A Review of nutrient requirements of blackcurrant in the UK

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Background

Blackcurrant is a key fruit crop in the UK, and whilst significant progress has been made in developing the sector (particularly with a successful breeding programme), nutrient management approaches are largely based on historic evidence which may no longer be relevant to UK production and climate. This review sets out to explore the current knowledge relating to best practice in nutrition management for blackcurrant, and to identify key knowledge gaps for future work.

Summary of main findings

- Existing recommendations for blackcurrant are likely to be outdated, especially for nitrogen, given the widespread uptake of modern cultivars. Scant information is available internationally, further illustrating the knowledge gaps in blackcurrant nutrient management.
- Nitrogen is likely to have the most significant impact on blackcurrant growth and yield, although the complexity of nitrogen balance in blackcurrant plantations between seasons and interaction with other effects (e.g. weather) makes it difficult to optimise nitrogen requirements for this crop.
- Recent changes to grower practice have seen a reduction in nitrogen application to blackcurrants: UK growers are typically applying between 80 – 120 kg N/ha/year to mature plantations, which is below the existing recommendation of 120 – 160 kg N/ha.
- Knowledge gaps remain regarding nitrogen applications to modern cultivars, with a specific need to better understand total crop nitrogen requirements during the life of a plantation and the optimum time to apply this nutrient during the season.
- Foliar and soil analysis are integral to developing a nutrient management plan for blackcurrant, although further evidence to link nutrient requirements with local conditions (especially in response to rainfall and irrigation) would be of benefit.
- Foliar feeding is now commonly used by UK growers to maintain bush nutrition, but the timing, frequency and dosage of products could be further examined to maximise the benefit of this approach.
- New methods of nutrient provision such as controlled release fertilisers and fertigation could offer new ways of managing nutrition in blackcurrant. To date, these have seen limited uptake by UK growers and as significant knowledge gaps remain with these approaches, future wider uptake by the industry may be limited.

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Introduction

Blackcurrant is a significant fruit crop in the UK, with 2,516 ha producing 13,000 tonnes of fruit per year (Defra, 2019) with the vast proportion of fruit grown for processing into the drinks market. The high value nature of the crop and high demand for consistent fruit quality (e.g. sugar and vitamin C content) has driven considerable investment in the crop which has seen the development of the widely successful James Hutton Research bred “Ben” series of cultivars. Despite this development, it is difficult to optimise certain aspects of production due to the complex nature of blackcurrant from a biological perspective; the availability of sugars (from photosynthesis) and nutrients available in the current season, together with that stored in the root and bark from the past season, interact with environmental conditions (e.g. temperature, rainfall) to determine yield in both the current and future seasons. Chief amongst these is the nutrient requirements (specifically nitrogen) which affect the ability of the crop to achieve potential yields, as well as affecting bush development and related factors such as canopy management requirement and disease risk.

Ensuring peak efficiency of nutrient application and use is of key concern given the impact of under- or oversupply of nutrients: undersupply of nitrogen is likely to affect productivity and reduce yields, whilst excess applications are liable to reduce fruit quality as well as incurring economic and environmental costs. Nutrition management in blackcurrant is complex compared to other common fruit systems. Plantations are likely to be in production for eight years or more, and stores of nutrients and sugars within the bark and root system means that crop condition and yield in a given year are influenced by both current and past conditions. For example, as flower bud initiation occurs in the autumn of the previous year, the condition of the crop will affect future yield potential (although achieved yield will ultimately be determined by environmental conditions at flowering and fruiting). Furthermore, local conditions (especially weather and soil moisture) are likely to have a significant effect on yield, independent of nutrient conditions, precluding typical approaches in nutrient optimisation that have been successfully employed in other crops.

The current fertiliser recommendations for blackcurrant are based on standards developed in the 1960’s, and there is significant concern that these are no longer appropriate for the predominant cultivars grown in the industry. Furthermore, growing techniques have shown considerable development which could be further exploited by growers seeking to optimise the nutrient regimes used in their blackcurrant plantations, especially as they seek to adopt practices developed in other sectors. For example, other horticulture sectors have benefited from nutrient assessments using leaf and sap analysis, precision soil mapping, new approaches to nutrition (e.g. foliar feed and organic production) or from high efficiency application methods such as fertigation or controlled release fertilisers. While some growers are likely to have adopted these techniques, significant knowledge gaps and lack of a defined best practice approach may prohibit their wider uptake.

To address these shortfalls, this desk study in nutrient management in blackcurrant was undertaken. A methodology was adopted which would explore current and historic recommendations for blackcurrant management in the UK and abroad, appraise current approaches in the UK sector and identify key areas where future work could be used to develop an updated approach to optimum nutrient management.

Objectives

The objective of this work was to carry out a desk study of current blackcurrant nutrition approaches in the UK, to review information from relevant work carried out on blackcurrant internationally and to identify areas where future work can be carried out to further our understanding of the optimum approach for nutrition management in blackcurrant.

Methodology

The initial scope was to review current UK practice in nutrition management of blackcurrant. To this end, several key growers were interviewed, and a prepared survey was sent to growers for their feedback. To support this a literature review was arranged including academic press and ‘grey’ literature such as grower advisory material from both the UK and overseas. The availability of overseas information was very limited. However, recommendations produced internationally (especially in the USA) have been used for reference alongside relevant academic papers.

Grower Survey

Eleven responses were received from the grower survey, covering a total cultivated area of 668 ha which is equivalent to 26.5% of the UK planted area of blackcurrant (2,516 ha, Defra Hort Stats, 2019). Only one grower was producing fruit for fresh consumption, with the vast proportion of fruit being grown for processing into the drinks industry. This is reflected in the cultivars grown, with “Ben Gairn” making up almost a quarter of the planted area (163 ha, 24.4%). The next most frequent varieties were “Ben Starav” (79 ha, 11.8%), “Ben Klibreck” (71 ha, 10.6%), with the majority of the remaining area other members of the “Ben” series (**Figure 1**).

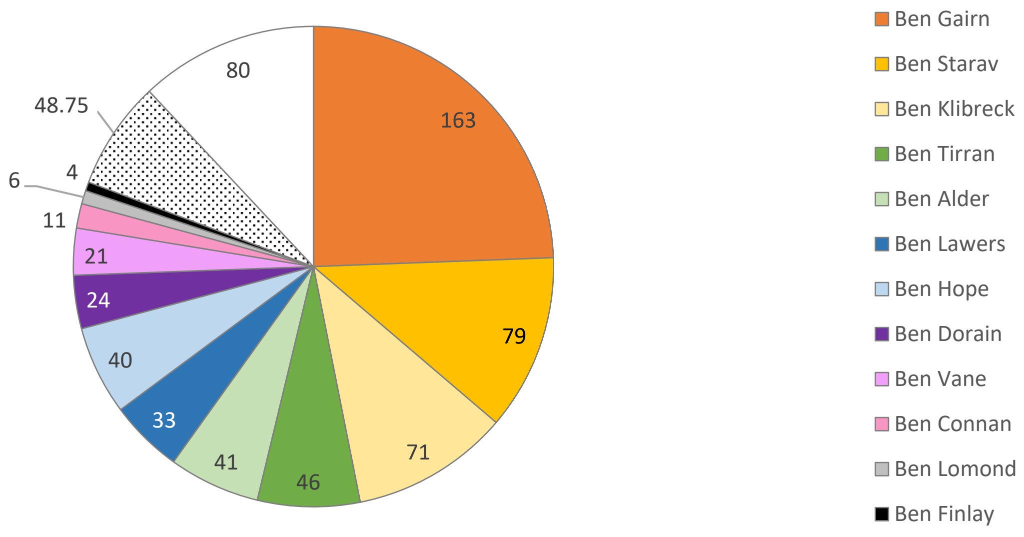

Figure 1. Area of each cultivar reported in the grower survey. Figures are provided for total area cultivated (ha). “Other” included licensed varieties.

