YORK POTASH LTD

APPLICATION TO CARRY OUT MINERAL WORKING AND ASSOCIATED DEVELOPMENT

September 2014

Appendices to
Major Development Test Planning Statement
Quod

YORKPOTASH
A Sirius Minerals Project

THE YORK POTASH PROJECT

APPENDICES TO a 5¢ PLANNING STATEMENT

September 2014
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Quod | Ingeni Building 17 Broadwick Street London W1F 0AX | 020 3597 1000 | www.quod.com

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APPENDIX 1

THE MINERALS AND WASTE JOINT PLAN (MWJP)

A1. The Minerals and Waste Joint Plan (MWJP) for the City of York, North York Moors and North Yorkshire will, once adopted, provide strategic and development management policies relating to minerals and waste developments and will replace Core Policies E and F of the NYMNPA Core Strategy and Development Policies.

A2. Following an initial public consultation in May/June 2013, an Issues and Options document was published for public consultation in February 2014 with responses due by 11 April 2014. The current timetable for preparing the plan assumes that a Preferred Options consultation will take place later in 2014, followed by an examination in summer 2015 and adoption in October 2015.

A3. This Appendix provides a summary of the most relevant issues and options contained in the emerging plan in respect of the proposals.

A4. The Issues and Options MWJP states that employment in mining and quarrying represents around 1% of employment in the Joint Plan area, recognising that Boulby Potash Mine is the largest employer in the North York Moors National Park (paragraph 2.6). The MWJP area is identified as a significant producer of minerals at a regional and, in some instances, national scale, with over 50 working quarries. Potash is considered to be an important mineral with Boulby Mine in the NYMNP being the UK's only potash mine (paragraph 2.63). Around a third of potash produced from the Boulby potash mine is exported from the UK according to the plan (paragraph 2.67).

A5. Commercial interest for a new potash mine in the NYMNP is identified as being one of the key issues and challenges for minerals that the MWJP will need to address. More generally, one of the key cross-cutting issues and challenges that needs to be addressed is:

> **"Whilst unemployment levels are relatively low, there is a drive for economic growth both within the Joint Plan area and nationally, for which minerals supply can play an important supporting role. The drive for economic growth is also relevant when considering the employment opportunities afforded by new minerals and waste developments (paragraph 3.5)."**

A6. Chapter 4 ('Development of a Vision and Objectives') of the Issues and Options document sets out the document's vision:

> **"Over the period to 2030 a careful balance will be maintained between meeting requirements for minerals and waste development and infrastructure**

> **whilst protecting and enhancing the Joint Plan area's environment, supporting its communities and strengthening its economy."**

A7. The vision and a series of 12 objectives are underpinned by the following interconnected priorities:

- Delivering sustainable waste management
- Achieving the efficient use of minerals resources
- Optimising the spatial distribution of minerals and waste development
- Protecting and enhancing the environment, supporting communities and businesses and mitigating and adapting to climate change.

A8. Chapter 5 ('Minerals') of the Issues and Options document considers the issues and puts forward potential options to help maintain continuity of supply, as well as long term availability, for each different mineral resource present in the Joint Plan area. It states:

> **"…it should be noted that no overall spatial approach applicable to extraction of all forms of mineral worked in the Plan area is proposed, mainly because minerals can only be extracted where they occur in economically viable quantities and this is fundamentally constrained by geology, and also because minerals worked in the Plan area serve very wide geographical markets ranging from local to international (paragraph 5.1)."**

A9. Paragraph 5.155 explains that there are various forms of potassium-bearing minerals which can be mined for potash including sylvinite, polyhalite and carnalite. Potash and salt resources are both found throughout the eastern part of the MWJP area, mainly within the NYMNP. They are currently mined at the Boulby Potash Mine in the north of the Park, which is the only mine of its kind in the UK and supplies both the UK and international markets (paragraph 5.156). Figure 15 provides a map illustrating the geographical extent of the potash resources. The MWJP then refers to York Potash Limited's proposals for a new mine within NYMNP approximately two kilometres south of Sneaton village and four kilometres south of Whitby, which would extract polyhalite.

A10. Paragraph 5.158 states:

> **"Potash and salt are all identified as minerals of local and national importance in the National Planning Policy Framework which requires policies to be included for their extraction. There is however no requirement within national**

> **policy to maintain a certain level of potash reserves. For this reason, and acknowledging the fact that the new potash mine proposed is a particularly complex project and at a relatively advanced stage in planning terms, it is not appropriate to consider allocating land for potash extraction within this Plan. Draft National Planning Practice Guidance on Minerals states that preferred areas or areas of search are not expected to be designated in National Parks. A new mine in the National Park would be classed as 'major development' and would need to be considered against the 'Major Development Test' (see glossary)."**

A11. This suggests that it is a planning application rather than the MWJP that will determine the proposals for a mine head at Dove's Nest.

A12. The Issues and Options document presents four options ('id34') for potash supply:

- **Option 1 -** Support an indigenous supply of potash from one location only.
- **Option 2 -** Support the principle of multiple sources of potash supply from within the Plan area.
- **Option 3 -** Support new locations for potash extraction outside of the North York Moors National Park only.
- **Option 4 -** Support extraction of potash from under the National Park as well as outside of the National Park but only support siting of surface infrastructure outside the National Park.

A13. Mineral safeguarding work undertaken by British Geological Survey for NYCC and the NYMPA has identified the potential extent of a safeguarding area for potash resources. The reports recommend safeguarding the whole of the resource, which reflects the potential for surface subsidence associated with underground mining to be constrained by certain forms of major or sensitive surface development (paragraph 5.161).

A14. The Issues and Options document presents two options ('id35') for safeguarding potash:

- **Option 1 -** Safeguard land above the area permitted for potash working only.
- **Option 2 -** Safeguard land above all of the potash resource.

A15. Paragraph 5.172 explains that the MWJP area has "a range of deep mineral resources namely coal (including coal bed methane), gas (including shale gas), gypsum, potash, polyhalite and salt." The extraction of these resources has the potential to sterilise another due to the fact that areas of the resources can overlap. The extraction methods used could also impact upon areas of underground mining for other resources, for example by causing instability or water ingress.

A16. The Issues and Options document presents two options (‘id38’) for safeguarding deep mineral resources:

- **Option 1 -** This option would include a policy which would require the developer to demonstrate that there would not be significant conflict with other areas and forms of deep minerals extraction.

- **Option 2 -** This option would identify ‘exclusion zones’ around areas of existing deep mineral extraction which would prevent the extraction of other resources where there is the potential for or there are known to be effects on these current areas of extraction.

A17. The Issues and Options document presents four options (‘id70’) for developments proposed within Mineral Safeguarding Areas. These can be summarised as follows:

- **Option 1 -** This option would indicate that within Minerals Safeguarding Areas non-minerals development will only be permitted in certain circumstances such circumstances are listed).

- **Option 2 -** This option would adopt a list of application types that would be exempt from consideration under the Minerals Safeguarding Area policy (possible exemptions are listed).

- **Option 3 -** In areas identified as underground coal or potash Minerals Safeguarding Areas, applicants proposing the following types of development would be required to consider the potential impacts on the proposed development arising from extraction of the safeguarded resources, as well as the potential for the surface development to sterilise the underlying resource (the types of development are listed).

- **Option 4 -** As an alternative to Option 3 in respect of underground coal safeguarding areas this option would not set out a specific approach to consultation for non-mineral development which is sensitive to mining subsidence, relying instead on the advice of the Coal Authority as a statutory consultee.

A18. Appendix 1 of the MWJP presents details of the specific sites that were submitted in response to the 'Call for Sites' which formed part of the initial public consultation in May 2013. Further consideration will be given to these sites as work on the MWJP progresses and a site assessment methodology has been prepared to inform this. Site MJP34 is 'Land between Sandsend, Whitby, Scarborough and West Ayton', which was proposed by York Potash Limited for the extraction of potash by underground methods.

A19. Appendix 2 ('Glossary') includes a definition of 'Major Development Test':

> **"The NPPF states that planning permission should be refused for major developments in National Parks and AONBs except in exceptional circumstances and where it can be demonstrated they are in the public interest. These applications should include assessment of:**
>
> - **The need for the development, including in terms of any national considerations, and the impact of permitting it, or refusing it, upon the local economy.**
>
> - **The cost and scope for having the development outside the designated area, or meeting the need in another way**
>
> - **Any detrimental effect on the environment, the landscape and recreational opportunities, and extent to which that could be moderated.**
>
> **Major Development in the context of the Major Development Test is not defined and is determined on a case by case basis."**

APPENDIX 2

DECISIONS ON OTHER MAJOR DEVELOPMENTS

B1. This Appendix reviews the planning policy assessment of five other major development proposals which have been previously determined and which are considered to be of immediate relevance to the assessment of YPL's proposals. These are:

- **Boulby Mine, Loftus** – a proposal for the retention and extension of an existing potash and salt mine was approved by North York Moors National Park Authority (NYMNPA) in 1998. Of particular note is that this site is located within the same National Park as the application site, it relates specifically to a potash mine and it authorises the mine's current operation.

- **Ebberston Well, Ebberston** – a proposal for gas production in the NYMNPA, which was approved by the Secretary of State in June 2012. Of particular note is that this site is located within the same National Park as the application site and was approved by the Secretary of State after the NPPF had come into effect.

- **Dry Rigg Quarry, Helwith Bridge** – a proposal for the continuation of mineral working ("gritstone" (siltstone)) in the Yorkshire Dales National Park, which was approved by the Yorkshire Dales National Park Authority in February 2012. Of particular note is that this proposal was for minerals development, is located within another National Park and has also been determined relatively recently.

- **British Sugar Factory, Cantley** – a proposal for sugar processing in the Broads Authority, which was approved by the Broads Authority in 2009.

- **Doreys Ball Clay Quarry, East Holme, Dorset** - a recent proposal for the extension of an existing mine for the mining of ball clay which was approved by Dorset County Council in February 2014. Of particular note is that the planning policy assessment centred on the application of the major development test as prescribed in the NPPF, given the application site's location within an Area of Outstanding Natural Beauty.

B2. A summary of each of the above proposals, including the way in which planning policies were applied and interpreted in each case, is provided below.

a) <u>Boulby Mine, Loftus, North York Moors National Park</u>

i. *Background*

B3. In 1998 NYMNPA granted planning permission to Cleveland Potash Limited (CPL) for the retention of an existing potash and salt mine, including all surface installations, buildings, plant etc and extension to the approved underground mine working area at Boulby mine (R0030043B). The permission authorised the mining of potash and salt for a further period of 25 years, expiring on 6 May 2023.

B4. The planning application was submitted in 1996 and considered by NYMNPA's Development Control Sub-Committee in 1997, with the planning permission being issued subsequently, following completion of a Section 106 Agreement.

B5. Boulby mine, which is the UK's only potash mine, was granted consent in 1968, following a public inquiry, and production mining began in 1973. The mine is located in the north eastern corner of the National Park, with the mine head and processing plant occupying approximately 32 ha of land, 1km inland from Boulby Cliffs, 1km south of Easington and 2 kms north of Staithes. The area of land with planning permission for potash extraction covered approximately 8,200 ha of land, with additional offshore mining rights controlled by the Crown Commissioners since they are outside of planning control.

B6. At the time of the application, the mine produced around 1.2 million tonnes of potash products (used mainly in the fertilizer industry) and 1 million tonnes of salt (used mainly for road de-icing) annually. Potash extraction took place 24 hours per day, 5 days a week with the creation of roads in the salt seam taking place mainly at weekends. The majority of this was transported from the site by a direct rail link with rail heads at Teesdock and Teesside. A maximum of 150,000 tonnes of product was transported by road each year with the maximum number of road vehicle loads per day being restricted to 66. The proposed extension to the mine envisaged no change to that transport pattern.

B7. The mine employed approximately 950 people, of which 90% lived within a 10 mile radius of Boulby. It provided around 50% of the total UK requirement of potash which was around 1 million tonnes. During 1995 CPL generated an income of some £96 million, of which £40 million was from export sales. It was calculated that CPL's contribution to the UK balance of payments in the same year was £76.5 million. On a more local level the direct wages of local employees at the mine was £26 million, with a further £27 million being spent on services and supplies many of which were sourced locally (NYMNPA Committee Report; paragraphs 6.1 – 6.2).

B8. The energy required for processing the extracted potash at the mine was provided by heavy fuel oil powered boilers which discharged flue gas to one of two 87.5m high stacks on the site. The other 87.5m high stack handled emissions from the three dryers used in the processing of the product and each dryer was equipped with its own dust emission control system.

B9. The solids from the filter press were discharged as a brine based slurry by gravity down an outfall pipe which discharged into the sea some 1.8km from the cliffs at Boulby. The annual discharge of insoluble material into the sea was approximately 140,000 tonnes, within the 146,000 limit of the discharge licence which was valid at the time. In 1996 CPL applied to increase the amount of discharge to 200,000 tonnes per year until December 1998 and 180,000 tonnes thereafter although the licensing application had not been determined by the Environment Agency at this time.

B10. The planning application proposed to extend the onshore mining area by 5,557 ha. It did not propose to extend or alter any of the surface buildings or operations, which would be retained. The application involved the area with existing planning permission, as well as the proposed extension, with the intention being that the new permission would apply to the whole of the operations of Boulby Mine, including the mine head and processing area. The applicants envisaged at the time that the extraction of potash from the whole of the application site would give a further 25 years of operation at Boulby Mine (ibid; paragraph 1.13).

ii. NYMNPA Assessment of the Proposals

B11. The NYMNPA committee report (section 9) referred to the planning policies and guidance in effect at the time of considering the application. It refers to general advice on major development applications being provided by PPG7:

> **"This states that major developments should not take place in the National Parks save in exceptional circumstances. Because of the serious impact that major development may have on the natural beauty of National Parks, applications for such developments must be subject to the most rigorous examination. Unlike the position elsewhere in England and Wales major development should be demonstrated to be in the public interest before being allowed to proceed. Consideration of such applications should therefore normally include an assessment of:**

> **(i) the need for the development in terms of national considerations, and the impact of permitting it or refusing it upon the local economy;**
>
> **(ii) the cost of and scope for developing elsewhere outside the area or meeting the need for it in some other way;**
>
> **(iii) any detrimental effect on the environment and the landscape and the extent to which that should be moderated.”**

B12. The report also referred to Circular 12/96, which re-stated the above policy, and MPG6, which stated all mineral applications in National Parks must be subject to the most rigorous examination and be demonstrated to be in the public interest before being allowed to proceed.

B13. With regard to regional policies, the report referred to several policies in the North Yorkshire Structure Plan, including policy M3 which, in essence, comprised the above Major Development Test, whilst also requiring an assessment of whether proposed maximum levels of output have regard to those required to meet the purposes which justify the development.

B14. As explained in the committee report, the above Major Development Test was also reiterated in policies contained in the Cleveland Structure Plan and North York Moors Local Plan which were in effect at the time.

B15. NYMNPA’s assessment of the proposals (section 18 of the committee report) can be summarised as follows:

- There is a national need for potash largely for use in the fertilizer and chemical industry. The whole question of need was examined in the previous public inquiry in 1968 when a decision was taken to allow exploration of the known potash reserves in the Boulby area to help satisfy the national need for potash.

- There are no alternative UK supplies of potash and although alternative sites for potash mines within and on the edge of the National Park have been looked at over the last 20 years these were dismissed because the environmental effects were considered unacceptable.

- This site still provides the UK's only source of potash and there is no evidence of any other proposals to provide alternative supplies within the UK. If potash is not mined at Boulby most of the UK's potash would need to be imported.

- The mine has now been in operation for over 20 years and with 950 employees it is the biggest single employer in East Cleveland. This operation constitutes a major factor in the local economy with an estimated annual input of over £50 million in terms of wages, services and goods bought.

- In this case the impact on the local economy of approving or refusing this proposal is significant and must be a major factor in the decision.

- There is little scope for developing this mine elsewhere in the area due to the location of the potash deposits and the fact the other possible sites would be likely to be in or on the edge of the National Park and so have equal or greater effect on the environment. The cost of relocating or providing new infrastructure for Boulby Mine in another location would be very significant and totally uneconomic.

B16. NYMNPA did, however, consider that the existing operations at Boulby had a significant effect on the environment and, therefore, an extension in time and area of the operations carried on here would continue these effects. This included identifying the significant visual impact of the buildings:

> **"The existing plant and buildings at Boulby have a significant effect on the appearance of the National Park. The impact of these buildings was one of the major issues at the public inquiry in 1968. At that time there was some investigation of alternative sites. The site eventually chosen had some landscape advantages being in a valley with high land to the north/west which provides a backcloth for views from the south and screening from views, from the Easington area.**
>
> **The scale of the buildings and plant is such that landscaping would not provide effective screening and so the buildings were architecturally designed to give a compact group that respected the existing landform as much as possible…"** (paragraphs 15.1; 15.2)

B17. The NYMNPA subsequently concluded:

> **"19.1 This is a major development of great importance to the local economy. Whilst there are detrimental effects associated with this operation, as**

> **there would be with any industrial operation of this scale, it is considered that planning conditions and other environmental legislation can reduce these to an acceptable level…**
>
> **19.4 There is a continuing national need for this mineral and the environmental effects of the proposal can be satisfactorily moderated through conditions and other controls. It is considered therefore that the proposal has met the tests for major development in National Parks set down in Government advice and development plan policies.**
>
> **19.5 This application has been rigorously examined and demonstrated to be in the public interest. Approval of this proposal is therefore recommended.”** [Emphasis added]

B18. The planning conditions attached to the 1998 permission require, amongst other things, submission of a restoration scheme for approval and its subsequent implementation once the minerals extraction has been completed. This was not required under the original planning permission for the mine.

iii. Summary Analysis

B19. NYMNPA’s assessment of the 1998 application clearly focused on whether the proposals were in accordance with the requirements of the Major Development Test. At the time of the application, this was set out in PPG7 and reiterated in the relevant regional and local policy documents. The wording and requirements of the test itself were very similar to that which is now included in the NPPF, including its specific reference to ‘exceptional circumstances’, ‘public interest’ and assessing the need for development in terms of ‘national considerations’. However, that said, the NPPF now also requires that great weight should be given to the benefits of the mineral extraction, including to the economy.

B20. As explained above, the NYMNPA concluded that the proposal had been rigorously examined and demonstrated to be in the public interest. Whilst not an explicit requirement of the Major Development Test, the authority considered there to be a national need for potash, rather than restricting itself to an assessment of national considerations. It also found that there were no alternative UK supplies of potash; the operation constituted a major factor in the local economy; there was little scope for developing a mine elsewhere outside of the National Park; and the environmental effects of the proposal could be controlled to an acceptable level through planning conditions and environmental controls.

B21. On this basis, the Major Development Test was considered to have been met by the NYMNPA and planning permission was granted accordingly. This conclusion was reached despite the clear recognition that the existing buildings, which included two 87.5m high stacks on the site, had a significant effect on the appearance of the National Park and that landscaping could not provide effective screening due to the scale of the buildings and the plant. The Boulby operation also involves the discharge of insoluble material into the sea via an outfall pipe which extends into the sea some 1.8km from the cliffs at Boulby.

B22. These findings are or particular relevance to the consideration of YPL's proposal since the terms of the Major Development Test, which the Boulby Mine was considered to meet, remain almost identical now. NYMNPA found that there was a national need for potash, there was no alternative UK supply of potash and there was little scope for developing a mine elsewhere outside of the National Park.

b) Ebberston Well, Ebberston, North York Moors National Park

i. *Background*

B23. In April 2010 Moorland Energy Limited (MEL) submitted parallel planning applications for a gas well site, pipeline and processing plant, the smaller part of which is located within NYMNP and the remainder in Ryedale District Council (RDC) to be determined by North Yorkshire County Council (NYCC) as the adjoining Minerals Planning Authority (NYM/2010/0262; NY/2010/0159ENV).

B24. During the early stages of processing the applications, officers from NYCC, NYMNPA and RDC agreed a protocol for handling the application, which was to determine that part of the application lying within NYCC's jurisdiction including the Gas Processing Plant element first and the second lesser element of the well site afterwards based on 'public interest' and 'proper planning of the locality'.

B25. In July 2011 MEL appealed against the non-determination of the planning applications and the appeal was subsequently recovered by the Secretary of State (SoS) for Communities and Local Government for his decision. A Public Inquiry was held in October/November 2011. The Inspector submitted his report to the SoS in February 2012, recommending that the appeals be allowed and planning permission be granted subject to conditions. The SoS issued his decision in June 2012, which agreed with the Inspector's conclusions and recommendation, and planning permission was duly granted.

B26. The Ebberston well site is an existing, but capped-off, well site located on the edge of Dalby Forest, approximately 4km to the north of the village of Ebberston, wholly within NYMNP. Two pipelines would be laid between the well site and the gas processing facility (one for gas and one for produced liquids). Approximately 650 metres of these pipelines would be located within the National Park boundary. Once constructed, the route of the pipeline would be reinstated to its former use (i.e. agriculture). The pipelines would transport the gas and liquids to the proposed Gas Processing Facility located on agricultural land at the junction of Hurrell Lane and New Ings Lane, which is located 10 metres outside of the National Park. The processing facility itself would cover an area of 2.2 ha, although the application site covered 5.7 ha, which would also accommodate related industrial structures, which would be a maximum height of 15 metres. Once the gas has been processed it would exit the plant via an underground pipeline to a location close to the main National Grid gas pipeline. The total land take of all elements contained in the application is 56.8 ha.

B27. In 2008 NYMNPA granted planning permission for the drilling and siting of a temporary borehole and access for exploration, testing and evaluation of hydrocarbons. In December 2010 permission was granted to allow the retention of the well site for a further two years.

ii. NYMNPA Assessment of the Proposals

B28. Although the applications were to be determined by the SoS, the Planning Inspectorate requested that NYMNPA submit a recommendation to the Secretary of State prior to the Public Inquiry, and the application was therefore considered by the NYMNPA Planning Committee in September 2011.

B29. Section 4 of the committee report describes the planning policy background, identifying the relevant documents as including the CSDP, MPS1, PPS7 and Circular 2010 on National Parks. It refers to the North Yorkshire Minerals Local Plan (adopted in 1997) which applies to land outside the NYMNP.

B30. The report refers to the major development test set out in MPS1 and PPS7. Paragraph 4.17 also refers to the Draft NPPF stating that local planning authorities should give significant weight to the benefits of the mineral extraction including to the economy and that it re-iterates the criteria against which major development proposals need to be assessed.

B31. NYMNPA considered the application as a whole, on the basis that the five distinct elements (the well site, pipeline, new access road, Gas Processing Plant and Above Ground Installation) were within one red line boundary. Notwithstanding this, it recognised that if determining the application, the Committee would only have jurisdiction over the part of the application within the National Park.

B32. NYMNPA's assessment of the application focussed on whether the proposal would meet the major development test. In summary, its conclusions (section 13) were as follows:

- The applicant states that the construction costs and impact of the gas processing facility are justified over its 20 year lifespan but officers remain unconvinced that the five to eight year 'proven' supply from the Ebberston well site is sufficient to prove a need amounting to the exceptional circumstances required by the major development test.

- The test also states that decisions must be made in light of the impact on the local economy. The applicants have stated that they anticipate the creation of around 20 permanent jobs and up to ten apprenticeship schemes, however officers consider that the impact of the development will be negligible in terms of the local economy. An assessment of the economic impact of the development does not demonstrate an overriding need for the proposal, and the proposals thereby do not fulfil the requirements of the first part of the major development test.

- The second stage in the major development test is to demonstrate that the need cannot be met in some other way than developing in the National Park. In terms of the well site, officers are satisfied that the proposal site is the most appropriate of those alternative sites considered. However, officers feel that the applicants have not demonstrated sufficiently robust information as to why the Gas Processing Plant cannot be co-located at the existing Knapton Gas Processing Plant. As the well site proposal is reliant upon the Gas Processing Plant and alternative sites for this have not been robustly demonstrated officers conclude that the proposal in its entirety fails to meet the requirements of the second stage of the major development test.

- The final stage of the major development test is the consideration of the effect on the landscape. The proposed Gas Processing Plant will introduce industrial features to Hurrell Lane, which is located just outside of the National Park boundary. Although it will be screened to a certain degree by the existing railway embankment and trees, the proposals for new planting to screen the site will appear alien in this open rural landscape, while the industrial appearance will harm the landscape setting. The combination of the new planting and remaining visual appearance of industrial structures is considered to significantly harm the visual setting of the National Park from views looking from the south of the application site. Officers concluded that the final step of the major development test had not been met.

- Officers accepted that the need for the well site on its own right is met under the major development test as the evidence regarding alternative sites demonstrates that there is no less environmentally harmful place to put the well site. However, the part of the proposal that falls within the National Park boundary comprises only one element of a larger application, which is considered will harm the landscape setting of the North York Moors and its' special qualities such as tranquillity and dark skies.

- The well site element is dependent on the Gas Processing Plant and so both elements are intrinsically linked. On balance it is not considered the national need for gas extraction and production as set out by the applicants outweighs the harm that the proposal in its entirety will have on the National Park and its wider landscape setting. For these reasons refusal is recommended as the proposal is considered to conflict the requirements of the major development test.

- Officers also had concerns regarding the lack of robust details submitted by the applicants regarding safety and residential amenity.

B33. Accordingly, NYMNPA submitted to the SoS a recommendation to refuse the application for 6 reasons which are summarised below:

1) The applicants have failed to robustly demonstrate that there is significant national need for the gas resources which would outweigh the harm that will be caused to this part of the National Park by the development and is therefore contrary to the Major Development Test.

2) The applicants have failed to demonstrate that there is a sufficient level of gas resources in the area to justify the construction of a Gas Processing Plant within close proximity to the National Park, which will set a precedent and create perhaps irresistible pressure for a number of further well sites within the National Park in as yet unknown locations, which might have a harmful impact on its character and special qualities.

3) The applicants have not provided robust evidence to satisfy the National Park Authority that there will be no safety risks, noise or light emissions from the development, which may adversely impact the residential amenity of nearby residents living in the North York Moors.

4) The proposed Gas Processing Plant will cause significant visual harm to the setting and special qualities including dark skies at night and tranquillity of the North York Moors National Park within the wider landscape when looking from the south

5) It has not been sufficiently demonstrated by the applicant that an alternative site for the proposal could not be both technically and environmentally acceptable.

6) The applicant has not provided sufficient information with regard to restoration of the land, either post operational life or in the event of abandonment.

iii. The Secretary of State's Assessment

B34. As explained above, the SoS agreed with the Inspector's conclusions and recommendation that the appeals should be allowed and granted planning permission in his letter dated 28 June 2012. Within his letter, the SoS endorsed in turn each of the Inspector's principal findings and conclusions on the proposals.

B35. In his report dated 24 February 2012, the Inspector reported the putative reasons for refusal recommended by NYMNPA, as outlined above, as well as 11 putative reasons for refusal that were recommended by North Yorkshire County Council (NYCC). In essence, NYCC's reasons for refusal related to the adequacy of the overall development scheme; the open countryside location of the gas processing facility; impact of the proposals on the local landscape, local environment and residential amenity; noise impact; impact on the setting of the National Park, land restoration and proven gas reserve. None of NYCC's reasons for refusal refer to, or relate directly to, the major development test.

B36. The Inspector identified that the statutory development plan comprised the Yorkshire and Humber Regional Plan 2008, the NYMNPA CSDP, the saved policies of the North Yorkshire Minerals Local Plan (NYMLP) 1997 and the saved policies of the Ryedale Local Plan (RLP) 2002. The latter two documents only relate to land outside of the NYMNP. He considered that relevant national policy included the draft NPPF, National Parks Circular 2010, PPS7 and MPS1. By the time that the SoS issued his decision letter, the NPPF had been published. He explained in his decision that he had not revisited issues which were carried forward in the NPPF or development plan documents, which had already been addressed in the Inspector's Report (IR), unless the approach of the NPPF led him to give different weight to a matter (paragraph 7).

B37. Having particular regard to the elements of MEL's proposals which are located in NYMNP, the SoS's and Inspector's conclusions can be summarised as follows:

- The siting and operation of the production well as proposed and the construction of the pipelines would not conflict with the NYMCS (or NYMLP in respect of land outside the NYMNP) (SoS letter paragraph 15; IR paragraphs 14.4.17, 14.4.22).

- The SoS agreed with the Inspector that the gas processing facility would introduce an obviously industrial plant into an area of generally open countryside, that parts of the plant would remain visible and incongruous features for most of its intended life, and that it would appear out of keeping with the surrounding countryside of the Vale of Pickering to the south and the Area of High Landscape Value to the north. He agreed that there was conflict with NYMLP policy 4/1 and RLP policy ENV1 but also agreed with the Inspector that, other than with regard to the limited visibility from certain parts of Thornton-le-Dale, the gas processing facility would not be visible from within the National Park and would not have a seriously detrimental impact on the NYMNP. The SoS also agreed with the Inspector that ***"the major development test, as now set out in NPPF paragraph 116, would not be failed"*** (SoS 19; IR 14.5.30-14.5.35).

- The Inspector concluded that the well site, pipeline, new access road and above ground installation would not result in an unacceptable visual impact on the landscape of this part of North Yorkshire, including views from and into the NYMNP. In respect of the gas processing facility, he stated:

- "For the NYMNPA emphasis was placed on the potentially detrimental impact on the setting of the NYMNP. While it is appropriate that proposals outside but close to the boundary of a national park should be assessed against their impact on that park, in this instance, other than with regard to the limited visibility from certain parts of Thornton-le-Dale described above, the plant on the GPF site would not be visible from within the NYMNP. Moreover, to the extent that the Fringe of the Moor AHLV forms a setting for the NYMNP here, there would be few places where the GPF would intrude into views from public vantage points across the AHLV and towards the NYMNP. I conclude that the proposal would not have a seriously detrimental impact on the setting of the NYMNP. I also conclude that the Major Development Test to be applied to proposals in or close to a national park would not be failed by these proposals." (IR 14.5.33)

- There are no sites other than the East Knapton site within reasonable proximity to the well site that could accommodate the gas processing plant and the East Knapton site clearly could not contain the plant. The SoS also placed little weight on MEL being able to occupy land adjacent to the East Knapton site (SoS 24; IR 14.9.1-41.9.14).

- The SoS attached ***"great weight to the benefits of the mineral extraction, including to the national economy".*** In particular, he took into account the annual value of gas to be produced from the well site, which would be £37.5m and at a rate of supply equivalent to the annual energy needs of over 75,000 dwellings (SoS 25; IR 14.10.1-14.10.5).

- The national and more limited local benefits of the scheme are sufficient to outweigh the more limited harms by way of visual impact on the landscape and, in the absence of an alternative scheme demonstrably capable of providing equivalent capacity with the same timescale, the SoS concluded that the appeals should be allowed (SoS 26; IR 14.10.12 –14.10.18).

- Although the SoS found the location of the gas processing facility in open countryside would conflict with policies in the NYMLP and RLP, in the absence of a suitable alternative site he was satisfied that this would not amount to an overriding in principle policy objection. ***"In favour of the scheme, the Secretary of State attaches great weight to the benefits provided by the proposals, including to the national economy. He has taken into account that the wellsite could provide gas at a rate equivalent to the annual energy needs of 75,000 dwellings; that the proposals could also enable other locked-in reserves to be exploited; that the supply of gas to the NTS [National Transmission System] permits a more flexible end use of that gas compared with immediate electricity production; along with other, more limited, local benefits."*** (SoS 33).

B38. The Inspector acknowledged the income to MEL of the wider gas resource (a gross figure of the order of £1 billion) with its benefit value to the local economy of £1m/pa compared to the value of tourism to the local economy of £387m/pa. However, whilst he considered the contribution of the scheme to the local economy to be small, he recognised that income sum of £1 billion also represents is the value of the gas resource in this part of the NYMNP to the national economy in terms of indigenous reserves that could displace imports (IR 14.10.3-14.10.4). The Inspector also stated that MEL acknowledged that it could not ask the Secretary of State to take account of the benefits of development that were not included in its current planning application, and noted that the annual value of the gas produced from this wellsite would be some £37.5m and a rate of supply equivalent to the annual energy needs of over 75,000 dwellings. However, the application did include the opportunity for the gas processing facility and pipelines to facilitate the recovery of further reserves (IR 14.10.5). The proposals would create temporary jobs for some 150 people and permanent posts for a further 23. The offer of 10 post gas-production apprenticeships would be over and above those numbers (IR 14.10.11).

B39. Ultimately, the SoS concluded that the factors which weigh in favour of the proposed development outweigh its shortcomings and overcome the conflicts with the development plan. Therefore, he did not consider that there were any material considerations of sufficient weight to justify refusing planning permission (paragraph 33).

iv. Summary Analysis

B40. As explained above, NYMPNA considered the proposals to be unacceptable for a number of reasons, principally that based on its interpretation the application failed to meet a series of requirements set out by the major development test. Accordingly, it concluded that the proposals failed the major development test and recommended that the SoS refuse planning permission for six reasons.

B41. However, as indicated above, both the independent Inspector that examined the application and the SoS came to a substantially different conclusion, considering that the proposals met the major development test, and recommending/granting planning permission respectively. This was based on their assessment of the proposals, which was underpinned by their interpretation and application of the major development test, which was notably different to that of NYMNPA.

B42. Moreover, it is important to recognise that in his decision letter the SoS clearly endorses each of the Inspector's principal findings and conclusions on the proposals, including his policy basis for assessing the application and his interpretation and application of the major development test.

B43. The most significant conclusion from this analysis is the way in which the SoS and Inspector applied the re-balanced national policy which was formally introduced by the NPPF's publication in March 2012. Accordingly, the SoS clearly attached great weight to the benefits of the proposal. This included attaching great weight to the benefits that the proposal would bring to the national economy, whilst clearly demonstrating that it was not necessary to consider 'testing' the proposals to establish whether there was a national need for the development.

B44. The SoS and Inspector also clearly considered the other two 'elements' of the major development test, namely the scope for developing outside of the designated area and any detrimental effect on the environment. Whilst not explicitly referring to 'exceptional circumstances' or 'public interest', both the SoS and Inspector concluded that the proposals met the major development test. Whilst the proposals would conflict with planning policies on visual impact, the benefits of the proposal were considered outweighs it shortcomings and overcome the conflicts with the development plan.

B45. This approach to the application and interpretation of planning policy, especially the major development test, contrasts with the now outdated approach that was promoted by NYMNPA which, in the absence of the NPPF, was overly reliant on the CSDP and gave insufficient regard to the benefits of mineral extraction.

B46. The consistency and clarity of the approach which was taken by both the SoS and the Inspector in this post-NPPF case would therefore seem to provide a clear basis for assessing other applications for major developments within, and close to, National Parks, including the interpretation and application of the major development test. This case would seem to be particularly relevant for informing the assessment of YPL's proposals, given that much of the policy framework is the same owing to its location in NYMNP, the MEL decision is relatively recent and the MEL proposals, like those being promoted by YPL, comprised a series of linked elements sited at different locations within, and near to, the National Park.

c) <u>Dry Rigg Quarry, Helwith Bridge, Yorkshire Dales National Park</u>

i. *Background*

B47. In 2012 the Yorkshire Dales National Park Authority (YDNPA) granted planning permission to Lafarge Aggregates Limited for the continuation of mineral working at Dry Rigg Quarry until December 2021 by deepening the current extraction area, including revised restoration proposals (C/49/603D). The quarry works a spur of Silurian "gritstone" (siltstone), known as the Horton Flags, which extends eastwards from beneath Moughton Nab, a prominent crag formed from beds of Carboniferous Limestone which overlay the gritstone.

B48. The planning application was submitted to the YDNPA in January 2011 and approved by its Planning Committee in August 2011, with the permission being issued in February 2012, following completion of a Section 106 Agreement.

B49. Dry Rigg Quarry, which covers approximately 26 ha, is located half a kilometre to the west of Helwith Bridge in Ribblesdale, within the Yorkshire Dales National Park. The quarry adjoins Swarth Moor SSSI along parts of its northern, eastern and southern boundaries.

B50. Planning permission was originally granted for the quarry in 1951 and a number of subsequent permissions were granted which permitted working of the quarry to be extended for limited periods of time, culminating in a 2005 permission that approved working for a further 4½ years, followed by a further short term permission granted in March 2010 which authorised working to continue until the end of May 2011.

B51. The planning application submitted in January 2011 sought permission for a more substantial period of time, namely an additional 10½ years working period up until the end of 2021. A further year would be required to undertake restoration works. Permission would enable an additional 3.5 million tonnes of stone to be produced by deepening the main, western part of the quarry by 41m and from a smaller area of extended working and deepening to the east of the processing plant.

ii. *Assessment of the Proposals*

B52. The principal planning policies that were considered to be relevant to determination of this application were the assessment criteria for major mineral developments in national parks set out in paragraph 14 of MPS1 and the balance of benefits referred to in Local Plan Policy MLP2 (committee report page

23). As explained above, the former stated that permission should only be granted for major mineral developments in National Parks in exceptional circumstances and where proposals are demonstrated to be in the public interest, with consideration of the proposals including the assessment of need, cost, alternative supply and effect on the environment. (Although MPS1 has now been replaced by the NPPF, paragraph 116 of the NPPF replicates this approach). Local Plan Policy MLP2 stated that **"…Extensions to existing quarries will be permitted only where they would result in overall benefits which could include benefits to the environment or residential amenity."**

B53. The committee report (page 24) for the application explains that Dry Rigg is one of three quarries in the Yorkshire Dales supplying high performance aggregate used in road surfacing. It clearly recognised that Dry Rigg is one of a limited number of sites in England that supply these materials and they are transported long distances by road. The YDNPA considered that a supporting statement submitted by the applicant provided a fair, independent overview of the position. This opined that the continuing availability of this aggregate in the UK aggregates market is important in the provision of safe road surfacings on a national scale over a wide range of circumstances on the road network. Closure of the quarry would put increased demand on others in the Yorkshire Dales National Park and elsewhere in the country (ibid; page 23). Nevertheless, it was not considered by YDNPA that this relative scarcity would constitute a "national need" for the stone that would justify overriding environmental concerns.

B54. YDNPA did consider that high specification aggregate tends to be transported over fairly long distances and seldom serves a mainly local market. Dry Rigg sends stone by road to a wide variety of destinations including the London area, Devon, Suffolk and North Wales. Serving these locations from elsewhere in Britain would change the distribution pattern, but would not increase overall costs in the way that supplying a local market from an outside source would. In some circumstances it could be beneficial to transport aggregate by rail or water rather than by road even if longer distances were involved (ibid; page 24).

B55. The main benefits of the proposals were considered to be:

- The retention of employment at the quarry (18 direct jobs) and associated jobs in haulage etc for a further 10½ years until the end of December 2021 and employment on restoration works until December 2022.

- The provision of an additional resource of 3.5 million tonnes of high specification aggregate by deepening the existing quarry and without extending the existing quarry boundaries.

- The complete removal of the north-west quarry tip, down to original ground level, as part of the final restoration, with a better integrated water management scheme for the restored site.

B56. The main disadvantages of the proposals were considered to be:

- The continuation of the HGV traffic to and from the site through Ribblesdale villages, Settle, Giggleswick and Long Preston for a further 10½ years with adverse impacts on local residents, the environment of the National Park and on the local tourist and commercial economy.

- The postponement of full restoration of the site with the retention of the artificial screening bunds for a further 10½ years with a continuing adverse impact on the visual appearance and environment of this part of the National Park.

B57. The YDNPA considered that any environmental benefits would be limited to the removal of the north west quarry tip and an improved water management scheme for the restored site, given in particular that the current approved restoration scheme is perfectly satisfactory and could be implemented within 12 months. It considered that while the current levels of road haulage of stone are maintained, the disadvantages of the proposal outweigh the advantages, such that the proposals are contrary to planning policy and should be refused.

B58. However, Lafarge offered to give a legal undertaking that from the end of 2013 no more than 150,000 tonnes of stone would be transported in any 12 month period from Dry Rigg along the B6479 either north or south through Ribblesdale. This would be enabled by the transfer of a significant proportion of the haulage from road to rail and would in effect reduce the road traffic from the quarry by more than half from the end of 2013. The YDNPA considered that, although this would not remove all road haulage it would be a very significant improvement (ibid; page 25).

B59. YDNPA officers recommended that the Planning Committee granted planning permission subject to: confirmation from the Environment Agency and Natural England that the proposals were satisfactory; completion of a Section 106 Agreement to, amongst other things, limit the road haulage movements (as above) and secure restoration of the site; and planning conditions.

B60. The Planning Committee resolved to grant planning permission in accordance with the officers' recommendation and the permission was subsequently issued in February 2012.

iii. Summary Analysis

B61. The YDNPA's planning policy assessment was based on applying the major development test (as imposed by MPS1 which was in effect at the time) and considering whether the proposal would result in overall benefits, in accordance with the most relevant policy in the development plan (Local Plan Policy MLP2).

B62. Determination of this application (9 August 2011) clearly preceded publication of the NPPF (March 2012) so the YDNPA was unable to draw upon paragraph 144 which gives great weight to the benefits of mineral extraction, including to the economy. (The Draft NPPF was published on 25 July 2011 for public consultation so had just been made available at this time).

B63. Although in this case YDNPA did not consider it necessary to assess the proposal against each individual element of the major development test in the committee report, the report clearly identified that the proposed extension of the quarry's operations would not meet a national need that would justify overriding environmental concerns.

B64. YDNPA's assessment was subsequently based on considering the particular benefits and disadvantages of the proposals, with the determining factor considered to be the transfer of a significant volume of haulage from road to rail to reduce the adverse impacts of the quarry's operation. On this basis, the proposal was judged to be acceptable.

B65. Although the scale and nature of this proposal differs considerably to that being promoted by YPL, the relevant planning authority applied the major development test (i.e. the same test now included in the NPPF). Whilst it clearly concluded that the proposal did not meet a national need and had a number of substantive disadvantages, the authority applied its overall planning judgment and, given the benefits that it would bring, considered this major minerals development in a National Park to be acceptable.

d) <u>British Sugar Factory, Cantley, the Broads</u>

i. Background

B66. In June 2009 the Broads Authority (BA) granted planning permission to British Sugar plc for works at its Cantley sugar beet factory comprising a new evaporator plant and associated equipment as part of an energy reduction scheme, and new buildings to accommodate a diversification of operations in order to handle raw sugar cane which would be transported to the site by road from the Outer Harbour at Great Yarmouth (BA/2008/307/FUL).

B67. The energy reduction scheme would improve the efficiency of the plant and reduce operating costs, whilst the proposed construction of new buildings was in response to impending changes in sugar quotas and the intention to increase processing capacity to respond to these. The proposed buildings included the Evaporator cylinder (height 26.5m, diameter 4.5m) and a series of other buildings which would be up to 25m high, 40m long and 19m wide.

B68. The planning application was submitted to the BA in September 2008 and approved by its Planning Committee in April 2009, with the permission being issued in June 2009, following completion of two Section 106 Agreements.

B69. The application site is located at the sugar beet processing factory operated by British Sugar plc at Cantley, within the Broads. The factory is located at the eastern end of the village and comprises an extensive area of approximately 60ha, extending in an east/north-east direction from the village. The factory site is bounded to the south by the River Yare and is bisected east-west by the Norwich to Yarmouth railway line and north south by a substantial drainage ditch.

B70. Cantley sugar beet processing factory was built in 1912 and processes sugar beet from across the region. At the time of the application, the factory handled approximately 1.3 million tonnes of beet sugar per annum through an annual “campaign” which lasts around 155 days from September to March. The beet is ‘lifted’ and transported to the site by road, with some hauliers taking return loads of pulp which is used for animal feed.

B71. The committee report explains that the landscape surrounding the site is, with the exception of Cantley Village to the west, open and largely given over to agriculture. The site lies in a sensitive location and is within 10km of 14 protected sites including SSSIs, SPAs and SACs. Of these, the largest is Halvergate Marshes which is subject to all of these designations and is also a Ramsar site. The entire complex is located within flood risk zone 3 (paragraphs 1.8; 1.9).

ii. Assessment of the Proposals

B72. Section 5 of the committee report lists PPS1, PPS7, PPG13 and PPS25 as national planning policy, although it does not include any further consideration of these policy/guidance documents. It subsequently cites relevant saved policies from the Broads Local Plan 1997 and policies from the Broads Core Strategy 2007. Local Plan Policy CAN1 (Cantley Sugar Beet Factory) states that development within the Cantley Sugar Beet Factory site, which is needed to meet the essential operational requirements of the factory, will be permitted provided that it meets the siting, design, environmental and amenity criteria listed.

B73. In considering the principle of the development, it was recognised that the factory was a major and important facility which supported the agricultural economy of north, south and east Norfolk and north Suffolk, employing around 118 people year round, rising to 155 during the campaign, and supported related employment, including within the agricultural and haulage sectors, both directly and indirectly. Over 900 growers delivered to the factory during the campaign, with payments totalling around £35 million. Notwithstanding, it was recognised that the impact of the annual campaign locally is considerable, particularly the effects from the traffic and the noise, and this has influenced planning policy (paragraph 6.1.1).

B74. British Sugar stated that the proposed development was necessary to diversify the economic base and strengthen the viability and competitiveness of the factory. The BA commented that, although British Sugar had not advised that without the proposed development the factory would be unviable and vulnerable to closure, this was a concern which had been expressed in representations received on the application (paragraph 6.1.3).

B75. In accordance with the requirements of Policy CAN1, BA considered whether the proposed development was needed to meet 'essential operational requirements'. The report explains that national sugar beet production is around 7 million tonnes of raw beet, which produces 1 million tonnes of sugar and 500,000 tonnes of animal feed comprising a pulp by-product. This is over half the sugar required annually in Britain, and also supplies an export market; the remainder of the national requirement is imported. The value of the crop to farmers is worth around £180 million and it is one of the most profitable arable crops. Sugar beet production is common on the flat land and sandy soils of East Anglia and the 4 sugar beet processing factories which handle the crop are located in the eastern part of the country at Newark, Bury St Edmunds, Wissington (near King's Lynn) and Cantley.

B76. BA concluded that, on this basis, taking account of the strategic importance of Cantley to the local economy and its unique geographical position in terms of access to developing port facilities at Great Yarmouth, the proposed development could be considered as essential to the operational requirements of the site. It also considered the proposal to be in accordance with the Regional Economic Strategy and Regional Spatial Strategy which were in effect at the time.

B77. The committee report then assessed the impact of the application on a topic-by-topic basis considering the proposed development to be acceptable in respect of its impact on the amenity of local residents (including noise, air quality and lighting), landscape character and appearance, ecology, flood risk and drainage. In addition, the highways impact was considered to be acceptable subject to securing a contribution of £100,000 for improvements to the B1140.

B78. The report also identified a further material consideration in relation to British Sugar's decision to choose Cantley, rather than one of its other three sites, for the proposed extension of its operations into the handling of raw sugar cane results in large part from its proximity to the developing port facilities at Great Yarmouth which will enable the importation of the raw materials. The planning application proposes the onwards transportation of the raw sugar to Cantley from the port by road, which had given rise to the question of why the raw materials cannot be transported either by river or rail given the factory's location adjacent to the River Yare and the railway line. This had been raised by a large number of consultees and local residents and would represent an environmentally exemplary and sustainable solution (paragraph 6.8.2). British Sugar indicated that it was prepared to investigate the possibility in the future and this was welcomed by the BA.

B79. The committee report concluded that this was a controversial proposal which generated a high level of interest locally, but which had wide implications across north, south and east Norfolk and north Suffolk. A large number of objections had been received, relating in the main to concerns over the adequacy of the access and the extension of the operational period. However, there had also been a high level of support and recognition of the importance of Cantley factory to the rural economy (paragraph 7.1). The BA identified the key issue in the determination of the application to be the adequacy of the access and considered that this could be addressed through securing the necessary highway improvements.

B80. Ultimately, the report summarised that this was an industrial operation on an industrial site and its location within the Broads is something of an historic anomaly. The factory is, however, part of the Broads landscape. The proposed development will not significantly change any of the existing impacts, but may instead protect the viability of the site against wider changes which might in themselves be of more detriment locally (paragraph 7.3). Accordingly, it recommended that planning permission was granted, subject to relevant conditions and Section 106 obligations. Planning permission was issued in June 2009, following completion of two Section 106 Agreements (one with Norfolk County Council regarding highway improvements; and one with the BA regarding the setting up and operation of a working group to look at the feasibility of a working group to look at the feasibility of transporting raw sugar cane to the site by river or rail).

iii. Subsequent Extension of Time Limit Permission

B81. In November 2012 the BA granted planning permission for an extension of time limit of the above planning permission (BA/2012/0111/EXT13W). The planning application was submitted in March 2012 and approved by the Broads Authority Planning Committee In June 2012, with the permission being issued in November 2012, following completion of a S106 deed of variation.

B82. The committee report explained that this provision to extend permissions was introduced nationally by the Government to enable developers to ‘renew’ existing planning permissions without the need for a full new application or full new assessment. It considered that, in effect, the principles and details of the scheme as previously approved are accepted, with a Local Planning Authority able to consider only those matters where development plan policies and/or other material considerations have changed significantly since the original grant of permission (paragraph 6.1).

B83. By the time this application was determined by the BA the NPPF was in effect, having replaced PPS7 (Sustainable Development in Rural Areas) and other national policy documents in March 2012. The principal policy against which the original application was assessed was policy CAN1 of the Broads Local Plan and, although the Broads Development Management DPD had been adopted at this date and there was an emerging replacement policy in the draft Site Specifics DPD, policy CAN1 had been saved and remained in effect. The BA considered that the assessment of the original application against policy CAN1 remained a sound assessment for the purposes of the application for an extension of time, having regards to the impact of the NPPF (ibid; paragraph 6.9).

B84. The committee report concluded that, having considered the impact of these changes, it was not considered that any of the policy developments significantly altered the policy context against which the application should be judged; the principle policy, CAN1, remains extant and, accordingly, there are not considered any policy grounds for refusal of this application (ibid; paragraph 7.3). In addition to policy changes, the publication of the NPPF was recognised as being a material consideration and to support the decision made in 2009 to approve the original application.

B85. Accordingly, it was recommended that permission be granted, subject to completion of a S106 deed of variation to maintain the legal obligation requiring payments to the Highways Authority, and this was agreed by the Planning Committee.

iv. Summary Analysis

B86. Whilst recognising the relevance of PPS7, the BA did not in this case give explicit consideration to the major development test or the related matters of public interest and exceptional circumstances.

B87. Its assessment was centred on the most relevant local plan policy (policy CAN1 of the Broads Local Plan) and, in accordance with the requirements of this policy, it considered whether the proposed development would meet 'essential operational requirements' at the site. The BA concluded that it would meet essential operational requirements, principally due to the strategic importance of the Cantley site to the local economy and its unique geographical position in terms of access to developing port facilities at Great Yarmouth. More specifically, it identified the diversification and viability benefits of the proposals, related employment benefits, the value of the sugar beet crop and the importance of meeting the requirements of the British and export markets.

B88. The BA recognised that this was a controversial proposal given that it was for an industrial operation on an industrial site within the Broads. However, this was viewed as an historic anomaly and it was concluded that the proposed development will not significantly change any of the existing impacts, but may instead protect the viability of the site against wider changes which might in themselves be of more detriment locally.

B89. When considering the extension of time application, BA recognised the relevance of the NPPF, which by then had replaced PPS7, concluding that its previous approach of basing its assessment of the proposals on Local Plan policy CAN1 remained sound and up-to-date, and accordingly granted permission for the extension of time.

e) Doreys Ball Clay Quarry, East Holme, Dorset

i. Background

B90. On 13 February 2014 Dorset County Council (DCC) granted planning permission (6/2013/0347) for a southerly extension to Doreys Pit to develop land, to the east of New Hall Farm, for the purposes of the winning and working of ball clay and ancillary operations, including amendments to part of the approved restoration details for areas within the existing Doreys ball clay works at Doreys Ball Clay Quarry, Holme Lane, East Holme, Dorset.

B91. The planning application was submitted by Imerys Minerals Ltd in June 2013 and approved by DCC's Planning Committee on 31 January 2014, with the permission being issued two weeks later, following completion of a Unilateral Undertaking under S106 of the Town and Country Planning Act 1990. Condition 2 of the permission requires the extraction of minerals to cease by 30 September 2026 and restoration for nature conservation and agricultural uses to be completed within the following year.

B92. The application proposed a major extension to a ball clay pit located 2.6km south west of Wareham within Dorset Area of Outstanding Natural Beauty (AONB), which lies within the administrative area of Purbeck District Council. According to the committee report (paragraph 2.1), Doreys Pit is one of the larger Ball Clay pits in the county, currently comprising about 17 ha occupied by current operations and a further 30 ha that have been restored. The total application area was 31.5 ha, of which 13.5 ha is a restored area within the existing site. Granting permission would therefore increase the total pit area from 47 ha to 65 ha.

B93. The site is located within the South Purbeck Heaths landscape character area as defined in the AONB Management Plan. There is an area of heathland that lies adjacent to the western boundary of the site which is designated as a Special Area of Conservation (SAC), Special Protection Area (SPA), Ramsar and a Site of Special Scientific Interest (SSSI). A similarly designated area lies 150m east of the site boundary. A Scheduled Monument (Three Lord's Barrow) is situated within/adjacent to the site (the application red line created an "island" that technically isolated the barrow from the site).

B94. The application sought permission to extract 50,000 tonnes per annum (tpa) of ball clay and 60,000 tpa of sand and gravel for 12 years. The application also included a new entrance to the site from Grange Road and a system of lorry routing that involves a haul road through the company's Furzeyground site.

B95. The committee report explains that ball clay is a mineral which only occurs in three areas of South West England, two in Devon and the other, The Wareham Basin, in Dorset. It states that ball clay is extremely important to the local economy and that the NPPF recognises it as a mineral of national importance. About 80% of the UK output is exported so the industry makes an important contribution to the country's balance of payments (paragraph 1.4).

B96. Imerys Minerals extracts ball clays from five pits in the Wareham Basin. Doreys Pit has the third highest output by volume. The clays vary across the basin in terms of their physical, chemical and fired colour properties and each pit can have a number of clay seams that produce different clays with different properties. To maintain the economic viability of Imerys Minerals' business a wide range of clays need to be available from a number of different pits (paragraph 1.5).

ii. Assessment of the Proposals

B97. Much of the application site was allocated as a preferred area for Ball Clay extraction within the 1999 Dorset Minerals and Waste Local Plan. However, about half of the area from which it is proposed to undertake mineral extraction (9.3 ha) is outside the preferred area and policy 37 of the 1999 Plan states that "the authority will not permit the extraction of Ball Clay within the Area of Outstanding Natural Beauty other than within the preferred areas". The application was therefore advertised as a departure from the Development Plan. However, the emerging Minerals Core Strategy is close to adoption and DCC considered that it could be accorded significant weight and that the proposals conformed with this Strategy (paragraph 6.19).

B98. The committee report referred to paragraph 144 of the NPPF which states that, when determining planning applications, local planning authorities should give great weight to the benefits of mineral extraction, including to the economy (paragraph 6.3). With regard to economic impact, the applicant's operations in Dorset were considered to be very important to the economy of the Wareham area. The applicant states that they currently employ 39 full time local staff and at least a further 10 part time employees and that in 2012 they spent approximately £2.5 million with local suppliers. When wages, local rates, etc are added, the contribution to the UK economy from the Dorset operations are calculated to be in the region of £5.5 million per annum. Obtaining consent for the extension at Dorey's Pit would make an important contribution to the applicant's ability to maintain their business in the County (paragraph 6.5).

