_3/ha). Sulphur uptake is greater for leeks (30 kg S/ha; 75 kg SO_3/ha), onions (40 kg S/ha; 100 kg SO_3/ha) and swedes (50 kg S/ha; 125 kg SO_3/ha) (**Figure *1***).

Recommendations:

- We recommend increasing the S recommendation for vegetable brassica crops (Brussels sprouts, cabbage, cauliflower and calabrese) to 50-75 kg SO_3/ha (the same as for oilseed rape). Amend the guidance on sulphur for Brussels sprouts, cabbage, cauliflower and calabrese crops to:

  "Where sulphur deficiency has been recognised or is expected, apply 50-75 kg SO_3/ha as a sulphate containing fertiliser at or soon after planting."
- There is a lack of evidence on which to base S recommendations for the other field vegetable crops. However, against a back drop of declining atmospheric S emissions and in view crop S uptake values similar/greater than that of wheat, we recommend guidance to apply S fertiliser to all other field vegetable crops where deficiencies are thought likely. Amend the guidance on sulphur for all other field vegetable crops to:

"Where sulphur deficiency has been recognised or is expected, apply 25 kg SO_3/ha as a sulphate containing fertiliser at or soon after planting."

- Amend the guidance on sulphur at the start of the Field vegetables section to:
  "Many field vegetable crops, particularly brassicas have a significant requirement for sulphur. There is evidence that brassica crops do respond to sulphur. Where sulphur deficiency has been recognised or is expected in vegetable brassicas, apply 50-75 kg SO_3/ha. There are no UK trials on the sulphur response of the other vegetable crops. However, atmospheric sulphur emissions have declined significantly and a yield response to sulphur in other crops is possible. Where sulphur deficiency has been recognised or is expected in other vegetable crops, apply 25 kg SO_3/ha. Sulphur should be applied as a sulphate containing fertiliser at or soon after planting. Crops are most at risk of sulphur deficiency where they are grown on light sandy soils, soils with a low organic matter content, and in high rainfall areas. Further guidance on sulphur can be found in the Principles section."

It should be noted that some commercial fertiliser/agronomy companies currently recommend S fertiliser rates for field vegetable crops that are higher than the revised S recommendations given above. Yara provide S recommendations for field vegetables which are generally greater and notably so for French/runner beans (175 kg SO_3/ha), carrots (245 kg SO_3/ha), celery (210 kg SO_3/ha), leeks (220 kg SO_3/ha), and lettuce (172 kg SO_3/ha) (Yara, 2015). The Allium and Brassica Centre also recommend up to 150 kg SO_3/ha for brassica vegetables and up to 120 kg SO_3/ha for onions based on grower experience where a response is likely (Andy Richardson, Allium and Brassica Agronomy, Pers. Comm., May 2016).

There is insufficient available data on which to recommend higher S application rates for vegetable crops in the revised RB209, however, the fact that field vegetable S recommendations given by agronomy companies varies from RB209 recommendations is confusing to farmers, and S response experiments on field vegetables to confirm optimum S application rates should be a priority area for future research.

4.3.5. Micro-nutrients

Guidance on diagnosing and treating micro-nutrient deficiencies is not currently given in the Field vegetables section of RB209. However, guidance is available to growers in the following AHDB Factsheets and Crop Walker Guides:

- AHDB Horticulture Factsheet 08/04. Carrots and Parsnips: Interpretation of leaf nutrient analysis results.
- AHDB Horticulture Factsheet 21/05. Brassicas: Interpretation of leaf nutrient analysis results.
- AHDB Horticulture Factsheet 22/05. Alliums: Interpretation of leaf nutrient analysis results.
- AHDB Crop Walkers Guides – Brassicas (2007), Outdoor Salads – Lettuce and Celery (2010), Alliums (2011), and Carrot and parsnip (2015).

In addition, AHDB Cereals & Oilseeds Information Sheet 25 '*Micronutrients for cereals and oilseed rape'* provides advice on diagnosing and treating micro-nutrient deficiencies and some aspects of this advice is common to all crops. Table 10 summarises advice on diagnosing micro-nutrient deficiencies from AHDB Horticulture Factsheets 08/04, 21/05 and 22/05 and AHDB Cereals & Oilseeds Information Sheet 25.

Table 10. Diagnosing micro-nutrient deficiencies.

Micronutrient	Soil risk factors	Soil analysis	Tissue analysis	Treating deficiencies
Boron (B)	Sandy soils High organic matter pH above 7 Deficiency can be triggered by over-liming	Hot water extract: deficiency is more likely below 0.8 mg B/l	Deficiency is more likely below 20 mg B/kg	If possible treat deficiencies with a soil applied fertiliser prior to planting. Deficiencies can also be treated using a foliar spray at an early growth stage.
Copper (Cu)	Organic and peat soils in the Fens and also leached sandy soils, particularly reclaimed heathland Shallow soils over chalk with high organic matter, sandy and peat soils	EDTA extract: deficiency is more likely below 1.0 mg Cu/l, unless soil organic matter is above 6%, when deficiency is more likely below 2.5 mg Cu/l	Deficiency is more likely below 5 mg Cu/kg. Tissue analysis is less reliable than soil analysis for diagnosing deficiencies.	If possible treat deficiencies with a soil applied fertiliser prior to planting. Deficiencies can also be treated using a foliar spray of copper oxychloride or cuprous oxide.
Manganese (Mn)	Symptoms are often transient. Deficiency can be triggered by over-liming Any soils with pH above 7.5. Sandy soils with pH above 6.5. Organic, peaty or marshland soils with pH above 6 Under-consolidated seedbeds, low soil temperatures and low rainfall.	Not reliable	Deficiency is more likely below 20 mg Mn/kg	Deficiencies can be treated using a foliar spray of manganese sulphate.
Molybdenum (Mo)	Soils with pH below 6.5	Ammonium oxalate extract: deficiency is more likely below 0.1 mg Mo/l	Insufficient information to be able to recommend this type of analysis	Use a liming material to raise the soil pH of acidic soils to 6.5. When soil pH is more than 7 and when treatment is necessary apply a soil or foliar treatment of sodium molybdate.
Zinc (Zn)	Sandy soils with high pH and high phosphate status. Deficiency is very rare in the UK.	EDTA extract: deficiency is more likely below 1.5 mg Zn/l	Deficiency is more likely below 15-20 mg Zn/kg	Deficiencies can be treated using soil- or foliar-applied fertilisers.

Recommendations:

- We recommend including a sub-section on micro-nutrients at the start of the Field vegetables section. This section should include the summary advice given in **Table *10*** and reference the AHDB Horticulture Factsheets 08/04, 21/05 and 22/05 and AHDB Horticulture Crop Walker Guides.

4.3.6. Techniques for applying fertilisers

The Field vegetables section in the 8th edition of RB209 included guidance on precision techniques for applying fertiliser, including starter fertilisers, bandspreading/placement of nitrogen and fertigation.

Starter fertilisers are normally small amounts of liquid fertiliser introduced into soil 25-30 mm below (or to the side) of seeds or transplants, and specifically designed to meet early nutrient demand and maintain growth until the normal fertiliser supply becomes available. The guidance in RB209 (8th edition) on starter fertilisers was based on the field studies by Rowse *et al*. (1995).

Burns *et al*. (2010) carried out a review of precision placement of fertiliser in vegetable crops. The research reviewed by Burns *et al.* (2010) showed that the initial growth benefits from injecting liquid starter fertilisers are often, although not always, maintained until commercial maturity, and can result in increased total yields and enhanced quality provided that supplementary fertiliser dressings are also applied. Burns *et al*. (2010) concluded that the use of injected starter fertiliser solutions in combination with a supplementary dressing of a conventional fertiliser increases the overall efficiency of nutrient use, and typically reduced fertiliser requirement of vegetable crops by up to half.

Burns *et al.* (2010) also reviewed precision band placement of granular fertilisers in vegetable crops. The 8th edition of RB209 provided guidance on 'band spreading/placement of nitrogen' although more recent work has shown beneficial effects of both N and P placement. Based on the work reviewed by Burns *et al.* (2010), the authors concluded that placement of N and P at half the recommended rate for a range of vegetable crops had no significant effect on final yields. In a more recent experiment, Sady *et al*. (2007) carried out a three year trial with white 'Galaxy' F1 cabbage in Poland comparing method of N application; 120 kg N/ha (i.e. 100% rate) was broadcast at planting of seedlings compared to 75% application rate placed at planting. In all years, placement of N fertiliser at the reduced (75%) rate increased cabbage yield compared to the control (100% N broadcast at planting).

Recent work in the UK as part of the LINK 'Targeted P' project (LK09136, AHDB Cereals & Oilseeds Research Review 83 '*Improving the sustainability of phosphorus use in arable farming*') aimed to determine if using fertiliser placement can maintain soil at a lower P Index whilst consistently achieving optimum yield. Although this work was on cereals, oilseed rape and potatoes the key findings (particularly in relation to potatoes) are also relevant to field vegetables. The project did provide evidence that placing P can increase potatoes yields compared to conventional broadcast application.

The LINK 'Targeted P' project concluded that improved targeting of phosphate through fertiliser placement is likely to be most important during the early stages of crop development when the root system is still small, yet plant growth and P demand is relatively large. Placing phosphate fertiliser close to the root system could benefit the establishment of most crops, but may be particularly useful for crops with rapid initial growth or root systems which may be slower to exploit the inter-row space, such as potatoes. The greater phosphate efficiency associated with placement is also considered to be due to reducing the soil volume in contact with the fertiliser, thereby reducing soil immobilisation effects.

Recommendations:

- We recommend amending the 8th edition guidance on techniques for applying fertiliser to include:
  "The use of injected liquid starter fertiliser in combination with a supplementary dressing of a conventional fertiliser can increase the overall efficiency of nutrient use, and typically reduces the total fertiliser requirement of field vegetables by up to half."
- We recommend amending the RB209 (8th edition) section on band spreading/placement to include N and P and including the following text:
  "Placement of phosphate fertiliser has been shown to increase yields compared to surface broadcast application on low P Index soils. Where fertiliser is placed, a small reduction in the recommended rate of phosphate could be considered."

4.4. Recent research relevant to specific crops

4.4.1. Asparagus

The 8th edition RB209 fertiliser recommendations for established asparagus crops were mainly based on the results of FV 152 (Dyer, 1996a; study of N responses) and FV 153 (Dyer 1996b; study of P and K responses).

More recently, AHDB Horticulture Factsheet 14/13 '*Asparagus nutrient management'* reviewed both UK and international asparagus nutrition research and guidance. The Factsheet highlights that whilst nutrient removal in harvested spears is relatively low, the quantity of nutrients stored in the roots and crowns can be much greater. A 5 t/ha harvest of spears will remove around 25-30 kg N/ha, 5-10 kg P/ha (11-23 kg P_2O_5/ha) and 20-30 kg K/ha (24-36 kg K_2O/ha), whilst the root system may store 300-500 kg N/ha, 30-50 kg P/ha (70-115 kg P_2O_5/ha) and 225-375 kg K/ha (270-450 kg K_2O/ha). The Factsheet also includes data from work in the US which shows that P nutrition is critical in years 1 and 2 to establish productive crowns.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of asparagus to fertiliser applications.

There has been no UK work on the nutrition of asparagus at establishment. AHDB Horticulture project FV 427 aimed to address this knowledge gap and identify optimum N and P treatments at establishment for maximum yield from new asparagus plantations, however this project was discontinued following poor establishment at the experimental site.

Recommendations:

- Include reference to AHDB Horticulture Factsheet and Crop Walker Guide:
  "Further information and photos of deficiency symptoms are available in the AHDB Horticulture Factsheet 'Asparagus nutrient management' and the AHDB Horticulture Asparagus Crop Walker Guide. Please visit horticulture.ahdb.org.uk to download or order your copy."

4.4.2. Brussels sprouts and Cabbage

Brussels sprouts

The 8th edition RB209 N recommendations for Brussels sprouts were validated against two N response experiments as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3. The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of Brussels sprouts to fertiliser applications.

Cabbage

The 8th edition RB209 N recommendations for cabbage were revised compared to the previous 7th edition and the recommendations were validated against three N response experiments (two on salad and one on bulb onions) as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3.

The literature review identified three papers which from the titles and abstracts suggested they contained information relevant to RB209; two studies focussing on N (detailed below) and one study from Poland (Skwierawska *et al*., 2008), looking at S response (see Section 4.3.4).

Kolota and Chohura (2015) conducted field experiments in Poland over three years looking at the effect of plant population and N fertiliser rate on head size of Dutch white cabbage (Kalorama F1 cultivar). Nitrogen was applied at two rates (150 and 300 kg N/ha) split into three applications. Increasing the N rate from 150 to 300 kg N/ha significantly increased total marketable yield, although there were insufficient N rates to determine the optimum N rate. Increasing the N rate also increased the accumulation of nitrates in the cabbage heads, and decreased the Ca concentration.

Ekbladh and Witter (2010) (Sweden) described the determination of critical N concentration of white cabbage. The principle of critical N concentration was used in the 8th edition of RB209 to allow growers to calculate field specific N recommendations based on expected crop yields (see Appendix 3). From two field experiments with repeated harvests of Dutch white cabbage and with N supply ranging from limitation to excess, Ekbladh and Witter (2010) described the relationship between plant nitrogen concentration PNC_c and weight per unit ground area of plant dry matter excluding roots (W) as $PNC_c = 5.1W^{-0.33}$

4.4.3. Cauliflowers and Calabrese

Cauliflowers

The 8th edition RB209 N recommendations for cauliflowers were slightly revised compared to the previous 7th edition. The N recommendations were validated against four N response experiments as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3. The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of cauliflowers to fertiliser applications.

Calabrese

The 8th edition RB209 N recommendations for calabrese were revised compared to the previous 7th edition. At the request of the Brassica Growers Association the calabrese N recommendations were separated from the cauliflower recommendations and slightly reduced as high rates of N can lead to spear rot.

The literature review identified two papers and one PhD thesis which from the titles and abstracts suggested they contained information relevant to RB209; all report results of experiments looking at the effect of N fertiliser applications to broccoli (one study from Turkey, one from Canada and the PhD thesis from Norway).

Bakker *et al.* (2008) investigated the effect of N fertiliser application rate (0, 50, 100, 150, 200, 300, 400 kg N/ha) on yield and quality of broccoli in two experiments (in 2001 and 2002) in Canada. Nitrogen was applied as ammonium nitrate prior to transplanting. In both years, the economic optimum yield was achieved at around 300 kg N/ha. Similarly, Yoldas *et al.* (2008) investigated the effect of N fertiliser application rate (0, 150, 300, 450 and 300 kg N/ha) on yield of broccoli in a single experiment in Turkey. Nitrogen was applied as ammonium nitrate in three split equal applications at sowing, 20 days after sowing and after cutting main heads. Yields increased from 27 t/ha from the zero N control to 33 and 35 t/ha at the 150 and 300 kg N/ha application rates respectively, and then declined at the higher N application rates. Yoldas *et al.* (2008) concluded that the optimum N rate was 300 kg N/ha.

The PhD thesis by Vagen (2005) investigated the effects of three N fertiliser rates (0, 120, and 240 kg N/ha) and two planting times (May or late June/July) on yield and N use of the early cultivar 'Milady' and the late cultivar 'Marathon' of broccoli on three silty loam soils varying in SMN in southern Norway in 1999 and 2001. Vagen (2005) found that a supply of 200-250 kg N/ha from a combination of SMN and applied N fertiliser was necessary to achieve optimal yields. This is consistent with the RB209 (8^{th} edition) recommendations of 235 kg N/ha at SNS Index 0.

4.4.4. Celery

When RB209 was last revised in 2010 there was insufficient data to include celery in the framework for calculating N recommendations (section 4.3.1), and no changes were made to the recommendations. The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of celery to fertiliser applications.

4.4.5. Peas and beans

Vining peas

AHDB Horticulture project FV 380 '*Identification of critical soil P in vining pea crops'* aimed to identify the levels of phosphate required in vining pea production to help growers maximise yield and quality. Field experiments were established on six sites with contrasting soil types and low initial soil P indices starting in autumn of 2010 and continuing over a staggered four year trialling sequence for two cropping seasons (i.e. season one; cereal, season two; vining peas) in the same place. The aim was to create large blocks with a wide range of Olsen P levels on the same site by applying various doses of triple superphosphate (TSP) at the start of each cereal crop year (autumn 2010, 2011 and 2012) to create treatments with 'stabilised' Olsen P values ahead of the vining pea crop (giving 18 months for P to stabilise). The target range of Olsen P levels once the Olsen P levels had equilibrated was from Index 0 or low Index 1 to Index 3. Results over 3 cropping years from the 6 sites suggest that Olsen P should be maintained at P Index 3 for vining pea crops. Critical P values to achieve 98% of maximum yield were around 27-41 mg/l (or a P Index 3). The mean yield response of vining peas grown on soils at a P Index 3 compared to an Index 2 was 0.8 t/ha.

Also at each site, there were additional treatments where ‘fresh’ TSP fertiliser was applied immediately prior to the vining pea crop (in spring 2012, 2013 and 2014) to create treatments with ‘fresh’ Olsen P values. A ‘low’ or ‘high’ dose of fresh phosphate was applied based on the amount of phosphate required to raise the soil P Index by 2 mg/l (‘low’ dose) or 8 mg/l (‘high’ dose). The quantity of phosphate applied varied between sites depending on the soil, but was a mean of *c*.200 kg P_2O_5/ha for the ‘low’ dose and *c*.620 kg P_2O_5/ha for the ‘high’ dose. Applying either a ‘small’ or ‘large’ fresh P fertiliser dose ahead of vining peas resulted in a mean yield response of 0.2 t/ha or 0.5 t/ha respectively over and above Index 2.

Most vining pea crops are grown in rotation with combinable arable crops for which the target P Index is 2. Where vining peas are grown in a mainly horticultural rotation it would seem sensible to maintain the P Index at 3; where vining peas are grown in a mainly arable rotation it may be preferable to maintain Index 2 and apply fresh P to the vining peas.

For most arable crops, the assumption is that optimum yield is achieved at P Index 2 and the principle for phosphate management is to maintain the soil at this target Index by replacing crop P offtake. The results from FV 380 have demonstrated that vining peas can be responsive to phosphate at Index 2. The quantities of fertiliser phosphate applied in FV 380 were calculated based on the amount required to raise the soil Index by a specified value and were well in excess of normal fertiliser phosphate applications to vining peas. RB209 (8^{th} edition) recommendations for phosphate for vining peas were for 100, 70, 40 and 0 kg P_2O_5/ha at indices 0-3 respectively. The results from FV 380 do not provide sufficient evidence to revise 8^{th} edition RB209 recommendations for phosphate (this was not the original aim of the project), however the work does highlight a need to confirm whether the 8^{th} edition RB209 recommendations are appropriate to achieve optimum yields of vining peas.

AHDB Horticulture project FV 428 investigated the influence of P starter fertilisers (with and without N) on pea yields. Primary Phosphate (containing N) and Microstar (no N) starter fertiliser were applied with the seed at drilling at 3 sites in both 2014 and 2015. Three rates of each starter fertiliser were used supplying 3-6 kg P_2O_5/ha with an application rate of 0.75-1.25 kg N/ha in the Primary Phosphate treatments. The treatments were applied to large (*c*.2 ha) un-replicated plots. The 2014 sites were all P Index 2; the 2015 sites were P Index 0, 2 and 3. In both years there was a trend for increased yields (of up to 4 t/ha) from starter fertiliser, although due to the lack of replication statistical analysis could not be performed. The results from both FV 380 and FV 428 demonstrate that peas are responsive to phosphate fertiliser and FV 428 highlights the potential to achieve this yield increase with much smaller targeted applications of phosphate fertiliser.

Some ‘starter’ nutrient products (i.e. Primary Phosphate) contain low amounts of N. There were no recommendations for N for peas in RB209 (8^{th} edition) and N is known to be detrimental to the formation of root nodules. It is not clear whether the very low N applications (i.e. <5 kg N/ha) in ‘starter’ fertiliser will reduce nodulation. Furthermore, some growers report that where peas are drilled in agronomically suboptimal conditions a small amount of N can improve crop establishment.