The majority of blackcurrant plantations were grown as part of a rotation, typically within arable crops including wheat, barley, oats, oil seed and maize although other growers reported the use of alternative break crops such as mustard or a grass fallow period in their rotation. Where rotations were used these were long, with four or five years between blackcurrant crops. Plantations grown in rotation were generally not specifically scheduled, but break crops were planted when an existing plantation reached the end of its harvestable lifespan. However, three growers reported they did not use a rotation.

Soil types varied between sandy loam to heavy clay, with pH values between 6.0 – 7.5. Whilst interrow spacing of 3m was widely reported, a range of spacings between rows were reported: typical bush spacings of 30 – 50 cm were reported giving densities of c. 6,500 – 10,000 plants per ha, although one grower reported spacings of 80cm giving 5,000 plants per ha.

All growers surveyed carried out some measure of nutrition analysis. Soil sampling was standard before planting and every three years for established bushes, although some growers reported annual analysis or supplemented soil analysis with calculations of crop offtake from harvest (e.g. phosphate from juice measurements) or foliar analysis. Some growers (particularly those using arable crops as part of their rotation) utilised precision analysis or soil scan mapping to guide nutrient applications, particularly for K management. Nutrient application strategies were commonly based on agronomist advice, historical resources (e.g. agronomic advice material supplied by processing customers) or knowledge transfer from other crops – this was particularly relevant where growers were utilising alternative crop nutrient approaches such as fertigation. Irrigation was frequently reported using a range of approaches including rain guns, hose reel or overhead sprinklers.

Blackcurrant nutrient requirements

Nitrogen (N)

Nitrogen is likely to be one of the key nutrients that will have an impact on bush development and ultimate yield, although it is difficult to define optimum application rates due to a variety of effects. Insufficient nitrogen can reduce bush growth and reduce yields, whereas excessive applications can overly promote vegetative growth while reducing fruit quality by lowering sugars and nutrient content and increasing risk of post-harvest rots. In addition to gross nitrogen availability, soil moisture can significantly affect the uptake and use of nitrogen by blackcurrant, and this can influence the timing of its application. Soil conditions and nitrogen uptake can be uncoupled somewhat by the use of foliar feeds (as discussed below) although this is unlikely to be used widely, due to the costs of application. The greatest N contribution reported by the grower survey was 5 kg N/ha applied as a foliar feed after harvest which was only 5% of the total applied.

In addition to general increases in biomass, nitrogen provision has been linked with flower number, ultimately affecting yield through berry number (Bould & Parfitt, 1972), with early spring applications having the biggest impact compared to applications in summer. Nitrogen could affect yield primarily through two routes: either an increase in the potential for fruit by increasing the number of flowers (and therefore the number of berries that can be set) and/or by increasing the extent to which berry potential is fulfilled by increasing the volume of sugars produced by photosynthesis in the leaves which can be utilised for berry filling. In the latter instance, factors which increase sugar availability (e.g. light penetration, canopy area) would lead to greater yields.

Research indicates that the former scenario is typical of blackcurrant (Toldam-Andersen & Hansen, 1993), so yield increases are most likely to be achieved through routes which promote increased flower bud initiation and berry setting. Therefore, optimisation of nitrogen provision to maximise the number of flower buds is likely to have the greatest impact on yield. This is further complicated by other effects on flower setting, particularly bush condition in the preceding season and climate during the bud initiation and bud break periods – this is reflected in studies that have shown that increased shoot number (greater leaf area and greater sugar availability during bud initiation) and water availability can also affect the overall yield independent of nitrogen availability (Goode & Hyrycz, 1970).

Overall, while nitrogen availability has strong potential to affect yield, the complex interaction between climate, past crop history and biological responses of the crop, are likely to preclude any easy assessment and recommendation for nitrogen provision. Ultimately the impact of nitrogen on yield will be the result of a complex interaction between initial yield potential (e.g. number of flowers incepted) and the fulfilment of that potential (availability of sugars from photosynthesis during fruit development). Both of these aspects will be influenced by the end of vegetative development in the past and current season, alongside climate effects. This is reflected in the breadth of current recommendations and records of current grower practice.

Current grower practice

Current recommendations for blackcurrant in the Nutrient Management Guide (RB209) are 160, 110, 120 and 140 kg N/ha for sandy, deep silt, clay and mineral soils respectively, although these recommendations are reduced to 70 – 120 kg N/ha for the “Ben” series of varieties (RB209, 2017). Average nitrogen applications reported by the grower survey was 112 kg N/ha, although there were some significant variations in rates applied (**Figure 2**). Only one grower was applying rates significantly above the lower generic RB209 threshold (135 kg N/ha), with the majority of growers applying either the minimum (120 kg N/ha) or significantly below this threshold. However, given the predominance of “Ben” series cultivars it may be more appropriate to view this in context of lower stated recommendation (70 – 120 kg N/ha) – against this threshold the majority of growers were applying the maximum amount of nitrogen recommended for these varieties, with only one grower approaching the lower threshold (81 kg N/ha). When adjusted for planting density, rates varied from 12g N/bush to 24g N/bush, with the greatest rate achieved at a site with a target density of 5k bushes/ha which achieved 24g N/bush.