B99. Given that the application site was located in an AONB, the committee report included an explicit assessment of the proposals against the major development test:

> **"Paragraph 116 of the National Planning Policy Framework (NPPF) says that applications for major developments in AONB should be refused except in exceptional circumstances and where it can be demonstrated that they are in the public interest. It identifies 3 considerations that should be assessed as follows:**
>
> - **The need for the development and its economic impact. The NPPF identifies ball clay as a Nationally Important Mineral. As identified in paragraph 6.5 above, the ball clay industry makes a substantial contribution to the local economy and refusing this application would have an impact on the applicant's ability to maintain their range of product blends and this could in turn reduce the economic viability of their business in Dorset. Accordingly it is considered that there is a need for the development in terms of paragraph 116 of the NPPF.**
>
> - **The cost of and scope for developing elsewhere or in meeting need some other way. Ball clay is found in only three locations in the UK, two in Devon and the Wareham Basin. The clays in Dorset have different properties to those in Devon, particularly in terms of their unfired (plastic) strength which is important for large products as they have the ability to stand, without slumping before they are fired. In Dorset the clays in the south of the basin are generally of higher quality than those in the north due to plastic strength. Some of the clays extracted from Doreys Pit are taken to Devon to contribute to their blended products. It can therefore be concluded that there is no scope for extracting these clays from outside the AONB in Dorset or elsewhere in the UK.**
>
> - **Any detrimental effect on the environment, landscape and recreational opportunities, and the extent to which that could be moderated. There is support for the proposed landscape mitigation measures which have enabled the conclusion that the development is**

> **acceptable / borderline acceptable by the Landscape and AONB Officers. The ecological impact is addressed in 6.23 and 6.24 below. The restoration proposal will improve biodiversity. The proposed permissive footpath will improve recreational opportunities (see 6.26).**
>
> **It can be concluded for the reasons above that there is compliance with the NPPF, Policies 5 and 6 of the Dorset Minerals and Waste Local Plan and Policy DM4 of the Emerging Minerals Core Strategy." (paragraph 6.22)**

B100. The committee report also concluded that, in respect of access, volume of traffic and road safety, there would be net benefits to the area from the proposed traffic routing of the applicant's traffic from Povington and Dorey's Pits through an off-highway haul road. These benefits are enabled by the proposal to create the new access onto Grange Road (6.27).

B101. Accordingly, the report recommended that planning permission should be granted, subject to conditions and a S106 undertaking to secure a financial contribution towards the Purbeck Transport Fund. The committee resolved to grant permission and this was subsequently issued in February 2014.

iii. Summary Analysis

B102. DCC's planning policy assessment centred on the application of the major development test as prescribed in the NPPF, given the application site's location within an AONB. The proposals were considered against the three specific criteria that comprise the test. In respect of need, DCC recognised that ball clay is, like potash, identified as a nationally important mineral in the NPPF and that there was a need for the development, given the substantial contribution that the ball clay industry makes to the local economy. It concluded that there was no scope for the development to occur outside of the designated area since, given the specific properties of the clays that are found only within the Wareham Basin within which the application site is located. DCC also concluded that the proposals were acceptable in respect of environment, landscape and recreational impacts given the biodiversity and recreational improvements, whilst also recognising that there would be net traffic benefits as a result of using the off-highway haul road.

B103. The committee report also referred explicitly to paragraph 144 in the NPPF which requires local authorities to give great weight to the benefits of mineral extraction, including to the economy.

B104. Accordingly, DCC considered that the proposal complied with the NPPF as well as relevant local adopted and emerging policies.

APPENDIX 3

‘THE AGRONOMIC CASE FOR POLYHALITE’ REPORT BY ADAS

The Agronomic Case for Polyhalite

8 April 2014

Submitted to:
Mr Robert Meakin
Sirius Minerals
7-10 Manor Court,
Manor Garth,
Scarborough
YO11 3TU

Prepared by:
Dr Pete Berry, Dr Fiona Nicholson, Dr Kate Storer, Dr Richard Weightman, John Williams and Prof. Brian Chambers
ADAS High Mowthorpe,
Duggleby, Malton,
North Yorkshire
YO17 8BP

Commercial - in - confidence

Executive Summary

Polyhalite ($K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$) is a *naturally occurring mineral* that contains crop available plant nutrients: potassium (14% declared as K_2O), sulphur (48% declared as SO_3), magnesium (6% declared as MgO) and calcium (17% declared as CaO). The generic term used to describe a variety of mined minerals and manufactured fertilisers that contain potassium (K) is potash, which is referred to in this report.

The constituent nutrients contained within Polyhalite are all essential for plant growth. **Potassium** is one of four major nutrients (along with nitrogen, phosphorus and sulphur) needed in large quantities for plant growth. **Potassium** controls the movement of sugars in plants, regulates plant cell water content and is important for enzyme function. **Sulphur** is an essential component of the amino acids cysteine and methionine, and is required for a number of important enzyme reactions controlling metabolic and growth processes. **Magnesium** is an important constituent of chlorophyll which is vital for photosynthesis, as well as having a key role in a range of enzyme-regulated physiological processes. **Calcium** has a major role in the structure, stability and formation of cell membranes, and in cell division. ***Potassium and sulphur are the most valuable nutrients in Polyhalite,*** because in many situations soil supply of these nutrients is insufficient to support optimal crop growth.

The global demand for agricultural production is estimated to *increase* by 60% in 2050 (compared with the present day), as a result of the increasing world population, changing diets and the use of crops to produce biofuels. These pressures have driven steady increases in crop yields and global fertiliser consumption, which is now estimated at 173 million tonnes of fertiliser per year.

> ***Potash*. Global potash consumption is predicted to grow at an average rate of 3% per annum**, to satisfy the increasing demand for food production. As a result, annual potash fertiliser production will need to increase by *c.*1.0 million tonnes K_2O per annum to satisfy global demand.
>
> ***Sulphur*. The increasing prevalence of sulphur (S) deficiency throughout the world**, as a result of reductions in atmospheric deposition and the need to increase crop production will increase the need for sulphur fertilisers. The current global sulphur deficit (i.e. crop sulphur requirement *vs.* sulphur fertiliser applications) has been estimated at 11 million tonnes of sulphur per annum. Polyhalite has a major contribution to make in this area.
>
> ***Magnesium***. Magnesium (Mg) fertilisers are important for several widely grown crops, including potatoes, sugar beet and, to a lesser extent, oilseed rape, cotton, oil palm and onions, particularly where these crops are grown on sandy/light textured soils that are inherently low in plant available magnesium.
>
> ***Calcium***. Calcium is a valuable fertiliser for specialist horticultural and fruit crops where low calcium levels can reduce crop quality and storage life.

A review was undertaken of pot and field-scale experiments designed to rigorously evaluate the effects of Polyhalite on the growth of a wide range of crop species; compared with (untreated) control treatments and other manufactured fertiliser treatments. The experiments were carried out by four internationally recognised organisations including: The University of Durham (UK), The University of Florida (USA), Shandong Agricultural University (China) and Texas AgriLife Research (USA). The data from these replicated experiments was analysed, using analysis of variance procedures.

Polyhalite has a potential advantage over muriate of potash (KCl) when used on crops which are sensitive to high chloride/salt concentrations (e.g. potatoes, rice, onions, peas, beans, mango, citrus, pepper, celery, carrot, cucumber, lettuce and melon etc. because of its lower salt index. Nutrient release tests showed that the **nutrients within Polyhalite quickly became available** for plant uptake following soil application. Polyhalite use had no measurable effects on soil pH and contains very low levels of potentially toxic elements.

Data from experiments published in the scientific literature (and those described above) showed that **Polyhalite significantly increased the growth** of a wide range of crop species including: corn, flax, oilseed rape, pepper, potato, sorghum, soybean, sugarcane and wheat. Polyhalite produced no negative crop growth effects in any of the experimental studies. In around 90% of experiments with a range of crop species, Polyhalite always produced an equal or greater growth response compared with other widely used potash fertiliser (when balanced for potash supply).

In order to identify the best-fit crops for Polyhalite, a review was carried out to estimate the amounts of potash, sulphur and magnesium removed from the soil by different crop species. Additionally, crops with a low tolerance to chloride/salt were identified, as these crops would be more appropriate for Polyhalite than MOP fertiliser use. **All of the major global crop species removed substantial amounts of potassium, sulphur and magnesium from the soil, and will therefore potentially benefit from Polyhalite fertiliser addition in situations where the soil supply of these nutrients is limiting**. The global quantity of nutrients removed from the soil in crop products for the top 16 global production crops (i.e. maize, rice, wheat, soybean, barley, cotton, rapeseed, sugar cane, oil palm, forage maize, cassava, grass, alfalfa, fodder pumpkins, potatoes, sugar beet) accounted for 85% of total dry matter production which amounted to 37.8 Mt of potash as K_2O, 13.3 Mt of sulphur as SO_3 and 13.3 Mt of magnesium as MgO.

Crops that fit particularly well with Polyhalite use are those with high potash, sulphur or magnesium requirements, and/or intolerance to chloride/salt. Crops that fit these categories include: sugar cane, sugar beet, silaged grass, silaged alfalfa, forage maize, oil palm, oilseed rape, soybeans, rice, potatoes, onions, and vegetable crops including brassicas, lettuce and carrot. These crops are grown in 414 million hectares throughout the world.

Polyhalite is very well suited for inclusion in blended/complex fertiliser products, with other N, P and K sources, to produce ***multi-nutrient fertiliser products***. Polyhalite can be used as a straight fertiliser, but in most situations it would not be practical to supply all crop potash requirements, because sulphur supply would greatly exceed crop demand, so use in blended/complex fertilisers will be the most common. Spreading tests with granulated Polyhalite and a blended Polyhalite-based fertiliser showed that they can be spread accurately at up to 36m, with commercial fertiliser spreading equipment.

In summary, Polyhalite is a valuable source of major plant available nutrients (i.e. potash, sulphur and magnesium) that can be used to produce ***multi-nutrient fertiliser products*** *or as a straight product. The main markets for Polyhalite will be supplying potash and sulphur, with magnesium important for specific crops. The world market for potash, sulphur, magnesium and calcium fertiliser products will* ***continue to expand,*** *because of the need to increase food production and, for sulphur, the continued decline in atmospheric deposition.*

The Science Panel was established by Sirius Minerals to review the technical and agronomic report on polyhalite produced by ADAS. The Panel received copies of drafts of the report and provided comments and amendments. As the members of the panel, we are satisfied that this report is a valid and reasonable summary of existing knowledge and relevant information. We agree with the principal conclusion that polyhalite is an effective source of potassium, magnesium, calcium and sulphur for crop nutrition. We further agree that markets for these nutrients exist currently worldwide in agriculture and horticulture and that they are expected to grow as world food demand increases.

[redacted]

Professor Ken Barbarick
Colorado State University

[redacted]

Professor Hans-Werner Olfs
Osnabrück University

[redacted]

9 April 2014.

Dr Clive Rahn
PlantNutrition Consulting

[redacted]

Dr Ian Richards
Ecopt

Contents

1. Objective

- **To provide an *evidence-based* review of the agronomic case for Polyhalite to support Sirius Minerals planning application for the York Potash Project**

2. Introduction

The global demand for agricultural production is estimated to increase by 60% in 2050 compared with the present day (FAO, 2012), as a result of the world population increasing from 7 billion to 9 billion, changes in diet towards more dairy and meat products, and the use of crops to produce biofuels. There is limited scope to expand the agricultural area, so increases in agricultural productivity must largely be achieved through increasing crop yields (tonnes per hectare). These ongoing pressures, together with increased fertiliser use and improvements through plant breeding have been driving global crop yield increases in most major species, such as cereals, maize and oilseed rape, Figure 1.

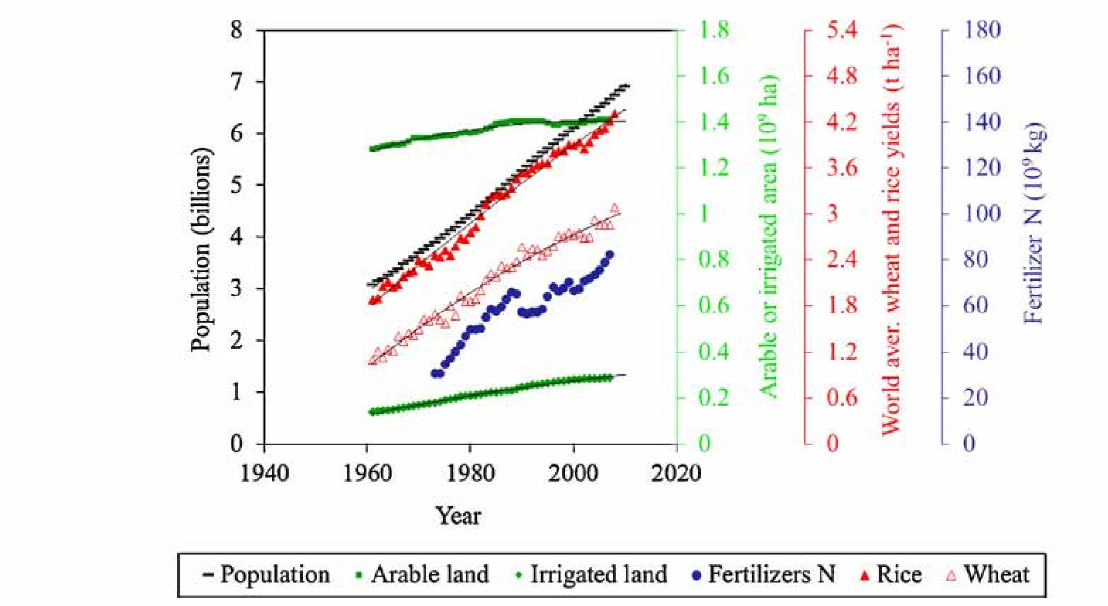

Figure 1. Evolution of population, arable area, world average wheat and rice yields, fertiliser N use, and irrigated area between 1960 and 2010. Figure adapted from Van Ittersum and Cassman (2013).

Increased crop yields, together with a greater intensity of cropping on existing land, will increase the need for nutrient additions and nutrients removed from the soil in crops. In order to be sustainable and to maintain soil fertility, these nutrients must eventually be replaced through the use of fertilisers. As a result of this, global fertilizer use has increased steadily over the last 50+ years to support the growing world population (Figure 2).

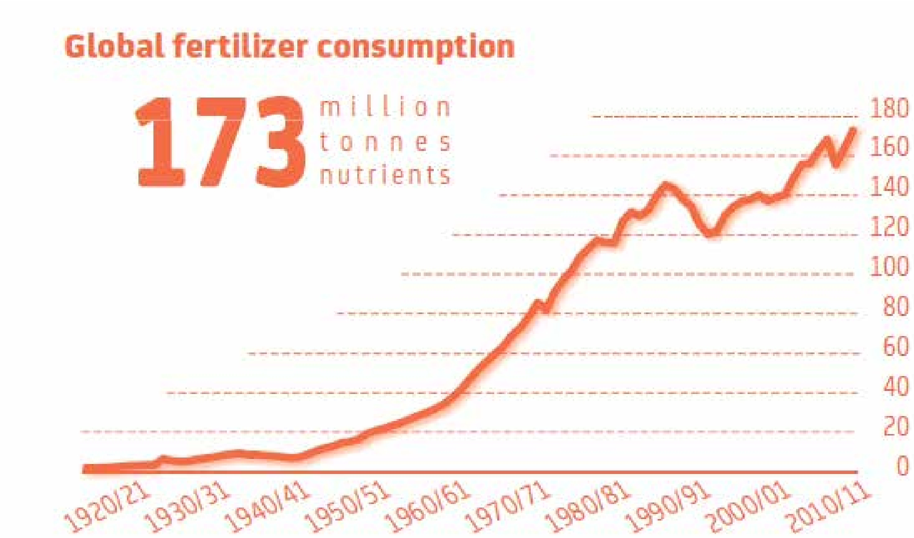

Figure 2. Global fertiliser consumption. Figure adapted from IFA (2013).

It is clear that the demand for more fertiliser will continue and this will include demand for the major nutrients required for plant growth i.e.: nitrogen, phosphorus, potassium, sulphur, magnesium and calcium, and other minor nutrients. All essential nutrients must be supplied in sufficient quantity, and in a form that is available for plant uptake, to enable the potential yield of the crop and its growing environment to be achieved. Potential yield will not be achieved if there is an insufficient supply of just one of the essential nutrients. This conforms with Liebig's law of the minimum principle, which states that plant growth is controlled not by the total amount of resources available, but by the scarcest resource (i.e. the limiting factor), Figure 3. It is therefore clear that crops must be provided with balanced nutrition, including a wide range of nutrients. It also follows that if any nutrient is limiting then the use efficiency of other nutrients, measured in terms of tonnes of yield per kilogramme of nutrient supplied, will be reduced. Increasing the supply of the limiting nutrient will therefore increase yields and increase the use efficiency of other nutrients.

Figure 3. Illustration of Liebig's law of the minimum; plant growth is controlled not by the total amount of resources available, but by the scarcest resource (limiting factor).

In order to increase global food production it is clear that demand will increase for fertilisers containing one or more of a wide range of nutrients. Hence, identifying new sustainable supplies of fertiliser nutrients will be important. One example of a new source of fertiliser is Polyhalite ($K_2Ca_2Mg(SO_4)_4{\cdot}2H_2O$) which is a naturally occurring mineral containing the plant available nutrients: potassium (14% as K_2O), sulphur (48% as SO_3), magnesium (6% as MgO) and calcium (17% as CaO).

3. Function and supply of potassium, sulphur, magnesium and calcium

3.1 Potassium

3.1.1 Plant requirement

Potassium (K) is one of four major nutrients (along with nitrogen, phosphorus and sulphur) needed in large quantities for plant growth. Potassium controls the movement of sugars in plants, regulates plant cell water content and is important for enzyme function. High yielding wheat crops (10 t/ha) typically take up 160 kg K/ha (200 kg K_2O/ha), whilst sugar cane can take up over 400 kg K/ha (500 kg K_2O/ha). The application of potash fertiliser to wheat and sugar beet grown on soils with a soil potassium (K) status of ADAS Index 0 (0-60 mg/l of K extracted using ammonium nitrate) can increase wheat grain yields by 19% and sugar beet yields by 33% (Defra, 2010).

3.1.2 Supply from the soil

Soil plant available potassium supply is influenced by the soil parent material. Clay and medium soils are usually well supplied with potassium, as a result of release from clay minerals. In contrast, sandy/light textured soils are naturally low in potassium, reflecting their low clay contents. On light sandy soils, it is possible for potassium ions to leach through the soil profile, beyond the crop rooting zone.

Soil analysis is used to quantify the extractable (readily-plant available) K content of soils and, in the UK, results are commonly related to an Index system. The “Fertiliser Manual (RB209)” (Defra, 2010) gives recommendations for the amount of potash that should be applied (from manufactured fertilisers and organic manures) to achieve economic optimum crop yields and to maintain or build-up soil reserves. The “Fertiliser Manual RB209” indicates that most arable/grassland crops will not respond to potash applications at ADAS soil K Index 2- (121-180 mg/l by ammonium nitrate extract) or above, and vegetable crops at Index 3 (241-400 mg/l) or above. At these Indices potash applications should be managed to maintain plant available K pools. However, at soil Indices of 0/1 (and 2 for vegetable crops) potash applications are recommended for crop response purposes and to build-up plant available K pools.

Data from 250,000 soil samples analysed by the Professional Agricultural Analysis Group (PAAG, 2013) indicated that 42% of UK grassland soils and 32% of arable/forage soils were Index 0/1 and hence require potash applications to achieve optimal crop growth (Figure 4). A further 30% of arable soils and 27% of grassland soils were at the target soil K Index of 2-, where potash applications are recommended to maintain soil K status. Data from the PAAG and Representative Soil Sampling Scheme (Webb *et al.*, 2001) indicate that there are no clear long-term trends in soil K status.

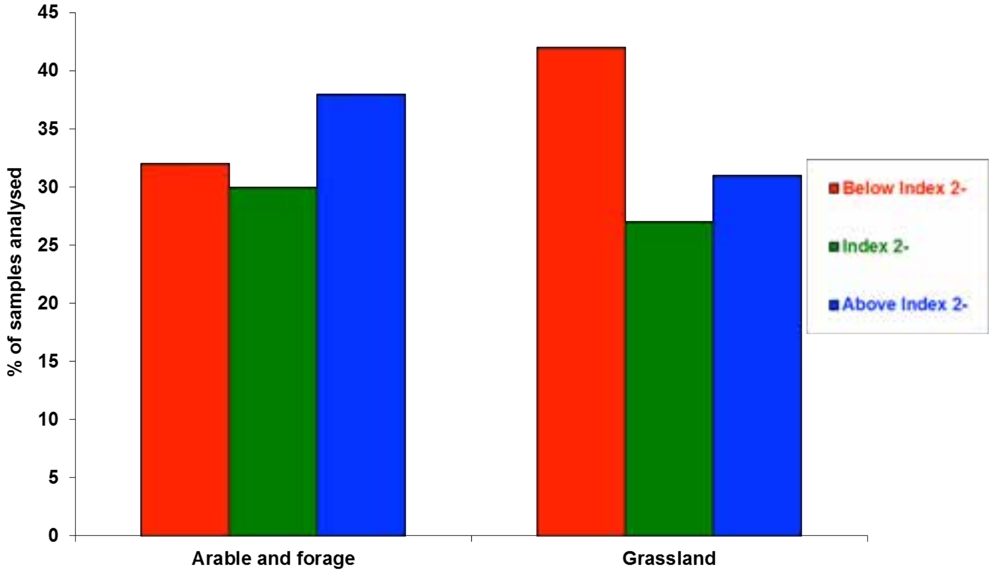

Figure 4. UK soil potassium indices of arable and grassland soils (PAAG, 2013).

3.1.3 Potash fertiliser production and consumption

The fertiliser trade has special terminology in which several nutrients are usually described and declared in oxide form. For example, potassium is taken up by plants in ionic form (K^+), but the concentration in fertilisers in most countries is declared in oxide form (K_2O). Potash is the term used for K_2O but it is often applied loosely, for example, muriate of potash for potassium chloride or sulphate of potash for potassium sulphate. Sometimes potash is used to describe fertiliser sources of potassium generally. Sulphur, calcium and magnesium are also usually described in oxide forms (SO_3, CaO and MgO, respectively). Outside the fertiliser trade, in technical and scientific documents, these nutrients are described in elemental forms. In this report, oxide (K_2O or potash, SO_3, CaO and MgO) or elemental (K or potassium, S, Ca and Mg) forms are used according to context.

More than 90% of the world's potash production is used as agricultural fertiliser; with relatively small quantities used in the manufacture of potassium-bearing chemicals, detergents, ceramics, pharmaceuticals and water conditioners.

Potash is currently produced in 12 countries, of which seven account for over 90% of world production. In 2011, total world potash production was *c.*35 Mt K_2O, with the UK currently producing about 1% of total market supply (Table 1). The total world consumption of potash in 2011 was 30.36 Mt K_2O (Table 2). China was the main user, with 26% of total world consumption, followed by Brazil (16%), USA (14%) and India (8%).

Table 1. Potash production by country in 2011 (USGS, 2013; FAOSTAT, 2013)

	United States Geological Survey Mineral Resources Program		**FAO**	
Country	**Production (Mt K_2O)**	**% of total**	**Production (Mt K_2O)**	**% of total**
1. Canada	9.79	29	9.92	28
2. Russia	6.28	19	7.09	20
3. Belarus	5.25	16	5.29	15
4. China	3.20	9	3.86	11
5. Germany	3.00	9	2.62	7
6. Israel	1.96	6	2.00	6
7. Jordan	1.20	4	1.40	4
8. USA	0.93	3	0.83	2
9. Chile	0.80	2	0.80	2
10. Brazil	0.45	1	0.36	1
11. UK	0.43	1	0.43	1
12. Spain	0.42	1	0.61	2
Others	-	-	<0.10	<1
Total	**33.71**	**100**	**35.26**	**100**

Global potash consumption more than doubled between the 1960s and the early 1980s. Between 1992 and 2007, global potash consumption steadily increased, driven by dietary changes in regions with high population growth, where there was an increased demand for meat, vegetables, fruits and vegetable oils. For example in China, during the late 1990's, 38% of potash was used for the production of vegetables and fruits, with a more recent assessment estimating that this had increased to 50% (Magen, 2009)

Table 2. Major potash consuming countries in 2011 (FAOSTAT, 2013).

Country	**Consumption (Mt K_2O)**	**%**
1. China	7.91	26
2. Brazil	4.71	16
3. USA	4.24	14
4. India	2.57	8
5. Indonesia	1.15	4
6. Malaysia	0.98	3
7. Belarus	0.77	3
8. Thailand	0.55	2
9. Poland	0.45	1
10. Others	7.04	23
Total	**30.36**	**100**
UK	0.26	<1

World consumption of potash dipped in 2008 and 2009, as demand temporarily reduced due to a substantial increase in the on-farm cost of potash fertiliser, however, consumption returned to pre-downturn levels in 2011 (Figure 5). Global potash consumption is predicted to grow at an average rate of 3% per annum (USGS, 2013), indicating that annual potash fertiliser production will need to increase by *c.*1.0 Mt to satisfy increased global demand.

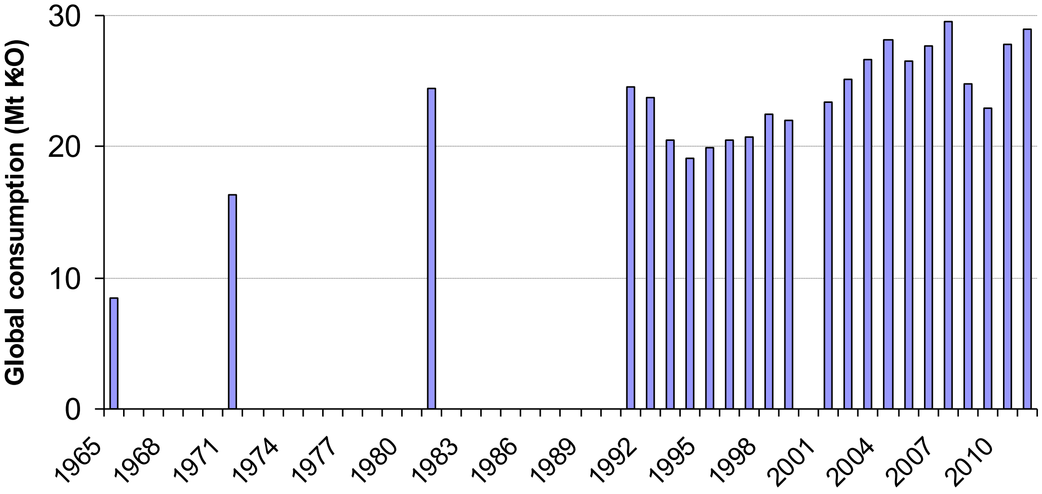

Figure 5. Global potash consumption since the 1960s (Stone, 2013; IPI, 1999).

FAO statistics (FAOSTAT, 2013) indicate that the UK is currently exporting around 0.27 Mt of K_2O and importing 0.18 Mt (equivalent to *c.*70% of the potash used in the UK). Data based on FAO statistics (FAOSTAT, 2013) indicate that UK potash consumption had declined from 0.39 Mt in 2002 to 0.26 Mt in 2011 (Figure 6).

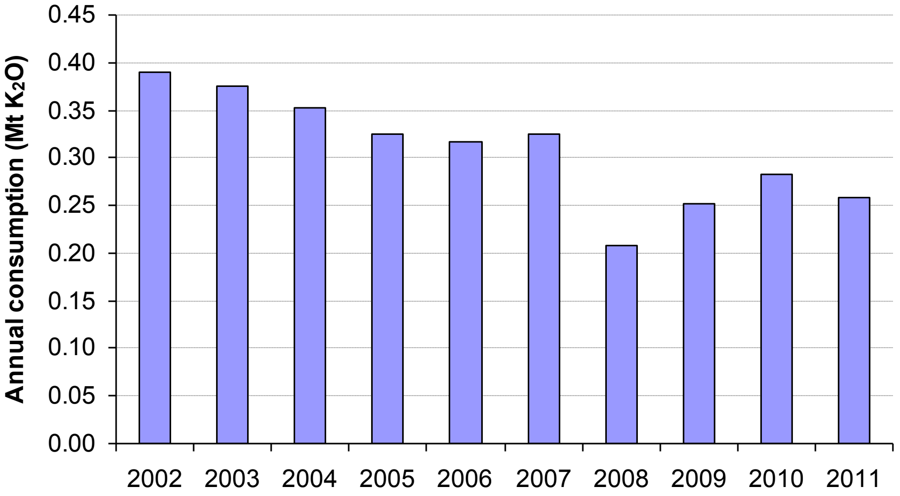

Figure 6. Recent trends in UK potash consumption (FAOSTAT, 2013).

The global demand for agricultural production as a result of the increasing world population, changing diets and the use of crops to produce biofuels, will result in a long-term sustained and increasing trend for potash consumption.

3.1.4 Potash use by crop type

Global potash application to different crop species is shown in Table 3 (Heffer, 2013). The greatest amount of potash use is on cereal crops, which receive about 37% of the total applications, followed by oilseeds (20% of total use). Thereafter, use is relatively evenly split between vegetables, sugar crops, root and tubers, and fibre crops. Cereals account for the largest proportion of potash use because of the large area grown annually, although the average application rate is relatively low. In contrast, the crop areas of sugar cane, sugar beet, root, tuber and vegetable crops are smaller, but rates applied are higher, as these crops have a higher potash requirement to optimise yields and quality.

Table 3. World potash use by crop type: 2010-2011 (Heffer, 2013).

Crop type	**Quantity (Mt K_2O)**	**Share (%)**
Wheat	1.7	6.2
Rice	3.5	12.6
Maize	4.1	14.9
Other Cereals	1.0	3.7
Cereals	***10.3***	***37.4***
Soybean	2.5	9.0
Oil Palm	2.0	7.2
Other Oilseeds	0.9	3.5
Oilseeds	***5.4***	***19.8***
Fibre Crops	0.8	2.8
Sugar Crops	2.1	7.7
Roots/Tubers	1.0	3.8
Fruits	1.8	6.6
Vegetables	2.8	10.0
Other Crops (e.g. Grasses)	3.2	11.8
Total	**27.4**	**100**

3.1.5 Potash supply from applications of organic manures

Organic manures are valuable sources of plant available nutrients that can be used to reduce, or in some cases, replace the need for manufactured fertiliser applications to satisfy crop potash demand. Annual total potash inputs to agricultural land in the UK were estimated 1.24 Mt K_2O, with 76% from handled livestock manures and grazing returns, 23% from manufactured fertiliser applications and around 1% from a combination of biosolids, compost and digestate (Table 4).

Potash loadings to UK arable land were estimated at 0.39 Mt K_2O/year, with manufactured fertiliser additions accounting for 49%, livestock manure applications 48% and around 3% from biosolids, compost and digestate additions (Table 5). Potash loadings to grassland were estimated at 0.85 Mt K_2O/year, with livestock manures accounting for 89%, manufactured fertiliser 11% and biosolids, digestate and compost <1% of additions (Table 6).

Table 4. Annual potash loadings to *agricultural land* in the UK.

Source	K_2O (tonnes)	% of total
Fertiliser[1]	283,000	23
Livestock manures[2]	943,000	76
- handled	(413,000)	
- deposited	(530,000)	
Biosolids[3]	3,000	<1
Compost[4]	10,000	1
Digestate[5]	2,000	<1
Total	1,241,000	100

[1] AIC UK Fertiliser Statistics (AIC, 2012); 2010/11
[2] MANURES-*GIS* (Defra, 2012) – E&W x 1.3 = UK
[3] Water UK (2010); 2008
[4] WRAP (2011); 2009
[5] ADAS estimate

Table 5. Annual potash loadings to *arable land* in the UK.

Source	K_2O (tonnes)	% of total
Fertiliser[1]	192,000	49
Livestock manures[2]	186,000	48
Biosolids[3]	2,500	<1
Compost[4]	8,000	1
Digestate[5]	1,000	<1
Total	389,500	100

[1] AIC UK Fertiliser Statistics (AIC, 2012); 2010/11
[2] MANURES-*GIS* (Defra, 2012) – E&W x 1.3 = UK
[3] Water UK (2010); 2008
[4] WRAP (2011); 2009
[5] ADAS estimate

Table 6. Annual potash loadings to *grassland* in the UK.

Source	K_2O (tonnes)	% of total
Fertiliser[1]	91,000	11
Livestock manures[2]	757,000	89
- handled	(227,000)	
- deposited	(530,000)	
Biosolids[3]	500	<1
Compost[4]	2,000	<1
Digestate[5]	1,000	<1
Total	851,500	100

[1] AIC UK Fertiliser Statistics (AIC, 2012); 2010/11
[2] MANURES-*GIS* (Defra, 2012) – E&W x 1.3 = UK
[3] Water UK (2010); 2008
[4] WRAP (2011); 2009
[5] ADAS estimate

The overall quantity of livestock manure applied to land reflects animal numbers; which have shown a gradual decline over the last decade. Compost and digestate applications to agricultural land in the UK are predicted by ADAS to increase from around 2.4 to 4 million tonnes of compost, and from around 1.4 million to 5 million tonnes of digestate, but even at these increased amounts, will only have a relatively small impact on the overall need for potash fertiliser additions to agricultural land.

The distribution of livestock manure loadings (Figure 7) reflects regional differences in animal stocking densities, with a greater proportion of manures applied in the west of the country (reflecting the high numbers of dairy cattle). Moreover, the potash supply from livestock manures is not in close proximity to arable (particularly cereal and oilseed rape) crops, where there are net crop offtakes of potash. *Note*: As organic manures are bulky and low in nutrient content (relative to manufactured fertilisers), long-distance transport is prohibitively expensive.

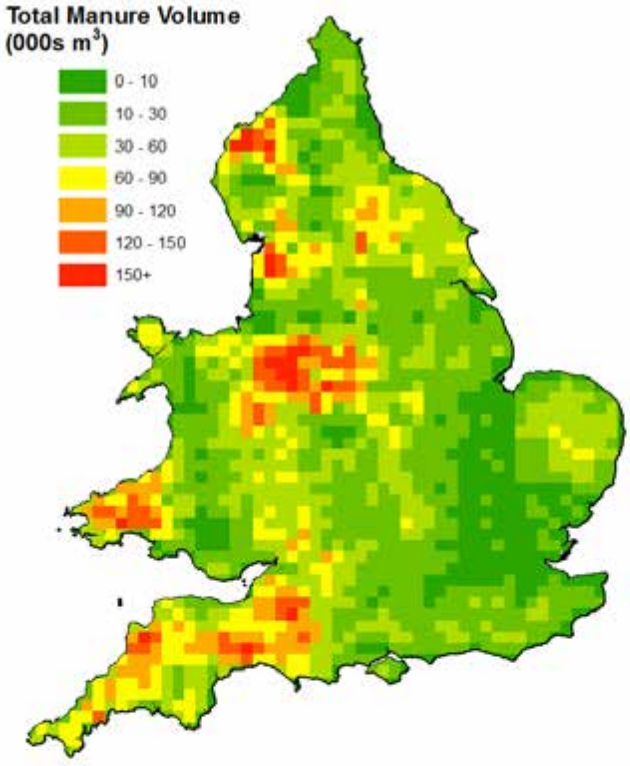

Figure 7. Distribution of livestock manure loadings in England and Wales (Defra, 2012).

3.2 Sulphur

3.2.1 Plant requirement

Sulphur is an essential component of the amino acids cysteine and methionine that are essential components of protein in plants, and is required for a number of important enzyme reactions controlling metabolic and growth processes within plant cells. Sulphur is taken up by plant roots as soluble sulphate (SO_4^{2-}) ions and should be applied as a sulphate containing fertiliser (Defra, 2010; HGCA, 2014) that is readily available for crop uptake. Many crops species take up large quantities of sulphur e.g. a high yielding oilseed rape crop (5 t/ha) will typically take up 250 kg SO_3/ha. Yield responses of up to 100% have been observed in oilseed rape (McGrath and Zhao, 1996) and cereal (Chalmers *et al.*, 1999) crops. Notably, sulphur fertiliser additions in deficient situations decrease acrylamide (a processing contaminant that can be found in cooked foods) concentrations in wheat grain (Curtis *et al.*, 2014).

3.2.2 Supply from the soil

The soil supply of plant available sulphur is controlled by the mineralisation (breakdown) of soil organic matter (and from atmospheric deposition). Notably, sulphate ions are mobile in soil and can be readily lost from soils via over-winter leaching, which is most likely on sandy soils in areas with high rainfall. Sulphur deficiency is most common on light/sandy soils, with symptoms commonly reported in oilseed rape and cereals (Chalmers *et al.*, 1999; Defra, 2010), as well as multi-cut silage grass on a wide range of soil types (Defra, 2010).

3.2.3 Supply from atmospheric deposition

Historically, an important source of plant available sulphur has been from atmospheric deposition. Sulphur, as sulphur dioxide, is released to the atmosphere from anthropogenic and natural sources (e.g. releases from volcanoes, oceans, biological decay and forest fires). The most important man-made sources are fossil fuel combustion, smelting, sulphuric acid manufacture, conversion of wood pulp to paper, refuse incineration and the production of elemental sulphur. Coal burning is the single largest man-made source of sulphur dioxide accounting for about 50% of annual global emissions, with oil burning accounting for a further 25-30% (Temis, 2013).

Sulphur from the atmosphere may be deposited to land via wet or dry deposition. Wet deposition is in the form of rain or snow, primarily containing sulphate anions and a very small proportion as sulphur containing particles that are scavenged in the rain. Dry deposition is primarily via the deposition of sulphur dioxide to plant and soil surfaces, but also includes a very small amount of sulphur-containing particles (McGrath *et al.*, 2002).

Air quality controls (particularly from coal-fired power stations) have resulted in decreasing sulphur concentrations in air and rain, which have led to decreased S inputs to agricultural land in Western Europe, and an increased need for sulphur fertiliser applications to maintain crop yields and quality. In the UK, data from Woburn (Bedfordshire) where sulphur concentrations in air and rain have been monitored for more than 30 years, showed that at the peak of sulphur emissions, more than 70 kg S/ha/yr was deposited from the air. By 1996-1998, this had declined to <10 kg S/ha/yr (McGrath *et al.*, 2002).

Nowadays sulphur deposition across most of the UK agricultural land area is typically less than 7 kg S/ha. Across the EU, sulphur deposition has declined by 75% between 1990 and 2010 (EEA, 2012).

Data from the USA National Atmospheric Deposition Programme (USNADP, 2010) also demonstrated that improvements in air quality were reducing atmospheric sulphur deposition and increasing the need for sulphur fertiliser applications to maximise crop growth. Sulphur deposition in north east USA reduced by *c.*40% (from a maximum 27 kg/ha SO_4 to 15-18 kg/ha SO_4; equivalent to 8.9 kg/ha S and 5-6 kg/ha S) between 1985 and 2009 (Figure 9), with deposition in more rural areas typically less than 3 kg/ha SO_4 (equivalent to 1 kg/ha S).

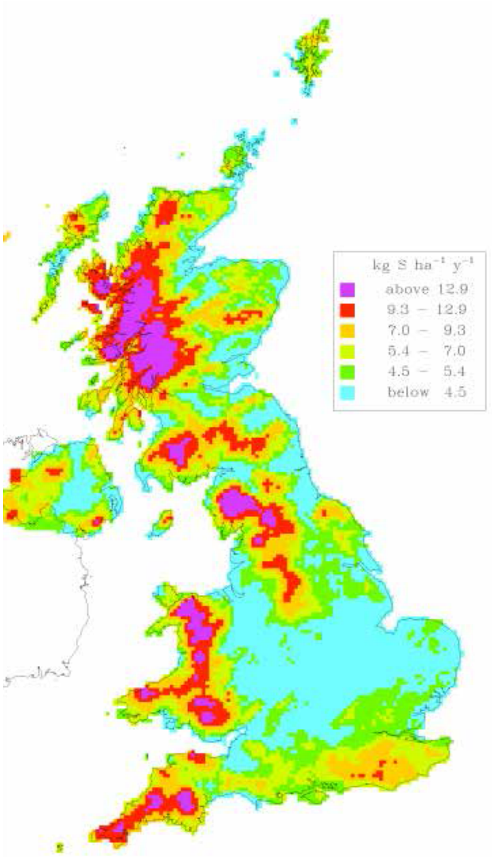

Figure 8. Sulphur (S) deposition rates in the UK in 2006 (Defra, 2010).

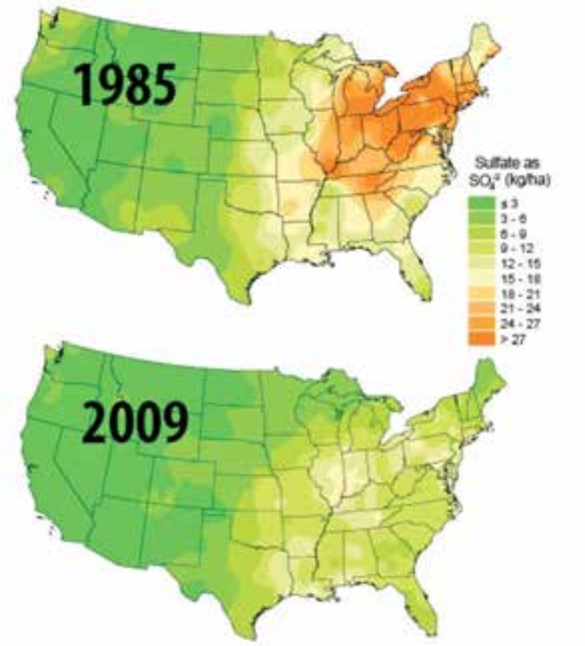

Figure 9. Sulphate (SO_4) deposition rates in the USA in 1985 and 2009 (USNADP, 2010). *Note*: SO_4 ÷ 3 = sulphur (S).

In China, wide regional differences in sulphur deposition have been reported, with high rates (up to 101 kg S/ha/year) measured in industrial areas with high rainfall volumes (Pan *et al.*, 2012). Blair (2002) also reported high sulphur deposition of up to 54 kg S/ha/year close to an industrial centre near the Yangtze River, with low levels of between 1.5 and 4.4 kg S/ha/year in more rural areas. In the longer term, air quality controls will lead to decreasing S deposition in urban areas.

Similarly in Australia and New Zealand, studies identified differences in sulphur deposition between sites, with the highest deposition (up to 41 kg S/ha/year) occurring near the coast (Blair, 1997; Blair, 2002) and returning to background levels (< 3 kg S/ha/year) 130 km in land from the sea.

3.2.4 Sulphur fertiliser production and consumption

Over the last three decades, for a number of reasons, many regions in the world have seen a fundamental shift in the agricultural sulphur balance toward deficit. Traditional fertilisers containing sulphur have been gradually replaced by 'high content' nitrogen and phosphate fertilisers that contain little or no sulphur; so while total N consumption world-wide doubled between 1974 and 1990, total sulphur consumption remained static at about 10 Mt S during the same period (Zhao *et al.*, 1999). In addition, yields of agricultural crops have increased markedly, resulting in the increased removal of sulphur from soils. Research in the UK has shown that (arable) soils do not store the anthropogenic sulphur that was deposited in the past, and that leaching is resulting in further decreases in soil sulphur status (Mc Grath *et al.*, 2002).

The Sulphur Institute (de Brey, 2006) estimated that the annual sulphur fertiliser deficit (crop sulphur requirement *vs.* fertiliser sulphur application) worldwide would be *c.*11 Mt S by 2014, and that Asia would be the largest potential market for sulphur fertilisers (in particular, China and India), with Africa and the America's also having large sulphur deficits (Figure 10).

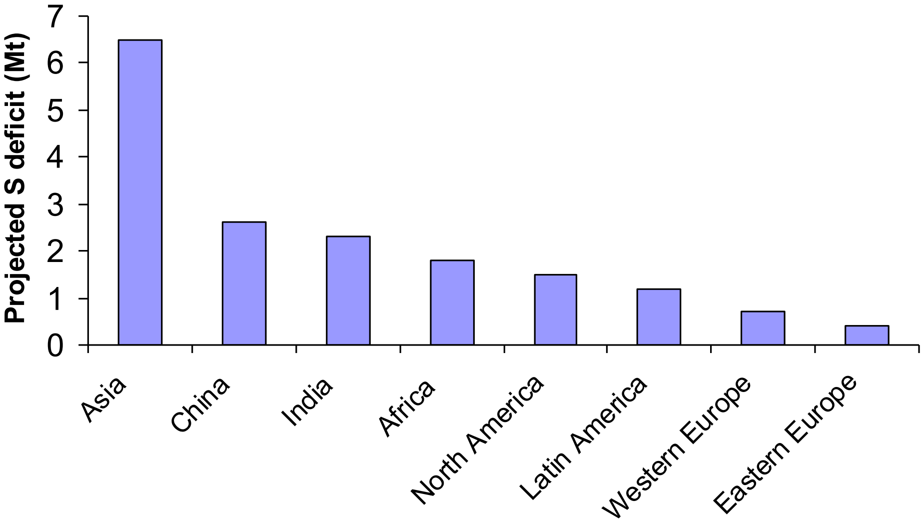

Figure 10. Projected worldwide S deficit in 2014 by region/country (de Brey, 2006).

Research carried out by The Sulphur Institute in various Asian countries showed that sulphur deficiency was limiting crop production (i.e. affecting crop yields and quality, as well as economic returns). For example, in India 77% of soils in 11 states were assessed to be deficient or potentially deficient in sulphur (Morris, 2003), and more than 30% of soils in China were assessed to be sulphur deficient (Messick and Fan, 2003). Moreover, the continued expansion of agricultural production (especially in oilseed, sugar, vegetables, tea and fruit crops) in Asian countries will increase the demand for sulphur fertiliser products (Messick and Fan, 2003).

3.2.5 Sulphur fertiliser use in the UK

The UK provides a good example of how reductions in atmospheric sulphur deposition have influenced the use of sulphur fertilisers. The British Survey of Fertiliser Practice (Holmes, 2013) has collected detailed information on sulphur fertiliser use since 1993, when only *c.*4% of the cereal crop area and *c.*8% of the oilseed rape area received an application of sulphur fertiliser. By 1997, the area receiving sulphur fertiliser had increased markedly to *c.*14% for cereals and *c.*30% for oilseed rape, and in 2012 around 50% of the cereal and 75% of the oilseed rape area received sulphur fertiliser applications (Figure 11).

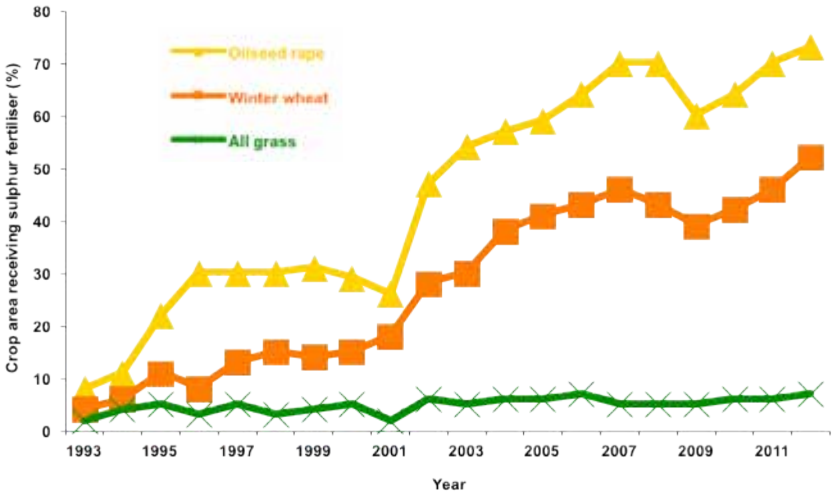

Figure 11. Proportion of oilseed rape, winter wheat and grassland crop areas receiving sulphur fertiliser applications (Holmes, 2013).

Commonly used sulphur fertilisers in the UK include ammonium sulphate (60% SO_3, 21% N), potassium sulphate (45% SO_3, 50% K_2O), gypsum (40% SO_3, 32% declared as CaO); these have comparable sulphur contents to Polyhalite (i.e. 48% SO_3). Between 1993 and 2012, the average sulphur fertiliser application rate increased from around 30 to 85 kg/ha SO_3 on oilseed rape, and from around 20 to 55 kg/ha SO_3 on cereals (Figure 12). Surprisingly, the grassland area receiving sulphur fertiliser (at around 5%) and the average application rate (at around 30 kg/ha SO_3) have largely remained unchanged since 1993 (Figures 11 and 12).

The “Fertiliser Manual (RB209)” (Defra, 2010) recommends 50-75 kg/ha SO_3 for oilseed rape crops, 25-40 kg/ha SO_3 to cereals, peas and beans where deficiency is likely, and 40 kg/ha SO_3 for each grass cut where deficiency is likely. Given the very low sulphur deposition rates in Britain there is now a strong argument for all oilseed rape crops and the majority of cereal crops to receive sulphur fertiliser applications (HGCA, 2014).

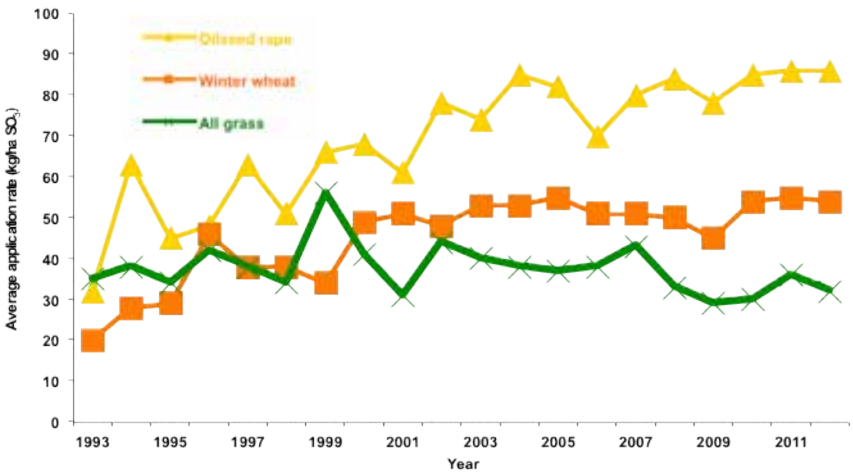

Figure 12. Average rates of manufactured sulphur fertiliser applied to oilseed rape, winter wheat and grassland (Holmes, 2013).

The increasing prevalence of sulphur deficiency throughout the world, as a result of reductions in atmosphere deposition, and the need to increase crop production will increase the need for sulphur fertilisers. Polyhalite has a major contribution to make in this area.

3.3 Magnesium

3.3.1 Plant requirement

Magnesium (Mg) is an important constituent of chlorophyll which is vital for photosynthesis. Additionally, magnesium has a key role in a range of enzyme-regulated physiological processes, including phosphorylation, assimilation of carbon dioxide and protein synthesis. A review carried out by Chalmers *et al*. (1999) showed that yield responses to magnesium could be up to 0.5 t/ha (17%) for cereals. Notably, Mg is important to the yield and quality of potatoes, sugar beet and many vegetable crops that are widely grown throughout the world.

3.3.2 Supply from the soil

Magnesium is present in soils in relatively easily weatherable ferro-magnesian minerals, such as biotite, serpentine, hornblende and olivine, and is present in secondary clay minerals, such as illite and montmorillonite. Soils may also contain substantial amounts of magnesium as magnesium carbonate ($MgCO_3$) or dolomite ($CaCO_3 \cdot MgCO_3$). The magnesium level in soil depends substantially on the parent material. A shortage of magnesium is most likely to occur on sandy soils, with low cation exchange capacity, especially where the latter is dominated by other cations (as in very acid or alkaline soils) and magnesium is subject to leaching losses. On heavier soils, weathering of soil minerals is usually sufficient to maintain satisfactory levels of plant available magnesium.

The “Fertiliser Manual (RB209)” (Defra, 2010) recommends that on Mg Index 0 soils (0-25 mg/l of Mg extracted using ammonium nitrate) cereals should receive 50-100 kg/ha MgO every 3-4 years, at Mg Index 1 (26-50 mg/l) oilseed rape and linseed should receive 50-100 kg/ha MgO every 3-4 years. Sugar beet and most vegetable crops are expected to respond to magnesium at Index 1 or less; and potatoes and most fruit crops to respond to magnesium at Index of 2 (51-100 mg/l) or less. For grass, 50-100 kg/ha MgO are recommended every 3-4 years, unless there is a risk of hypomagnesaemia in grazing livestock, where larger amounts may be justified to maintain soil Mg Index 2.

Recent data published by the Professional Agricultural Analysis Group covering commercial and research laboratories in the UK (PAAG, 2013), from a total of >175,000 samples, showed that 13% of arable soil samples had an Mg Index of 1 or less.

3.3.3 Magnesium fertilisers

Commonly used magnesium fertilisers include, Kainit (5% MgO, 11% K_2O, 26% Na_2O, 10% SO_3), Kieserite (25% MgO, 50% SO_3), calcined magnesite (80% MgO) and magnesium sulphate (16% MgO, 33% SO_3). Data quantifying the amount of magnesium fertiliser used in the UK are not published. In this report (Section 4), we estimate that the total world crop offtake of magnesium is 4.9 Mt per annum (which equates to 8 Mt MgO). The majority of this magnesium offtake would need to be replaced by fertilisers, as livestock manures and biosolids generally contain only small to moderate amounts of magnesium (Roques *et al*., 2013). Only about 7 kg/ha MgO is deposited from the atmosphere (Anon, 1998), although this can be higher near to the sea (Archer, 1985).

3.4 Calcium

Calcium has a major role in the structure, stability and formation of cell membranes, and in cell division (Bould *et al*., 1983). Calcium is taken up by plants in moderate amounts, similar to those for magnesium and sulphur. The vast majority of soils supply sufficient calcium for arable and forage crops in the UK, as long as they are not allowed to become too acidic.

Calcium deficiency can occur under conditions of extreme soil acidity, in which case aluminium and manganese toxicities are the main cause of poor growth. Poor growing conditions can reduce calcium, as well as the other nutrient uptake, but it is likely that deficiency symptoms of other nutrients would be manifested before calcium. Calcium is usually only applied as a fertiliser in specialist horticultural situations (e.g. in hydroponic solutions for glasshouse production of crops such as tomatoes), to fruit and vegetable crops (e.g. apples and lettuce) where low calcium levels can reduce crop quality and storage life (Archer, 1985), to peanuts (IFA, 1992; TAES, 2001) and to oil palm (IFA, 1992).

Polyhalite contains calcium (17% declared as CaO) in similar concentrations as in other fertilisers, such as calcium nitrate (29% declared as CaO), single super phosphate (35% declared as CaO) and Gafsa rock phosphate (32% declared as CaO) that are widely used throughout the world.

3.5 Summary

- **Global *potash consumption* is predicted to grow at an average rate of 3% per annum,** to satisfy increasing demand for food production from the growing world population.
- **Annual *potash fertiliser production* will need to increase by *c.*1.0 Mt K_2O** to satisfy increased global demand.
- Livestock manures and other organic materials are useful sources of plant available potash. However, practical and economic considerations (i.e. the uneven spatial distribution of livestock manures which are mainly concentrated in the west of Britain and associated~~,~~ transport costs etc.) limit the potential for manures to replace to any great extent fertiliser potash use in the arable east of Britain.

- **There is an increasing prevalence of *sulphur deficiency***, as a result of reductions in atmospheric deposition and an increased need for sulphur fertilisers to support crop production.
- The current **global sulphur deficit** (i.e. crop sulphur requirement *vs.* sulphur fertiliser applications) has been estimated at 11 million tonnes sulphur per annum.
- **Magnesium fertilisers** are important for several widely grown worldwide crops, including potatoes, sugar beet and, to a lesser extent, oilseed rape, cotton, oil palm and onions; particularly where these crops are grown on sandy/light textured soils that are inherently low in plant available magnesium.
- **Calcium fertilisers** are important for specialist horticultural and fruit crops where low calcium levels can reduce crop quality and storage life.

4. Review of existing published and unpublished information on the effects of Polyhalite on plant growth

4.1 Published literature

A number of published studies have investigated the effects of Polyhalite on plant growth for a range of species. Barbarick (1991) showed that Polyhalite resulted in statistically significant increases in the growth of sorghum-sudangrass in glasshouse experiments. The following four studies were summarised in Barbarick (1991). Lepeshkov and Shoposhnikova (1958) showed that Polyhalite was at least as effective as potassium sulphate for potato and flax production. Panitkin (1967) concluded that Polyhalite produced more plant growth than potassium sulphate for potatoes and beets because of the magnesium supplied by the Polyhalite. Terelak (1975) found that Polyhalite was as effective as potassium chloride plus potassium sulphate in producing corn, rye, mustard, and oats. Mercik (1981) showed that Polyhalite outperformed potassium sulphate in the growth of spring barley and Italian ryegrass. The literature summarised above showed that Polyhalite increased the growth of several different plant species and was at least as effective as potassium chloride or potassium sulphate. It should be recognised that for all the studies, apart from Barbarick (1991), the nutrients in the fertiliser treatments were not fully balanced, which means that the Polyhalite responses compared with other fertilisers may be attributed to sulphur or magnesium, in addition to potash.

