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

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1. Abstract

In 2015/2016, NIAB CUF and ADAS were commissioned by AHDB to collate and review published data that might inform revision of existing fertiliser recommendations for potato crops grown in England and Wales (RB209 8th edition – the "Fertiliser Manual"). The review was limited to data that had not been included in the last review process (generally 2009 to date) and was also restricted to production systems and climates similar to those found in the UK. The over-arching principles of the review process were:

- To consult as widely as possible with the UK potato supply chain, suppliers and stakeholders.
- To objectively assess the provenance of any data supplied and then weight the supplied data accordingly.
- Where possible to cross reference and ensure consistency with other sources of published advice to growers and agronomists.
- To ensure that recommendations and guidance would not be changed unless there was compelling, defensible evidence that would support these changes.

The relatively limited experimental evidence available supported the nitrogen (N) recommendations in the "Fertiliser Manual (RB209)" and the validity of a system based on soil nitrogen supply, variety and season length and no changes were recommended to current N rates. However, recent AHDB funded work highlighted the importance of not exceeding recommended rates since this was associated with loss of yield. Other work showed the importance of timely N applications and how N use efficiency was improved by using 'placement' systems. Optimisation of tillage systems (e.g. reduced depth of destoning) was shown to have no effect on SNS or on the efficiency of fertiliser use.

Potassium, phosphate and magnesium recommended application rates will not be changed. However, recent evidence from a LINK funded project suggested that, due to increased efficiency of use, phosphate application rates could be reduced where fertiliser is placed. The review also concluded that "Fertiliser Manual (RB209)" tuber nutrient removal rates (5.8 kg K_2O/t FW and 1.0 kg P_2O_5/t FW) were appropriate.

Evidence supplied by CUPGRA and by British Sugar suggested that the incidence of common scab was reduced by application of calcium containing materials at the time of planting. There was not sufficient data for a recommendation to apply liming products but the advice not to lime before potatoes has been removed.

Against a background of decreasing sulphur emissions from UK industry, a recommendation to apply 25 kg SO_3/ha where S deficiency may be likely has been included. This recommendation is consistent with recommendations published in the SRUC Technical Note TN633.

The review process produced no evidence concerning the benefits of micronutrient applications and growers are advised to refer to the ‘Principles’ section or to a FACTS qualified agronomist.

2. Introduction

2.1. Aims and objectives

i. Review of research on potato crop nutrition undertaken since the publication of the 8th edition of RB209
ii. Identify knowledge gaps within current best practice and prioritise requirements for future research
iii. Produce an AHDB Research Review report for potatoes
iv. Update the RB209 potatoes section including amalgamation of "Fertiliser Manual (RB209)" sections 3 and 4 and relevant appendices.

3. Methodology

Relevant data and information from industry contacts (Appendix I) and from Defra and AHDB projects was collated and reviewed for evidence produced since 2009. In addition, 'Web of Science' searches were carried out using keyword combinations to find relevant UK-affiliated research on yield response of potatoes to applied fertiliser carried out since 2009.

3.1. Online searches

'Web of Science' is a web-based scholarly research database and search facility that provides access to bibliographic information such as the Science Citation Index (http://apps.webofknowledge.com). Combinations of keywords, search strings and Boolean operators were used to reduce bias and provide more focused and productive results. The geographical range was limited to United Kingdom and North-Western European affiliated research papers.

Scientific papers identified by the online search were initially screened using the title of the evidence to check its relevance to addressing the aims and objectives. The second filter used the full abstract to check for relevance and to select research papers that would be used in the review. The quality of the collated data was assessed for scientific rigour and relevance.

3.2. Projects and data

Evidence and data was collated from the following sources:

- LINK Project LK09136. Improving the sustainability of phosphorus use in arable farming.
- AHDB Potatoes Project R405. Improving canopy and nitrogen (N) management for the GB Potato Crop.

- AHDB Potatoes Project R443. Review: Potash Requirements of Potatoes.
- AHDB Potatoes Project R295. Testing reduced N rates through a grower collaboration project.
- AHDB Potatoes Project R444. Managing cultivations and cover crops for improved profitability and environmental benefit in potatoes.
- AHDB Potatoes Project R459. Improving cultivation practices in potatoes to increase window of workability and structural stability.
- Defra/WRAP Project OMK001-01/WR1212. Field experiments for quality digestate and compost in agriculture and field horticulture.
- Defra Project SCF0308. Review of crop requirements for sulphur and the adequacy of current sulphur fertiliser recommendations.
- AHDB Cereals & OilseedsProject RR78. Review of non-NPKS nutrient requirements of UK cereals and oilseed rape.
- Defra Sustainable Arable Link Project. Producing low acrylamide risk potatoes.
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4. Response of potato to applied nutrients

4.1. Response of potato to applied nitrogen fertilisers

4.1.1. AHDB derived data

The four AHDB funded projects that are relevant to the review process are:

- AHDB Potatoes Project R405. Improving canopy and N management for the GB Potato Crop.
- AHDB Potatoes Project R295. Testing reduced N rates through a grower collaboration project.
- AHDB Potatoes Project R459. Improving cultivation practices in potatoes to increase window of workability and structural stability.
- AHDB Potatoes Project R444. Managing cultivations and cover crops for improved profitability and environmental benefit in potatoes.

Improving canopy and N management for the GB Potato Crop (AHDB R405)

This project was carried out by Cambridge University Farm (CUF, now NIAB CUF) and ran from 2008-2011. Earlier work in AHDB Potatoes project R273, showed that the N nutrition of the potato crop and its effect on yield potential could be interpreted by reference to radiation absorption. There were five key messages from R405 and all are concerned with improving N use efficiency and yield potential:

Allocation of new varieties to determinacy groups

Projects R273 and R405 demonstrated varietal differences in N uptake and redistribution. This understanding was used to develop a protocol that could be used to place varieties in their RB209 determinacy group without the need for time consuming and expensive N response experiments (e.g. see Table 19 in Allison *et al.* 2012). A development of this methodology is now used commercially for the agronomic optimisation of crisping varieties.

Recommendation. There is an opportunity here to further develop and implement this methodology so that the determinacy groups published in RB209 are underpinned by objective data.

N uptake and yield potential

Several experiments in R405 (and in the earlier R273) have demonstrated a linkage between maximum, total (e.g. tuber and haulm) N uptake and yield potential. Factors that impede N uptake (e.g. compaction and insufficient water) will reduce yield potential. Once created the potential as set by the crops' N uptake will not be realised should normal physiological function be disrupted by water stress, disease or defoliation.

Recommendation. In the guidance notes, emphasis should be placed upon the importance of maintaining good soil conditions and that nutrition cannot be considered in isolation from other agronomic inputs (e.g. water and ag-chem).

Timing of N applications

Analysis has shown that N uptake by the potato crop is most rapid shortly after crops emergence and then slows so that at about 50 days after emergence (DAE) N uptake ceases and the crop survives by redistribution of N reserves. Several studies in both experimental plots and commercial crops showed that the potential benefits of top-dressing decreased with the interval from crop emergence. Thus, from R405 (and R273) a general recommendation has been developed to apply top-dressings at about the time of tuber-initiation (*c*.20 days after crop emergence) and to avoid top-dressing much later than 40-50 DAE.

Recommendation. Guidance notes should stress the importance of early N applications and limited value of late applications.

'Placing' of N application

Potatoes are widely spaced row crops where average inter-row spacings of 91cm are common. Furthermore, de-stoning/de-clodding operations at planting create heterogeneous soil condition between ridges/beds and furrows. Penetrometer data (e.g. Figure 32 in Allison *et al*., 2012) showed that soil resistance in the furrow bottoms is not conducive to root growth. Anecdotal evidence and limited experimental evidence (e.g. Table 77 in Allison *et al*., 2012) showed that root length density was smaller underneath the furrow than at an equivalent depth underneath beds. The spatial distribution of roots suggested that the efficiency of uptake of N would be increased by application methods that prevented N from falling into furrow bottoms. This hypothesis was not tested directly in this project but use of a Horstine AirStream N applicator which used shoes to 'place' N in the bed during the planting operation showed that N rates could be reduced without detectable effects on yield. Furthermore, this type of technology facilitates the use of urea since the risks of ammonia volatilisation are reduced due to the N being incorporated at planting depth.