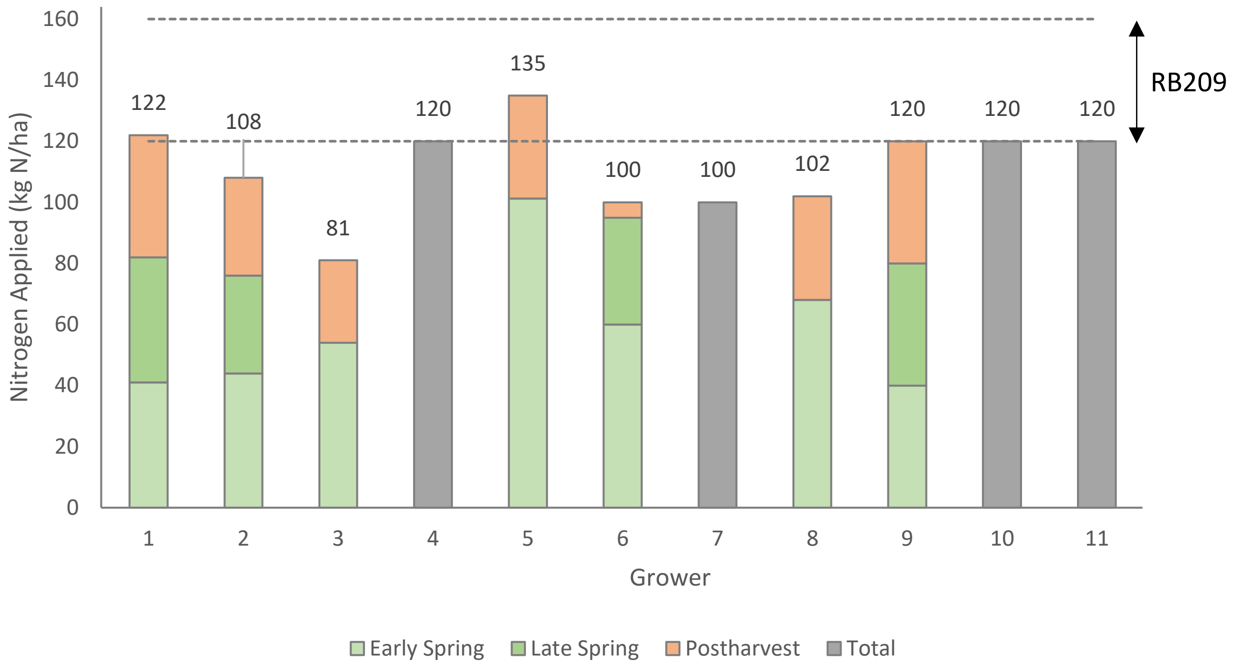

Figure 2. Summary of reported nitrogen applications for mature plantations on a per ha basis. Where split applications were reported, the proportion applied in the early spring, late spring and post-harvest periods are identified. Where only a total application rate was reported this is shown in grey. The total figure of kg N/ha is presented. The current recommendations for blackcurrant are also plotted for reference (RB209, 2017).

The majority of growers surveyed reported split nitrogen applications, with the most typical regime based around three equal applications in the early spring, late spring and after harvest. Foliar applications of nitrogen were reported by two growers as a potassium nitrate or urea spray after harvest or multiple applications of Maxicrop Triple. The sole use of calcium ammonium nitrate as a nitrogen source was reported by some growers, whilst others applied nitrogen as urea or as part of compound fertiliser mixes.

Nitrogen recommendations

A range of nitrogen recommendations that have been made for UK blackcurrant are summarised in

Table 1 below. Historical ranges of nitrogen requirements have varied widely, with the greatest range seen between 37.5 kg N/ha (Beechams, 1973) and 150 kg N/ha (MAFF, 1973a) although these are likely to correspond to varieties that are now largely obsolescent. However, historic recommendations are significantly lower than the current upper threshold in RB209 (160 kg N/ha). It is also noteworthy that current recommendations exceed likely estimates for crop offtake. This is likely to be around 82 kg N/ha (assuming a nitrogen use efficiency of 65%, and a reported offtake of 55 – 65 kg N/ha for a 10-12 t/ha crop), upon which a soil applied maintenance recommendation of 100 kg N/ha or above is based (Craighead *et al*., 2007).

Whilst current recommendations do allow for differences in vigour seen with the 'Ben' series of cultivars, the upper range of these recommendations still reflect nitrogen rates that were historically recommended for cultivars based on vigour differences. Furthermore, there is no adjustment to current recommendations for differences in site rainfall and irrigation practice. Some historical recommendations adjust nitrogen application rates depending on summer rainfall (as outlined in **Table 1**) and Atwood (2008) notes that both irrigation and greater rainfall will increase nitrogen requirements due to increased leaching from the soil or greater vegetative development. The growers surveyed in this study did not vary applications according to rainfall, as they had insufficient knowledge or available time for fine tuning applications to match rainfall and irrigation inputs.

It is also noteworthy that the current RB209 recommendation does not include nitrogen application before planting (including blackcurrant as a generic fruit crop) with nil applications listed for all soil indices. Historical recommendations have included the use of nitrogen before planting. Pre-planting applications of nitrogen vary between recommendations, from the inclusion of a compound fertiliser (Beechams, 1973) or the inclusion of poultry manure (SmithKline Beecham, 1992), to none in the current RB209. Whilst pre-planting applications may be of benefit (particularly where organic matter is included to develop the soil structure) this may not be required if break crops have been previously used and the soil has had a high organic matter. Current processing recommendations are for 70 – 100 kg N/ha at establishment and during the first/second non-cropping years, which could include farmyard or poultry manure before planting to supplement formulated fertiliser applications. Wójcik & Filipczak (2015) reported that growth and yield achieved in plants receiving annual nitrogen applications after planting, compared with equal doses of pre-planting manures.

A combination of nitrogen sources should be used, including calcium nitrate, calcium ammonium nitrate (CAN) and urea in equal proportions sufficient to achieve the total application. The inclusion of CAN will avoid significant impact on soil acidity whilst promoting slower release of N under rainy conditions to improve uptake. It is recommended that banded applications are utilised when applications of greater than 50 kg N/Ha are used, to avoid root scorching and damage (Smith Kline Beecham, 1992 now GlaxoSmithKline). However, current usage tends to be lower (especially where split across the season) so this provision may be unnecessary in current practice.

Table 1. Summary of historic recommendations of nitrogen applications in the UK

<table>
<tr><th>Recommendation</th><th>Notes</th><th>Reference</th></tr>
<tr><td>3 cwt per acre of a 10:20:20 fertiliser before planting (15 kg/ha N).

Young Bushes – 3 Years after Planting
<table>
<tr><th>Variety Vigour*</th><th>Rainfall*</th><th>Kg N/ha</th></tr>
<tr><td rowspan="2">High</td><td>High</td><td>37.5</td></tr>
<tr><td>Low</td><td>37.5-50</td></tr>
<tr><td rowspan="2">Low</td><td>High</td><td>50</td></tr>
<tr><td>Low</td><td>50-75</td></tr>
</table>
Mature Bushes
<table>
<tr><th>Variety Vigour*</th><th>Rainfall*</th><th>Kg N/ha</th></tr>
<tr><td rowspan="2">High</td><td>High</td><td>37.5-50</td></tr>
<tr><td>Low</td><td>50-100</td></tr>
<tr><td rowspan="2">Low</td><td>High</td><td>75-100</td></tr>
<tr><td>Low</td><td>100-125</td></tr>
</table>
*Hilltop Baldwin and Wellington are given as examples of low and high vigour varieties respectively.