4.2 Sirius Minerals research

4.2.1 Methodology

During 2012 and 2013, Sirius Minerals funded a series of experiments to investigate the effects of Polyhalite on a range of crop species. The experiments were carried out by four internationally recognised organisations including: The University of Durham (UK), The University of Florida (USA), Shandong Agricultural University (China) and Texas AgriLife Research (USA). Each study included a range of replicated treatments, comparing the effects of Polyhalite addition on plant growth compared with a nil (control) treatment, a chemical formulation containing the equivalent nutrient amounts to Polyhalite and a range of other commercial fertiliser products. Nitrogen and phosphate fertiliser were added to ensure that the experiments were not limiting for these major nutrients.

The data from these replicated experiments were statistically analysed, using analysis of variance procedures in Genstat version 12.1 (Lawes Agricultural Trust, 2009), to assess the overall effects of Polyhalite addition on crop growth. The majority of these studies were pot based, hence most responses were quantified in terms of total crop dry matter growth, rather than saleable yield. The characteristics of the soils used in each study are summarised in Table 7. These data show that plant available K was high in the soils used in the experiments carried out at Shandong Agricultural University and Texas AgriLife Research (in 2012), which reduced the likelihood of a crop growth response to potash in these experiments.

Table 7. Summary of the characteristics of the soils used in Sirius Minerals experiments (all experiments pot based, except Texas 2012 and 2013)

	Durham (Nafferton)†	Durham (Woburn)	Shandong (Mountain Tai††)	Texas (2012) - field				Texas (2013) - field		Texas	Florida			
Crops studied	Soybean/ Wheat	Wheat, OSR/ Cotton	Peanut/ Corn	Onion	Pepper	Potato	Sorghum	Soybean	Sugarcane	Pepper	Corn	Corn	Sugarcane	Sugarcane
Texture class	Clay loam	ND	Sandy loam	Hidalgo sandy clay loam	Willacy fine sandy loam	Hidalgo sandy clay loam	Willacy fine sandy loam	Hidalgofine sandy loam	Hidalgo, sandy loam clay	Sunshine MetroMix	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH	6.3	ND	7.0	7.4	7.9	8.0	7.2	7.8	8.1	6.0	7.0	7.1	6.7	6.9
Available P (mg/kg)	9^{+}	37 to 44^{+}	ND	29.7	31.4	41.3	40.5	9.8	32.8	26.4	16.7	2.0	5.4	1.1
Available K (mg/kg)	82	ND	309	510	475	391	400	151	159	78.9	5.4	8.1	5.5	4.4
Available S (mg/kg)	46	ND	127	24	11.9	17.1	9.5	14	17.1	188	13.5	12.9	4.5	3.2
Available Mg (mg/kg)	203	ND	290	405	354	371	401	61.3	90.6	226	16.4	29.1	7.4	7.7
Available Ca (mg/kg)	ND	ND	670	6241	3121	3973	4344	3023	11133	ND	263	329	69.3	82.2

Nutrient measurements assumed to be available nutrients, but this is not stated for all trials.
Available nutrients measured using †Morgan's or ††Mehlich 3 extraction.
$^{+}$mg/litre,
ND = data not available

4.2.2 Results

Polyhalite properties

The risk of salt damage to plants from Polyhalite use is lower than from other commonly used fertilisers. The salt index value (measured in water) of Polyhalite is lower than other commonly used fertilisers, such as muriate of potash (Table 8).

Table 8. Salt index values for different fertiliser products (Anon. 1986).

Fertiliser	Salt index
Polyhalite	87
SOP	46
MOP	116
SOP-M	43
$NaNO_3$	100

Notes: SOP: sulphate of potash (K_2SO_4); MOP: muriate of potash (KCl); SOP-M: sulphate of potash magnesia ($2MgSO_4 \cdot K_2SO_4$); $NaNO_3$: sodium nitrate.

In the majority of cases, the use of Polyhalite did not significantly affect electrical conductivity – a measure of salt concentration (3 studies) when compared to soil which did not receive Polyhalite during the experiment. The only experiment where Polyhalite addition affected the soil electrical conductivity (EC), was in the Durham oilseed rape experiment, where Polyhalite increased the EC from 0.097 to 0.207 mS/cm. Notably, a similar increase was also measured following addition of the chemical fertiliser equivalent for Polyhalite. An EC increase from applying fertiliser would be expected, due to an increase in salt concentration. The EC values reported were below levels that would be expected to impair plant growth (Anon., 2000).

Information from the Sirius Minerals experiments (4 trials) showed that in the majority of cases Polyhalite did not significantly affect soil pH; and where there was an apparent pH decrease this was almost certainly due to salt build-up effects (Russell, 1983). Polyhalite is a *neutral salt* that has no appreciable effect on soil pH. In contrast, applications of elemental sulphur will cause acidification, as a result of the release of hydrogen ions during the oxidation of sulphur to sulphate; see equation below:

$$2S + 3O_2 + 2H_2O \longrightarrow 4H^+ + 2SO_4^{2-}$$

The University of Florida conducted nutrient release and nutrient leaching studies and showed that 85% of the potash in Polyhalite was available for plant uptake after one week. Leaching losses from Polyhalite as a percentage of the amount applied after 20 days were 40-50% for K and S, 60-70% for Ca and 10-15% for Mg, thereby confirming that the nutrients in Polyhalite are readily soluble and will be available for plant uptake in the short-term after application.

Crop response

In just over half of the experiments, the addition of Polyhalite resulted in a statistically significant and positive growth response in terms of biomass production, after several weeks of growth (Table 9). Positive growth responses were measured in corn, oilseed rape, sugarcane and wheat. The high soil K levels in the Shandong peanut study (Table 7) almost certainly explain the lack of observed yield effects. The unexpected lack of response in cotton, potato and soybean yields recorded in single pot experiments was most probably a result of atypical conditions (i.e. the use of small volumes of soil in the pot studies that are likely to have limited crop growth) that affected the way that these crop species responded to the fertiliser treatments. In terms of yield, Polyhalite resulted in a positive increase in the majority of crops studied, including corn, oilseed rape, pepper, potato, sorghum, soybean and sugarcane (Table 9).

Table 9. Response in biomass (either above-ground, below-ground or total biomass) or crop yield to the addition of Polyhalite (positive, negative or no response) for each plant species compared to no potash fertiliser addition in all studies.

Trial	Crop	Number of trials	Biomass	Crop yield	Yield measure
Shandong†	Corn	1	Positive	Positive (PH12)	Corn cob weight
Florida	Corn	2	Positive	Positive (1 of 2)	Corn cob weight
Durham	Cotton	2	No response	ND	ND
Texas	Onion	1	ND	No response	Bulb
Durham	OSR	1	Positive	Positive	Seed FW††
Shandong†	Peanut	1	No response	No response	Seed weight
Texas	Pepper	2	ND	Positive	Fruit
Durham	Potato	1	No response	No response	Potato tuber
Texas	Potato	1	ND	Positive	Potato tuber
Texas	Sorghum	1	ND	Positive	Grain
Durham	Soybean	1	No response	ND	ND
Texas	Soybean	2	ND	Positive (PH, PH12 and PH14)	Grain
Florida	Sugarcane	1	Positive	Positive (PH12 and PH16)	Cane yield
Florida	Sugarcane	1	No response	No response	ND
Durham	Wheat	4	Positive	ND	ND
Durham	Wheat	1	No response	ND	ND
Number of positive responses			**9 of 16***	**10 of 15****	

†Soil K level high.
††FW=fresh weight therefore could be a moisture effect.
PH = Polyhalite. PH12/PH14/PH16 = difference Polyhalite formulations.
ND=no data
*Only 16 experiments measured whole crop biomass out of a total of 23.
**Only 15 experiments measured crop yield out of a total of 23.

In nearly all cases, where fertiliser addition resulted in a positive biomass or crop yield response, the addition of Polyhalite resulted in an increase in biomass growth (Table 10 and data from Durham University pot study in Figure 13) and/or crop yield (Table 11 and data from Texas AgriLife study in Figure 14) that was greater than or equal to that found using other commercial fertilisers with a substantial potash content.

Table 10. Percentage of comparisons in which the above- or below-ground plant growth in response to Polyhalite addition was either greater than or equal to that of the other fertilisers as determined using ANOVA with least significant difference (LSD) comparisons as *post hoc* analyses ($P < 0.05$).

Fertiliser	Greater or equal response				Greater response			
	Above-ground	Crops under study	Below-ground	Crops under study	Above-ground	Crops under study	Below-ground	Crops under study
Chem[†]	100	Wheat	100	Wheat	67	Wheat	33	Wheat
CPH[†]	100	Wheat	100	Wheat	100	Wheat	67	Wheat
SOP[††]	100	Wheat, OSR, Corn	100	Wheat, OSR, Corn	0	Wheat, OSR, Corn	25	(Wheat), OSR, Corn
MOP[††]	100	Wheat, OSR, Corn	100	Wheat, OSR, Corn	50	Wheat, OSR, Corn	75	Wheat, OSR, Corn
SOP-M[†]	67	Corn, OSR, (Wheat)	100	Corn, OSR, Wheat	33	Corn, OSR	67	Corn, OSR
Overall mean	**94%**		**100%**		**47%**		**53%**	

( ) indicates crops for which Polyhalite did not perform equally or greater than the fertiliser being compared in any study, which may have been due to sulphur supply differences between SOP-M, SOP and Polyhalite.

[†] number of experiments = 3, [††] number of experiments = 4;

OSR: Oilseed Rape;

Chem: chemical fertiliser equivalent of Polyhalite to balance potash supply only; CPH: calcined (i.e. heat treated) Polyhalite; SOP: sulphate of potash (K_2SO_4); MOP: muriate of potash (KCl); SOP-M: sulphate of potash magnesia ($2MgSO_4 \cdot K_2SO_4$).

Table 11. Percentage of cases in which the yield response to Polyhalite was either greater than or equal to that of the other fertilisers, as determined using ANOVA with least significant difference (LSD) comparisons as *post hoc* analyses ($P < 0.05$).

	Greater or equal response		Greater response	
Fertiliser	%	Crops under study	%	Crops under study
Chem†	100	OSR	100	OSR
CPH†	100	OSR	100	OSR
SOP†††	83	Potato, Field Pepper, Soybean, Sugarcane, Corn, (GH Pepper)	17	Potato
MOP†††	100	Potato, Corn, Field Pepper, Soybean, Sugarcane	33	Potato, Corn
SOP-M†	100	Corn	100	Corn
Blend††	75	Potato, Field Pepper, Sugarcane, (GH Pepper)	25	Potato
Overall mean	**89%**		**41%**	

( ) show crops where Polyhalite did not perform equally or greater than the fertiliser being compared in any trial
OSR: Oilseed Rape. GH Pepper: Glasshouse pepper.
† number of experiments = 1; †† numbers of experiments = 4; ††† number of experiments = 6.
Chem: chemical equivalent of Polyhalite to balance potash supply only; CPH: calcined (i.e. heat treated) Polyhalite; SOP: sulphate of potash (K_2SO_4); MOP: muriate of potash (KCl); SOP-M: sulphate of potash magnesia ($2MgSO_4 \cdot K_2SO_4$).

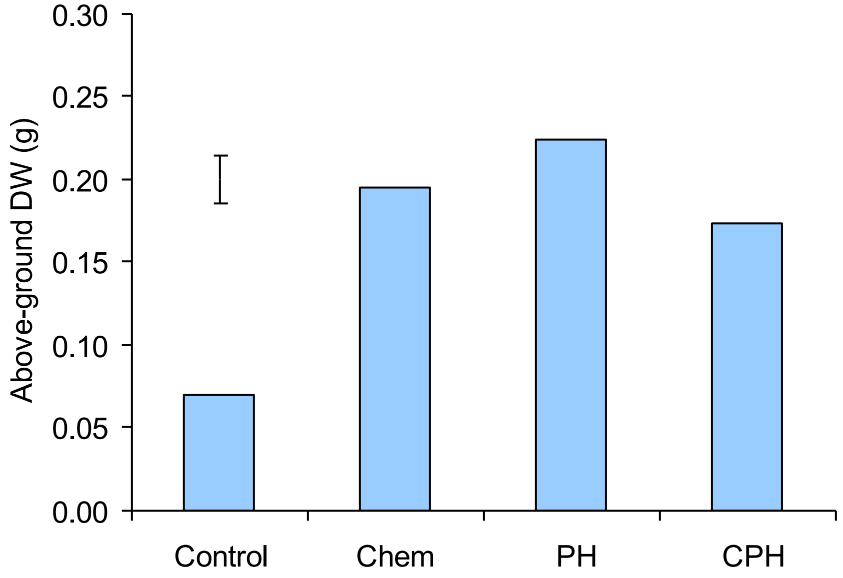

Figure 13. Above-ground dry weight (DW) of wheat plants (Cordiale variety) grown on soils with addition of either Chem (chemical equivalent of Polyhalite), PH (Polyhalite) or CPH (calcined Polyhalite) fertilisers compared to no potash fertiliser addition. Data are a mean across 4 K rates between 100 to 600 mg K/kg for Chem/PH/CPH from a pot-based experiment carried out by the University of Durham. Error bar represents the least significant difference (LSD) at $P = 0.05$.

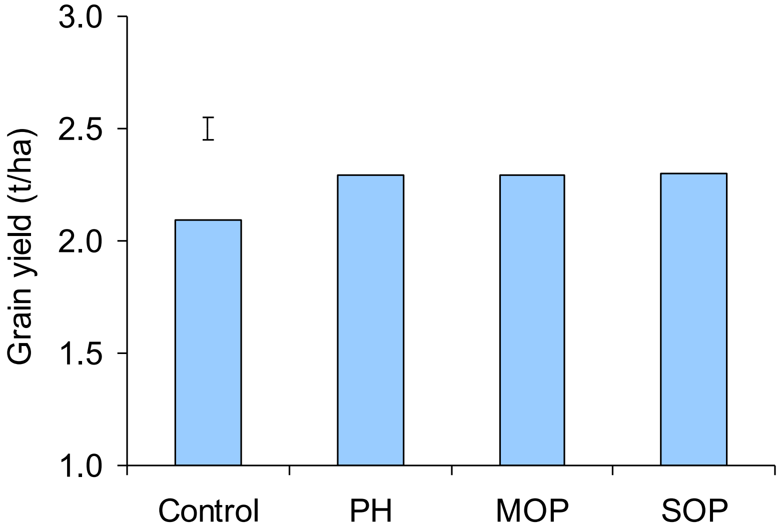

Figure 14. Grain yield (t/ha) of a field grown soybean crop with addition of either PH (Polyhalite), MOP (muriate of potash, KCl), SOP (sulphate of potash, K_2SO_4) or no potash fertiliser addition (control). Data are a mean across 4 K rates between 50 and 250 kg K/ha for PH/MOP/SOP carried out in summer 2013 by Texas AgriLife Research. Error bar represents the least significant difference (LSD) at $P = 0.05$.

Conclusions from the research funded by Sirius Minerals were in agreement with the findings of Barbarick (1991) who showed that the potash supply from Polyhalite was at least as effective as that from MOP and SOP. For the crop species where there was no significant response to Polyhalite (potato, soybean and cotton), there was only one case where either MOP, SOP or SOP-M gave a significantly greater response than Polyhalite (i.e. MOP for soybean). *Note*: some caution should be taken in interpreting these results, because although the potash content of the fertiliser applications was usually equivalent for each fertiliser added, the fertilisers almost always differed in the content of other nutrients including sulphur, magnesium and calcium and these were not accounted for or balanced in any of the studies reported. Therefore, the differences observed may not necessarily be a result of greater potash availability for plants, but instead may be related to the availability of one or more of the other nutrients.

A summary of Sirius Minerals ongoing R&D programme is provided in Appendix I. Field studies are being undertaken in the UK on grassland, oilseed rape and winter barley, and glasshouse studies on a range of crops (including celery, cotton and soybean). In the US, field studies are being undertaken on soybean, corn, spinach, squash, sugarcane, potatoes and tomatoes, and glasshouse studies on cabbage and corn. Similarly in China, field studies are being undertaken on apples and tomatoes, and glasshouse studies on corn and peanuts; in Brazil field studies as being undertaken on sugarcane and; in Malaysia studies are being undertaken on oil palm propagation.

4.3 Summary

- Published and Sirius minerals funded research studies showed that **Polyhalite increased plant growth in a wide range of crop species** including: corn, flax, oilseed rape, pepper, potato, sorghum, soybean, sugar cane and wheat.
- **Polyhalite had *no negative crop growth effects* in 23 experiments and its salt index was less than muriate of potash**. Polyhalite (as expected) increased the level of soil electrical conductivity in some studies, but not to a level that would be injurious to plant growth. Polyhalite had *no measurable effects* on soil pH.
- In around 90% of experiments with a range of crop species, **Polyhalite always produced an equal or greater growth response** compared with other wider used potash fertilisers (when balanced for potash supply).
- **Polyhalite produced an equal or greater growth response** to sulphate of potash in 8 of 9 experiments (when balanced for potash supply).
- Polyhalite provides valuable inputs of **sulphur, magnesium and calcium**, which increase its utility*; it is much more than just a source of potash.*

5. Polyhalite multi-nutrient fertiliser

5.1 Introduction

The crop species that are most likely to have the greatest requirement for Polyhalite-based fertiliser products are crops with a large demand for potash, sulphur and magnesium, and crops growing on soils with low levels of these nutrients. Also, the low chloride content of Polyhalite makes it more suitable for use on chloride/salt sensitive crops than muriate of potash (KCl), particularly in arid and semi-arid environments.

5.2 Global crop production

Global crop production for the years 2009 to 2011 was retrieved from the FAOSTAT (2013) database and mean annual production was calculated for each crop on a fresh weight basis. As the moisture content of crop species varies widely the mean global production value was modified to account for this variation, using percentage dry matter values for the top 61 crops; which represent *c.*95% of global production on a fresh weight basis. The crops were then ranked based on dry matter production, as this provides a better representation of global nutrient requirements than fresh weight production. The top 16 crops accounted for *c.*85% of global production on a dry matter basis and included seven grain crops, a range of non-grain crops and three types of forage crop (Table 12). These crops are grown on 414 million hectares of land throughout the world.

Yield data (tonnes per hectare) for the top 16 global production crops were also obtained from the FAOSTAT database (for the same period), and annual average fresh weight yields calculated (Table 13). The yield data were then corrected for dry matter content to produce average dry matter yields (Table 13).

Nutrient concentrations in harvested crop dry matter were identified for each of the top 16 global production crops and combined with dry weight yield data (tonnes per hectare) to estimate nutrient offtakes (kg/ha) for each crop. This value was then multiplied by the area of production and converted into an estimated total nutrient offtake for each crop (Table 15).

In the majority of circumstances, the nutrient offtake value provides the most appropriate guide of the fertiliser requirement, except where non-yield components of the crop are also removed (e.g. straw for grain crops). In the latter situation, the total amount of nutrients taken up by the crop provides a more appropriate guide of the fertiliser requirement. For crop species such as cereals, it is necessary to estimate the nutrient harvest index (proportion of the nutrient found in the harvested component of the crop as a percentage of the total crop nutrient content) Table 14. Nutrient offtakes for each crop (kg/ha) and on a worldwide basis (millions of tonnes) based on total crop biomass production are summarised in Table 16.

Note: Wherever possible, the values used for harvest indices, yields and nutrient contents were sourced from the literature. However, it was not always possible to do this and some assumptions were made to create a robust data set. For example, the nutrient harvest indices of seed cotton were assumed to be the same as oilseed rape, and similarly where values were missing these were estimated by taking an average of similar crop species and scaling to the crop in question. Also, the following assumptions were made for yield component nutrient content data: the barley grain sulphur concentration was assumed to be the same as for wheat; sugarcane was assumed to be the same as for the whole plant; soybean was calculated assuming an average yield of 2.5 t/ha; pumpkin, cassava and oil palm fruit sulphur contents were estimated as an average of other vegetables; and oil palm fruit magnesium values were assumed to be the same as for oil palm kernels.

5.3 Global nutrient needs

5.3.1 Crop productivity and nutrient uptake

Globally over the 2009 to 2011 period, the highest yielding crop in terms of dry production was maize and the highest yield crop on a fresh weight basis was sugarcane (Table 12). Grain crops in the top 16 accounted for 56% of global production on a dry weight basis; with forage maize, grasses and alfalfa also important in terms of dry matter production (making up 6% of global production). While grain crops dominated in terms of total global production, non-grain crops including sugar beet, sugarcane and palm fruit oil dominated in terms of dry weight yield (tonnes per hectare), Table 13.

Nutrient harvest indices tended to be positively related to dry matter harvest indices (Table 14). For example, potatoes had a large dry matter harvest index of 0.55 and comparatively high nutrient harvest indices of 0.24 - 0.47. In contrast, pumpkins had a low dry matter harvest index of 0.18 and comparatively low nutrient harvest indices of 0.08 - 0.15. This is logical, since crop species with a large proportion of dry matter in the harvested component would also be expected to have a large proportion of nutrients in the harvested component. However, it was apparent that some crop species had a very wide variation in nutrient apportionment between the harvested component (e.g. seed) and the straw. For example rice, contains 37% of total plant dry matter in the seed, but only 10% of its K.

Table 12. Mean annual fresh and dry weight production of the top 16 global production crops, and percentage of global production represented by each crop for 2009 to 2011 (on a dry weight basis) (FAOSTAT, 2013).

Crops	Global fresh weight production (million tonnes)	Percentage dry matter content (%)	Global dry weight production (million tonnes)	Percentage of global dry weight production (%)
Grain crops				
Maize	852	86	732	17
Rice, paddy	703	86	604	14
Wheat	680	86	585	14
Soybeans	250	90	225	5
Barley	136	86	117	3
Seed cotton	69	92	63	2
Rapeseed	62	91	56	1
Non-grain crops				
Sugar cane	1721	30	516	12
Oil, palm fruit	227	75	170	4
Forage and silage, maize	422	24	99	2
Cassava	244	36	87	2
Forage and silage, grasses	414	20	83	2
Forage and silage, alfalfa	384	20	77	2
Potatoes	347	22	76	2
Pumpkins for Fodder	1053	7	74	2
Sugar beet	244	23	56	1
Total	**7807**		**3620**	**85**

Table 13. Mean annual crop yield on a fresh and dry weight basis for the top 16 global production crops for 2009 to 2011 (FAOSTAT, 2013)

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Crops	Fresh weight yield (tonnes/ha)	Dry weight yield (tonnes/ha)
Grain crops		
Maize	5.17	4.44
Rice, paddy	4.36	3.75
Wheat	3.08	2.65
Soybeans	2.46	2.21
Barley	2.72	2.34
Seed cotton	2.13	1.95
Rapeseed	1.90	1.73
Non-grain crops		
Sugar cane	71.25	21.38
Oil, palm fruit	14.26	10.69
Forage and silage, maize	34.28	8.06
Cassava	12.53	4.45
Forage and silage, grasses	18.56	3.71
Forage and silage, alfalfa	26.68	5.34
Potatoes	18.42	4.03
Pumpkins for Fodder	12.46	0.87
Sugar beet	52.12	11.99

Table 14. Dry matter and nutrient harvest indices for the top 16 global production crops.

Crops	K Harvest Index	S Harvest Index	Mg Harvest Index	Dry matter Harvest Index	References for dry matter harvest index
Grain crops					
Maize	0.33	0.57	0.29	0.48	Stöckle *et al.*, 2013
Rice, paddy	0.10	0.64	0.43	0.37	Yang & Zhang, 2010
Wheat	0.27	0.45	0.54	0.48	Hay, 1995;Stöckle *et al.*, 2013;Yang & Zhang, 2010
Soybeans	0.61	0.67	0.22	0.30	Stöckle *et al.*, 2013
Barley	0.28	0.32	0.25	0.51	Garstang, 1994;Hay, 1995;Yang & Zhang, 2010
Seed cotton*	0.24	0.27	0.23	0.32	
Rapeseed	0.42	0.22	0.23	0.32	Berry & Spink, 2009
Non-grain crops					
Sugar cane	0.74	0.74	0.74	0.74	Raman *et al.,* 2013
Oil, palm fruit**	1.00	1.00	1.00	1.00	
Forage and silage, maize**	1.00	1.00	1.00	1.00	
Cassava	0.55	0.37	0.30	0.57	Alves, 2002
Forage and silage, grasses	1.00	1.00	1.00	1.00	Gobin *et al.*, 2011
Forage and silage, alfalfa†	1.00	1.00	1.00	1.00	
Potatoes	0.42	0.47	0.41	0.55	Hay, 1995
Pumpkins for Fodder	0.14	0.15	0.13	0.18	Irannejad *et al.,* 2011
Sugar beet	0.31	0.59	0.50	0.70	Scott *et al.*, 2013

Cited references are for dry matter harvest index values (i.e. the ratio of harvested product in total above ground dry matter production). Mean value used where range given.

*assumed same as oilseed rape.

†grasses.

**assumed to be whole crop.

The estimated *nutrient offtakes* in yield were generally higher for the non-grain crops than grain crops, particularly for potassium as generally a greater proportion of the whole plant is harvested for non-grain crops (Table 15).

- Crops with high potassium offtakes per hectare included: sugar cane, sugar beet, grasses, alfalfa and maize.
- Crops with high sulphur offtakes included: grasses, rice, soybean, alfalfa, sugar cane and oil palm.
- Crops with high magnesium offtakes included: sugar cane, alfalfa, oil palm, sugar beet and maize.

Grasses and alfalfa can be both grazed by livestock and silaged; grazing will return most of the nutrients to the field, whereas silaging will remove the nutrients from the field.

The nutrient harvest indices (Table 14) were used to convert the yield nutrient offtake values into *nutrient uptakes* for the whole. The grain and non-grain crops had similar values for nutrient uptake, apart from the high K uptake of sugar cane and sugar beet (Table 16).

- Crops with high potassium uptakes included; sugar cane, sugar beet, pumpkins, alfalfa, rice, cotton and maize.
- Crops with high sulphur uptakes included; oilseed rape, rice, wheat, soybean, cotton, grasses.
- Crops with high magnesium uptakes included; sugar cane, cotton, soybean, sugar beet, rapeseed, oil palm.

When total nutrient uptakes are considered, as opposed to nutrient offtakes, several new crops are identified as having high potassium, sulphur and magnesium requirements – including for potassium: rice, cotton and pumpkins, for sulphur: rapeseed, wheat and cotton and, for magnesium: rapeseed, soybean and cotton.

Table 15. Estimated nutrient offtakes in *yield* (kg/ha) and globally (million tonnes) for K, S and Mg for the top 16 global production crops.

Crops	Estimated nutrient offtakes in yield (kg/ha)			Estimated total global nutrient offtakes in yield (million tonnes)		
	K	S	Mg	K	S	Mg
Grain crops						
Maize	18.2	4.4	5.3	3.00	0.73	0.88
Rice, paddy	10.5	2.7	1.5	1.69	0.43	0.24
Wheat	13.2	3.2	3.2	2.92	0.70	0.70
Soybeans	24.3	14.4	6.9	2.47	1.46	0.70
Barley	7.0	2.8	3.0	0.35	0.14	0.15
Seed cotton	23.5	5.1	6.8	0.76	0.16	0.22
Rapeseed	17.1	8.6	4.7	0.56	0.28	0.15
Non-grain crops						
Sugar cane	428	10.7	32.1	10.33	0.26	0.77
Oil, palm fruit	40.6	10.7	19.2	0.65	0.17	0.31
Forage and silage, maize	91.8	9.7	9.7	1.13	0.12	0.12
Cassava	30.2	4.4	2.2	0.59	0.09	0.04
Forage and silage, grasses	78.0	16.3	5.6	1.82	0.38	0.13
Forage and silage, alfalfa	133	13.3	14.4	1.97	0.20	0.21
Potatoes	17.9	4.2	2.8	0.34	0.08	0.05
Pumpkins for Fodder	28.8	0.9	1.7	2.43	0.07	0.15
Sugar beet	85.1	7.2	12.0	0.40	0.03	0.06
Total	**-**	**-**	**-**	**31.41**[+]	**5.30**[++]	**4.88**[+++]

[+] 37.8 Mt potash (K_2O)

[++] 13.3 Mt sulphur as SO_3

[+++] 8.1 Mt magnesium as MgO

Table 16. Estimated nutrient uptakes in *total biomass* (kg/ha) and globally (million tonnes) for K, S and Mg for the top 16 global production crops.

Crops	Estimated nutrient uptakes in total biomass (kg/ha)			Estimated total global nutrient requirements (million tonnes)		
	K	S	Mg	K	S	Mg
Grain crops						
Maize	55.2	7.8	18.4	9.10	1.29	3.03
Wheat	49.0	7.1	5.9	10.83	1.56	1.30
Soybeans	39.9	21.4	31.1	4.05	2.18	3.17
Barley	25.1	8.8	12.2	1.25	0.44	0.61
Seed cotton	97.0	19.0	29.1	3.14	0.61	0.94
Rapeseed	40.7	39.2	19.9	1.32	1.28	0.65
Non-grain crops						
Sugar cane	578	14.4	43.3	13.95	0.35	1.05
Oil, palm fruit	40.6	10.7	19.2	0.65	0.17	0.31
Forage and silage, maize	91.8	9.7	9.7	1.13	0.12	0.12
Cassava	55.0	12.0	7.4	1.07	0.23	0.14
Forage and silage, grasses	78.0	16.3	5.6	1.82	0.38	0.13
Forage and silage, alfalfa	133	13.3	14.4	1.97	0.20	0.21
Potatoes	42.2	9.1	6.9	0.79	0.17	0.13
Pumpkins for Fodder	208	5.7	13.1	17.53	0.48	1.10
Sugar beet	275	12.1	24.0	1.28	0.06	0.11
Total	**-**	**-**	**-**	**86.80**[+]	**10.19**[++]	**13.56**[+++]

[+] 105 Mt potash (K_2O)

[++] 25.5 Mt sulphur as SO_3

[+++] 22.6 Mt magnesium as MgO

5.3.2 Salt and chloride sensitivity

Salt may affect plants via two mechanisms: (chloride/sodium) toxicity or osmotic salt effects. Salt effects are most likely in arid and semi-arid areas of the world; they are only likely in temperate agriculture where high rates of fertiliser are applied close to the drilling/planting of sensitive crops.

Chloride/sodium ions may be toxic to plants, independent of any osmotic effects, and is most likely where perennial crops are exposed to salt for prolonged periods. Polyhalite does not contain chloride or sodium ions, and therefore has a potential advantage of over the most commonly used K fertiliser, muriate of potash (KCl). Of the major crops covered in this report, potatoes are the most sensitive to chloride. Some minor crops, also have a low chloride tolerance including: peas, field beans, cocksfoot grass, parsnip, mango, citrus, pepper, broad beans, cucumber, lettuce, melon and onions (Table 17).

An osmotic effect of a salt can reduce the availability of water to plants, this can occur not only in the presence of chloride or sodium ions, but also other soluble salts, including nitrate, bicarbonate, sulphate etc. Thus, crops are often classified based on their ‘salt’ tolerance to take account of this osmotic effect. The osmotic status of soils can be assessed by measuring the electrical conductivity of the soil solution, with elevated electrical conductivity levels indicating greater salt concentrations. All soluble fertilisers will increase the salt content of the soil solution. However, some fertilisers cause a greater salt concentration than others.

The osmotic potential of different fertilisers is measured in terms of their salt index, where sodium nitrate has a score of 100. Polyhalite fertiliser has been shown to have a salt index of 87 compared with muriate of potash fertiliser which has a salt index of 116 (Anon, 1986). Of the top 16 global production crops, rice is sensitive to salt, with maize, sugar cane, cassava, soybeans, potatoes, alfalfa and pumpkins moderately sensitive to salt (Table 17). Other minor crops with a low salt tolerance include lettuce, onion, radish, celery, carrot and field beans (Tanji & Kielen, 2002).

5.3.3 Crop quality

Adequate nutrient provision is important not only for crop yields, but also for crop quality, including sensory (appearance, texture etc.), nutritional, functional and storage properties (Gerendás & Führs, 2013). This is especially relevant in fruit and leafy crops, which are not the highest production crops worldwide, but are high value crops and have significant demand for the nutrients in Polyhalite.

In order to maintain crop quality, Patterson (2014) recommended low-level calcium applications, regardless of pH, for crops including apples, beans, cabbage, carrots, tomatoes and potatoes, as calcium deficiency can limit the shelf life of these crops, as a result of bitter pit, hypocotyl necrosis, club root, cavity spot, blossom end rot, tip burn in salads and internal browning, respectively. Notably, calcium is recognised as the most important element in maintaining post-harvest quality in apples and other fruit horticultural crops (HDC, 2013). For most crop species, soil potash additions generally only have a small or no effect on the crop quality (Greenwood *et al*. 1980; Lester *et al*., 2010). However, there are some specific crops that can benefit from potash additions beyond yield increases alone. For example, potash additions can help to improve the colour quality, prevent uneven ripening and prevent irregularly shaped fruit in tomatoes (Hartz, 1999). Notably, in the case of Polyhalite use, potassium sulphate can have advantages over MOP use where low dry matter levels are a concern in potatoes (Defra, 2010). A recent meta-analysis showed that magnesium addition to sites that were deficient can improve the quality of agricultural crops (Gerendás & Führs, 2013). However, there was no evidence that magnesium additions above those required for maximum crop yields further improving crop quality (Gerendás & Führs, 2013).

The sulphur requirement of plants is strongly linked to their nitrogen requirement (*Jamal et al*., 2010) and as such if there is not sufficient sulphur available, it is likely that yields and/or crop quality will decline, as a combined result of insufficient nitrogen and sulphur (Jamal *et al,*. 2010). McGrath *et al.* (2002) showed that insufficient sulphur in wheat grain resulted in reduced loaf volumes. Also, a Yara study showed that the addition of sulphur (as sulphate of potash) increased the dry matter content of white cabbage (Yara, 2013) and improved storage quality.

Table 17. The chloride and salt tolerance of the top 16 global production crops.

	Chloride tolerance**	Salt tolerance***
Grain crops		
Maize	Tolerant	Moderately sensitive
Rice, paddy	Tolerant	Sensitive*
Wheat	Tolerant	Moderately tolerant
Soybeans	Tolerant	Moderately tolerant
Barley	Tolerant	Tolerant
Seed cotton	Tolerant	Tolerant
Rapeseed	Tolerant	Tolerant
Non-grain crops		
Sugar cane	Tolerant	Moderately sensitive
Oil, palm fruit	Tolerant	ND
Forage and silage, maize	Tolerant	Moderately sensitive
Cassava	Tolerant	Moderately sensitive
Forage and silage, grasses	Tolerant	ND
Forage and silage, alfalfa	ND	Moderately sensitive
Potatoes	Partially tolerant/sensitive	Moderately sensitive
Pumpkins for fodder	ND	Moderately sensitive
Sugar beet	Chloride loving	Tolerant*

ND = no data.
*Less tolerant during seedling stage.
**K+S (2013)
***Tanji & Kielen (2002)

5.3.4 Best-fit crops

Estimated nutrient offtakes (Table 16) were used to assess whether each of the top 16 global production crops had a high, medium or low demand (on a relative three tier ranking scale) for potassium, sulphur and magnesium relative to each other (Table 18). Additionally, crop tolerance to salt and chloride was summarised in Table 18. The best-fit crops for Polyhalite were ones with a high demand for potassium, sulphur and magnesium, and those that were also sensitive to salt/chloride. The majority of the top 16 crop species had moderate or high requirements for potash, sulphur and magnesium, and/or were sensitive to salt/chloride; the exceptions being wheat and barley. However, wheat and barley (and oilseed rape) will also be a good fit for Polyhalite in high yielding regions, where potassium and sulphur uptake and offtakes will be higher than average; particularly where straw is removed for animal bedding or energy production.

The net nutrient offtakes estimated for grasses and alfalfa are appropriate where these crops are cut for silage and the crop is removed from the field. In situations where these crops are grazed, a proportion of the grazed nutrients will be returned to the soil. However, excreta returns from animals tend to be spatially variable which together with nutrient leaching, means that grazed fields still require additional nutrients (either from manufactured fertilisers or organic manures).

The demand for sulphur fertiliser is less where atmospheric deposition is high. Our analysis (in Chapter 3.2) concluded that the atmospheric deposition of sulphur had decreased to agronomically negligible levels in many regions of the world, mainly due to changes in fuel use and power station air cleaning technologies. The main exception was parts of China, where regions close to the industrial centres still have high sulphur deposition levels. However, rural areas of China have low deposition rates in the range of 1.5-4.4 kg S/ha/yr. This means that the demand for sulphur fertiliser will be low in parts of China where crops such as rice, wheat, barley, sorghum, potatoes, maize and oilseed rape are grown close to industrial areas. However, these crops, apart from barley and sorghum, have a moderate demand for K and in the case of rice are sensitive to salt, so there would still be an agronomic case for Polyhalite use.

While this report has focused on the top 16 global production crops, there are other minor crops that may also have a high demand for the nutrients in Polyhalite. One example is onions, which has an estimated uptake of 35 kg S/ha, which is close to that of oilseed rape. Another example is carrots which has a high potassium content (Rust & Buskirk, 2008; USDA, 2013), second only to the K content of pumpkins (Preston, 2010). The potash fertiliser requirements of other crops can also be high compared with the major production crops. For example in the UK, potash recommendations for cereals grown on soils at K Index 0-1 are 130-145 kg/ha K_2O (Defra, 2010). Also, potash recommendations for crops including kale, brussel sprouts, cabbage, cauliflowers, lettuce, radishes, leeks, onions, carrots, swedes and turnips are all greater than 250 kg/ha K_2O on K Index 0/1 soils (Defra, 2010). At the extreme, celery has a very high potash recommendation of 450 kg/ha K_2O, as do potatoes at 360 kg/ha K_2O (Defra, 2010) at soil K Index 0. Similarly, most fruit crops and many vegetable crops have a requirement for magnesium (Defra, 2010). Notably, adequate nutrient provision is important not only for crop yields, but also for crop quality, which is especially important for ‘high value’ fruit and horticultural crops that have a significant demand for the nutrients in Polyhalite.

Table 18. Predicted potassium (K), sulphur (S) and magnesium (Mg) demand based on *nutrient offtake* for each of the top 16 global production crops, and an indication of the salt and chloride (Cl) and salt tolerance of each crop.

Crops	Nutrient demand (based on estimated nutrient *offtake* in kg/ha)			Salt/Cl tolerance*
Grain crops	**K**	**S**	**Mg**	
Maize	Med	Med	Med	Moderate
Rice, paddy	Low	Low	Low	Sensitive
Wheat	Low	Low	Low	Tolerant
Soybeans	Med	High	Med	Moderate
Barley	Low	Low	Low	Moderate
Seed cotton	Med	Med	Med	Tolerant
Rapeseed	Med	Med	Med	Tolerant
Non-grain crops				
Sugar cane	High	High	High	Moderate
Oil, palm fruit	Med	High	High	Tolerant
Forage and silage, maize	High	Med	High	Moderate
Cassava	Med	Med	Low	Moderate
Forage and silage, grasses	High	High	Med	Tolerant
Forage and silage, alfalfa	High	High	High	Moderate
Potatoes	Med	Med	Low	Sensitive
Pumpkins for Fodder	Med	Low	Low	Moderate
Sugar beet	High	Med	High	Tolerant

*K+S (2013);Tanji & Kielen (2002)

Examples of typical fertiliser recommendations for a range of crops are summarised in Table 19. These show that potash was recommended for all 13 crops, sulphur was recommended for 7 crops and magnesium was recommended for 6 crops. *Note*: The sulphur recommendations from the World Fertiliser Use Manual (Wichmann, 1992) are likely to be underestimates of present day requirements, because the manual was published in 1992: since then atmospheric sulphur deposition has fallen in many regions of the world, and crop yields and tonne nutrient demand/uptake will have increased.

Table 19. Examples of recommended fertiliser additions (kg/ha).

Crop	**Location**	**Source**	**N**	**P_2O_5**	**K_2O**	**SO_3**	**MgO**
Maize	Brazil	IFA	50-90	50-80	30-60	50	ND
Rice	Bangladesh	IFA	80	28	17	50	ND
Wheat	UK	RB209	220	60	55-85	50	0
Soybean	US	IFA	0	30-40	50-100	0	0
Barley	UK	RB209	160	60	45	40	0
Cotton	US	IFA	60-90	0-110	0-135	14	48
Rapeseed	UK	RB209	220	50	40	75	12-25
Sugar cane	India	IFA	100-250	60	80	ND	ND
Oil palm*	Malaysia	IFA	170-230	70-90	65-105	ND	12-20
Potato	UK	RB209	150	170	300	0	80
Sugar beet	UK	RB209	120	50	100	0	75
Onion	EU	IFA	100-200	100-200	200-300	ND	20-40
Grass	UK	RB209	120	40	80	40	0

Sources
IFA – World Fertiliser Use Manual (Wichmann, 1992)
RB209 – “Fertiliser Manual (RB209)” (Defra, 2010); HGCA (2014)
ND = no data

*Fertiliser input for maximum exploitation of the genetic yield potential of mature plants

5.3.5 Summary

- All of the major global crop production species remove *substantial amounts* of potassium, sulphur and magnesium from soils, and will therefore potentially **benefit from Polyhalite fertiliser additions** in situations where the soil supply of these nutrients is limiting.

- **Crops which fit particularly well with Polyhalite use are those with high potassium, sulphur and/or magnesium requirements, and/or intolerance to chloride/salt.** Crops which fit into these categories include: sugar cane, sugar beet, grass silage, alfalfa silage, forage maize, oil palm, oilseed rape, soybeans, rice, potatoes and onions, and minor crops including brassica vegetables, lettuce and carrots. These crops are grown on 414 million hectares worldwide.

- **Polyhalite fertiliser can have an advantage over muriate of potash fertiliser for crops which are salt/chloride sensitive**, including: potatoes, onions, peas, field beans, cocksfoot grass, mango, citrus, pepper, celery, carrot, cucumber, lettuce and melon (particularly where they are grown in arid and semi-arid environments) and more widely glasshouse (i.e. grown under cover) crops.

- The potential of Polyhalite *to increase crop quality* is limited for most ‘broad acre’ crops, but there are some fruit/horticultural crops which do benefit, including top fruit from calcium, tomatoes and lettuce from calcium and potassium, and potatoes where low tuber dry matters are a problem.

- The analysis of crop nutrient offtakes has enabled *the total quantity of nutrients removed from the field in crop products* to be estimated for the top 16 global production crops (which account for *c.*85% of total dry matter production). Nutrient offtakes for these crops amounted to 37.8 Mt K_2O (31.4 Mt K), 13.3 Mt SO_3 (5.3 Mt S) and 8.1 Mt of MgO (4.9 Mt Mg). These estimates can be used to assess how much nutrient must be applied to replace crop offtakes from the soil. *Nutrient uptakes* to support crop growth and yields were 105 Mt K_2O (86.8 Mt K), 25.5 Mt SO_3 (10.2 Mt S) and 22.6 Mt MgO (13.6 Mt Mg).

6. Polyhalite use in agriculture

Sirius Minerals has identified the potential for Polyhalite to be used as a valuable raw material for the production of bulk multi-nutrient (blended or complex) fertiliser products for domestic and export markets, see Plate 1. As part of the product and market development strategy, Sirius Minerals and a major UK blender have agreed to work together to develop product specifications for bulk products and formulations for fertiliser products utilising Polyhalite for British and Irish markets.

Plate 1. Polyhalite fertiliser.

6.1 Fertiliser strategies for UK crops

Efficient nutrient management relies on crop available nitrogen, phosphorus potassium, sulphur, magnesium and trace elements being supplied in balance and in synchrony with crop requirements. Nutrients supplied in manufactured fertilisers (or organic materials) should be used to supplement soil nutrient supplies to meet crop requirements. Application timing, to ensure nutrients are available during periods of active crop growth, is also important especially for nitrogen and sulphur (as sulphate), which can be lost from the soil by leaching. Under-supply of any nutrient will limit crop yields and quality, and will reduce the efficient crop uptake of other nutrients. On the other hand, excessive nutrient supply can reduce crop yields and quality and increase the potential for nutrient losses to the wider environment.

The balance of plant available potash (14% K_2O) and sulphur (48% SO_3) in Polyhalite makes it suitable for use in blended fertilisers (with for example: ammonium nitrate, triple super phosphate, mono and diammonium phosphate etc.) and complex compound fertiliser products that contain more than one nutrient. Compound fertiliser products are attractive to farmers, because they have the potential to reduce application costs. Moreover, it is important that a broad range of compound fertiliser products are available to farmers to satisfy the demands of contrasting crop nutrient requirements and soil nutrient supply situations.

Generally, it would not be appropriate to use straight Polyhalite to supply all of crop potash requirements, because the quantities required would result in excessive crop available sulphur supply. Excess sulphur can affect crop quality, for example, through increasing glucosinolate levels in oilseed rape seed, which reduce the feed quality of the rape-meal (Schnug, 1989). Also, excess sulphur can interfere with copper, molybdenum and selenium uptake in grass crops, and the availability of copper in livestock diets (ADAS, 1991).

Crop nitrogen, phosphate, potash and sulphur requirements for winter wheat, oilseed rape (including magnesium) and first cut silage grass in the "Fertiliser Manual

(RB209)" (Defra, 2010) are summarised in Tables 20, 21 and 22, along with example Polyhalite-based blended fertiliser products to provide a balanced supply of nutrients. Notably, nutrient concentrations in the Polyhalite-based blends are similar to those in other blended/complex fertilisers that are widely used in agriculture in the UK.

For winter wheat, the "Fertiliser Manual (RB209)" (Defra, 2010) recommends that 'early' should be applied in late February/early March, with the balance applied in one or more applications between early April and early May; see Table 20 for Polyhalite blend/complex supplying crop sulphur needs and early N.

Table 20. Fertiliser requirements (kg/ha) of *winter wheat* and nutrient supply from potential Polyhalite blended/complex fertiliser products (N supply would be supplemented by top-dressing).

RB209 Recommendations				Fertiliser Product	Nutrient supply			
N^a	P_2O_5	K_2O	SO_3	$N:P_2O_5:K_2O:SO_3$	N	P_2O_5	K_2O	SO_3
220	60[b]	45[b]	40	350 kg/ha 10:20:20:12[+] (25% Polyhalite)	35	70	70	42
220	0[c]	45[c]	40	150 kg/ha 20:0:8:27[++] (56% Polyhalite)	30	0	12	40

Notes: a – Soil Nitrogen Supply Index 1; b – Soil P Index 2 and K Index 2-; c – Soil P Index 3 and K Index 2-

[+] 10:20:20:12 blend/complex components – Polyhalite; ammonium nitrate; diammonium phosphate; and muriate of potash.

[++] 20:0:8:27 blend/complex components – Polyhalite; ammonium nitrate; and muriate of potash.

For oilseed rape, the "Fertiliser Manual (RB209") (Defra, 2010) recommends that applications of less than 100 kg/ha N should be applied at the start of spring growth (late February/early March) and for applications greater than 100 kg/ha N, half should be applied in late February/early March and the remainder by late March/early April; see Table 21 for Polyhalite complex/blend supplying crop sulphur needs and 'early' N and K. For oilseed rape crops with large canopies following winter, it is recommended to delay the first N split until after the start of stem extension (often in late March/early April) to reduce lodging risk (HGCA, 2012). However, it is advised that sulphur is applied in early spring (Defra, 2010), which often leads to a conundrum for growers and agronomists, as most sulphur products contain significant amounts of N. Therefore, straight Polyhalite would provide a valuable option for growers to supply sulphur, as well as potash and magnesium to large oilseed rape crops, without applying unnecessary nitrogen fertiliser. Similarly, straight Polyhalite would provide a valuable option to supply sulphur where there was no need for nitrogen (e.g. legume crops), particularly in Nitrate Vulnerable Zones.

Table 21. Fertiliser requirements (kg/ha) of *winter oilseed rape* and nutrient supply from potential Polyhalite blended/complex fertiliser products (N supply would be supplemented by top-dressing).

RB209 Recommendations					Fertiliser Product	Nutrient supply				
N^a	P_2O_5	K_2O	SO_3	MgO	$N:P_2O_5:K_2O:SO_3:MgO$	N	P_2O_5	K_2O	SO_3	MgO
190	50^b	40^b	75	$12-25^b$	450kg/ha $20:10:10:17:2^+$ (35% Polyhalite)	90	45	45	77	9
190	0^c	45^c	75	$12-25^c$	300 kg/ha $20:0:8:27:3^{++}$ (56% Polyhalite)	60	0	24	81	10

Notes: a – Soil Nitrogen Supply Index 1; b – Soil P Index 2, K Index 2 – and Mg Index 1; c - Soil P Index 3, K Index 2- and Mg Index 1

$^+$ 20:10:10:17:2 blend/complex components – Polyhalite; ammonium nitrate; diammonium phosphate; and muriate of potash.

$^{++}$ 20:0:8:27:3 blend/complex components – Polyhalite; ammonium nitrate; and muriate of potash

For first cut silage, the “Fertiliser Manual (RB209)” (Defra, 2010) recommends that around 40 kg/ha N should be applied in late February/early March and the remainder in April, more than six weeks before cutting. Also, that sulphur should be applied in early spring on all crop types and for each grass-silage cut; see Table 22 for Polyhalite blend/complex supplying crop sulphur needs and ‘early N.

Table 22. Fertiliser requirements (kg/ha) for *first cut grass silage* and nutrient supply from potential Polyhalite blended/complex fertiliser products (N supply would be supplemented by top-dressing).

RB209 Recommendations				Fertiliser Product	Nutrient supply			
N	P_2O_5	K_2O	SO_3	$N:P_2O_5:K_2O:SO_3$	N	P_2O_5	K_2O	SO_3
120	40^a	80^a	40	350 kg/ha $13:5:23:12^+$ (25% Polyhalite)	45	21	94	42

a - Soil P Index 2: Soil K Index 2-

$^+$ 13:5:23:12 blend/complex components – Polyhalite; ammonium nitrate; diammonium phosphate; and muriate of potash.

The example compound fertiliser products in Tables 20-22 have been formulated for early spring application to provide the first N dressing and all of the sulphur requirement for the different crop types. In addition, Polyhalite-based compound fertiliser products would be suitable for application to magnesium responsive crops (e.g. fruit, vegetables, potatoes and sugar beet) grown on soils that are naturally low in magnesium (e.g. light sandy soils).

Polyhalite can be included in blended fertilisers to allow balanced applications of sulphur, potash and magnesium as multi-nutrient fertiliser products in the UK and throughout the world.

6.2 Spreading tests

Spreading tests carried out by SCS Spreading and Sprayer Testing Ltd demonstrated the good spreading characteristics of granulated Polyhalite, with coefficients of variation in the range 4-6% over 24m, 32m and 36m spreading widths, and for a Polyhalite-based blended fertiliser (20:10:10) a coefficient of variation of 5.5% over a 36m spreading width; these are representative of spreading distances used in commercial arable systems, see Appendix II. A coefficient of variation for spreading of 10% is normally considered good and one of *c.*5% very good.

6.3 Organic farming systems

Polyhalite has been certified as suitable for use in organic farming systems by the Soil Association and the Organic Farmers and Growers Approved Inputs scheme (Figure 15).

Organic Farmers & Growers
Approved Inputs Scheme

Certificate of Evaluation for Compliance

York Potash Ltd

[redacted]

This Certificate, at all times, remains the property of

CERTIFICATE OF REGISTRATION

York Potash

Licence number: AL22600

7-10 Manor Court
Scarborough
North Yorkshire
YO11 3TU

Issue date: **11 June 2013** Expiry date: **31 March 2014**

[redacted]

Figure 15. Organic certification for Polyhalite.

6.4 Potentially toxic elements

Granulated Polyhalite fertiliser has been produced by Sirius Minerals on a trial basis and analysed by SGS laboratories; see Appendix III. The nutrient content of the product was similar to Polyhalite values reported in the literature (e.g. Barbarick, 1991) Potentially toxic element (PTE) concentrations were also very low (Table 23) with PTE loading rates several orders of magnitude lower than the maximum permissible average annual rates of addition over a 10 year period (DoE, 1996).

Table 23. Potentially toxic element concentrations in Polyhalite and loadings from a typical application rate.

Element	Polyhalite content (g/t)	Maximum permissible average annual rate of addition over a 10 year period (g/ha)	Loading from 250 kg/ha Polyhalite (g/ha)
Zinc	<0.5	15,000	<0.13
Copper	1.1	7,500	0.28
Nickel	0.3	3,000	0.08
Cadmium	<0.5	1,500	<0.13
Lead	0.7	15,000	0.18
Mercury	<0.02	100	<0.01
Chromium	0.4	15,000	0.10

6.5 Summary

- **Polyhalite is a valuable source of readily crop available potash, sulphur and magnesium** and contains very low levels of potentially toxic elements.
- Polyhalite can be used as a *straight fertiliser,* especially where there is a high demand for sulphur and a low demand for other nutrients (e.g. forward oilseed rape crops) or where there is a need for sulphur and no nitrogen (e.g. for legume crops in Nitrate Vulnerable Zones).
- In most situations it would *not be appropriate* to supply all of crop potash requirements, using straight Polyhalite, because sulphur supply would exceed crop demand.
- **Including Polyhalite in blends allows balanced applications of sulphur, potash and magnesium to be made as multi-nutrient fertilisers.**
- Fertiliser spreading tests demonstrated the **good spreading characteristics** of granular Polyhalite and a Polyhalite-based blend up to 36m, with coefficients of variation in the range 4-6%.
- Polyhalite has been **certified for use in organic farming systems** which is a useful niche market.

7. Conclusions

- Polyhalite is a *naturally occurring mineral* that contains the crop available nutrients: potassium (14% declared as K_2O), sulphur (48% declared as SO_3), magnesium (6% declared as MgO) and calcium (17% declared as CaO). Potash and sulphur are the most valuable nutrients in Polyhalite, because in many situations the soil supply of these nutrients is likely to be insufficient for optimal crop growth.

- **Global potash consumption is predicted to grow** at an average rate of 3% per annum, to satisfy the *increasing demand for food* from the growing world population. As a result annual potash fertiliser production will need to increase by *c.*1.0 Mt K_2O to satisfy increased global demand.

- The increasing prevalence of *sulphur deficiency* throughout the world, as a result of reductions in atmospheric deposition and the need to increase crop production to meet the demands of the growing global population will **increase the need for sulphur fertilisers**. The current global sulphur deficit (i.e. crop sulphur requirement vs. sulphur fertiliser applications) has been estimated at 11 million tonnes of sulphur per annum.

- Magnesium fertilisers are important for *several widely grown crops* including potatoes, sugar beet and, to a lesser extent, oilseed rape, oil palm, cotton and onions, especially on sandy/light textured soils.

- Data from published and Sirius Minerals-funded research showed that **Polyhalite increased the growth of in a wide range of crop species** including: corn, flax, oilseed rape, peppers, potatoes, sorghum, soybeans, sugarcane and wheat. Polyhalite produced *no negative crop growth effects* in any of the experiments reviewed, its salt index was less than that of muriate of potash and it resulted in *no measurable adverse effects on soil pH or the level of soil salinity* (electrical conductivity). In around 90% of experiments with a range of crop species, Polyhalite always produced an equal or greater growth response compared with other commonly used potash fertilisers (when balanced for potash supply).

- **All crops will benefit from applications of Polyhalite-based fertiliser products**, where the soil supply of any of the nutrients supplied by Polyhalite is limiting potential crop growth. ‘Best-fit’ crops for Polyhalite use are those with a high potassium, sulphur and/or magnesium requirement and include: sugar cane, sugar beet, grass silage, alfalfa silage, forage maize, oil palm, oilseed rape, soybeans, rice, onions, vegetable brassicas and lettuce.