Further, albeit limited, research has showed that N applied as a broadcast top-dressing that fell into the furrow bottoms was not used efficiently by the potato crop and technologies (e.g. band application of liquids) that minimised the amount of N deposited into the furrow would be likely to improve N use efficiency.

Recommendation. Although the evidence base is limited there is an opportunity to increase N use efficiency by adopting N application technologies that minimise the amount of N falling into furrow bottoms.

Effect of irrigation on N requirement

Experiments in 2009 (with Estima) and 2010 (with Desiree), as part of project R405, tested the effects of N application rate (0 or 200 kg N/ha), irrigation (rain-fed or scheduled irrigation) or shading (none or a *c*.45 % reduction in incident solar radiation) in factorial combination with four replicates of each treatment. These data are summarised in Table 1 and Table 2.

Table 1. Effect of irrigation and shading on total tuber fresh weight (FW) yield in two seasons.

Total tuber FW yield (t/ha)		**Unshaded**		**Shaded**		
Year	**Irrigation**	**0 kg N/ha**	**200 kg N/ha**	**0 kg N/ha**	**200 kg N/ha**	**Mean**
2009	Rain-fed	33.6	51.2	35.3	50.6	42.7
	Irrigated	43.0	84.8	41.3	63.0	58.0
	S.E. (21 D.F.)		1.14			2.27
2010	Rain-fed	33.4	60.8	31.3	47.0	43.1
	Irrigated	48.7	84.6	45.8	64.8	61.0
	S.E. (21 D.F.)		1.26			2.52

Table 2. Effect of irrigation and shading on total (haulm and tuber) nitrogen (N) uptake in two seasons.

Total N uptake (kg N/ha)		**Unshaded**		**Shaded**		
Year	**Irrigation**	**0 kg N/ha**	**200 kg N/ha**	**0 kg N/ha**	**200 kg N/ha**	**Mean**
2009	Rain-fed	82	156	94	171	126
	Irrigated	97	241	110	190	160
	S.E. (21 D.F.)		3.5			6.9
2010	Rain-fed	102	204	104	169	145
	Irrigated	129	265	125	228	186
	S.E. (21 D.F.)		5.4			10.7

As expected, these experiments show that tuber yields were reduced by shading, absence of irrigation and omission of N fertiliser. In crops receiving no N fertiliser, total (haulm and tuber) N uptake was larger in irrigated crops than in rain-fed. Furthermore, the efficiency of N use (as estimated by the increase in N uptake in relation to the amount of N applied) was also larger in irrigated crops. These data suggest that irrigation allows the crop better access to soil nitrogen supply (SNS) and to N derived from fertiliser.

Recommendation. These data suggest that whilst use of irrigation increases yield, fertiliser requirement may not need to increase pro-rata due to increased efficiency of N use (NB also see data from the CUF Reference Crop experiment later in this section).

Grower Collaboration Project (AHDB R295)

The Grower Collaboration Project (AHDB R295) was started in 2007 as a knowledge transfer (KT) project to assist in the rapid implementation of research findings by growers and their agronomists. In each year, *c*. five growers or grower groups would supply their intended cropping plans to researchers at Cambridge University Farm (now NIAB CUF). The researchers would then assess these plans in the light of the most recent research and, when appropriate, suggest modification to the agronomy that would achieve (or improve on) the intended output (e.g. as total or marketable yield) but with better use of inputs (e.g. seed, N fertiliser and water). If the "modified" agronomy differed by more than ± 10 % of the grower's "standard" agronomy then a 'split-field' comparison was set up between the contrasting agronomies and outputs (yields, crop quality and economics) were assessed at the end of the season. It should be stressed that treatments within these split-field comparisons were not replicated and great care needs to be taken when interpreting the data. Similarly, the selected fields should not be considered representative of wider UK production and it would not be appropriate to extrapolate conclusions from this project to make inferences about UK cropping in general.

For the 22 valid comparisons, the mean 'standard' N application rate was 196 (± 5.3) kg N/ha compared with 168 (± 4.9) kg N/ha for the 'modified' crops. The mean total tuber yield for the standard and modified crops was 57.0 (± 2.35) and 61.3 (± 2.64) t/ha, respectively. A 'T' test on the yield data showed that reducing the N application rate by 28 kg N/ha was associated with a statistically significant increase in total yield of 4.3 t/ha. The mean, mid-point RB209 recommendations for these fields was 140 (± 7.0) kg N/ha. These data suggest that growers tend to apply N at the upper end of the range of N applications given in RB209 and this strategy is probably guided by the hypothesis that the agronomic and economic consequence of applying excess N are smaller than applying insufficient N. The data from R295 show that excess N reduces yield (probably as a consequence of adversely affecting partitioning between tubers and haulm) and emphasises the fact that the range in "optimum" N application for an individual crop is relatively narrow. It should be noted that the reductions in yield caused by excess N adversely affecting partitioning would be more noticeable in crops defoliated whilst they still had appreciable crop canopies. For crops that had been allowed to fully senesce naturally these depressive effects of excess N are likely to have been much smaller.

Recommendation. In the guidance notes growers should be warned about the possible negative consequence of applying "insurance" N.

Improving cultivation practices in potatoes to increase window of workability and structural stability (AHDB R459).

This project ran from April 2012 to March 2015 and a final report was submitted in August 2015 (Stalham & Allison 2015). The principal aim of this program was to investigate the effects of cultivation strategy (principally de-stoner depth) on soil conditions, crop yield and quality. In twelve of these experiments, depth of destoning was studied in factorial combination with two rates of N application (0 or 200/250 kg N/ha) and total (haulm and tuber) N uptake was measured at the final sampling. The purpose of the experiment was to determine whether destoner depth affected N mineralisation and, in turn, N uptake. For all twelve experiments de-stoner depth had no effect on soil mineral N or on crop N uptake and, in consequence, there was no evidence that N application rates needed to be altered if a shallow de-stoning policy was adopted. With the exception of one site, all the experiments were carried out on SNS Index 0 fields (as determined by the field assessment method) and expected to supply < 60 kg N/ha. However, for the eleven, Index 0 fields, the average total N uptake in crops receiving no additional fertiliser was 121 kg N/ha. These data suggest that the intensive cultivations used to create potato seed beds stimulates the mineralisation of substantial amounts of N which are not fully accounted for in the 8th edition of RB209 ("Fertiliser Manual").

Recommendation. Growers do not need to adjust N applications in relation to changes in typical depths of de-stoning. We should consider whether SNS Indices 0 or 1 are appropriate for potato crops.

Managing cultivations and cover crops for improved profitability and environmental benefit in potatoes (AHDB R444)

This project ran from April 2011 to March 2015 and a final, updated, report was submitted to AHDB in August 2015 (Silgram *et al*. 2015). The principle aims of this project were to compare plough and no-plough cultivation for creating potato seed beds and the effects of cover cropping. Cover crops were tested in two seasons (2012 and 2014) and at two locations (Telford and Dundee) giving four experiments in total. Nitrogen uptake by the cover crops was very variable and ranged from only 2 kg N/ha for winter oilseed rape (Dundee 2012) to 98 kg/ha for a cover crop of white mustard grown at Telford in 2014. On average, cover crops were estimated to supply between 10-50 kg N/ha to the following potato crop. These data suggest that cover crops are capable of taking up substantial amounts of N from the soil that might have otherwise been leached and an appreciable proportion may be made available to the subsequent potato crop. The authors note that once they have been incorporated, the amount of N made available to subsequent crops was dependent in part on the C:N ratio of the residue.

Recommendation. Allowances should be made for the likely supply of N from incorporated cover crop residues. However growers will need guidance on how to assess the amount of N taken up by the cover crop and what proportion is likely to be made available. Growers should refer to the 'Principles' section for further information.