*High rainfall is defined as annual rainfall and irrigation above 625ml.</td><td>Recommendations are for minor applications to be made after harvest, with the bulk of application made in March.</td><td>(Beechams, 1973)</td></tr>
<tr><td>140 kg/ha if rainfall <350mm, or 70 kg/ha if rainfall >350mm.</td><td></td><td>(RB209 1st Ed., 1973)</td></tr>
<tr><td>150kg/ha if rainfall <350mm, 75 kg/ha if rainfall >350mm.</td><td>Spring application, with recommendation for foliar analysis in mature bushes.</td><td>(MAFF, 1976a)</td></tr>
<tr><td>140 kg/ha if rainfall <350mm, or 70 kg/ha if rainfall >350mm.</td><td>Notes that these recommendations may be excessive for mature bushes, and promotes leaf analysis.</td><td>(MAFF, 1976b)</td></tr>
<tr><td>For young bushes up to second harvest:
<table>
<tr><th>Period</th><th>kg N/Ha</th></tr>
<tr><td>Feb/Mar</td><td>37</td></tr>
<tr><td>Apr/May</td><td>47</td></tr>
<tr><td>Postharvest</td><td>26</td></tr>
<tr><td>Total</td><td>110</td></tr>
<tr><td>Feb/Mar</td><td>35</td></tr>
<tr><td>Apr/May/Jun</td><td>67</td></tr>
<tr><td>Total</td><td>102</td></tr>
</table></td><td>Rates for mature bushes are altered by cultivar based on vigour. Lower rates are suggested for varieties such as Ben Lomond compared with Hilltop Baldwin.

Requirements for additional applications if rainfall exceeds 350mm are noted.</td><td>(SmithKline Beecham, 1992)</td></tr>
</table>

<table>
<tr><td>For Mature bushes:<table><tr><th>Period</th><th>kg N/Ha</th></tr><tr><td>Feb/Mar</td><td>52/37</td></tr><tr><td>Apr/May</td><td>54/34</td></tr><tr><td>Total</td><td>106/71</td></tr></table></td><td></td><td></td></tr>
<tr><td><table><tr><th>Plantation Age</th><th>Total N (kg/ha)</th></tr><tr><td>Establishment, years 1 – 2</td><td>70-100</td></tr><tr><td>1st cropping years (year 3-4)</td><td>70-100</td></tr><tr><td>Full cropping (year 4 onward)</td><td>70-120</td></tr><tr><td>Flailed regrowth, non-cropping year.</td><td>100-120</td></tr></table></td><td>For areas with summer rainfall >350mm, lower rates of application should be used.</td><td>(Lucozade Ribena Suntory, 2018)</td></tr>
</table>

Across the world, very little has been published on nutrient requirements for blackcurrant. In trials carried out in New Zealand, Craighead *et al.* (2007) reported that nitrogen was the main nutrient to which blackcurrant responded in pot trials, although field studies showed no correlation between soil nitrogen content and blackcurrant yield above a minimum threshold. It was estimated that a soil nitrogen content of 95 – 100 kg N/ha would be required to yield 10-12 t/ha of fruit, and that applications would be required to maintain levels in response to an annual uptake of 55 – 65 kg N/ha by the crop. Additional nitrogen requirements may be necessary if there is high rainfall during the growing season due to additional canopy growth, and the authors recommend that nitrogen levels approaching 150 kg N/ha may be required for higher yield potential. However, higher levels of organic material that typically occur in New Zealand soils may limit the extent to which these rates would be translatable to UK sites (Atwood, 2010).

Recommendations in the USA vary with bush age, ranging from 7.7 g N/bush at planting to 28.5 g N/bush in a five year old crop (Barney & Fallahl, 2009), or 11 – 23 g N/bush (University of Massachusetts) although these are likely to be subject to similar variability of soil, climate and cultivar effects. Few published nutritional studies are available for blackcurrant, and the majority of published material comes from glasshouse trials which are of limited benefit for commercial production. Other published material reflects localised conditions such as a predominance of organic production (e.g. Denmark) or production for fresh fruit rather than processing. Therefore, the uniqueness of the UK blackcurrant market, coupled with climate and cultivar effects, makes it difficult to translate any work from outside of the UK into current commercial practice here.

Timing of applications

Typical current practice is to split nitrogen applications across multiple points during the season. Current recommendations are to split applications equally between late dormancy, flowering and post-harvest periods, or with two thirds during leafing and the remaining third after harvest. For example, Lars (1964) reported greatest nitrogen uptake after bud burst into early summer, so provision in the spring will ensure sufficient soil reserves are available with the seasonal increase in demand. This will also ensure that sufficient N is available to address periods of key uptake including early season root growth, helping to promote leaf condition during fruit development and supporting flower bud development in the autumn. This strategy also helps to reduce the risk of crop damage, the risk of excessive growth after frost damage and potential leaching losses, enabling growers to match applications to perceived crop requirements and environmental conditions such as summer rainfall rates.

The majority of growers surveyed for this review split their applications into either two (spring and post-harvest) or three (early to mid-April, May and September). Divisions were either equal, or with marginally greater proportions of N applied in the early season. It is noteworthy that Atwood (2010) reported that soil assessments at a limited number of sites after harvest indicated that good reserves of soil nitrogen were available precluding the use of post-harvest applications, although without further exploration the commonality of this circumstance is unclear.

Lastly, there is some evidence that nitrogen applications to the bark can promote dormancy breaking in blackcurrant. Smith & Follas (2014) reported a 5-10 day advance in bud break and flowering with calcium nitrate when applied in conjunction with a surfactant. Plants of 'Magnus' and 'Ben Ard' sprayed with 25 kg/ha of calcium nitrate in early spring, led to early flowering in both varieties. It was noted that the flowering window was more condensed in ‘Magnus’ plants (but not ‘Ben Ard’), which was seen as beneficial for consistency of fruiting. Spring applications should be carefully timed to avoid leaching (when applied too early) whilst ensuring that sufficient quantities are available for early season root and shoot development. As such, applications should be timed between late March and early April, although local soil and weather conditions should be taken into account.

A key recommendation is for post-harvest applications in the autumn of at least 25 – 40 kg N/ha to coincide with autumn root growth and higher soil moisture to promote uptake and use. Interestingly, an unpublished trial in Denmark reported that full nitrogen application after harvest was equally effective without incurring any adverse effects on yield, although large applications before the winter may increase leaching rates in sites prone to high winter rainfall.

Cultivar effects

A common theme for existing recommendations in the UK is to alter rates to match cultivar requirements. A range of recommendations were historically given for processing (e.g. Beechams, 1973), but were not listed in RB209 initially although lower applications for the ‘Ben’ series of cultivars is included in the current edition. The greatest impact of varying nitrogen application will be seen on vigour, although changes to rooting architecture and depth may also affect how well a cultivar will respond to nitrogen applications. In the grower survey, four growers reported using different nutrient approaches between cultivars, whilst five growers did not. Adjusting nutrition was seen as an additional tool to control growth of certain cultivars, with reduced spring applications to vigorous cultivars a common technique. One grower reported an additional 10 kg N/ha to ‘Ben Tirran and ‘Ben Gairn’ compared with ‘Ben Vane’ (100 vs. 90 kg N/Ha). Other growers felt other interventions (e.g. varying by soil analysis, plant growth rates or moisture) were sufficient to control growth.