- **Polyhalite is very well suited for inclusion in blended (complex) compound fertiliser products,** with other sources of nutrients, to produce *multi-nutrient* fertiliser products. Polyhalite can be applied as a straight fertiliser, but in most situations it would not be practical to supply all of crop potash requirements because sulphur supply would greatly exceed crop demand.

In summary, Polyhalite is a valuable source of plant available potash, sulphur and magnesium that can be applied alone or used to produce multi-nutrient fertiliser products. The market for potash, sulphur and magnesium fertiliser products will increase in the future because of the need to increase food *production and, for sulphur, the continued decline in atmospheric sulphur deposition.*

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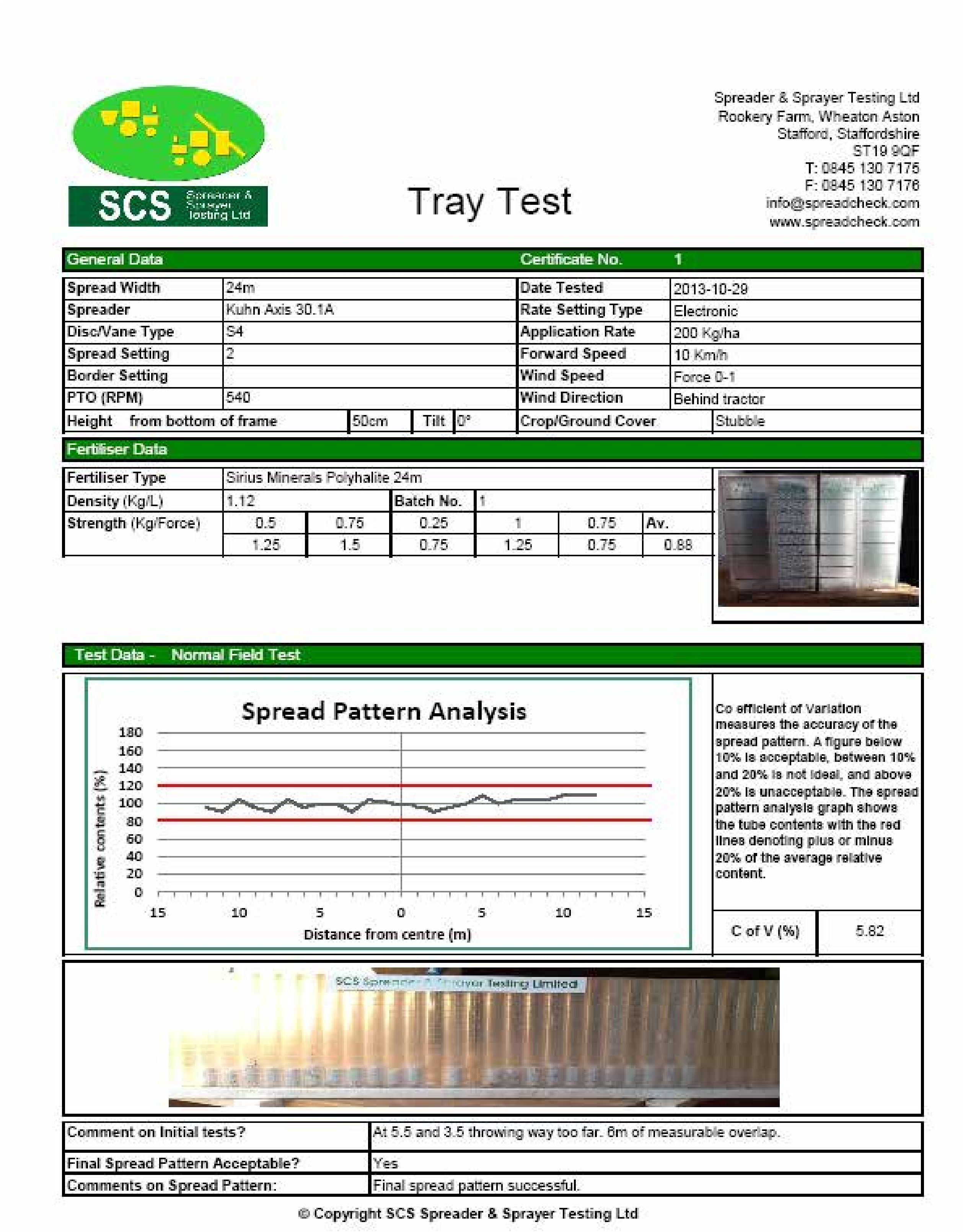
APPENDIX I: Summary of Sirius Minerals Ongoing R&D Programme

	2013				2014											
	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	Trial Type
ADAS																
Grass						✎	🟦	🟦	🟦	🟦	🟦	🟦	■		🟩	Field
Durham University																
Cotton	■	🟩														Greenhouse
Oilseed rape	🟩															Greenhouse
Oilseed rape 2	🟦	■		🟩												Greenhouse
Potato	🟦	■		🟩												Greenhouse
Soybean	■	🟩														Greenhouse
Soybean 2	🟦	🟦	🟦	■		🟩										Greenhouse
Wheat	■	🟩														Greenhouse
Wheat 2	🟦	■	■		🟩											Greenhouse
Harper Adams University																
Oilseed rape	✎	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	■		🟩	Field
University of Warwick Crop Centre																
Barley (Winter)		✎	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	■		🟩		Field
Celery				✎	🟦	🟦	🟦	■		🟩						Glass
Texas A&M University																
Soybean	■	■	■													Field
Spinach			✎	🟦	🟦	■		🟩								Field
Squash							✎	🟦	■		🟩					Field
Sugarcane	🟦	🟦	🟦	🟦	🟦	🟦	■	■	■	■	■	■	■	■	■	Field
University of Florida																
Cabbage			✎	🟦	🟦	■		🟩								Greenhouse
Corn			✎	🟦	🟦	🟦	🟦	🟦	■		🟩					Greenhouse
Corn 2	🟦	■	🟩													Field
Soybean	🟦	■														Field
Tomatoes			✎	🟦	🟦	🟦	■		🟩							Field
Commercial Trial																
Corn	🟦	■														Field
Potato	🟦	🟦	🟦	🟦	■											Field
Soybean	🟦	■														Field
Shandong Agricultural University																
Apples	🟦	■		🟩												Field
Corn	■		🟩													Glass
Peanuts	■		🟩													Glass
Tomatoes	■		🟩													Field
University of Sao Paulo																
Sugarcane		✎	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	■		🟩		Field
AAR																
Oil palm propagation	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	■							Nursery

✎ Planting 🟦 Growing Period ■ Expected Harvesting 🟩 Expected Reporting

APPENDIX II: SCS Tray Test Spread Pattern Analysis (24, 32 and 36m) for granular Polyhalite and 36m for a Polyhalite-based blend



Tray Test

Spreader & Sprayer Testing Ltd
Rookery Farm, Wheaton Aston
Stafford, Staffordshire
ST19 9QF
T: 0845 130 7175
F: 0845 130 7176
info@spreadcheck.com
www.spreadcheck.com

General Data		Certificate No.	1
Spread Width	24m	Date Tested	2013-10-29
Spreader	Kuhn Axis 30.1A	Rate Setting Type	Electronic
Disc/Vane Type	S4	Application Rate	200 Kg/ha
Spread Setting	2	Forward Speed	10 Km/h
Border Setting		Wind Speed	Force 0-1
PTO (RPM)	540	Wind Direction	Behind tractor
Height from bottom of frame	50cm Tilt 0°	Crop/Ground Cover	Stubble

Fertiliser Data

Fertiliser Type	Sirius Minerals Polyhalite 24m					
Density (Kg/L)	1.12		Batch No.	1		
Strength (Kg/Force)	0.5	0.75	0.25	1	0.75	Av.
	1.25	1.5	0.75	1.25	0.75	0.88

Test Data - Normal Field Test

Co efficient of Variation measures the accuracy of the spread pattern. A figure below 10% is acceptable, between 10% and 20% is not ideal, and above 20% is unacceptable. The spread pattern analysis graph shows the tube contents with the red lines denoting plus or minus 20% of the average relative content.

C of V (%)	5.82

Comment on Initial tests?	At 5.5 and 3.5 throwing way too far. 6m of measurable overlap.
Final Spread Pattern Acceptable?	Yes
Comments on Spread Pattern:	Final spread pattern successful.

SCS Spreader & Sprayer Testing Ltd

Tray Test

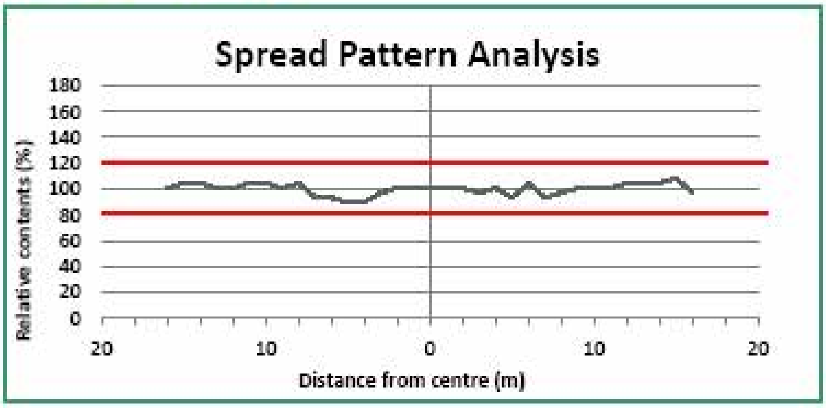
Spreader & Sprayer Testing Ltd
Rookery Farm, Wheaton Aston
Stafford, Staffordshire
ST19 9QF
T: 0845 130 7175
F: 0845 130 7176
info@spreadcheck.com
www.spreadcheck.com

General Data		Certificate No.	1
Spread Width	32m	**Date Tested**	2013-10-29
Spreader	Kuhn Axis 30.1A	**Rate Setting Type**	Electronic
Disc/Vane Type	S8 VXR	**Application Rate**	200 Kg/ha
Spread Setting	3.5	**Forward Speed**	10 Km/h
Border Setting		**Wind Speed**	Force 0-1
PTO (RPM)	540	**Wind Direction**	Behind tractor
Height from bottom of frame	50cm **Tilt** 0°	Crop/Ground Cover	Stubble

Fertiliser Data

Fertiliser Type	Sirius Minerals Polyhalite 32m					
Density (Kg/L)	1.12		**Batch No.**	1		
Strength (Kg/Force)	0.5	0.75	0.25	1	0.75	**Av.**
	1.25	1.5	0.75	1.25	0.75	0.88

Test Data - Normal Field Test



Co efficient of Variation measures the accuracy of the spread pattern. A figure below 10% is acceptable, between 10% and 20% is not ideal, and above 20% is unacceptable. The spread pattern analysis graph shows the tube contents with the red lines denoting plus or minus 20% of the average relative content.

C of V (%)	4.44

Comment on Initial tests?	
Final Spread Pattern Acceptable?	Yes
Comments on Spread Pattern:	Good pattern, but only 2-3m of measurable overlap.

Spreader & Sprayer Testing Ltd
Rookery Farm, Wheaton Aston
Stafford, Staffordshire
ST19 9QF
T: 0845 130 7175
F: 0845 130 7176
info@spreadcheck.com
www.spreadcheck.com

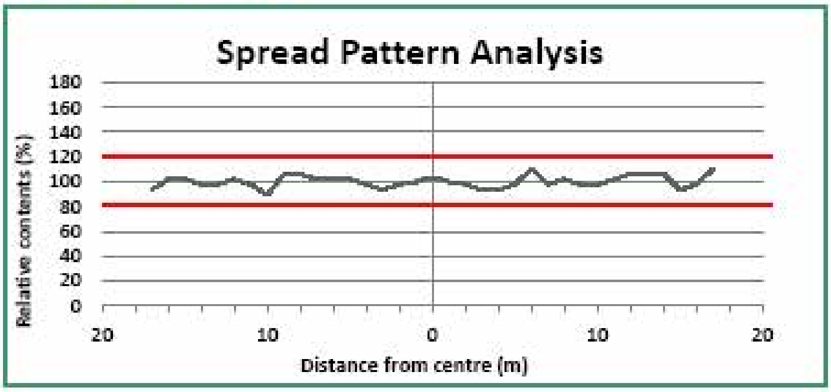
Tray Test

General Data		Certificate No.	1
Spread Width	36m	**Date Tested**	2013-10-29
Spreader	Kuhn Axis 30.1A	**Rate Setting Type**	Electronic
Disc/Vane Type	S8 VXR	**Application Rate**	200 Kg/ha
Spread Setting	4.5	**Forward Speed**	10 Km/h
Border Setting		**Wind Speed**	Force 0-1
PTO (RPM)	540	**Wind Direction**	Behind tractor
Height from bottom of frame	50cm Tilt 0°	**Crop/Ground Cover**	Stubble

Fertiliser Data

Fertiliser Type	Sirius Minerals Polyhalite 36m					
Density (Kg/L)	1.12		**Batch No.**	1		
Strength (Kg/Force)	0.5	0.75	0.25	1	0.75	**Av.**
	1.25	1.5	0.75	1.25	0.75	0.88

Test Data - Normal Field Test



Co efficient of Variation measures the accuracy of the spread pattern. A figure below 10% is acceptable, between 10% and 20% is not ideal, and above 20% is unacceptable. The spread pattern analysis graph shows the tube contents with the red lines denoting plus or minus 20% of the average relative content.

C of V (%)	4.75

Comment on Initial tests?	
Final Spread Pattern Acceptable?	Yes
Comments on Spread Pattern:	Good pattern. Only 2-3m of overlap.

Spreader & Sprayer Testing Ltd
Rookery Farm, Wheaton Aston
Stafford, Staffordshire
ST19 9QF
T: 0845 130 7175
F: 0845 130 7176
info@spreadcheck.com
www.spreadcheck.com

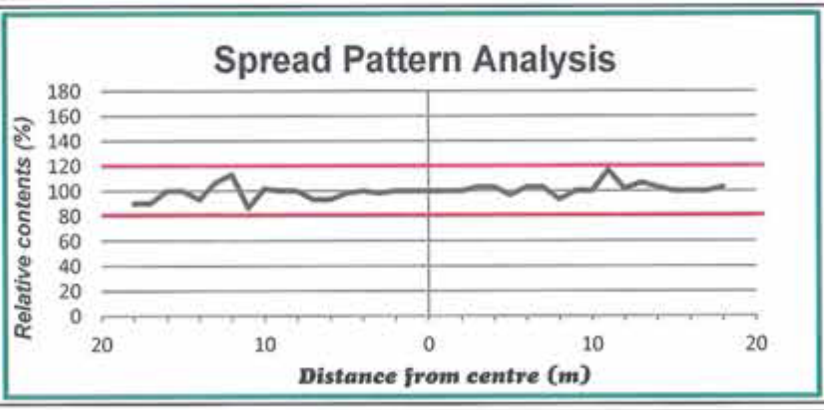
Tray Test

General Data		Certificate No.	York Potash
Spread Width	36m	**Date Tested**	2013-12-17
Spreader	Kuhn Axis 30.1	**Rate Setting Type**	Electronic
Disc/Vane Type	S8	**Application Rate**	250 Kg/ha
Spread Setting	6.5	**Forward Speed**	12 Km/h
Border Setting	N/A	**Wind Speed**	Force 0
PTO speed	600	**Wind Direction**	N/A
Height from side of disc	50/56cm **Tilt** +3°	**Crop/Ground Cover**	Stubble

Fertiliser Data

Fertiliser Type	York Potash 20-10-10					
Density (Kg/L)	0.89		**Batch No.**	Hand mix		
Strength (Kg/Force)	5	6	6.25	3.5	10	**Av.**
	7	4	5.5	6	8	6.25

Test Data - #N/A



Co efficient of Variation measures the accuracy of the spread pattern. A figure below 10% is acceptable, between 10% and 20% is not ideal, and above 20% is unacceptable. The spread pattern analysis graph shows the tube contents with the red lines denoting plus or minus 20% of the average relative content.

C of V (%)	5.52

Comment on Initial tests?	
Final Spread Pattern Acceptable?	Yes
Comments on Spread Pattern:	Acceptable pattern but not enough red MOP going past 12m and a tendency to heap at wider widths

APPENDIX III: Poly 4 Granular Product Specification Sheet

PRODUCT SPECIFICATION SHEET

SIRIUS
MINERALS PLC

Product Specifications / Effective 1 May 2013 / Location United Kingdom

POLY4
A Sirius Minerals Product

GRANULAR

DESCRIPTION

Product	POLY4 — A multi-nutrient mineral: Polyhalite — $K_2SO_4.MgSO_4.2CaSO_4.2H_2O$
Manufacturer	Sirius Minerals PLC
Applications	POLY 4 can be used for direct application and to produce fertilizers where a multi-nutrient is required. Organic compound producers can also use it as a source of essentially chloride-free potassium.

CHEMICAL ANALYSIS[1]

Component/Equivalent	Units	Typical Quantity
Potassium	K_2O%	14.06
Sulphur	SO_3%	47.80
Magnesium	MgO%	6.02
Calcium	CaO%	16.74
Trace Elements		
Magnesite	$MgCO_3$%	3.0
Anhydrite	$CaSO_4$%	3.34
Halite	NaCl%	3.07
Boron	B ppm	300

[1] Analysis of 93% polyhalite

PHYSICAL ANALYSIS

Parameter	Units	Description
Colour	–	Grey, Grey White or White Solid
Solubility	–	Slow release soluble in water
Particle Size[2]	mm	2–4 (95%)

[2] Also available as powder

Converting Oxide to Elemental Form			
K_2O – Multiply by 0.83	SO_3 – Multiply by 0.4	CaO – Multiply by 0.72	MgO – Multiply by 0.60

T: +44 1723 470 010
E: commercial@siriusminerals.com
7–10 Manor Court, Manor Garth, Scarborough YO11 3TU, UK
Registered Address- 3rd Floor Greener House, 66-68 Haymarket, London SW1Y 4RF, UK
Company Registered Number: [illegible]

SIRIUS
MINERALS PLC

APPENDIX 4

THE FOOD AND ENVIRONMENT RESEARCH AGENCY (FERA)

Future Need and Role of Potash in UK Food Production

Final Report to York Potash

June 2012

Kate Somerwill*, Sarah Hugo*, Dr Andrew Crowe*, Dr Nigel Boatman*, Dr Andrew Hart*, Ruth Laybourn*, Dr Alistair Murray*, Dr Stephane Pietravalle*, & Dr Ian Richards†

* Food and Environment Research Agency, Sand Hutton, York

† Ecopt, Bredfield, Suffolk

Contents

Contact:	Kate Somerwill	**Tel No:**	01904 462 417	**Email:**	Kate.somerwill@fera.gsi.gov.uk
Approved By:	Sarah Hugo	**Date:**	31/05/2012		

Executive Summary

1. This report was commissioned to look at the current use of potash in UK agriculture and to establish a baseline for use when projecting potash demand in to the future. Additionally, it was decided that evidence relating to the York Potash manifesto needed referencing in order to produce a more robust document.

2. Published evidence relating to statements in the York Potash Manifesto is assessed and the degree to which these statements are supported is considered. Current potash use and crop requirements in the UK are discussed before looking at the current state of UK agriculture.

3. In general the published evidence supports the statements in the York Potash Manifesto.

4. Fertiliser potash is used extensively in the UK on tillage crops and grassland although its use has decreased in recent years. Evidence suggests that this decrease is causing potassium reserves in UK soils to fall and this will have to be replenished to maintain high yields.

5. The most common form of potash used is muriate of potash (potassium chloride, MOP) although sulphate of potash (potassium sulphate, SOP) is beneficial for some high value crops, as it contains sulphur.

6. Of the 6 million ha of croppable land, 50% of the area is devoted to cereal production with almost two thirds of this being wheat. The area of grassland is double that of croppable land. The majority of holdings in the UK are under 20ha in area with “grazing” being the most common farm type.

7. Of UK arable crops, potatoes and celery have the highest required rates of potash application. However, due to their much greater areas, grass and cereals account for most of the fertiliser potash applied. The future areas of cereals, potatoes and grassland will have a large influence on the future potash requirements of the UK.

8. In order to assess what the potash requirements of the UK may be in the future, recent research was scanned for forward-looking agricultural scenarios from which potash requirements might be derived.

9. Forty four groups of scenarios were identified and assessed using 13 selection criteria. This reduced the number of appropriate scenarios down to those originating from the National Ecosystem Assessment (NEA 2011).

10. In the National Ecosystem Assessment, six scenarios were created for each of two climate change predictions to assess how ecosystem services (services provided by ecosystems that benefit human life and associated quality of life) may alter under different futures. The project was part funded by Defra and ran from 2009 to 2011. Quantitative predictions of crop areas in future scenarios were produced.

11. The NEA scenarios do not that suit the requirements of this project exactly. However, despite some issues related to the methodology of the study, it represents the best available scenarios to assess what the UK's future potash requirements may be.

12. From the literature review several possible impact factors were identified and a question for each one was produced. These questions aimed to assess the severity of any potential impacts and were addressed by groups (or individuals, where appropriate) of experts at Fera and Ecopt. After each question, the expert group was asked to assess how certain they were of their answer. It was assumed that fertiliser potash supplies disappear in 2012 and the expert groups assessed the effect of this, on these scenarios (including the baseline scenario) to 2060.

13. It has been assumed that no alternatives, that could completely replace fertiliser potash, are available. It has also been estimated that yields would start to be affected within 3 years to several decades of the loss of fertiliser potash, depending upon soil type, climate, cropping and management practices.

14. The predicted results show expected increases in the effects of drought stress and pest and disease stress and a decrease in nitrogen uptake. Overall, decreases in yields and quality of crops are predicted and this would need to be addressed by an increase in food imports. These predicted yield decreases are expected to worsen under high climate change as is the UKs ability to source food from abroad.

15. Overall, the analysis indicates, that a lack of fertiliser potash would have a serious and negative impact on crop yields that would need to be accounted for by increasing food imports. This may not be a sustainable way for the UK to ensure its future food security due to the increased reliance on foreign trade links and production, and the vulnerability to increasing food prices. However, it should be remembered that if new techniques to improve recycling of potassium were developed, the impacts predicted here would be much reduced.

1. Introduction

This report was commissioned to look at the current use of potash in UK agriculture and to establish a baseline for use when projecting potash demand in to the future. Additionally, it was decided that evidence relating to the York Potash manifesto needed referencing in order to produce a more robust document. Published evidence relating to statements in the York Potash Manifesto is assessed and the degree to which these statements are supported is considered. Current potash use and crop requirements in the UK are discussed before looking at the current state of UK agriculture.

In order to assess what the potash requirements of the UK may be in the future, recent research was scanned for forward-looking agricultural scenarios from which potash requirements might be derived. Finally, knowledge collated during the literature review section was used to assess these agricultural scenarios to predict the future need of potash in UK agriculture. The final output is a high level assessment of the potential impacts on agriculture of a future scenario where potash is not available to UK growers.

2. Literature Review of Current Potash Use

2.1. Introduction

Potassium (K) is an essential nutrient of plants and plays a central role in several vital functions such as protein transport, enzyme activation and carbohydrate production amongst others (Britto & Kronzucker 2008, Kinpara 2003, Huffman 1982). Potassium is taken up by plants in ionic form (K^+) but in agricultural industries is expressed conventionally in oxide form (K_2O) commonly called potash. For example, the concentration in muriate of potash is declared as 60% K_2O even though the material is potassium chloride.

The main sources of K for agricultural crops in the UK are inorganic potash fertilisers (BSFP 2010) and, in grassland areas, livestock manures. Potash is mined across the world with commercial mining starting in 1861 in Germany (Darst 1991). World fertiliser potash consumption in 2009 was 21.5 million tonnes K_2O (FAO 2012).

Muriate of potash (MOP, potassium chloride) is the most widely available, cheapest form of potash fertiliser. Sulphate of potash (SOP) is more expensive but can be beneficial for some high value crops (Defra 2010a, Marchand & Bourrie 1999, QianXin *et al*. 1999) that require sulphur as well as potassium for optimum growth. Outside the UK, in dry regions, MOP can cause chloride accumulation in some soils which can cause leaf death and yield decline (Kafkafi *et al.* 2001), and so is not suitable for chloride sensitive crops (Sajjad *et al.* 2005). With the UK's high rainfalls, this accumulation does not occur due to high rates of chloride leaching.

In 2010 in the UK 47% of the cropped area received fertiliser potash with an overall application rate (the average application rate across the cropped area) of 25kg K_2O/ha (BSFP 2010). Potash fertilisation in the UK aims to maintain available soil K at levels that produce optimum yields (see section 2.5 for details). In West Europe[1] there is an annual surplus of potash of around 2 million tonnes, although this has been predicted to decrease over the coming years (FAO 2011).

---

[1] FAO defines West Europe as Austria, Belgium. Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom. (FAO 2011)

Not only does potash increase crop yields, it also has other less obvious benefits. Potash has been shown to improve the quality of fruits, vegetables and cereals (Lester *et al.* 2010, Ahmad *et al.* 1984) and to increase plant resistance to biotic (e.g. disease) and abiotic (drought, salinization, extreme temperatures) stresses (Amtmann *et al.* 2008, Cakmak 2007, Romheld & Kirkby 2010). This raised stress tolerance could be of increasing importance in the light of climate change in the UK.

In this review we consider published evidence relating to statements in the York Potash Manifesto regarding the benefits of potash, and assess the degree to which these statements are supported by the literature. We then look at the current use of potash in the UK and the potash requirements of UK crops (both current and future). Finally, K depletion in soils is considered.

The information gathered in this document will be used to create a baseline that will allow exploration of the use of fertiliser potash under different future scenarios. It will also highlight which crops are likely to have a larger impact on future potash demand and pick-up on any secondary effects of potash, the importance of which may increase in future scenarios (e.g. tolerance to biotic and abiotic stresses).

2.2. Evidence list, detailing source and content of all evidence relating to the York Potash Manifesto

The York Potash Manifesto was assessed and statements related to agricultural potash use, that would benefit from supporting evidence, were extracted. These are detailed below with the page number of the manifesto to which they relate.

- Yields – "Farmers use potash….to maintain good crop yields and strong harvests." Potash is needed to maintain high crop yields (pg 4)
- Quality and efficiency – "Sustaining increased livestock herds requires greater efficiency from grass and arable land and this requires farmers to use more potash to increase yields" (pg 4)
- Arable land area – "Advent of biofuel technology… increasingly less arable land available for food supply." (pg 4)
- Diets – "people demand more protein rich diets" (pg 4)
- Substitutes – Potash has no commercial substitute (pg 4)
- Green energy – "Green energy crops also require potash" (pg 4)
- Food security – "The world therefore requires higher-yielding crops to maintain both quality of life and to prevent food shortage….Potash is essential in order to enable this to happen." (pg 5)

Evidence relevant to the agricultural sections of the York Potash Manifesto is detailed in Table 2.1. These are divided into evidence for and against the statements made: the findings are discussed below. The literature review was targeted at Defra reports and publications of the International Potash Institute and the Potash Development Association, plus a structured Web of Science search. The search process and terms used in the data trawl are detailed in Appendix A. Despite extensive searching a relatively low number of references were found that were suitable for use in this report (see reference list and Table 2.1).

2.2.1. Yield, Efficiency and Quality:

A few studies referenced here show no increase in yield with increased potash application (possibly due to high levels of available K already present in soils); however these were far outweighed by the number of studies that found an increase in yield with increased potash use and so support the Manifesto (see Table 2.1 for references). In terms of quality, the review document by Lester *et al.* (2010) is particularly useful; of all published materials found during the 2010 review, over 85% showed an increase in crop quality for vegetables and fruit correlated with increased potash application. This trend is also seen in cereal crops (Ahmad & Rahman 1984).

2.2.2. Green Energy and Arable Land Area

Two green energy crops are commonly grown in the UK: miscanthus and willow. The potash requirements of both are detailed in the Fertiliser Manual published by Defra (Defra 2010a). Further details of these requirements are given in section 2.4 as are the potash requirements for oilseed rape (grown, in part, for biodiesel) and cereal crops/sugar beet (grown, in part, for bioethanol). There is also evidence to support the statement that land used for growing food has been switched to biofuel production. The proportion of crop area contributing to biofuel and bio-energy production in the UK is relatively small at the moment (Renewable Fuels Agency. 2011). Whether this value increases or not depends on several factors including EU and UK policy (incentives for growing bio-energy crops) and market prices of food and biofuel crops (Sherrington & Moran 2010).

2.2.3. Diets and Food Security

All references sourced, show that in developing countries, diets are likely to change and will have an increasing demand for meat products. Additionally, in order to increase crop yields in these countries, fertiliser applications will need to be increased. Many developing countries currently have K deficits in soils which will need to be addressed in order to increase yields and help to secure global food security.

Table 2.1. Evidence list of documents relevant to the agricultural sections of the York Potash Manifesto.

Link to York Potash Manifesto	Relevant Content	Reference	For / Against
Yield, quality and efficiency	Increased yield seen with increased potash application. Increased quality of wheat grains with potash use.	Ahmad, I. & Rahman, S. 1984. Yield, protein and amino acid composition of wheat grain (*Triticum aestivum*) as influenced by potash fertilizer. *Pakistan Journal of Agricultural Research*. 5: 2, 96 - 101.	For
Yield, quality and efficiency and Food security	A lack of potassium in soils can lead to decreases in yields. Potassium depletion in many developing countries leads to low yields.	Cakmak, I. 2010. Potassium for better crop production and quality. *Plant Soil*. **335**, 1 - 2.	For
Yield, quality and efficiency	Increase in yield up to 60ppm of plant available potash, however no increase after 100ppm available potash	Chen, M. L. & Zhou, X. D. 1982. Effect of potash fertilizer on the yield of rapeseed. *Zhejiang Agricultural Science (Zhejiang Nongye Kexue*). 6, 312 - 315.	Mixed
Yield, quality and efficiency and substitutes	Potassium is needed to gain maximum yields. Potash varieties are the most common source of potassium in agriculture with other potassium sources being locally important.	Cooke, G. W. 1975. *Fertlizing for Maximum Yield*. Granada Publishing Limited.	For
Yield, quality and efficiency and green energy	Yield may decrease with low potash levels in soils. Potash requirements of miscanthus and willow.	Defra 2010a. *The Fertiliser Manual – 8th Edition.* The Stationary Office.	For
Yield, quality and efficiency	Yields increased with increased potash use	Fauconnier, D. 1976. An experiment with application of potash fertilizers. *Revista de Agricultura, Piracicaba, Brazil*. 51: 1, 17 - 21.	For
Yield, quality and efficiency	Onion yield increased with potash fertiliser	Geetha, K., Raju, A. S., Rao, P. C. & Reddy, M. S. 2000. Effect of individual and combined application of FYM and potash fertilizer on yield and potash nutrition of onion in Alfisol. *Journal of Research ANGRAU*. 29: 4, 34 - 39.	For
Yield, quality and efficiency	There is an increase in yield depending on the potassium requirements of the crop and the level of available potassium in the soil	Johnston, A. E. & Krauss, A. 1999. The essential role of potassium in diverse cropping systems: future research needs and benefits. 16th World Congress of Soil Science, Motpellier, France, 20 - 26 August 1998. pg 101 - 120.	For
Yield, quality and efficiency	If soil available K is low, applying potash will improve yields for arable crops and grass.	Johnston, A. E. 2007. Potassium, magnesium and soil fertility: long term experimental evidence. *Proceedings No. 613, The International Fertiliser Society, Leek.*	For

Link to York Potash Manifesto	Relevant Content	Reference	For / Against
Yield, quality and efficiency	With potassium fertilization a small increase in yield was seen	Mohr, R. M., Grant, C. A., May, W. E. & Stevenson, F. C. 2007. The influence of nitrogen, phosphorus and potash fertilizer application on oat yield and quality	For
Yield, quality and efficiency	Fertiliser treatments that were balanced to include all major nutrients (N, P, K) increased yield	ShuYun, L., ShuTing, D., BingQiang, Z., XiuYing, L & Zhenzhan, Z. 2007. Effects of long-term fertilization on activities of key enzymes related to nitrogen metabolism of maize leaf. *Acta Agronomica Sinica*. 33: 2, 278 - 283.	For
Yield, quality and efficiency	No significant increase in maize yield with increased potash use. However, no measure of initial potassium concentrations in test soils was carried out, and results suggest the crop was limited by nitrogen availability rather than potassium.	Srinivas, P. S. & Panwar, V. P. S. 2003. Combined effects of intercropping maize with pulses and potash fertilizer on stem borer, *Chilo partellus*. *Annals of Agricultural Research*. 3, 461 - 465.	Against
Yield, quality and efficiency	There was no significant change in yield with addition of potash fertiliser although levels of available potassium in test soils were already high.	Wankhade, R. S., Choudhari, M. H. & Jadhao, B. H. 1996. Effect of graded doses of phosphorus and potash fertilizers on growth and yield of garlic. *Journal of Soils and Crops*. 6: 1, 36 - 39.	Against
Yield, quality and efficiency	Increased yield was seen in the 9th and 10th year of the study at one site. However, withholding potash did not reduce the yield over an 8 year period in limestone soil.	Withers, P. J. A., Unwin, R. J., Grylls, J. P. & Kane, R. 1994. Effects of withholding phosphate and potash fertilizer on grain yield of cereals and on plant - available phosphorus and potassium in calcareous soils. *European Journal of Agronomy*. 3: 1, 1 - 8.	Mixed
Yield, efficiency and quality	Increased yield was seen with increased potash applications. Increased quality with potash use: Decreased arsenic and lead (chinese cabbage) and chromium and lead (lettuce) were seen with potash fertiliser use.	XiaoJing, W., ZhengYin, W., Huan, Z., Fang, L., YanXia, C., HuaHui, X. & Rong, L. 2011. Effects of potash fertilizer on yields, contents of heavy metals and nitrate in chinese cabbage and lettuce. *China Vegetables.* 10, 64 - 68.	For
Yield, efficiency and quality.	Increased yield with potash applications. Increased quality with potash use: increased protein and ascorbic acid content.	ZhenYun S., Jian, S., Feng, Y. & DeJun, W. 2004. Effects of potash fertilizer on increase of yield, and improvement of quality of cauliflower. *Soils and Fertilizers*. 4, 17 - 19.	For
Yield, quality and efficiency and food security	Geographic variation in response to potash fertilisation	Thiyagarajan, T. M., Backiyavathy, M. R. & Savithri, P. 2003. Nutrient management for pulses - a review.	Mixed

Link to York Potash Manifesto	Relevant Content	Reference	For / Against
Yield, efficiency, food security and quality	Potential link between yield declines and potassium deficiency in India. So many separate reports on potassium fertilisation raising crop quality, that research should now focus on communicating this to farmers and increasing potassium uptake efficiency.	Romheld, V. & Kirkby, E. A. 2010. Research on potassium in agriculture: needs and prospects. *Plant Soil*. **335**, 155 - 180.	For
Quality and efficiency	Potassium increases quality of fruit and vegetables	Lester, G. E., Jifon, J. L. & Makus, D. 2010. Impact of potassium nutrition on food quality of fruits and vegetables: a condensed and concise review of the literature. *Better Crops*. **94**, 18 – 21.	For
Arable land area	UK cropped area has remained relatively constant over recent years, with 3% of the available arable land not cropped in 2011. Oilseed rape (grown for several purposes, one of which is biofuel production) has increased in area from 404,000 ha (2000) to 742,000 ha (2011) See Figure 2.1 for cropping trends from 1984 onwards.	Defra stats. 2011. UK timeseries: 1984 - 2011. http://www.defra.gov.uk/statistics/foodfarm/landuselivestock/junesurvey/junesurveyresults/	Mixed
Arable land area	54% of all biofuels used in UK (including imports) come from land previously classed as "Cropland".	Department for Transport (2011). Biofuels statistics quarterly year to April 2011. http://www.dft.gov.uk	For
Arable land area	Land formerly used in food production is switched to biofuel development in Brazil. However, it is not clear if this trend will continue in the long-term.	Rathmann, R., Szklo, A. & Schaeffer, R. 2009. Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate. *Renewable Energy*. 35: 1, 14 - 22.	For
Arable land area	An estimated 5.1% of oilseed rape, 8.4% of sugar beet and <0.1% of wheat in the UK is used to supply biofuels	Renewable Fuels Agency. 2011. Year Two of the RTFO. http://www.renewablefuelsagency.gov.uk/.	For
Diets	There is likely to be increased demand for meat products in developing countries	Herrero, M. & Thomton, P. K. 2010. Mixed crop livestock systems in the developing world: present and future. Advances in Animal Biosciences. 1, 481 - 482.	For
Diets	Increasing urbanisation leads to an increase in demand for protein from meat. This trend has been seen in several developing countries in recent years	Kearney, J. 2010. Food consumption trends and drivers. Phil. Trans. R. Soc. B. 365, 2793 - 2807.	For

Link to York Potash Manifesto	Relevant Content	Reference	For / Against
Substitutes	Potential to use wood ash as a source of potassium in recycled fertilisers in Norway.	Haraldsen, T. K., Brod, E. M. & Krogstad, T. 2012. Quality requirements for wood ash as a K component in recycled NPK fertilizers. Ash 2012, Stockholm, Sweden January 25 - 27.	For
Substitutes and food security	Farmers excluded from commercial markets (usually in developing countries) could use potassium silicate rocks as an alternative potassium source. Potassium deficits in soils across much of Africa.	Manning, D. A. C. 2010. Mineral sources of potassium for plant nutrition. A review. *Agronomy for Sustainable Development*. **30: 2**, 281 - 294.	For
Substitutes	Commercial brands of organic fertiliser outperform mineral fertilisers although the difference is not significant	Zahradnik, A. & Petrikova, K. 2007. Effect of alternative organic fertilizers in the nutritional value and yield of head cabbage. *Zahradnictvi (Horticultural Science)*. **34: 2**, 65 – 71.	Against
Substitutes	Treatments with potassium rock and rock solubilising bacteria increased yields by 30% (although no reference to how this compares to commercial fertilisers)	HyoShim, JaeSung & KyungDong. 2006. Rock phosphate and rock-solubilising bacteria as alternative, sustainable fertilizers. *Agronomy for Sustainable Development*. **26: 4**, 233 – 240.	Mixed
Substitutes	Highest yields in banana were obtained with a combination of cement kiln flue dust, distillery effluent and commercial potassium.	Jeyabaskaran, K. J., Pandey, S. D. & Gomadhi, G. 2003. Effect of potassium-rich cement kiln fine dust and distillery effluent as substitute for potassium fertilizer on growth, yield and quality of ‘Ney Poovan’ banana.	For
Substitutes	Highest yield seen with commercial fertilisers or a mix of commercial and manure.	Merzlaya, G. E., Afanas’ev, R. A., Efrmmov, V. F., Nesterovich, I. A., Agrokhimiya, A. A. & Krivova, L. S. 1993. Agroecological evaluation of traditional and alternative fertilizer application systems in a fodder crop on cultivated dernopodzolic soil. *Agrokhimiya*. **11,** 60 – 67.	For
Food security	Increased fertiliser use in developing countries could increase yields and help to secure future food production	Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M. & Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. *Science*. **327: 5967**, 812 - 818.	For

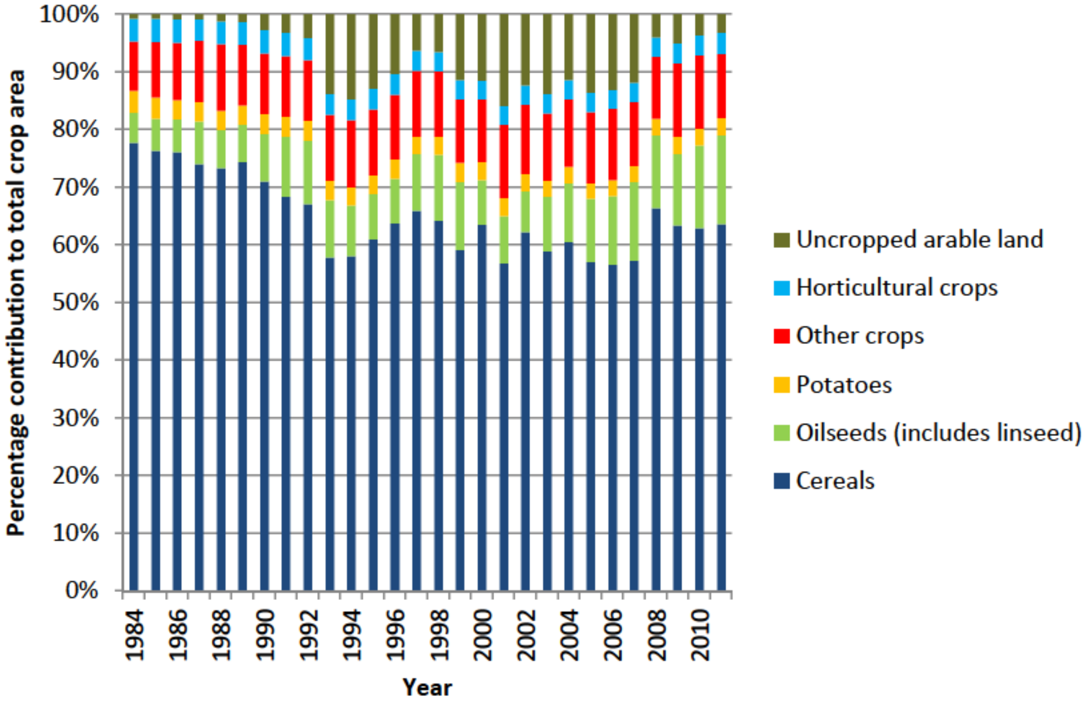


Figure 2.1. Cropping patterns for the UK from 1984 to 2011. The decrease in uncropped arable land between 2008 and 2009 is probably caused by the ending of set-aside in 2008. Values taken from Defra report 'UK timeseries: 1984 – 2011' (Defra stats, 2011).

2.2.4. Substitutes

Potassium is an essential crop nutrient for which there is no substitute. However, there are materials other than manufactured fertilisers that contain potash and that can be applied to soil to increase the supply to crops. The most important of these are livestock manures. In areas where there are large livestock populations, much of the total requirement for applied potash can be met, in principle, by manures. In practice, manures are not applied efficiently but are over-applied on some fields and under-applied on others. The nutrient concentration in manures is relatively low (Defra 2010a) making transport uneconomic and further restricting the efficiency of use. In the UK for example, livestock manures are produced mainly in the west but are not transported to the mainly arable east.

Alternative sources of potash include composts, anaerobic digestate, ashes and some industrial wastes. There is very little potash in sewage sludge and derived products (Defra 2010a). The amounts of potash applied to land in these materials are small relative to those in fertilisers and manures, but are growing. Around 2 million tonnes of compost were produced in the UK in 2005/06 and the volume has been increasing by 20% annually. Anaerobic digestion is being promoted by government and the volume of digestate suitable for land application will grow. Greenwaste compost contains around 5.5 kg K_2O/t and food waste compost around 8 kg/t (Defra 2010a). Anaerobic digestate contains around 2 kg K_2O/t (WRAP 2011). The potash in manures and organic wastes is largely in water-soluble form so is readily available to crops and equivalent to fertiliser potash.

In the UK, around 670,000t poultry litter are burned annually to generate electricity and ash that is used as a fertiliser (Fibrophos web site). Poultry litter ash also is imported from the Netherlands (Cropkare web site). The ash contains typically 12% K_2O in forms somewhat less readily available than that in fertiliser potash.

Even allowing for growth in volume, these alternative materials will contribute a minor proportion of the potash required for UK agriculture. More efficient use of livestock manures will have some impact but a substantial requirement for fertiliser potash will remain for the foreseeable future.

Manufactured fertilisers based on mined material represent the only source of ‘new' potash. The alternative materials recycle potash. In future, efficient recycling of nutrients is likely to be emphasised but mined potash will remain essential to replace inevitable losses of available potash from soils and to deal with inefficient recycling.

2.2.5. Conclusions

In general the statements made in the York Potash Manifesto are supported by evidence from published literature. Potash (both MOP and SOP) increases crop yield and crop quality in most cases. Arable land is being used to produce energy crops at the expense of food production, although in the UK this is not at large scale and the future trends are unclear. In developing countries diets are becoming more meat rich and are increasing the demand for meat products. Additionally, reported K deficits in many countries could be limiting current yields. Correcting these deficits could increase crop yields and so increase global food security.

Some alternative sources of potash suitable for land application are commercially available for small markets or for areas where access to global markets is not possible. These include bulky organic materials like composts that can not be transported long distances economically. Others, like ashes, are produced in relatively small amounts at present. Together, these alternative sources make a minor contribution to applied potash requirements. This might change in future but there will remain a substantial requirement for manufactured potash fertilisers for the foreseeable future.

On the whole, this part of the research has identified evidence that supports the statements made in the York Potash Manifesto. A list of the key references for each statement is shown below.

- Yields -- Romheld & Kirkby 2010, Johnston 2007
- Quality and efficiency ------------------------------ Lester *et al.* 2010
Romheld & Kirkby 2010
- Arable land area ------------------------------------ Renewable Fuels Agency 2011, Department for Transport 2011
- Diets --- Kearney 2010
- Substitutes --- See Table 1
- Green energy -- Defra 2010a
- Food security --------------------------------------- Romheld & Kirkby 2010

2.3. Current potash use in UK agriculture

In Scotland, England and Wales the annual British Survey of Fertiliser Practice (BSFP) quantifies the average use of fertilisers on agricultural crops and grass across the region. This survey provides a detailed breakdown of the fertiliser usage on different crops and has produced a time series showing the trend in potash use (kg K_2O/ha) from 1983 to present.

In Northern Ireland trade and production statistics are used to produce a general guide to the amount of fertilisers used (http://www.dardni.gov.uk/agricultural-statistics-ferts). A survey similar to that in Britain is not carried out, as such any statistics which cover the UK as a whole are based on the amount of fertiliser produced and sold to the agricultural industry. They do not take account of the area of crop that is treated and do not show the amount of fertiliser used on each crop type. For this reason, we are choosing to use the findings of the BSFP as the most complete record of current potash use.

The long-term trend in potash use in Britain shows a steady decline from 1983 onwards (BSFP 2010). On tillage crops[2], a five year average shows a decrease in overall rate of application (defined as the total amount of K_2O applied divided by the total area of the crop) from an average of 64kg K_2O/ha in 1983 – 1987 to 42kg K_2O/ha in 2006 – 2010 (Figure 2.1). On grassland, the average rate of K_2O application has also decreased, with a relatively stable period in the 1980s (31 - 33kg/ha) before dropping off through the 1990s onwards (Figure 2.2) to 14kg K_2O/ha in 2010.

The downward trend in potash use can also be seen in individual tillage crops with winter wheat, winter and spring barley, oilseed rape, maincrop potatoes and sugar beet seeing declining usage from 1983 to 2010 (Table 2.2). In these crops, the average amounts of K_2O applied have been smaller than the amounts removed in harvested crops since the late 1990s (Johnston 2007).

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[2] BSFP defines tillage crops as "as all crops except grass, forestry, glasshouse crops and uncropped land designated as 'set-aside' under the Single Payment Scheme" (BSFP 2010).

Table 2.2. Overall potash usage on main tillage crops from 1983 to 2010 (given as five year average, kg K_2O/ha).

Crop	1983 - '87	1998 - 2002	2006 - '10
Winter Wheat	52	48	34
Spring Barley	47	55	49
Winter Barley	59	63	49
Oilseed Rape	57	46	33
Maincrop Potatoes	269	230	216
Sugar Beet	146	102	91

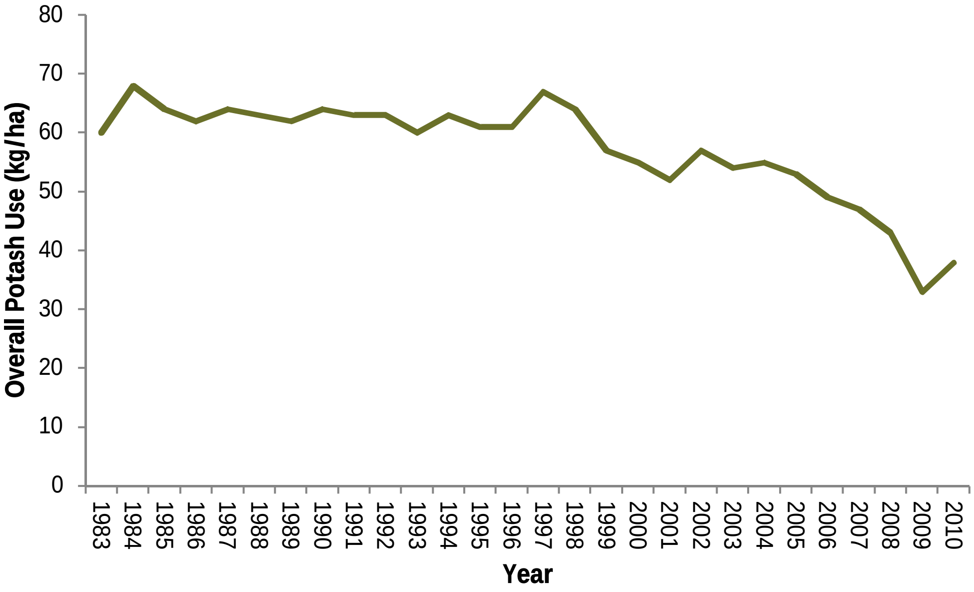
The lowest recorded usage of potash occurred in 2009 with an all-time low of 12kg/ha on grassland and 33kg/ha on tillage crops. Usage has increased in 2010 (to 14kg/ha and 38kg/ha respectively) but it is not clear if this will continue. According to the BSFP (2010), a reduction in the proportion of crop area receiving a potash treatment accounts for much of the long term decrease in overall usage.

A further indication of declining fertiliser potash use is in the trade statistics published by the Agricultural Industries Confederation (AIC 2011). These show total UK fertiliser K_2O consumption declined from 409,000t in 1999/00 to 251,000t in 2009/10.

There is concern that this decline in the use of potash is lowering the K reserves in soils and could cause declining yields in the future (BGS 2011, PDA 2007). An indication of this decline comes from the publications of the Professional Agricultural Analysis Group (PAAG) which show that 36% of soil samples analysed in the UK fall below the recommended soil threshold for optimum yields (PAAG 2011). Although these data should be interpreted critically (no formal sampling procedure is used to gather the soil samples which might not be representative of UK agricultural soils) they do at least give an indication of K levels in UK soils.

The low levels of fertiliser potash use are not sustainable in the long term if crop yields are to be maintained. Fertilizers Europe forecast a 15% increase in fertiliser K_2O consumption in the UK between 2011 and 2020 and a 30% increase in the EU27 (Fertilizers Europe 2011).

a)



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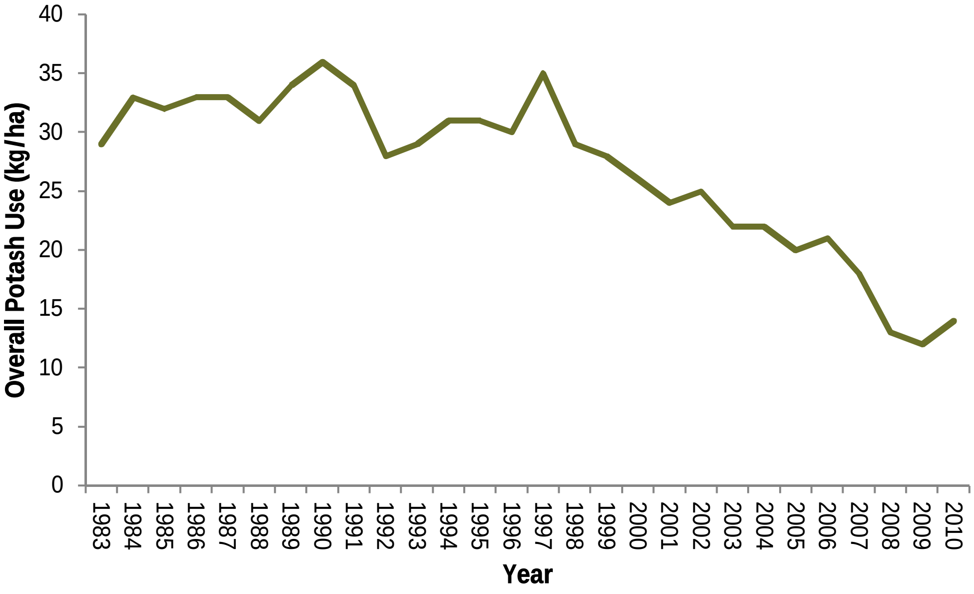

Figure 2.2. Overall potash use on a) tillage crops and b) grassland in Britain. Values taken from the British Survey of Fertiliser Practice, 2010

2.4. Potash requirements of UK grown crops (key crops currently and in the future)

As potassium is an essential nutrient, any deficiency in the amount of available soil potassium will affect crop yield and, in some cases, quality. With reduced growth the crops capacity to take up other nutrients will be restricted. This can leave readily available nitrogen in the soil at risk of leaching during the following winter. Most UK arable crops and grass achieve full growth when exchangeable soil K is 150 mg/l or greater, equivalent to K Index 2- (Defra 2010a). Some crops such as beans need somewhat more available soil K (Johnston 2007). Fertiliser potash is applied to ensure an adequate level of available soil K taking into account the crop to be grown, the yield expected and the soil K Index. The target soil K Index is 2- for UK arable crops and grassland and 2+ for vegetables. If the soil is at this Index, sufficient potash is applied to replace that in the harvested crop. If the Index is 0 or 1, more potash is applied to replace removal and to help increase the Index (Defra 2010a).

The applied potash requirements (kg K2O/ha) of current UK crops at target Index are shown in Figure 2.3. The majority of fruit and vegetables have large potash requirements when compared to cereal and forage crops and grassland. Potatoes and self-balancing celery have by far the greatest potash requirements however, the relative areas of each crop differ (in 2010 potatoes = 136,000 ha, and celery = 855 ha in 2007 (PUS 2007 - 2010)).

In terms of the amount of fertiliser potash applied (tonnes K2O), grass is by far the most important UK crop. The low rate of application (14 kg K2O/ha) is outweighed by the large area (6.3 million hectares) (BSFP 2010). Grass is followed by cereals and then potatoes (Figure 2.4).

The most common form of potash fertiliser is MOP however, as discussed earlier, certain crops benefit from the use of SOP due to chloride sensitivity (Defra 2010a, Sajjad et al. 2005) or the need for sulphur as well as potash. According to the Fertiliser Manual (Defra 2010a), where the amount needed exceeds 120 kg K2O/ha, SOP should be used for raspberries (1,573ha grown in 2010 (PUS 2010)), redcurrants (71ha grown of red and white currants in 2010 (PUS 2010)) and gooseberries (155ha grown in 2010 (PUS 2010)). SOP can also be used for potatoes grown for processing as it has a smaller effect on tuber dry-matter content than does MOP (Dickins et al. 1962). Additionally Qianxin et al. (1999) found an increased yield and quality in vegetable crops with applications of SOP compared to MOP. SOP contains sulphur as well as potash and would be useful for a wider range of crops and situations given a smaller price disadvantage against MOP.

With climate change and the prediction for warmer and wetter weather in the UK, it is possible that cultivation of some crops will become more economically viable in the UK because the changed conditions might suit them, or it may be possible to reduce inputs under future climates. In addition, some crops currently grown under glass may become suitable for field production, while other glasshouse-grown crops will require less energy to produce a viable yield. Increased availability of water might favour these crops. Climate change may also have the effect of making some of our staple crops less economic to produce.

Drier conditions during the growing season could affect potash requirement. Potassium in the soil solution moves towards the root by diffusion through soil water and by ‘mass transport’ (passive movement with the flow of water). Low soil moisture can therefore limit this movement and crop responses to applied potash might be greater in dry than in wetter conditions (Kuchenbach et al. 1986). Further reference to the potash requirements of future crops will be included in the impact assessment section of this project as the crops predicted to grow in the future will be dependent upon the scenario used. Additionally, green energy crops and bio-fuel crops may account for larger areas of cropped land.