However, there is no scientific evidence to support this. The current NVZ Regulations (The Nitrate Pollution Prevention Regulations 2015) include an Nmax limit of zero for peas and beans; this prohibits growers within an NVZ applying any N fertiliser to peas.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of vining peas to fertiliser applications.

Peas for fresh market, broad beans and runner beans

There are no N recommendations for peas for fresh market or broad beans in RB209 (8th edition). The N recommendations for runner beans were not changed when RB209 was last revised (2010) and runner beans are not within the framework for calculating N recommendations (section 4.3.1). The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of peas (market pick), broad beans or runner beans to fertiliser applications.

4.4.6. Lettuce and leafy salads

New work on baby leaf lettuce and wild rocket enables these crops to now be included within RB209. We recommend combining the current fertiliser recommendations for lettuce with the new recommendations for baby leaf lettuce and wild rocket in a 'Lettuce and leafy salads' page in the revised RB209.

Lettuce

The 8th edition RB209 N recommendations for lettuce were substantially revised compared to previous 7th edition recommendations; N recommendations were reduced at SNS Index 0, but were increased for crops grown on higher SNS Index soils (**Table *11***) in order to take into account the poor rooting of the crop. The revised 8th edition RB209 N recommendations for lettuce were validated against three N response experiments on Crisp lettuce as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3.

Table 11. Fertiliser N recommendations for lettuce.

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
8th edition	200	180	160	150	125	75	30
7th edition	250	200	150	100	25	0	0

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of *field grown* lettuce to fertiliser applications.

Baby leaf lettuce

AHDB Horticulture project FV 418 '*Baby leaf lettuce: N response studies to maximise yield and manage nitrate levels'* aimed to provide recommendations for N fertiliser for baby leaf lettuce grown and harvested as young leaves for the bagged salad market. AHDB Factsheet 16/14 '*Nitrogen* *recommendations for optimizing yield and quality of baby leaf lettuce'* provides guidance to growers based on the conclusions of FV 418. The project quantified yield response to N on five commercial grower sites (representative of the geographic spread of UK baby leaf lettuce production) to determine the optimum N needed to produce a marketable crop while remaining below the EU limit for Total Nitrate Concentration (TNC) of 3000 mg/kg. In 2013 six N response studies were carried out for red (one Red Cos and two Red Batavia) and green baby leaf (Green Cos, Green Tango and Green Batavia) lettuce varieties (three of each colour/variety type). Experiments were carried out through the summer into early autumn (crops sown from early May to early August), representing the main UK growing season and both first and second crops. Nitrogen was applied at 6 rates (0, 40, 80, 120, 170 and 220 kg N/ha) as CAN, with each treatment replicated four times.

Significant yield responses to applied N were only seen at two locations where the initial background SMN was at or below 30 kg N/ha prior to applying N treatments. At these two sites, further applications of N above 40 or 80 kg N/ha had no significant effect on yield and when TNC was also taken into account, only one crop still justified addition of a modest amount (40 kg/ha) of fertiliser N. In the remaining four response data sets where the initial SMN was 116-265 kg N/ha, yield declined with the addition of fertiliser N indicating that N was becoming toxic to the crop at these levels. The main reason for the yield decrease appeared to be lower plant density (resulting from poorer emergence).

AHDB Factsheet 16/14 provides new N recommendations for baby leaf lettuce (**Table *12***). These recommendations have been calculated based on crops of baby leaf lettuce with N offtakes of 65 kg N/ha and fresh weight yields of between 21 t/ha (red) and 30 t/ha (green), assuming N from mineralisation of 11 kg N/ha, rooting depth of 30 cm, recovery of soil mineral N of 100% and recovery of fertiliser N of 60%.

Table 12. Nitrogen recommendations for baby leaf lettuce.

SNS Index	0	1	2	3	4	5	6
SMN kg N/ha to 30 cm	<20	20-27	28-33	34-40	41-53	54-80	>80
N recommended kg N/ha	60	50	40	30	10	0	0

These recommendations can be compared to the measured response at the six sites in FV 418:

- At the one SNS Index 1 site (N recommendation 50 kg/ha) yields increased up to 80 kg/ha N, although TNC were exceeded where fertiliser N was applied.
- At the one SNS Index 2 site (N recommendation 40 kg/ha) yields increased up to 40 kg N/ha.
- At the four SNS Index 6 sites (N recommendation of 0 kg/ha) there was no requirement for additional N (yields decreased when N fertiliser was applied).

Wild rocket and baby leaf spinach

AHDB Horticulture projects FV 370a '*Wild rocket: N response studies to manage and reduce nitrate levels*' and FV 370b '*Wild rocket and baby leaf spinach: Impacts of nitrogen and phosphorus fertiliser applications on yield and quality*' aimed improve recommendations for fertiliser use in wild rocket and baby leaf spinach. AHDB Factsheet 08/13 '*Nitrogen recommendations for optimizing yield and minimising nitrate levels in baby leaf salad crops*' provides guidance to growers based on the conclusions of FV 370a and FV 370b.

In FV 370a the yield response to N was quantified at six sites representative of the geographic spread of UK wild rocket production in 2011. Experiments were carried out through the summer into early autumn, representing the main UK growing season and covering both first and second crops. Nitrogen was applied as CAN at 6 application rates (0, 40, 80, 120, 170 and 220 kg N/ha), replicated 4 times and arranged in a randomised block design.

Significant yield responses to applied N were only seen at two sites where initial background SMN (0-30 cm) was at or below 65 kg N/ha prior to applying N fertiliser. At these two sites, further applications of N above 40 kg/ha had no significant effect on yield. At the other four sites, where the initial SMN (0-30 cm) was in the range 82-205 kg N/ha, it is likely that soil N was sufficient to match crop demand. At two of these sites, yields were seen to decline in response to applied N because the initial SMN levels (0-30 cm) before drilling the crop were very high (>200 kg N/ha) and further applied N probably became toxic to plant growth.

The EC TNC limit for rocket is 6000 mg NO_3-N/kg. FV 370a found that the application of fertiliser N significantly increased TNC at harvest; where only 80 kg N/ha was applied, 25% of samples exceeded the 6000 mg NO_3-N/kg.

AHDB Factsheet 08/13 provides new N recommendations for wild rocket (**Table *13***). These recommendations have been calculated based on a fresh weight yield of 20 t/ha with an N offtake of 113 kg N/ha (mean N offtake measured in FV 370a and FV 370b) and rooting depth of 30 cm. Mineralisation of soil organic matter is estimated to be 22 kg/ha, recovery of soil mineral N is assumed to be 100% and recovery of fertiliser N is assumed to be 60%.

Table 13. Nitrogen recommendations for wild rocket.

SNS Index	0	1	2	3	4	5	6
SMN kg N/ha to 30 cm	<20	20-27	28-33	34-40	41-53	54-80	>80
N recommended kg N/ha*	125	115	100	90	75	40	0

* Recommendations may need to be revised down if there is a risk of exceeding TNC e.g. for late season crops grown under dull conditions.

The project also looked at the effect of previous crop residues on fertiliser N response; this work highlighted that late-season rocket crops which have had previous crop residues incorporated and a previous application of N within the same season will have large amounts of readily available N in the soil for rapid crop uptake. These residues must also be taken into account when planning N fertiliser use to avoid the risk of over-applying N fertiliser, which increases the risk of exceeding the TNC limit. FV 370a concludes that whilst for first sown crops, SNS can be estimated using the FAM, for second or third sown crops the FAM is less accurate and in these situations SNS is best estimated by measuring SMN close to and prior to planting the later crops.

Following on from FV 370a, project FV 370b aimed to improve recommendations for N and P applications for wild rocket and baby leaf spinach. A series of six N and P response experiments were carried out (three with wild rocket and three with baby leaf spinach) in 2012 at commercial sites in Dorset, Kent, Norfolk, Shropshire and North Wales. Nitrogen was applied as CAN at three rates: zero N, recommended N rate (from FV 370a and shown in **Table *13***) and at the recommended N rate plus 50 kg N/ha. Phosphorus was applied as Omex's TPA coated TSP broadcast and incorporated prior to drilling at six rates: 0, 50, 100, 150, 200 and 250 kg P_2O_5/ha. The six P rates were applied at each N rate in a fully factorial design (in three blocks) such that individual responses to N and P as well as their interactions could be assessed.

The six sites had P indices in the range 3-6 prior to drilling. There was no crop response to P fertiliser at any of the wild rocket or baby leaf spinach sites, which is perhaps not surprising given the high initial soil P indices. FV 370b quantified the crop phosphate offtake for wild rocket as 21 kg/ha P_2O_5 and for baby leaf spinach as 28 kg P_2O_5/ha, and noted that these crop offtake figures could be used as a basis for fertiliser P planning to ensure that growers who are maintaining soil P indices of 3 replace crop P_2O_5 offtake.

As found in FV 370a, there were strong effects of N on yield. Three of the sites (two rocket and one spinach) with low initial SMN (22-39 kg/ha SMN to 30 cm) responded to 110-120 kg/ha applied N. One spinach site with an initial SMN of 67 kg/ha (to 30 cm) responded to 60 kg/ha applied N. Two sites (one rocket and one spinach) with high initial SMN (143 and 137 kg/ha SMN to 30 cm, respectively) showed no response to N fertiliser. The N response from the wild rocket sites broadly support the N recommendations produced in FV 370a and published in AHDB Factsheet 08/13 (**Table *13***).

FV 370b measured mean total N offtake of 69 kg N/ha for baby leaf spinach (range 41-122 kg N/ha offtake). AHDB Factsheet 08/13 suggests the same guidelines for calculating N recommendations for wild rocket could be used for baby leaf spinach (i.e. taking into account crop N offtake, assuming mineralisation from organic matter of 22 kg/ha, soil N recovery 100% and crop N recovery of 60%). Based on the mean crop N offtake of 69 kg/ha this gives N recommendations of 55, 40, 30, 20 and 0 kg N/ha at SNS indices of 0-4, respectively. However, FV 370b notes that these recommendations are notably lower than those given in the Fresh Crop Protocol for spinach (125 kg/ha at SNS Index 0); part of this discrepancy might be that the average N offtake measured in FV 370b of 69 kg/ha was an underestimate, and FV 370b notes that given the wide range in N offtakes more work is needed. For this reason, AHDB Factsheet 08/13 does not give specific N recommendations for baby leaf spinach and we are not recommending inclusion of N recommendations for baby leaf spinach in this revision of RB209.

Nitrogen response experiments in FV 418 (baby leaf lettuce) and FV 370 (wild rocket) were carried out on baby leaf lettuce sown between early May and early August, and on wild rocket sown from late April to late July, and therefore cover the main UK growing season for both crops. However, grower experience shows that some earlier season crops (sown February to early April) which are grown in cold or adverse conditions may in some cases require higher N application rates than recommended in **Table *12*** and **Table *13*** (Chris Wallwork, Agrii, Pers. Comm., May 2016). Discussions with growers indicate that in these circumstances up to an additional 60 kg N/ha for baby leaf lettuce and up to 25 kg N/ha for wild rocket may be necessary. Whilst both FV 418 and FV 370 showed that it important to ensure that fertiliser N applications do not cause the crop to exceed TNC limits, grower experience has shown that additional N applied to early season crops grown in cold/adverse conditions has not caused TNC limits to be exceeded. Therefore we recommend inclusion of additional guidance text allowing up to an additional 60 kg N/ha for baby leaf lettuce and 25 kg N/ha for wild rocket grown in these circumstances.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of field grown baby leaf lettuce or wild rocket to fertiliser applications.

Recommendations:

- Combine fertiliser recommendations for lettuce, baby leaf lettuce and wild rocket in a new 'Lettuce and leafy salads' page in RB209.
- No changes to the 8th edition fertiliser recommendations for lettuce.
- Include the new N fertiliser recommendations for baby leaf lettuce (**Table *12***).
- Include the new N fertiliser recommendations for wild rocket (**Table *13***).
- Include the following text guidance re N fertiliser applications to early season crops grown in cold/adverse conditions:

  "Early season crops grown in cold or adverse conditions might in some cases require up to an additional 60 kg N/ha for baby leaf lettuce or 25 kg N/ha for wild rocket, to maximise yields. If applying additional nitrogen, Tissue Nitrate Concentration analysis is recommended."
- Include the following text guidance on minimising nitrate levels:

  "EU legislation stipulates nitrate limits for leafy salad and growers need to ensure N applications do not cause crops to exceed these limits. This is particularly important for late season crops of leafy salad where even small amounts of fertiliser may lead to high tissue nitrate concentration (TNC)."
- The 8th edition RB209 P, K and Mg recommendations for lettuce are noted as being sufficient for a second crop grown in the same year. In the absence of any other work on the P, K or Mg response of baby leaf lettuce or wild rocket, we recommend that the 8th edition P, K and

Mg recommendations for lettuce are extended to baby leaf lettuce and wild rocket with the caveat that these recommendations are sufficient for multiple leafy salad crops grown in the same season. FV 370b measured an average (across sites) maximum crop phosphate offtake for wild rocket of 21 kg P_2O_5/ha; the 8th edition P_2O_5 recommendation at the target P Index of 3 is 100 kg/ha and therefore sufficient to replace offtake from multiple wild rocket crops.

- Include the following text re Tissue Nitrate Concentration (TNC)

  "EU legislation stipulates nitrate limits for leafy salad and growers need to ensure N applications do not cause crops to exceed these limits. This is particularly important for late season crops of leafy salad where small amounts of fertiliser may lead to high tissue nitrate concentration (TNC)."

- Include reference to the relevant AHDB Factsheets
  "Further information is available in AHDB Horticulture Factsheets 'Nitrogen recommendations for optimising yield and quality of baby leaf lettuce' and 'Nitrogen recommendations for optimising yield and minimising nitrate levels in baby leaf salad crops', and in the AHDB Horticulture Lettuce & Celery Crop Walker Guide. Please visit horticulture.ahdb.org.uk to download or order your copy."

4.4.7. Radish, sweetcorn and courgettes

Radish

The 8th edition RB209 N recommendations for radish were substantially revised compared to previous 7th edition recommendations; N recommendations were reduced at SNS Index 0, but were increased for crops grown on higher SNS Index soils in order to take into account the shallow rooting of the crop. However, experimental N response data on radish was not available to validate the revised N recommendations. Information on yields, N uptake and rooting depth used in the framework for calculating N recommendations are based on the German KNS System (Carmen *et al*., 2007).

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of radish to fertiliser applications.

Sweetcorn

AHDB Horticulture project FV 409 '*Nitrogen and phosphorus recommendations for optimising yield and quality of sweetcorn*' aimed to improve the understanding of responses to N and P fertilisers for sweetcorn. An AHDB Factsheet (in press) provides guidance to growers based on the conclusions of FV 409.

Eleven N response field experiments were completed over two cropping seasons, at three early and three late sown sites in 2013, and three early and two late sown sites in 2014 on commercial farms in West Sussex, Hampshire and the Isle of Wight. Nitrogen was applied at six rates – 0, 60, 120, 180, 250 and 320 kg N/ha and at the following three application timings:

- Two-way: split 2/3 in seedbed at drilling, 1/3 at growth stage V4-V6[2] (= current practice)*,
- Three way split: 1/3 in seedbed at drilling, 1/3 at growth stage V4-V6, 1/3 at flowering,
- Two-way split: none at drilling, 1/2 at growth stage V4-V6, 1/2 at flowering.

*The maximum applied in the seedbed was 100 kg N/ha to follow 8th edition RB209 recommendations.

Yield responses to N were recorded in just over half of the crops. At these sites with SNS indices 0 and 1, N application rates of between 160 and 250 kg/ha were needed to provide optimum yields. These application rates were greater than 8th edition RB209 recommendations, and the new AHDB Horticulture Factsheet gives revised N recommendations which should be incorporated into RB209 (**Table *14***). These revised N recommendations are in good agreement with international N advice for maximum yield of sweetcorn (220 kg N/ha; IFA, 1992).

Table 14. 8th edition and revised N recommendations for Sweetcorn.

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
8th edition	150	100	50	0*	0*	0*	0*
Revised	220	175	125	75	0*	0*	0*

*A small amount of nitrogen may be needed if soil nitrogen levels are low in the top 0-30 cm of soil

The application timing experiments indicated that providing most of the N early in growth, to ensure it is available prior to the sweetcorn's maximum period of demand for vegetative growth (V6 – R1)[2], appears to be the best strategy with respect to matching crop uptake to optimise cob yields. Cobs from two of the early crops showed a weakly significant increase in weight when the N was applied in the seedbed, compared to timings where no or little N was applied in the seedbed. Application timing made no significant difference to the cob weights of the late sown crops, probably due to the higher SMN at drilling. In these cases less N could be applied in the seedbed. The new AHDB Horticulture Factsheet recommends that *'Growers should apply N as two or three applications, with up to 100 kg N/ha applied in the seedbed and the balance top-dressed at V4-V6'.* This is in agreement with the advice in RB209 (8th edition) to *'Apply no more than 100 kg N/ha in the seedbed. Apply the remainder as a top-dressing when the crop is fully established'*

Six P response field experiments were completed over two cropping seasons, at two early and one late sown site in both 2013 and 2014 on commercial farms in West Sussex and. Phosphorus was applied at as TSP broadcast and incorporated prior to planting at six rates - 0, 60, 120, 180, 240 and 320 kg P_2O_5/ha. There were no significant detectable yield responses to applied phosphate at any

[2] Sweetcorn growth stages: V = vegetative, R = reproductive. See AHDB Horticulture Factsheet for more information.

of the six sites and no effects on other quality attributes such as sweetness. Prior to drilling, the experimental sites had soil P indices in the range 2 to 3 and a positive yield response may not have been expected. FV 409 concludes that there is no yield response of sweetcorn to broadcast phosphate fertiliser at soil P Index 3, but it is good practice to maintain soil P Indices and thus replace the expected phosphate offtake in the crop. Measured crop phosphate offtake was 25 kg P_2O_5/ha where cobs were removed and 50 kg P_2O_5/ha where the whole crop was removed. The target P Index for field vegetables, including sweetcorn, is Index 3. RB209 (8th edition) recommendations at P Index 3 (25 kg P_2O_5/ha) were sufficient to replace crop phosphate offtake where only the cobs were removed. However, if the whole crop is removed (e.g. for silage), the new AHDB Horticulture Factsheet recommends that growers should apply an additional 25 kg P_2O_5/ha (at soil Index 0-3) to account for the greater crop phosphate offtake. Note that FV 409 did not look at potash response or measure crop potash offtake.

The literature review identified one other European study which investigated the N response of sweetcorn (Bavec *et al*., 2013). This study was carried out over 3 years (2007-2009) in Slovenia. Nitrogen was applied as fertiliser (CAN and ENTEC 26) and organic materials (pumpkin oil cake and pig manure digestate) at rates of 0, 70, 120, 170 and 220 kg N/ha. Soil mineral N measured prior to drilling (0-90 cm) was low at 17-19 kg N/ha (equivalent to SNS Index 0). Marketable yield increased up to the highest rate of 220 kg N/ha; averaged over the three years marketable yields were 9.3, 10.9, 11.3, 11.8 and 12.2 t/ha at the 0, 70, 120, 170 and 220 kg N/ha rates, respectively. These results support the revised higher RB209 recommendations for sweetcorn at SNS Index 0.

Recommendations:

- Update N recommendation to those in **Table *14***.
- Include reference to the new Factsheet:
  "Further information is available in the AHDB Horticulture Factsheet 'Nitrogen and phosphorus recommendations for optimising yield and quality of sweetcorn.' Please visit horticulture.ahdb.org.uk to download or order your copy."

Courgettes

When RB209 was last revised in 2010 there was insufficient data to include courgettes in the framework for calculating N recommendations (section 4.3.1), and no changes were made to the recommendations. The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of courgettes to fertiliser applications.

4.4.8. Onions

The 8th edition RB209 N recommendations for onions were revised compared to the previous 7th edition to split the N recommendations between bulb and salad onions; the recommendations were validated against three N response experiments (two on salad and one on bulb onions) as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3.