It is difficult to fully define the interaction between cultivar and nitrogen regime, especially as this will also be subject to local and seasonal differences in climate and overall growth response. There is strong precedence for varied nitrogen applications by cultivars, and cultivar-specific responses to nitrogen dosage have been reported in redcurrant (Papp *et al*., 1984). A recent study in Romania demonstrated that responses to different foliar feed products showed strong correlation with feed composition, with a high N feed only having a significant impact on one of the three cultivars tested (Vâtcă *et al*., 2020a) whilst other components (e.g. boron) had the greatest impact on other cultivars. Reported differences in nutrient response between cultivars was sufficient to independently model growth responses to crop nutrition to optimise foliar fertiliser applications, with nitrogen content a chief determinant of response (Vâtcă *et al*., 2020b).

Updating nitrogen recommendations

Current nitrogen recommendations in the UK are based on work initially carried out in the late 1960’s, and changes in cultivars and growing systems may mean that these recommendations are no longer fit for purpose (Atwood, 2010). Difficulties examining the impact of nitrogen applications in isolation from climate effects preclude direct assessments of crop nitrogen requirements, and potential interaction with the application of other nutrients makes it difficult to identify optimum nitrogen requirements in isolation (Atwood, 2008). There has been varying correlation between total N and yield (Atwood, 2010), most likely as a result of other factors affecting outputs such as weather conditions influencing fruit setting. It is likely that N availability will only affect yield if levels fall below a minimum threshold. Rates of nitrogen application have declined in the UK since the 1990’s with a corresponding decline in typical soil nitrogen reserves in blackcurrant plantations (Atwood, 2010) which is likely to have occurred as growers sought to better understand the link between yield and nitrogen application.

Besides existing recommendations, it is difficult to define optimum nitrogen rates, particularly as the amount of nitrogen available to the plant will be an integrated level of current and past applications (due to storage in the roots and stems), alongside interactions such as climate (e.g. effects of shoot growth and water availability) and pest/disease impact once a minimum level has been achieved. The interaction of nitrogen availability and other factors such as post-harvest disease risk in fruit and chilling requirements further complicates optimum nitrogen levels.

In addition to looking at cultivar/timing effects, it may be beneficial to further link nitrogen applications with climate, especially given the increased availability of remote sensing tools, so greater understanding between climate and nitrogen requirements is likely to be of significant benefit to growers. However, any link between irrigation/rain and nutrient provision would also be linked to local factors such as soil type (e.g. increased leaching in sandy soils), climate (rate of vegetative development, crop water uptake) and cultivar (e.g. rooting depth) so this may be difficult to elucidate without significant investigation. A common recommendation is for nitrogen application to be increased in the event of low summer rainfall – SmithKline Beecham (1992) recommended applications to be increased if irrigation/rainfall was less than 350ml, with more specific recommendations given in earlier works – see **Table** 1. However, this was not widely reported as common practice in the grower survey, particularly as the links between rainfall and crop nutrient requirements were not widely understood. Up-to-date weather records on the local scale would also be required to ensure that sufficient applications are made to achieve target yields. Similarly, the link between nitrogen availability, bud break and chilling requirements could be explored further to provide tools for growers to match nitrogen applications with local climates in a reactive fashion to optimise fertiliser use.

Leaf monitoring has been shown to be insufficient for determining crop need, particularly given that N levels are diluted in bushes with more foliage, and it was recommended that N sampling of leaf material occur early in the season or be viewed in the context of leaf volume/canopy area to provide meaningful indicators. However, leaf potassium levels were sufficiently indicative of crop need, with optimum leaf content of 1.3 – 1.8% potassium (Craigshead *et al*., 2007).

Phosphorus (P)

Phosphorus is required for root and shoot development and is particularly important in young plantations. Phosphate is also important for fruit set, so while mature plantations are unlikely to require large applications, where linked with soil analysis, additions may be beneficial. Phosphate applications varied between the growers surveyed. Some growers did not apply additional phosphate due to existing high soil content (index 4+), whilst other growers reported applications of up to 125 kg/ha every 3 – 5 years based on soil analysis. Where annual applications were required, rates of 40 – 100 kg/ha were reported, with applications made in the early spring or at bud burst. This may be applied as a compound fertiliser or in combination with nitrogen and potassium. Phosphate was also applied through foliar applications of products such as Wuxal Top P as discussed below.

Current recommendations for phosphate applications are listed in **Table 2** below, and correspond to earlier recommendations given in the 1970's by MAFF and early processing industry recommendations, to maintain soil index levels at 2 or 3 (**Table 3**). International recommendations were more varied, with recommendations in the USA for annual applications of 2lbs triple super phosphate per 1,000 ft^2, or 47 kg P_2O_5/ha (Colorado State University, 2017) or for 22.5 – 28.5g P_2O_5 per bush, or 146 – 185 kg P_2O_5/ha assuming 6.5k bushes/ha (Barney & Fallahi, 2009).

Table 2. Current RB209 recommendations of phosphate applications for blackcurrant.

Soil Index	0	1	2	3	4 and Above
	kg P_2O_5/ha				
Pre-planting	200	100	50	50	0
Established	110	70	40	40	0

Table 3. Summary of historic recommendations of phosphate applications in the UK.

Recommendation			Notes	Reference
3 cwt per acre of a 10:20:20 fertiliser before planting (30 kg/ha P_2O_5).			Application of compound fertilisers containing sulphate of potash with applications split between spring (March) and postharvest (October/November)	(Beechams, 1973)
Young Bushes – 3 Years after Planting				
Variety Vigour*	Rainfall*	Kg P/ha		
High	High	37.5		
	Low	37.5-50		
Low	High	50		
	Low	37.5-50		
Mature Bushes				
Variety Vigour*	Rainfall*	Kg P/ha		
High	High	25-37.5		
	Low	25-37.5		

<table>
<tr><td>
<table>
<tr><td rowspan="2">Low</td><td>High</td><td>25-37.5</td></tr>
<tr><td>Low</td><td>25-37.5</td></tr>
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*High rainfall is defined as annual rainfall and irrigation above 625ml.
</td><td></td><td></td></tr>
<tr><td>40-75 kg/ha P_2O_5 (30-60 units per acre)</td><td>Spring application.</td><td>(MAFF, 1976)</td></tr>
<tr><td>
<table>
<tr><td>Soil P Index</td><td>P_2O_5 Applications kg/ha</td><td>units/ac</td></tr>
<tr><td>0</td><td>110</td><td>90</td></tr>
<tr><td>1</td><td>70</td><td>55</td></tr>
<tr><td>2</td><td>40</td><td>30</td></tr>
<tr><td>3</td><td>40</td><td>30</td></tr>
<tr><td>3 +</td><td>0</td><td>0</td></tr>
</table>
</td><td>Annual spring applications recommended for acidic soils, but double applications applied every two years are recommended for maintenance applications in index 2 or 3 soils.</td><td>(MAFF, 1976)</td></tr>
<tr><td>
<table>
<tr><td>Soil P Index</td><td>P_2O_5 kg/ha</td></tr>
<tr><td>0</td><td>110</td></tr>
<tr><td>1</td><td>70</td></tr>
<tr><td>2</td><td>40</td></tr>
<tr><td>3</td><td>40</td></tr>
<tr><td>3 +</td><td>0</td></tr>
</table>
</td><td></td><td>(RB209, 1st Ed)</td></tr>
<tr><td>Application to maintain soil index 2+ or 3.</td><td></td><td>(Smithkline Beecham, 1992)</td></tr>
<tr><td>Adjustment of soil index to 3+ or 4.
<table>
<tr><td>Plantation Age</td><td>Total P (kg/ha)</td></tr>
<tr><td>Establishment, years 1 – 2</td><td>20-50</td></tr>
<tr><td>1st cropping years (year 3-4)</td><td>25-35</td></tr>
<tr><td>Full cropping (year 4 onward)</td><td>0-30</td></tr>
<tr><td>Flailed regrowth, non-cropping year.</td><td>30-50</td></tr>
</table>
</td><td>Applications as triple super phosphate, muriate of potash and compound feed.</td><td>(Lucozade Ribena Suntory, 2018)</td></tr>
</table>