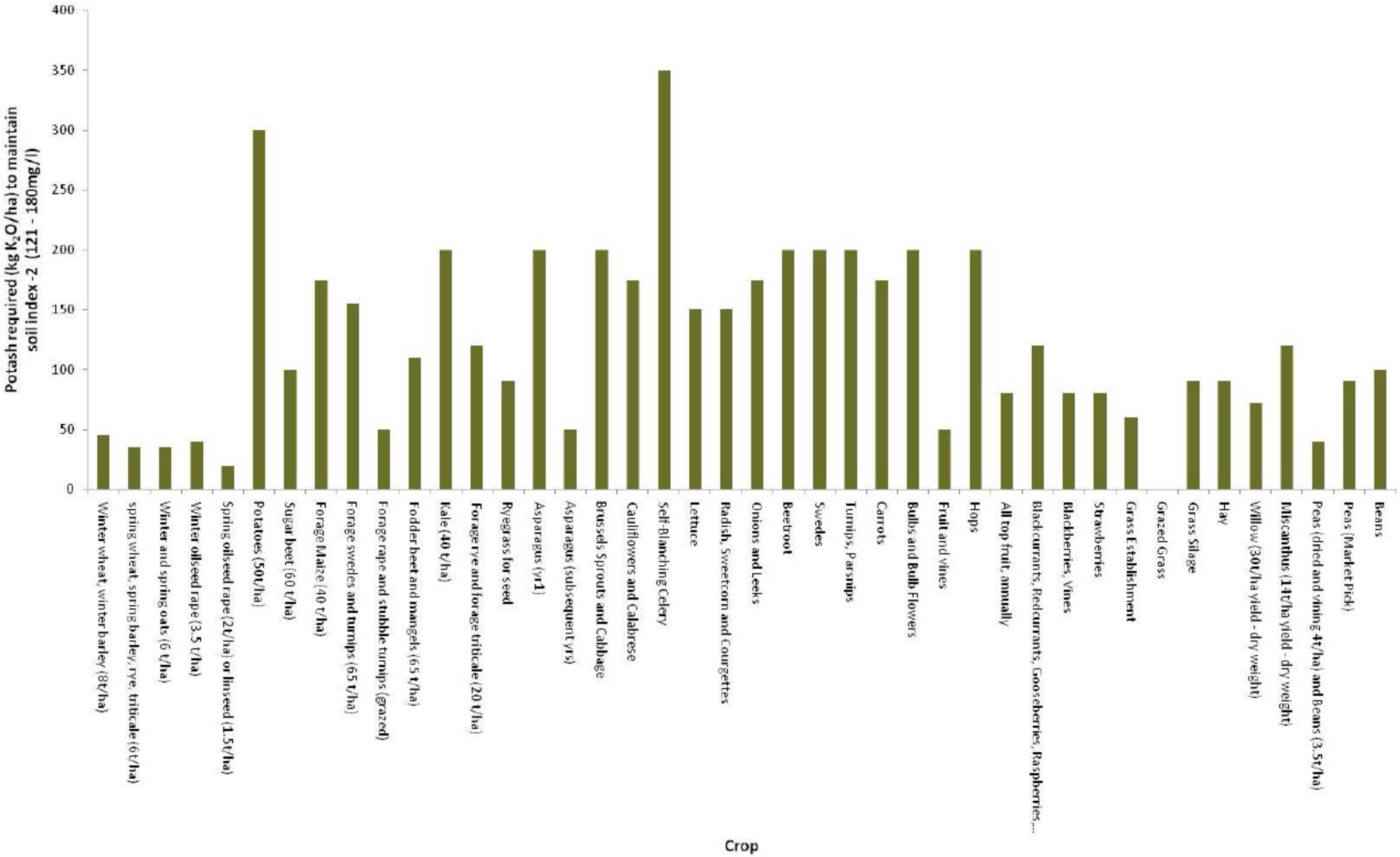

Figure 2.3. Overall potash requirements of UK crops to maintain soil Index 2- as defined as the target soil index in the Fertiliser Manual (Defra 2010a). For willow and miscanthus the value given relates to the amount of potash taken off in the given crop yields and relate to 2.4 kg/t and 8.5 kg/t respectively. For arable and forage crops the values relate to the given yield. Values taken from the Fertiliser Manual (Defra 2010a).

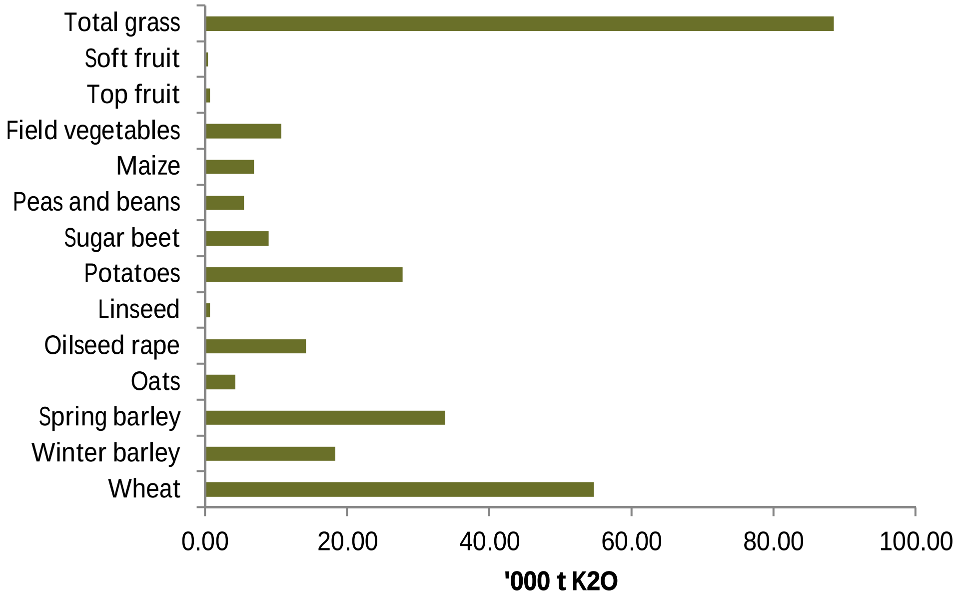

Figure 2.4. Fertiliser potash consumption by crop in Great Britain (2010). Values taken from BSFP 2010.

2.5. Nutrient depletion

Potassium is present in soils in four main forms: i) soil solution (immediately available K), ii) Exchangeable (readily available K), iii) Slowly-exchangeable K (slowly available) and iv) Structural K (very slowly available) (Romheld & Kirkby 2010, Graley 1981, Graley 1978). The first three pools are of most importance in terms of K uptake by plant roots, but the fourth pool does slowly replenish soil K when the structural K is released by weathering.

Fertiliser recommendations in Britain are aimed at maintaining the optimal concentration of available nutrients in the soil. For potash this is especially important as it moves slowly through soil to become available to crops. Once a negative crop growth effect is noticed, fresh applications of potash are unlikely to have any impact on crop growth and yield (Defra 2010a). Typically, crop yield, in K depleted soils increases rapidly with potash application and then slowly levels off to a point at which addition of extra potash has little or no effect on yields (Johnston & Krauss 1999). Maintaining soil K levels at this turning point produces high yields that would show little or no improvement with additional potash treatments. The Fertiliser Manual (Defra 2010a) recommends this value is reached at soil index 2- for arable crops and grass.

In agricultural soils, available K decreases due to removal in harvested crop, conversion to less available forms and, in some soils, leaching. The amount of potash removed at harvest varies with crop species from around 2 kg K_2O/t in some vegetables to 10-12 kg K_2O/t in cereals where straw is removed to 16 kg K_2O/t in peas (Defra 2010a).

Potassium can be lost from the soil by leaching though amounts are small except on sandy soils. Average leaching losses of around 1.2 kg K_2O/ha per 100 mm drainage have been reported for loams and clayey soils (Askegaard *et al*. 2004). In experiments in Denmark, leaching losses of 0.6 kg K_2O/ha and 8.4 kg K_2O/ha per 100 mm drainage were found for soils with 24% and 5% clay respectively (Askegaard *et al*. 2004).

Some heavy clay soils (excluding carboniferous clay) contain K that can be slowly released and made available to crops (Defra 2010a, Johnston 2007). On these soils, leaching of K does not occur unless excessive amounts are applied over a series of years (Cooke 1975). Both these factors mean these clay soils do not become depleted in K as quickly as other soils, although the amount of K provided by the soil may not meet the full requirements of the crop (Defra 2010a).

Crop management practices affect the rate of K depletion. James *et al.* (1975) found a decrease in soil available K with forage crops over a nine year study, but an increase with grain crops when only the grain was harvested and the stubble incorporated in to the soil.

Once depletion has occurred, crop yields suffer (Cakmak 2010, Defra 2010a). Withers *et al.* (1994) demonstrated a 50% decline in soil K levels in limestone and chalk soils over an 8 and 12 year period respectively. This corresponded to a decline in cereal yield at the chalk site in from year 9 onwards (although not at the limestone site, where the trial did not run for as long).

Depletion of available soil K occurs at differing rates depending on the crop type, K content of the crop yield, climate, and soil type (Defra 2010a). However, serious K depletion in most agricultural soils does not occur rapidly and Defra suggest that soils should be sampled every 4 – 5 years to ensure optimum K concentration is maintained (Defra 2010a). Although soils may be capable of storing / replenishing potash for a period, topical applications will be needed to maintain soils at the correct soil index and achieve optimum yields.

2.6. The current farming landscape in the UK

2.6.1. Nitrogen applications

Nitrogen is the most important nutrient driving crop yields in the UK. In 2009/10, slightly more than 1 million tonnes of N was applied to crops and grass. From 1983 to present, average fertiliser nitrogen application to tillage crops has been within the range 145 – 150kg N/ha (except for a decline in 1992-93 as a result of the introduction of set-aside). Grasslands receive a much lower average rate of application than tillage crops with an average rate of 121kg/ha from 1983 to 1999 and from 1999 onwards, application rates have declined to 63kg/ha in 2010 (BSFP 2010).

2.6.2. Pesticide usage

The Pesticide Usage Surveys carried out on a rotational basis across the UK are used to source all data regarding pesticide usage on crops. For details of reports please see http://www.fera.defra.gov.uk/scienceResearch/science/lus/pesticideUsageFullReports.cfm (PUS 2007 - 2011). Fungicides were the most common pesticide used in the UK in 2010. For wheat crops, 98.2% of land received a treatment at an average application rate of 0.3kg/ha. On grassland (in Great Britain) this average application rate ranges from 0.69kg/ha on new leys (with 25% of the area treated) to 1.39kg/ha on rough grazing (with 1% of the area treated). Seven percent of pasture grassland (the largest area of crop at 5.5 million ha) was treated and the average application rate was 0.89 kg/ha. On potatoes, the average application rate in the UK in 2010 was 0.52 kg/ha with just less than 100% of the crop treated.

2.6.3. Irrigation

The Defra 2010 Irrigation Survey (Defra 2010b) is used in this section to give an idea of total water usage in England. In 2010, 70 million m^3 of water were used for irrigation on 2,200 holdings on outdoor crops and grass equating to 83,000 ha. Main crop potatoes and vegetables account for 48% and 25% respectively of this total water usage (38% and 25% of total irrigated area). Grassland only accounted for 3% of total water usage for irrigation. In Scotland, Northern Ireland and Wales, similar surveys have not been carried out

2.6.4. Average national yields

All data in the following section was taken from the Defra report “Crop areas, yields and production, livestock populations and the size of the agricultural workforce” (Defra 2011). Information on yields of cereals and oilseeds is collected each year and presented in Figure 2.5. Wheat yields have shown the largest increase (1.7 t ha^{-1}) from 1987 to 2011 (7.7 t ha^{-1} in 2011) although they have remained fairly constant from the 1990s onwards. Oats have shown a similar pattern with increasing yields to the mid-1990s and a fairly constant trend since then. Oilseed rape yields have increased in recent years, whilst the yield of triticale has seen a decrease.

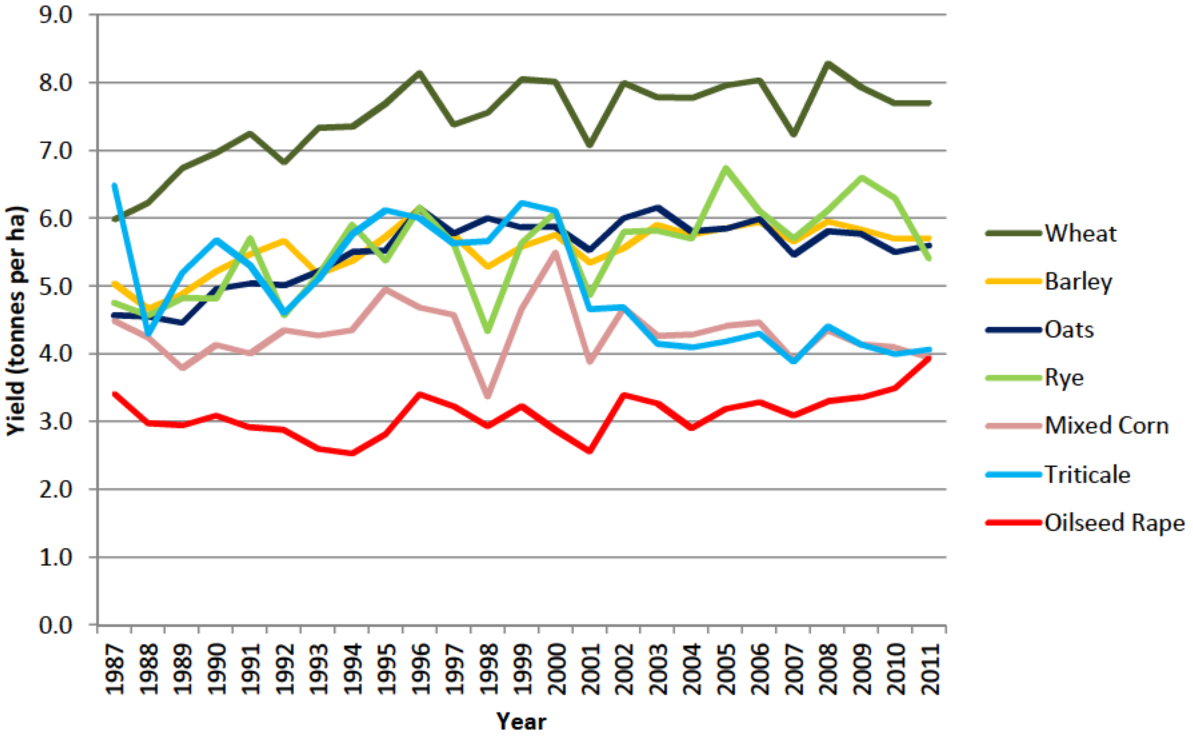

Figure 2.5. Average national yields for cereals and oilseeds from 1987 to 2011. Data sourced from Defra 2011.

2.6.5. Food security

In a 2008 report entitled “Ensuring the UK’s Food Security in a Changing World” (Defra 2008a), Defra stated that although the UK is currently food secure it is not (and is unlikely to ever be) self-sufficient. Global food supply is vital to the UK’s food security as good global trade links allows the UK to be resilient to disturbances in supply as people can switch to alternative sources if needed. This does not, however, diminish the importance of UK food production to our and global food security. To ensure our continued food security into the future, Defra states that an increase in global production is needed (in part) and this will mean the continued and sustainable use of fertilisers (Defra 2009).

2.6.5. Agriculture

All data for the following section are taken from Defra’s 2010 report “Agriculture in the UK” (Defra 2010c). In 2010 there were 6 million ha of arable land with 50% of this devoted to cereal production. Wheat is the most common crop in the UK, covering just less than 2 million ha. Grassland (permanent and common rough grazing) covered 11 million ha. Ten million cattle and calves, 31 million sheep and lambs, 4.5 million pigs and just fewer than 164 million poultry were recorded in 2010.

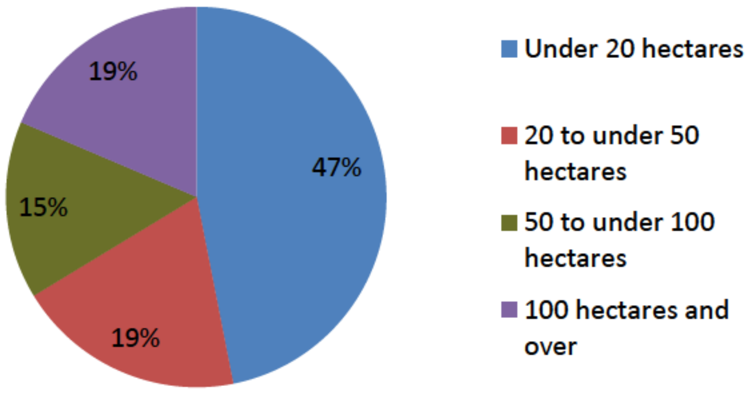

Figure 2.6. Size distribution of UK commercial holdings in 2010

Between 2005 and 2010 a 10% decrease in the number of commercial holdings was recorded with 222,000 present in 2010. Of these, 47% were less than 20ha in area (Figure 2.6). In England the most common farm type was lowland grazing livestock followed by general cropping and then cereal farms, whilst in Wales and Scotland the 'other' farm type was most common. In Northern Ireland grazing of livestock in less favourable areas (uplands) was the most common farm type recorded (Figure 2.7).

In the UK 466,000 people employed in agriculture in 2010 and the average age of holders was 59 in 2007.

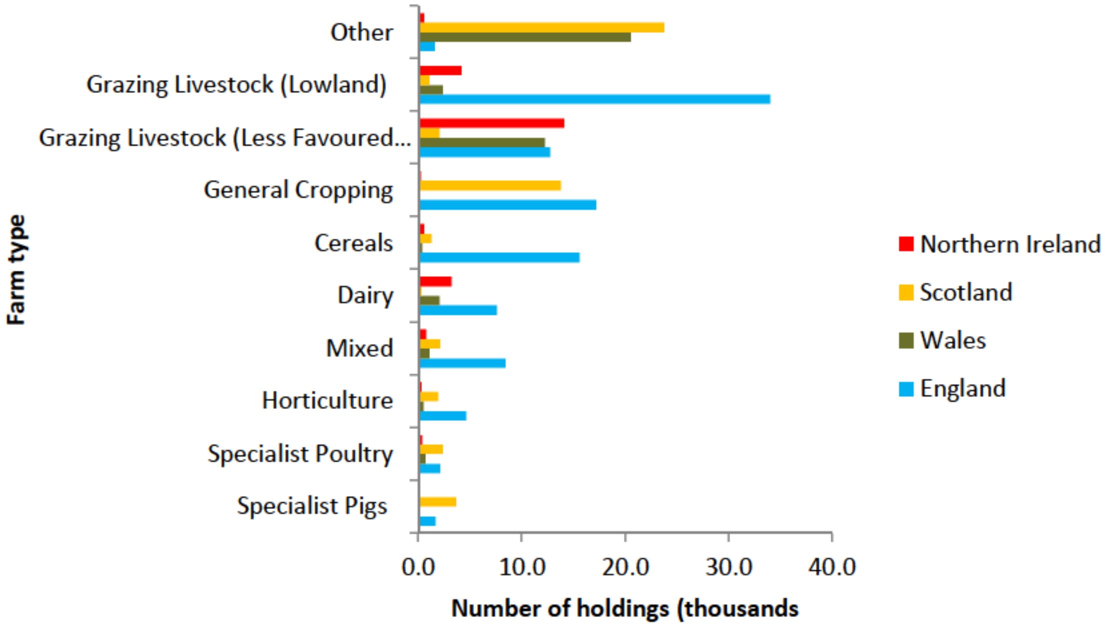

Figure 2.7. Distribution of UK commercial holdings by farm type in 2010.

2.7. Discussion and key points identified

The published evidence generally supports the statements made in the York Potash manifesto. Potash increases crop yields and quality and as the area of arable land devoted to food production has decreased, it is important to use what is available as efficiently as possible. Effective fertilisation forms part of this.

Fertiliser potash is used extensively in the UK on tillage crops and grassland although its use has decreased in recent years. Available evidence suggests that this decrease is causing K reserves in UK soils to fall. If this is the case, usage will need to increase if the high yields the UK currently achieves are to continue.

The UK is currently food secure but there is a need to ensure this continues in the future. Fertiliser potash can play a role in re-balancing the large potassium deficits that are evident in other areas of the world, and it is believed that this will increase crop yields in these areas. The knock on effect of this would be greater global food security.

Fifty percent of the UK croppable area is devoted to cereal production with almost two-thirds of this being wheat. The area of grassland is double that of croppable land. The majority of holdings in the UK are under 20ha in area with “grazing” being the most common farm type. Although cereals and grass have low potash requirements, they occupy significant proportions (78%, Defra stats 2011) of our cultivated land, and are established ‘staples’ for UK productivity.

Muriate of potash (potassium chloride) is the main source of potash in manufactured fertilisers. Potassium sulphate (SOP) is more expensive but offers some agronomic advantages as it contains a second nutrient, sulphur, and is chloride-free.

Looking to the future, climate change could have an impact on the importance of potash. The interaction between potassium and biotic/abiotic stresses that may increase in frequency and severity under future climates (e.g. drought, pests) may impact on the importance of potash.

Grassland and cereals receive most of the fertiliser potash used in the UK due to the large areas grown. These crops will play a key role in establishing the future importance of fertiliser potash. Application rate is greater for potatoes and for some vegetables but the areas currently grown are much smaller.

3. Selection of Possible Future Scenarios

3.1. Introduction

In order to assess what the future potash requirements of the UK might be, it is necessary to know what the future agricultural landscape may look like. The crops that are grown, how society deals with problems, how farming has developed (sustainable or intensified) and how reliant the UK is on food imports will all impact on how much potash the UK will need in the future and what the effects will be if potash becomes unavailable.

To develop an idea of what the future may look like, sets of agricultural scenarios were identified and assessed using the selection criteria described in Section 3.2. The scenarios that have passed the screening exercise will be used to assess what impacts a ‘no potash’ situation might have on agriculture in the future. It is therefore important that any scenarios considered provide information, in sufficient detail, on what the potential future agricultural landscape will look like.

When using future scenarios it is important to interpret them in the proper way. These scenarios are predictions of the future subject to a particular set of conditions and should be used to compare the differences between futures given differing drivers of change. Where possible a full set of scenarios should be considered together as any future reality is likely to be a mix of several different future scenarios.

3.2. Scenario selection

In total 44 groups of future scenarios were found to be available for use in this project and these have been listed in Appendix B. These scenarios were sourced from published literature and Defra-funded projects. The scenarios were then filtered using a set of selection criteria that identify the details that a scenario must include to meet the project aims ('critical') and those that would be of benefit to the study if they were included ('optional') (Table 3.1). The selection criteria were defined in conjunction with Fera's expert statisticians, agricultural ecologists and land use change scientists.

Of the scenarios that were filtered out at this stage, over 57% (25 scenarios) did not extend to near 2060 (with most only predicting to around 2020 (17 scenarios)). A further 25% (11 scenarios) did not include the current climate projections from UKCIP3 and of those remaining, 14% (6 scenarios) either did not focus on agriculture or did not include cropping patterns in their predictions.

Two scenario sets remained after this initial filtering: the scenarios developed for the National Ecosystem Assessment (NEA 2011) and the agricultural scenario developed as part of the UK's Climate Change Risk Assessment (CCRA 2012). However, due to concerns regarding the methods used to predict future yields in the CCRA (Semenov, *et al.* 2012) it was decided that only the NEA scenario sets should be carried forward to the next stage of the project. The CCRA did list potential future crops however, these are not likely to be major contributors to the UK farming industry in the future (Table 3.2).

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[3] UKCIP is the UK Climate Impacts Programme. For further details see http://www.ukcip.org.uk/.

Table 3.1. The selection criteria used to assess the suitability of the 41 scenarios found.

	Criteria	Reason
Critical	Only UKCIP	The scenarios selected should use the most up to date and widely accepted climate scenarios and should be UK focussed
	Full UK Only Scenarios	The scenarios selected should cover the whole of the UK (as opposed to regions / counties) and should be UK focussed
	Relevant to agriculture	Any scenario needs to be focussed on agriculture as this is the key land use in this project
	Details cropping patterns	The changes in cropping patterns could have large impacts on the future requirements of potash
	Quantitative	Any quantitative measures should be used above qualitative to give a better idea of what the future agricultural industry might look like
	To 2060 (and beyond)	To meet the project aims the scenarios should go to at least 2060
	Climate change	Climate needs to be included in the scenarios due to the large impacts this could have on water availability and crop growth
	Technology (production, agriculture)	How technology is used in the future may alter the potash requirements of UK crops
	Energy	The area of biofuels grown may have a large impact on the use of potash
	Food Security	The stability of food security should be discussed on some level in the scenarios
Optional	Plant diseases	An increase in plant disease could influence the importance of potash
	Resources	How much resource (other fertilisers, water) is put in to agricultural land may also influence potash use
	Values (attitudes to production)	How people view agriculture, overcome problems and source their food will have an impact on future potash use

Table 3.2. New crop opportunities highlighted in CCRA – Agriculture report.

Crop	Distribution
Amaranth	South UK
Globe artichoke	South UK
Chamomile	South UK
Dill	South UK
Ethiopian mustard	South UK
Fennel	South UK
Gold of Pleasure	South UK
Soya bean	South UK
Sunflower	South UK
Thyme	South UK
Grape	South UK
Echium	Central UK
Garlic	Central UK
Rocket	Central UK
Elder	UK wide
Juniper	UK wide
Lupin	UK wide
Marjoram	UK wide
Nettle	UK wide
Peppermint	UK wide
Sea buckthorn	UK wide
Yarrow	UK wide

3.3. Shortlisted scenarios

3.3.1 National Ecosystem Assessment

Six scenarios (Table 3.3) were created for both a high and low climate change scenario to assess how ecosystem services (services provided by ecosystems that benefit human life and associated quality of life) may alter under different futures. The project was part funded by Defra and ran from 2009 to 2011. All requirements as described in Section 3.2 are met by this scenario set. Quantitative predictions of crop areas in future scenarios are provided.

Table 3.3. Description of the six scenarios developed for the National Ecosystem Assessment.

Scenario	Description
Green and Pleasant Land	Biodiversity and landscape conservation are key in this scenario with rural locations managed to maintain and improve aesthetics. Agri-environment schemes are popular and farming is low input.
Nature at Work	Biodiversity conservation is a priority. Increase in managed woodland. Decrease in meat, replaced by crop protein. Some non-native species introduced.
World Markets	Food is very readily available but is low quality. Farming is industrial and large scale. Desalinisation plants built along the east coast to provide water.
National Security	Protecting UK jobs is a high priority. Technological development (including agriculture) is subsidised by the state. Biodiversity is less important than securing food, fuel and timber. Due to increased energy prices (from climate change) agriculture moves towards optimisation rather than intensification.
Local Stewardship	Local food products are important. Sustainable management of resources is a priority. Technological innovation is less important.
Go with the Flow	Follows today's socio-political and economic trends resulting in a future roughly based on today's ideals (including some improvements in environmental sustainability). Public are less keen on adopting many global or national environmental standards (business and industry even less so). and a lot of environmental progress is hindered.

The scenarios were created using a morphological analysis (which matched drivers of change to potential trends) before using Bayesian belief networks to create quantitative predictions of land cover. Finally, the CSERGE Agricultural Land Use Model (Fezzi and Bateman 2011) was used to split each land cover type into land uses in each square of a 2 x 2km grid that covered the UK. The agricultural land uses available are:

- Cereals
- Oilseed rape

- Other arable
- Root crops
- Temporary grassland
- Permanent grass
- Rough grazing

No estimate of future yields or future crops are given in these scenarios and the predicted value (as farm gross margin) for agricultural production was derived using current values for inputs (fertilizers, pesticides) and yield costs and amounts. This was done so that the assessment of scenarios could focus on the impact of climate change on provisioning services without confounding the model with economically driven change. It is therefore reasonable to use these scenarios to evaluate the future requirement for potash based on current application rates and the area of cropping in each of the scenarios. Despite these limitations in the modelling methodology, these scenarios are by far the most suited to this project and are supported by Defra.

3.4. Next steps

The NEA scenario set will be used in the next section of the project to assess the impacts that a lack of potash may have on UK agriculture in the future. This will involve qualitatively estimating the total potash requirements for each scenario before addressing the question below.

1) Consider the impacts on items a. to f. below, should potash (both muriate of potash (MOP) and sulphate of potash (SOP)) not be available to growers in the UK.
    a. the food supply chain and the country's ability to feed the population;
    b. crop types grown and patterns of production;
    c. holding size and distribution;
    d. plant disease levels, and associated with this, the application of pesticides;
    e. uptake, and therefore application of, nitrogen fertilisers;
    f. need for irrigation;

These impacts will be assessed for both MOP and SOP where appropriate. The assessment will be carried out for each future scenario and for the current UK farming situation. The associated uncertainties in the impact assessment will also be presented.

4. Review of Possible Future Scenarios

4.1. Introduction

In order to assess the future importance of potash to UK agriculture a potash scenario is used in conjunction with the socio-economic scenarios previously sourced. This scenario has been defined by York Potash as follows:

Potash Scenario *is "a future situation where potash (both muriate of potash and sulphate of potash) is suddenly unavailable to UK growers; no potash is produced in the UK and it cannot be imported"*

It should be remembered that this scenario is extremely unlikely to occur and is being used purely to highlight the potential importance of potash in the future of UK food production.

This report is the final stage in the project and applies knowledge collated during the literature review to the selected agricultural scenarios under the potash scenario described above. The final output is a high level assessment of the potential impacts on agriculture of a future scenario where fertiliser potash is not available to UK growers.

4.2. Methodology

In order to assess the potential impacts of the potash scenario on UK agriculture, twelve separate agricultural scenarios from the National Ecosystem Assessment (NEA 2011) six social-economic scenarios all with high and low global warming predictions) were used in the analysis. From the literature review several possible impact factors were identified and a question for each one was produced. These questions aimed to assess the severity of any potential impacts (Figure 4.1) and were addressed by groups (or individuals, where appropriate) of experts at Fera and Ecopt with expertise in fertilisers, agronomy, the agri-environment, plant pests and disease, the NEA scenarios, socio-economics and genetically modified organisms. All questions asked are detailed in Appendix E.

The impacts and effects described in Figure 4.1 were assessed in groups (yield, quality and production [boxes 1, 2, 6, 12 and 13], abiotic stress [boxes 3, 7 and 14], biotic stress [boxes 4, 8, 9 and 15] and nitrogen uptake [boxes 5, 10, 11]) with a series of questions which flow through to an overall answer (Box 1). The baseline scenario was assessed first before moving on to the NEA scenarios (Go with the Flow (GwF), Green and Pleasant Land (GPL), Nature at Work (N@W), World Markets (WM), National Security (NS), Local Stewardship (LS)).

The initial assessments were carried out on a low climate change future, before being repeated for high climate change futures. This repetition was carried out only if the direction of change in low and high climate futures was expected to be different, otherwise it can be assumed that the expert group judged the change would only continue to a greater extent under high climate change.

After each question, the expert group was asked to assess how certain they were of their answer. The IPCC guidance on uncertainty (Mastrandrea *et al.* 2010) was used to do this for the initial assessment of the baseline scenario. The certainty for all other scenario answers was simply shown as being more or less certain than that for the original baseline scenario (Table 4.1).

In order to summarise the responses, symbols (Table 4.1) were used to signify the answer and the expected direction of change, along with descriptive answers to the questions. The evidence used to address each group of questions was listed.

The severity of any change depends on how important potash is in agriculture in the UK. Each scenario (including the baseline scenario) was explored to extract information which may be pertinent to the importance of potash. This information (Appendix D) was then passed to the experts to help them address the responses to the Potash Scenario in each of the NEA scenarios. The main areas of information searched for are detailed below:

- Intensity of farming
- Abundance of organic farms
- Abundance of mixed farms
- Holding size
- Agricultural use of marginal land
- Soil management
- The use of genetically modified organisms (GMO)
- Pesticide regulation
- Market gardens
- Reduced consumption levels in society
- The use of new crops
- The level of food imports
- The adaptability of the society
- Society's main drivers
- Readiness for climate change

The NEA socio-economic scenarios describe the direction in which society is heading and describe a future to 2060 that developed while fertiliser potash was available. In this assessment, it was assumed that fertiliser potash supplies disappear in 2012 and the expert groups assessed the effect of this, on these scenarios (including the baseline scenario) to 2060. When assessing the impacts on the baseline and future scenarios, the experts considered what would happen to 2060 if fertiliser potash were to become unavailable now, considering the trends in the above factors in each scenario.

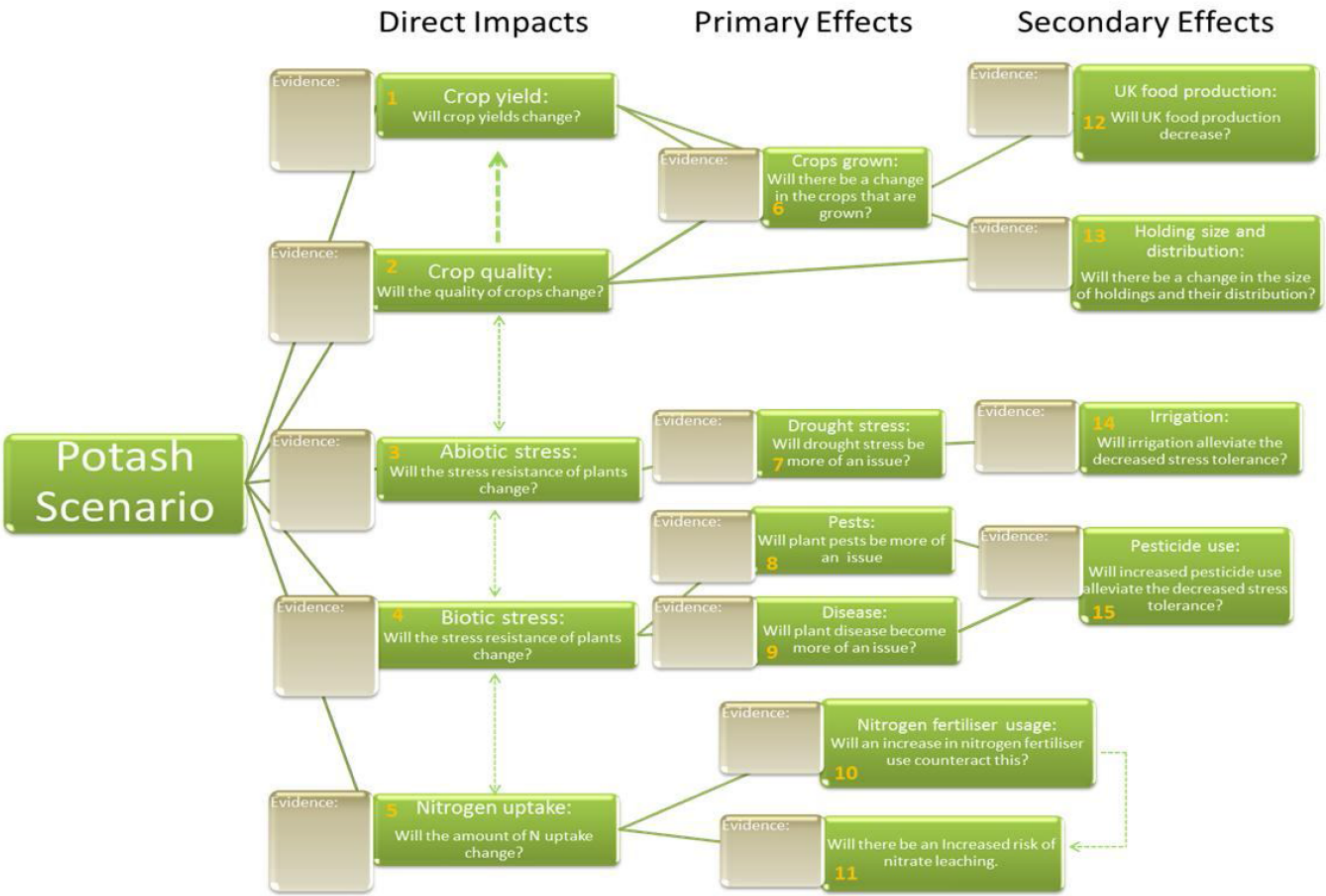

Figure 4.1. The direct impacts, primary and secondary effects that a lack of potash may cause and the questions considered in this report.

Box 1: Example of questioning process.

Yield, quality and production:

1. Will crop yields decrease?
2. Will crop quality decrease?
3. Considering your answers to 1 and 2, will there be a change in the crops that are grown?
4. Thinking about questions 1 to 3, will there be a change in the size of holdings and their distribution?
5. Overall, do you feel there would be a decrease in UK food production?
6. Will an increase in food imports counteract any production decrease?
7. Overall, will food supply be reduced, taking account of all the factors that influence both UK production and imports?

These questions are first answered for the baseline scenario before moving through each of the future scenarios (Table b1).

Will crop yields decrease?	Baseline Scenario	Go with the Flow Scenario	World Markets Scenario
	Answer 1	Would answer 1 change if there were technological improvements in agriculture?	Would answer 1 change if there was increase in the number of organic farms?

Table b1: Example of questioning process to move through the scenarios for each question.

Table 4.1. Symbols used to specify direction of change and certainty in the answers.

	Symbol	Meaning
Question Answers	+	Expected increase
	-	Expected decrease
	o	No change expected
	?	Too uncertain to say
	y	Yes
	n	No
Uncertainty in Baseline Scenario	99 - 100%	Virtually certain
	90 - 100%	Very likely
	66 - 100%	Likely
	33 - 66%	About as likely as not
	0 - 33%	Unlikely
	0 - 10%	Very unlikely
	0 - 1%	Exceptionally unlikely
Change in Uncertainty from Baseline Scenario	+++ - - -	Much more certain (+) / uncertain (-)
	++ - -	More certain (+) / uncertain (-)
	+ -	Slightly more certain (+) / uncertain (-)
	+ / -	No change in certainty
	?	Too uncertain to say

4.3. Results

Summary tables for each answer are given (Tables 4.5 to 4.8). Full answers to all questions in all scenarios are provided in Appendix E. The references used to answer each question are listed in Appendix C.

4.3.1. Assumptions in scenario assessment

4.3.1.1. Substitutes

Throughout the impact assessment the availability of potash substitutes is critical; if fertiliser potash can be substituted, the impacts of our potash scenario will be lessened or even non-existent. The section below details the likely situation with regard to potash substitutes under the Potash Scenario as described in Section 1.

There are two types of possible substitution for fertiliser potash:

- Other nutrients that can assume part of the role of potassium (K) in plant nutrition;
- Other materials that contain potassium and that can be applied to crops.

Potassium is an essential crop nutrient for which there is no full substitute. However, in some plant species of maritime origin, sodium can substitute partially for potassium in its role as an osmoregulator. Of these species, *Beta vulgaris* in the forms of sugar beet, fodder beet, beetroot and mangels, is a significant crop in the UK. Sodium application (usually as salt) can help in maintaining plant water relations where soil K is low (Table 4.2). Sodium recommendations are based largely on two series of field experiments, one in the 1970s (Draycott & Bugg 1982) and the second in 2000-2005 (Milford *et al.* 2008, PDA 2011).

Table 4.2. Recommended rates of K_2O and Na_2O application for sugar beet (kg/ha) (Fertiliser Manual)

	K Index			
	0	1	2	3+
Potash (K_2O)	160	130	100	0
Sodium (Na_2O) (use K Index)	200	200	100*	0

* only where exchangeable soil sodium is less than 25 mg Na/kg

As has been previously mentioned, certain crops, such as potatoes are sensitive to chloride toxicity, however, an application of 200 kg Na_2O/ha as salt, equivalent to 240 kg Cl/ha would raise soil chloride concentration by only around 80 mg/l and would not cause chloride damage even to the most sensitive crops.

This partial substitution could delay the effect of reduced potash input for these particular crops. Eventually however decreasing soil available potassium would interfere with the other essential roles of potassium in enzyme activation and sugar transport and even these crops would suffer adverse growth and yield effects.

There are materials other than manufactured fertilisers that contain potash and that can be applied to soil to increase the supply to crops. The most important of these are livestock manures. In areas where there are large livestock populations, much of the total requirement for applied potash can be met, in principle, by manures. In practice, manures are not applied efficiently but are over-applied on some fields and under-applied on others. The nutrient concentration in manures is relatively low (Defra 2010a) making transport uneconomic and further restricting the efficiency of use. Nevertheless, amounts of potassium in livestock manures are large, comparable to the amounts applied in manufactured fertilisers, and there is scope for improved utilization. In England and Wales, livestock manures produced every year contain around 300,000 tonnes of K2O (Defra 2008b). Used rationally to minimize local variation in soil available potassium, this amount would delay adverse effects of a loss of fertiliser potash input. This beneficial effect would likely be restricted to areas with significant livestock populations.

Alternative sources of potash include composts, anaerobic digestate, ashes and some industrial wastes. There is very little potash in sewage sludge and derived products (Defra 2010a) (loss of potassium during sewage treatment is the main route by which potassium leaves the soil/crop/livestock/human system). Amounts of potash applied to land in these materials are small relative to those in fertilisers and manures but are growing. Around 2 million tonnes of compost were produced in the UK in 2005/06 and the volume has been increasing by 20% annually. Anaerobic digestion is being promoted by government and the volume of digestate suitable for land application will grow. Greenwaste compost contains around 5.5 kg K_2O/t and food waste compost around 8 kg/t (Defra 2010a). Anaerobic digestate contains around 2 kg K_2O/t (WRAP 2011). The potash in manures and organic wastes is largely in water-soluble form so is readily available to crops and equivalent to fertiliser potash.

In the future it may be possible to extract potassium from waste water at sewage treatment plants on a commercial scale. Precipitation of potassium from sewage and livestock manures as potassium struvite (potassium ammonium phosphate) has been researched and shown to be feasible (e.g. at Delft University, Wilsenach *et al.* 2007). However, it is currently not economically attractive but it could be a possible reaction to the loss of fertilizer potash. Current research is aimed at producing potassium struvite as a source of phosphate rather than potassium (Richards & Johnston 2001) and so further refinement of the technology would be needed. Depending up on the efficiency of this, it could significantly close the potassium cycle, by reducing the loss to water (as mentioned above). However, it is too uncertain to predict if this would be likely to happen in the NEA scenarios or how effective it would be. An extensive quantitative analysis would be needed to determine the net effect on potassium input to soils.

In the UK, around 670,000t poultry litter are burned annually to generate electricity and ash that is used as a fertiliser (Fibrophos web site). Poultry litter ash also is imported from the Netherlands (Cropkare web site). The ash contains typically 12% K_2O in forms somewhat less readily available than that in fertiliser potash.

Even allowing for growth in volume, these alternative materials are likely to contribute a minor proportion of the potash required for UK agriculture. More efficient use of livestock manures will have some impact but a substantial requirement for fertiliser potash will remain for the foreseeable future (unless effective methods to extract potassium from waste water are developed, even then there is likely to be a lag between removal of potash from agriculture, development of technology and widespread use meaning benefits would probably only be seen in the long-term). In this assessment it is assumed that manufactured fertilisers based on mined material represent the only source of 'new' potassium. The alternative materials recycle potassium, but the potassium cycle has not been fully closed by extraction at waste water sites. In the future, some compensation might be possible through more efficient recycling of nutrients but this would only delay the inevitable decrease in soil available potassium, and the impacts this may have.

4.3.1.2. Time taken for K depletion in soils

If fertiliser potash were no longer available in the UK, soil potassium reserves and crop yields would be expected to decline at rates dependent on soil properties and on the effectiveness of potassium recycling (which might be expected to increase).

The current level of potassium in soils would affect the speed with which different areas experienced the effects of no additional potash usage. As discussed previously, in UK soils an index of 2 or higher would indicate that potassium supply, in the absence of applied potash, should be adequate for a 3 – 4 year period. At lower Indices, crop yields might be affected immediately due to potassium deficiency. The Professional Agricultural Analysis Group (PAAG 2011) of UK laboratories publishes an annual report showing the percentages of soil samples analysed in the different soil K Indices. Values for the latest 2010/2011 report, based on 32000 samples from arable soils and 19000 samples from grassland soils are given in Table 4.3.

Table 4.3. Percentage of 51,000 soil samples in each soil index sourced from the PAAG (2011)

	Percentage of samples in Index							
Soil Index	0	1	2-	2+	3	4	5	>5
Arable	4	28	30	18	15	3	1	0
Grass	7	33	26	15	14	3	1	0

Some 32% of samples from arable soils and 40% of those from grassland soils were in Index 0 or 1 where crop yields could be affected by potassium deficiency. A broad quantitative conclusion can be drawn from this; it seems that lack of availability of fertiliser potash could have an immediate (within 3-4 years) effect on crop yields across some 30-40% of arable and grassland soils. The decline in soil K reserves and in crop yields will be much more variable in the other 60-70% of soils due to the variability in soil types, climate, cropping and management practices across the UK. As a rough estimate, it could occur anywhere between 5 years (on lighter soils) and several decades (on heavier soils); however a high degree of uncertainty is associated with this.

4.3.2. Yield, quality and production

During this part of the assessment, it became clear that holding size was not likely to have an impact on the overall question regarding UK food supply. For this reason the question was removed from the analysis and assessed separately. In several cases (baseline, GPL and WM), the change in holding size was too uncertain to assess as it would be affected by farm margins and farmer behaviour, both of which are difficult to predict. In the remaining scenarios, the impacts were scenario specific and showed no real trend. In GwF, where a decrease in mixed farming would be expected, the Potash Scenario may make this decline less pronounced. In the NS, it could be expected that marginal land would drop out of production. Little change in farm size would be seen in LS due to the sustainable agriculture and low severity of other impacts caused by the Potash Scenario. For N@W the increase in mixed and organic farms would work against a large increase in holding size. In general, the predictions given are associated with a medium degree of certainty (33 – 66%).

In all scenarios, a decline in crop yield and quality was predicted, with the decline in yields set to worsen under high climate change. Scenarios with more sustainable, low input agricultural systems

(GPL, N@W, LS) are expected to show less of a decrease, whilst high input systems (NS, WM) are predicted to show larger decreases which may be eased by GM and biotechnology developments in crop breeding (also in GwF). These factors (sustainability and crop breeding) also impact on the severity of the predicted declines in UK food production with LS and GPL predicting lower decreases in production. These predictions were all associated with a high degree of certainty, apart from NS and GwF, due to uncertainty in the ability of crop breeding to counter-act the drop in yield.

Quantifying the degree to which crop yields will be affected is extremely difficult, due to variability in other external factors (climate, soil type, cropping and farm management). There have been a limited number of long-term UK trials that provide some empirical evidence on the effects of not applying fertiliser potash. These mainly have been at Rothamsted and at the Saxmundham and Woburn experimental sites that are managed by Rothamsted. Rothamsted and Saxmundham are on soils that would be expected to release potassium over long periods (so effects on soil reserves and crop yields would therefore be smaller than those that might occur elsewhere) and Woburn is on a lighter sandy loam soil.

These long-term studies show a 65% decrease in soil exchangeable K in an 87 year period (Rothamsted site, Johnston *et al.* 2001), a decrease in spring barley yield (Hoosfield experiment, Rothamsted Research 2006) between nitrogen, phosphate and potash treatments (6.14 t/ha) and nitrogen and phosphate treatments (3.11 t/ha), (Rothamsted Research 2006) and crop yield differences developing as soil K levels diverged under different treatments (Table 4.4).

Table 4.4. Recorded yields in index 3 and index 0 soils at Woburn (Johnston et al. 2001)

	Crop yield (t/ha)	
	Index 3 (311 kg K/kg)	Index 0 (36 mg K/kg)
Potatoes	44.3	10.1
Sugar beet sugar	7.32	2.80
Barley	4.37	2.82
Oats	5.04	4.62

As a rough estimate, if the recycling of potash remained at the current national level the long-term effect of not applying fertiliser potash on many soils could be a reduction of cereal yields to around 2-3 t/ha. Yield might be greater on some clay soils but the national average yield probably would trend towards these values. Again as a rough estimate, the period needed to reach these national yields following the loss of fertiliser potash might be 20 to >100 years depending on the effectiveness of efforts to improve recycling.

In addition to the direct effects of potash deficiency on plant function, there are also indirect effects via interaction with pests and diseases, water availability, nitrogen etc. that will also affect yields and are dealt with in following sections. These different effects were assessed independently by different experts.

The majority of scenarios predicted a change in crops grown with a switch to / increasing importance of crops with lower K requirements (GwF, N@W, NS), a decrease in high K demanding crops (GwF, N@W) or an increase in complex rotations to allow soil nutrients to build up (LS). All scenario descriptions (except GPL) stated there would be an increase in the area of protein crops and root crops and a decrease in the area of cereals (predicted if allowed to progress with potash available). In order to assess the likely changes in the crops that will be grown, the potash requirements of the new protein crops were sourced (Figure 2). In the majority of cases it was predicted that a smaller increase in the area of root crops would be seen (due to the high potash requirements) and a smaller decrease in the area of cereals. Protein crops required a similar amount of potash to grass cut for silage and hay production but much more than for grazed grassland and so where protein crops replaced grassland, a slight increase in the baseline potash requirements of the UK could be expected as a result of this switch.

The loss of muriate of potash (MOP), as the most widely used form of fertiliser potash, is likely to affect all crops at some point (depending upon their potassium requirements and soil conditions). Sulphate of potash (SOP) has been shown to be beneficial for some high value crops (Defra 2010a, Marchand & Bourrie 1999, QianXin et al. 1999) and would be useful for a wider range of crops and situations given a smaller price disadvantage against MOP. Assuming SOP is used on crops, in the scenarios, as it is currently, its loss would affect potatoes as well as soft fruits and other high value crops and could impact whether or not some of these crops are grown. Unfortunately, no estimate of the area of soft fruits is given in the NEA scenarios and so it is too uncertain to assess what these changes may be.

Only in WM was no change predicted, and this is due to the high economic driver in this scenario and the large industrial farms likely geared towards specific crop types. These factors mean it would be difficult to switch to production of alternative crops and it may be cheaper to source food from abroad. The expert group were more uncertain of their predictions of crop change, particularly in LS (due to uncertainty regarding which crops may be available to switch to and how able the society would be to adopt complex rotation patterns), than they were of the yield and quality predictions.

Only for NS was it predicted that food imports would not increase to meet the decline in UK food production due to the lack of food globally (as all nations need to increase self-sufficiency), the already decreased level of food imports and a large increase in trade barriers. In all other scenarios, food imports would meet the decline in production however in two of the scenarios the sustainability (baseline) and likelihood of being able to source enough food (WM) is uncertain. High climate change exacerbates the problem of sourcing food globally and decreases the likelihood of sourcing food in GwF. There is a high degree of certainty (90 – 100%) associated with these predictions, except in the cases of N@W and LS.

Overall, the scenarios suggest that UK food supply would not decrease (apart from NS and WM) but we would be heavily reliant on food imports which may not be sustainable in the long run, especially in the face of high climate change. The certainty assessments ranged between 33% and 100%, with LS having the lowest certainty assessment (33 – 66%), as the experts were unsure how severe any reduced production would be in such a low input system.

Figure 4.2. Potash requirements of UK crops, including soybean. Data from Defra (2010a). Soybean requirements from Imas & Magan (2008).

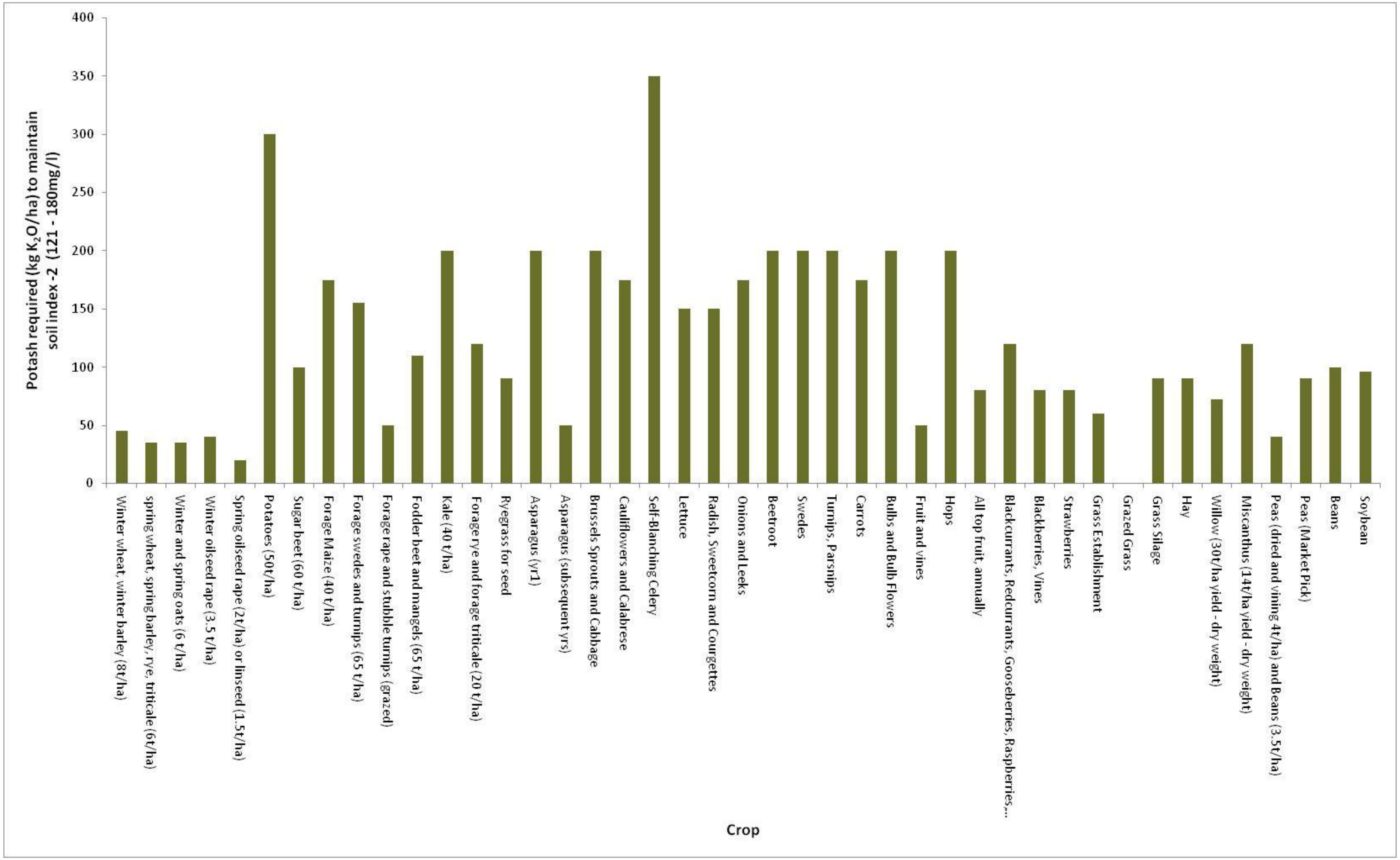

Table 4.5. Summary of the predicted impacts of the Potash Scenario on yield, quality and production as defined by the expert group. The answer to the question followed by the expected direction of change (where appropriate) and then the uncertainty assessment (given in brackets) for each prediction.

Question	2010 Baseline	GwF	GPL	N@W	WM	NS	LS
1. Will crop yields decrease?	y, - (90 - 100%)	y, - (-)	y, - (+)	y,- (+)	y, - (+)	y,- (-)	y, - (+ / -)
2. Will crop quality decrease?	y, - (90 - 100%)	y, - (-)	y,- (+)	y, - (+)	y, - (++)	y, - (--)	y, - (+ / -)
3. Considering your answers to 1 and 2, will there be a change in the crops that are grown?	y (66 - 100%)	y (+)	y (+ / -)	y (+)	n (+ / -)	y (+)	y (-)
4. Overall, do you feel there would be a decrease in UK food production?	y, - (90 - 100%)	y, - (+ / -)	y, - (-)	y, - (+)	y, - (+++)	y, - (+)	y, - (+ / -)
5. Will an increase in food imports counteract any production decrease?	y, + (90 - 100%)	y, + (++)	y, + (+)	y, + (-)	y, + (++)	n, o (+)	y, + (-)
6. Overall, will food supply be reduced, taking account of all the factors that influence both UK production and imports?	**n, o (66 - 100%)**	**n, o (66 - 100%)**	**n, o (66 - 100%)**	**n, o (66 - 100%)**	**y, - (90 - 100%)**	**y, - (99 - 100%)**	**n, o (33 - 66%)**

4.3.3. Plant stress

The role potassium plays in plant resistance to biotic and abiotic stress has been well researched and it has been shown that potash can be of benefit in both. In the sections below, biotic stresses (example of plant pests and disease) and abiotic stress (example of drought resistance) are assessed.