The literature review identified three papers, which from the titles and abstracts suggested they contained information relevant to RB209; two studies from the USA assessing N response (detailed below) and one study from Poland (Skwierawska *et al*., 2008), looking at S response (see Section 4.3.4).

Boyhan *et al*. (2010), applied an organic pasteurized and pelleted fertiliser made from poultry waste (4% N, 0.9% P and 2.5% K) to short day onions in a field experiment in Georgia, USA at application rates equivalent to 170 and 225 kg N/ha; total yields increased from 40 to 55 t/ha from the 170 and 225 kg N/ha treatments, respectively. Although the 225 kg N/ha rate used by Boyhan *et al.* (2010) was higher than 8th edition RB209 recommendations for onions (160 kg N/ha at SNS Index 0), N availability may have been lower than from inorganic N fertilisers.

Halvorson *et al.* (2008) carried out field experiments (2 site years) in Colorado USA to compare the yield response of onions grown under drip and furrow irrigation to N fertiliser applied as a controlled release polymer coated urea at six rates from 0 to 224 kg N/ha. In 2005 maximum onion yields were achieved at *c*.130 kg N/ha, however in 2006 there was no yield response to applied N fertiliser. The authors concluded that the greater N response in 2005 probably reflected a lower level of mineralisable soil N in the 2005 site due to the previous four years of corn with conservative N application rates compared to the 2006 site where soybean was grown in the previous year and relatively high rates of N were applied to the previous crop. This highlights the importance of assessing soil N supply to inform fertilizer N application rates.

4.4.9. Leeks

The 8th edition RB209 N recommendations for leeks were substantially revised compared to previous 7th edition recommendations; N recommendations remained the same at SNS Index 0, but were increased for crops grown on higher SNS Index soils (**Table *15***) in order to take into account the shallow rooting of the crop. The 8th edition RB209 recommendations also allowed application of an additional 100 kg/ha of ‘supplementary’ N depending on the appearance of the crop to support growth and colour. The allowance for ‘supplementary’ N was based on grower practice and experience, rather than evidence from field experiments.

Table 15. Fertiliser N recommendations for leeks.

SNS Index	0	1	2	3	4	5	6
	N rate (kg N/ha)						
8th edition	200	190	170	160	130	80	40
7th edition	200	150	100	50	0	0	0

AHDB Horticulture project FV 350 *‘Nitrogen requirements of leeks’* aimed to validate the revised N fertiliser recommendations for modern F1 Hybrid varieties of leeks and to provide justification of the need for supplementary N fertiliser during the overwinter period. AHDB Horticulture Factsheet 32/12 '*Nitrogen requirements for leeks'* provides guidance to growers based on the conclusions of FV 350.

In 2009 and 2010, field trials were carried out on a sandy loam soil at Wellesbourne (SNS Index 0 in 2009 and SNS Index 1 in 2010) to test the N response of over-wintered leeks (cultivar Belton). In 2009 N was applied at five rates (0, 180, 240, 360 and 480 kg N/ha) and in 2010 N was applied at six rates (0, 75, 150, 200, 300 and 500 kg N/ha). In the 2009 crop, there was a large yield increase between 0 and 180 kg N/ha and yields then plateaued at the higher N rates. In the 2010 crop, yields increased up to 200 kg N/ha, but then declined at the higher N rates. These measured yield responses can be compared to RB209 (8^{th} edition) recommendations of 200 kg N/ha for the 2009 crop and 190 kg N/ha for the 2010 crop, and provide support for RB209 (8^{th} edition) recommendations at low SNS indices, however there is still a need to test the 8^{th} edition RB209 recommendations at higher SNS Index sites.

Crop growth and N uptake was also measured during the season. In 2009 the crop was drilled in May and most of the growth and N uptake occurred between August and November. In 2010, the crop was planted (transplants) in July and most of the growth and N uptake occurred between August and December. In both years, N recovery within a month of establishment was less than 3% of the N applied as fertiliser. FV 350 recommends that:

Fertiliser N should be split to match the growth of the crop, as large amounts of fertiliser applied within 2 months of drilling an overwintered crop are likely to be inefficiently used. It is more beneficial to apply additional N in the summer than it is to apply large amounts to the seedbed.

The 8^{th} edition of RB209 recommended that growers "Apply no more than 100 kg N/ha in the seedbed. The remainder should be applied as a top-dressing when the crop is fully established". Based on the results from FV 350 we recommend that guidance on N application timing is amended to:

"Fertiliser N should be split to match the growth of the crop and usually no more than 50 kg N/ha should be applied in the seedbed for drilled crops and no more than 100 kg N/ha for transplants. The remainder should be applied as one or two top-dressings when the crop is fully established".

In addition to testing the response of leeks to main season N applications, FV 350 also tested the effects of 'supplementary' N applied in the autumn/winter period. However, in both years the results were affected by severe weather. In 2009, the crop failed to overwinter due to severe weather (so results are presented from the November assessment of marketable yield). The 2010 planted crop also suffered from severe weather, but at an earlier stage of growth than the 2009 crop and so was able to recover to produce yield of marketable quality in April 2011. The project did provide some evidence that supplementary autumn N could be beneficial. In 2009 there was a yield benefit of 20% at the November harvest in response to 100 kg/ha of additional N applied in August and September.

However, in 2010 there was a yield loss of up to 20% where the additional N had been applied in September and October because the additional N increased sensitivity of the crop to frost damage. FV 350 and AHDB Horticulture Factsheet 32/12 give the following advice to growers on supplementary overwinter N:

Where leeks are to be harvested in the autumn, the application of supplementary N in August and September may be justified. For over-wintered crops, when summer N requirements are met, additional N may cause reductions in yield due to frost intolerance.

Following on from FV 350, project FV 350a '*Quantifying over-winter nitrogen requirements of the leek crop'* aimed to further improve our understanding of and further refine recommendations for 'supplementary' over-winter N. Work was carried out in three commercial leek crops representing early, mid and late maturing varieties in 2013/14 season. All crops were grown on light sand soils with low SNS (Index 0-2). Experimental treatments assessed responses to both the rate of supplementary N (up to 100 kg N/ha for early and mid-maturity crops, and up to 150 kg N/ha for the late maturity crop) and its timing (fertiliser N applied in 50 kg/ha increments) on marketable yield non-marketable crop fractions, and total N offtake (and hence N requirements).

At each of the sites, the main season N fertiliser application was applied by the grower at the RB209 (8^{th} edition) recommended rate, and a nil N control treatment was included to quantify the response to applied N. At the early and mid-maturity leek sites, the main season N application by the grower increased marketable yields by 28 and 13 t/ha respectively, compared to yields of the nil N areas of the crop. However, at the late maturity site there was no increase in yield in response to the main N application. The lack of a response to N at the late site was unexpected, because although this site had an SNS Index of 2, which was higher than the other two sites (SNS indices of 0 and 1), a response to the main application of N would still have been expected. The late maturing crop had a much lower total N uptake in October compared with the other two crops suggesting that its slower rate of development represented a lower N requirement early in the season. The authors note that these observations broadly support the 8^{th} edition RB209 recommendations for early and mid-maturity varieties, but highlight the need for further work to confirm the suitability of RB209 recommendations for late leek maturity types.

The project found that 'supplementary' N increased the yield of marketable plants for the early and mid-maturity varieties, mainly due to a reduction in the number of undersize plants rejected. For the early maturity crop, 50 kg N/ha applied in early autumn (October/November) increased the proportion of marketable plants. There was evidence that applying 100 kg N/ha in early autumn (50 kg N/ha in October and November) was beneficial to marketable fresh weight yields (but not proportion of crop harvested) in the early crop, but at such levels of application, greater amounts of SMN and crop residue N were left after harvest. For the mid maturity crop, 90 kg N/ha applied in early autumn (October/November) was beneficial to marketable yields and did not leave excessive SMN behind after harvest. The largest responses to supplementary N were seen in the mid maturity crop.

However, for both the early and mid-maturity crops, later applications of N (50 kg N/ha in both November and January) reduced the proportion of marketable plants. There was no benefit of supplementary N for the slower growing late harvested crop.

It should be noted that the results from FV 350a are based on a single mild season. The project report notes that despite the potential benefits of supplementary N, crops over-fertilised with N can become more frost sensitive, and that in a harsh winter, marketable yields could have been lower with supplementary N. In the previous FV 350 project too much N led to an increased risk of frost damage.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of leeks to fertiliser applications.

Recommendations:

- Amend the guidance on N application timing to:
  "Fertiliser N should be split to match the growth of the crop and usually no more than 50 kg N/ha should be applied in the seedbed for drilled crops and no more than 100 kg N/ha for transplants. The remainder should be applied as one or more top-dressings when the crop is fully established".
- Amend the guidance on additional 'supplementary' N to:
  "An additional top-dressing of 50-100 kg N/ha in the autumn may be beneficial where the risk of frost damage is low, on all soils except peat, to support growth and colour."
- Update AHDB Horticulture Factsheet 32/12 'Nitrogen requirements for leeks' to incorporate the results from FV 350a.
- Include reference to the updated Factsheet and AHDB Horticulture Crop Walker Guide:
  "Further information is available in AHDB Horticulture Factsheets 'Nitrogen requirements for leeks' and in the AHDB Horticulture Allium Crop Walker Guide. Please visit horticulture.ahdb.org.uk to download or order your copy."
- The current NVZ Regulations (The Nitrate Pollution Prevention Regulations 2015) do not allow N to be applied to leeks during the closed period (1st September to 15th January) unless supported by written advice from a FACTS Qualified Adviser. We recommend that AHDB liaise with Defra to add leeks to the list of crops to which N fertiliser can be applied during the closed period based on a maximum application rate of 100 kg N/ha. It should be noted where an exemption to the closed spreading period is given, the maximum N rate cited is a legal maximum and cannot be exceeded on the basis of advice from a FACTS Qualified Adviser. If the revised edition of RB209 is published before this revision to the NVZ regulations is made, the following text should be included:
  "Under NVZ rules, no fertiliser N should be applied to leeks during the closed period unless supported by written advice from a FACTS Qualified Adviser. If applying N in

the closed period then a FACTS Qualified Adviser must provide a written recommendation."

4.4.10. Root crops

Beetroot, swedes, turnips and parsnips

The 8th edition RB209 N recommendations for beetroot, swedes, turnips and parsnips were revised compared to the previous 7th edition. The recommendations were validated against two N response experiments on beetroot and one on parsnips as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3. The N recommendations for turnips were based on those of parsnips, however, experimental N response data on turnips were not available to validate the revised N recommendations. The N recommendations for swedes were separated from parsnips and turnips based on data available, but the recommendations have not been validated by any recent response trials.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of these root crops to fertiliser applications.

Carrots

The 8th edition RB209 N recommendations for carrots were revised compared to the previous 7th edition. The recommendations were validated against two N response experiments as part of Defra Link Project P164 (Smith, 2001) as detailed in Appendix 3

The literature review identified two papers which from the titles and abstracts suggested they contained information relevant to RB209; both papers report results of experiments looking at the effect of N fertiliser applications to carrots (one study from Norway and one from Canada).

Seljasen *et al*. (2011) investigated the effect of genotype, soil type, year and fertiliser rate on carrot yield and quality (taste, firmness and shape) on sandy, loamy and peat soils in south-eastern Norway. Optimum fertiliser rates for yield and quality of grade one roots was between 80 and 160 kg N/ha and between 0 and 120 kg K_2O/ha, depending on soil type and rainfall. Carrots grown on peat soil had the highest quality scores for taste and firmness. Year and variety had the greatest impact on quality with soil type and fertiliser rate having less influence.

Veitch *et al*. (2014) investigated the effect of N fertiliser application rate (0, 50, 100, 150, 200, 300, and 400 kg N/ha; 60% pre-emergence and 40% 8 weeks after emergence) on carrot yield and quality in Kings County, Nova Scotia, Canada (soil type not specified). Overall, optimum yields were achieved at N rates of 150 kg N/ha and further addition did not significantly improve yields or quality.

The optimum N rates reported by Seljasen *et al.* (2011) and Veitch *et al*. (2014) are higher than 8th edition RB209 recommended N rates of 100, 70 and 40 kg N/ha at SNS Indices 0, 1 and 2, respectively. The two UK N response experiments reported by Smith (2001) (and detailed in Appendix 3) had lower optimum N rates of 91 and 82 kg N/ha (both SNS Index 1 sites).

4.4.11. Bulb and bulb flowers

The 8th edition RB209 N recommendations for bulb and bulb flowers were reduced at SNS Index 0 compared to the previous 7th edition recommendations following discussion with growers and agronomists. The AHDB Horticulture Narcissus Manual (Hanks, 2013) includes the 8th edition RB209 fertiliser recommendations for bulb and bulb flowers, and also provides details of the historic research on which these fertiliser recommendations are based.

AHDB Horticulture studentship project CP 107 *'The application of precision agronomy to UK production of Narcissus'* (2013-2016) includes field trials examining different production approaches including bulb density, planting depth, bulb orientation and fertiliser placement. The field experiments on fertiliser placement are currently on-going and will provide results that may be relevant to a future revision of RB209. These experiments are comparing the effect of placed compared to broadcast N fertiliser, with the following treatments: zero K, broadcast K and K placed at rates of 100%, 75%, 50% and 20% of the broadcast rate.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of bulb or bulb flowers to fertiliser applications.

Recommendations:

- Include reference to the AHDB Horticulture Narcissus manual
  "For further information see the AHDB Horticulture Narcissus manual. Please visit horticulture.ahdb.org.uk to download or order your copy."

4.4.12. Herbs

There were no fertiliser recommendations for herbs in the 8th edition of RB209. AHDB Horticulture Project FV 359 aimed to examine the crop yield, quality and shelf life responses of field grown coriander and mint to N fertiliser. The project also provided information on the P and K nutrition of these herbs.

Coriander

The response of coriander to six levels of applied N (0, 60, 110, 160, 230, 300 kg N/ha) was assessed at Wellesbourne on crops drilled in May, July and August 2009. The SNS Index of the soil was 0. Nitrogen application was split as one third as a base dressing and two thirds as a top dressing. In addition, in two separate trials in Hampshire drilled in June and August 2009, all the N was applied as a top dressing in five levels (0, 52,131, 204, 276 kg N/ha). The SNS Index of the soil was 5 in the first crop and 1 in the second. Estimates of yield were made by sampling each crop on three occasions (i.e. two interim samples and a final harvest sample). The lowest N level application treatment above which no further significant increases in yield were obtained was determined. This N level decreased with drilling date and also with time of sampling. For the first drilling in May, yield was highest at 230-300 kg/ha fertiliser N, equivalent to 255-325 kg/ha 'available' N (i.e. fertiliser N plus SMN to 30 cm depth at drilling), for the second drilling in July at 110-160 kg/ha N (154-24 kg/ha available N), and for the third August at 60 kg N/ha (81 kg/ha available N). Yields at the Hampshire site were less responsive to N applications due to the higher background levels of N. No further yield increase occurred above the 52 and 0 kg N/ha applications for the June and August drilled crops respectively. Leaf colour was poor below available levels of N of 131-150 kg/ha; however, above this level of N, there was no further improvement in leaf colour (greenness). Preliminary N fertiliser recommendations were based on the average results obtained from the drilled crops at the Wellesbourne and Hampshire sites (**Table *16***). These rates would be suitable for coriander crops drilled in July. For crops drilled in May, a higher level of available N of 230 kg/ha could be justified although this requires further investigation. For crops drilled in August, although yield may not be affected by reducing fertiliser N to 60 kg N/ha (81 kg/ha available N), in view of the poorer leaf colour, the N levels in **Table *16*** should be maintained.

The initial K Index of the soil was 2 at both the Wellesbourne and Hampshire sites; the P indices were 5 and 4 respectively. Applying an additional 166 kg K_2O/ha at the Wellesbourne site had no significant effect on yield or quality of coriander. Preliminary P and K recommendations for coriander, based on offtake of crops grown at Wellesbourne and in Hampshire, are shown in **Table *16***.

Table 16. Preliminary fertiliser recommendations for coriander.

Soil Index	0	1	2	3	4	5	6
N rate (kg/ha)	140	125	115	105	90	55	30
P_2O_5 (kg/ha)	175	125	75	25	0	0	0
K_2O (kg/ha)	315	265	215 (2-) 165 (2+)	75	0	0	0

Mint

Mint is a perennial herb with a repeat harvest requirement as well as a longer term production period (typically up to 5 years). Trials at two sites, at Wellesbourne and in Berkshire, examined the nutrient requirement of the crop in the first two years. Plots were planted with rooted Spanish mint transplants in May 2009 at both sites with the aim of establishing the crop for more detailed work in the second year of the project. The SNS Index of the soil was 0 at Wellesbourne and 5-6 in Berkshire. Rates of applied N between 0 and 300 kg/ha were tested with fertiliser applied as a base dressing prior to transplanting and then again as a top dressing each time the crop was topped. Plots were topped on two occasions in year 1 (June and August) to assist establishment and then cut back at the end of the season (early October). In year 2, plots were topped on three occasions (May, July and September). Shoot material that was removed on each occasion quantified for 'yield' as well as shoot mineral content. At Wellesbourne, maximum yield of mint cut at the end of the first season was associated with the highest rate of N on each occasion. In year 2, the optimum available N was in the range 178-283 kg/ha for the yield of tops of all three cuts, where available N was fertiliser N plus mineral N to 30 cm soil depth. At the Berkshire site, there was no significant yield response to applied

N in year 1, probably due to the high level of background N in the soil. No usable yield data was obtained from the Berkshire site in year 2. Preliminary recommendations for mint N requirements have been calculated for each of three cuttings in an established crop (**Table *17***).

Table 17. Preliminary fertiliser recommendations for each cutting of a mint crop in Years 1 and 2.

Soil Index	0	1	2	3	4	5	6
N rate (kg/ha)	180	170	160	150	130	100	70
P_2O_5 (kg/ha)	175	125	75	25	0	0	0
K_2O (kg/ha) Yr 1	200	150	100 (2-) 50 (2+)	0	0	0	0
K_2O (kg/ha) Yr 2	280	230	180 (2-) 130 (2+)	40			

The figures in **Table *17*** assume that the base material from the shoots (and the associated N content) is removed from the field after cutting. If the bases remain in the field after cutting, the figures should be reduced by 30 kg N/ha to allow for the N content of the shoot bases which becomes available to the next cutting.

In year 1, leaf greenness was not influenced by level of available N. However, in year 2 of the crop, leaf greenness of mint was improved by N applications, but there were no further increases in greenness at levels of available N above 122-172 kg/ha. Product shelf life, mainly limited by leaf necrosis and yellowing was not affected by N levels in year 1 or the first cut of year 2. However, in the second and third cuts in year 2, product shelf life decreased with increasing N level, particularly above an available N of 200 kg/ha. If the recommendations in **Table *17*** are followed, lack of leaf greenness and product shelf life should not be issues.

The initial K Index at the Wellesbourne and Berkshire sites was 2. At Wellesbourne in year 1, the K offtake in each cutting was 20 – 106 kg K_2O/ha; in year 2 it was 212 – 315 kg K_2O/ha. Based on these offtake figures, preliminary K recommendations for each cutting in years 1 and 2 of a mint crop are shown in **Table *17***. These recommendations are based on mineral offtake of crops grown at Wellesbourne and in Berkshire. The initial P indices were 4-5 at Wellesbourne and 5 at the Berkshire sites. At Wellesbourne in year 1, the P offtake in each cutting was 7-25 kg P_2O_5/ha; in year 2 it was 41-55 kg P_2O_5/ha. Based on these offtake figures, preliminary P recommendations for each cutting in years 1 and 2 of a mint crop are shown in **Table *17***.

The literature review did not identify any other new (i.e. since 2009) relevant published research looking at the response of coriander or mint to fertiliser applications.