Applications may be recommended post-harvest to improve distribution in the soil column by washing through with rainfall during the winter. Higher rates may be recommended on sites with lower rainfall (<630mm/year total rainfall/irrigation), particularly in younger bushes with less developed root systems (Beechams, 1973). Phosphate mobility is also significantly affected by soil pH, with peak mobility seen around a pH of 6.5. It is noteworthy that Craighead *et al*., (2007) reported that phosphate was unlikely to be limiting, even where soil levels are below optimum, particularly in established plantations. Craighead *et al.* also reported relatively low P offtakes of up to 6 kg/ha/year, which support the use of reduced dosage rates and/or delaying applications to every second or third year. Such an approach would require accurate dosing during establishment to ensure early root growth is not impaired, although the potential use of precision mapping before harvesting may support this. Soil sampling at depth, particularly in cultivars with deeper root systems, may also be beneficial to understand the proportion of P present in the soil when considering application rates allowing the dose to be matched with crop requirements.

Potassium (K)

The availability of potassium can affect shoot length and works synergistically with nitrogen applications to encourage shoot growth and enhance yield output. High applications may be required in conditions of heavy cropping, although excessive applications can risk magnesium deficiency as the presence of high concentrations of K^+ ions in the soil can restrict the uptake of Mg^{2+} ions. Current recommendations for potassium are listed in **Table 4** below, with a recommendation that pre-planting applications should be fully cultivated into the soil before planting to avoid root scorch, and that sulphate of potash should be used for applications greater than 120 kg K_2O/ha. Like phosphate, potassium applications are generally recommended in the early/late season when increased rainfall is likely to promote penetration of feed into the soil to aid uptake.

Growers surveyed for this review used a range of potassium application rates. Rates of 90 – 120 kg K_2O/ha were reported, although some growers reported ranges down to nil application depending on soil analysis, including precision mapping. Some growers reported annual application in early spring (typically included with nitrogen applications around bud break) although some growers reported applications only every two to three years. There was some interest in the depth of potassium availability in the soil relative to root penetration, and there was a belief that higher soil concentrations lower in the soil profile could be used to support less frequent applications. Compared with RB209 recommendations these largely correlate with a maintenance of an index of around 2 – 3. A range of recommendations have been given historically for potassium requirements (**Table 5**). Existing recommendations are comparable with earlier recommendations (e.g. MAFF, 1976b) and early editions of RB209. International recommendations are variable. Annual applications for mature bushes are for 225g/bush of a 10:10:10 fertiliser (146 kg K_2O/ha assuming 6.5k bushes per ha) (Barney & Fallahi, 2009).

Table 4. Current RB209 recommendations of potassium applications for blackcurrant.

Soil Index	0	1	2	3	4 and Above
	kg K_2O/ha				
Pre-planting	200	100	50	0	0
Established	250	180	120	60	0

Table 5. Summary of historic recommendations for potassium in blackcurrants.

<table>
<tr><th>Recommendation</th><th>Notes</th><th>Reference</th></tr>
<tr><td>3 cwt per acre of a 10:20:20 fertiliser before planting (30 kg/ha K).

Young Bushes – 3 Years after Planting
<table>
<tr><th>Variety Vigour*</th><th>Rainfall*</th><th>Kg K/ha</th></tr>
<tr><td rowspan="2">High</td><td>High</td><td>50</td></tr>
<tr><td>Low</td><td>75</td></tr>
<tr><td rowspan="2">Low</td><td>High</td><td>50</td></tr>
<tr><td>Low</td><td>50-75</td></tr>
</table>
Mature Bushes
<table>
<tr><th>Variety Vigour*</th><th>Rainfall*</th><th>Kg P/ha</th></tr>
<tr><td rowspan="2">High</td><td>High</td><td>75</td></tr>
<tr><td>Low</td><td>75</td></tr>
<tr><td rowspan="2">Low</td><td>High</td><td>50-75</td></tr>
<tr><td>Low</td><td>75</td></tr>
</table>
*Hilltop Baldwin and Wellington are given as examples of low and high vigour varieties respectively.

*High rainfall is defined as annual rainfall and irrigation above 625ml.</td><td>Application of compound fertilisers containing sulphate of potash with applications split between spring (March) and postharvest (October/November)</td><td>(Beechams, 1973)</td></tr>
<tr><td>125 kg/ha K_2O (100 units per acre)</td><td>Spring application.</td><td>(MAFF, 1976a)</td></tr>
</table>

<table>
<tr>
<td>
<table>
<tr><th>Soil P Index</th><th colspan="2">K_2O Applications</th></tr>
<tr><th></th><th>kg/ha</th><th>units/ac</th></tr>
<tr><td>0</td><td>250</td><td>200</td></tr>
<tr><td>1</td><td>180</td><td>145</td></tr>
<tr><td>2</td><td>120</td><td>100</td></tr>
<tr><td>3</td><td>60</td><td>50</td></tr>
<tr><td>3 +</td><td>0</td><td>0</td></tr>
</table>
</td>
<td>Annual applications are recommended for deficient soils, with sandy soils likely to become deficient. At index 2 or 3 applications every other year can be used.</td>
<td>(MAFF, 1976b)</td>
</tr>
<tr>
<td>
<table>
<tr><th>Soil K Index</th><th>K_2O kg/ha</th></tr>
<tr><td>0</td><td>250</td></tr>
<tr><td>1</td><td>180</td></tr>
<tr><td>2</td><td>120</td></tr>
<tr><td>3</td><td>30</td></tr>
<tr><td>3 +</td><td>0</td></tr>
</table>
</td>
<td></td>
<td>(RB209 1st Ed., 1973)</td>
</tr>
<tr>
<td>
<table>
<tr><th>Plantation Age</th><th colspan="2">K Index</th></tr>
<tr><th></th><th>Baldwin</th><th>Lomond</th></tr>
<tr><td>Young bushes up to 2nd harvest</td><td>2+ to 3-</td><td>3+ to 4-</td></tr>
<tr><td>Mature bushes – 3rd harvest +</td><td>3- to 3+</td><td>4- to 4+</td></tr>
</table>
.
<table>
<tr><th>Plantation Age</th><th colspan="2">Total K (kg K/ha)</th></tr>
<tr><th></th><th>Baldwin</th><th>Lomond</th></tr>
<tr><td>Young bushes up to 2nd harvest</td><td>75</td><td>100</td></tr>
<tr><td>Mature bushes – 3rd harvest +</td><td>94</td><td>125</td></tr>
</table>
</td>
<td>Avoid applications of muriate of potash at rates greater than 125 kg K/ha.