4.1.2. Other data

Studies funded by Cambridge University Potato Growers Research Association (CUPGRA) at Cambridge University Farm (CUF) have examined the effects of irrigation on the yield and N requirement of two contrasting varieties: Estima (determinacy group 1) and Cara (determinacy group 4). In each year, the experiment was planted on a similar date and used similar sized seed. Rates of N application ranged from 0 to 330 in 30 kg N/ha increments for Estima and 0 to 220 in 20 kg N/ha increments for Cara. The experimental design has varied slightly over the course of the experiment but essentially comprised main plots of irrigated or rain-fed crop into which were allocated sub-plots testing variety. The N treatments were then applied using a systematic design to individual rows of the sub-plots. Irrigation was scheduled using an optimised Penman-Monteith based system. The SNS in each year was Index 1 and all crops were allowed to grow for a full season (e.g. crops were sampled at near complete senescence at the end of the season). The optimum N application rate and the total tuber FW yield at the optimum were determined by fitting 'split-line' model to the data. The data are summarised in Table 3.

Table 3. Summary of the effects of irrigation on the nitrogen (N) fertiliser requirements of two contrasting varieties. (Source: Cambridge University Farm).

	Estima				Cara			
	Rain-fed		Irrigated		Rain-fed		Irrigated	
	(kg N/ha)	(t FW/ha)	(kg N/ha)	(t FW/ha)	(kg N/ha)	(t FW/ha)	(kg N/ha)	(t FW/ha)
2006	76	31.9	75	67.7	22	50.1	30	65.7
2007	144	46.4	180	52.7	190	61.9	200	50.4
2008	300	69.3	206	52.1	151	63.3	84	76.6
2009	208	44.5	244	75.9	n.a.	n.a.	n.a	n.a.
2010	0	16.8	247	65.7	166	67.1	>=220	86.1
2011	90	21.2	210	38.0	60	27.4	69	41.6
2012	240	63.9	270	72.2	180	61.0	94	70.9
2013	168	34.6	270	78.6	140	60.6	200	97.9
2014	120	57.2	120	71.9	100	65.4	60	71.3
2015	150	34.2	225	67.8	40	76.9	43	86.7
Mean	150	42.0	205	64.3	117	59.3	111	71.9
S.E.	27	5.5	20	4.0	21	4.6	25	5.9
CoV	58	41.7	31	19.8	54	23.4	67	24.8

As expected the data show that, on average, rain-fed crops yielded less than irrigated crops although the benefits of irrigation were variable from season to season. On average, the response to irrigation was larger in Estima (53 %) than in Cara (21 %). The 8th edition of RB209 would have mid-point N recommendations of 245 kg N/ha for Estima and 140 kg N/ha for Cara in each season. When averaged over irrigation treatments, the optimum N application for Estima was 177 kg N/ha (associated with a yield of 53.1 t/ha) compared with an optimum of 114 kg N/ha and a yield of 65.6 t/ha for Cara. These data generally support RB209 (8th edition) N recommendations and, on average, demonstrate the large difference in N requirements for determinate and indeterminate crops grown using similar agronomies. However, the large year-to-year variation in yields and optimum N application rates are noteworthy. For Cara, there was no evidence that rain-fed crops required less N than irrigated crops, but for Estima the N requirement for rain-fed crops was 55 kg N/ha less than for irrigated. These data would suggest that depending on the grower's attitude to risk, the N applications for rain-fed determinate crops could be reduced. However, for full-season determinate varieties, excess N has relatively little effect on partitioning and a safer option may be to apply an amount of N determined by season length and SNS irrespective of whether the crop was irrigated or not.

Recommendation. When considered together with other experiments these data suggest that, in general, N application rates do not need to be adjusted for rain-fed or irrigated crops. Although for rain-fed determinate crops RB209 (8th edition) recommendations may be excessive.

In total, seven N response experiments were found and analysed. These data were derived from AHDB Potatoes and Defra funded projects and encompassed a range of seasons, soil types and varieties. Exponential plus linear curves were fitted to the data, where Y is the total tuber yield, N is the N application rate and a, b and c are parameters estimated using a least-squares method.

$$Y = a + b.r^{N} + c.N$$

The results of this analysis are shown in Table 4.

Table 4. Summary table showing results from recent nitrogen response experiments.

Experiment	1	2	3	4	5	6	7
Season	2010	2009	2011	2012	2014	2012	2014
Project	AHDB R295	AHDB R295	Defra OMK001-001	AHDB R444	AHDB R444	AHDB R444	AHDB R444
Location	Lincs	Lincs	Notts	Shrops	Shrops	Angus	Angus
Variety	Marfona	M. Piper	Harmony	M. Piper	Royal	Rooster	Rooster
Determinacy group	2	3	2	3	4	3	3
Previous crop	Cereal	Peas	Cereal	Cereal	Cereal	Cereal	Cereal
Soil texture	Deep silt	Deep silt	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy clay loam
Season length (days)*	76	128	109	126	129	96	77
Mid-point of RB209 (kg N/ha)	90	130	185	180	140	145	100
Max N rate tested (kg N/ha)	350	350	300	280	210	240	180
Variance in yield explained by curve (%)	67.5	40.2	58.3	84.5	51.6	63.9	27.8
N for maximum yield (kg N/ha)	> N max	163 ± 28	> N max	> N max	> N max	> N max	148 ± 118
N for 95 % of max. (kg N/ha)	134		90	243	130	176	

Estimates of the N needed to achieve maximum yield were only achieved for two out of the seven experiments. For the remainder, the ‘C’ parameter was non-significant and, in consequence, there was no optimum and yield continued to increase to an asymptotic value. For these experiments, the optimum N application was defined as that needed to achieve 95 % of the asymptotic yield value. For individual sites there were differences between the midpoint of the RB209 recommendation and the 'optimum' determined by N response experiments and, in some cases, these difference were large (e.g. Expt 3 and Expt 4). However, for all seven sites the average RB209 recommendation was 138 kg N/ha and this is similar to the average optima determined by experimentation (151 kg N/ha). Collectively, these data support the existing recommendation but also illustrate some of the limitations of N response experiments.

Recommendation. These data broadly support existing N recommendations so no changes to existing tables are suggested. Data highlight methodological limitations to using N response data to underpin recommendations and alternatives should be sought.

As expected, a literature search using Web of Science® produced many papers and articles that fulfilled the search criteria. Of the 99 papers and article titles, abstracts were sought for about one quarter (24) of these papers but only 1 reference (Vos, 2009) was thought of sufficient relevance for the review process.

Regular introduction of new varieties that fill marketing niches or that have superior agronomic properties to existing varieties is a feature of UK potato production. It has long been recognised that there are large differences in the N requirements of varieties grown for similar season-lengths and this information is used within existing recommendations. The current (8^{th} edition) includes 25 varieties whereas the AHDB Potatoes publication Crop Nutrition for Potatoes (October 2013) has the determinacy grouping for 75 varieties. Together with consultations as part of this review process the following amalgamated table (Table 5) is suggested for inclusion in the new fertiliser recommendations. The figures in bold in the table indicate those varieties for which we have data from several N response experiments and where we have confidence in the variety group. However, for most varieties these data are missing and the variety groups have been determined by the opinions of plant-breeders, agronomist and other stakeholders. This lack of objective accurate data probably results in some varieties (particularly the newer ones) being systemically over or under-fertilised and this will affect the variety's performance and long-term viability.

Recommendation. The development of protocols to rapidly place varieties in their correct groups is needed by the industry.

Table 5. Amalgamated table of determinacy groups. Values in bold are based on many nitrogen response experiments.