The results from FV 359 and the new fertiliser recommendations for herbs have been discussed with British Herbs (formally known as the British Herb Trade Association). The results from FV 359 provide a basis for the guideline fertiliser recommendations for coriander and mint given here, but should not be extrapolated as the basis for recommendations for other herb crops. The results and fertiliser recommendations from FV 359 broadly support industry experience of fertiliser rates required to optimise yields where growing conditions are similar to those in FV 359. However, there are a number of other factors that can influence fertiliser requirements such as time of planting (coriander), age of crop (mint), expected yield, crop quality and end market. Therefore, the fertiliser recommendations given here should be considered guidelines figures and may need to be adjusted based on local experience.

There are a range of other herbs grown in the UK for which there is very limited information to base fertiliser use. Priorities for future research have been discussed with British Herbs who would like to explore the availability of crop nutrient offtake data for the range of herb species grown in the UK. Crop nutrient offtake data may be available from growers and researchers in the UK and internationally (from countries where growing systems are similar to those in the UK) and can be used to help inform fertiliser use.

Recommendations:

- Include coriander and mint within the revised RB209 with the N, P and K recommendations given in **Table *16*** and **Table *17***.
- Include the following guidance text in RB209:

  Coriander - nitrogen

  "Apply no more than 100 kg N/ha in the seedbed. The remainder should be applied as a topdressing when the crop is fully established.
  The fertiliser recommendations given here should be considered guidelines figures and may need to be adjusted based on local experience and taking into account factors such as planting date, expected yield and end market."

  Mint - nitrogen

  "In the establishment year, apply no more than 100 kg N/ha before planting. The remainder should be applied as a topdressing when the crop is fully established.
  For established crops, the nitrogen recommendations are per cut, and should typically be split into two topdressings. Avoid over-fertilising mint as shelf life is reduced when soil mineral N to 30 cm depth is over 200 kg/ha.
  The fertiliser recommendations given here should be considered guidelines figures and may need to be adjusted based on local experience and taking into account factors such as age of crop, expected yield and end market."

  Potash – coriander and mint

  "Coriander and mint take up large amounts of potash which must be replaced in order to maintain the target soil Index. The actual amount of potash removed by the crop can be calculated from the known yield and the amount of potash per tonne fresh weight shown in Appendix 2."

- Include phosphate and potash crop offtake figures (in kg per tonne of fresh material) for coriander and mint in Appendix 2 (mean figures from FV 359):
    - Coriander: 0.8 kg P_2O_5/t and 5.5 kg K_2O/t fresh material
    - Mint: 1.0 kg K_2O/t and 3.9 K_2O/t fresh material

5. Review of evidence to support RB209 recommendations for fruit

5.1. Industry consultation

There was very limited response following the initial industry consultation; only one individual responded directly to the consultation with a request to resolve the guidance on banded fertiliser N application and herbicide/grass alleyways (which is discussed further below). Additional comment on specific crops and current industry practice was subsequently sought from a number of individual agronomists/consultants/researchers.

5.2. Crops included

The 8th edition of RB209 included fertiliser recommendations for top fruit (apples, pears, cherries and plums), soft fruit (strawberries, blackcurrants, redcurrants, gooseberries, raspberries, loganberries, tayberries and blackberries) and substrate grown strawberries. Guidance was given on interpreting leaf analysis for blueberries, although there were no fertiliser recommendations for blueberries.

Fertiliser recommendations given in the Fresh Produce Crop Protocols are the same as recommendations given in RB209 (8th edition). The Fresh Produce Crop Protocol for blueberries gives fertiliser recommendations (lower than for the other soft bush/cane fruit), which were not in the 8th edition of RB209.

The 8th edition of RB209 included recommendations for substrate strawberry production, but not for substrate grown raspberries, blackberries or blueberries. We recommend that AHDB consider inclusion of nutrient recommendations for substrate grown raspberries, blackberries & blueberries in a future revision of RB209 (i.e. 10th edition in 2019 or later). Recommendations would need to be based on new research; this is discussed further in section 5.4.3.

5.3. Principles of nutrient use for fruit

Changes to industry practice potentially affecting fertiliser use

Fertiliser recommendations for top fruit have changed little since the first edition of RB209 in 1973. For apples the fertiliser recommendations are presumably based mainly on trials with the older varieties such as Cox and Bramley. Historically, problems with Cox spot and control of red spider mite meant that larger quantities of N were required to maintain the canopy. However, better control of red spider mite and the introduction of newer apple varieties has changed the situation. Bramley remains the only culinary variety, however the area of Cox is declining and the areas of Gala and Braeburn in combination are significantly greater than Cox. In addition there has been an increase in the area of ‘club’ varieties.

There have also been some key changes to industry practice for top fruit which are not reflected by the recommendations in RB209 (8^{th} edition):

- There has been an increase in intensive apple production systems either as close planted single rows or post and wire systems.
- There has been an increase in the use of foliar feeding (mainly on apples, pears and cherries; less so with plums), which was not covered in RB209 (8^{th} edition). There is very little publically available trials information in the UK on foliar feeding. Some of the commercial agronomy companies are now advising foliar feeding, drawing on common practice in Belgium and Holland, and using leaf/sap analysis and crop appearance to fine tune recommendations. However, there is a significant variation of product (rates and formulations) applied, raising doubts as to whether much is based upon scientific research.
- Guidelines for interpretation of leaf analysis given in RB209 (8^{th} edition) were based on leaves sampled in mid-August. Some growers and agronomists are now using early leaf and sap analysis; however, there were no guidelines in RB209 for interpreting these analysis.
- Growers are increasingly using fertigation, in intensive (Fruit Wall) systems. The 8^{th} edition of RB209 referred to fertigation of young apple trees; however we consider that if a grower had a fertigation system in place nowadays that it would be likely to be used for the life of the orchard and not just for the young trees.
- There has been a modernisation of the cherry industry with an increase in new plantings under polythene with fertigation.

For soft fruit, there has been an increase in fertigation of soil grown crop. Furthermore, over the last 10 years there has been a shift in production away from soil-grown to in-substrate production. As a result a high proportion of strawberries, raspberries, blackberries and blueberries are grown in substrates.

Nitrogen

The N recommendations for established top fruit and established soft bush/cane fruit in the 8^{th} edition of RB209 had not been revised since 6^{th} Edition. RB209 6^{th} Edition changed the structure of the N recommendations for fruit to give N recommendations for different soil types rather than for high and low rainfall areas. However, the quantity of N recommended in the 8^{th} edition was broadly similar to recommendations in the first (1973) Edition of RB209 (Table 18). The exception is for strawberries, where the recommendations were revised in the 6^{th} Edition; N recommendations remained the same at SNS Index 0, but were increased at SNS indices 2-4.

In RB209 (8^{th} edition) N recommendations for top fruit were given for both grass/herbicide strip and overall grass management. Overall grass management remains in traditional orchards, however the majority of orchards are under grass/herbicide strip management. Overall herbicide management has now largely been phased out, mainly due to environmental concerns, and N recommendations for overall herbicide management systems were removed from the 8^{th} edition of RB209.

Table 18. Comparison of N recommendations for established top and soft bush/cane fruit in 8th and 1st editions of RB209.

	8th edition RB209 (2010)	1st edition RB209 (1973)	
		Low rainfall (<355 mm)	High rainfall (>355 mm)
Established top fruit – grass/herbicide strip management (kg N/ha)			
Desert apples	30-80	75	50
Culinary & cider apples	60-110	125	88
Cherries	90-140	112	75
Pears & plums	90-140	150	100
Established soft bush/cane fruit (kg N/ha)			
Blackcurrants	110-160	150	75
Other soft bush/cane fruit	70-120	100	50

The 8th edition of RB209 stated that for grass/herbicide strip management the N recommendations '*are for the complete orchard area and should be reduced pro-rata where nitrogen is applied to the herbicide strip only'*. Most growers will not want to apply N fertiliser to the grass strip and providing they have suitable application equipment are likely to target fertiliser applications to the herbicide strip. However, this guidance in RB209 (8th edition) has caused confusion among agronomists and growers and clarification would be useful.

This guidance was included as a footnote to the top fruit N recommendation table in 7th edition. Prior to that the 6th edition included the following guidance within the text:

"In grass alley/herbicide strip orchards the tree roots are largely confined to the strip and fertiliser should be applied to the herbicide strip only. Therefore the rate per treated area should remain the same but the overall fertiliser use is reduced."

The 3rd, 4th and 5th editions included similar guidance:

"In the grass alley/herbicide strip orchards the tree roots are largely confined to the strip and fertiliser can be applied to the herbicide strip only. The amount applied should be reduced proportionally."

Clarification was sought from individuals involved in previous revisions of RB209. As noted earlier, the N recommendations for top fruit have changed little since the first edition of RB209 and the advice for further reductions for band application to the herbicide strip came later (in 3rd edition). This advice was based on the results of David Atkinson's work in the 1970's at East Malling showing that tree roots are pre-dominantly within the herbicide strip area. Those involved in previous revisions of RB209 were happy with the advice for herbicide strip orchards to reduce inputs proportionally according to strip area (Mike Marks, Pers. Comm., May 2016) and there is no evidence on which to change this advice.

Recommendations:

- Update the wording of the current footnote for top fruit N recommendations to –
  "In grass alley/herbicide strip orchards the tree roots are largely confined to the strip and fertiliser can be applied to the herbicide strip only. The nitrogen recommendations given here are for the complete orchard area and should be reduced proportionally where nitrogen is applied to the herbicide strip only."

Phosphate and potash

The principle of P and K fertiliser use for fruit is understood to be to replace crop uptake (for establishment) or offtake (for established crops) at the target soil Index with an Index adjustment where the soil is below the target soil Index. For fruit, RB209 (8^{th} edition) gave recommendations to maintain soil indices at P and K indices of 2 and 3 (i.e. the same recommendations are given at both Index 2 and Index 3). The RB209 8^{th} edition P, K and Mg recommendations for fruit had not been updated since the 2^{nd} Edition (1979).

For phosphate, the recommendations for establishment used the Index adjustments of +150 and +50 kg P_2O_5/ha at Index 0 and 1, respectively. For established top fruit, the Index adjustments were +20 and + 60 kg P_2O_5/ha at Index 0 and 1, respectively, and for soft fruit were +20 and + 60 kg P_2O_5/ha at Index 0 and 1, respectively. There were no P recommendations at Index 4.

For potash, the recommendations for establishment used the Index adjustments of +150 and +50 kg K_2O/ha at Index 0 and 1, respectively. For established fruit, the Index adjustments were +60 or 70 and +130 or 140 kg K_2O/ha at Index 0 and 1, respectively. There was a recommendation of 60 kg K_2O/ha at Index 3 for soft bush/cane fruit (excluding blackberries).

Data on typical crop yields and crop phosphate and potash content has been collated (where available) to calculate typical crop phosphate (**Table *19***) and potash offtake (**Table *20***). A comparison of phosphate and potash recommendations at target soil indices with typical crop offtakes shows that 8^{th} edition recommendations are sufficient to replace crop offtakes (at the target indices), with 'surpluses' of 12-37 kg P_2O_5/ha and 16-103 kg K_2O/ha per year.

This advice to adjust fertiliser application rates pro-rata where fertiliser is applied to the herbicide strip area only was also included for the P, K and Mg recommendations. Unlike for N, RB209 (8^{th} edition) did not give different P and K recommendations for grass/herbicide strip management and overall grass management. As discussed above, the principles of P, K and Mg fertilisation is to replace crop offtake at the target soil Index, therefore we consider that the recommended P, K and Mg rates should not be reduced if the fertiliser is banded.

Recommendations:

- Remove the guidance to adjust P, K and Mg applications pro-rata where fertiliser is applied to the herbicide strip only.

Table 19. Top fruit and soft fruit phosphate recommendations in RB209 (8th edition) and crop phosphate offtake.

Crop	P recommendation (kg P_2O_5/ha)						Yield (t/ha FW)	P_2O_5 (kg/t FW)	P_2O_5 offtake (kg/ha)	Target Index Rec –offtake
	Index 0	Index 1	Index 2	Index 3	Index 4	Index 5				
Top fruit, before planting	200	100	**50**	**50**	0	0	*	*	*	*
Apples, dessert	80	40	**20**	**20**	0	0	30[c]	0.2[e]	6	+14
Apples, culinary							30[c]	0.2[e]	6	+14
Apples, cider							40[c]	0.2[e]	8	+12
Pears							15[c]	0.3[e]	4.5	+16
Cherries							6[c]	0.4[e]	2.4	+18
Plums							15[c]	0.2[e]	3	+17
Soft fruit, before planting	200	100	**50**	**50**	0	0	*	*	*	*
Blackcurrants	110	70	**40**	**40**	0	0	6.5[c]	1.4[e]	9.1	+31
Redcurrants							*	*	*	*
Gooseberries							*	*	*	*
Raspberries							9.3[c]	0.3[e]	2.8	+37
Loganberries							*	*	*	*
Tayberries							*	*	*	*
Blackberries							*	*	*	*
Strawberries							20.5[c]	0.4[e]	8.2	+32

- Source of yield data: [a] RB209 8th edition Appendix 10; [b] Trial data; [c] Provided by industry; * No data
- Source of P_2O_5 offtake data: [d] RB209 8th edition Appendix 5; [e] USDA crop offtake database (www.plants.usda.gov/npk/main); * No data

Table 20. Top fruit and soft fruit phosphate potash recommendations in RB209 (8th edition) and crop potash offtake.

Crop	K recommendation (kg K_2O/ha)						Yield (t/ha FW)	K_2O (kg/t FW)	K_2O offtake (kg/ha)	Index 2 Rec –offtake
	Index 0	Index 1	Index 2-	Index 2+	Index 3	Index 4				
Top fruit, before planting	200	100	50	50	0	0	*	*	*	*
Apples, dessert	220	150	80	80	0	0	30[c]	1.6[e]	48	+32
Apples, culinary							30[c]	1.6[e]	48	+32
Apples, cider							40[c]	1.6[e]	64	+16
Pears							15[c]	1.6[e]	24	+56
Cherries							6[c]	2.6[e]	16	+64
Plums							15[c]	2.1	32	+49
Soft fruit, before planting	200	100	50	50	0	0	*	*	*	*
Blackcurrants	250	180	120	120	60	0	6.5[c]	3.9[e]	25	+95
Redcurrants							*	*	*	*
Gooseberries							*	*	*	*
Raspberries							9.3[c]	1.8[e]	17	+103
Loganberries							*	*	*	*
Tayberries							*	*	*	*
Blackberries	220	150	80	80	0	0	*	*	*	*
Strawberries							20.5[c]	2.1[e]	43	+37

- Source of yield data: [a] RB209 8th edition Appendix 10; [b] Trial data; [c] Provided by industry; * No data
- Source of K_2O offtake data: [d] RB209 8th edition Appendix 5; [e] USDA crop offtake database (www.plants.usda.gov/npk/main); * No data

Sulphur

The 8th edition of RB209 did not include S recommendations for fruit crops or mention the potential need for S for fruit crops. There has been no work in the UK looking at the S requirements of fruit and we are not aware of anecdotal reports of S deficiency in fruit. However some growers are now questioning whether in view of the continuing decline in atmospheric S deposition (section 4.3.4) there is a need to apply S.

In the absence of UK field experiments to quantify the S requirement of fruit, the relationship between N and S can be used as an indication of the likely S requirement. The N:S ratio in most crops is fairly consistent at around 12:1, and therefore the S requirement can be estimated as one twelfth of the crop N requirement. Based on this relationship, an established fruit crop requiring 100 kg N/ha would require 8.3 kg S/ha (equivalent to 19 kg SO_3/ha).

Recommendations:

- There is a lack of evidence on which to base S recommendations for fruit. However, against a back drop of declining atmospheric S emissions we recommend including the following guidance on S at the start of the Fruit section:

  "Fruit crops are not generally thought to be responsive to sulphur. However, atmospheric sulphur emissions have declined significantly and a yield response to sulphur is possible in some circumstances. Where sulphur deficiency has been recognised or is expected, apply 15-25 kg SO_3/ha. Sulphur should be applied as a sulphate containing fertiliser in the spring. Crops are most at risk of sulphur deficiency where they are grown on light sandy soils, soils with a low organic matter content, and in high rainfall areas. Further guidance on sulphur can be found in the Principles section."

5.4. Recent research relevant to specific crops

5.4.1. Top fruit

Apples

H-UK/HONE Project *'More sustainable orchards trials. Determine optimum nitrogen rates on apple trees and effect of twin N nitrifying bacteria on yields'* aimed to determine the optimum N rate for cider apples. The project tested the effects of five N application rates (0, 50, 100, 150 and 200 kg N/ha) at three sites over three years. Due to large variabilities in yields between sites, treatments and replicates, the project was unable to determine optimum N rates; leaf and fruit analysis indicated that other nutrients may have been limiting yields. The project also measured SMN at each site at the beginning and end of each season. Soil mineral N levels varied between sites and years, but were fairly consistently; about 100 kg/ha lower at the end of the season than at the beginning.

Soil mineral N testing is generally of most value where SMN levels are likely to be high or uncertain. Where SMN levels are high at the beginning of the season growers can reduce their fertiliser N use.

However, SMN testing is not recommended in RB209 for fruit and as N recommendations are not split by SNS Index growers may have difficulty in interpreting the results of SMN analysis.

The current on-going AHDB Horticulture project TF 214 '*Improving nitrogen use efficiency, sustainability and fruit quality in high density apple orchards*' aims to compare the efficiency of broadcast nitrogen fertiliser application with commercial fertigation/irrigation. Treatments include zero N control, 60 kg N/ha broadcast applied, and 60 and 25 kg N/ha applied via fertigation. The project is on-going and may be suitable to inform a future revision of RB209 (i.e. 10th edition in 2019 or later).

A recent review by Colgan and Rees (2015) examined the future research needs for improving the storage quality of UK Apples and Pears including factors that influence the uptake of calcium (Ca) into apples and storage requirements for existing and new apple varieties. Calcium is an essential nutrient for maintaining fruit quality during storage. Bitter pit, water core and general tissue senescence in apples are all associated with low concentrations of Ca in the fruit. Foliar Ca sprays are generally more effective at increasing fruit Ca concentrations than soil applied Ca, and Ca sprays are routinely used on apples for storage.

Minimum concentrations of mineral nutrients for Cox and Bramley fruit were given in the 8th edition of RB209 and The Best Practice Guide for Apple Production (AHDB Horticulture, 2010). Although these standards were developed for Cox and Bramley, in the absence of additional experiments they have also been applied to more recently introduced apple varieties. Colgan and Rees (2015) identified a number of key research needs including:

- Identifying the optimum Ca concentration for Gala and Braeburn for long-term storage.
- Determining the optimum length of spray programmes on maximum Ca distribution in fruit and the influence of available free Ca on bitter pit and other low Ca disorders (i.e. diffuse core browning in Braeburn).

The 8th edition of RB209 included advice that Ca deficiencies can be corrected by foliar sprays of Ca, however guidance on Ca application rates or timings was not given. The Best Practice Guide for Apple Production (AHDB Horticulture, 2010) provides more detailed advice on modifying tree nutrition for optimal storage quality, including rates and timings for Ca sprays.

The literature review identified seven papers and one MSc thesis which from the titles and abstracts suggested they contained information relevant to RB209; four experiments looking at the effect of N supply (from USA, Denmark, Poland and Canada), one experiment looking at the effect of foliar N and Ca sprays (USA), one experiment looking at the effect of P applications (USA) and two studies which measured whole tree nutrient uptake (USA and South Africa). A number of these studies report results from experiments using apple varieties not commercially grown in the UK (i.e. Fuji), however the main conclusions of this work may still be relevant to UK growers and these studies are therefore included as part of this review.

The N requirements of tree fruit are relatively low and a response to applied N will depend on background SMN concentrations; whilst some studies report a positive yield response to applied N, others showed no effect. Although it may be necessary to apply N to maximise yields, over application of N can negatively affect fruit quality. Wrona (2011) found no effect on yields of 'Jonagored' apples (grown on M.9 rootstock in Poland) of annual applications of between 0 and 100 kg N/ha from planting in 2000 to 2009. Similarly, Neilsen *et al.* (2009) found no effect on yield of 'low' and 'high' annual applications of N equivalent to *c*.22 kg N/ha and 122 kg N/ha, respectively on cultivars Ambrosia, Cameo, Fuji, Gala and Silken grown on M.9 rootstock in Canada, when averaged over the first six growing seasons. However, Neilsen *et al*. (2009) found that the higher N application rate was associated with a decline in fruit quality including decreases in fruit firmness and at a high crop load, reductions in percent red colour.