4.3.3.1. Biotic stress (example of plant pests and pathogens)

In general, plants grown in soils with sufficient plant available potassium are less vulnerable to plant pests and diseases than those grown in potassium deficient soils (Romheld & Kirkby 2010). It is thought that the decrease in biotic stress in potassium balanced plants is due to potassium acting to decrease cell permeability and susceptibility of tissues to pathogens, its involvement in increasing cell wall thickness and in decreasing the concentration of low molecular weight compounds necessary for pest and pathogen feeding (Romheld & Kirkby 2010, Katan 2009).

However, there is conflicting evidence as in some cases addition of potassium increases the occurrence of some pests and diseases. In a review of 165 studies Prabhu *et al.* (2007) found that potassium decreased pest and disease occurrence in 70% of cases, but increased it in 30%. This finding was mirrored by Perrenoud (1990) in a review of 2449 studies concerning the interaction between potassium and plant health. This included over 400 pests and diseases. It was found that potassium decreased incidence of pests and disease in 65% of cases and increased it in 28%. The pattern of the change in incidence differed between different groups of pathogens. For fungal and bacterial diseases, 70% showed a decrease. This dropped to 60% for insects and mites. In contrast, the incidence of viruses and nematodes increased with increased potassium availability. Amtmann *et al.* (2008) found that *Arabidopsis thaliana*, grown on potassium deficient soils, under experimental conditions, accumulates insect deterrent metabolites that were thought to counteract any increased susceptibility due to potassium deficiency.

The impact of potassium is not always clear but it can be said that in general, plants with an adequate potassium supply are more resistant to pests and disease particularly for fungal and bacterial diseases. The impact on viruses and nematodes is much less certain.

The expert group decided that there was so much uncertainty around the impacts of climate change on pests and disease that this could not be fully assessed. Therefore only one set of assessments was done for a low climate change situation. Additionally, the impacts of the

Potash Scenario on viruses and nematodes are equally uncertain due to the conflicting pieces of evidence.

In all but two scenarios (GPL and LS due to the lower intensity of farming) plant pests and diseases are predicted to increase as a result of the Potash Scenario with a certainty of 66 – 100% (lower certainty in NS due to uncertainty in the pest and disease impact of market gardens). This increase is expected to be worse in highly intensive farming (GwF, WM and NS).

The use of additional pesticides should counter-act the decreased pest and disease resistance assuming effective pesticides can be sourced by technological advances and / or decreased pesticide legislation (N@W, NS, LS). Where legislation increases (more likely), pesticides may not be available that are able to control specific pests and diseases (NS). In GwF there is concern that the new invasive species (assuming some are plant pests and diseases) could pose problems if there were difficulties in getting a suitable pesticide. In WM, the increase in invasive species is counteracted by the increased technological development. In GPL due to the low intensity organic farming, and the expectation that the Potash Scenario will have little or no effect on plants, it is predicted that farmers would not increase pesticide treatments. Again the certainty assessment showed the experts were 66 – 100% certain, although this was lower for N@W (experts were unsure if low intensive systems would use pesticides if pest and disease pressure increased) and NS (experts were uncertain if increased pesticide legislations would mean suitable products could not be sourced).

Yields were predicted to decrease due to the additional biotic stress placed on plants by pests and diseases in three scenarios (baseline, GwF, NS) due to an increase in pesticide legislation and the risk of being unable to source or adapt to new spraying techniques and products. The certainty associated with these predictions was relatively low for baseline and NS scenarios at 33 – 66%. The remaining scenarios are predicted to not show any decline in yields due to pest and disease pressure and have a higher degree of certainty of 66 – 100% (except N@W with a certainty of 33 – 66%).

Table 4.6. Summary of the predicted impacts of the Potash Scenario on biotic stress as defined by the expert group. The answer to the question followed by the expected direction of change and then the uncertainty assessment (given in brackets) for each prediction.

	2010 Baseline	GwF	GPL	N@W	WM	NS	LS
Will plant pests and diseases stress increase?	y, + (66 - 100%)	y, + (+ / -)	n, o (+ / -)	y, + (+ / -)	y, + (+ / -)	y, + (-)	n, o (+ / -)
Will additional use of pesticides and fungicides counteract the decreased biotic stress tolerance?	y, + (66 - 100%)	y, + (+ / -)	n, o (+ / -)	y, + (-)	y, + (+)	n, o (-)	y, + (+)
Overall, will crop yields suffer due to pest and disease impact?	**y, -** **(33 - 66%)**	**y, -** **(66 - 100%)**	**n, o** **(66 - 100%)**	**n, o** **(33 - 66%)**	**n, o** **(66 - 100%)**	**y, -** **(33 - 66%)**	**n, o** **(66 - 100%)**

4.3.3.2. Abiotic stress (example of drought stress)

When plants are placed under abiotic stress (drought, chilling, high light intensity, salinity and heat), an increase in the formation of reactive oxygen species (ROS) is seen (Romheld &Kirkby 2010). These ROS can have negative impacts on plant health (Cakmak 2005). Plants with an adequate supply of plant available potassium show lower levels of these damaging ROS in cells even when under abiotic stress such as drought (Cakmak 2005). Addition of potassium fertiliser to crop plants has been shown to raise their drought and salinity stress tolerance (Romheld &Kirkby 2010). In the UK, this could have larger implications than currently, when considering potential changes in climate.

Across all scenarios it is expected that the effects of water stress will increase although the severity of this is uncertain particularly in GwF where drought tolerant varieties could be bred that could reduce the impacts of water stress (also in WM and NS where GM technology could be used to breed drought tolerant varieties). In scenarios with low input, sustainable farming systems the impacts are also decreased (GPL, N@W, LS).

In all scenarios, except LS, it is unlikely that additional irrigation will be able to counteract the effects of the increased water stress, due to the increased pressure on water supplies predicted in the future. In LS, the decreased farm size and increase in small holdings will mean people can employ water saving measures (e.g. collecting rain from roofs and water butts) to secure water for irrigation.

Overall, yields are expected to decrease as a result of the increased effects of water stress due to a removal of potash from agricultural systems. Again breeding of drought tolerant varieties, low intensity farming and increase in small holdings lessen the expected decrease in yields. The use of marginal land in NS increases the risk of reduced crop yields, as drought prone land cannot be avoided when aiming for self-sufficiency in food. All predictions on yield are associated with high certainty (ranging between 66 – 100%).

The impacts on water stress, availability of water for irrigation and on yields are all predicted to worsen under high climate change.

Table 4.7. Summary of the predicted impacts of the Potash Scenario on drought stress as defined by the expert group. The answer to the question followed by the expected direction of change and then the uncertainty assessment (given in brackets) for each prediction.

	2010 Baseline	GwF	GPL	N@W	WM	NS	LS
Will the effects of drought stress increase?	y, + (90 - 100%)	y, + (--)	y, + (-)	y, + (-)	y, + (-)	y, + (-)	y, + (-)
Will additional irrigation alleviate the decreased drought stress tolerance?	n, o (66 - 100%)	n, o (+ / -)	n, o (-)	n, o (-)	n, o (+)	n, o (+ / -)	y, + (-)
Overall, will crop yields suffer due to drought stress?	**y, -** **(90 - 100%)**	**y, -** **(66 - 100%)**	**y, -** **(66 - 100%)**	**y, -** **(66 - 100%)**	**y, -** **(90 - 100%)**	**y, -** **(90 - 100%)**	**y, -** **(66 - 100%)**

4.3.5. Nitrogen uptake

The several essential functions of potassium within plants include enzyme activation, pH stabilization and osmoregulation (these are reviewed by Marschner 1995). Functions of potassium and nitrogen in the plant are related in several ways. Both are involved in protein synthesis (one of the enzymes activated by potassium is nitrate reductase that mediates the first step in conversion of nitrate-N to protein) and in water regulation (potassium and nitrate ions are the main solutes in vacuoles).

It would be expected that any deficiency in supply of potassium would affect nitrogen uptake and assimilation either directly or indirectly via an effect on plant growth. In laboratory experiments, potassium supply has been shown to affect nitrate uptake by roots and its subsequent translocation in the plant (Blevins *et al.* 1978). The expectation also has been confirmed in field trials where potassium supply has been shown to be related to nitrogen uptake and crop yield (Wolton *et al.* 1968, Milford and Johnston 2007). These examples serve to illustrate the effect of inadequate potash supply in restricting nitrogen uptake by crops.

If no fertiliser potash is applied, the degree of deficiency in a particular crop will vary with soil and agronomic conditions. In lighter soils, lack of fertiliser potash can have an immediate effect. However, some heavier soils, for example those derived from boulder clays, can release significant amounts of potassium for many decades (Johnston 1986). Inadequacy of potassium also depends on nitrogen supply. A potash supply that is adequate where small amounts of fertiliser nitrogen are applied can become inadequate if the nitrogen rate is increased so raising crop growth potential.

The consequences of a restriction in nitrogen uptake due to inadequate potassium supply include reduced crop yield (and in some cases, quality), waste of fertiliser nitrogen and increased risk and extent of nitrate leaching. Visible symptoms of potassium deficiency in a crop become apparent when the deficiency is serious. Lesser deficiencies that still affect nitrogen uptake might not be noticed by the grower who would not adjust fertiliser nitrogen use. The nitrogen that is applied but not taken up by the crop would remain in the soil after harvest, largely in the nitrate form that is susceptible to leaching (Richards *et al.* 1996).

If fertiliser potash were not available, there would be a reduction in annual input to UK soils of around 250,000 t K_2O (AIC 2011). In the short term, use of other nutrients probably would change little. There would be reduced uptake of nitrogen as potassium deficiencies developed. Deficiencies would appear in some soils before others and in some crops before others. Potatoes growing on light soils might suffer deficiency first and cereals on heavy clays much later. Where the level of soil available K was high, deficiency would be delayed for several years until the soil became depleted due to offtake of potassium in harvested crops.

At this stage, overall fertiliser nitrogen use could exceed crop requirement. There would be additional residual nitrogen in the soil after harvest and the risk and extent of nitrate leaching would increase. Compliance with the EC Nitrate Directive would be compromised and there could be additional costs for nitrate removal from drinking water. In the longer term, the restriction in the yields of crops and forages (and so the amounts of manures produced) due to potassium supply would be recognized. A new equilibrium would emerge based on a lower supply of potassium, reduced nitrogen uptake and requirement by crops and grass and consequent reduction in use of fertiliser nitrogen.

In the assessment of nitrogen uptake and leaching it was predicted that uptake would decrease in all scenarios and would lead to a decrease in yields (certainty of 90 – 100% in all cases). This would not be offset by increasing the amount of nitrogen fertiliser applied to crops and any attempt to do this would cause a larger increase in nitrate leaching.

The risk and extent of nitrate leaching is manageable if a decrease in nitrogen fertiliser application matches the reduction in fertiliser potash (N@W, WM, NS). If this adaptation is not seen then nitrate leaching would increase as is expected in GwF and baseline scenarios where farmer adaptation would only be seen in the long-term. In addition, in scenarios with lower yields and intensity (GPL and LS), smaller amounts of N would be applied to crops and so the risk of any leaching would be lower than in the baseline. However, it should be noted that the certainty for some of these predictions (N@W, WM, NS) is fairly low (33 – 66%) as it is not clear how quickly growers would reduce fertiliser N applications in high yield scenarios. The inability to achieve yield increases in N@W, NS and WM, or even to sustain current yields, could make these scenarios unviable. The impacts of climate change on these trends is too uncertain to predict, but is unlikely to alter the direction of the predicted impacts (e.g. nitrogen uptake would still decrease which could lead to an increased risk of nitrate leaching if farmers do not adapt).

Table 4.8. Summary of the predicted impacts of the Potash Scenario on nitrogen uptake and leaching as defined by the expert group. The answer to the question followed by the expected direction of change and then the uncertainty assessment (given in brackets) for each prediction.

	2010 Baseline	GwF	GPL	N@W	WM	NS	LS
Will the amount of nitrogen taken up by crops decrease?	y, - (90 - 100%)	y, - (+ / -)	y, - (+ / -)	y, - (+ / -)	y, - (+ / -)	y, - (+ / -)	y, - (+ / -)
Will there be an increase in the amount of nitrate leaching?	y, + (90 - 100%)	y, + (+ / -)	n, o (+ / -)	n, o (--)	n, o (--)	n, o (--)	n, o (+ / -)

4.4. Conclusions

The potential impacts of the Potash Scenario assessed here are varied but in general would lead to a decrease in crop yields, a greater reliance on food imports and could put the UK in a much more insecure position with regard to food supply, considering the global impacts of climate change and other potential changes that could reduce the availability of food globally.

The reduction in nitrogen uptake, increased risk of abiotic stress (particularly under high climate change) and biotic stress could all work together (alongside the direct yield decrease due to potassium deficiency limiting growth) to reduce yields (Table 4.9). Yields could possibly decrease to as low as 2 – 3 t/ha eventually for cereals. Again, yields might be greater on some clay soils, but the national average yield probably would trend towards these values. These yields may be seen in 20 to >100 years depending on the effectiveness of efforts to improve recycling.

Table 4.9. General conclusions for questions related to UK food supply

Potential change	Direction of change	Number of scenarios predicting the change
Nitrogen uptake	↓	7
Impact of plant pest and disease	↑	5
Impact of drought stress	↑	7
Yields	↓	7
Quality	↓	7
Switch to alternative crops	↑	6
UK food production	↓	7
Food imports	↑	6
UK food supply	↔	**5**

It is expected that under high climate change the decrease in yield will be more severe as an increase in abiotic stress is seen. Additionally, a high climate change future will make it harder to produce food globally and so could decrease the likelihood of the UK importing sufficient quantities of food to replace that lost due to the removal of potash from agricultural systems.

Potential mitigation measures may not have a high likelihood of counter-acting these expected changes due to other limiting factors. In the case of drought stress, there may not be the water available for additional irrigation as there will be an increased pressure on water resources. With biotic stress, suitable pesticides to treat pests and diseases may not be available. In some cases, suitable mitigation measures may not exist such as for the predicted decrease in nitrogen uptake in crops. Where mitigation techniques are available their sustainability and security (increased food imports) are unclear.

Several assumptions have been made throughout this impact assessment. Perhaps the most significant is that any substitutes available will not be able to fully replace potash and eliminate the risk of decreased yields. As previously stated, this may not be the case, but is too uncertain to assess and so this assumption had to be made. The uncertainty assessments associated with the predictions in sections 4.3.2 to 4.3.5 are valid given this assumption. No certainty assessment, of the likelihood of this assumption being correct has been made, as it is too uncertain to assess. If a method is developed that will allow the efficient extraction of potassium from waste water it is possible that a decline in yields would not be seen, that its severity would decrease or that its onset would be delayed. However, any benefit of more efficient potassium re-cycling through the development of new technologies and methods could take many years and may only come into widespread use in the long-term. Some short-term declines in yields from a lack of potash would be felt and additional food would have to be sourced from abroad.

The quantitative estimates of yield decline and length of time for potassium reserves in soils to fall are uncertain. Many factors are involved in determining rate of soil potassium declines and the yields achieved. These factors vary spatially and temporally (soil types, climate, cropping and management practices) and so the long-term experiments run by Rothamsted are not necessarily applicable to the UK as a whole. They do however give a suggestion of the type of yields and time taken to reach these yields, which could be expected.

Overall, it can be said from this analysis, that a lack of potash would have a serious and negative impact on yields that would need to be accounted for by increasing food imports. This may not be a sustainable way for the UK to ensure its future food security due to the increased reliance on foreign trade links and production and the vulnerability to increasing food prices. It should be remembered that if new techniques to recycle potassium from waste water were developed, the impacts predicted here would be much reduced.

5. Conclusions

Currently, fertiliser potash is used extensively in the UK on tillage crops and grassland although its use has decreased in recent years. Evidence suggests that this decrease is causing potassium reserves in UK soils to fall and this will have to be replenished to maintain high yields. The most common form of potash used is muriate of potash (potassium chloride, MOP) although sulphate of potash (potassium sulphate, SOP) is beneficial for some high value crops, as it contains sulphur. Potatoes and celery have the highest required rates of potash application. However, due to their much greater areas, grass and cereals account for most of the fertiliser potash applied.

Despite the fact that the NEA scenarios used here do have limitations in their methodology, they are by far the most suited to this project and are supported by Defra. Analysis of these scenarios against the Potash Scenario, gives serious and negative predictions for future crop yields and quality and suggests an increased reliance on food imports to account for this. These impacts are expected to worsen under climate change. The sustainability of high food imports in the future is unclear.

When considering these impacts it should be remembered that it has been assumed that no suitable alternatives to potash are available (only potassium recycling at current rates). If new methods for potassium recycling are developed, it is possible that a decline in yields would not be seen, that its severity would decrease or that its onset would be delayed. However, any benefit of more efficient potassium re-cycling is only likely to be seen in the long-term meaning some short-term (within 3 – 5 years from potash disappearance) declines in yields would be seen.

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Appendix A – Literature Search Methodology

Summary of searches February / March 2012

General web searching used Google ‘Advanced‘ search option identified a number of potentially useful sites, namely:

1. The Potash Development Association - http://www.pda.org.uk/index.html
2. The International Potash Institute - http://www.ipipotash.org/en/index.php
3. Which gives access to the ‘Potash Review’ 1956 -1995 - http://www.ipipotash.org/en/review.php

Also various monographs were identified on the Defra and other sites. Searching was then carried on the OVID host’s version of the CAB Abstracts database 1973 to 2012, this identified 139 items which were downloaded of which 26 were relevant to the review. Search terms used are below:

1 potash industry {Including Limited Related Terms} (23376)
2 potash industry.mp. [mp=abstract, title, original title, broad terms, heading words] (49)
3 ("potash fertiliser*" or "potash fertilizer*").mp. [mp=abstract, title, original title, broad terms, heading
words] (15746)
4 ("potash fertiliser*" or "potash fertilizer*").ti. (111)
5 (review* or future or importance or crucial or key).ti. (103830)
6 3 and 5 (140)
7 6 not 4 (139)

Additional searches were then carried out to cover “How long will it take for the levels of potash in soils to fall?” and “Potash has no commercial substitute”. Therefore additional searches were performed concentrating especially on K in soils and potash substitutes; these retrieved 204 and 76 items respectively of which 3 and 5 were relevant to the review. Search terms used are below:

Potassium in soils:

1 (soil or soils).mp. [mp=abstract, title, original title, broad terms, heading words] (689314)

2 (potassium or potash).ti. (20347)

3 1 and 2 (8202)

4 (level or levels or deplet* or remov* or leach* or extract* or decreas* or avail*).ti. (229092)

5 3 and 4 (1212)

6 (soil or soils).ti. (269221)

7 5 and 6 (777)

8 7 and "availability".sa_suba. (204)

Potash substitutes:

1 potash.mp. [mp=abstract, title, original title, broad terms, heading words] (17578)

2 potassium.mp. [mp=abstract, title, original title, broad terms, heading words] (115109)

3 (fertliser* or fertilizer*).mp. [mp=abstract, title, original title, broad terms, heading words] (235835)

4 2 and 3 (41103)

5 1 or 4 (42417)

6 (substitute* or alternative*).ti. (24080)

7 5 and 6 (76)

Appendix B – Table of considered scenarios

Name	Description	Consider	Reason
Climate Change Risk Assessment for the Agricultural Sector	**Created to assess the potential risks (and any opportunities) resulting from climate change in the UK. Funded by Defra and published in January 2012.**	**Yes**	**Fulfils all the selection criteria**
NEA Scenarios	**Scenarios created to assess how ecosystem services may alter under different futures. The project was part funded by Defra and ran from 2009 to 2011.**	**Yes**	**Fulfils all the selection criteria**
DETR / UKCIP - Socio-economic futures scenarios for climate impact assessment	Created to assess the potential impacts of changing climate in the UK	No	Does not detail cropping patterns
Environment Agency - Social scenarios for water resources 2050	Aimed to be a tool to be used by the Environment Agency to assess water and waste policies	No	Does not focus on agriculture
Foresight Project, Office of Science and Technology - Flood and Coastal Defence Project. UK flood risk 2030 to 2100: Responding to the challenge.	Developed to assess the future of flood and coastal defence in the UK	No	Does not focus on agriculture
Foresight Intelligent Infrastructure Project - Intelligent Infrastructure Futures: the scenarios - towards 2055	Focuses on the design and implementation of infrastructure in the UK	No	Does not focus on agriculture
Shell International - Shell energy scenarios to 2050	To consider the future of energy to 2050	No	Does not focus on agriculture
Department of Innovation - Powering our lives: Sustainable energy management and the built environment.	To assess the potential changes in the built environment to 2050	No	Does not focus on agriculture
Catham House - Thinking about the Future of Food. The Catham House Food Supply Scenarios	Aims to assess the future changes to food supply globally and their impacts on the EU / UK to 2020	No	Does not go to 2060

Name	Description	Consider	Reason
Environment Agency Scenarios 2030	Assessment of the future pressures on the UK environment. Designed to be a tool for policy makers	No	Does not go to 2060
BERR - Long term scenarios project, 2020	Created to assess the robustness of the Business, Enterprise and Regulatory Reform Team's (BERR) energy strategy to 2020	No	Does not go to 2060
Foresight 2020 scenarios	Focuses on social and economic trends. Considers what he UK might be like in 2020	No	Does not go to 2060
Food Ethics Council - Future Scenarios for the UK Food System. A toolkit for thinking ahead	Looking into what food might be eaten in the UK in 2022 and where it will be sourced from / to	No	Does not go to 2060
Exploring the future - guidance toolkit for using Environment Agency Scenarios 2030	More focussed on land use than the above. Looking at changing land use and policy implications	No	Does not go to 2060
Yorkshire Futures - The future of Yorkshire and Humber: trends and scenarios to 2030	To assess what Yorkshire might look like in the future	No	Does not go to 2060
Shell Global Scenarios to 2025	To consider the future of energy to 2025	No	Does not go to 2060
RELU - Rural Futures Scenarios 2020	To define social and economic research needs in order to promote rural economies	No	Does not go to 2060
Department of Innovation, Universities and Skills (DIUS) - UK futures: Society and Economy 2030	Aimed at analysing DIUS policies and strategies	No	Does not go to 2060 and does not focus on agriculture
Humanitarian Futures Programme - Humanitarian Futures: Planning from the future	Assessing how responses to humanitarian crises may be effected by policy	No	Does not go to 2060 and does not focus on agriculture
CIPFA - The future of services to the public - reviewing the pressures and challenges for long term change	Defining what the future of public services may be to 2030	No	Does not go to 2060 and does not focus on agriculture

Name	Description	Consider	Reason
Carnegie UK Trust - The shape of civil society to come and scenarios for civil society to 2025	To assess how the future could affect civil society in UK and Ireland	No	Does not go to 2060 and does not focus on agriculture
HSL - The future of health and safety in 2017	To assess the likely situation of health and safety in the workplace in 2017	No	Does not go to 2060 and does not focus on agriculture
The Countryside Agency - Is this the future we want? Land management scenarios in the south west	To start a debate on the future of land based economies in the South West of England to 2012	No	Does not go to 2060 and does not focus on agriculture
Foresight - the US Environmental Protection Agency	Created to identify potential future risks to the Environment	No	Does not go to 2060 and does not focus on UK
European Environment Agency (EEA) - Land use scenarios for Europe: qualitative and quantitative analysis on a European scale	How European land use may change in the future	No	Does not go to 2060 and does not focus on UK
Ofgem - Project Discovery Energy Market Scenarios	Created to assess the ability of current energy markets to deliver sustainable energy to 2020	No	Does not go to 2060 and focuses on energy
The Commission of Architects and the Built Environment (CABE) and The Royal Institute of British Architects (RIBA) - Housing Futures	Created to enable future opportunities and barriers to housing development	No	Does not go to 2060 and focuses on housing
European Commission - European Real Estate Scenarios: Nirvana or Nemesis	To assess what European property will be like in 2020	No	Does not go to 2060 and focuses on housing
King Sturge - Global Real Estate Scenarios	To consider the future of the real estate industry in 2015	No	Does not go to 2060 and focuses on housing
Marine Ecosystems - Alternative future scenarios for marine ecosystems (AFMEC)	Developed to assess the changes in marine ecosystems and use to 2036	No	Does not go to 2060 and focuses on marine ecosystems
The East of England Development Agency - Scenario planning: developing a shared understanding of the influences on the economic development of the East of England	Created to assist in the development of strategic economic futures for the East of England	No	Does not go to 2060 and focuses on the East of England

Name	Description	Consider	Reason
Urban land institute - The global city 2030	Created to look at the changes to cities globally.	No	Does not go to 2060 and focuses on urban land
The Countryside Agency - The state of the countryside, 2020	Assessed the possible future of the England countryside	No	Does not go to 2060 and only covers England
The United Nations Environment Programme - Global Environmental Outlook: environment for development GEO-4	Assessment of the future interactions between environment and society	No	Does not use UKCIP
The Intergovernmental Panel on Climate Change - Special report on emissions scenarios	Created to assess potential impacts of industry and society on future emissions of green house gasses	No	Does not use UKCIP
Millennium Ecosystem Assessment Scenarios	Created to explore how ecosystem change could impact on human well-being	No	Does not use UKCIP
Eururalis	Assessing the future land use of Europe	No	Does not use UKCIP
ATEAM	Assess the risks posed by global change, to human sectors reliant on ecosystem services	No	Does not use UKCIP
CLUE	Considers changing land use and land cover	No	Does not use UKCIP
Stockholme Environment Institute - Great Transition. The promise and lure of the times ahead.	Looking at the future social shape of the world	No	Does not use UKCIP
EEA Prelude	Created to explore what future European landscapes look like	No	Does not use UKCIP and does not detail cropping patterns
Foresight	To provide an evidence base for changing land use patterns in the future	No	Does not use UKCIP and does not detail cropping patterns
Tyndall Centre for Climate Change Research - UK Hydrogen Futures to 2050	Developed to explore supply pathways that would promote hydrogen fuel use in the UK	No	Does not use UKCIP and does not focus on agriculture
Re-assessing drought risks for UK crops using UKCIP02 climate change scenarios	Used to assess the future drought related yield loss under different climates	No	Uses old UKCIP projections

Appendix C – Evidence used to answer questions

Table A.1. Sources of evidence used in answering yield, quality and production questions.

Number	Relevant Content	Reference
1	A lack of potassium in soils can lead to decreases in yields. Potassium depletion in many developing countries leads to low yields.	Cakmak, I. 2010. Potassium for better crop production and quality. *Plant Soil.* **335,** 1 - 2.
2	Potassium is needed to gain maximum yields. Potash varieties are the most common source of potassium in agriculture with other potassium sources being locally important.	Cooke, G. W. 1975. *Fertilizing for Maximum Yield*. Granada Publishing Limited.
3	Yield may decrease with low potash levels in soils. Potash requirements of miscanthus and willow.	Defra 2010a. *The Fertiliser Manual – 8th Edition.* The Stationary Office.
4	There is an increase in yield depending on the potassium requirements of the crop and the level of available potassium in the soil	Johnston, A. E. & Krauss, A. 1999. The essential role of potassium in diverse cropping systems: future research needs and benefits. *16th World Congress of Soil Science, Motpellier, France, 20 - 26 August 1998*. pg 101 - 120.
5	If soil available K is low, applying potash will improve yields for arable crops and grass.	Johnston, A. E. 2007. Potassium, magnesium and soil fertility: long term experimental evidence. *Proceedings No. 613, The International Fertiliser Society, Leek.*
6	With potassium fertilization a small increase in yield was seen	Mohr, R. M., Grant, C. A., May, W. E. & Stevenson, F. C. 2007. The influence of nitrogen, phosphorus and potash fertilizer application on oat yield and quality. Canadian Journal of Soil Science. **87(4)**, 459-468
7	No significant increase in maize yield with increased potash use. However, no measure of initial potassium concentrations in test soils was carried out, and results suggest the crop was limited by nitrogen availability rather than potassium availability.	Srinivas, P. S. & Panwar, V. P. S. 2003. Combined effects of intercropping maize with pulses and potash fertilizer on stem borer, Chilo partellus. *Annals of Agricultural Research.* **3**, 461 - 465.
8	There was no significant change in yield with addition of potash fertiliser although levels of available potassium in test soils were already high.	Wankhade, R. S., Choudhari, M. H. & Jadhao, B. H. 1996. Effect of graded doses of phosphorus and potash fertilizers on growth and yield of garlic. *Journal of Soils and Crops.* **6 (1)**, 36 - 39.

Table A.1. (cont.). Sources of evidence used in answering yield, quality and production questions.

Number	Relevant Content	Reference
9	Increased yield was seen in the 9th and 10th year of the study at one site. However, withholding potash did not reduce the yield over an 8 year period in limestone soil.	Withers, P. J. A., Unwin, R. J., Grylls, J. P. & Kane, R. 1994. Effects of withholding phosphate and potash fertilizer on grain yield of cereals and on plant - available phosphorus and potassium in calcareous soils. *European Journal of Agronomy* . **3 (1)**, 1 - 8.
10	Potential link between yield declines and potassium deficiency in India. So many separate reports on potassium fertilisation raising crop quality, that research should now focus on communicating this to farmers and increasing potassium uptake efficiency.	Romheld, V. & Kirkby, E. A. 2010. Research on potassium in agriculture: needs and prospects. *Plant Soil* . **335,** 155 - 180.
11	Potassium increases quality of fruit and vegetables	Lester, G. E., Jifon, J. L. & Makus, D. 2010. Impact of potassium nutrition on food quality of fruits and vegetables: a condensed and concise review of the literature. *Better Crops* . **94**, 18 – 21.
12	Potassium is needed to gain maximum yields and high levels of quality	Pettigrew, W. T. 2007. Potassium influence on crop yield and quality. Proceedings No. 614, The International Fertiliser Society, Leek.
23	In some crops of maritime origin, notably sugar beet, sodium can substitute to some extent for potassium as a solute (Draycott and Bugg 1982, Marschner 1995). For this crop, effects of reduced potassium supply could be delayed by increased application of sodium.	Draycott, A. P. and Bugg, S. M. (1982). Response by sugar beet to various amounts and times of application of sodium chloride fertilizer in relation to soil type. *The Journal of Agricultural Science,* **98**, 579-592. Marschner, H. (1995). *Mineral Nutrition of Higher Plants* . Academic Press, London.
25	If fertilizer potash were not available, there would be a reduction in annual input to UK soils of around 250,000 t K_2O	AIC. (2011). *Fertiliser Statistics 2011* . Agricultural Industries Confederation, Peterborough.

Table A.2. Sources of evidence used in answering biotic stress questions.

Number	Relevant Content	Reference
10	High potassium levels correspond to a decrease in the incidence of disease.	Romheld, V. & Kirkby, E. A. 2010. Research on potassium in agriculture: needs and prospects. *Plant Soil* . **335**, 155 - 180.
13	Potassium decreases cell permeability, susceptibility of tissues to penetration and is involved in increasing the thickness of cell walls. The increase in disease resistance is particularly obvious on potassium deficit soils.	Katan, J. 2009. Mineral nutrient management and plant disease. *Optimizing Crop Nutrition.* **21,** 6 - 8.
14	In a review of 165 experiments looking at fungal, bacterial and nematode diseases, 117 showed a decrease in disease incidence with increased potassium and 48 showed an increase in disease with increased potassium availability.	Prabhu, A.S., N.D. Fageria, D.M. Huber, and F.A. Rodrigues. 2007. Potassium and plant disease. p57-78. *In* : Datnoff, Elmer and Huber (eds.). 2007. Mineral Nutrition and Plant Disease. *APS Press, St. Paul, MN.*
15	The majority of reviews of potassium and pest / disease interactions show high potassium levels decrease the occurrence of disease. However, some show an increase with increased potassium. In **some** cases, where potash is applied, it is thought that chlorine rather than potassium is creating the increased resistance in the plant. Potassium deficient Arabidopsis thaliana, grown under experimental conditions, are shown to accumulate insect deterrent metabolites suggested to counteract any increased susceptibility due to potassium deficiency.	Amtmann, A., Troufflard, S. & Armengaud, P. 2008. The effect of potassium nutrition on pest and disease resistance in plants. *Physiologia Plantarum* . **133,** 682 - 691.
16	Review of 2449 studies concerning the interaction between potassium and plant health. Covering over 400 pests and diseases. Decreased incidence of pests and disease in 69% of cases and increased in 28%. 70% of fungal and bacterial diseases, 60% of insects and mites decreased. Whereas the incidence of viruses and nematodes increased with increased potassium availability.	Perrenoud, S. 1990. Potassium and plant health. IPI Research Topics No. 3. International Potash Institute, Basel.

Table A.3. Sources of evidence used in answering abiotic stress (drought stress) questions.

Number	Relevant Content	Reference
10	Optimising potassium nutrition leads to a decrease in the accumulation of cell damaging reactive oxygen species (ROS). Potassium fertilisation causes an increase in drought and salinity resistance.	Romheld, V. & Kirkby, E. A. 2010. Research on potassium in agriculture: needs and prospects. *Plant Soil* . **335**, 155 - 180.
17	Stress causes accumulation of ROS in plants which can cause damage. Potassium decreases the production of ROS and increases drought and salinity resistance.	Cakmak, I. 2005. The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *J. Plant Nutr. Soil Sci.* **168,** 521 - 530.

Table A.4. Sources of evidence used in answering nitrogen uptake questions.

Number	Relevant Content	Reference
10	Potassium facilitates transport of sugars to roots, thus promoting root growth and ion uptake.	Romheld, V. & Kirkby, E. A. 2010. Research on potassium in agriculture: needs and prospects. *Plant Soil* . **335**, 155 - 180.
18	Sufficient plant available potassium is needed for plants to show a yield response to additional nitrogen fertilisation. If insufficient potassium levels are present then additional nitrogen has no effect.	Johnston, A. E. & Milford, G. F. J. 2008. Potassium and nitrogen interactions in crops. Potash Development Association, York, UK.
19	potassium supply has been shown to affect nitrate uptake by roots and its subsequent translocation in the plant	Blevins D G, Barnett N M and Frost W B (1978) Role of potassium and malate in nitrate uptake and translocation by wheat seedlings. *Plant Physiology* , **62**, 784-788.
20	As the amount of nitrogen fertiliser applied to crops increases, the relative uptake is positively related to the amount potash applied.	Wolton K M, Brockman J S, Brough D W T and Shaw P G (1968) The effect of nitrogen, phosphate and potash fertilizers on three grass species. *Journal of Agricultural Science* , **70**, 195-202.
21	In long-term experiments at Rothamsted and Saxmundham, the amount of nitrogen in harvested grain (wheat grain in 1984) was greater at the higher level of soil available potassium.	Johnston A E (1986) Saxmundham Experimental Station 1899-1986. A review of achievements during 1965-1986. Rothamsted Report for 1986, Part 2 265-279.
22	Sugar beet nitrogen uptake at soil K Index 0 was 82% of that at soil K Index 2- where 150 kg N/ha was applied.	Milford G F J and Johnston A E (2007) *Potassium and nitrogen interactions in crop production* . Proceedings No. 615, The International Fertiliser Society, Leek.
23	In some crops of maritime origin, notably sugar beet, sodium can substitute to some extent for potassium as a solute. For this crop, effects of reduced potassium supply could be delayed by increased application of sodium.	Draycott, A. P. and Bugg, S. M. (1982). Response by sugar beet to various amounts and times of application of sodium chloride fertilizer in relation to soil type. *The Journal of Agricultural Science,* **98**, 579-592. Marschner, H. (1995). *Mineral Nutrition of Higher Plants* . Academic Press, London.
24	The nitrogen that is applied but not taken up by the crop would remain in the soil after harvest, largely in the nitrate form that is susceptible to leaching	Richards I R, Wallace P A and Paulson G A (1996) Effects of applied nitrogen on soil nitrate-nitrogen after harvest of winter barley. *Fertilizer Research* , **45**, 65-67.

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APPENDIX 5

POLYHALITE MARKET STUDY CRU REPORT

CRU Reference number:

April 2014

Polyhalite Market Study: April 2014

A report prepared for Sirius Minerals

THE INDEPENDENT AUTHORITY
MINING | METALS | FERTILIZERS

CRU Strategies, a division of CRU International Limited
Chancery House, 53-64 Chancery Lane, London, WC2A 1QS, UK

Tel: +44 (0)20 7903 2000 Fax: +44 (0)20 7903 2172 Website: www.crugroup.com

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Chapter 5 – Polyhalite Demand Curve

Executive Summary

1. Introduction

The objective of this report is to make an independent assessment of the market *potential* for polyhalite to be produced from the York Potash Project.

In preparing this assessment CRU has taken a technical approach, based upon the intrinsic value of polyhalite from a nutrient perspective and applied economic theory to estimate the range of market demand at different prices.

2. CRU Strategies

CRU Strategies is part of the CRU Group, a well-respected and independent market analysis company focussed entirely on the mining, metals and fertilizer industry segments. We publish a wide range of reports available on subscription that monitor, analyse and forecast market developments across the fertilizer industry. In addition to the analysis and forecasting products, CRU Group publishes "*Fertilizer Week*" which is a weekly newsletter that surveys the markets and publishes prices that are widely used by the industry in commercial contracts.

CRU Strategies is the management consulting division of the CRU Group providing independent and proprietary advice to the world's leading metals, mining and fertilizer companies, suppliers to the industry, governments and financial institutions. We have extensive experience in providing market strategy reports for IPOs, feasibility studies and lenders market reports, where our input is highly valued due to our understanding of the market and the integrity and independence of our conclusions.

3. Assessment Methodology

CRU's approach to determining the market potential has looked at the substitution opportunity for polyhalite into a number of existing fertilizer markets. This has been done based on the nutrient value, which in turn is determined by detailed market pricing data. In addition the analysis considers the impact of production volume, freight costs to target markets, application costs and the response of competitor fertilizer suppliers, in order to develop global demand curves for polyhalite. The analysis is focused on demand in 2018; the year first production is expected from the project.

The global demand curves demonstrate the size of the potential market for polyhalite when used in the following applications:

1. As a direct competitor with potassium magnesium sulphate products

2. As a competing source of K_2O with MOP and SOP
3. As a feedstock for fertilizer blends (NPK's)
4. As an alternative source of sulphur to SSP and AS

Polyhalite has a value based upon the nutrient value of its constituent parts; it also has a value as a multi-nutrient fertilizer product. CRU is of the opinion that if the product was sold at a substantial discount to this value, the market would be extremely large. Conversely, if the product were marketed at a high price where only a few niche consumers could recognise the value as such, then the market would be extremely limited. The second example ('niche product at a premium') represents CRU's understanding of the current status of the polyhalite market (UK only) with certain farmers prepared to take polyhalite at a premium price.

Between the two extremes referenced above, there will be a price (determined by the market) at which Sirius Minerals will be able to place all of the production from the York Potash Project. This price will likely vary with the chosen production rate and dependent on a number of variables.

4. Potash and NPKs

The Sirius Minerals marketing strategy has identified the potential use of polyhalite as a feedstock for the production of bulk blend or compound NPK's. This report provides an overview of the NPK market and assesses the ability to include polyhalite in NPK blends with added macronutrients through the use of a fertilizer blending model developed by CRU.

CRU's analysis' shows that polyhalite can be a cost competitive source of macronutrients to a wide range of NPK formulations with added magnesium and/or sulphur. The intrinsic value of polyhalite was found to vary between $106.80 and $197.80 per tonne of polyhalite based on 2018 prices, depending on the ratio of nutrients in the blend. The results validate Sirius Minerals' claims that polyhalite has the potential to be used as a feedstock in the formation of NPKs.

5. Sulphur

Polyhalite contains a similar amount of sulphur per tonne (19%) as other common sulphur fertilizers, such as, ammonium sulphate (24%) and super single phosphate (11-14%). This creates the potential for polyhalite to compete with these products as a source of sulphur in blends or as a direct application fertilizer.

The case studies presented show that there is a high degree of variation over time and across regions in the implied value sulphur in fertilizers. Value appears to be more related to what the market is willing to pay for the product, based on the way it affects farmer yields and thus incomes rather than the cost of production. This is most evident in the comparison of pricing in Europe (a large ammonium sulphate exporter) and the Americas where the soil is highly sulphur deficient. The impact is an implied value for the sulphur content of polyhalite of $10-15/t in Europe and upwards of $100/t in the Americas.

6. Potassium Magnesium Sulphate

Polyhalite can be included in the classification of potassium magnesium sulphate (SOPM) fertilizers. A number of SOPM fertilizers are sold commercially into the market and provide the best like-for-like comparison with polyhalite. CRU Strategies provides an overview of the current potassium magnesium sulphate market and a case study of two prominent North American products – Trio and K-Mag.

Current producers of SOPM are able to achieve a significant premium in excess of the MOP value of the potassium content of their products. This premium is thought to exist due to a combination of the following factors: 1) additional macronutrients (magnesium, sulphur); 2) chlorine-free potash content; and 3) the potential premium from the ability to apply magnesium at the same time as potassium.

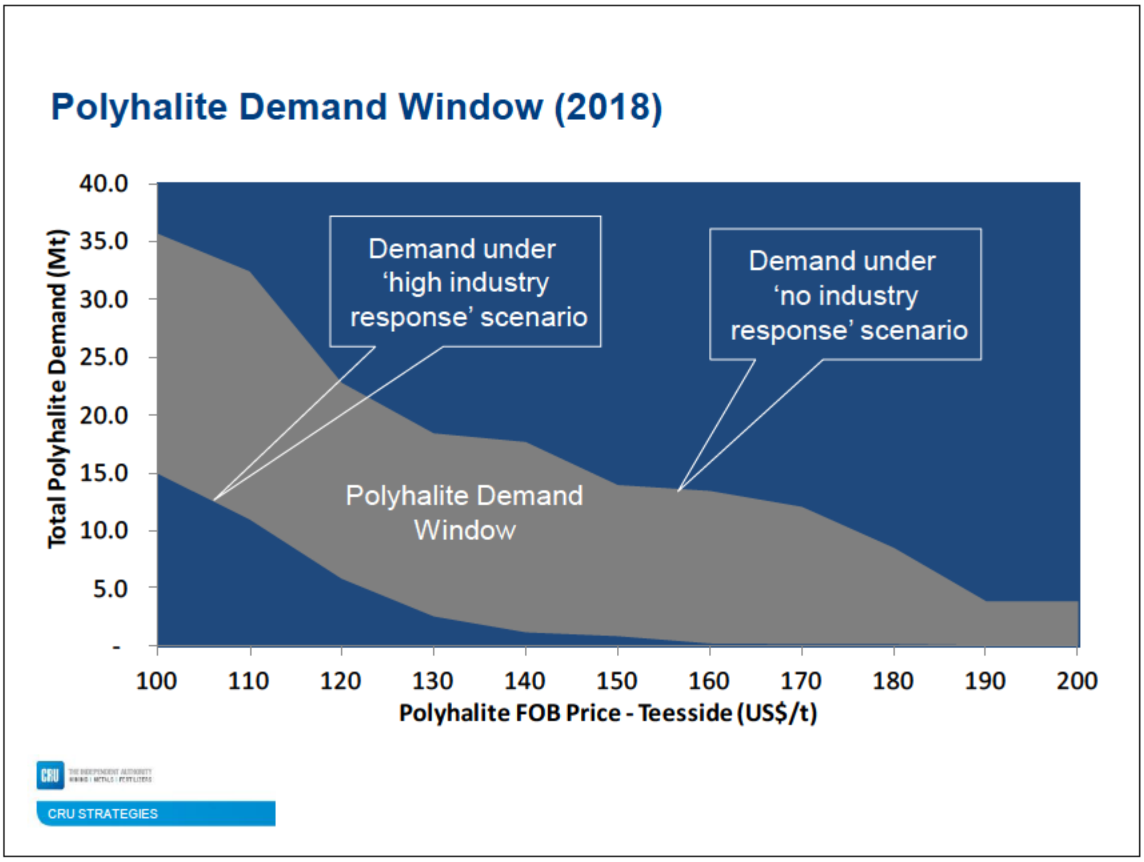
7. Polyhalite Demand Assessment

CRU Strategies has assessed the demand for polyhalite over a range of prices to determine a polyhalite demand window. This 'demand window' represents CRU's assessment of the likely extremes of demand at various price points based on the response of existing producers of substitute products to the production from the York Potash Project.

The most conservative of the scenarios considered in this report evaluates the demand for polyhalite against the marginal cost of production for substitutable products. This scenario is titled the '*High Industry Response*' and represents the lower bound of the demand window. In this scenario existing producers choose to reduce profits in the short term in order to protect market share in the long term. This cost cutting approach by incumbent producers can only be implemented over the short to medium term, beyond this timeframe prices would return to market levels as marginal producers choose to focus on other markets where returns are higher.

If Sirius Minerals were to establish York Potash in the market then it would be expected that through industry rationalisation prices of substitute products would rise above breakeven costs. The second pricing scenario models the situation in which incumbent producers elect to sacrifice market share in order to maintain higher prices. The demand for polyhalite under this assumption is shown by the upper bound of the demand window and is called the '*No Industry Response*' scenario.

The two scenarios represent the extremes of possible responses by incumbent fertilizer producers to a new entrant in the market (i.e. Sirius Minerals). CRU Strategies is of the opinion that the range of values between these two curves captures the demand for polyhalite based on expected 2018 fertilizer prices and demand. The exact position of sales volume and price within this 'demand window' will depend on the strategy implemented by Sirius Minerals. CRU Strategies has not attempted to identify a specific price point.



Key Conclusions of CRU Strategies Demand Assessment

The demand analysis indicates that **even in the most conservative of scenario's considered** (the *High Industry Response* case) the potential demand at prices below $130 in 2018 is large enough to absorb the initial forecast production volume of Sirius Minerals across a range of agricultural markets worldwide. In addition, the analysis indicates in the *High Industry Response* case that the potential demand at prices below $110 in 2018 is large enough to absorb the full 13Mt per annum production capacity of York Potash.

Achieving volumes above the *High Industry Response* case will depend on the competitive response of incumbent producers, the ability of Sirius Minerals to obtain the value premium associated with chlorine-free potash when replacing other potassium fertilizers and to reach a broad customer base. Both of these latter requirements will be closely related to the capacity of Sirius Minerals and its distributors to market polyhalite as a bulk commodity and not a niche organic fertilizer.

The outputs of the demand curve analysis show relatively good correlation with the current sales performance of Sirius Minerals. Current reports indicate that Sirius has secured multi-year commitments for ~4.8Mt per annum, indicating that demand already exists in the market for this relatively unproven product. The sales commitments are comprised of:

- 1.5 Million t/y in off take agreements in China and the US.
- 2.0 Million tonnes in Memorandums of Understanding (MOUs) which represent a mutual agreement between parties to form a long-term partnership with key terms that serve the basis for negotiating the clauses of a polyhalite supply contract
- 1.3M t/y in Framework Sales Agreements or Letters of Intent with fertilizer manufacturers in Europe, South America and elsewhere.

Comments from the company indicate that the offtake contracts have been based on the nutrient content of polyhalite at market prices. This would indicate values for polyhalite of FOB $150 and above, depending on the nutrient requirements of the buyer, a demand point that falls safely within the demand window presented above.

In summary, the analysis conducted by CRU Strategies on the fertilizer industry indicates that a market exists for polyhalite if sold as a bulk commodity at lower prices than current supply of polyhalite and at levels that are price competitive with the various existing fertilizer products.

Impact of Yield Studies on Demand Window

As part of the Sirius Minerals marketing strategy they have commissioned a number of crop trials from Agricultural departments of Universities throughout the world. The purpose of which is to prove the performance of polyhalite relative to other potassium containing fertilizers, and assure the market that the product will not have a detrimental impact on yields. This is standard practise for the introduction of a new product into market and will continue in parallel to the development of production facilities until polyhalite reaches the market in 2018.

CRU Strategies has **not** made a judgement on the potential yield improvements of polyhalite in on-farm yield, nor has it taken the yield studies presented as fact. Instead CRU Strategies has elected to assess the size of any potential demand boost from higher yields by calculating the value of a 10% or 20% yield increase on a variety of crops assuming a yield pass through of 23%.

In general, the impact of an accepted 20% yield improvement (assuming a yield pass through of 23%) is a shift in the demand curve to the right by $20-25 per tonne of polyhalite. Looking at the cut-off point for 5 Mt of polyhalite demand a 20% yield increase would move this most conservative of scenario's value from $120/t to $140/t. Likewise, at 13 Mt of polyhalite demand a 20% yield increase would move this most conservative of scenario’s value from $100/t to $130/t.

Chapter 1 – Introduction

The objective of this report is to determine the market *potential* for polyhalite. It has taken a technical approach, based upon the intrinsic value of polyhalite from a nutrient perspective and applied economic theory to estimate the range of market demand at different prices. Inherent in our calculations is the premise that consumers make rational decisions based upon the value of the polyhalite to their particular need. Given the size and global nature of the market this is considered a robust assumption.

Polyhalite has a value based upon the nutrient value of its constituent parts; it also has a value as a multi-nutrient fertilizer product. If the product were sold at a substantial discount to the nutrient value of its constituent parts, the market would be extremely large. Conversely, if the product were marketed at a high price where only a few niche consumers could recognise the value as such, then the market would be extremely limited. The second example ('niche product at a premium') represents the current status of the polyhalite market (UK only) with organic farmers prepared to take polyhalite at a premium price.

Between the two extremes referenced above, there will be a price (determined by the market) at which Sirius Minerals will place their production. This price will vary with the chosen production rate. A demand curve is presented in Chapter 5 that clearly identifies the expected market size at varying production rates and sale price.

Polyhalite is an evaporite mineral consisting of potassium, sulphur, calcium and magnesium with a chemical formula of $K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$. It is most suitable for use within the fertilizer industry because it contains four of the six essential macro-nutrients required for plant growth. Improved understanding of the role of each macro-nutrient and their interdependencies in the search for ever higher agricultural yields has raised the profile of multi-nutrient fertilizers in recent years.

The fertilizer industry involves the mining, beneficiation and / or manufacture of hundreds of millions of tonnes of different products that are ultimately applied globally to improve the yield and quality of crops grown to feed our planet's population. There is a wide range of fertilizer products that serve different parts of the global agricultural market. For example, a product designed to improve yields and quality at an orange plantation in Florida may be valued highly if it contained magnesium and was chloride free whereas a wheat farmer in Eastern Europe may place no value on these aspects.

1.1 The CRU Methodology

CRU's approach to determining the market potential has looked at the substitution opportunity for polyhalite into a number of existing fertilizer markets. This has been done based on the nutrient value, which in turn is determined by detailed market pricing data. The CRU Group is a well-respected and independent market analysis company focussed entirely on the mining, metals and fertilizer industry segments. We publish a wide range of reports available on subscription that monitor, analyse and forecast market developments across the fertilizer industry. In addition to the analysis and forecasting products, CRU Group publishes "*Fertilizer Week*" which is a weekly newsletter that surveys the markets and publishes prices that are widely used by the industry in commercial contracts.

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In addition to understanding prices and supply-demand dynamics, CRU Group also analyses costs in some detail so we are in a position to understand the fundamentals of the market and can forecast the potential of a new entrant gaining market share by delivering nutrients at or below the current market price.

The following chapters look at the potential for polyhalite in NPKs (a term that encompasses a wide range of fertilizer products that are blended to meet the specific agricultural needs) and the potential as a source of sulphur and magnesium to substitute existing fertilizer product. The table below compares the nutrient value of some of the more commonly used fertilizers and their current market size with polyhalite. It also presents the market size for NPKs, the nutrient content of which is highly variable.

Table 1.1: Fertilizers

Product	N	P	K_20	S	MgO	Ca	Global Market Size, 2013 (Mt)
Polyhalite	-	-	14%	19%	6%	12%	0.06
Muriate of potash (MOP)	-	-	60%	-	-	-	56.5
Sulphate of potash (SOP)	-	-	50%	17%	-	-	4.9
Single superphosphate (SSP)	-	20%	-	11-14%	-	20%	39.3
Ammonium Sulphate (AS)	21%	-	-	24%	-	-	25.2
Langbeinite (SOPM)	-	-	22%	22%	18%	-	1.5
Keiserite	-	-	-	20%	25%	-	1.1
NPKs (Compunds)	var.	var.	var.	var.	var.	var.	82.9
NPKs (Blends)	var.	var.	var.	var.	var.	var.	70.5

Source: CRU

As can be seen from the table above, there are a large number of fertilizer markets into which polyhalite can be marketed and each of these will value the product differently. When assessing the substitution opportunity, the current demand is converted into polyhalite equivalent tonnes. For example, from a magnesium perspective, 1 tonne of langbeinite is equivalent to 3 tonnes of polyhalite; this calculation has been completed for all the relevant target markets.

By understanding the expected cost of production and price for the target fertilizers in 2018 (available from CRU's suite of Market Outlook publications), CRU has then determined the price at which substitution is possible. Through looking at both the cost of production and expected market price CRU has identified the boundaries of the potential market. Effectively, these two approaches represent the level of industry response to the arrival of a new market entrant. Considering the cost of production as the hurdle for substitution represents a high industry response (i.e. the market incumbents are willing to sell their products at the cost of production to maintain market share) and this situation cannot last indefinitely since these market participants will not generate a profit. CRU estimates that such a state of affairs could only last for 12-18 months maximum.

The upside for substitution is the scenario when the incumbents allow polyhalite to take market share – this could be likely in very large markets where the incumbent may already be constrained in supply and the arrival of a new market entrant may indeed stimulate new demand – this may be the case with SOPM in North America.

CRU has not considered additional yield benefits in its base case scenario. This is not because we do not believe in the agronomy tests, we are not qualified to make a judgement on this issue and believe an independent specialist will report on these trials. The impact of yield will be very positive for market potential since relatively small increases in yield deliver significant value for the farmer and, by extension, the supplier of the superior product. An example is provided in Chapter 5 which assumes a 10 and 20% yield improvement and assumed a conservative 23% flow-through of value to the supplier – the results show significant market potential for polyhalite. Note: ‘flow-through’ is the assumption of how much of the additional value of the superior yield is captured by the supplier and our estimate is based on a case study of a different yield-improving fertilizer product.

There are a range of potential outcomes for the market potential of polyhalite and these will be influenced by:

- The intrinsic value of the nutrient content (in turn influenced by commodity prices and the global / regional supply demand balance);
- The perceived and, over time, the actual benefits of using polyhalite with respect to yield improvements (small increases in yield can deliver significant benefits to a farmer which translate into higher prices that the market will be prepared to meet)
- Industry response to the arrival of a new product – CRU assumes that incumbent players in the market will not ignore the loss of market share to a new product and have modelled a range of industry response
- The marketing efforts of Sirius Minerals.