Variety	Group	Variety	Group	Variety	Group
Accord	1	**Hermes**	**3**	Pentland Dell	3
Agria	3	Innovator	1	Pentland Javelin	2
Amanda	2	Juliette	2	Pentland Squire	3
Ambo	3	Kerr's Pink	3	Picasso	3
Amora	3	Kestrel	2	Premiere	1
Annabelle	1	**King Edward**	**3**	Record	3
Anya	1	Lady Balfour	4	Rembrandt	2
Arcade	2	Lady Christl	3	Rocket	1
Asterix	4	Lady Claire	2	Romano	2
Atlantic	2	**Lady Rosetta**	**2**	Rooster	3
Cabaret	3	Lady Valora	3	Royal	4
Caesar	3	**Marfona**	**2**	**Russet Burbank**	**3**
Cara	**4**	Maris Bard	1	Sante	3
Carlingford	2	**Maris Peer**	**2**	Sassy	3
Charlotte	2	**Maris Piper**	**3**	Saturna	3
Colmo	1	Maritiema	2	Saxon	2
Cosmos	3	Markies	4	Shannon	2
Courage	2	Melody	2	Shepody	2
Cultra	3	Minerva	1	Slaney	3
Daisy	3	Miranda	2	Stemster	3
Desirée	3	Morene	3	Vales Emerald	1
Dundrod	2	Mozart	2	Vales Everest	4
Endeavour	2	Nadine	2	Vales Sovereign	4
Eos	3	Navan	3	Valor	3
Estima	**1**	Nicola	2	Victoria	3
Fambo	3	Orchestra	2	Vivaldi	2
Fianna	3	Orla	2	Wilja	2
Harmony	2	Osprey	2	Winston	1

4.2. Response of potato to applied potash fertilisers

4.2.1. AHDB derived data

The potash recommendations for potatoes in the 8th edition of RB209 are based on the need to replace the amount of potash removed in tubers in order to maintain the soil K level at the target Index of 2 using the standard offtake figure of 5.8 kg K_2O per tonne fresh weight of tubers and assuming a crop yielding 50 t/ha. Adjustments for lower Indices are based on the standard adjustment of subtracting 30 kg/ha K_2O per Index used for all arable crops in RB209. There is a nil recommendation at soil K Index 4 and over. Advice is given to adjust potash use for higher or lower yielding crops using the standard offtake figure of 5.8 kg K_2O/t tubers. Dampney *et al*. (2011) reviewed the scientific evidence for the potash requirements of potatoes for AHDB in 2011; the review assessed available information on the response of tuber yield to potash application, the removal of potash in potato tubers and the effect of potassium supply on potato health and quality.

Although many trials, albeit mostly now quite old, have shown tuber yield responses to potash, especially at low soil K Indices, these responses have usually been quite small and to potash rates that are less than the amount of potash needed to replace potash removal in tubers, i.e. an application of potash sufficient to replace offtake will be higher than the amount of potash needed for maximum yield. The most recent AHDB Potatoes-funded potash response experiments on potatoes were carried out between 1989 and 1999 and reported by Allison *et al*. (2001a); 33 field experiments tested potash rates of 0, 85, 170, 250 and 320 kg/ha K_2O on the variety Estima. Statistically significant yield responses to potash application were only obtained at 7 of the 33 experiments. Optimum potash application rates ranged between 105 and 250 kg/ha K_2O and were less than the quantity of potash removed in the tubers. Potassium is also implicated in some tuber quality requirements which are important for end-users and processors. The review by Dampney *et al*. (2002) considered evidence for the impact of potash applications on potato quality including the risk of bruising, effect on enzymic browning, fry colour and after-cooking darkening, and concluded that the research evidence suggests that levels of potash that give optimum yield, and are sufficient to replace potash offtake, are also sufficient to reduce quality defects.

The review concluded that there was no evidence that potash applied at rates higher than needed to replace the potash removed in tubers provided either a yield response or any consistent or significant improvement in crop quality. However, the review did note that the evidence based for the 8th edition potash removal standard of 5.8 kg K_2O/t of tubers is limited, and commonly makes use of old data on low yielding and outdated varieties. As part of this RB209 review, additional data on tuber K_2O and P_2O_5 tuber content have been collated from recent AHDB Potatoes and Defra funded experiments and from values reported in the literature (Table 6); this more recent data supports the continued use of the 5.8 kg K_2O/t potash removal standard as appropriate for modern varieties.

Table 6. Data sources for removal of potash and phosphate in potato tubers.

Source	Location	Samples/sites	Variety	Potash kg/t K_2O	Phosphate kg/t P_2O_5
Data cited by Dampney et al. (2011)					
ADAS, Fancett 1979	UK			5.9	1.2
Allison *et a*l. (2000)	UK	13 experiments	Mixed	5.2	*
Allison *et al.* (2001a)	UK	33 experiments	Mixed	5.1	*
Anderson & Hewgill (1978)	*			5.8	*
Burton (1996)	*			6.0	*
Duengeverordnung (1996)	Germany			6.0	*
Gunasema (1969)	UK			5.5	*
DGER/SCPA, (1993)	France			6.0	*
Kunkel *et a*l. (1973)	US		Russet Burbank	4.7	1.4
Loue (1977)	France	23 experiments		5.3	*
Russell (1973)	UK			5.7	1.6
SAC (1996)	UK	24 seed stocks	Mixed	6.1	1.0
Widdowson & Penny (1975)	UK	4 experiments	Pentland Crown, Record, King Edward	6.2	1.0
New data					
Srek *et al*. (2010)	Czech Republic	1 experiment	Ditta	5.7	1.0
Tein *et al*. (2014)	Estonia		Not given	5.9	1.2
Kilikocka *et al.* (2015)	Poland	1 experiment	Irga	5.7	1.6
Sirius unpublished data (2014)	UK	1 experiment	Royal	6.2	1.5
Defra/WRAP Project OMK001-01/WR1212	UK	Gleadthorpe (2011)	Harmony	4.3	0.4
Defra/WRAP Project OMK001-01/WR1212	UK	Harper Adams site (2011)		5.2	0.9
LINK Project LK09136	UK	Tamworth site (2012)	Crisps4all	*	1.4
LINK Project LK09136	UK	Old Rayne site (2012)	Maris Peer	*	0.7
LINK Project LK09136	UK	Tamworth site (2012)	VR808	*	1.3
			Mean (all data)	**5.6**	**1.1**
			Mean (new data)	**5.5**	**1.1**

4.2.2. Other data

Sirius Minerals have provided unpublished data from a potash response experiment on potatoes carried out in 2014 on a sandy loam soil in Scotland. The soil was SAC K Index M-, equivalent to RB209 Index 2. The experiment assessed the effect of three different potassium fertilisers (Muriate of Potash, Sulphate of Potash and Polyhalite) applied at rates equivalent to 0, 75, 150, 225, 300 and 375 kg/ha K_2O, with each treatment replicated 4 times. There were no statistically significant differences ($P>0.10$) between rate of potash or source of potash on total tuber yield. Data on tuber potash and phosphate offtake from this experiment has been added to the database of offtake figures (Table 6). The literature review did not identify any other new (i.e. since 2009) published research from North-West Europe looking at the effect of potash application on potato yields.

Recommendation: No change to RB209 (8th edition) recommended potash rates or guidance on application.

4.3. Response of potato to applied phosphate fertilisers

The potato crop is traditionally recognised as needing high rates of phosphate in order to produce high yields. The amount of phosphate recommended for soils at P Index 2 or 3 in 8th edition of RB209 is more than sufficient to replace the phosphate removed by a 50 t/ha crop (about 50 kg P_2O_5/ha based on a tuber offtake figure of 1.0 kg/t P_2O_5). The guidance in 8th edition of RB209 states that 'the surplus phosphate will help to maintain the soil at a target P Index 2 for an arable crop rotation and should be allowed for when assessing the need for phosphate of one or more following crops. Dampney *et al*. (2002) reviewed the response of potatoes to phosphate for Defra prior to the revision of the last edition of RB209. The review concluded that the research base for phosphate recommendations on potatoes is very weak. The majority of response experiments were carried out before 1980 when varieties, growing methods and soil types used for growing potatoes were very different to current practice. Furthermore, very few response experiments have been carried out with modern varieties, at high soil P indices or under management practices of de-stoning, irrigation or bed systems of production. Based on the available P response data, Dampney *et al*. (2002) concluded that the then current (i.e. 7th edition RB209) recommendations were a 'sensible framework', with the possible exception of P Index 0 where responses above the recommendations seemed common, although the authors noted that this may be of little practical significance as very few potato crops are grown on soils with P Index 0. The review also noted that there was very little P response experimental data at the common higher P Indices of 3-5, and the review highlighted this as a priority area for future research.