In contrast, studies by Wang and Cheng (2011) and Kühn *et al*. (2011) showed yield increases from applied N. Wang and Cheng (2011) assessed the effect of four N rates (8.8, 26.4, 52.7 and 105.4 g N per tree) on yield and quality of 'Gala' apples grown on M.26 rootstock in USA and found that application of N increased yields, but decreased fruit quality. The trees receiving the lowest N supply had lower yields (17.8 kg/tree), smaller fruit and lower soluble solids, but firmer fruit than those receiving higher N amounts; yields increased from 17.8 kg/tree at the lowest N application rate to a maximum of 20.9 kg/tree at 52.8 g N per tree.

In the experiment by Kühn *et al*. (2011) in Denmark, 'Pigeon' apples were grown with five N fertigation rates (14, 42, 70, 112 and 224 mg N/l irrigation water – equivalent to 10.4, 29.8, 49.4, 77.8 and 152 kg N/ha) and three widths of herbicide strip (0.2, 0.5 and 1.0 m). Fruit yield was influenced by both N rate and width of the herbicide strip; on the two narrower strips (0.2 and 0.5 m) the highest yields were obtained with fertigation levels of 112-224 mg N/l, whilst on the widest herbicide strip (1.0 m) yield did not vary between 70 and 224 mg N/l. Kühn *et al.* (2011) showed that the wider the herbicide strip, the lower the N fertigation rate necessary for optimal fruit production. The study also showed that increasing the N application rate delayed picking time and that excess N fertigation (at 224 mg N/l) increased vegetative growth and reduced fruit colouration.

Fallahi and Eichert (2013) reviewed the mechanisms of foliar nutrient uptake and reported results from experiments assessing the effectiveness of foliar application of Ca and foliar compared to soil applications of N in 'Fuji' apples grown in the USA. Fallahi and Eichert (2013) concluded that both N and Ca can be applied as foliar sprays, however N should also be applied to the soil as the N requirements of the apple tree are unlikely to be met through foliar N applications alone. The authors also concluded that foliar applications of Ca in the form of calcium chloride ($CaCl_2$) can be as effective as more expensive chelated Ca sprays.

The literature review identified one experiment examining the response of apples to applied P; Neilsen *et al*. (2008) assessed the effect of annual fertigation at bloom time of 20 g P/tree compared to no P fertiliser on cultivars Ambrosia, Cameo, Fuji, Gala and Silken grown on M.9 rootstock in

Canada. The application of P in irrigation water resulted in a 20% increase in cumulative yield across all cultivars during the first five fruiting seasons. Leaf and fruit P concentrations were consistently increased by the P fertiliser with few differences among the cultivars. The response of apples to applied P will depend on the quantity of available P in the soil. Neilsen *et al*. (2008) measured KCl extractable P concentrations of <1 mg P/kg in the soil; although a KCl extract is not directly comparable to an Olsen's extract (used as the basis for fertiliser recommendations in RB209), this does indicate very low P availability in the soil. Although this study demonstrates a yield response to P, it did not assess the effect of P application rate. The application rate used (20 g P/tree) is equivalent to 153 kg P_2O_5/ha (based on a planting density of 3 m between rows and 1 m between trees) and is higher than recommended in the 8th edition of RB209 (80 kg P_2O_5/ha at P Index 0). Neilsen *et al*. (2008) concluded that the best apple performance was associated with leaf P concentrations above 0.22% and fruit concentrations between 10 and 12 mg P/100 g fresh weight, which are comparable to RB209 (8th edition) recommended 'satisfactory' P concentrations (0.20-0.25% P in Cox leaves, 0.18-0.23% P in Bramley leaves, and 9-12 mg P/100g fresh weight in fruit).

Cheng and Raba (2009) measured nutrient uptake of six year old 'Gala' apple trees grown on M.26 rootstock in a sand culture with optimal fertigation (USA). The authors used sequential excavation of whole trees combined with ^{15}N labelling of the current season's N supply to determine nutrient uptake. The net accumulation of N, P, K, Ca, Mg and S from bud break to fruit harvest was 19.8, 3.33, 36.0, 14.2, 4.4 and 1.6 g/tree, respectively. Analysis of ^{15}N uptake showed that most of the N demand by new growth at bloom was provided by tree reserve N; remobilisation of N from perennial parts of the tree was found to support rapid fruit expansion from the end of shoot growth to fruit harvest. The most rapid uptake from current season's N supply occurred from bloom to the end of shoot growth, corresponding to the highest tree N demand.

In a similar experiment in South Africa, Kengueehi (2008) measured nutrient uptake of two and three year old 'Gala' apple trees. The net accumulation of N, P, K, Ca, Mg and S in the two year old trees was 29.2, 3.5, 19.3, 18.4, 3.6 and 1.7 g/tree, respectively – generally similar (although lower K) to the values reported by Cheng and Raba (2009). Kengueehi (2008) calculated the nutrient requirements of the two year old trees taking into account nutrient export in fruit, leaf fall and pruning as well as nutrient uptake into the tree as 34.5, 3.7, 23.8, 23.9, 5.8 and 1.8 g/tree of N, P, K, Ca, Mg and S, respectively.

Pears

AHDB Horticulture project TF 198 '*Developing water and fertiliser saving strategies to improve fruit quality and sustainability of irrigated high-intensity, modern and traditional pear production'* aimed to developed irrigation scheduling regimes for intensive pear orchards to increase water and nutrient use efficiency and reduce leaching without reducing Class 1 yields or quality. The project developed a 'low risk' irrigation strategy to schedule irrigation once the lower irrigation set point of 120 kPa was reached. Since trees were fertigated at each irrigation event, the total amount of macro and micro nutrients applied were reduced in proportion to the irrigation volume. The irrigation test regime delivered water and nutrient savings of between 62 and 85% compared to the commercial controls and class 1 yields and fruit quality were maintained or improved.

This project highlights the potential of improved fertigation to improve nutrient use efficiency and reduce overall fertiliser use in orchards. However, it is not possible from the results of this project to give advice on reductions in fertiliser use from improved fertigation. Although efficient fertigation has the potential to improve nutrient use efficiency, long term reduced application of P, K and Mg (below that required to replace crop nutrient offtake) may lead to a reduction in soil indices and potential yield penalty.

The literature review identified three papers which from the titles and abstracts suggested they contained information relevant to RB209; one experiment looking at the effect of fertiliser application method (Oregon, USA) and two Polish experiments looking at the effect of foliar Ca sprays.

Yin *et al*. (2009) conducted a field experiment from 2005 to 2006 in Oregon, USA to evaluate the effects of split fertigation and band placement of N and P compared to conventional surface broadcast application in 'Anjou' pears. Treatments included (i) broadcast application of N and P on the soil surface in the 10 foot wide weed free strip centred on the tree rows, (ii) band placement of N and P on both sides of tree rows in 1 x 1 foot ditches (width x depth) and (iii) fertigation of N and P split into five equal applications during the growing season. Fertiliser N and P was applied at a rate of 112 kg N/ha and 141 kg P_2O_5/ha for the surface broadcast and band placement treatments, and at 90 kg N/ha and 113 kg P_2O_5/ha for the fertigation treatment. Split fertigation and band placement increased leaf N concentration and increased marketable fruit yield by 21% (split fertigation) and 11% (band placement), due to a combination of slightly higher overall yields and reduced fruit superficial scald during cold storage. Overall, the authors conclude that split fertigation at 80% of recommended N and P application rates for broadcast application can provide adequate N and P nutrition for bearing pear trees over the long run. This is consistent with advice in RB209 (8th edition) that fertigation will allow fertiliser rates to be reduced compared to surface broadcast, although guidance in RB209 (8^{th} edition) was that fertiliser rates may be reduced by up to 50%.

Gąstol and Domagala-Świątkiewicz (2009) carried out an experiment in Poland in 2004 and 2005 to examine the effects of different foliar Ca sprays on the mineral composition of 'Conference' pears. Calcium plays an important role in quality and storability of both apples and pears and in some countries Ca sprays are recommended to improve fruit quality and storability. Treatments included four different Ca sprays applied five times at two week intervals followed by five at one week intervals. The Ca sprays increased fruit Ca content from 9.2 mg Ca/100g fresh weight on the untreated control to a mean of 10.5 mg Ca/100 g fresh weight in 2004 and from 7.6 mg Ca/100g fresh weight on the untreated control to a mean of 9.5 mg Ca/100 g fresh weight in 2005. The authors noted that environmental factors during the season had a significant impact on the efficiency of the foliar sprays and that macronutrient uptake was strongly year dependent.

Wójcik *et al*. (2014) also looked at the effects of foliar Ca sprays on the quality and storability of 'Conference' pears in a separate study in Poland. The results of the study showed that for mature 'Conference' pear trees, $CaCl_2$ sprays in the summer (five spray treatments during the period of 6-14 weeks after full bloom at rates of 2-5 kg $CaCl_2$/ha) plus in the autumn (one application applied 7 days before harvest) at a rate of 20-25 kg $CaCl_2$/ha improved fruit Ca status and simultaneously inhibited pear ripening. The authors conclude that pre-harvest fall sprays of $CaCl_2$ a high rates (20-25 kg $CaCl_2$/ha) are a valuable supplement to summer Ca sprays and should be recommended in 'Conference' pear orchards to improve fruit storability, particularly to reduce internal browning.

These results are potentially of interest to UK growers, however detailed guidance on Ca sprays is currently beyond the scope of guidance within RB209. The 8^{th} edition of RB209 included guidance on interpreting apple fruit analysis (but not pear fruit analysis), including advice that Ca deficiencies can be corrected by foliar sprays of Ca, however more detailed guidance on application rates or timings is not given.

Cherries

The literature review identified four papers which from the titles and abstracts suggested they contained information relevant to RB209; one experiment looking at the effect postharvest foliar nutrient sprays (Poland) and three studies (from Poland, Hungary and Serbia) which included measurement of leaf nutrient concentrations.

Wójcik and Morgaś (2015) examined the effect of postharvest foliar sprays of N, boron and zinc on mature 'Schattenmorelle' sour cherry during 2008-2010 in Poland. Foliar nutrient sprays are used by some growers to improve tree nutrition; sprays can be applied either pre- or post-harvest. This study was designed to assess the effectiveness of post-harvest sprays. The cherries were sprayed with boric acid-B, ethylenediaminetetraacetic acid (EDTA)-Zn, and urea-N at 40–50 days prior to initiation of leaf fall including the following treatments: (i) spray of N at a rate of 23 kg N/ha; (ii) spray of boron and zinc at doses of 1.1 kg B/ha and 0.5 kg Zn/ha. The study found that post-harvest boron sprays were effective in increasing the boron status in cherry flowers, however post-harvest sprays of N and zinc did not improve tree nitrogen or boron status in the following season. The 8^{th} edition of RB209 advised that confirmed deficiency of boron or zinc can be treated with foliar sprays, however no guidance is given on application rates or timings.

Pacholak *et al*. (2011), looked at the effect of N fertilisation on leaf nutrient concentration of cherries of the 'Lutowka' cultivar type IR2 between 2002 and 2009 in Poland. Hrotkó *et al*. (2014) carried out a four year study in Hungary looking at the effect of different rootstocks on the nutrient concentration of sweet cherry leaves in high density orchards of the cultivars 'Petrus' and 'Rita'. Similarly, Milošević *et a*l. (2015) measured leaf nutrient status of four sweet cherry cultivars (May Early, Germersdorfer, Sunburst and Celeste) in Serbia. Table 21 shows the range of mean leaf nutrient concentrations measured by Pacholak *et al.* (2011), Hrotkó *et al*. (2014) (for the different rootstocks) and Milošević *et al*. (2015) (for the different cultivars), and compares these values to the values given in the 8th edition of RB209 as the 'satisfactory nutrient range'.

Table 21. Leaf analysis – range of concentrations reported by Pacholak et al. (2011), Hrotkó et al. (2014) and Milošević et al. (2015) for cherry leaves compared to 'satisfactory range' given in RB209 (8th edition).

Nutrient	Pacholak *et al*. (2011)	Hrotkó *et al.* (2014)	Milošević *et al.* (2015)	RB209 (8th edition) satisfactory range
	% in dry matter			
Nitrogen	1.8-2.7	1.7-2.9	2.6-3.4	2.4-2.8
Phosphorus	0.17-0.30	0.19-0.30	0.20-0.27	0.20-0.25
Potassium	1.2-1.5	0.8-1.7	1.0-1.2	1.5-2.0
Magnesium	0.45-0.64	0.45-0.75	0.28-0.41	0.20-0.25
	mg/kg in dry matter			
Manganese	*	30-45	15-49	30-100
Boron	*	34-44	19-23	20-40
Zinc	*	11-13	14-24	15-30
Copper	*	6-9	12-21	7-15
Iron	*	86-110	119-172	45-250

Leaf nutrient concentrations reported by the three studies were generally within the 'satisfactory' range given by RB209 (8th edition) for N and P, below the 'satisfactory' range for K and above the 'satisfactory' range for Mg. Pacholak *et al.* (2011) found that leaf nutrient content depended on fertilisation, the age of the trees and seasonal weather conditions; N fertilisation increased leaf N content and decreased leaf P and Mg contents, whilst older trees had higher leaf N concentrations, but lower leaf P and K concentrations. Hrotkó *et al*. (2014) found differences in leaf nutrient concentrations from the different rootstocks and concluded that rootstocks affect the uptake and supply of nutrients, and Milošević *et al*. (2015) concluded that the accumulation of leaf nutrients was cultivar dependent, but inconsistent. Whilst it is useful to compare the measured range of values with those given in RB209 (8th edition), as soil type and growing conditions will have a large impact on nutrient uptake, guidance to growers on satisfactory nutrient concentrations in leaves should ideally be based on research from the UK.

Recommendations - top fruit

- Include reference to the AHDB Horticulture Apple Best Practice Guide
  "For further information see AHDB Horticulture Apple Best Practice Guide. Please visit horticulture.ahdb.org.uk to download your copy".

- We recommend research to quantify the value of SMN sampling for fruit; this would provide evidence on which to give advice on the interpretation of SMN analysis for fruit in a future revision of RB209.
- Fertiliser recommendations for fruit have changed little since the first edition of RB209 in 1973 and there is a need for new research to clarify the nutrient requirements of modern top fruit varieties under current production systems.

5.4.2. Soft fruit

Blackcurrants

SF 012 '*Nitrogen requirements for blackcurrant processing crops'* presents a worldwide literature review of the N requirements of blackcurrant processing crops. The 8th edition RB209 recommendations for blackcurrants (110-160 kg N/ha depending on soil type) appear to be based on the work of Bould and subsequently Bradfield (1969) at Long Ashton Research Station. Since that work was carried out cultivars and growing systems have changed. In current commercial practice whilst adequate N nutrition is required to support growth and achieve optimum yields, excess N supply is avoided as it can lead to excessive vegetative growth which can shade fruit and thereby reduce fruit ascorbic acid concentration, reduce fruit sugars and increase soft rots. Although rates of up to 160 kg N/ha were recommended in the 8th edition of RB209, in practice almost all growers apply less – normally in the range 70-120 kg N/ha depending on soil type, variety and rainfall, the higher rates being applied to 'hungry' soils in the drier east, the lower rates being sufficient in the wetter west and north, where typically higher levels of rainfall improve utilisation. It should be noted that we have received comment from industry that the RB209 (8th edition) recommendation rates were too high and should be reduced to 70-120 kg N/ha (Rob Saunders and Harriet Roberts, Pers. Comm, May 2016). As we have no data to support this, we do not recommended a reduction in the recommended N rates at this time, however we suggest inclusion of the following footnote which has been discussed and agreed with Rob Saunders (Hutchinson's) and Harriet Roberts (Lucozade Ribena Suntory):

"For blackcurrants, varieties developed by James Hutton Ltd in the 'Ben' series typically require 70-120 kg N/ha. Higher nitrogen rates may reduce fruit quality for processing."

Commercially growers are advised to increase N rates where growth is inadequate and decrease rates where growth is excessive. The satisfactory nutrient range of N in blackcurrant leaves (fully expanded leaves on extension growth, sampled prior to harvest) given in the 8th edition of RB209 was 2.8-3.0% dry weight and was supported by two research reports by Farm Advisory Team Ltd to SmithKline Beecham (Cox, 1991; Anon, 1993). SF 012 also notes that leaf N concentration may offer a good means of checking that N supply is not substantially sub-optimal. This is consistent with advice in RB209 (8th edition) for N applications to soft bush/cane fruit which stated '*The rate should be adjusted according to the amount of growth required and the results of leaf N analysis*'.

SF 012 reported understanding of industry practice (in 2008) as being about half of the UK plantations managed with overall herbicide and the other half with grassed alleyways; today more like three quarters of plantations have grass alleys (Harriet Roberts, Pers. Comm, April 2016). When applying fertilisers the 8th edition RB209 guidance assumed it was common practice to apply compound fertilisers broadacre in mature plantations regardless of alleyway cover, except where fertigation is used; however, the majority of growers apply topdressings of N as a banded application to the herbicide strip beneath bushes at rates reduced from those published. SF 012 notes that blackcurrant roots can explore alleyway areas for nutrients. However, if there is adequate N supply within the row, then any competition for N between the alleyway vegetation and blackcurrant plants is likely to be of minor importance.

The 8th edition RB209 included the following guidance for N *'For blackcurrants, fertiliser should be applied to bare soil only or at rates increased to compensate for the grass'* – this guidance was inserted in the 8th Edition revision. It is not clear on what evidence this was included. SF 012, which was completed in 2008 prior to publication of the 8th edition of RB209, does not suggest N rates should be increased to compensate for the grass. Consultation with blackcurrant agronomists suggest that current practice (which is typically for lower N rates than recommended in the 8th edition of RB209) is to band apply and not to increase applications where there are grassed alleyway. Therefore, we recommend removing this sentence from the text.

The 8th edition of RB209 did not include recommendations on N application timing to blackcurrants. Nitrogen application timing is likely to affect availability for uptake. Larsen (1964) showed that uptake increased rapidly after bud burst and remained high until the end of July. Thus the period April to July is when applied N should be made available to the plant. Current commercial 'good practice' is to split N applications across 3 approximately equal applications timed for late dormant, May and post-harvest, or applied 66% at leafing-out and 33% post-harvest. This is supported by some Danish field trials carried out over five years which demonstrated that N supply in the spring and early summer is important for growth and yield in blackcurrants. However, supply after harvest coincides with a flush of root growth and contributes to better flower buds and thereby a better potential harvest the following year (Harriet Roberts, Pers. Comm, April 2016). We recommend including the following advice on N application timing *'For blackcurrants apply N in two or three applications, either split across 3 approximately equal applications timed for late dormant, May and post-harvest, or applied 66% at leafing-out and 33% post-harvest'*

SF 12 (221a) '*Blackcurrants: Evaluation of soil nitrogen assessments and the use of controlled release nitrogen fertilisers*' reports the results of a survey of SMN levels in 12 blackcurrant plantations in 2009 and 2010. Nitrogen recommendations for fruit vary according to soil type, but not according to soil N supply. An earlier survey by Marks (1995) showed that SMN levels could be quite high in blackcurrant plantations (mean SMN 165 kg/ha from a survey of 10 blackcurrant plantations in 1992). However, industry have reduced N applications rates to blackcurrants since 1992, and the average SMN reported by SF 12 (221a) was considerably lower at around 20 kg/ha in 2009 and 40 kg/ha in 2010. Based on these relatively modest SMN levels and the strong seasonal factors that can limit yields, SF 12 (221a) concludes that routine annual testing of soil N is not really justified, although ideally growers should be aware of typical SMN levels in their plantations.