Slow build up of K after planting.

Lower rates than those reported may be sufficient for Baldwin, but may be higher than states for Lomond.</td>
<td>(Smithkline Beecham, 1992)</td>
</tr>
<tr>
<td>
<table>
<tr><th>Plantation Age</th><th>Total K (kg/ha)</th></tr>
<tr><td>Establishment, years 1 – 2</td><td>0-50</td></tr>
<tr><td>1st cropping years (year 3-4)</td><td>70-100</td></tr>
<tr><td>Full cropping (year 4 onward)</td><td>70-100</td></tr>
<tr><td>Flailed regrowth, non-cropping year.</td><td>40-120</td></tr>
</table>
</td>
<td></td>
<td>(Lucozade Ribena Suntory, 2018)</td>
</tr>
</table>

It is worth noting that there is some reference to cultivar differences to potassium response, with rates varied according to plant vigour in the 1992 SmithKline Beecham recommendations. Vâtcă *et al*. (2020b) reported an interaction between cultivar and foliar applications of K_2O and nitrogen (alongside calcium oxide) in terms of branch extension and development. Craighead *et al.*, (2007) reported that potassium removal for a 10-12 t/ha crop is likely to approach 43 – 59 kg K/ha. The latter authors also reported that a decrease in potassium availability gave suitable yield outputs without indicating deficiency symptoms, and suggested that current recommendations based on healthy plant analysis may be overestimating the amount of potassium required before declines in yield or crop condition were observed. Overall, there has been little published regarding potassium requirements for blackcurrant, although the potential interaction with nitrogen applications could render this a key area for further study.

Other important nutrients for blackcurrants

The grower survey identified that the majority of growers applied only a limited range of other nutrients, typically using foliar fertilisers, and only when the need is indicated by foliar analysis. Boron applications in April at bud break as a foliar spray was commonly reported, although one grower reported specific applications of manganese. Only minor recommendations are available for micronutrients (normally Fe, Mn, Cu, Zn, Mo, B, Cl) in blackcurrant, and the majority of these are based on historic figures.

Magnesium (Mg - a macronutrient) may become deficient, especially in low vigour cultivars after picking or in crops grown on free-draining sandy or acid soils. Blackcurrant can have a higher requirement for magnesium compared to other crops. Magnesium can be applied as a foliar spray (as discussed below) or through magnesian lime. Historic recommendations of applications of 60, 40 or 30 kg Mg/ha are given for soil indices of 0, 1 or 2 respectively, with nil application above 2 (MAFF, 1976b). Magnesium requirements will be increased in soils with a high potassium content as the presence of high concentrations of K^+ ions in the soil can restrict the uptake of Mg^{2+} ions.

Calcium (Ca – a macronutrient) is required for root and shoot formation but is unlikely to be limited in adequately limed soils although be aware that **Iron** (Fe) and **Manganese** (Mn) availability can be reduced to the point of deficiency in over-limed soils with a pH above 6.5 (MAFF, 1976b). It is also worth noting that there is an apparent interaction between the availability of potassium and calcium (Vâtcă *et al*. 2020b; Craighead *et al.,* 2007) and so optimum levels of these nutrients may need exploring on calcium deficient soils.

Boron (B - a micronutrient) may be required to ensure adequate fruit set, with deficiency symptoms linked to premature flower and fruit drop, especially under conditions of water stress (Craighead *et al.,* 2007). While **Sulphur** (S – a macronutrient) uptake can be significant (5-7 kg S/ha for a 10-12t/ha crop), additional applications may not be required if sulphur-containing fertilisers are used for other nutrients (e.g. sulphate of potash) (Craighead *et al.,* 2007). Foliar analysis may be particularly useful in determining micronutrient status, particularly of boron and manganese (Wójcik & Filipczak, 2018). It was reported that differences in response to foliar feeds (as discussed below) could in part be attributable to different micronutrient requirements (Vâtcă *et al*., 2020a) although these effects are likely to be negligible in comparison with responses to other nutrients such as nitrogen.

Alternative methods of fertiliser management

Foliar feeding

A significant number of growers reported the use of foliar feeds in blackcurrant. A range of products including Maxicrop, Headland Complex, Wuxal Top P and Kristalon Red were reported. These were used in a variety of situations ranging from routine application (e.g. an application of Kristalon Red included with every spray from bud break to the end of May) to spot applications in response to deficiency (particularly of magnesium and manganese). A number of growers also reported the use of foliar feeds in dry periods, particularly post-harvest. There was also a perception that foliar sprays can also benefit bud break consistency in the early season, and that applications improve specific features such as improved leaf condition and size to reduce sun scorch on the fruit, whilst minimising bush stress.

Foliar application of nutrients offers a range of benefits, although the specific use of many products in blackcurrant has not been widely examined resulting in a paucity of recommendations. Direct application to the plant may reduce nutrient leaching and environmental impact, whilst increasing the speed at which nutrients are available to the plant (especially if applied in situations of deficiency), particularly of low mobility nutrients. However, feedback from growers suggested that foliar feeds were considered to be more beneficial as an enhanced background support for nutrition rather than of use as a spot treatment for a specific deficiency (particularly as problems are likely to be difficult to mitigate if identified only at the foliar stage).

Some growers interviewed for this review reported using a broad range of foliar spray products (summarised in Table 6 below), although their use was not restricted solely to nutrition management. Other modes of action included bio-stimulant activity (e.g. promotion of root development) or as an aid for breaking bud dormancy. Likewise, growers perceive that some products applied for pest/disease control may also offer a nutritional benefit. Examples include phosphite used for fungicidal action, or flowable sulphur application for gall mite control.

Trials in Romania have shown strong responses to foliar nutrient applications and interestingly product response varied depending upon the cultivar treated (Vâtcă *et al*., 2020a). Applications made at 10% and 50% open flower, and again after petal fall (corresponding to 0, 14 and 28 days) led to increases in both vegetative development (branch length) and yield of 14.7 - 36% when compared to an untreated control. The level of increase depended on cultivar treated. Different cultivars showed optimum responses to different foliar feeds – the early ripening 'Tines' cultivar gave the greatest response to a feed containing 7.25% N/14.5% K_2O (v/v) with high Fe, Mn, Mo and Zn, whilst a 3.7% N/1.9% K_2O/0.18% CaO (v/v) feed with low Mn, Fe and Zn was recommended for the mid-season ripening 'Ruben' cultivar. It is likely that foliar feeds containing nitrogen are likely to have the greatest crop responses, with additional interactions with other nutrients, specifically K and Ca (Vâtcă et al., 2020b). The use of high nitrogen foliar feeds would need to be taken into consideration when developing a wider nutrient management strategy as discussed above. However, two growers in the survey reported the appreciable application of nitrogen as foliar fertilisers (e.g. Maxicrop Triple, or 5 kg/ha foliar spray of urea) and this may be an effective method to stimulate canopy condition in the short term.