4.3.1. AHDB derived data

Johnston *et al*. (2013) reviewed potato phosphate response data from the Saxmundham experimental site from between 1969 and 1974. The paper reports data complied as part of AHDB Cereals & Oilseeds project RD-2008-3554, i.e. prior to the 8th edition revision of RB209. The Saxmundham experimental site has plots with a range of well-established levels of Olsen P and response curves relating potato yield to Olsen P were fitted statistically to determine the asymptotic yield and the Olsen P associated with 98% of that yield, i.e. the 'critical' Olsen P. The arithmetic mean asymptotic yield for potatoes was 43.2 t/ha and the associated critical Olsen P was 26 mg/kg. Although asymptotic yields for potatoes were achieved in some years on soils with less than this average critical Olsen P, there were two years when much more than average Olsen P was required to achieve the asymptotic yield. The authors note that the requirements for more Olsen P in these years is probably due to the soil physical conditions and possibly reflects the fact that the current soil cultural practice for potatoes, namely de-stoning and preparing beds of near uniform soil, was not used in the Saxmundham experiments. The authors conclude that this data support the RB209 (8th edition) recommendation to maintain soils growing arable crops (including potatoes) at P Index 2 (16-25 mg/L Olsen P).

Most recently, the LINK 'Targeted P' project (LK09136, AHDB project RD-2007-3454 'Improving the sustainability of phosphorus use in arable farming') included potato crops at three of the ten field experiments between 2011 and 2014. The project aimed to determine if using fertiliser placement and novel fertilisers can maintain soil at P Index 1 (as opposed to 2) whilst consistently achieving optimum yield. Potato phosphate response experiments were carried out at Tamworth, Staffordshire in 2012 (variety Crisps4all) and 2014 (variety VR808), and at Old Rayne, Aberdeenshire in 2012 (variety Maris Peer). Treatments included a nil phosphate control, triple super phosphate (TSP) broadcast and then incorporated at 40, 80 and 160 kg/ha P (equivalent to 92, 183 and 367 kg/ha P_2O_5), and TSP placed at 40 and 80 kg/ha P. At Tamworth in 2012 (P Index 1), there was no effect of phosphate application rate or method on total yield ($P>0.05$); mean total yield from the nil P control was 45.4 t/ha compared to an average of 45.5 t/ha from the broadcast TSP treatments (mean of 40, 80 and 160 kg/ha P rates) and 39.4 t/ha from the placed TSP treatments (mean of 40 and 80 kg/ha rates). At Tamworth in 2014 (P Index 1), application of phosphate significantly increased total yield ($P<0.05$), although there was no further significant increase in yield with increasing application rate (40, 80 or 160 kg/ha P). Placement of TSP increased ($P<0.05$) total yields by c.13% compared to broadcast TSP; mean total yield from the nil P control was 40.2 t/ha compared to an average of 44.4 t/ha from the broadcast TSP treatments (mean of 40, 80 and 160 kg/ha P rates) and 50.0 t/ha from the placed TSP treatments (mean of 40 and 80 kg/ha rates). At Old Rayne in 2012 (SAC P Index Low, equivalent to RB209 P Index 1), application of phosphate increased total yields ($P=0.051$), although as seen at Tamworth in 2014, there was no evidence of any further increase in yields with increasing application rate (40, 80 or 160 kg/ha P). Placement of P increased ($P<0.05$) total yields by c.8% compared to broadcast TSP; mean total yield from the nil P control was 31.9 t/ha compared to an average of 34.0 t/ha from the broadcast TSP treatments (mean of 40, 80 and 160 kg/ha P rates) and 36.6 t/ha from the placed TSP treatments (mean of 40 and 80 kg/ha rates). Data from the LINK 'Targeted P' project show that potatoes are responsive to phosphate at low P Index sites. It was not possible to fit a response curve to the yield data at these sites and therefore economic optimum P rates were not calculated. The three sites were all P Index 1 and have an RB209 (8th edition) recommendation of 210 kg/ha P_2O_5, however at these sites there was no evidence of a further yield increase above the first P rate tested (40 kg/ha P, equivalent to 92 kg/ha P_2O_5). Although this may indicate that at these sites the economic optimum P rate was below the current 8th edition RB209 recommendation; there is currently insufficient evidence to change the current recommendations.

Data from the LINK ‘Targeted P’ project does however provide evidence that placing P can increase potatoes yields compared to conventional broadcast application. 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.

4.3.2. Other data

Defra project HH3509SFV ‘Targeting Phosphorus Fertiliser Applications to Roots of Wide-Row Crops’ (2005-2010) aimed to assess to what extent P application to potatoes can be reduced by placing starter P fertiliser within the root zone. Three years of field trials were conducted at Wellesbourne (soil P Index 3) to assess the effect of application rate and distance of placement from the seed tuber of P fertiliser. Fertiliser P was applied as TSP broadcast at 130 kg/ha of P_2O_5 and compared to placed TSP fertiliser at 0, 5, 10, 25, 50 and 100% of the broadcast rate. In addition, there were six treatments to assess the depth and distance of placement from the seed (6 x 0”, 6 x 3”, 6 x 6 “, 3 x 0”, 3 x 3” and 3 x 6” at a single rate of 65 kg/ha P_2O_5). Over the three years of field trials there was no significant ($P>0.05$) effect of treatment observed for tuber yield per plant. The project concludes that there is little evidence to support the use of P fertiliser placement for potatoes on these soils (i.e. sandy loam with a soil P Index 3 or greater). However, it is possible that the lack of yield response from placement of P fertiliser at this site is because this high P Index site was not responsive to P. The more recent LINK ‘Targeted P’ project (LK09136) demonstrated a yield benefit from placement of P at lower P Index sites.

The literature review identified two studies from Sweden which looked at the effect of fertiliser phosphate application strategy. Ekelöf *et al*. (2012) looked at the effect of foliar phosphate fertiliser application to potatoes grown in pots under controlled environmental conditions; the study aimed to determine the impact of soil moisture and soil P supply on the responsiveness to foliar P. Foliar P was applied twice – once 18 days after emergence just before tuber initiation, and the second 10 days later, at application rates between zero and 50 kg/ha P (115 kg/ha P_2O_5). Ekelöf *et al.* (2012) found that plants within the ‘moist’ treatment showed a greater yield response (on average 10% yield increase) to foliar P application compared to plants grown under ‘dry’ soil conditions (on average, no yield increase), even though no visual water stress symptoms were observed. These results suggest that water status is of importance for the responsiveness to foliar P and may be related to the diffusion of P through the leaf cells, which requires a good plant water status, and the authors therefore suggest that irrigation should be scheduled before the application of foliar P. Although the study by Ekelöf *et al*. (2012) demonstrated a yield response to foliar P, the study was carried out under controlled environmental conditions; Allison *et al*. (2001b) tested the effects of foliar P application in six field experiments in the UK and found no significant response on either yield or tuber number, even though two of the experiments were carried out on soils with a P Index of 0 and included treatments that received no soil applied phosphate. Currently, neither the 8th edition of RB209 nor the AHDB Potatoes 'Crop nutrition for potatoes' guide provide guidance on foliar P application, and we conclude that there is not currently sufficient evidence to change this. However, considering the results of Ekelöf *et al.* (2012), we recommend that any future research on foliar P should also include consideration of plant water status. In a later study, Ekelöf *et al*. (2014) evaluated the effects of splitting the application of P fertiliser into multiple applications during the growing period of potatoes grown in pots under controlled environmental conditions. The results from the study show that recovery of fertiliser P can be significantly increased if the P supply was split, however the split P applications did not significantly increase tuber yields, i.e. the potato plants took up more P, but didn't convert this increased P uptake into greater yield. Currently, the 8th edition of RB209 and the AHDB Potatoes 'Crop Nutrition for Potatoes' guide recommend that all the phosphate fertiliser should be applied in the spring and either worked into the seedbed or placed at planting. There is not currently sufficient evidence to suggest that split P applications are beneficial or to change the current guidance on application timing.

Recommendations: No change to current RB209 (8th edition) recommended phosphate applications rates. However, a modification to the text re. placement is appropriate:

- *RB209 (8th edition) text – Where fertiliser is placed, a small reduction in the recommended rate of phosphate and potash could be considered.*
- *Suggested revised RB209 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.*

Note, that the current RB209 (8th edition) potash recommendations are based on replacing crop offtake, and therefore should not be reduced if the potash fertiliser is placed.

4.4. Response of potato to applied magnesium fertilisers

4.4.1. AHDB derived data

The 8th edition of RB209 recommended 120 kg/ha MgO for soils at Mg Index 0, 80 kg/ha MgO for soils at Mg Index 1 and 40 kg/ha MgO for soils at Mg Index 2. Since the revision of RB209 in 2009 (8th edition) there has been no new AHDB funded research on Mg nutrition of potatoes.