Recommendations - blackcurrants

- Include blackcurrants in with the current foot note for Redcurrants etc. *'With continuing change in varieties, adjust nitrogen rates depending on plant vigour'*
- Include the following guidance as a footnote to the N applications for blackcurrants:
  "For blackcurrants, varieties developed by James Hutton Ltd in the 'Ben' series typically require 70-120 kg N/ha. Higher nitrogen rates may reduce fruit quality for processing."
- Remove the current guidance '*For blackcurrants, fertiliser should be applied to bare soil only or at rates increased to compensate for the grass'*
- Include the following guidance on N application timing:
  "'For blackcurrants apply N in two or three applications, either split across 3 approximately equal applications timed for late dormant, May and post-harvest, or applied 66% at leafing-out and 33% post-harvest"

Raspberries and blackberries

The literature review identified three papers, which from the titles and abstracts suggested they contained information relevant to RB209; one experiment from Sweden looking at the effect of N and K fertilisation on blackberry fruit quality, one study from the US looking at the seasonal variation in mineral nutrient content of blackberry leaves, and a literature review covering nutrition of both raspberries and blackberries.

Ali *et al*. (2011) conducted a glasshouse study in Sweden for one season where pot grown blackberries were fertilised with two levels of N (60 and 100 kg N/ha) and potash (80 and 125 kg K_2O/ha) and levels of nutrients and bioactive compounds in fruit and levels were measured. The authors note that high N availability has previously been considered to over-stimulate vegetative growth, often resulting in weaker fruit development and poor fruit set, reduced sugars and vitamin C. However, in this study there were no differences in berry yield between the different fertilisation rates and the high N supply was found to increase the total sugar content. Furthermore, the highest levels of vitamin C were found for treatments with high K, while high N only resulted in low content of vitamin C when the K level was low. The 'high' N level used in the study is within the range recommended by RB209 (8^{th} edition; 70-120 kg N/ha) and the 'high' potash level used is very close to the RB209 (8^{th} edition) recommendation at K Index 2 (120 kg K_2O/ha). Ali *et al*. (2011) conclude that by optimising plant nutrition, phytonutrient concentrations can be maximised and maintained in fresh and stored berry crops.

Strik and Bryla (2015) reviewed research and current guidance on the nutrition of raspberries and blackberries (mainly focussed on US production), including typical fertiliser N recommendations, nutrient uptake and partitioning within the plant and leaf nutrient analysis. Growers in the US typically base N fertiliser decisions on results of tissue analysis of primocane leaves taken in later July to early August, the results of soil analysis every few years, and observations of annual growth (cane number, diameter and height, and fruiting lateral length), yield, colour of leaves, and fruit quality (amount of rot and drupelet set). Research on N uptake has shown that floricane plants require fertiliser N in early spring for primocane growth and for growth of floricanes (fruiting laterals and fruit). Research has suggested that a split application of granular fertiliser N (first half about 1 week before primocane emergence and the second half about 1 month before first harvest) is best for maintaining current season yield and good primocane growth for next season's yield. The review also cited unpublished research which compared split broadcast fertiliser N application with fertigation every 2 weeks; in each case the plants were fertilised with *c*.80 kg N/ha per year and after two years there was very little difference in yield and leaf N concentrations between treatments.

Recommended N application rates in the US vary depending on raspberry/blackberry type and production region, but are typically around 30-60 kg N/ha in the establishment year and 55-90 kg N/ha for established crops, which is lower than the RB209 8th edition recommendations (range 70-120 kg N/ha). Strik and Bryla (2015) also collated recommended leaf nutrient sufficiency levels for raspberries and blackberries published in different regions of the US; these are similar to the 'satisfactory' range published in the 8th edition of RB209 (**Table *22***).

Table 22. Leaf nutrient sufficiency levels for raspberries and blackberries published in US guidance compared to 'satisfactory range' given in RB209 (8th edition).

Nutrient	Oregon[1]	California[2]	North eastern US[3]	RB209 (8th edition) satisfactory range
	% in dry matter			
Nitrogen	2.3-3.0	2.0-3.0	2.0-3.0	2.4-2.8
Phosphorus	0.19-0.45	0.25-0.40	0.25-0.40	0.20-0.25
Potassium	1.3-2.0	1.5-2.5	1.5-2.5	1.5-2.0
Magnesium	0.3-0.6	0.3-0.9	0.6-0.9	0.30-0.35
	mg/kg in dry matter			
Manganese	50-300	50-200	50-200	30-100
Boron	30-70	30-50	30-70	20-40
Zinc	15-50	20-50	20-50	15-30
Copper	6-20	7-50	6-20	7-15
Iron	60-250	50-200	60-250	45-250

[1].Hart *et al*. (2006); [2].Bolda *et al*. (2012); [3].Bushway *et al.* (2008)

Strawberries

The literature review identified four papers on the nutrition of soil grown strawberries, which from the titles and abstracts suggested they contained information relevant to RB209; two on sulphur (from USA) and two on boron (from Turkey and Brazil).

Santos (2010) and Santos (2012) reported the results from experiments looking at the response of soil grown strawberries to sulphur applied prior to planting. In the earlier study, Santos (2010) demonstrated an increase in fruit weight and number where S was applied, but did not assess the effect of S application rate. In the later study, Santos (2012) conducted an experiment to assess the effect of S application rate (equivalent to 0, 70, 140, 350, 560 and 770 kg SO_3/ha) and found that the 140 kg SO_3/ha application rate resulted in the highest strawberry fruit yield, root biomass and leaf greenness; there was no further benefit of applying S at higher application rates. It should be noted that 140 kg SO_3/ha is much higher than the application rates recommended in RB209 (8^{th} edition). The 8^{th} edition of RB209 did not include S recommendations for any fruit crops; the revised RB209 includes a suggested recommendation of 25 kg SO_3/ha where deficiency has been recognised or is expected.

Esringu *et al.* (2012) conducted a two year field experiment in Turkey to assess the optimum application rate of boron to strawberries. The authors note that many soils in Turkey are high pH and mico-nutrient deficiencies such as boron and iron have been shown in fruit crops. In this experiment boron was applied as Borax at rates of 0, 1, 3 and 9 kg B/ha. The application of boron increased strawberry yields and increased leaf tissue boron concentration from 2.3-3.3 to 25-29 mg B/kg. The authors estimated the economic optimum boron rate was 5.5 kg B/ha. In another study from Brazil, Lemiska *et al*. (2014) looked at the effects of applying B to the soil (at 0 and 4 kg B/ha) combined with foliar sprays of 0, 240, 480, 720 and 960 g B/ha) on strawberry growth and yields. Foliar application of B increased plant growth and fruit production, with maximum fruit production achieved with *c*.570 g B/ha. However, the application of 4 kg B/ha to the soil reduced root and shoot growth. Although both of these studies demonstrated a yield response to boron, the optimum application rate reported by Esringu *et al*. (2012) was above the level that resulted in yield reduction in the experiment of Lemiska *et al.* (2014). High applications of boron are known to be toxic to plant growth and these studies highlight the importance of correct application rates for the specific growing conditions. Boron deficiency is generally rare in UK fruit crops and RB209 8^{th} edition guidance was to treat deficiency with a foliar spray. Tissue analysis from the zero boron control treatment in the study by Lemiska *et al.* (2014) of 2.3-3.3 indicates severe deficiency; guidance within RB209 (8^{th} edition) suggested that the optimum range for tissue concentration of boron is 20-40 mg B/kg, with deficiency indicated below 15 mg B/kg.

Blueberries

The blueberry crop is relatively new to the UK with growers largely adopting pot grown production systems primarily because of problems associated with soil type and pH. The 8^{th} edition of RB209 did not include fertiliser recommendations for blueberries (although it did include guidance on interpreting leaf analysis). The Fresh Produce Crop Protocol for Blueberries recommends 50 kg N/ha, 10 kg P_2O_5/ha (at P Index 2) and 20 kg K_2O/ha (at K Index 2) for established plantations. Recent research on blueberry nutrition in the UK has focussed on pot grown blueberries (SF 137, section 5.4.3); the literature review did not identify any other UK research on blueberry nutrition. However research on blueberry nutrition and fertiliser recommendations are available from the main blueberry producing countries of the USA and Canada (accounting for >80% of world production) and Poland (which is the main European blueberry producer accounting for 3% of world production). The literature review identified nine papers, which from the titles and abstracts suggested they contained information relevant to RB209; five from USA, one from Canada and three from Poland.

Various studies have examined the effect of N fertiliser on the growth and yield of blueberries. Bryla and Machado (2011) and Bañados *et al.* (2012) report results from separate experiments in Oregon (USA) looking at the effect of N fertilisation (50, 100 and 150 kg N/ha application rates) on 'Bluecrop' blueberry growth. Both studies found that application of 50 kg N/ha produced the most growth, whereas application of 100 and 150 kg N/ha reduced plant growth and increased plant mortality, which in both studies was attributed to salt stress from the higher application rates of ammonium sulphate. The results of these studies are consistent with the 50 kg N/ha recommendation in the Fresh Crop Protocol and highlight the importance of not over applying N. In another study in Oregon, on 'Bluecrop' blueberries Vargas and Bryla (2015) compared N fertiliser application via fertigation with granular N fertiliser and found that yields were 12-40% greater where N was applied via fertigation.

In an experiment in British Columbia (Canada), Ehret *et al.* (2014) applied N at rates equivalent to 0-150% of current recommendations in the first 4 years after planting 'Duke' blueberries either with three equal applications of broadcast granular N fertiliser each spring or by fertigation through the drip irrigation system with 10 equal applications of liquid N injected every 2 weeks from early spring to late summer. Current recommendations in British Columbia are to increase N incrementally with plant size from 15 kg N/ha in the first year after planting up to 155 kg N/ha once plant reach full maturity at approximately 8 years (British Columbia Ministry of Agriculture and Lands, BCMAL, 2016). On average, plants produced 2.0 t/ha of fruit during the first year of production, 7 t/ha during the second year and 13 t/ha during the third year. Yield did not increase with rate of N application in the first year, but did so in the last two. Yield was also greater (by 15-19%) with fertigation than with broadcast fertiliser application in all years. The authors concluded that fertigation was the more effective method of N application producing more shoot growth and greater yields with less N than broadcast applications of fertiliser.

In Florida (USA), Williamson and Miller (2009) also observed an increase in growth from increasing fertiliser application rate. The authors conducted an experiment on 2-3 year old 'Misty' and 'Star' blueberry plants grown in pine bark beds on top of soil and found that canopy growth increased linearly as fertiliser rate increased up to the highest rate tested of 81 g N, 11.8 g P and 44.6 g K per plant per year.

In Poland, Glonek and Komosa (2013a) conducted a three year field experiment on a 10 year old 'Bluecrop' blueberry plantation. The effect of fertigation with three nutrient solutions (F1, F2 and F3) was investigated compared to drip irrigation (with no fertigation) on growth and yield. Nutrient solution F1 contained 100 mg N/l, 30 mg P/l and 60 mg K/l; nutrient solution F2 contained 50% more nutrients and F3 100% more. Fertigation was applied in addition to broadcast fertiliser application to maintain soil nutrient concentrations at recommended levels. Yield under the influence of drip fertigation (compared to drip irrigation) increased yields for F1 by 17.3%, F2 by 21.9% and F3 by 5.3%. Total nutrient application rates applied for treatments F1 and F2 (via both fertigation and spread fertiliser) were 19-24 g N/bush (80-100 kg N/ha), 10-12 g P/bush (95-115 kg P_2O_5/ha) and 7-10 g K/bush (50-60 kg K_2O/ha).

As part of the same study Glonek and Komosa (2013b) measured the effect of fertigation on leaf nutrient concentrations. Fertigation increased concentrations of N, K and Ca and decreased the concentration of Mg. Glonek and Komosa (2013b) compared measured nutrient concentrations of blueberry leaves to those given as guideline ranges by Eck (1988) and used mainly in the USA, and those given by Pliszka (2002) and commonly used in the Netherlands (**Table *23***). Guideline leaf nutrient sufficiency levels given by Eck (1988) and Pliszka (2002) are consistent with those given in the 8th edition of RB209 (**Table *23***). In a separate study in Oregon Strik and Vance (2015) examined the seasonal variation in leaf nutrient concentration and concluded that leaf samples for diagnosing plant nutrient status should be taken late-July to mid-August when most nutrients are fairly stable.

Table 23. Leaf nutrient sufficiency levels for blueberries given by Eck (1988) and Pliszka (2002), compared to measured values by Glonek and Komosa (2013) and 'satisfactory range' given in RB209 (8th edition).

Nutrient	Eck (1988) Guidelines used in USA	Pliszka (2002) Guidelines used in Netherlands	Glonek and Komosa (2013b)	RB209 (8th edition) satisfactory range
	% in dry matter			
Nitrogen	1.8-2.1	2.25-2.75	1.52-2.17	1.8-2.0
Phosphorus	0.12-0.40	0.20-0.30	0.16-0.39	0.08-0.4
Potassium	0.35-0.65	0.45-0.75	0.27-0.66	0.4-0.7
Magnesium	0.12-0.25	0.15-0.25	0.13-0.22	0.13-0.25
	mg/kg in dry matter			
Manganese	50-350	50-350	78-266	30-100
Boron	30-70	20-50	36-63	20-40
Zinc	8-30	10-30	8-14	15-30
Copper	5-20	8-20	2-5	7-15
Iron	60-200	60-200	43-61	45-250

In another study from Poland, Ochmian and Kozos (2014) examined the effect of foliar Ca fertilisers on the quality of fruits from two cultivars of highbush blueberry. At the fruit growth stage, bushes were sprayed four times with different Ca solutions every 10 days. All fertilisers caused an increase in the Ca concentration of fruit, although only two of the five Ca sprays improved fruit firmness

5.4.3. Substrate soft fruit production

The 8th edition of RB209 included recommendations for soil grown soft fruits. However, over the last 10 years there has been a change in practice, primarily due to problems of soil borne disease, for some sectors of the UK soft fruit industry away from in soil to in substrate production. As a result a high proportion of strawberries, raspberries, blackberries and blueberries grown for fresh fruit sale via the multiples are grown in substrates. Nutrient recommendations for substrate grown crops are given as a feed recipe and need to take into account the nutrient needs of the crop and the quality of the irrigation water, and in the case of crops with a plantation life of two or more years the amount of nutrients retained at the end of one growing season within a substrate & potentially available to a crop as a new growing season commences.

Recommendations for substrate strawberry production were included for the first time in the 8th edition of RB209, but there were no recommendations for in substrate grown raspberries, blackberries or blueberries. The recommendations for substrate strawberry production were based largely on research and recommendations derived by Philip Leiten at the Meerle Research Station in Belgium. There has been little or no recent research work on which to derive a complete and sound set of nutrient recommendations for other in substrate grown soft fruit. Most commercial growers of these crops base their fertigation on advice from the feed companies, who in turn draw on international work/practice in other countries. Most agronomists use the strawberry feed recipe for substrate raspberry production, however it is unclear whether this delivers the correct amount of N.

Recommendations – substrate soft fruit:

- AHDB consider inclusion of nutrient recommendations for substrate growth raspberries, blackberries & blueberries in a future revision of RB209 (i.e. 10th edition in 2019 or later). Recommendations would need to be based on new research.
- Recommendations for substrate grown raspberries could be derived from research to test the strawberry feed recipe with different N application regimes on raspberries.

Substrate grown strawberries

The advice and guidelines for nutrient solutions given in RB209 (8th edition) were based on guidance in AHDB Horticulture Factsheet 06/07 '*Principles of strawberry nutrition in soil-less substrates*'. Factsheet 06/07 gives advice on feed recipes for a typical Junebearer (Elsanta) and Everbearer crop grown in both peat and coir based media (Elsanta only) and for different stages of crop growth during the season (starter to first green fruit and fruiting). The guidelines for nutrient solution for substrate strawberry production given in RB209 (8th edition) covered the range of values given in Factsheet 06/07, but did not differentiate between different stages of growth.

In addition to Factsheet 06/07, the AHDB Horticulture Strawberry Feed Calculator is available to help growers to calculate the quantities of fertiliser required to achieve the target nutrient feed solution. Growers can enter analysis of their water supply and the calculator will work out the required volume of acid to add (to remove bicarbonate from the water) and the quantity of nutrients this will add. The Strawberry Feed Calculator can be used for both substrate and soil grown strawberry crops.

Current irrigation management guidelines for substrate growers given in Factsheet 06/07 are to irrigate to achieve 10% runoff and to feed continuously with each irrigation event. By irrigating to run-off, the grower ensures that the runoff and the conductivity in the growing media are maintained within a limit of no more than 10% higher than the input EC. Since the last revision of RB209, AHDB Horticulture projects SF 107 '*Managing water, nitrogen and calcium inputs to optimise flavour and shelf-life in soil-less strawberry production'* and SF 136 '*Improving water and fertiliser use efficiencies and fruit quality in commercial substrate strawberry production'* have investigated the potential to increase water and nutrient use efficiency in substrate grown strawberry production.

In AHDB Horticulture project SF 107, new techniques to save water and fertiliser use in substrate grown crops of 'Elsanta' and 'Sonata' were developed. An irrigation scheduling regime that matched water supply to demand, thereby eliminating run-off, was designed using irrigation set points based on plant responses to decreasing substrate moisture contents. In scientific experiments, water and fertiliser savings of 15% for Elsanta and 45% for Sonata were achieved without sacrificing any Class 1 yield, compared to a commercial 'control' regime where run-off averaged 20% over the season. Since nutrients were added at each irrigation event, the fertiliser and water savings were the same.

In the subsequent AHDB Horticulture project SF 136, this irrigation regime was tested on two commercial grower holdings. Irrigation was triggered irrigation automatically so that coir volumetric moisture contents were maintained between upper and lower set points, irrespective of changing evaporative demand. Water and fertiliser savings of 17% and 11% were achieved on the two grower holdings, whilst Class 1 yields were maintained and berry quality was improved.

The results from SF 107 and SF 136 suggest that significant water and fertiliser savings can be achieved in commercial substrate production without affecting berry size, Class 1 yields or fruit quality if irrigation is scheduled to match demand with supply.

The literature review identified two papers on the nutrition of substrate grown strawberries, which from the titles and abstracts suggested they contained information relevant to RB209. In addition a number of papers were identified looking at different substrate types; these are not summarised here as guidance on substrate type is beyond the scope of crop nutrition guidance within RB209.

Choi and Lee (2012) examined the effect of feed solution P concentration (0, 0.5, 1, 2,4 & 6 mM P, equivalent to 0, 15, 31, 62, 124 and 185 mg P/l) on micro-nutrient deficiencies and found that young leaves of plants grown with feed solution P levels higher than 2-4 mM P (equivalent to 62-124 mg/l P) developed interveinal chlorosis. RB209 8th edition recommendations for strawberry feed solution was for 46 mg P/l, which is below the level shown to induce micro-nutrient deficiency symptoms in this study.

Khayyat *et al.* (2013) studied the effect of supplementary K added to strawberry feed solution with high background sodium chloride concentrations. The authors demonstrated that high sodium chloride (35 mmol/l; equivalent to 2.04 g NaCl/l) in feed solutions can strongly affect the vegetative growth of strawberries and that supplementary K has the potential to moderate the negative effects of the sodium chloride. It should be noted that the sodium chloride concentration in the feed solution used by the authors is much higher than used in UK production, however, the study does demonstrate that plant nutrition can have an important effect on the ability of the plant to withstand stress and the results may be relevant to UK growers who have higher than optimum sodium chloride concentrations in irrigation water.

Recommendations:

- Include the following text in guidance on substrate strawberry production:
  "Careful scheduling of irrigation will help to improve water and nutrient use efficiencies. Recent work has shown savings of 10-20% where irrigation is scheduled to match demand with supply. Monitor substrate moisture content to establish which irrigation events can be reduced to save water and fertiliser.
- Include reference to the Factsheet 06/07 and the Strawberry Feed Calculator:
  "For further information see AHDB Horticulture Factsheet 06/07 Principles of strawberry nutrition in soil-less substrates and the AHDB Horticulture Strawberry Feed Calculator
- Consider updating AHDB Horticulture Factsheet 06/07 to include guidance on irrigation scheduling to improve water and nutrient use efficiencies.