Chapter 2 – Potash and NPKs

Summary

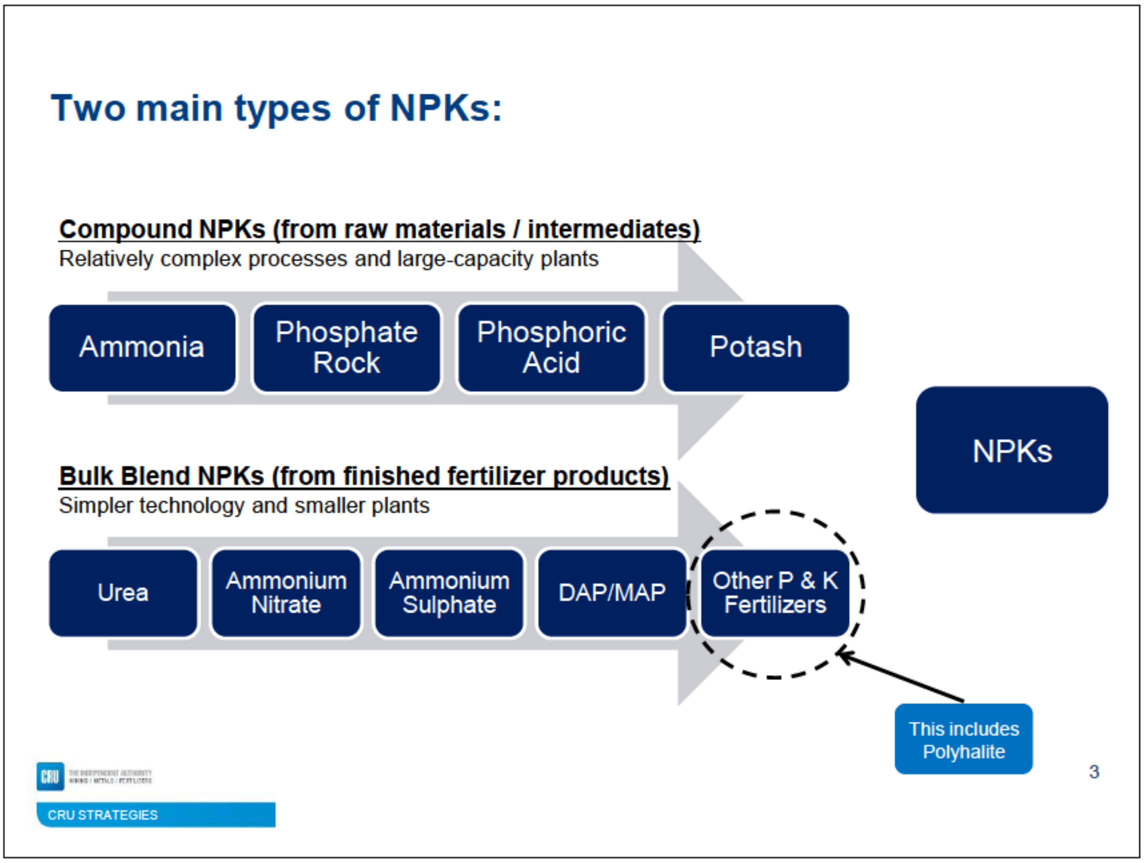
The Sirius Minerals marketing strategy has identified the potential use of polyhalite as a feedstock for the production of bulk blend or compound NPK's. This chapter provides an overview of the NPK market and assesses the ability to include polyhalite in NPK blends with added macronutrients through the use of a fertilizer blending model developed by CRU. Finally, the chapter finishes by calculating the implied value of polyhalite by assigning a value to each of the four macronutrients (potassium, magnesium, calcium and sulphur) in polyhalite.

The analysis' shows that polyhalite can be a cost competitive source of macronutrients to a wide range of NPK formulations with added magnesium and/or sulphur. The intrinsic value of polyhalite was found to vary between $106.80 and $197.80 per tonne of polyhalite, depending on the ratio of nutrients in the blend. The results validate Sirius Minerals' claims that polyhalite has the potential to be used as a feedstock in the formation of NPKs.

2.1 Introduction

As discussed in the introduction, the primary nutrients are N, P and K and the industry provides a myriad of fertilizers formulated to meet the varied needs of consumers (farmers) that take into account soil type, crop type, and previous fertilizer applications. These varied needs are increasingly met by a range of fertilizer mixes, collectively called "NPKs", many of which regularly include magnesium and sulphur, often to target particular soil deficiencies.

The formulation of NPKs can start from fertilizer raw materials and intermediates, or from finished fertilizer products. The following slide introduces the two common types of NPKs, called Compounds or Bulk Blends.



Two main types of NPKs:

Compound NPKs (from raw materials / intermediates)
Relatively complex processes and large-capacity plants

Bulk Blend NPKs (from finished fertilizer products)
Simpler technology and smaller plants

This includes Polyhalite

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2.2 NPK Production

Bulk blends were developed more than fifty years ago in the United States as a means of delivering the main fertilizer materials to farms in a more economic form than the bagged granular NPK compounds that were the norm elsewhere. Currently, bulk blends dominate supply in North and Latin America, where they are responsible for over 95% of the production of solid NPKs. In Europe, blends account for roughly one third of production. In Asia, where the proportion is around 20%, bulk blending is a minor component of fertilizer supply and does not yet appear to have yet penetrated India and China, (the two largest Asian markets), to the same extent as their North American counterparts. In Africa, a relatively small regional market for fertilizers, blends have been growing in importance and are now bigger than compounds. India, China and Africa represent growing markets for fertilizers and recent buying trends indicate an increasing appetite for NPKs.

The NPK compound production capacity is dominated by the Europe, South / South-East Asia and the Former USSR with estimated capacity of over 70% of world capacity. The Russian producers have been particularly active in the export market following the collapse of their domestic market in the early 1990s. They have built international sales by leveraging low raw material costs to offer highly competitive NPK formations, in particular 16-16-16. The large quantities and low prices effectively turned this product into a commodity fertilizer, which is now commonly quoted as a benchmark price for NPK fertilizers.

Table 2.1: NPK Global Market Forecast (‘000 t)

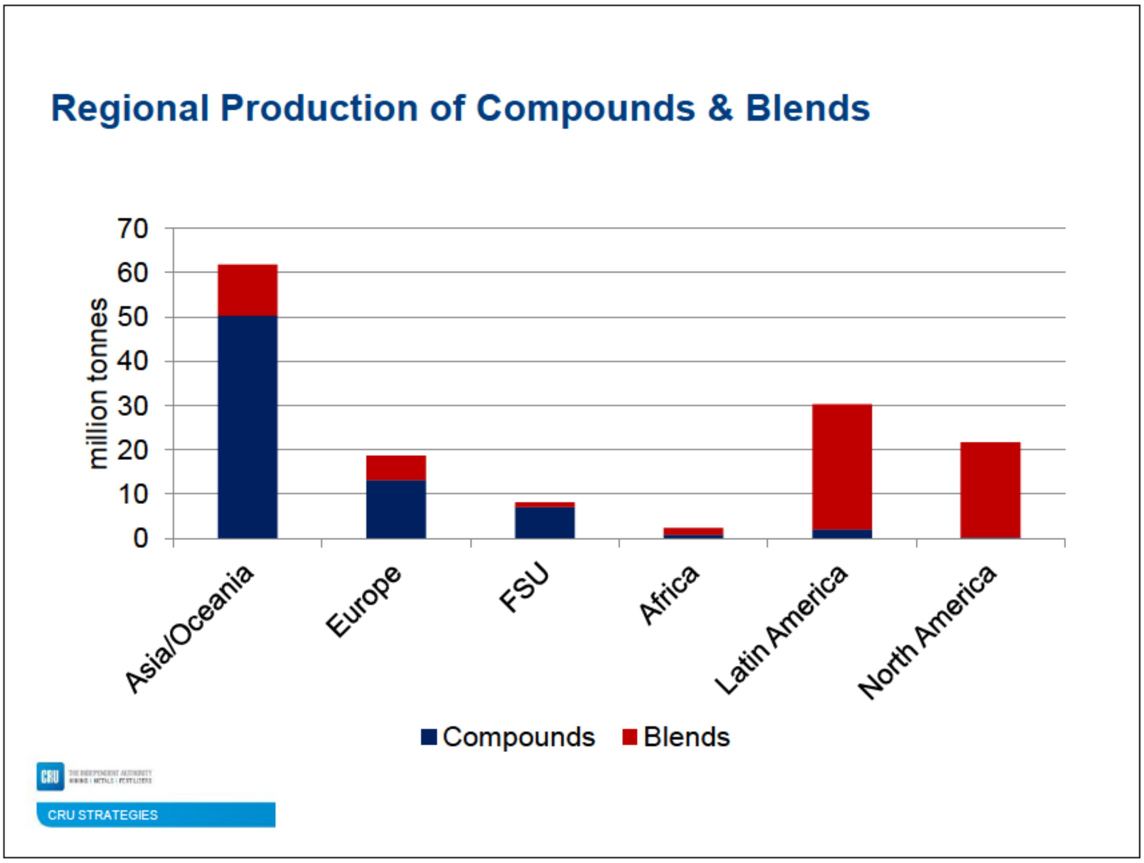
	2012	2013	2014	2015	2016	2017	CAGR (13-17)
World Total	143,000	153,398	154,604	155,835	157,548	158,984	**1.8%**
Compounds	73,700	82,917	82,917	82,917	83,373	83,524	**2.1%**
Blends	69,300	70,481	71,686	72,918	74,176	75,460	**1.4%**

Data: CRU

CAGR – Compound Annual Growth Rate

Based on the production figures above, the total market for NPKs is 143 million tonnes, of which 73.7 and 69.3 mn tonnes are compounds and dry blends respectively. These values are the basis for CRU Strategies growth forecast for the NPK market. Using the current known compound plant list and capacities, an annual production of 73.7 mn tonnes of compound NPKs equates to a usage rate of 75.9%. This usage rate is applied to the future capacity of compound production facilities, taking into account new facilities that may come online, to forecast growth in the NPK compound market. The CAGR for compound NPKs between 2012 and 2017 is forecast to be 2.1%, resulting in a market size of 83.5 mn tonnes in 2017.

Dry blend NPK production (and consumption) is predominately driven by the developed agricultural industries of North and Latin America, combining to account for 71% of the market. The growth in these markets is expected to be lower than other developing regions as any increase in arable land is expected to be small and crop yields increases reach their limit. The forecast takes these factors into account in predicting a CAGR for dry blend production of 1.4% between 2012 and 2017.



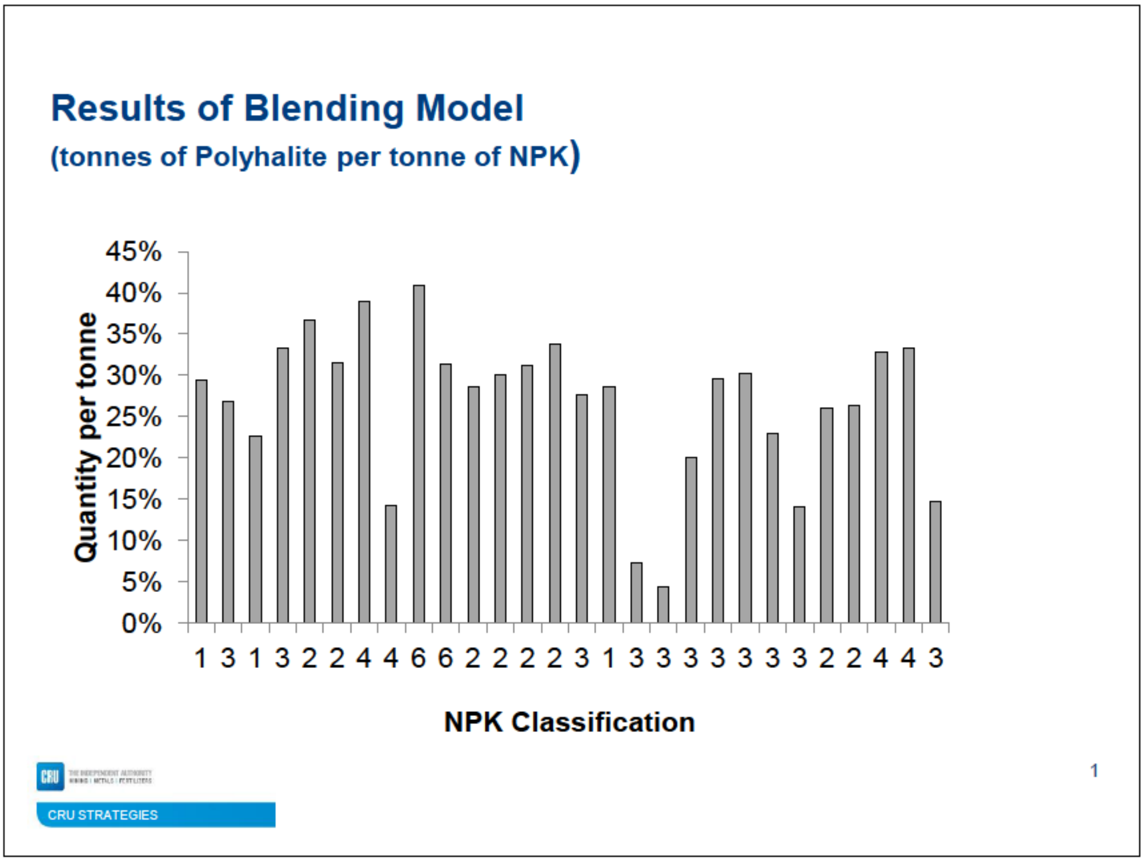
Regional Production of Compounds & Blends

2.3 Polyhalite Consumption in NPKs

CRU developed a blending model to calculate the lowest cost combination of raw materials to meet the specifications of various NPKs. The model was run for 28 different NPK combinations currently sold in the UK, Europe and other global markets from a range of current suppliers. Each fertilizer has been categorised into one of six classifications:

1. NPK
2. NPK plus sulphur
3. NPK plus sulphur and magnesium
4. NPK plus magnesium
5. NP plus sulphur
6. KN plus sulphur

The output of the blending model identifies the quantity of polyhalite (wt%) required in each of the mixtures. The graph shows clearly a wide range of polyhalite consumption in various NPKs. Some blends are well suited to the natural constituents of polyhalite and up to 40% by weight of the NPK specification can be met by polyhalite. Others only have a small quantity of polyhalite.



Results of Blending Model

(tonnes of Polyhalite per tonne of NPK)

1

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The model also calculated the expected price point for polyhalite at which it would be deemed economic to substitute other raw materials. The price range \$100-\$210/t is wider than the range of intrinsic values due to low nitrogen and high sulphur NPK specifications. This type of NPK cannot be achieved with ammonium sulphate and must rely on another, more expensive, source of sulphur. This work is developed further in the construction of the demand model presented here in Chapter 5.

2.4 NPK Pricing

The analysis seeks to build a value for polyhalite in two ways, firstly upon the cost of the constituent materials in their most commonly purchased forms. Second, the report will analyse the value that so-called "premium" NPK blends that contain added macronutrients can achieve in the market. The analysis answers the following questions:

- Value of the potash content (K_2O)
- The value of chlorine-free potash content
- Value of the sulphur and magnesium components of polyhalite

It should be noted that the availability of pricing data for "premium" NPKs is limited, and the analysis partly based upon CRU's understanding of the market.

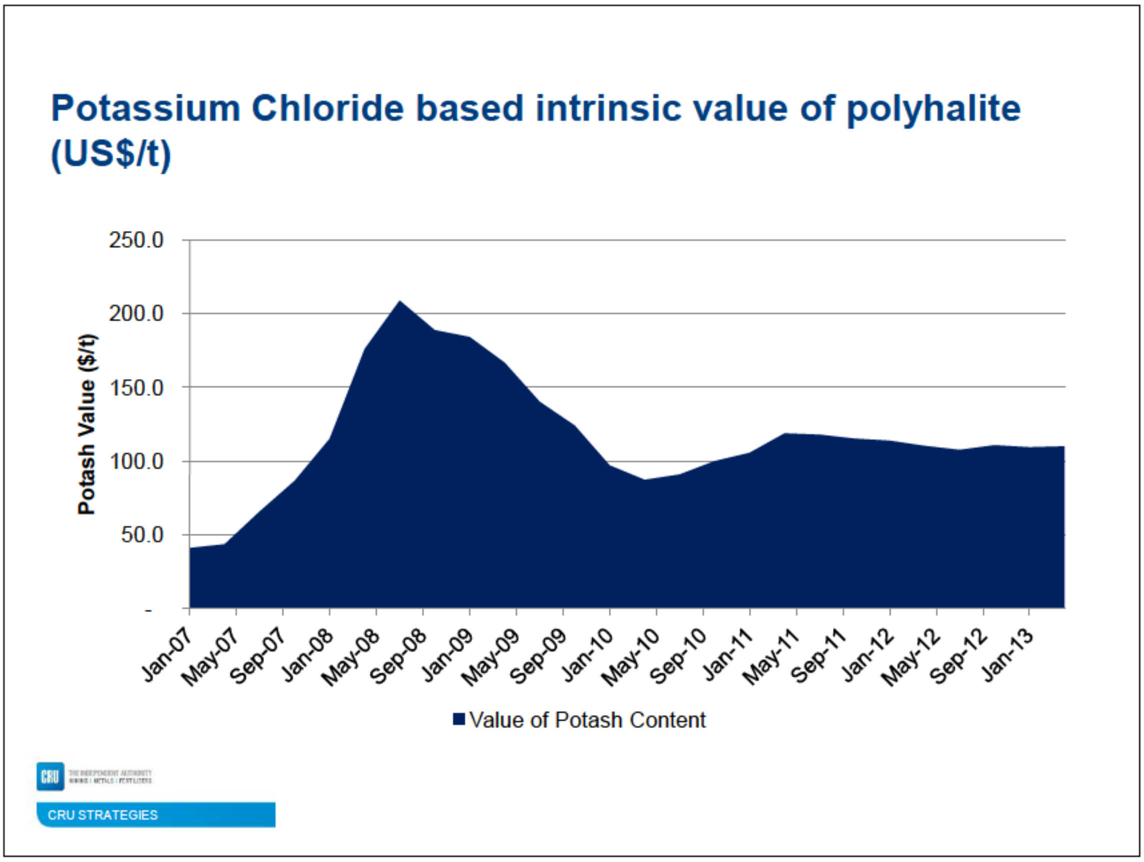
2.4.1 Constituent Value

Potash

Potash is the standard industry word for a potassium containing fertilizer and can exist as either chloride form (MOP) or sulphate form (SOP). The total potash content of a fertilizer is described in units of K_2O to assist in comparison between the two different sources. Typically, fertilizers with potash in the sulphate form (i.e. polyhalite) are sold at a premium to the chloride form. In order to perform a more robust analysis of the value for polyhalite CRU first estimated the value of the potash component against potassium chloride prices before calculating the premium for chlorine-free potash (SOP).

MOP is most commonly obtained from underground deposits of sylvinite, an ore that contains halite (sodium chloride) and sylvite (potassium chloride), and trace amounts of other minerals. The ore grade for most potash containing ore typically ranges from as low as 10% to 40% KCl, placing polyhalite at the middle of the spectrum with 14% K_2O (22.5% KCl - eqv). The industry is large, with annual capacity in 2012 of over 68 million tonnes, it is well understood from an agronomy standpoint, and applicable to a wide range of crops across the globe.

As such, the potash content of polyhalite can be considered to set a floor for the intrinsic value, representing the minimum price a seller is likely to accept. Based upon the pricing of MOP (60% K_2O) the potash value of polyhalite is shown in the table below. The value of the potash content in polyhalite peaked at over $200 per tonne in July 2008 before losing half that value in the next 18 months. Since the beginning of 2010 the value of the potash content has averaged $106.80, with a low of $87.30 in April 2010 and a high of $118.80 in April 2011.



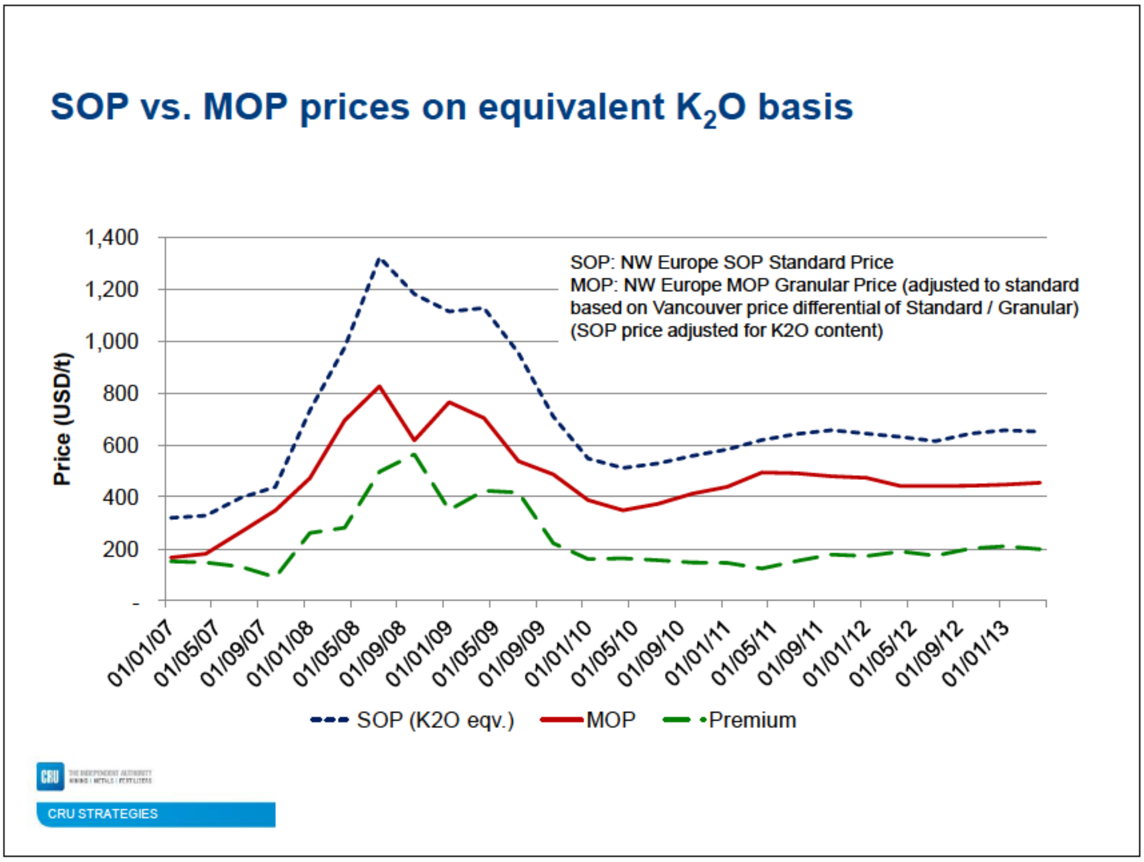
Potassium Chloride based intrinsic value of polyhalite (US$/t)

Chlorine-Free Potash Value

The most common form of potassium fertilizer is potassium chloride (MOP, muriate of potash), accounting for over 80% of the global market. The presence of chlorine in a fertilizer is not an issue for the majority of soils and crops. However, there are some cases where arid soils are prone to the accumulation of chloride ions, or crops are particularly sensitive to chloride, such as many fruits and vegetables and other premium crops. This sensitivity gives rise to a market for potassium sulphate (SOP, sulphate of potash) where, as the name suggests, the chloride is replaced with sulphate either through chemical conversion (secondary production) or the processing of potassium minerals (kainite or polyhalite).

This niche market for chlorine-free potash in the form of SOP is estimated at approximately 4.9 million tonnes in 2013 and commands a price premium per unit of potash over conventional MOP. This premium is partly due to the additional processing costs incurred by secondary producers. As the chlorine-free attribute of polyhalite may command a premium above the nutrient content of the ore it is important to estimate the premium for chlorine-free potash.

The value of chlorine-free potash has been estimated by comparing the NW Europe SOP Standard price with that of the NW Europe MOP Granular price as supplied by Fertilizer Week.



As shown in the graph above, SOP consistently sells at a premium to MOP on a K_2O equivalent basis. This premium has averaged 39% since the beginning of 2010, with a high of 47% and a low of 25%. Using these numbers a chlorine-free premium per unit (1% of a tonne) of K_2O can be calculated as averaging $2.47 since 2010. For polyhalite this equates to a premium of between $25-45 per tonne since 2010, with an average of $34.6 per tonne, based on the 14% K_2O content in polyhalite (14 x $2.47 = $34.6).

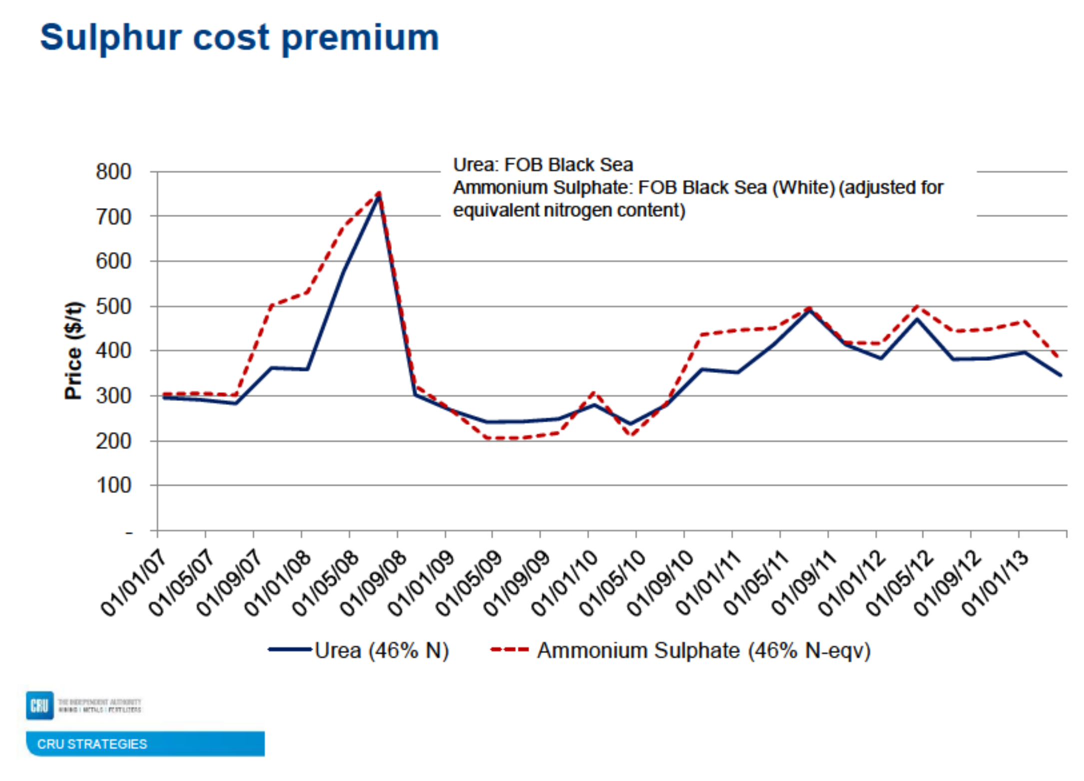
This premium will also account for part of the value of the sulphur content in polyhalite when displacing the purchase of SOP. However, if the buyer is displacing MOP with the purchase of polyhalite then no chlorine-free premium will exist, but a sulphur value may exist. This is an important point as double counting of 'intrinsic value' could easily occur.

Sulphur

The addition of sulphur into NPK fertilizer blends and compounds has gained popularity in agricultural circles as sulphur deficient soils have become an increasing problem. The rise in sulphur deficiency is attributed to improved control of sulphur and other gas emissions from coal power stations. This environmental improvement has reduced the occurrence of acid rain, a source of sulphur for many agricultural areas, which has lead to sulphur deficient soils.

For blenders to incorporate sulphur into an NPK compound or blend the most practical source of sulphur for NPK producers is ammonium sulphate (21% N, 24% S). The nitrogen component of ammonium sulphate means that it is most commonly added at the expense of urea

(46% N). The additional cost to NPK producers of including sulphur can be estimated as the cost of ammonium sulphate minus the value of the nitrogen component in the form of urea.



The sulphur cost has been estimated and the graph above depicts the historical cost of urea and ammonium sulphate based on Black Sea prices on an equivalent nitrogen content of 46%. Ammonium sulphate is a popular product for NPK producers in Europe since the sulphur content comes at a relatively small cost. Between 2010 and 2012, the premium charged for the sulphur content is estimated to have averaged $12.6, equating to a potential sulphur value in polyhalite of $12.0 per tonne. (Note: the sulphur market is seen to be regional (see Chapter 3) and valuing the sulphur content on the European market is considered the most conservative.)

Magnesium

Magnesium, like sulphur, is a commonly added macronutrient to NPK compounds and blends, particularly in magnesium deficient areas such as Central America and South-East Asia. NPK producers intending to add magnesium to their products have a choice of feedstock between magnesium sulphate (kieserite) and potassium magnesium sulphate (langbeinite).

Although magnesium sulphate can be manufactured, most of the production comes from natural sources. One of the most common is kieserite ($MgSO_4.H_2O$). Approximately 60% of potassium magnesium sulphate is mined in the USA from langbeinite and sold under the brands Trio and K-Mag, 30% is produced and consumed in China and 10% is processed from Harlsaz by German company K+S.

Before undertaking a price analysis for magnesium it should be noted that the magnesium sulphate pricing is not at all transparent and the analysis completed by CRU relies on pricing from international trade data or pricing released by producers (Trio). The analysis completed shows that for NPK producers the most economic way to add magnesium is through the use of Chinese kieserite, which results in the lowest per unit cost of $2.69 or $22.16 per tonne of polyhalite. German kieserite is significantly more expensive than synthetic Chinese kieserite, with an estimated per unit cost of $8.44 or $50.45 per tonne of polyhalite. Another source of magnesium is Langbeinite and the analysis indicates an estimated value of $41.66 per tonne. CRU has therefore taken the conservative view for the premium associated with the magnesium content of polyhalite at $22.16 per tonne.

Calcium

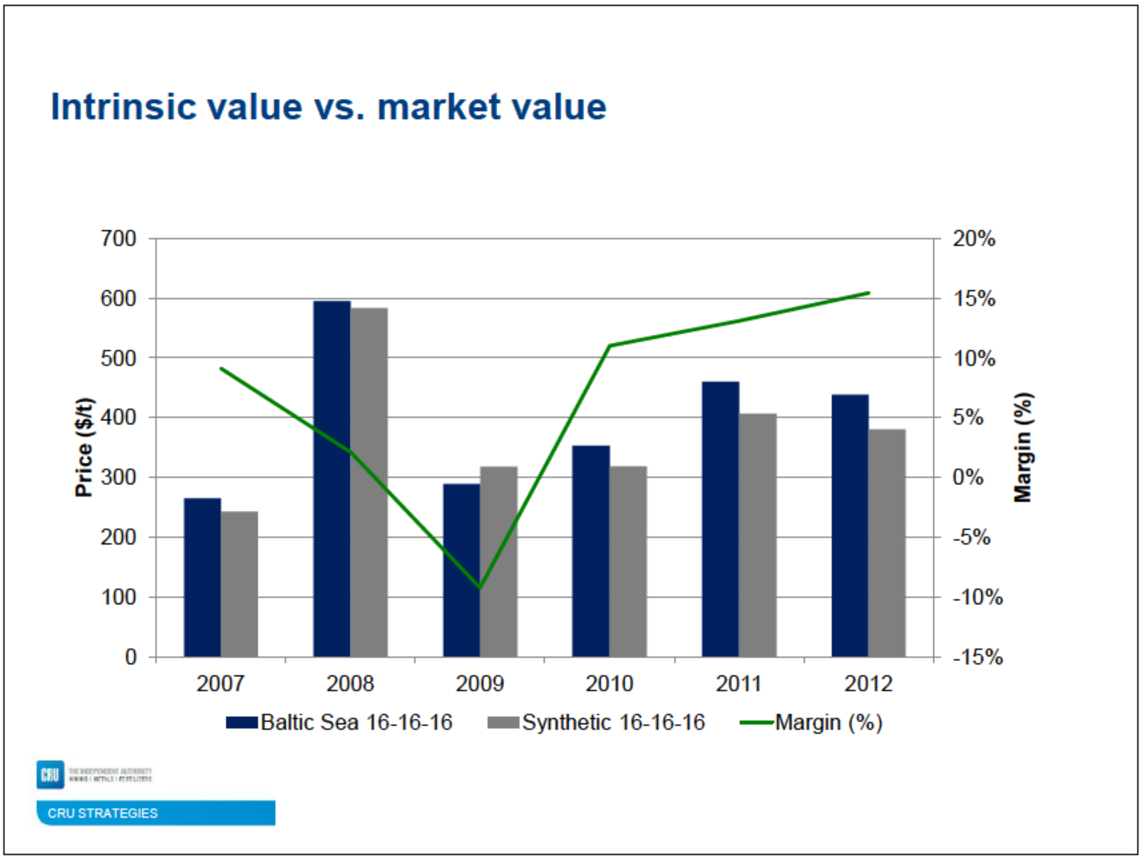
In addition to potassium, magnesium and sulphur, polyhalite also contains significant quantities of another common macronutrient in calcium (17% by weight). The presence of calcium in soils is believed to assist crop growth in a number of ways, including but not limited to:

- Participating in the metabolic processes of other nutrient uptake
- Promoting proper plant cell elongations
- Strengthening cell wall structure
- Protecting against heat stress

CRU Strategies recognises the agronomical benefits of the calcium content of polyhalite in providing a more balanced crop fertilizer. However, for the purpose of evaluating the intrinsic value of polyhalite no additional value has been assigned to the calcium content.

Price Effect – Combining NPKs

To complete the price analysis it is important to compare the intrinsic value of each component with the market value of a NPK product. This analysis is shown in the slide below, which represents the annual price of a globally traded NPK 16-16-16 product with the costs of the product using the values calculated above. We can see that the value of the Baltic Sea 16-16-16 is typically 10-15% above the cost of the raw materials, this most likely represents the premium paid to NPK producers for the costs and effort involved in production.



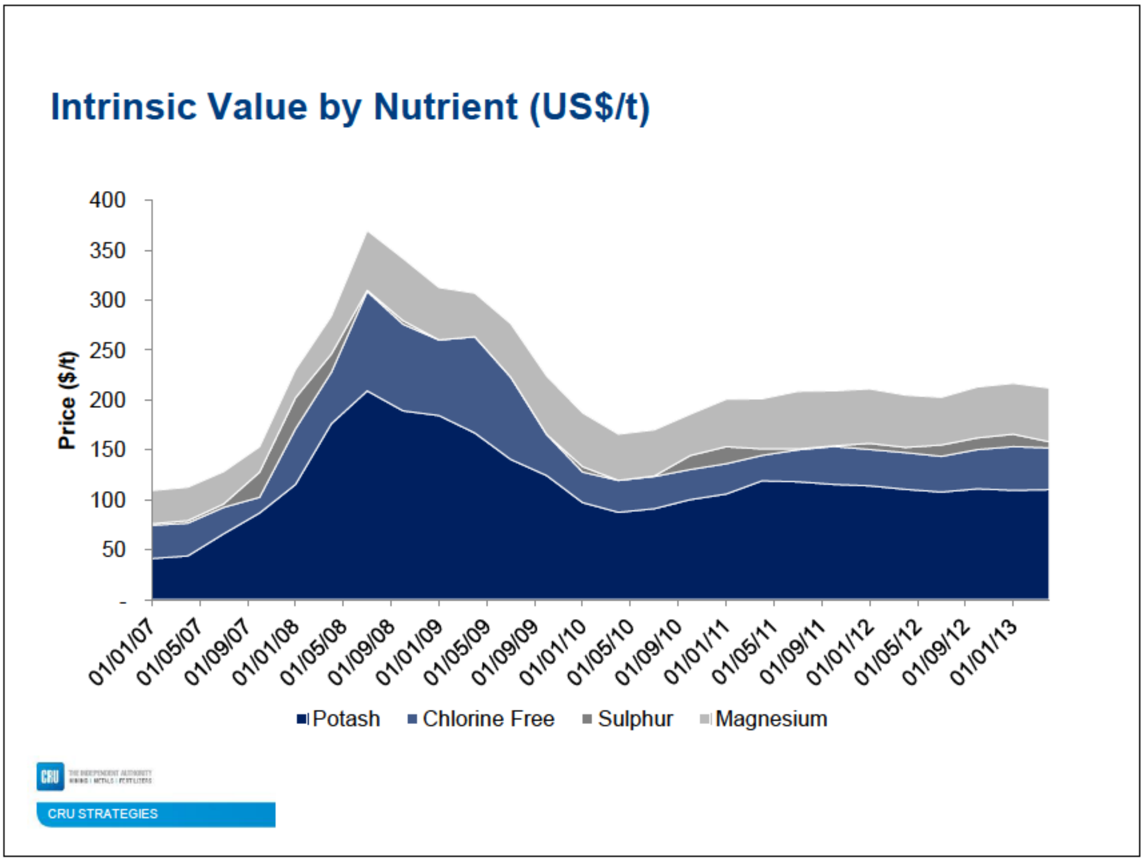
Intrinsic value vs. market value

2.4.2 Pricing Conclusions

Using the above analysis a range for the intrinsic value of polyhalite can be calculated as between $106.80 and $197.80. The breakdown of intrinsic value by constituent part is shown in the figure below. In this case the buyer is willing to pay a premium for the chlorine-free potash content (i.e. displacing SOP) and the magnesium content based upon the displacement of German kieserite as a feedstock. As both kieserite and SOP contain sulphur, combining to contribute 9.6% sulphur, it is unlikely that there would be a further premium associated with the remaining 9.5% sulphur in polyhalite. However, as this analysis represents a best case situation a further value for sulphur has been included.

The graph shows that polyhalite prices peaked in 2008, when supply/demand dynamics resulted in a large rise in potash prices, but have then remained relatively stable since the beginning of 2010.

The large developed nature of markets for the major raw materials of potash, phosphate and nitrogen drive price consistency across the market. Evidence for this is in the small margin available for NPK producers on the wholesale market. This consistency of prices provides a greater level of certainty for the value of the potash component of polyhalite than the other macronutrients. This is particularly reflected in the range of intrinsic values estimated for magnesium, where a number of niche products can be used as a potential supply source.



Intrinsic Value by Nutrient (US$/t)

The value of macronutrients in the market demonstrated in this data analysis supports the anecdotal evidence of producers, where sulphur and magnesium are increasingly becoming common constituents of NPK products.

Chapter 3 – Sulphur

Summary

Polyhalite contains a similar amount of sulphur per tonne (19%) as other common sulphur fertilizers, such as, ammonium sulphate (24%) and super single phosphate (11-14%). This creates the potential for polyhalite to compete with these products as a source of sulphur in blends or as a direct application fertilizer. This chapter investigates polyhalite's right to play in this market by evaluating the value of the sulphur content of ammonium sulphate and single super phosphate in different markets.

The case studies presented below show that the implied value sulphur in fertilizers shows a high degree of variation over time and across regions. Value appears to be more related to what the market is willing to pay for the product, based on the way it affects farmer yields and thus incomes rather than the cost of production. This is most evident in the comparison of pricing in Europe (a large ammonium sulphate exporter) and Americas where the soil is highly sulphur deficient. The impact is an implied value for the sulphur content of polyhalite of $10-15/t in Europe and upwards of $100/t in the Americas.

3.1 Introduction

Following N, P and K; sulphur (S) is an essential plant nutrient. It contributes to an increase in crop yields in several different ways:

- it provides a direct nutritive value; and
- it improves the use efficiency of other essential plant nutrients, particularly nitrogen and phosphorus and some micronutrients, such as Zn, Fe, Cu, Mn and B;

In general, sulphur has similar functions in plant growth and nutrition as nitrogen and plant requirements for the two are comparable. Current world demand for sulphur is estimated by CRU to be approximately 55.7 mn tonnes in 2013, 85% of this are converted into sulphuric acid which has a wide variety of uses. The total global market for the sulphur based fertilizers; AS, SSP, SOP and SOPM is estimated at 10.6 mtpa in 2012 on a sulphur (S) only basis. This market is expected to increase to 11.9 mtpa in 2017, a CAGR of 3.2%. Approximately 90% of this market will be supplied in the form of SSP or AS.

It is generally accepted that the world's soils are becoming increasingly sulphur-deficient. The major reasons for this are the following:

- more sulphur is removed from the soil as a result of the adoption of intensive cropping systems, the introduction of high-yield crop varieties, and increasing use of irrigation;
- less sulphur is added to the soil due to the increasing proportions of high-analysis, sulphur-free fertilizers, such as urea, DAP/MAP, and potassium chloride;
- lower sulphur dioxide emissions are reducing atmospheric availability, one of the important historical sources of sulphur for agriculture around industrial areas.

Table 3.1: Sulphur Fertilizers

Product	NPK	S	Advantages	Disadvantages
Ammonium sulphate	21-0-0	24%	Widely used	Acidifies soil
Ammonium thiosulphate	12-0-0	26%	Only liquid form of S fertilizer	Available only in developed markets
Single superphosphate	0-20-0	11-14%	Simple manufacturing process	High leaching risk
Sulphate of potash	0-0-50	16-18%	Increass quality of some crops	Expensive premium product
Gypsum	0-0-0	22-24%	Additional value as soil amendment	Leaches, difficult to handle
Elemental sulphur	0-0-0	90%+	High analysis, no leaching	Slow uptake, acidifying to the soil
Langbeinite	0-0-22	22%	Multinutrient values	Limited availability, expensive

Source: IFA, CRU

3.2 Case study: ammonium sulphate

CRU estimates that the global market for ammonium sulphate was around 23.1 mn tonnes in 2013. Only 15% of world ammonium sulphate production is voluntary (i.e. targeted production from reacting ammonia with sulphuric acid) and even this production is usually in a chemical complex that has a surplus of one or other of these materials from its other activities.

The majority of AS production (54%) is a by-product of caprolactum manufacture. This is a building block for a number of nylon-based fibers and related chemicals. A further 16% of production is a by-product of coke oven production of coke. The balance is also by-product from a number of other chemical processes, the operation of emissions control systems and, recently, from some of the new pressure acid leaching projects in the nickel industry. The by-product nature of ammonium sulphate production means that supply does not necessarily reflect demand and price is set largely by competition among buyers, rather than by reference to the production costs of the suppliers.

Table 3.2: Forecast AS consumption and production (mn ty) 2012-2017

	2012*	2013	2014	2015	2016	2017
Demand						
North America	2.4	2.6	2.7	2.7	2.8	2.8
Europe	2.8	2.9	2.9	2.9	2.9	2.9
Latin America	4.7	4.5	4.6	4.6	4.6	4.6
South East Asia	4.4	4.9	5.2	5.5	5.7	5.9
China	2.8	3.2	3.6	3.8	4.0	4.2
Rest of w orld	5.3	5.1	4.9	4.9	4.9	4.8
Total	22.4	23.2	23.9	24.4	24.9	25.2
Supply						
North America	3.7	3.7	3.8	3.8	3.8	3.8
Europe	4.6	4.5	4.5	4.5	4.5	4.5
Latin America	2.8	2.9	3.0	3.0	3.0	3.0
Russia/CIS	2.2	2.1	2.1	2.1	2.1	2.1
China	5.0	5.8	6.5	6.9	7.3	7.7
Rest of w orld	4.1	4.2	4.0	4.1	4.2	4.1
Total	22.4	23.2	23.9	24.4	24.9	25.2

Source CRU

* Actual data

Ammonium sulphate contains two nutrients – nitrogen and sulphur. Theoretically, it is possible to determine the value of sulphur in the ammonium sulphate by subtracting the value of the nitrogen from the ammonium sulphate selling price. The nitrogen value can be established from the price of alternative sources of nitrogen that do not contain other nutrients, namely ammonium nitrate or urea. The following table summarizes these calculations for ammonium sulphate FOB Black Sea (a major export region) and fob Midwest. In conducting this analysis we have used the price for the white grade of ammonium sulphate associated with caprolactum operations because this is a direct application product.

Table 3.3: Value of sulphur in ammonium sulphate, 2006-2012

		2006	2007	2008	2009	2010	2011	2012
Black Sea								
(a) Based on Urea								
Urea price	$/t	222.81	307.87	492.82	249.71	288.10	423.51	406.05
Value of 1 tonne nitrogen	$/t	478.13	660.66	1057.55	535.85	618.25	908.82	871.34
Value of nitrogen in AS	$/t	101.36	140.06	224.20	113.60	131.07	192.67	184.72
Ammonium sulphate price	$/t	90.73	161.61	259.21	101.77	140.37	206.33	207.62
Residual	$.t	-10.63	21.55	35.01	-11.83	9.30	13.66	22.89
Implied sulphur value	$/t	-43.76	88.69	144.07	-48.69	38.28	56.21	94.21
(b) Based on AN								
Ammonium nitrate price	$/t	144.85	202.49	317.89	165.46	229.55	309.40	292.30
Value of 1 tonne nitrogen	$/t	413.85	578.54	908.25	472.75	655.87	883.99	835.14
Value of nitrogen in AS	$/t	87.74	122.65	192.55	100.22	139.04	187.41	177.05
Ammonium sulphate price	$/t	90.73	161.61	259.21	101.77	140.37	206.33	207.62
Residual	$.t	2.99	38.96	66.66	1.55	1.33	18.92	30.57
Implied sulphur value	$/t	12.31	160.34	274.33	6.36	5.46	77.87	125.80
US Midwest								
(a) Based on Urea								
Urea price	$/short ton	262.56	379.21	573.94	315.27	354.63	467.74	529.54
Value of 1 tonne nitrogen	$/short ton	563.44	813.77	1231.63	676.55	761.02	1003.73	1136.36
Value of nitrogen in AS	$/short ton	119.45	172.52	261.10	143.43	161.34	212.79	240.91
Ammonium sulphate price	$/short ton					224.63	344.45	366.97
Residual	$.short ton					63.29	131.66	126.06
Implied sulphur value	$/short ton					260.45	541.80	518.77
(b) Based on AN								
Ammonium nitrate price	$/short ton	258.04	310.99	443.06	282.53	296.13	366.53	410.10
Value of 1 tonne nitrogen	$/short ton	737.26	888.54	1265.90	807.23	846.07	1047.23	1171.73
Value of nitrogen in AS	$/short ton	156.30	188.37	268.37	171.13	179.37	222.01	248.41
Ammonium sulphate price	$/short ton	119.45	172.52	261.10	143.43	161.34	212.79	240.91
Residual	$.short ton	-36.85	-15.85	-7.27	-27.71	-18.03	-9.22	-7.50
Implied sulphur value	$/short ton	-151.65	-65.24	-29.90	-114.01	-74.20	-37.95	-30.86

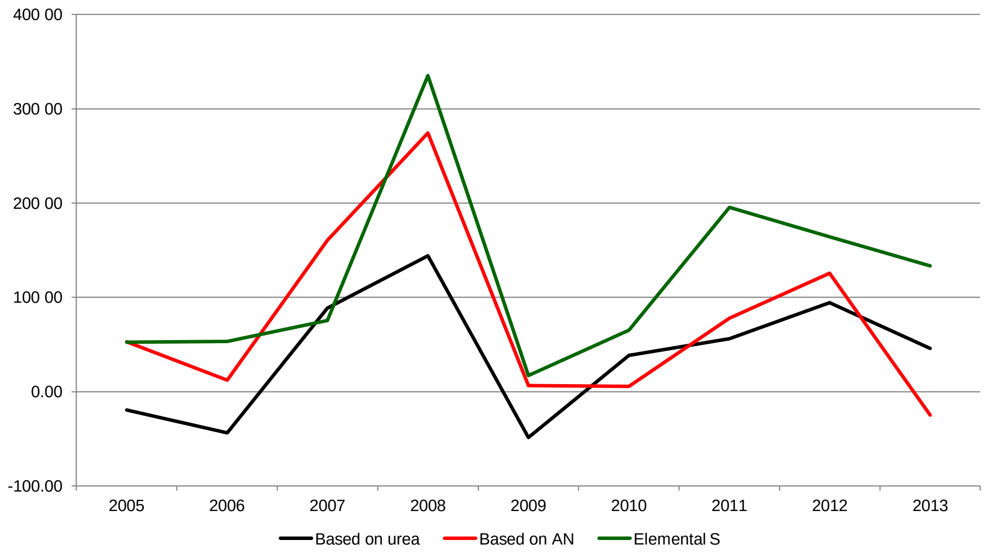
Source Fertlizer Week, CRU

What is striking about this data is the extremely unstable valuations that are implicit in the historical prices structure of the ammonium sulphate, urea and ammonium nitrate markets.

It is clear that there are two (or more) quite different markets here and the reason is the involuntary nature of ammonium sulphate production influencing the Black Sea price and the relative isolation of the US market.

Let us first consider the **Black Sea market**: There is a relationship between the value of sulphur in elemental form and its value in ammonium sulphate but it appears to be counter-intuitive. The value of sulphur in ammonium sulphate is less than its value in elemental form. If we look at the period 2009-2013, which removes the obvious disturbance associated with the 2007/8 commodity bubble and global financial crisis, we can conclude that sulphur in ammonium sulphate has been selling for about 33% of the elemental sulphur price.

Value of sulphur in the Black Sea, 2005-2013, $/t



CRU STRATEGIES

Sulphur in a sulphate form is a far *better* fertilizer product than elemental sulphur (polyhalite is in the sulphate form). At first sight it is illogical for a superior product to sell at a lower price than an inferior product. The explanation, of course, is that the production of ammonium sulphate is mostly involuntary so the price does not reflect normal economic considerations. It simply reflects the state of competition among buyers.

We have limited supporting evidence for this from conditions in the south-east Asia market for ammonium sulphate. Fertilizer Week started reporting these prices in 2013. So far the average price has been $171/t, which is equivalent to the value of nitrogen in urea delivered to that region. In other words, south-east Asia is getting its sulphur free and CRU believes that the explanation is that the growth in Chinese caprolactum production of has created an ammonium sulphate surplus in the region.

Looking at the **US market**, and a very different and more complex picture emerges. If we compare ammonium sulphate and urea, there is an enormous implied sulphur value in the Midwest market, currently over $500/t S, which is many multiples of the elemental sulphur price. Sulphur content is not the only reason for a premium. The form of nitrogen in urea is different from that in ammonium sulphate and this may affect uptake in certain crops. However, when we value sulphur content of ammonium sulphate using the nitrogen value of ammonium nitrate, there is a large negative value, averaging $85/short ton since 2005.

Part of the explanation for this may be factors unique to the US market such as

- the US is almost entirely a liquid sulphur market, with no market for elemental sulphur;
- almost all ammonium nitrate is consumed internally in fertilizer plants to make urea ammonium nitrate (UAN) with little or no merchant market;
- the US steel industry has almost entirely moved away from coke production, removing this by-product source of ammonium sulphate; and
- the three main caprolactum suppliers have invested quite heavily in additional process steps to upgrade the physical properties of their product so as to create a very clean granular product whose physical characteristics allow it to be readily blended with other common fertilizer products; in other words, there are higher production costs.

For these reasons, US prices for sulphur and ammonium nitrate may not be entirely reliable.

Over the past 4 years, ammonium sulphate prices in the US have been more than $175/t higher than ammonium sulphate prices in the Black Sea. Since this is vastly in excess of any logistical costs, we must conclude that the ammonium sulphate market in not global but regional in nature and that it is also being marketed as a specialized product into targeted applications in the US.

From the perspective of polyhalite, the analysis suggests that the US market would value the sulphur content more highly and discussions with customers to date have supported this conclusion.

3.3 Case study: single super phosphate

Single superphosphate (SSP) was once the most commonly used fertilizer, but other phosphorus fertilizers have largely replaced SSP because of its relatively low P content of around 20% compared with over 60% for DAP, MAP and TSP.

CRU calculates regional production of SSP based upon the consumption of sulphuric acid in the production of SSP. From these numbers the total market size of SSP in 2012 was approximately 38.1 mn tonnes per year; just over 50% of this production occurred in China, with Brazil and India also major producers. The majority of SSP produced is consumed in the country of production or neighbouring countries, hence production figures are a fair estimation of regional consumption.

Table 3.4: SSP production by country (million tonnes SSP)

	2012	2013	2014	2015	2016	2017	2018	CAGR (13-18)
China	19.4	20.1	20.8	20.8	20.8	20.8	20.8	**0.70%**
Brazil	6.1	6.4	6.5	6.7	6.9	6.9	6.9	**2.40%**
India	3.9	4.1	4.3	4.5	4.6	4.6	4.6	**3.10%**
Egypt	1.3	1.3	1.3	1.3	1.3	1.3	1.3	**0.00%**
New Zealand	1.2	1.3	1.3	1.4	1.4	1.4	1.4	**3.00%**
Total Main Countries	32.0	33.2	34.3	34.7	35.0	35.1	35.1	**1.80%**
ROW	6.1	6.1	6.3	6.5	6.6	6.6	6.6	1.60%
Total World	**38.1**	**39.3**	**40.6**	**41.2**	**41.6**	**41.6**	**41.6**	**1.80%**

Data: CRU

One way to look at the economics of this market is to quantify the cost structure of the local producers and compare this with the import price of SSP. Upon completing this analysis, the apparent manufacturing margin for local producers is in the region of $68/t-$80/t which looks generous for what is a very simple process. Other plants will have higher logistics costs on either the raw materials or the final SSP product which could reach $20/t-$25/t, hence the marginal producer’s margin would be more reasonable.

Although the evidence is far from comprehensive, CRU is of the opinion that that it supports the proposition that imported SSP is priced to compete with imported rock and acid.

Another way of looking at this is to derive a phosphate value from alternative sources of phosphates and then subtract this to find a value for sulphate in the SSP. In turn the phosphate value can be derived from the price of a product like MAP, subtracting the N value based on the urea that it displaces. These calculations for 2013 are set out in the following table.

Table 3.5: Value of sulphur in SSP in Brazil, 2013

S value in SSP

	Average	October	Notes
Valuing P2O5			
MAP price, CFR Brazil	493.73	408.50	Fertlizer Week quotation
Urea price, CFR Brazil	363.60	320.70	Fertlizer Week quotation
Nitrogen value based on urea	780.25	688.20	Assumes 46.6% N
Nitrogen value in MAP	85.83	75.70	Assumed 11% N
P2O5 value in MAP	407.90	332.80	By subtraction
Valuing SSP			
Estimated CFR price	218.34	196.25	Prior table
P2O5 value in SSP	156.88	128.00	Assumes 20% P2O5
S Value in SSP	61.46	68.25	By subtraction
S value at 100%	558.69	620.46	Assumes 11% S in SSP

Source CRU

This analysis produces a very high implied sulphate value in Brazil. For reference, in October 2013 it was possible to land elemental sulphur in Brazil for around $100/t. However, it may be worth noting that, in the absolute, this figure is not dissimilar to the $518/short ton which we estimated for the United States in table 3.3 above using a similar urea-based analysis.

3.4 Implications

It is difficult to draw clear conclusions about the potential value of the sulphate content of the polyhalite product that Sirius is proposing. In terms of competing with ammonium sulphate in the United States or SSP in Brazil, the product could have quite substantial value. If we strip out the value of the N in ammonium sulphate and the P in SSP, we end up with large implied sulphate values – nearly $560/t in 2013. However, it needs to be stressed that the two case study markets described above have limited volumes:

- US consumption of AS is around 3.6 mn tonnes (in sulphur equivalent terms this is 3.0 mnn tpy of polyhalite); however the US is a net exporter of this product; and
- Brazilian consumption of SSP is around 6.3 mn t (in sulphur equivalent terms this is 3.6 mn tpy of polyhalite)

The main implication is that the value of sulphate in a fertilizer product is not directly related to the price of elemental sulphur. In fact it may not be practical to try to isolate the value of individual nutrients in fertilizers of this kind. Value appears to be more related to what the market is willing to pay for the product based on the way it affects farmer yields and thus incomes. The Sirius product is going to be attractive to farmers who want to add K to their soils as well as S and it will therefore need to be priced by reference to the combination of alternative fertilizers available to them given their crop types and soils, adjusted of course for any yield affects.

The apparent regional bias in pricing for AS and SSP, particularly in the Americas, is a finding that will be incorporated into the development of a global polyhalite demand curve in Chapter 5 where we consider the ability to compete directly as a source of sulphur in niche markets. However, if competing on a commodity scale in global market, it is CRU's opinion that value should be determined based on Black Sea pricing. This would imply a value of $60/t of sulphur, which equates to $11.40 for the sulphur content in each tonne of polyhalite. But as discussed above this value could be closer to $100/t in the America's where implied sulphur values are much higher.