4.4.2. Other data

Orlovius and McHoul (2015) examined the response of potatoes to applied magnesium fertiliser in six field experiments in the East of England. The field experiments were located on sites with Mg Index of 0 (4 sites) or 1 (2 sites) in a randomised block design with six replicates of three treatments:

i. Control (zero MgO)

ii. 100 kg/ha MgO applied as calcined magnesite

iii. 100 kg/ha MgO applied as Kieserite

Application of 100 kg/ha MgO as Kieserite increased tuber yields (by a mean of 3.3 t/ha across all sites compared to the control); this increase was statistically significant at three of the six sites and statistically significant when averaged across all sites. In comparison, the application of 100 kg/ha MgO as calcined magnesite resulted in a smaller yield increase (average 0.8 t/ha across all sites compared to the control), which was not statistically significant at any of the individual sites or when means of data from all sites were calculated. The authors also measured leaf Mg concentrations and found that application of Kieserite increased foliar Mg concentration by a mean of 43% and the application of calcined magnesite increased foliar Mg concentrations by a mean of 14%. The results of these experiments indicate increased Mg availability of magnesium sulphate (Kieserite) compared to magnesium oxide (calcined magnesite) reflecting the higher water solubility of the magnesium sulphate, and highlight the importance of applying a water soluble form of Mg fertiliser when a yield response is expected. The field experiments only looked at the effect of two application rates (0 and 100 kg/ha MgO) and do not therefore provide sufficient information with which to review the suitability of the current RB209 (8th edition) recommended rates. The 100 kg/ha MgO application rate used is within the range currently recommended (120 kg/ha MgO at Index 0 and 80 kg/ha MgO at Index 1) and was sufficient to increase tuber yields. It should be noted that these experiments were not balanced for the sulphur in the Kieserite because (i) a response to sulphur was not expected and (ii) because of the practicality of balancing for sulphur (J. McHoul pers. Comm.), however foliar Mg analysis support the conclusions of a response to Mg.

Recommendation: No change to current RB209 (8th edition) recommended magnesium rates or guidance on application.

4.5. Response of potato to applied calcium and fertiliser and liming materials

4.5.1. AHDB derived data

No new data found to review.

4.5.2. Other data

Three experiments were done by Cambridge University Farm (CUF, now NIAB CUF) in 1998 and 1999. These were funded by Cambridge University Potato Growers Research Association (CUPGRA) and although the experiments were done before the last review in 2010, they merit inclusions in the light of more recent *Limex*® data supplied by British Sugar plc.

The first experiment was done at CUF in 1998 and tested in factorial combination the effect of N source (ammonium nitrate or ammonium sulphate) and N application rate (0, 80 160 and 240 kg N/ha) on Maris Piper. Gypsum (at 475 kg N/ha) was applied to additional plots where ammonium nitrate had been applied as the N source. Each treatment combination was replicated three times although one replicate was lost due to the effects of late-blight. The experiment was planted with Maris Piper on 12 May 1998 and a final yield assessment was taken on 25 August. Tuber yield and scab data are summarised in the table below. These data show that total and ware yield was increased by application of N although there were no statistically significant differences between sources of N. When averaged over N treatments, the severity of common scab was reduced from 19.1 % of surface area affected with no gypsum to 11.7 % when 90 kg gypsum/ha had been applied.

Table 7. Effect of nitrogen (N) source and gypsum on yield and severity of common scab in a crop of Maris Piper grown at Cambridge University Farm in 1998.

Ammonium nitrate (AN) or sulphate (AS)	kg N/ha	kg gypsum/ha	Tuber yield > 10 mm (t/ha)	Tuber yield > 40 mm (t/ha)	Severity of common scab (% of area)
AN	0	0	54.8	51.1	21.9
AN	80	0	81.1	77.5	19.4
AN	160	0	88.9	85.0	24.1
AN	240	0	82.1	77.9	16.5
AN	0	475	55.5	42.1	7.4
AN	80	475	83.8	67.3	8.4
AN	160	475	71.7	73.0	18.9
AN	240	475	90.0	75.3	11.9
AS	0	0	51.6	47.8	21.9
AS	80	0	79.8	72.0	16.6
AS	160	0	68.6	75.5	18.9
AS	240	0	86.1	79.3	13.2
S.E. (11 D.F.)			6.57	6.94	4.35

The second experiment was done on Maris Piper grown near Ross on Wye, Herefordshire and tested, all combination of three rates of lime (0, 3.5 and 7.0 t/ha as builders' lime with a neutralising value of 73.6 % as CaO) and four rates of potassium (0, 150, 300 and 450 kg K_2O/ha as potassium sulphate). The four blocks with main-plots testing lime application rate and sub-plots testing potassium application rate. The crop was planted on 20 May 1999 and the final sampling was taken on 11 October 1999. Soil pH at planting was 5.2. The main effects of lime on yield and incidence of common scab are summarised in Table 8.

Table 8. Effect of lime applications immediately before planting on yield and severity of common scab in a crop of Maris Piper grown at Ross-on-Wye in 1999.

Lime application rate (t/ha)	Tuber yield > 10 mm (t/ha)	Tuber yield > 40 mm (t/ha)	Severity of common scab (% of surface area)
0	37.1	34.6	2.0
3.5	39.2	36.6	1.7
7.0	32.8	29.7	1.4
S.E. (4 D.F.)	1.37	1.43	0.39

These data show that tuber yields were significantly reduced at the largest rate of lime application but there was no evidence that high rates of lime were associated with an increased incidence of common scab.

The third experiment was done at Cambridge University Farm and tested the effects of gypsum (0, 0.5, 1.0 and 5.0 t/ha) and three further treatments: calcium chloride (640 kg $CaCl_2$/ha); potassium sulphate (1050 kg K_2SO_4/ha) and potassium chloride (852 kg KCl/ha) on the yield and quality of Maris Piper. Each treatment was replicated four times and allocated at random to blocks. The experiment was planted on 28 April 1999 and the final sampling was taken on 4 October 1999. Soil pH in untreated plots was 7.0. The effects of the treatments on yield and incidence of common scab are summarised in Table 9.

Table 9. Effect of nitrogen source and gypsum on yield and severity of common scab in a crop of Maris Piper grown at Cambridge University Farm in 1999.

Treatment	Tuber yield > 10 mm (t/ha)	Tuber yield > 40 mm (t/ha)	Severity of common scab (% of surface area)
Control	87.3	82.8	12.4
0.5t gypsum/ha	89.8	84.3	10.9
1.0 t gypsum/ha	84.5	78.9	7.3
5.0 t gypsum/ha	87.1	81.7	6.7
852 kg KCl/ha	101.1	94.2	10.7
1050 kg K_2SO_4/ha	95.9	91.1	7.0
640 kg $CaCl_2$/ha	92.3	87.1	7.3
S.E. (18 D.F.).	5.50	5.56	1.6

None of the treatments had a significant effect on yield but there was a tendency for the severity of common scab to be reduced as the rate of gypsum application was increased or when calcium chloride had been applied however these effects were not statistically significant.

More recently, work carried out by Crop Intellect for British Sugar plc has shown that application of spent, sugar factory lime ("LimeX", with a neutralising value of *c*. 25 %) resulted in statistically significant increases in total and marketable yield in several field experiments (

Table 10). Fifteen replicated field trials were carried out across five farms around East Anglia from 2012-2015. The treatments consisted of a control and LimeX applications of between 3 and 10 t/ha; each treatment was replicated five times and arranged in a randomised block design. Crop Intellect conclude that the increase in marketable yield was a consequence of a reduction in the severity of common scab. In these experiments the optimum rate of LimeX was determined to be 7.5 t/ha.

Table 10. Summary of effects of LimeX applications of yield and quality of potato crops grown in East Anglia in 2012-2014. Responses are significant at 5 % level unless non-significant (n.s.). Adapted from presentation supplied by British Sugar plc (pers. comm. Richard Cogman).