Substrate grown raspberries

AHDB Horticulture project SF 118 '*Irrigation scheduling of raspberry as a tool for improving cane management'* aimed to improved water and nutrient use efficiencies in substrate grown raspberry production. The project showed that irrigation scheduling using coir volumetric moisture contents as set points delivered good marketable yields, reduced or eliminated run-through and optimised water and fertiliser inputs. The recommended advice given above on irrigation scheduling for substrate grown strawberries is applicable to all substrate grown soft fruit.

Two different nutrient solutions were used depending on whether the plants were in the vegetative or fruiting stage of growth; these feed solutions were formulated by an agronomist taking into account mineral analysis of the mains water. However, the project did not specifically look at nutrition of the crop and there is currently insufficient information on which to give recommendations for nutrient solution for substrate grown raspberries.

Substrate grown blueberries

As noted in Section 5.4.2, the blueberry crop is relatively new to the UK with growers largely adopting pot grown production systems. Blueberry bushes are usually fed using drip irrigation with a specific blueberry feed. AHDB Horticulture project SF 137 '*Timing of nitrogen applications to optimise growth and yield without adversely affecting fruit storability and frost sensitivity*' aimed to ascertain the effects of different N application regimes on growth, yield, storage and frost sensitivity of pot grown blueberries ('Duke' and 'Aurora') to address gaps in knowledge about the timing of and optimum N feed regimes. Although N is important for encouraging growth, high N applications during fruiting have been shown to reduce fruit firmness in a number of crops and may reduce storage life, and later N applications are believed to increase sensitivity to frost.

SF 137 investigated the effect of applying N at three concentrations to pot-grown blueberry plants and on varying the N concentration in the feed at three critical growth phases to see which N rate will maximise yields while reducing the risk of frost or cold injury to flowers or bushes. In the first year of the project (2012), a batch of container grown plants of varieties Duke and Aurora were given one of three rates of N (60, 120 and 180 mg/l N) between March and October. The second part of the project (2012-2015) then looked at the effect of increasing and decreasing N feed levels during three key phases of growth: early spring growth, fruiting and autumn flower initiation, compared to giving plants a low, standard, or high N rate throughout.

In general throughout the project there was little effect of varying feed N concentrations throughout the season or for periods within the season on any of the parameters measured for either variety, including vegetative growth, yield and fruit quality attributes. The project concluded that N feed concentrations of 60 mg/l appear to be adequate for pot grown commercial blueberries.

The results from SF 137 provide valuable information to growers on N applications to pot grown blueberries and this information is suitable for inclusion in RB209. However, if substrate grown blueberries were to be included in RB209, guidelines should also be given for the other macro and micro nutrient elements in the feed solution. SF 137 only looked at N and no information is given on the concentration of other nutrients in the feed solution.

Recommendations:

- Substrate grown blueberries not to be included in the next revision of RB209.
- Further work (review or experimental) to provide guidelines on other macro- and micro-nutrient concentrations in feed solution for substrate grown blueberries.

6. Gaps in knowledge and future research required

6.1. Knowledge gaps identified

6.1.1. Crops included within RB209

- Priority crops for inclusion within a future (i.e. 10th edition in 2019 or later) revision of RB209 are rhubarb and substrate grown raspberries, blackberries & blueberries. New work would be required before these crops could be included.

6.1.2. Knowledge gaps for specific nutrients

Phosphorus

- Efficiency of placed phosphate compared to broadcast phosphate – relevant to all field vegetable crops, but target research to poor rooting crops and responsive crops i.e. vining peas, sweetcorn.

Potash

- There has been no recent research on the potash response of field vegetable crops. Research is needed to quantify the optimum potash application rates to a range of field vegetables (i.e. brassica, legume and root crops) and to confirm whether the current target K Index of 2+ is appropriate/attainable on light textured soils.
- Collate more recent phosphate and potash crop removal figures for all field vegetable crops to provide accurate information on crop offtake on which growers can base their fertiliser decisions and to inform future revisions of RB209.

Sulphur

- There is a lack of research on the S requirements of field vegetables or fruit. Current S recommendations are based on an understanding of S requirements of arable crops. There is a need for S response experiment in a range of crops to quantify optimum S application rates.

6.1.3. Knowledge gaps for specific crops

Due to the large number of crops, many of which cover relatively small areas, there is a significant lack of recent research on the fertiliser requirements of many of the field vegetable crops and most fruit crops. Some research gaps have been identified for specific crops below, however this is by no means an exhaustive list.

Leeks

- FV 350 and FV 350a validated current RB209 N recommendations at low SNS Index sites, however there is a need to test these recommendations at higher SNS Index sites (Index 3 and above).
- Further work is required to understand the patterns of growth and N uptake of late leek maturity types, to confirm whether these should ultimately be reflected in separate recommendations in any future revision of RB209.

Vining peas

- FV 380 and FV 428 demonstrated that vining peas are response to phosphate at Index 2. This highlights a need to confirm whether RB209 (8^{th} and 9^{th} edition) recommendations are appropriate to achieve optimum yields of vining peas.

Herbs

- Review of crop nutrient offtake data for the range of herb species grown in the UK. The review should consider data available from the UK (from growers) and internationally (from countries where growing systems are similar to those in the UK) and can be used to help inform fertiliser use for other herb species (RB209 includes fertiliser recommendations for mint and coriander only).

Fruit

- Fertiliser recommendations for fruit have changed little since the first edition of RB209 in 1973 and there is a need for new research to clarify the nutrient requirements of modern soft and top fruit varieties under current production systems.
- Research to quantify the value of SMN sampling for fruit; this would provide evidence on which to give advice on the interpretation of SMN analysis for fruit in a future revision of RB209.

6.2. Current on-going research suitable to inform future revisions of RB209

The following on-going projects may provide evidence suitable to inform the next revision of RB209:

- CP103. The application of precision agronomy to UK production of Narcissus.

  Data on the effect of broadcast compared to placement of N fertiliser.

- CP 107c. The application of precision farming technologies to drive sustainable intensification in horticulture cropping systems.

  Field experiments looking at variable rate N will include N response experiments on two brassica crops.

- TF 214. Improving nitrogen use efficiency, sustainability and fruit quality in high-density apple orchards.

  Field experiments comparing N fertiliser applied via fertigation with broadcast application.

7. References

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Tim Casey & Philip Lilley (Leek Growers Association)

Tom Davis (British Herb Trade Association)

Appendix I – Organisations and individuals invited to submit data to inform the review

Organisations contacted as part of the wider review to request data relevant to all work packages

Agrii

Association of Independent Crop Consultants

CF Fertilisers

Ecopt

Frontier

Harper Adams University

HL Hutchinson's

International Fertilizer Society

James Hutton Institute

K&S Kali

Omex

Potash Development Association

Rothamsted Research

Rothamsted Research North Wyke

SOYL

SRUC

Teagasc

Yara

Organisations contacted to request data specific to WP6 Horticulture

AHDB Grower Associations

Allium and Brassica centre (Andy Richardson)

Barfoots (Neil Cairns/Nathan Dellicott)

Berry Gardens (Richard Harnden)

Berryworld (Tim Newton)

David Norman (independent agronomist)

Demeter Technology (Anne Noble)

DLV Plant (Dennis Wilson)

Elsom's (Robin Wood)

FAST (Tim Biddlecomb)

G's Growers (Ed Moorhouse / Emma Garfield)

Hortifeed (Chris Norris)

Huntapac (Andrew Molyneux)

Intercrop (Thane Goodrich)

Liz Johnson (independent agronomist)

Greentech (Phil Effingham)

Produce World (John Sedgwick)

RJM Agronomy Ltd (Robert Meakin)

Solufeed (Dick Holden)

Staples (James Morrell)

Tozer seeds (Alec Roberts)

Valley Produce (Chris Daking)

VCS Agronomy (Tom Will)

Vitacress (Andy Elworthy)

Appendix 2 – Fresh Produce Crop Protocols guidance on fertiliser rates for crops not in RB209

Fresh Produce Crop Protocols are available from http://assurance.redtractor.org.uk/standards/fresh-produce-crop-protocols

Celeriac

Soil Index	0	1	2	3	4	5	6
	kg/ha						
N	180	150	110	0	0	0	0
P_2O_5	250	200	125	100	50	0	0
K_2O	450	400	325	210	50	0	0
MgO	150	100	0	0	0	0	0

Chicory

Soil Index	0	1	2	3	4	5	6
	kg/ha						
N - all soils	75	40	0	0	0	0	0
N - peat soils	40	0	0	0	0	0	0
P_2O_5 - all soils	200	150	100	50	25	0	0
P_2O_5 - peat soils	250	200	125	100	50	0	0
K_2O	150	100	50	25	0	0	0
MgO -sands/light soils	100	50	30	0	0	0	0
MgO - other soils	60	60	30	0	0	0	0

Chinese cabbage/pak choi/choi sum

Soil Index	0	1	2	3	4	5	6
	kg/ha						
N - Chinese cabbage	340	300	260	220	170	60	0
N - Pak choi /choi sum	250	200	75	22	0	0	0
P_2O_5	200	150	100	50	0	0	0
K_2O	300	250	200 (2-) 150 (2+)	60	0	0	0
MgO	150	100	50	0	0	0	0

Garlic

SNS or soil Index	0	1	2	3	4	5	6
	kg/ha						
N - spring established	175	125	100	25	0	0	0
N - overwintered*	50	0	0	0	0	0	0
P	200	150	100	50	0	0	0
K	250	200	150 (2-) 100 (2+)	0	0	0	0
Mg	150	100	0	0	0	0	0

* Seedbed N is only required on mineral soils. Spring topdressing of up to 100 kg N/ha may be required.

Herbs

Crop	Timing	N	Timing	N	P_2O_5	K_2O
Basil	Before cut	100	After cut	75	125	125
Chives	Before cut	125	After cut	75	250	125
Dill	Before cut	75 + 75	After cut	75	125	125
Marjoram	Before cut	180	After cut	180	180	180
Mint	Before cut	90	After cut	80	60 to 125	125 to 180
Oregano	Before cut	180	After cut	180	125	125
Parsley	Before cut	60	After cut	125	30 to 90	50 to 125
Rosemary	Before cut	125	After cut	60	125	125
Sage	Before cut	125	After cut	60	30 to 90	90 to 180
Tarragon	Before cut	250	After cut	250	100	120
Thyme	Before cut	125	After cut	60	125	125

Notes: Fertiliser requirement will vary enormously with soil status, crop life and quality desired. It should be possible to revise some of the above rates, based on results from herb research, commissioned by AHDB Horticulture. This would be best done with your fertiliser advisor taking account of analyses for your growing site plus time of year. The initial work highlighted a need to be vigilant in the application of nitrogen as herb response varied from month to month and had clear effects on herb product shelf life.

Kale

Soil Index	0	1	2	3	4	5	6
	kg/ha						
N	240	210	180	140	90	50	0
P_2O_5	110	80	50	0	0	0	0
K_2O	260	230	200 (2-) 170 (2+)	130	0	0	0
MgO	150	100	0	0	0	0	0

Spinach

SNS Index	0	1	2	3	4	5	6
	kg/ha						
N	125	100	75	50	0	0	0
P_2O_5	250	200	150	100	50	0	0
K_2O	275	225	175 (2-) 125 (2+)	50	0	0	0
Mg	150	100	0	0	0	0	0

Notes: Nitrogen - Top dressing rates will vary between the requirement for a baby leaf crop and that of a mature spinach crop. Baby leaf crops will require less nitrogen than a mature full leaf crop. Baby leaf crops are defined as crops harvested between the cotyledon and 8 true leaf stage. As a general rule, no more than 100 kg N/ha should be applied as a top dressing for the first crop. Subsequent crops may require only half this amount of N. Nitrogen applications for over-wintered spinach should be applied only in the spring. For spring, summer and autumn crops applications should be made as close to the point of crop establishment as possible rather than later, towards the point of harvest.

Appendix 3 – Derivation and validation of the framework for estimating the fertiliser requirement of field vegetable crops (8th edition RB209)

Fertiliser Manual Decision Support Gap Filling (Field Vegetables) IF0150

Technical Document – Derivation and validation of the framework for estimating the fertiliser requirement of Field Vegetable Crops

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02/12/08

1. INTRODUCTION

It became clear in 2006 that the 7th edition of the National Fertiliser Recommendations, RB209, published by MAFF in 2000 was in need of revision. Consequently Defra have funded the revision with Professor Keith Goulding of Rothamsted Research in overall charge. Several sections are being revised and it is hoped that the new *Fertiliser Manual* will be available in spring 2009.

The field vegetables section has been revised by Dr Clive Rahn (University of Warwick) and Nigel MacDonald (ADAS) supported by an expert group consisting of representatives from the main commodity organisations, crop associations and HDC. Changes were needed to reflect increasing yield levels and to provide a transparent system for calculating fertiliser demand. The new recommendations are based on the best data available. The organisation of the recommendation tables remains the same but there are some differences which will be briefly explained here.

The largest changes have occurred with the N recommendations which are now based on a transparent framework linked to crop demands. This enables some adjustment of recommendations to take account of local conditions and crop type. The lack of recent field trial research testing N response of the great diversity of crops was problematic but overcome by asking a series of questions. These included making some assessment of commercial yields in practice, how much crop had to be grown in order to achieve such yields, what was the associated nitrogen content and where did that come from. These questions formed the basis for the framework for revised nitrogen recommendations.

The answers to these questions came from a variety of sources, with contributions from growers and the expert group. Experimental data some going back to the 1970s provided some fundamental information about the relationship between the size of the crop and its nitrogen off-take when optimally fertilised. It provided information on the relationship between marketable yield and whole crop yield at optimum N levels. Where data was not available from the UK it was sourced from overseas with data from a German recommendation system filling some gaps.

Some of the information used was already present in decision support models such as WELL_N and EURotate_N. In the new *fertiliser manual* the release of N from soil organic matter is explicitly taken into account. The models referred to above have provided estimates of the amounts supplied. Large amounts of nitrogen, around 120 kg/ha

N can be supplied from soil organic matter to long season crops such as Brussels sprouts. This is in contrast with short season crops such as lettuce where only 20 kg/ha N is supplied.

The amounts of nitrogen supplied by the incorporation of previous crop residues is taken into account in the SNS supply Index as in the previous version of RB209. The importance of the assessment of soil mineral nitrogen especially where brassica residues have been incorporated cannot be underestimated. Residues can contain over 200 kg/ha N and if well managed can provide most of the nitrogen need of the following crop. In dry winters on silt soils, SNS 4 or 5 can be achieved. Measures of soil mineral N taken at appropriate times can provide information on the ability of the soil to supply nitrogen. This is important in a wide range of conditions, in dry winters to confirm the amounts available but also after wet winters to check how much N is available in the root zone.

Vegetables have a range of rooting depths; some crops like brassica can be well in excess of 90 cm but others like salad onions might only root to 30 cm. Rooting depth can make a large difference to the ability of a crop to extract nitrogen, particularly from previously incorporated crop residues. The values used in the framework of the new *fertiliser manual* were estimated from yields and by comments from the expert panel, and data from experiments carried out in the UK and other parts of Europe.

In the new recommendations, greater allowance has been made for rooting depth and as a consequence the recommendations for shallow rooted crops at high N supply indices have been increased. Some crops have increased recommendations due to larger expected yields. High yields do not always mean more N fertiliser being required as increased rooting depth might make a larger supply of N available from the soil. Calabrese and cauliflower are dealt with separately as it was felt that the amount of N given to calabrese should be lower to reflect the high risk of spear rot. As a result of HDC and Defra funded work on overwinter brassica crops, more specific recommendations are provided in the new edition to support raising of the maximum proposed limits on N supply in the NVZ close periods. Another expert group has extended the manures section to include nutrient supply from a wider range of materials including composts.

The framework in the field vegetables section of the new *fertiliser manual* provides a set of recommendation tables that can be adjusted according to yield, crop rooting depth, previous crop residues and organic matter status. . Additionally the framework does allow flexibility for adding new crops or for more easily revising further editions of the recommendations.

The framework is described in more detail in Section 2 and its validation across crops and for individual crops is described in Section 3.

2. CALCULATION OF THE FERTILISER NITROGEN REQUIREMENT FOR FIELD VEGETABLE CROPS

Where sufficient data was available, the nitrogen fertiliser recommendations are based on a three step framework,

- **Size of the crop -** the size, frame, or weight of the crop needed to provide optimal economic production;
- **Nitrogen uptake -** the optimum nitrogen uptake associated with a crop of that size;
- **Supply of Nitrogen -** based on the N supply from the soil within rooting depth including the potential N mineralised from soil organic matter.

The data used within the framework was sourced from a database containing the properties of optimally fertilised crops taken from N response field experiments carried out in the UK since the 80s by WHRI or ADAS. The number of experiments per crop varied considerably. In some cases where insufficient data was available for this approach, data from Fink et al. (1999) and from the German KNS recommendation system (Carmen et al., 2007) was used to define the N uptake. The N uptake was then subsequently scaled for the UK estimate of yield. Where insufficient data was available for this approach, the recommendations were left as they were in the previous version of RB209.

Data for fresh weight marketable yields was based on the best data available which in most cases was the aforementioned sets of data but in some cases where the varieties and cropping practices led to increased productivity, the views of growers and the field vegetable expert group were taken into account.

SIZE OF CROP (t/ha dry weight yield)

Dry weight yield *= (Fresh weight yield * dm%/100)/dry weight-harvest Index*

Fresh weight yield (t/ha) – i.e the yield of marketable produce which is expected to be removed from the field in commercial practice.

Data for fresh weight marketable yields was based on field experiments or expert opinion for well grown crops. Marketable yield is defined as that removed from the field, and may be larger than data in Defra Horticultural Statistics which represents the yield after further packhouse grading..

Dry matter % = dry matter % of marketable produce for optimally fertilised crops.

In some cases the dry matter content of product was significantly related to marketable yield(x) For example as the yields of lettuce increased dry matter content (Y) of marketable product declined,

Lettuce Y = - 0.117x+10.6 (r2=0.66, n=15)

Leeks followed a different trend but this needs to be checked against more data before the next revision.

Leeks Y = 0.20x+4.8 (r2=0.36, n=8)

Dry weight-harvest Index – proportion of the whole crop that is taken for market expressed on a dry weight basis. – in onions 81% (0.81) of the green crop is bulb. For Brussels sprouts only 26% (0.26) of the crop grown is produced as sprouts.

This is the overall harvest Index – i.e. proportion of whole crop grown harvested and removed from the field.

= Marketable product harvested (t/ha) /Total dry matter yield (t/ha)
Expressed on a 100% dry matter basis.

For some crops Leeks, All types of Cabbage, Calabrese harvest Index (Y) increased as expected marketable yields (x) increased. (data not shown).

Leeks Y = 0.0098x + 0.11 (r2=0.67, n=7)
Cabbage Y = 0.0034x + 0.28 (r2=0.91, n=4)
Calabrese Y = 0.007x + 0.058 (r2=0.65, n=5)

N UPTAKE IN OPTIMALLY GROWN CROP (kg/ha)

Total N Uptake kg/ha = *Dry weight yield t/ha x N% x10*

N_{Crit} % - This is the estimated nitrogen concentration of an optimally fertilised whole plant at harvest. Generally N concentration declines as yields increase.

$$\%N_{Crit} = a(1 + be^{-0.26W})$$

Where a and b are parameters controlling the shape of the curve. W = total dry matter yield t/ha.

The data has been derived from experiments. Generally the relationships were similar to those that have been used to define critical N concentrations for the decision support models EU-Rotate_N, N_ABLE and WELL_N models (Greenwood 2001).

The industry requested that the recommendations for calabrese and cauliflower be split from each other. Calabrese is prone to rotting heads and it is assumed that the critical N content for good quality heads is lower than that for optimum growth. Further work should be carried out to validate this.

Equally the critical N curve for Leeks may be higher than that currently used in these recommendations as the crop is judged on colour as well as growth. The extra 100 kg/ha is justified on this basis but will need further research to check it.