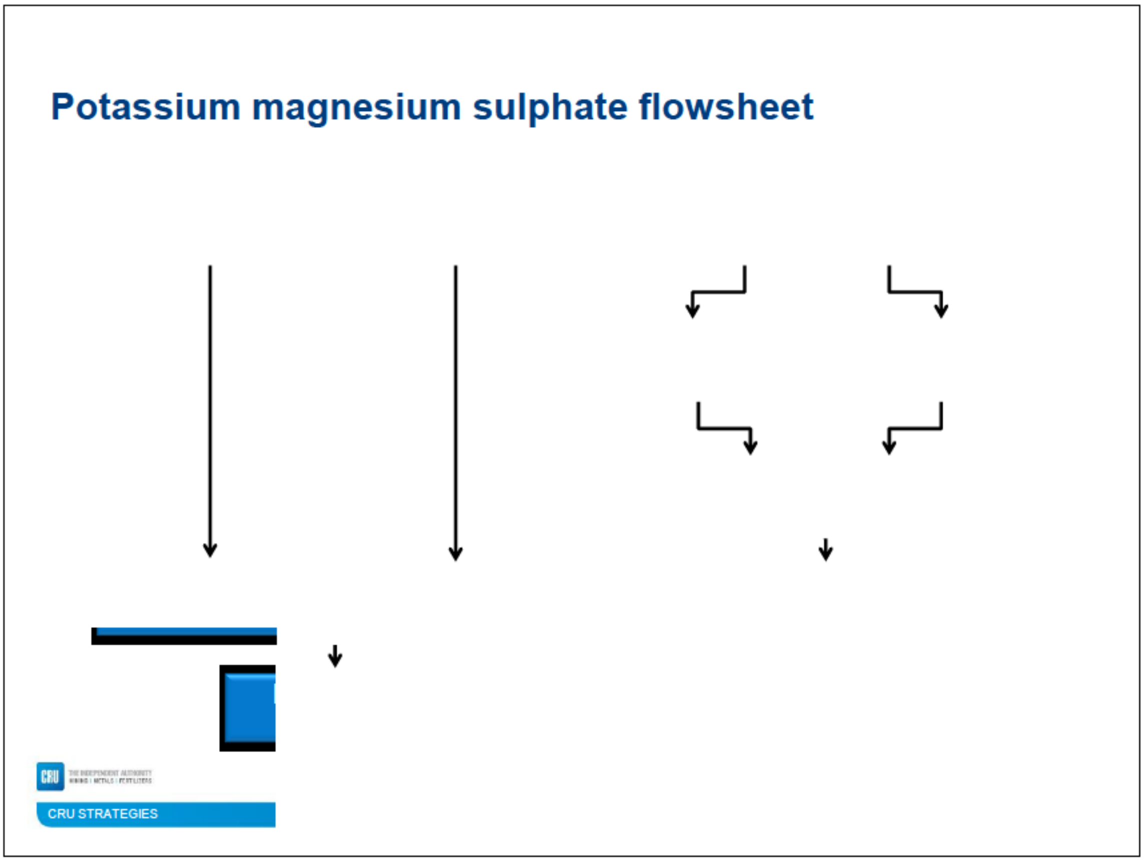
Chapter 4 – Potassium Magnesium Sulphate (Langbeinite)

Summary

Polyhalite can be included in the classification of potassium magnesium sulphate (SOPM) fertilizers. A number of SOPM fertilizers are sold commercially into the market and provide the best like-for-like comparison with polyhalite. In this chapter CRU Strategies provides an overview of the current potassium magnesium sulphate market and a case study of two prominent North American products – Trio and K-Mag. The analysis concludes that current producers in this market are able to achieve a significant premium in excess of the MOP value of the potassium content of their products. This premium is thought to exist due to a combination of the following factors: 1) additional macronutrients (magnesium, sulphur); 2) chlorine-free potash content; and 3) the potential premium from the ability to apply magnesium at the same time as potassium.

4.1 Introduction

Potassium magnesium sulphate (SOPM), also known as langbeinite, is a fertilizer which contains both potassium sulphate (SOP) and magnesium sulphate. It can be mined as a natural product or derived by simply mixing the two sulphates. Currently production only occurs in three countries; the USA, China and Germany. In the USA, it is mined as natural langbeinite ore by Intrepid Potash and Mosaic, both with operations in New Mexico. China mainly recovers potassium magnesium sulphate from natural brines (schoenite), whereas Germany mines a potash ore named Hartsalz, which is then converted into Potassium Chloride and Magnesium Sulphate before being recombined to form potassium magnesium sulphate. The important difference in the process in Germany is that producers have the flexibility to vary the production output of kieserite (Magnesium Sulphate) in favour of other products, such as, potassium chloride, magnesium chloride, potassium sulphate or magnesium sulphate.



Potassium magnesium sulphate flowsheet

Total output from potassium magnesium sulphate producers in recent years has been between 1.3-1.5m tonnes, equating to 0.3m tonnes of K_2O. Due to the relatively small production volumes potassium magnesium sulphate is considered a specialty fertilizer, marketed to growers that have special requirements for chloride-free fertilizer and/or additional magnesium requirements. One area of the market that satisfies these needs are higher-value crops, such as oranges, bananas and coffee.

Competition within this market will come from a number of sources; firstly, growers can meet chlorine-free potassium requirements with potassium sulphate (SOP) and nutrient magnesium with kieserite. Second, the German potash industry also supplies other potassium magnesium fertilizers in which the potash component is chloride (Korn-Kali) and potash ore (Magnesia-Kainite) and magnesium is in the form of kieserite. These German products will not satisfy the needs of the chlorine-free market, but have been competitive within the South-East Asian market where the oil palm sector consumes a large quantity of magnesium.

4.2 Market Outlook for Potassium Magnesium Sulphate

Potassium magnesium sulphate is a niche fertilizer that has been produced for a long time in Germany and the United States, and for which demand has been established in their respective regional markets. Both groups of producers have invested heavily in promoting the agronomic benefits of this fertilizer for specific crops and growing conditions. They succeeded in building up and maintaining demand for around 1 million t/y potassium magnesium sulphate fertilizer in Europe and in the Americas.

Table 4.1: Potassium magnesium sulphate consumption forecast to 2020

Region	2011	2015	2020	change	CAGR
N. America	530	545	560	+30	+0.6%
C&S. America	215	245	275	+60	+2.5%
Europe	150	150	150	0	0.0%
ROW (excl. China)	95	105	115	+20	+1.9%
Subtotal	990	1,050	1,100	+110	+1.0%
China	320	450	480	+160	+4.1%
World	**1,310**	**1,495**	**1,580**	**270**	**+2.1%**
equivalent K_2O	***303***	***347***	***365***	**62**	

Note: Thousand tonnes product.

In preparing the demand forecast, CRU has noted that Europe and North America are mature fertilizer markets with little potential for growth (given the current pricing structure adopted by the incumbent players) in total nutrient requirement. There are better prospects in Latin America, but the additional tonnage consumed in this region will have little impact on global growth. Most other regions are insignificant users of potassium magnesium sulphate, and this situation is not expected to change unless a significant downwards shift in pricing occurs. Thus world demand outside China is forecast to grow at only 1% annually during the next ten years.

The outlook in China is dependent on the possible of entry of a big new producer to the market. We have assumed that the proposed SIC Luobupo potassium magnesium sulphate plant will not proceed in the forecast period. Under this assumption consumption is expected to grow at 4.1%. However, if SDIC Luobupo is successfully implemented and supported by a strong marketing effort this growth rate could be as high as 11%.

It should be noted that the above market outlook does not take into account the introduction of large quantities of polyhalite into the market at competitive prices since polyhalite could be considered a potassium magnesium sulphate.

4.3 Case Study – Langbeinite Pricing

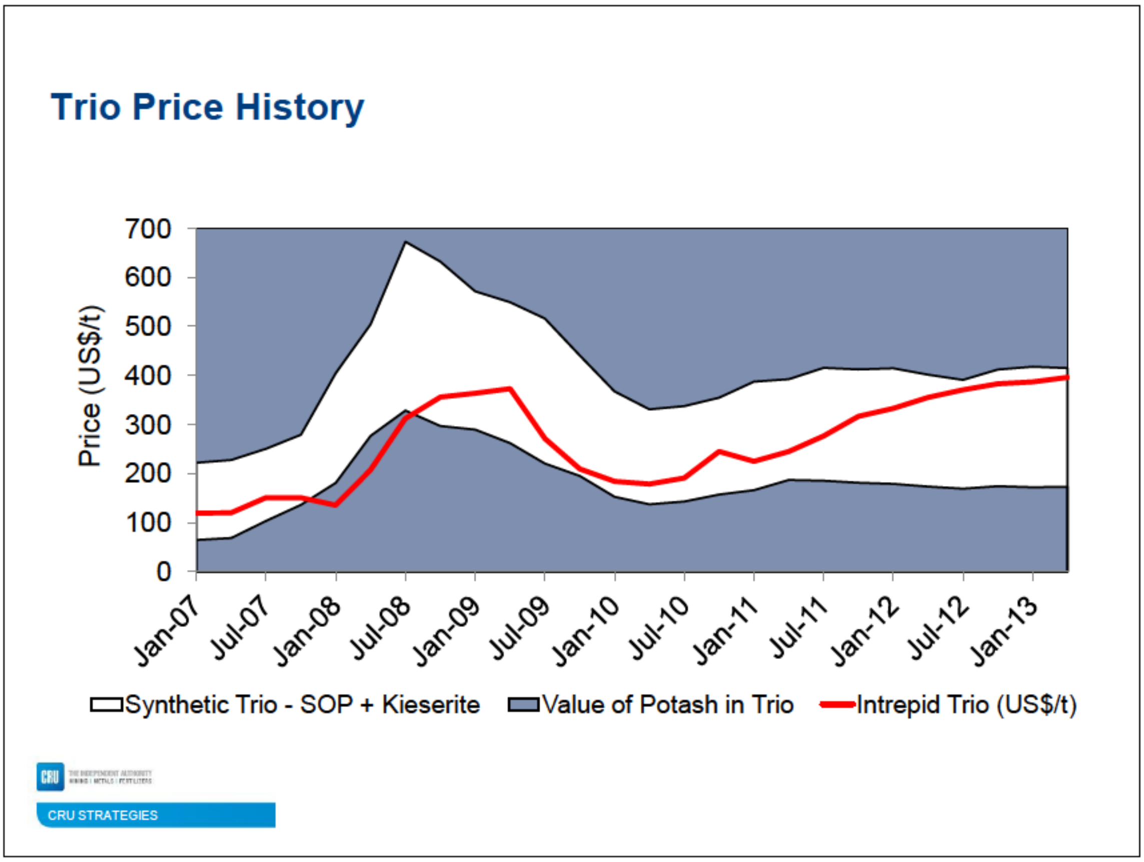
The similarities between polyhalite and langbeinite – both are naturally occurring multi-nutrient ores containing potassium, sulphur and magnesium – means that the pricing for langbeinite may help shed light on a number of questions surrounding the price of polyhalite. This section examine the following issues

- The link between MOP / SOP prices and langbeinite
- The existence of a premium for langbeinite over and above the potash content
- The value attributed to other macronutrients apart from potassium

4.3.1 United States

The ability to create a near perfect substitute for langbeinite through the use of other raw materials creates a price range in which we would expect Trio and K-Mag to trade. A price floor for the product would be the value of the potash component alone; and a price ceiling can be replicated by combining potassium sulphate (SOP) and magnesium sulphate in the form of kieserite.

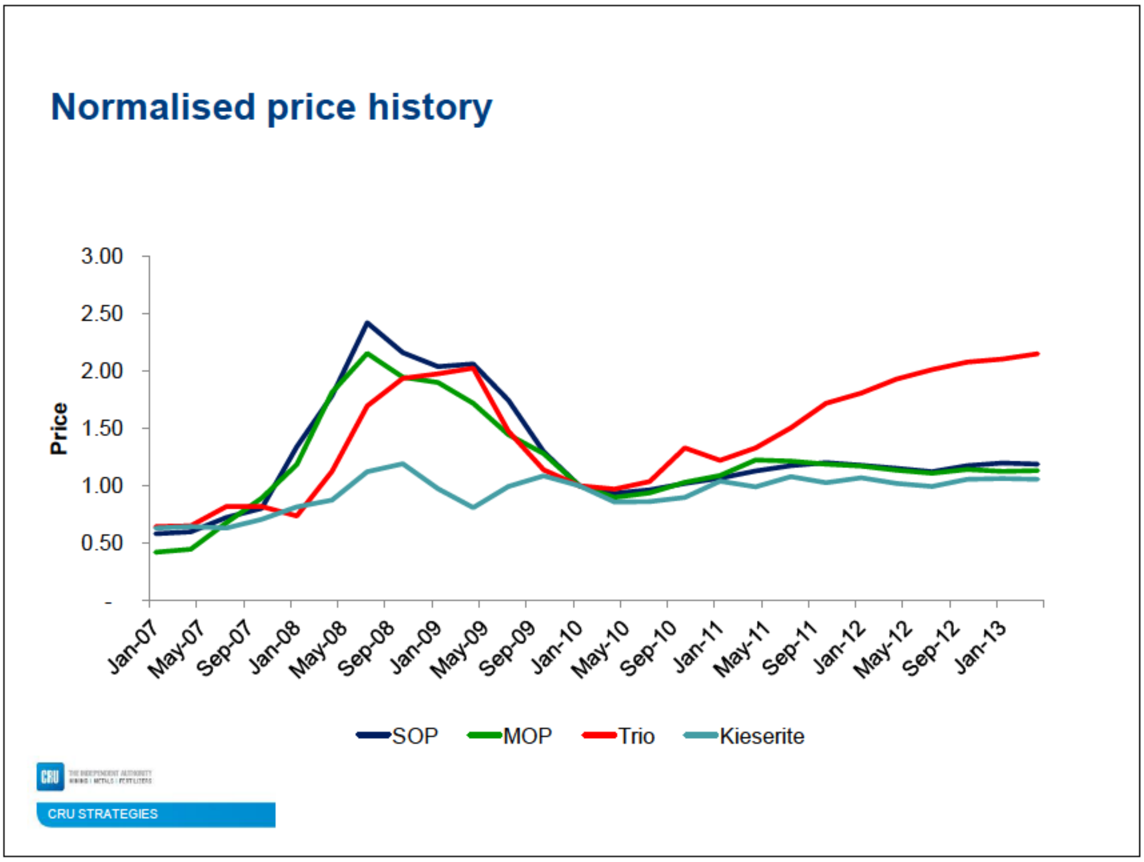
For this analysis, we benefit from transparent pricing – both available in list prices circulated to customers and public reporting of net realised prices. These prices have been compared to the calculated value of a tonne of 'synthetic' Trio in the figure below. The lower shaded area represents the value of the potash contained in Trio, the top shade are represents the price at which it becomes cheaper to use a combination of SOP and kieserite and the white area represents the expected trading range.



Trio traded at a discount to potash content or marginally above the value of potash for the majority of the three year period beginning Jan-07 and ending Jan-10. This pricing also represents a significant discount to SOP on an equivalent K_2O basis and little or no value for the other macronutrients (magnesium, sulphur). There are a number of possible explanations for this discount:

1. Historically, langbeinite concentrate was relatively cheap to produce and was seen as an intermediary in the production of SOP in the United States. Hence, it was logical to price it more cheaply as it required less processing that SOP.
2. As a relatively new product the original strategy was to build up a market for potassium magnesium sulphate in North America by pricing it as a potash fertilizer with magnesium, and not seek a premium for being chloride-free.
3. Trio publishes prices ahead of time for US sales; this appears to have caused a delay in price adjustment as the value of potash rose steeply in 2008, leading to Trio being sold at a discount to the value of potash.

From 2010 onwards, the relationship between Trio, Potash and Kieserite pricing is seen to change. The premium for Trio over the potash content alone rises from 21% in Q1 2010 to 129% Q2 2013. The rapid increase in the price of Trio is shown in the figure below, which has been normalised by setting Q1 2010 as the base price. The price of Trio can be easily divided into two time periods: pre-2010, it follows the general movements in the price of potash, SOP and MOP; and post-2010, which is characterised by a strong growth in price while prices for SOP, MOP and kieserite all remain flat.



The explanation for the rise in sales price of Trio is likely to be a combination of many factors. Intrepid Potash states in its 2012 that "there appears to be a growing awareness of the agronomic value of the magnesium and sulphate in this speciality product [Trio], resulting in stronger pricing relative to potash over the last year".

This is indeed a possible explanation but other factors are also likely to have had an impact, including, an increased marketing effort, leading to the realisation that Trio is cost competitive for the magnesium deficient soils on the east coast of the US. Also, it is possible that some supply issues have placed an upwards pressure on prices. Production at Intrepid Potash has not matched demand since 2010 leading to a reliance on stockpiled product which is nearly depleted. Additionally, in 2009 the output from Mosaic's Carlsbad mine was 35% lower than 2008 or 2010. The tightening of supply appears to have catalysed an increase in sales price that producers have been able to maintain post-supply issues.

The price of Trio now trades at a modest discount to the pure cost of the raw materials, SOP and kieserite, and has done since the middle of 2012. It may be possible for the price of Trio to exceed the cost of the raw materials in the near future. This could occur due to a combination of the following effects:

1. Transportation costs of kieserite – Most of the supply of kieserite come from Germany making it subject to bulk shipping costs.
2. A premium placed on the ability to apply both magnesium and potassium in one application; reduced workload for growers.
3. Brand loyalty from growers

4.3.2 China

The Chinese potassium magnesium sulphate industry sells nearly all of its production domestically. Prices have been consistently higher than those of SOP or MOP when compared on a 23% K_2O basis. Since 2012 the average premium paid for SOPM over of SOP prices, on an equivalent K_2O basis, has averaged $43.4 /t. The value of this premium has been in a steady decline since Jan-10 when it was over $100 /t.

Using the average premium since 2012 we can calculate an implied value of $98.6/t for synthetic kieserite produced in China. When compared to the July 2011 export price of $160/t for synthetic kieserite it indicates that average Chinese farmer does not currently place the same value on the magnesium content as their American counterparts.

4.3.3 Germany

As discussed in the supply section of this chapter the production of potassium magnesium sulphate in Germany is the result of combining potassium sulphate with kieserite. This gives German producers the ability to vary production between potassium sulphate, kieserite and potassium magnesium sulphate as dictated by market demand. As such, CRU expects that the pricing strategy of K+S Kali would ensure that potassium magnesium sulphate was not sold at a discount to the value of each of the constituents. If this was not the case then K+S Kali would not be maximising revenues.

4.3.4 Pricing Conclusions

From the above analysis it is clear that in each of the major producing regions potassium magnesium sulphate is sold at a premium to its potash content. This premium reflects a number of factors:

- Additional macronutrients (magnesium, sulphur)
- Chlorine-free potash content
- Potential premium from the ability to apply magnesium at the same time as potassium

As a potassium magnesium sulphate these results can be seen as a positive for the marketability of polyhalite. The size of the demand for polyhalite in this application will be estimated in Chapter 5, taking into account regional consumption patterns, transportation costs and nutrient content.

Chapter 5 – Polyhalite Demand Curve

Summary

In this chapter CRU Strategies estimates the demand curve for polyhalite based upon fertilizer demand and pricing in 2018. The analysis takes into account the transportation costs from the UK to target markets, the pricing response of incumbent producers and potential yield benefits of polyhalite over other nutrient sources.

The analysis concludes that the potential demand for polyhalite is in excess of initial production of Sirius Minerals for polyhalite prices between US$120 and US$180 per tonne (FOB Teesside). With the exact price point achievable by Sirius Minerals depending on the level of pricing competition from incumbent producers, acceptance of yield benefits and marketing efforts.

These conclusions are based upon demand before accounting for the potential benefits of yield improvements from polyhalite over other nutrient sources. If these benefits are included the price points at each demand level increase by $25-40 per tonne of polyhalite.

5.1 Introduction

In this chapter, CRU Strategies seeks to link the inferred value for polyhalite determined in Chapters 1-4 to a likely price achievable for Sirius Minerals. Chapter 5 considers the impact of production volume, freight costs to target markets, application costs and the response of competitor fertilizer suppliers, in order to develop a global demand curve for polyhalite. The analysis is focused on demand in 2018; the year first production is expected from the project, although full initial production is not expected until 2020.

The global demand curve will demonstrate the size of the potential market for polyhalite when used in the following applications:

- As a direct competitor with potassium magnesium sulphate products
- As a competing source of K_2O with MOP and SOP
- As a feedstock for blends
- As an alternative source of sulphur to SSP and AS

A key unknown when forecasting the demand curve for polyhalite in 2018 is the pricing response of the incumbent suppliers to a new competitor. To account for this CRU has calculated multiple pricing scenarios with different degrees of industry reaction, in order to show the spectrum of potential demand for polyhalite. Further information on the three pricing scenarios can be found in section 5.4. Finally, the analysis seeks to include and quantify the potential increase in demand following the positive outcomes of crop trials fertilized with polyhalite compared to K_2O containing blends and straight fertilizers. Throughout the analysis a number of assumptions have been made where absolute results are unknown, when presented with a decision CRU Strategies has endeavoured to make the most conservative assumption in order to provide a more robust estimate of potential demand.

The chapter has been organised to cover the following topics:

5.2 Demand Curve Methodology and Assumption

5.3 Fertilizer Application Costs

5.4 Reaction of Incumbent Suppliers

5.5 Demand Curve Outputs

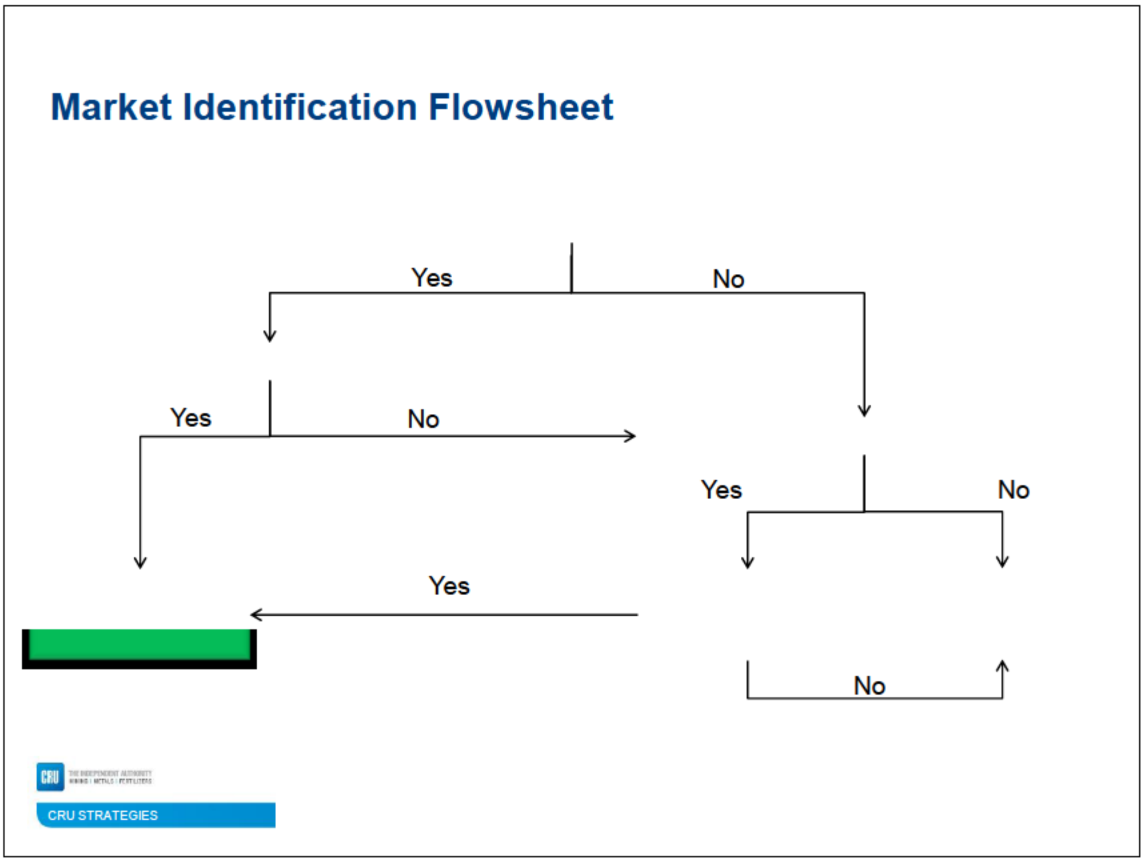
5.6 Yield Improvement Value Calculations

5.2 Demand Curve Methodology

This section of the report will lay out the methodology and assumptions used by CRU to estimate the market size for polyhalite. In essence, CRU's market research and analysis were broken down into three separate sections, nutrient demand, fertiliser prices and the cost of production for each of the products in each target market in 2018. This allowed CRU to evaluate the potential market size for different polyhalite equivalent prices (adjusted for nutrient content) as well as evaluate the potential market size if competitors actively seek to compete on price.

The key, overarching assumption that underpins the demand curve analysis is that farmers will be 100% willing to switch between different sources of the same macro-nutrient. This means that a farmer will use ammonium sulphate in preference to polyhalite if it is marginally cheaper, and vice versa. Anecdotal evidence suggests that farmers are slower to change between nutrient sources or adopt new practises than industrial NPK producers. Thus the demand curve represents the potential demand for polyhalite at a given price; the actual sales achieved will be dependent upon the success of Sirius Mineral's marketing efforts, and those of the NPK producers who purchase polyhalite. It should be noted that the marketing efforts appear to have been successful to date, with 4.8Mt of production placed via agreements with customers.

The methodology used by CRU is schematically drawn below and utilised CRU's price, costs, and demand forecasts for 2018:



Market Identification Flowsheet

5.2.1 Demand forecasts for 2018

Demand for the major fertilizer products in 2018 have been listed below by product and region for reference.

Table 5.1: Demand in 2018 (Million tonnes)

Million tonnes	MOP	SOP	SOPM	Kieserite	AS	SSP
Europe	10.8	1.1	0.2	0.2	2.4	0.7
North America	10.7	0.4	0.6	0.1	2.8	0.2
South America	14.3	0.3	0.3	0.0	2.8	6.6
India	7.9	0.1	0.0	0.0	0.7	3.6
China	14.7	2.8	0.5	0.0	5.2	14.2
SE Asia	8.1	0.1	0.5	0.9	6.0	1.5
SS Africa	0.0	0.3	0.0	0.0	0.1	0.0
ROW	4.8	0.5	0.0	0.2	5.5	5.9
Total	71.3	5.6	2.0	1.5	25.5	32.6

Data: CRU

5.2.2 Converting Demand to Polyhalite Equivalent Tonnes

In order to calculate the demand for polyhalite it was necessary to convert forecast demand for each product into equivalent polyhalite values. The basis for this calculation is that a farmer will need to replace the total quantity of the key nutrient with the same amount of nutrient within polyhalite.

Table 5.2: Conversion to Tonnes of Polyhalite - Equivalent

Methodology

Volume	Product	K2O content in product	K2O content in polyhalite	..is equivalent to (tonne polyhalite equivalent)
1 tonne of..	MOP	60%	14%	4.3
1 tonne of..	SOP	50%	14%	3.6
1 tonne of..	Langbeinite	22%	14%	1.6

	Product	MgO content in product	MgO content in polyhalite	..is equivalent to (tonne polyhalite equivalent)
1 tonne of..	Langbeinite	18%	6%	3.0
1 tonne of..	K+S product	10%	6%	1.7
1 tonne of..	Schoenite	6%	6%	1.0
1 tonne of..	Kieserite	25%	6%	4.2

	Product	S content in product	SO3 content in polyhalite	..is equivalent to (tonne polyhalite equivalent)
1 tonne of..	AS	24%	19%	1.3
1 tonne of..	SSP	11%	19%	0.6

5.2.3 Price forecasts for 2018

The following price forecasts were used in the calculation of the demand curve in various markets for polyhalite:

Table 5.3: Product prices by major region, 2018 ($/tonne)

US$/tonne	MOP	SOP	Kieserite	SOPM	AS*	SSP	Urea	MAP
North America	425	572	232	304	315	196	384	470
China	352	537	253	246	159	211	309	504
Latin America	385	575	243	314	217	269	343	495
India	349	538	242	324	205	231	367	493
Europe	343	495	246	289	207	192	421	493
SE-Asia	380	540	210	334	195	227	305	495
Africa	328	516	240	334	196	217	352	477

Data: CRU

* Production cost for synthetic

5.2.4 Cost of production calculations

A key component of the analysis was the calculation of production cost for each fertilizer as this sets the price below which a producer would no longer be able to compete with polyhalite. For some products, potash (MOP) and phosphate rock, CRU has well established production costs curves, which provided the costs of the marginal producer in each region. For the remaining products the cost of production was estimated in one of two ways

1. If the 2013 cash costs were reported by the producer they were extrapolated to 2018 costs based upon CRU Strategies macro-economic forecasts.
2. Estimated based upon the cost of raw material, conversion costs and overheads.

The estimated average 2018 production costs for the marginal production method of each product in each region are summarised in the table below.

Table 5.4: Cost of Marginal Production (US$/t)

US$/tonne	MOP	SOP	Kieserite	SOPM	AS*	SSP
North America	267	520	171	248	195	184
China	262	512	99	226	-	157
Latin America	294	522	173	267	190	178
India	269	532	135	-	171	177
Europe	240	495	160	266	164	161
SE-Asia	281	527	124	292	195	178
Africa	246	516	168	-	172	-

Data: CRU

* Production cost for synthetic

5.2.5 Converting Prices to Polyhalite Equivalent Tonnes

Conversions of market prices for each product to an equivalent value for polyhalite were undertaken on a nutrient composition basis in keeping the approach used in chapters 1-4 of the study. In the case of sulphur containing fertilizers, AS and SSP, this involved subtracting a value for the nitrogen component based on the forecast urea price leaving the value for sulphur. This value was then rebalanced to reflect the composition of polyhalite before adding the value of the 14% potash to determine the final value. Examples of this methodology for SOP prices are shown below:

Table 5.5: Example of Price Conversion

SOP		2012	2013	2014	2015	2016	2017	2018
SOP Price (Europe)	$/t	553.60	548.00	475.00	450.00	460 00	493.00	495.00
Value of 1 tonne of K2O	$/t	1107.21	1096.00	950.00	900.00	920 00	986.00	990.00
K2O Content of Polyhalite	%	14%	14%	14%	14%	14%	14%	14%
Implied Polyhalite value	$/t	155.01	153.44	133.00	126.00	128 80	138.04	138.60

Data: CRU

5.2.6 Estimate Freight Costs

Teesport's major cargo handling facility, Tees Dock, is one of the few deep water tidal facilities in the UK. It handles approximately 50 million tonnes of cargo a year. The Redcar Ore Terminal, a deep-sea bulk terminal operated by Corux handles some 100 Capesize and Panamax size vessels a year.

CRU’s dry bulk freight model was used to generate an ocean freight forecast of Panamax and other dry bulk carries. This in turn was used to estimate the cost of transporting polyhalite from Teesside to target markets, incorporating, time charter costs, fuel costs, canal charges, voyage distance, ship size, port changes and voyage route. The outputs of this analysis, shown in the table below, are used to determine the delivered cost of polyhalite from Teesside to target markets.

Table 5.6: Ocean freight rates for key destinations (US$/tonne from Teesport)

	2013	2014	2015	2016	2017	2018	2019
New Orleans	20.7	21.2	20.8	20.8	21.9	22.8	24.0
Santos	23.3	23.8	23.4	23.4	24.6	25.6	26.9
Qingdao	49.2	50.6	50.4	50.6	52.9	54.7	57.3
Rotterdam	6.0	6.2	6.1	6.1	6.5	6.8	7.2
Lagos	19.2	19.6	19.3	19.3	20.3	21.1	22.3
Surabaya	43.2	44.5	44.5	44.6	46.7	48.3	50.5
Port Kelang	40.5	41.7	41.7	41.9	43.8	45.3	47.4
Cartagena	20.2	20.7	20.3	20.3	21.4	22.2	23.4

Data: CRU

5.3 Fertilizer Application Costs

The costs of fertilizer application at the farm level are not insignificant. The lower potassium content of Polyhalite when compared to other straight potassium fertilizers means a larger quantity of fertilizer will need to be applied to meet the same K_2O requirement. In this section we estimate the costs of applying 1 tonne of fertilizer, regardless of nutrient content. This value is then incorporated into the demand model as a penalty costs, in much the same way as a freight costs is applied. This section also considers a case study that indicates that the on-farm costs of polyhalite application may be lower when considered in collaboration with other nutrient sources.

5.3.1 Costs of fertilizer application

From the perspective of the farmer, there are two elements to the cost of fertilizer – the material itself and the cost of operating the equipment that spreads it on the field. These latter costs consist of both fixed and variable elements. The fixed cost is primarily the ownership of the tractor and spreader equipment. In most cases, this cost does not vary if a farmer needs to make multiple passes over his fields to apply fertilizers. However, a minority of farmers rent equipment or outsource the application work, and the associated fees, which then become a variable cost. The variable costs include primarily fuel and labour, but there is also a significant maintenance expense (replacement parts, lubricants and service costs) that is a function of the hours that a piece of equipment operates.

CRU estimates that fuel costs are about 45% of total application costs in a relatively high-wage industrial economy and at least 60% in a developing country, which reflects the lower cost of labour. Based on the fuel consumption per acre of different kinds of equipment, we estimate application costs in a range of $0.50/ha to $1.15/ha depending on type of equipment and country. Converting this into a cost per tonne of fertilizer depends on the application rate, which differs widely from one crop to another and from one country to another. However, a reasonable range of costs is from $5/t to $25/t. For the purposes of this study we have used $15/t, while recognizing that there is a considerable degree of uncertainty around this value. We have also assumed that there will be no change to the number of passes required when switching to polyhalite.

It should be noted that the multi-nutrient nature of Polyhalite may eliminate the need for other sulphur or magnesium bearing fertilizers and the need to apply sulphur ‘top-ups’ throughout the season. If this is the case then the additional costs of fertilizer application below can be considered to be at the higher end of what can be expected in actual practice. However, due to the variability in application practises and fertilizer combinations used in the agricultural sector, CRU Strategies has elected to calculate application cost differences based on the like for like calculation below. This can be considered to be the more conservative approach (i.e. actual application costs are likely to be lower than the values used in this study).

Table 5.7: Application Costs by Product

	AS	SSP	MOP	SOP	SOPM	Kieserite
Primary Nutrient in 1 tonne	240.00	110 00	600.00	500.00	180.00	250.00
Equivalent Polyhalite required	1.26	0 58	4.29	3.57	3.00	4.17
Additional Cost	$ 3.95	$ (6 32)	$ 49.29	$ 38.57	$ 30.00	$ 47.50
Additional Cost per t(Polyhalite)	3.13	- 10 91	11.50	10.80	10.00	11.40

Source: CRU Strategies

5.3.2 Case Study – Fertilizer Application

The above analysis compares the application costs of Polyhalite when it is directly substituted for a straight fertilizer. In practice, the multi-nutrient nature of polyhalite will enable farmers to reduce application volumes of other fertilizers, such as kieserite (if used) and ammonium sulphate. In this case study we take into account the reduced volumes of other fertilizers that would otherwise be applied as a well balanced portfolio of nutrients.

The example outlined below relates to fertilizer consumption on maize in the eastern part of the Corn Belt in the United States. Required fertilizer application is based upon nutrient uptake volumes published in the International Fertilizer Association (IFA) crop manual, and calculated by Barber & Olson on a 9.5 t/ha yielding field.

Table 5.8: Case Study – Fertilizer Application

	N	P2O5	K2O	MgO	S
Nutrient Recommendations	129 00	71.00	47.00	18 00	12.00

	Urea	DAP	MOP	Kieserite	Ammonium Sulphate	Application Cost
Mix 1 - Conventional (No Mg)	220 04	154.35	78.33	-	40.35	$ 7.40
Mix 2 - Conventional	220 04	154.35	78.33	72 00	-	$ 7 87

	Urea	DAP	Polyhalite	Kieserite	Ammonium Sulphate	Application Cost
Mix 3 - Polyhalite (No Mg)	220 04	154.35	335.71	-	-	$ 10.65
Mix 4 - Polyhalite	220 04	154.35	335.71	-	-	$ 10.65

Same number of passes			
Additional application cost (No Mg)	$	9.70	per tonne of polyhalite
Additional application cost	$	8.28	per tonne of polyhalite
One less pass			
Additional application cost (No Mg)	$	-0.30	per tonne of polyhalite
Additional application cost	$	-1.72	per tonne of polyhalite

Source: CRU Strategies

The analysis presents two alternative fertilizer application methods, the first without the use of additional magnesium from kieserite and the second with kieserite. When we compare each application methodology with the alternative option of using polyhalite we see that the need to apply kieserite or ammonium sulphate is removed. Although the total reduction of fertilizer from kieserite and ammonium sulphate does not completely offset the increase from polyhalite, it does reduce the additional application cost from $11.20 to $9.70 and $8.28 per tonne of polyhalite respectively. If the use of Polyhalite reduces the need for additional passes to apply magnesium (typically applied every 2-3 years) or a top-up application of sulphur then the cost differential is further reduced to a point where it may not be more expensive to apply polyhalite.

Due to the variability in application practises and fertilizer combinations used in the agricultural sector, CRU Strategies has elected to calculate application cost differences based on the like for like calculation in Section 5.3.1.

5.4 Response of Incumbent Suppliers

With the emergence of Polyhalite as a new supplier into the industry, incumbent producers will need to choose between sacrificing market share in order to maintain prices or to discount prices and protect market share. The decision of which tactic to employ will depend on the size of market share that is at risk, i.e. the larger the market share captured by polyhalite the more intense the competitive response (price cutting).

To account for this CRU has calculated the predicted polyhalite demand curve under the following two scenarios of varying degrees of competition.

- High industry response – Prices are reduced to the point at which the incumbent suppliers are only covering the cash costs of production.
- No industry response – Incumbent suppliers choose not to change prices and instead sacrifice market share to polyhalite.

The range between Scenario's 1 and 2 represents the two possible extremes of industry reactions, and hence show the entire spectrum of demand variation due to industry reactions. CRU believes that it is unlikely that either Scenario 1 or 2 will eventuate, and instead actual demand will sit somewhere between the two.

In the case of Scenario 1, producers would no longer be making a profit, a situation that they will only tolerate in the short-term if it means protecting market share in the future. However, at some point in the medium-term suppliers will look to return to profitability by increasing prices. If they are unable to increase prices they will look to employ their capital in other industries that offer higher returns. The following bullet points capture the key assumptions for Scenario 1:

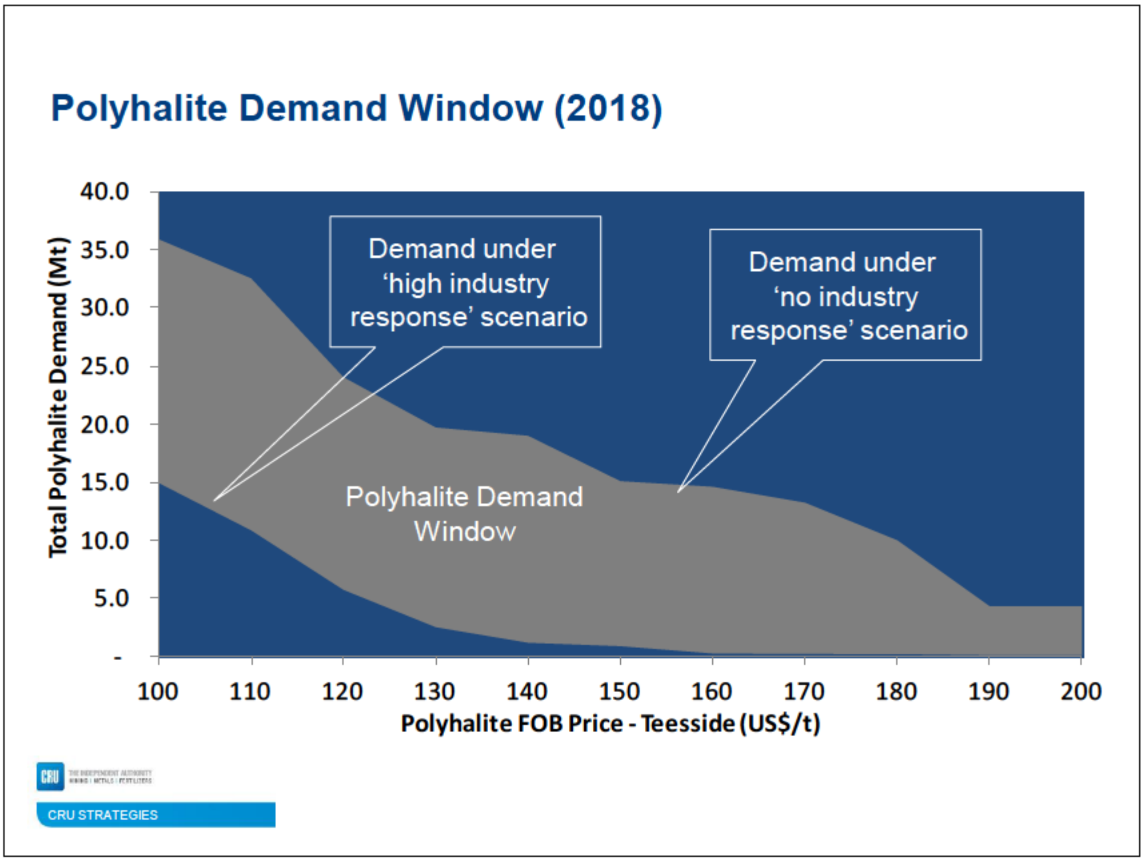
- An extreme scenario in which all prices will be reduced to the point which all the global incumbent suppliers are only covering the cash cost of production
- Likelihood that all global incumbent supplier will pursue this response strategy is unlikely as volumes produced by Sirius Minerals are not significant enough, however this may occur in some niche markets (i.e. SOPM)
- High industry response demand curve will only last for a finite period of time before companies have to prioritize and choose to maximize shareholder value. CRU Strategies estimates that the period of time that producers would operate at cash cost may last 12 to 18 months.
- All additional costs in relation to substitute a product for polyhalite (e.g. fertilizer application cost; logistical costs) are incorporated in this analysis.

Scenario 2 represents a situation where suppliers are happy to lose market share. Historically, with the possible exception of the MOP market, the fertilizer industry has been a price taker preferring to maintain production volumes at lower prices rather than protect prices through cutting production. There are a number of factors that lead to this situation including; economy of scale in the production process, cash flow requirements, storage costs, and the cyclic nature of the industry amongst many others. The combined effect is that incumbent suppliers are incentivised to maintain market share in order to minimise production costs per unit and be best positioned for a potential recovery in the market. The following bullet points capture the key assumptions for Scenario 2:

- An extreme scenario in which incumbent suppliers choose to not change prices and instead sacrifice market share to polyhalite
- Likelihood that all global incumbent supplier will pursue this response strategy is unlikely
- All additional costs in relation to substitute a product for polyhalite (e.g. fertilizer application cost; logistical costs) are incorporated in this analyses.

5.5 Demand Curve Results

Based on the research done in Chapters 1-4 and the pricing analysis above, CRU has calculated the size of the market and the price level associated with selling polyhalite. The outcomes of this analysis are the demand curves shown in the figure below. The two curves represent the predicted demand for polyhalite under the two extremes of competitor responses outlined in section 5.4. The two curves provide a window in which CRU Strategies believes actual demand for polyhalite in 2018 will fall.



The exact positioning within the window for polyhalite demand in 2018 will depend on a number of factors relating to both the acceptance of a new fertilizer by consumers and the response of incumbent producers. Representing the demand curve for polyhalite as range or 'window' allows CRU to account for these unknowns and speak with greater certainty about the demand for polyhalite in 2018. In CRU's opinion it is unlikely that demand would fall below the 'high industry response' demand curve, conversely, it is not anticipated that demand would exceed the 'no industry response' scenario.

At a high level the following general trends in the demand for polyhalite can be observed.

1. Potential demand for polyhalite exceeds 5.0 million tonnes per year in the following situations:
    a. Polyhalite prices less than or equal to $120/t FOB Teesside
    b. Polyhalite prices less than or equal to $180/t FOB Teesside where incumbent producers do not adjust pricing.
2. Potential demand for polyhalite exceeds 13 million tonnes per year in the following situations:
    a. Polyhalite prices less than $110/t FOB Teesside
    b. Polyhalite prices less than or equal to $170/t FOB Teesside where incumbent producers do not adjust pricing.

3. The chlorine-free characteristic of polyhalite significantly increases the potential demand when replacing potassium containing fertilizer products.

4. Demand comes from a diverse base across multiple products and regions, polyhalite's multi-nutrient characteristic allows it to gain small amounts of demand across other product groups.

Table 5.9: Polyhalite Demand (2018, million tonnes)

Polyhalite Price (US$/t) FOB Teesside	High Industry Response (18 Months max.)	Polyhalite Demand Window	No Industry Repsonse (Very Unlikely)
At $100/tonne	14.89		35.89
At $110/tonne	10.80		32.53
At $120/tonne	5.66		24.00
At $130/tonne	2.43		19.66
At $140/tonne	1.09		18.95
At $150/tonne	0.79		15.03
At $160/tonne	0.16		14.54
At $170/tonne	0.11		13.17
At $180/tonne	0.11		9.93
At $190/tonne	0.01		4.24
At $200/tonne	0.00		4.24

Assumption: No additional yield benefit

Data: CRU

The analysis here focuses on the outputs of the demand curve under the **high industry response pricing scenario and does not incorporate the potential yield improvements** through the use of polyhalite over other commercial fertilizers. This scenario has been selected as it is the **most competitive environment that Sirius Minerals is likely to face in the 2018 market**, providing a more rigorous test of the market potential. The key drivers for market size discussed in the sections below will also be relevant for the other pricing scenario's, however, the prices at which polyhalite is competitive will be higher (as shown in the figure above).

5.5.1 Demand for Polyhalite in UK Market

Currently the only UK supplier of polyhalite, Cleveland Potash, has successfully marketed relatively small quantities (60,000-70,000 tpa) as a direct-use fertilizer at premium prices. Given, the increase in demand shown at lower prices outside of the UK it would be fair to assume that a second polyhalite producer, marketing a large amount of product at lower prices would enable the market to grow.

According to trade data, the UK imports 17,000 t of kieserite, 350,000 t of MOP, 220,000 of AS and just of 5,000 t of SOP. Given, the geographical advantage of Sirius over other suppliers of fertilizer from mainland Europe. CRU Strategies estimates that the long term demand for polyhalite at FOB prices of $110/t to $150/t would be between 100,000-200,000 tonnes per year. This number could be expected to increase if the potential yield benefits of polyhalite gain acceptance in the agricultural sector.

5.6 Yield Improvement Value Calculations

As part of the Sirius Minerals marketing strategy they have commissioned a number of crop trials from Agricultural departments of Universities throughout the world. The purpose of which is to prove the performance of Polyhalite relative to other potassium containing fertilizers, and assure the market that the product will not have a detrimental impact on yields. This is standard practise for the introduction of a new product into market and will continue in parallel to the development of production facilities until Polyhalite from York Potash reaches the market in 2018.

Although the studies will continue to be progressed through the next 4 years, a number of studies have been obtained and shared with CRU Strategies. These results have been summarised in the table below, and show that in many of the studies polyhalite has delivered superior yields to other potash containing fertilizers (blended and straight).

Table 5.10: Summary of Polyhalite Crop Trials

Crops	University	Type	Yield Parameter	K2O per Hectare	Reference	Yield Increase
Sorghum Wheat	A&M	Field	Head weight	25.00	MOP	12%
Sorghum Wheat	A&M	Field	Head weight	155.00	MOP	2%
Peppers	A&M	Field	Fresh weight	23.00	MOP	6%
Peppers	A&M	Field	Fresh weight	155.00	MOP	2%
Potatoes	A&M	Field	Tuber fresh weight	240.00	MOP	24%
Onions	A&M	Field	Colossal yield	120.00	MOP	28%
Wheat	DU	Greenhouse	Aerial fresh weight (30d)	100.00	MOP	26%
Corn	SAU	Greenhouse	Aerial fresh weight (40d)	100.00	MOP	10%
Corn	SAU	Greenhouse	Aerial fresh weight (50d)	100.00	MOP Blends vs. Poly blends	44%
Wheat Gallant	DU	Greenhouse	Aerial fresh weight (30d)	80.00	Synthetic Polyhalite	10%
Wheat Cordiale	DU	Greenhouse	Aerial fresh weight (30d)	80.00	MOP	38%
Oilseed rape	DU	Greenhouse	Seed fresh weight	80.00	Synthetic Polyhalite	10%
Peanuts	SAU	Greenhouse	Fresh weight	200.00	MOP Blends vs. Poly blends	42%

Source Sirius Minerals

1 A&M is Texas A&M University

2 DU is Durham University

3 SAU is Shandong Agricultural Uninversity

5.6.1 Value of higher yields

CRU Strategies has **not** made a judgement on the potential yield improvements of polyhalite in on-farm yield, nor has it taken the yield studies presented above as fact. Instead CRU Strategies has elected to assess the size of any potential demand boost from higher yields by calculating the value of a 10% or 20% yield increase on a variety of crops. The crops selected for the study are Corn, Soybeans, Oil Palm, Wheat, Rice and Sugar Beet, with data for farm costs from the

USDA and the IPO prospectus for Felda Holdings Bhd, the world's largest producer of crude palm oil (CPO).

The absolute value of yield increase at the farm level are summarised in the table below. The following assumptions were made in order to complete the calculations.

- Variable costs were assumed to increase proportionally with yield increases in order to account for increase productions costs. In reality, each cost of each incremental tonne of yield would decrease due to economies of scale. This assumption can be considered to be a conservative estimate of any cost increase.
- Variable costs included a variety of cost categories as classified by the USDA, including, 'Custom operations', 'Fuel, lube and electricity', 'Repairs', 'Other variable expenses', 'Hired labour' and 'Opportunity cost of unpaid labour'.
- No change in the costs of seed, fertilizer or chemicals as a result of higher yields
- No adverse impact on the useful life of equipment due to higher processing rates
- The value of yield benefits is shared between farmers, fertilizer distributors and fertilizer producers, such that, 23% of the yield value is passed through to the miner. This assumption is based upon the outcomes of a similar multi-nutrient product marketed by Mosaic, called M*icroEssentials*.

Table 5.11: Value of 10% and 20% yield increase per hectare (US$/t)

Yield Value (per hectare)

	Corn	Soybeans	Oil Palm	Wheat	Rice	Sugar Beet
Base Case						
Variable Costs	301.36	141.01	804.26	166.87	829.55	1,032.93
Total Costs	1,432.95	371.49	1,314.83	709.27	2,317.34	2,185.78
Revenue	1,739.14	1,204.85	2,058.76	729.67	2,659.85	2,592.00
Farmer Profit	306.20	833.36	743.93	20.40	342.50	406.22
10% Yield Increase						
Variable Costs	331.49	155.11	884.68	183.56	912.50	1,136.23
Total Costs	1,463.08	385.59	1,395.26	725.96	2,400.30	2,289.07
Revenue	1,913.06	1,325.34	2,264.64	802.64	2,925.83	2,851.20
Farmer Profit	449.98	939.74	869.38	76.68	525.53	562.13
Incremental Value	143.78	106.38	125.45	56.28	183.03	155.91
Miner Profit Share	33.07	24.47	28.85	12.94	42.10	35.86
20% Yield Increase						
Variable Costs	361.63	169.22	965.11	200.25	995.46	1,239.52
Total Costs	1,493.22	399.70	1,475.68	742.65	2,483.25	2,392.36
Revenue	2,086.97	1,445.82	2,470.51	875.60	3,191.82	3,110.40
Farmer Profit	593.75	1,046.13	994.83	132.96	708.56	718.04
Incremental Value	287.56	212.77	250.90	112.56	366.06	311.81
Miner Profit Share	66.14	48.94	57.71	25.89	84.19	71.72

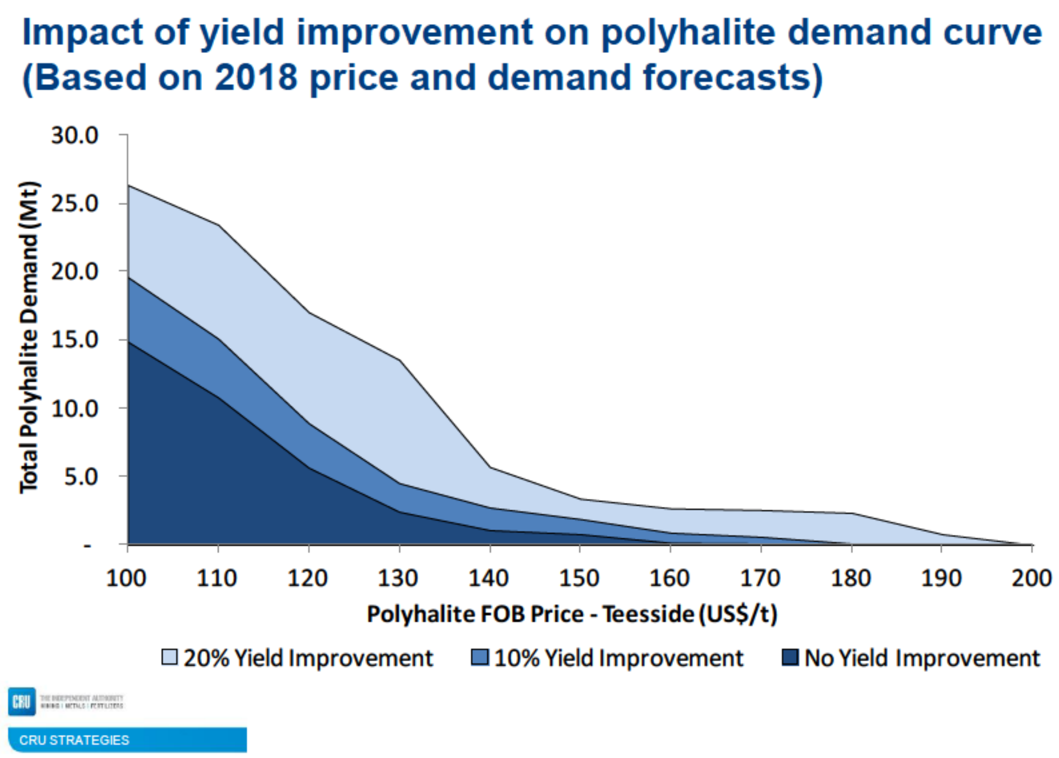
Source: USDA Farm Studies (exc. Oil Palm), Felda Holdings Bhd (IPO Prospectus)

5.6.2 Impact of yield studies on demand curve

The following figure illustrates the impact of improved production yields at 10% and 20% on the polyhalite demand curve, assuming a yield pass through of 23%. The comparison has been based upon the demand curve under the ‘High Industry Response’ pricing assumptions, where producers cut prices to the cost of production. This situation would only be expected to last for the short term (estimated 12-18 month).

In general, the impact of an accepted 20% yield improvement (assuming a yield pass through of 23%) is a shift in the demand curve to the right by $20-25 per tonne of polyhalite. Looking at the cut-off point for 5 Mt of polyhalite demand a 20% yield increase would move this most conservative of scenario’s value from $120/t to $140/t. Likewise, at 13 Mt of polyhalite demand a 20% yield increase would move this most conservative of scenario’s value from $100/t to $130/t.

In the long-run the acceptance of field studies showing the yield benefits of polyhalite due to uniform nutrient distribution, slow-release and secondary nutrients could add significant value. However, until general market acceptance of polyhalite as a product is achieved, it may be difficult for Sirius Minerals to command the premiums shown in the figure and table below. Nevertheless, the potential yield benefits may encourage farmers to try polyhalite at standard prices, and in turn accelerate the acceptance of polyhalite as a viable alternative to other potassium containing fertilizers.


Impact of yield improvement on polyhalite demand curve (Based on 2018 price and demand forecasts)

Glossary of Terms

Potash	Potash refers to potassium compounds and potassium-bearing materials, the most common being potassium chloride (KCl).
MOP	Muriate of Potash, alternative name for potassium chloride fertilizer.
SOP	Sulphate of Potash, alternative name for potassium sulphate
AS	Ammonium Sulphate
SSP	Single Super Phosphate
SOPM	Potassium Magnesium Sulphate, an umbrella term for any fertilizer that contains potassium sulphate and magnesium sulphate.
Langbeinite	The mineral name for SOPM mined in the United States, and is marketed under the brands names K-Mag and Trio.
Kieserite	The mineral name for magnesium sulphate (MgSO4)
NPK	An acronym for “Nitrogen, Phosphate, Potassium” and refers to a fertilizer that contains all three elements.
FOB	An acronym for "free on board", meaning that the buyer pays for transportation of the goods