Year	Site	Soil type	Change in stem population	Change in tuber populations	Change in total tuber yield	Change in marketable yield
2012	Hay	Calcareous silt	n.s.	n.s.	n.s.	Increase
2013	Hay	Calcareous silt	n.s.	n.s.	n.s.	Increase
2013	Bannister	Silty clay	n.s.	n.s.	Increase	Increase
2013	Davis	Peaty	n.s.	n.s.	n.s.	n.s.
2013	Johnson	Loam over clay	n.s.	n.s.	Increase	Increase
2014	Bannister	Calcareous silt	n.s.	n.s.	n.s.	Increase
2014	Grant	Peaty	n.s.	n.s.	Increase	Increase
2014	Abrey	Sandy loam	n.s.	n.s.	Decrease	Decrease
2015	Bannister	Calcareous silt	n.s.	n.s.		Increase
2015	Grant	Peaty	n.s.	n.s.		Increase
2015	Abrey	Sandy loam	n.s.	n.s.		n/s
2015	Hay	Calcareous silt	n.s.	n.s.		n/s
					Mean response	6.5 t/ha

Collectively these data suggest that the application of calcium containing products (e.g. lime and gypsum) may reduce the severity of common scab thereby increasing marketable yield.

Recommendation. These data are interesting since they challenge a long-standing/widespread view on the effects of calcium/liming materials on potato yield and quality. Suggest moderation of existing advice in RB209. May be beneficial to conduct large scale literature review to understand how current advice was derived before making further changes to recommendations.

4.6. Response of potato to applied sulphur fertilisers

The current 8th edition of RB209 does not give a recommendation for sulphur (S) fertiliser for potatoes. The AHDB Potatoes ‘Crop Nutrition for potatoes’ Guide includes the following text on S: Although S is an essential plant nutrient, there is no evidence that S fertiliser needs to be applied to the potato crop even on land where other crops (i.e. oilseed rape) are known to need S fertiliser. Although atmospheric deposition of S has declined markedly in recent years due to reduced industrial pollution, the supply of natural sources of S is still regarded as sufficient for the potato crop. However, the possibility of S deficiency in potatoes in the future cannot be ruled out. If deficiency does occur, it is most likely to show first in crops grown on deep sand soils with low organic matter and in areas that are well away from industrial pollution. In contrast, Scottish fertiliser recommendations (TN633) include a recommendation for 25 kg/ha of SO_3 for potatoes where S deficiency is expected. This recommendation is based on unpublished data from the early 1980s where Norman Scott at the Macaulay Land Research Institute showed a yield response to S in potatoes (Alex Sinclair, Pers. Comm.).

4.6.1. AHDB derived data

There has been no AHDB funded research on S nutrition of potatoes (either pre or post the last revision of RB209).

4.6.2. Other data

Technical note TN633 published by the Scottish Rural College in October 2013, recommend an application of 25 kg SO_3/ha (*c.* 10 kg S/ha) where sulphur deficiency is expected. There is no equivalent advice for potatoes in the current edition of RB209 (8th edition). In the late 1990s, Cambridge University carried out two experiments that tested, amongst other factors, the effects of N source (ammonium nitrate or ammonium sulphate) on the yield of potato crops. These data are summarised in the Table below and show that there was no evidence in these experiments that there was a benefit of using sulphur containing fertilisers.

Table 11. Summary of effects of ammonium nitrate and ammonium sulphate on potato yield in two experiments in 1998.

Nottinghamshire 1998			**Cambridge 1998**		
kg N/ha	**Ammonium nitrate**	**Ammonium sulphate**	**kg N/ha**	**Ammonium nitrate**	**Ammonium sulphate**
0	28.0	27.3	0	54.8	47.8
150	38.7	37.1	80	81.1	72.0
300	43.5	48.3	160	88.9	75.5
450	49.3	46.2	240	82.1	79.3
Mean	39.9	39.7	Mean	76.7	68.6
S.E. (14 D.F.)	2.13		S.E. (7 D.F.)	7.46	

However, S is an essential plant nutrient required by potatoes. 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. A recent Defra funded review (SCF0308) 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 Defra 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/ha SO_3) and least in Wales (*c*. 7-10 kg/ha SO_3).

Recent UK research on S and potatoes has focussed on the impact of S on the formation of acrylamide, a suspected carcinogen, during high temperature cooking. Elmore *et al*. (2007, 2010) report results of a study where three varieties of potatoes (King Edward, Prairie and Maris Piper) were grown in a glasshouse in pots containing vermiculite under conditions of either severe S depravation or an adequate supply of S, in order to examine how S deficiency affects acrylamide formation in cooked potatoes. In this study, acrylamide formation was lowest from the tubers grown under S deficient conditions, with the application of S increasing acrylamide formation. Tuber yields were also measured; tuber yields grown under conditions of extreme S deficiency were reduced by 44-88% compared to the potato plants which had received S.

Following on from the glasshouse experiments of Elmore *et al.* (2007,2010), Muttucumaru *et al*. (2013) conducted a field experiment at Woburn in 2010 in which 13 varieties of potatoes were treated with different combinations of N (0, 100 or 200 kg/ha N) and S (0, 15 or 40 kg/ha S, equivalent to 0, 45 and 100 kg/ha SO_3) fertiliser to examine the effect of N and S on free amino acids, sugars and acrylamide forming potential. Muttucumaru *et al*. (2013) showed that N application can affect acrylamide forming potential in potatoes, but that the effect is type (French fry, chipping and boiling) and variety dependent, with most varieties showing an increase in acrylamide forming in response to increase N, but two showing a decrease. In contrast to the results from the glasshouse experiments reported by Elmore *et al*. (2007, 2010), where potatoes were grown in the field, the application of S fertiliser had no significant effect on free asparagine concentrations. However, S application was shown to reduce glucose concentrations and, possibly as a result of this, mitigate the effect of high N applications on the acrylamide forming potential of some of the French fry type potatoes. There was no effect of S application in tuber yields. On balance, although there is some evidence that S may have a beneficial effect on quality for some varieties, there is currently insufficient evidence to recommend S application to potatoes for crop quality; any S recommendation should be based on the need to maximise yields.

The literature review did not identify any other new (i.e. since 2009) published research from North-West Europe looking at the effect of S application on potato yields. However, recent research from Eastern Europe (Poland) has demonstrate a yield response in potatoes to applied S. Kilkocka *et al.* (2015) conducted a field experiment in Poland between 2004 and 2006 in which S was applied in different forms (elemental S and as potassium sulphate) and rates (0, 25 and 50 kg/ha S, equivalent to 0, 62 and 125 kg/ha SO_3), and found a significant increase in tuber yields (c.1.6 t/ha increase) from the application of both types of S fertiliser. Similarly, Barczak *et al.* (2013) carried out field experiments in Poland between 2003 and 2005 where S was applied at 0, 20 and 40 kg/ ha S (equivalent to 0, 50 and 100 kg/ha SO_3) as ammonium sulphate, potassium sulphate and elemental S. Barczak *et al*. (2013) found a significant increase in tuber yields from the application of S (both rates and forms), with mean yield increases (compared to the control) of 7.2, 5.3 and 14.4% in the three successive years.

In the absence of UK based field experiments to quantify the S requirement of potatoes, 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 a typical potato crop requiring 160 kg/ha N would require 13 kg/ha S (equivalent to 33 kg/ha SO_3). The PDA (2011) report results from a French data set which measured the S uptake of potatoes as *c.*40 kg/ha SO_3 and showed that the measured S uptake was close to that estimated from the crop N uptake assuming a 12:1 N:S ratio. Furthermore, a potato crop S uptake of 40 kg/ha SO_3 (PDA, 2011) is very similar to the S uptake of a winter wheat crop (Zhao *et al.*, 2002) for which we have an existing S recommendation of 25-50 kg/ha SO_3.

Recommendation. There is a lack of UK evidence on which to base a S recommendation for potatoes. However, against a back drop of declining atmospheric S emissions and in view of yield responses measured in other countries, we recommend guidance to apply S fertiliser to potatoes where deficiencies are thought likely. Recommended RB209 text:

- *Potato 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. Where sulphur deficiency has been recognised or is expected, apply 25 kg/ha SO_3 as a sulphate containing fertiliser in the seedbed.*

4.7. Response of potato to fertiliser containing copper, manganese, zinc, iron, boron and molybdenum

4.7.1. AHDB derived data

No new data found to review

4.7.2. Other data

A series of experiments (that tested other factors) funded by AHDB Potatoes and CUPGRA in 1998 and 1999 measured the concentration of selected trace elements in potato tubers (Table 12). Tuber concentrations of manganese (and to a certain extent copper) were larger in those crops which had a close association with livestock (the non-CUF crops).