SUPPLY OF NITROGEN AND CALCULATION OF FERTILISER REQUIREMENT

Fertiliser Requirement (FR) is calculated from

$$FR = \left(NUptake - \left(MineralisedN + SoilMinN \times Rdepth/90\right)\right) / \, Fert\,\mathrm{Rec}$$

Mineralised N – amount of N released from soil organic matter by mineralisation during the cropping period. This is normally estimated between planting and harvesting but for some crops such as lettuce and onions where early N supply is important a shorter period has been chosen; see table 1.

The calculations are based on mineralisation within the WELL_N model (i.e 0.7 kg/ha @ 15.9 degree C) scaled for temperature in a similar way to Parton et al. (1987). When soil temperature is less than 4 degrees mineralisation is assumed to be negligible. The data set for temperature was that used in WELL_N for Wellesbourne 1982.

SoilMinN – Soil mineral N to 90 cm depth.

It is assumed as in the other sections of RB209 that soil mineral N is used with 100% efficiency. Attempts were made by the arable group to refine the estimation of this without success. The soil mineral N amounts assumed for each Index are shown below.

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SNS Index	*Soil mineral N figure assumed kg/ha N to 90 cm*
0	*50*
1	*70*
2	*90*
3	*110*
4	*140*
5	*200*
6	*250*

In calculating crop nitrogen requirements, the available soil mineral N is adjusted for the estimated mineral N within the rooting depth. Where growers only sample to rooting depth the figures should be scaled to 90 cm depth before using the recommendation tables.

There are situations following wet winters on light soils where the amounts of mineral N in the soil to 90 cm can be very small, much less than the 50 kg/ha assumed for SNS Index (0). In these instances larger amounts of fertiliser can be justified.

RDepth - Rooting Depth is generally related to the dry matter yield of the crop and is calculated as 10 cm depth per tonne of total dry matter yield, with the exception of onions and leek which are shallower rooted. Maximum rooting depth is assumed to be not more than 90 cm. There will be circumstances on fertile soils where rooting is much deeper so potential N supply is larger than assumed in these tables.

This general relationship was derived from papers by Greenwood et al. (1982, 1989). Danish research has indicated that rooting of some crops can be deeper than 90 cm but practical recommendations cannot easily be based on this without assessment of soil mineral N to a much greater depth which is not practical.

Fert Rec – Fertiliser recovery assumed to be 60%

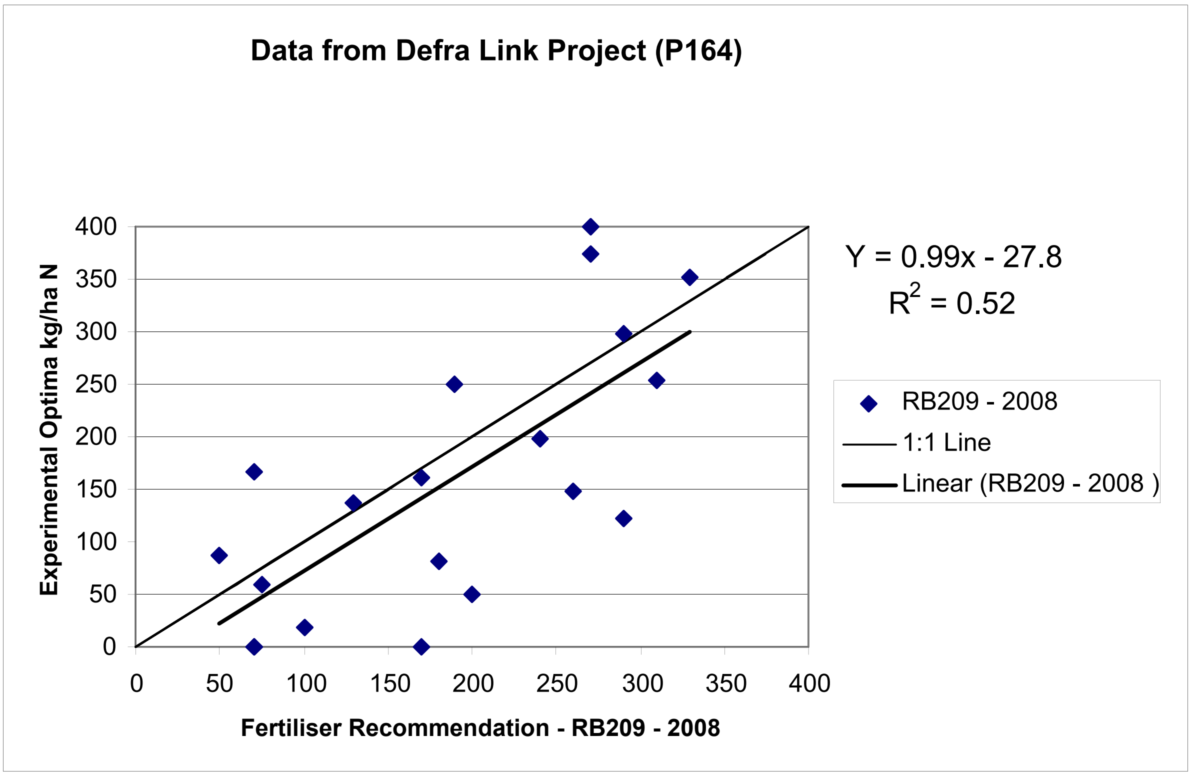
Fertiliser recovery was assumed to be 60% the same figure assumed in the previous versions of RB209. Some direct measurements of fertiliser recovery were made in 1996 using ^{15}N and ranged from 30% for lettuce to 72% for onions but with a median value of 56%.

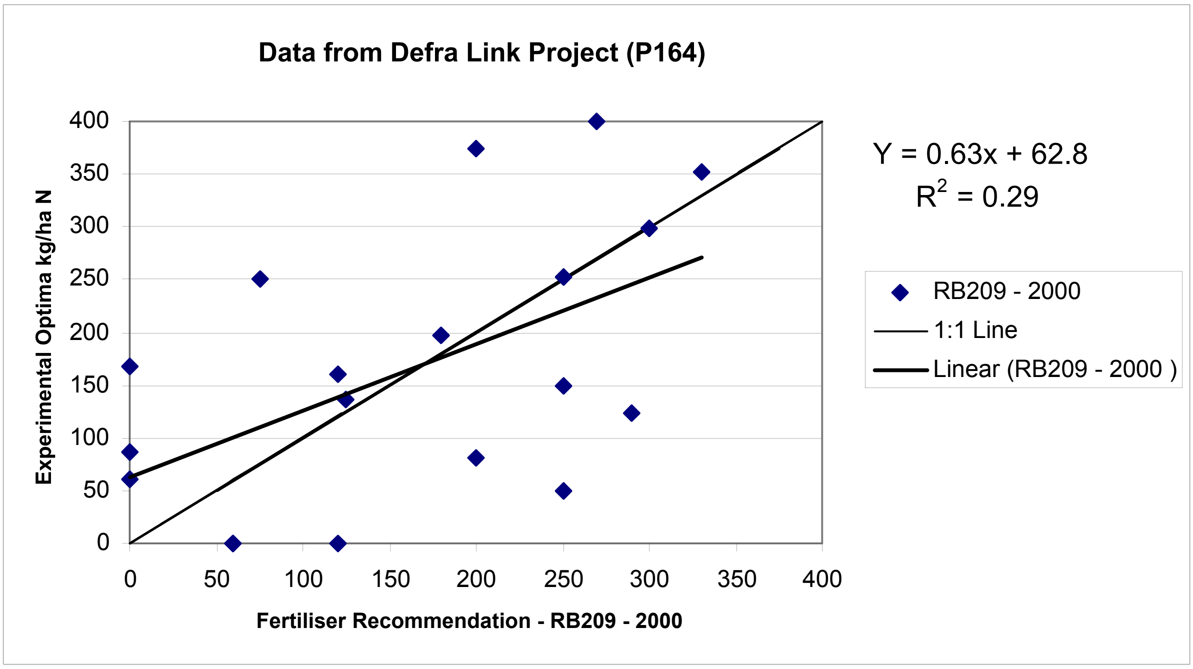
3. VALIDATION OF DATA

GENERAL VALIDATION

The figures presented below show the results of a test of the new fertiliser recommendations against data from 20 experiments carried out as part of the Defra Link Project P164 (Smith, 2001). Fertiliser recommendations from the revised version of RB209 explains 52% of the variation in experimental optima ($p>0.001$) compared with the previous version which only explained 29% of the variation. ($p = 0.02$). Additionally the recommendations from the revised version are not significantly different from the line of equality. Overall the predicted yields, obtained by applying the revised N recommendations, are the same as obtained in the experiments and within the range of 87-118% of the optimum or maximum yields.

The general increase in recommendations at high SNS indices for shallow rooted crops is supported by the data from these experiments. There are no longer any situations where no fertiliser is recommended where a clear response is gained in experiments. Validations for a selection of individual crops are shown in the following sections.


Data from Defra Link Project (P164)
Experimental Optima kg/ha N
Fertiliser Recommendation - RB209 - 2008
0
50
100
150
200
250
300
350
400
Y = 0.99x - 27.8
R^2 = 0.52
RB209 - 2008
1:1 Line
Linear (RB209 - 2008)


Data from Defra Link Project (P164)
Experimental Optima kg/ha N
Fertiliser Recommendation - RB209 - 2000
0
50
100
150
200
250
300
350
400
Y = 0.63x + 62.8
R^2 = 0.29
RB209 - 2000
1:1 Line
Linear (RB209 - 2000)

VALIDATION OF DATA – INDIVIDUAL TABLES

The data used for validation were taken from the series of experiments carried out as part of a Defra Link Project P164, Smith (2001) during 1998 and 1999 to test the N response of a range of horticultural crops, in a range of locations, on a range of soils. Where data is limited other evidence is referred to as necessary.

In the original work, the optimum N for each site was estimated using the Linear Exponential curve as used by Goodlass et al (1997). The optimum N (Opt N) was defined as the level where a further 10 kg/ha fertiliser N increases yield by less than 1%. In order to calculate the yields at the new recommendation levels the data was refitted using the linear exponential model.

NOTE - At some sites fertiliser response was strong even at the highest levels of fertiliser tested (This was true even where the maximum N levels tested were much larger than current RB209 levels). In these situations the yields predicted by RB209 are compared with the maximum yields obtained in the experiment.

ASPARAGUS

The recommendations were discussed with Victor Aveling, Chairman of the Asparagus Growers Association and the changes made supported by data from the FV152 project funded by HDC.

BRUSSELS SPROUTS AND CABBAGE

BRUSSELS SPROUTS

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Max yield
Sprouts I98	59 (0)	352 (20.9)	330 (20.0)	96
Sprouts K98	85 (2)	>400 (23.7)	270 (20.6)	87

Note - K98 the yields were larger than in the 20t allowed in the framework. If 24t/ha was used in recommendation framework the recommendation becomes 340 kg/ha N which yields an estimated 22.3 or 94% of the maximum yield in the experiment.

CABBAGE

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Max yield
D W Cabbage L98	104 (3)	198 (72.5)	240 (75.5)	104
DW Cabbage U99	67 (1)	253 (44.2)	310 (46.9)	106
Cabbage-Savoy J99	69 (1)	298 (22.5)	290 (22.3)	99

Data from the Netherlands demonstrated that the framework could be used for much higher yielding crops than we see in the UK. When these recommendations were presented to the expert group they were regarded as being too high for UK conditions.

CAULIFLOWERS AND CALABRESE.

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Opt yield
Autumn Cauliflower P98	18.9 (0)	123 (16.7)	290 (18.2)	109
Autumn Cauliflower P99	123 (4)	0 (7.2)	170 (7.8)	108
Summer Cauliflower H98	67 (1)	149 (28.4)	260 (31)	109
Summer Cauliflower H99	125 (4)	161 (24.6)	170 (24.7)	100

At the request of the Brassica Growers Association the calabrese recommendations are now separated and lower than those for cauliflower crops. Data from P164 showed a response to 250 kg/ha N even when the Soil N supply Index was 5. The reason for this is not clear but further research may be necessary to determine conditions affecting the N response of the crop. (Data not included)

CELERY

Not in framework – recommendations as 2000 edition

PEAS

Not in framework – recommendations as 2000 edition

LETTUCE, RADISH, SWEETCORN and COURGETTES

LETTUCE

Data available for several experiments. In the 7th edition of RB209 the N recommendation declined too rapidly with increasing SNS Index and many experiments showed responses to N fertiliser where none was recommended; this error has been corrected in the new recommendation system.

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Opt yield
Crisp Lettuce F99	52 (0)	50 (37.1)	200 (36.4)	118
Crisp Lettuce Q98	179 (5)	60 (24.2)	75 (24.5)	101
Crisp lettuce R98	80 (1)	81 (42.4)	180 (40)	94

Data from HH3506SFV also supports the increase of recommendation for high levels of SNS (data not shown). The previous version of RB209 would have recommended no fertiliser to be applied at the Q98 site producing a yield of only 21.1 t/ha which is 87% of the optimum yield.

RADISH

Yields uptake and rooting depth based on KNS system. Radish is a shallow rooted crop so recommendations at high SNS indices need to reflect this and so have been raised.

SWEETCORN AND COURGETTES

Not in Framework

ONIONS AND LEEKS

ONIONS

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Opt yield
Bulb Onion – sets C98	68 (1)	137 (53.3)	130 (53.1)	99
Salad Onion S299	186 (5)	87 (7.9)	50 (7.4)	94
Salad Onion (red) s1999	105 (3)	18 (18.1)	100 (21.4)	118

In the previous version of RB209 the recommendations for bulb and salad onions were the same – the framework has allowed them to be separated. In the previous versi on of RB209 the recommendation at SNS Index 5 (S299) would have only been nil providing a yield of only 5.86 t/ha 74 % of optimum yield.

LEEKS

A difficult crop with large responses to N which cannot completely be taken account of in the framework. Experiments carried out in the eighties at Luddington showed responses to very large amounts of N in excess of 500 kg/ha. The critical N curve for leeks in the WELL_N model appears to be lower than in the datasets in the framework. WELL_N is not used by Leek growers as it provides poor recommendations. It is likely that the optimum N concentration for colour and growth may be higher than that for growth alone. The recommendations in the framework will likely grow the crop but not sufficiently green for market. The critical N concentrations for leeks needs to be tested and revised..

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Max yield
D Stone 1998 F98	89 (2)	375 (41.0)	170+100 (38.6)	94%
Luddington 1987 site 21	165 (5)	200 (31.9)	80+100	95%

Luddington 1988 site 22	101 (3)	>500 (41.7)	160+100 (37.2)	89%
Luddington 1989 site 23	111 (3)	>500 (38.8)	160+100 (34.3)	89%

Note even at SNS Index 5 a large response to applied fertiliser which supports the increase in recommendations at high SNS Indices.

In the Luddington experiments all the N was applied at planting/establishment – growers currently apply N more gradually over the growing period – with up to 40 kg/ha a month being applied during the winter months. More experimental work should be carried out on the N response of modern leeks varieties with N split more evenly over the growing period.

ROOT CROPS

BEETROOT

Types of beetroot range from small beet for canning to high yielding beet for processing. It was difficult to represent all types of beet with one recommendation system. However beet is known to be highly responsive to N. Target yield level and its associated yield was taken from Fink 1999. The lower yielding types are still likely to require large amounts of N as rooting will be shallow.

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Opt yield
D Stone 1998 J98	158 (4)	>250 (44.2)	190 (40.9)	92
NT2605	49 (0)	300 (18 .4)	285 (18.2)	99

In the previous version of RB209 the recommendation at SNS Index 4 (J 98) would have only been 75 kg/ha N providing a yield of only 35.9 t/ha 81 % of optimum yield.

PARSNIPS

The N uptake used the N uptake figure for KNS based on field yields sourced by ADAS Yield i.e 48/40 * 200.

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Max yield
D Stone 1999 B99	112 (3)	167 (28.7)	70 (28.6)	100

Earlier data from work carried out in the 70's by Greenwood suggested optima of 194 and 148 kg/ha N at SNS Index 0. This compares with a recommendation of 170 kg/ha in the new recommendation.

SWEDES

Swedes are separated out from parsnips and turnips on the basis of data available but recommendations have not been validated by any recent response trials. Data from work carried out in the 70's by Greenwood suggested an optima of around 100 kg/ha N at SNS Index 0. This compares with a recommendation of 135 kg/ha N in the new recommendation.

TURNIPS

N recommendations based on those of Parsnips which are similar to previous version of RB209. The recommendations not validated by any recent trials.

Earlier data from work carried out in the 70's by Greenwood suggested optima of around 150 kg/ha N at SNS Index 0. This compares with a recommendation of 170 kg/ha N in the new recommendations.

CARROTS

Experiment	Soil min N (SNS INDEX)	Opt N kg/ha and (yield t/ha) Experiment	RB209 and estimated yield at rec level	% Max yield
D Stone 1998 E98	66 (1)	0 (90.7)	70 (83.6)	92
D Stone 1998 G98	79 (1)	57 (81.9)	70 (81.7)	100

BULBS AND BULB FLOWERS

The recommendations were discussed with key bulb experts and crops can be down for more than a single year. The recommendations at Index 0 were higher than necessary and dropped.

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APPENDIX ONE – THE RECOMMENDATION FRAMEWORK

Table Background information for Derivation of Crop Nitrogen Requirement of Field Vegetable crops .
((k) N uptake taken from German KNS System 2007)

Crop	Fresh Mkt Yield t/ha	% Dry matter Marketable	Dry wt harvest Index	Total dry matter t/ha	Relation N% and dry matter yield 'a'	'b'	% N	Tot N uptake kg/ha	Minlise kg/ha	Period dates	Root depth cm	Recovery Fert %
Brussels sprouts	20.3	17.0	0.26	13.3	2.50	3.50	2.8	368	121	20/5-17/12	90	60
White Cabbage Storage	110.0	8.6	0.65	14.6	2.55	0.80	2.6	378	122	1 /5-12/11	90	60
Head Cabbage - pre Christmas	60.0	8.6	0.48	10.8	2.55	0.80	2.7	288	44	18/5-19/7	90	60
Head Cabbage post Christmas	53.0	8.6	0.46	10.0	2.55	0.80	2.7	270	74	31/7-15/01	90	60
Collards Pre Christmas	20.0	8.6	0.34	5.1	3.45	0.60	4.0	203	51	16/7-24/9	45	60
Collards Post Christmas	30.0	8.6	0.38	6.8	3.45	0.60	3.8	260	41	15/9-15/01	60	60
Cauliflower (Over Winter)	-	-	-	8.1	3.45	0.60	3.7	300	85	30/7-10/03	75	60
Calabrese	16.3	10.4	0.17	10.0	1.80	3.50	2.3	226	36	27/04-25/06	90	60
Cauliflower summer	30.6	8.2	0.37	6.8	3.45	0.60	3.8	259	44	21/5 – 21/7	75	60
Lettuce (Crisp)	45.5	5.3	0.50	4.8	2.60	1.10	3.4	165	22	15/05-15/06	45	60
Radish	50.0	-	-	-	-	-	-	100_K	24	2/05-11/06	30	60
Bulb onions spring	60.5	12.7	0.81	9.4	1.20	3.50	1.6	147	20	13/03-12/05	60	60
Bulb onions overwintered	60.5	12.7	0.81	9.4	1.20	3.50	1.6	147	20	as above	60	60
Salad onions	30.0	12.7	0.81	4.7	1.20	3.50	2.4	114	20	as above	30	60
Salad onions overwintered	30.0	12.7	0.81	4.7	1.20	3.50	2.4	114	20	as above	30	60
Leeks	47.0	14.2	0.57	11.8	2.00	4.00	2.4	279	132	21/4-12/12	45	60
Beetroot	60.0	-	-	-	-	-	-	270_K	65	18/5-16/08	60	60
Parsnips and (Turnips)	48.0	-	-	-	-	-	-	241_K	92	30/03-27/08	90	60
Swede	84.8	11.7	0.62	16.0	1.35	1.87	1.4	222	92	30/3-27/08	90	60
Carrots	150.0	11.4	0.81	21.2	0.82	7.00	0.8	178	66	2/05-8/08	90	60

Insufficient Data to include Asparagus, Celery, Peas and Beans, Sweet Corn, Courgettes, and Bulbs