Table 12. Tuber yield and concentration of selected micronutrients measured in experiments in 1998 and 1999.

Site	Year	Variety	Tuber DW yield (t/ha)	Copper (mg/kg DM)	Manganese (mg/kg DM)	Zinc (mg/kg DM)	Boron (mg/kg DM)
Bazeley	1998	Estima	11.3 ± 0.25	3.6 ± 0.13	14.2 ± 0.27	-	-
Bazeley	1998	Hermes	12.2 ± 0.42	3.0 ± 0.09	13.1 ± 0.33	-	-
CUF	1998	Estima	10.7 ± 0.38	4.1 ± 0.09	7.5 ± 0.21	-	-
CUF	1998	Courlan	7.6 ± 1.28	4.6 ± 0.18	7.6 ± 0.07	-	-
CUF	1998	Hermes	13.9 ± 1.50	4.0 ± 0.19	6.9 ± 0.21	-	-
CUF	1998	Maris Piper	16.6 ± 0.50	4.0 ± 0.12	8.2 ± 0.19	-	-
Lamden	1998	Estima	12.3 ± 0.38	7.7 ± 0.83	19.1 ± 0.53	-	-
CUF	1999	Maris Piper	19.3 ± 0.49	3.2 ± 0.15	6.2 ± 0.28	11.0 ± 040	-
CUF	1999	Estima	14.9 ± 0.23	4.1 ± 0.10	6.0 ± 0.12	-	-
Torpoint	1999	Estima	9.2 ± 0.28	-	-	-	7.2 ± 0.12

A review of available literature on Web of Science® was completed on 1st February. Search terms included the relevant nutrient (boron, copper, iron, manganese and zinc) together with the search terms “potato*”and “fertili*er” (where the * is a wild card to capture ‘potato’ and ‘potatoes’ and ‘fertiliser and ‘fertiliser’. Searches were restricted to North-West Europe (UK, Ireland, France, Belgium, Netherlands, Denmark, Finland, Sweden and Norway).

For boron (B), the literature search produced three references all by the same author and from the titles were judged to be of little relevance to this review and no abstracts or papers were reviewed. For copper (Cu), the literature search produced three references. From the titles of the papers it was determined that these papers would offer little to the review process and neither abstracts nor full papers were reviewed. For iron (Fe), the literature search found three papers that met the search criteria. However, none were judged to be of value for the review process and neither abstracts nor full papers were reviewed. For manganese, the search terms produced just two results. One relating to agricultural use of wastewater in Bangladesh the other to rice production. Neither abstracts nor full papers were sought. For zinc (Zn), the literature search produced eight papers that met the criteria. Of these, one paper (a review by Ahmad *et al.* (2012)) was of sufficient interest to warrant reviewing an abstract but no further action was then taken.

Recommendations. In the absence of any dose-response information criteria for the application of micronutrient cannot be devised. Growers should be referred to micronutrient in the ‘Principles’ section and to consult with FACTS accredited advisors.

5. 'New' recommendations

Since the last review process which led to the revisions included in the 8th edition of RB209 there has been relatively little new, relevant work in the UK or in North-West Europe. However the following revisions will be suggested for inclusion in the new edition.

5.1. Nitrogen

- No changes to N application rates in relation to SNS, determinacy and season length
- Cross reference to AHDB Potatoes publication 'Crop Nutrition for Potatoes (October 2013)'
- Expand varietal list to encompass 'Crop Nutrition for Potatoes' and industry consultation
- Slightly expand guidance notes to emphasise the importance of early N applications and opportunities to increase N use efficiency

5.2. Potash

- No changes to application rates of K_2O in relation to soil Index
- Review confirms that a removal rate of 5.8 kg K_2O/t FW is appropriate for modern production systems.

5.3. Phosphate

- No changes to application rate of P_2O_5/ha in relation to soil Index
- No change to removal rate (1.0 kg P_2O_5/t FW).
- Where phosphate fertiliser is placed, reductions in application rate could be considered.

5.4. Magnesium

- No change to application rates of MgO in relation to soil Index and no changes to guidance notes.

5.5. Calcium & liming materials

- Due to evidence from CUPGRA and British Sugar funded experiments suggest removal of the warning relating to liming before potato crops.

5.6. Sulphur

- In response to reducing S inputs and data on crop S removal in tuber, suggest inclusion of a recommendation to apply 25 kg SO_3 where responses are thought likely.
- Refer growers to 'Principles' section' for further guidance.

5.7. Micronutrients

- No recommendations but refer growers to ‘Principles’ section or further guidance
-

6. Gaps in knowledge and where future research is required

6.1. Nitrogen

- There is a need to develop cost-effective protocols for the rapid and objective allocation of varieties into determinacy groups. Currently, new varieties are often allocated on anecdotal evidence resulting in some varieties being over or under-supplied with N and thus failing to reach their full potential. It is probable that some, potentially useful, varieties were rejected at an early stage of commercialisation due to inappropriate N recommendations.
- There is little quantitative data that will help growers adjust N recommendation in response to positive soil potato cyst nematode (PCN) tests. Anecdotal evidence suggests that in the presence of PCN, growers will tend to increase the N application by *c*. 15-20 kg N/ha to help mitigate the impaired rooting system. However, there is no evidence to show if this strategy has merit or whether a reduction in N application rate may be more appropriate.

6.2. Potassium

- None identified in this review

6.3. Phosphate

- There is very little experimental data on P response at higher soil P Indices of 3-5
- Possible opportunities for fine-tuning phosphate recommendations in relation to soil type (e.g. P fixing capacity)
- Any future research on response to foliar P should include consideration of plant water status

6.4. Magnesium

- None identified in this review.

6.5. Calcium

- Data submitted by CUPGRA and British Sugar suggest that application of calcium containing materials may <u>reduce</u> the incidence of common scab. It would be useful to conduct a larger review of available data (to include data under-pinning the 8th edition recommendations to avoid applications of liming materials).

- Depending on the outcome of review, some new experimental/survey work may be appropriate.

6.6. Sulphur

- This review has shown that the total (haulm and tuber) uptake and removal (tubers) of sulphur is *c*. 8 % that of nitrogen. However, these data are from a relatively small sample of experimental crops and the data were collected in the late 1990s. Similar data are needed from contemporary, commercial crops.
- Experimental data are also needed to relate environmental factors (e.g. soil texture, organic matter content, use of organic manures, proximity to industrial/urban centres etc.) to the probability of yield/quality responses to S containing fertilisers.

6.7. Trace Elements (Boron, Copper, Iron, Manganese and Zinc)

- There is currently a paucity of quantitative evidence that relates soil or tissue test results to the probability of a statistically significant response to an application of trace elements. It is probable that many crops already receive prophylactic application of trace elements particular those grown on soils where trace element deficiency are observed in other crops (e.g. on light textured or on soils with high organic matter contents).

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Appendix 1

Table A1. Potato supply chain partners contacted as part of review process in autumn 2015.

Organisation	Type
Potato Processors' Association	Trade body
Fresh Potato Suppliers Association	Trade body
British Potato Trade Association	Trade body
Walkers (UK) PepsiCo	Processing sector
Lamb Weston Meijer	Processing sector
McCain (UK) Ltd	Processing sector
Greenvale AP	Fresh market sector
Branston Potatoes	Fresh market sector
Albert Bartlett	Fresh market sector
Co-op Farms	Fresh market sector
Produce World	Fresh market sector
Cygnet PB	Breeder
Harper Adams University College	Academic
The James Hutton Institute	Academic
Cranfield University	Academic
Manor Fresh	Fresh market sector
Spud Agronomy Services	Agronomy Services
Scottish Agronomy	Agronomy Services
University of Nottingham	Academic
SRUC/SAC Consulting	Agronomy Services
Demeter Technology	Agronomy Services
KWS	Breeder
Agrico	Breeder
SASA	Research
UPL	Fertiliser AgChem Manufacturer
British Sugar	Sugar Processor