A number of foliar feeds are available to growers in the UK (including organic products), but on-label recommendations for bush fruit are generalised or absent, so refining their use can be difficult (**Table 6**). Furthermore, the application process incurs high labour costs so clear evidence of the cost/benefit, optimum window for application and length of use will also need to be demonstrated. Tank mixing foliar feeds with other products will minimise additional labour inputs, although this can incur a risk of foliar damage and care should be taken to follow manufacturers' compatibility recommendations and the advice of experienced agronomists. While there is strong potential for foliar feeding to enhance the nutritional status of UK blackcurrant crops, further evidence of their benefits should be elucidated to support growers wishing to utilise such products, particularly in the absence of targeted on-label recommendations.

Table 6. Summary of foliar spray products used in blackcurrant as identified by the grower survey.

Product	Manufacturer	Notes	Rates
Misc.	Misc.	Water-soluble potassium nitrate	3 kg/ha
AminoA Flo	AminoA	Amino acid-based bio-stimulant with added N, K, Fe and Mg. Apply bud burst to harvest.	2 - 5 l/ha
Hortiphyte	Hortifeeds	4-25-16 foliar feed with phosphite, may promote rooting. Apply from fruiting.	3 - 4 l/ha
Headland Boron	Headland	Soluble boron formulation applied before flowering.	1.25 - 2.5 l/ha
Headland Complex	Headland	Various formulations applied twice before harvest, and once after harvest to aid recovery.	4 kg/ha
Maxicrop Triple	Maxicrop	Liquid seaweed feed and bio-stimulant.	12 l/ha
Wuxal Top-P	Certis	5-20-5 foliar fertiliser with micronutrients applied at flower initiation.	2 - 3 l/ha
Kelpak	Kelpak	Organic macro/micronutrient fertiliser	2 - 4 l/ha
Kristalon Red	Yara	12-12-36 foliar feed with micronutrients	4 kg/ha

Drip irrigation and fertigation

One technical solution for optimised nutrient provision to blackcurrant could be the use of drip irrigation/fertigation systems. The provision of a liquid-based feed applied through drippers has seen wide uptake by other soft fruit sectors, most notably strawberry and cane fruit, where it has offered significant increases in nutrient and water use efficiency whilst ensuring that supplies to the crop can be finely matched to crop needs, as opposed to base/top dressing nutrients and irrigating with rain guns etc. A key benefit of this method is that nutrients and electrical conductivity (EC) can be tailored to crop demands to slow fruit growth and boost berry yield and flavour. Ostermann & Hansen (1988) reported that drip irrigation improved shoot extension in dry years and increased yield in the subsequent season, although differences were not seen in wetter years. This largely correlates with observations from UK growers using drip irrigation, who reported that this approach can improve growth and mitigate sub-optimal weather conditions. The approach also accelerates vegetative growth so that newly planted bushes may produce a harvestable yield in the second (rather than third) season. This may also require different crop management strategies such as increased centre pruning to trim back young growth from mature branches. There is also a gap in our knowledge of optimal feeding techniques such as feed composition, EC/pH at application and thresholds for application. For example, irrigation based on optimal soil moisture thresholds showed significant variation between soil type and nutrition status (Hoppula & Salo, 2005) and variation of the fertigation regimen is likely to interact with climate, soil type and cultivar.

A fertigation programme would need to be bespoke to the requirements of a specific site, including rainfall, plantation age, condition and cultivar choice. It would also need to accommodate local water analysis to ensure target EC values can be realistically met. Any deficiencies highlighted in a soil analysis should be remedied in the winter/early spring. Any requirement for a top dressing of N (c. 30 – 50 kg N/ha) should be made to the crop as it breaks dormancy while there is still sufficient soil water to avoid the need for irrigation. The fertigation programme should vary with crop development stage, with different rates of application during the pre-flowering, late flowering/fruiting and post-harvest periods. This would be formulated to achieve reduced potassium with increased nitrogen either side of flowering to support leaf and shoot development, with phosphate and magnesium applied before and after harvest to drive root, leaf and flower bud development. Overall application rates would aim to achieve RB209 rates in total (less the initial base dressing) over the main growing period. A typical fertigation programme is provided in **Table 7** below.

Table 7. Example fertigation program for blackcurrant. (Atwood, Personal Communication)

Growth Stage	N Rate	Nutrient Ratios				Weeks	Nutrients Applied (kg/ha)			
	(kg/ha/week)	N	P_2O_5	K_2O	MgO		N	P_2O_5	K_2O	MgO
Pre-flowering	3	22	7	22	2.5	6	18	6	18	2
Flowering/Fruiting	3	15	0	30	0.2	8	24	0	48	0
Post-harvest	3	22	7	22	2.5	6	18	6	18	2

Improving our understanding of the optimum timing of application and nutrient requirements for crop responses would benefit future blackcurrant fertigation. We also need to learn more about its interaction with different cultivars, crop age and management. The wider uptake of this approach may be hindered by increased costs through both the provision of the drip irrigation infrastructure and labour costs of installation. However, the combined water/nutrient use efficiency benefits and potential to enhance yields and mitigate prolonged dry spells without supplementary irrigation may prove attractive.

Controlled release fertiliser

There has been limited research into the use of controlled release fertiliser (CRF) for blackcurrant. A small, non-replicated trial by Atwood (2010) compared the conventional application of 90 kg N/ha (60 kg N from a compound fertiliser and 30 kg N from ammonium nitrate) with 60 kg N/ha from a controlled release fertiliser to a single row of Ben Hope. The CRF-treated row showed reduced leaf condition with greater yellowing, although yields were comparable with the conventional treatment despite receiving 30 kg N/ha less with both giving 8.7 t/ha. In this instance it was considered that nutrient availability from the CRF was reduced due to dry summer conditions so that nitrogen requirements during rapid growth in late May/early June were better met by the straight application. Based on this study, the increased costs of CRF use were not considered justified compared with straights use.. However, with further optimisation of CRF use and testing in more varied climate may be of benefit when exploring the use of slow-release fertiliser use.

Organic production

Organic production in the UK is uncommon, as there is little demand for organic crops in the main processing market for blackcurrant. One grower reported the use of cover crops between rows including blends of radish and vetch to provide a mulch. Pedersen (2002) reported the successful use of cover crops for blackcurrant in organic production, although the subtility of cover cropping may be linked with variety choice – deeper rooted varieties may be less prone to root damage during cultivation of the cover crop into the soil.

Planning nutrient applications

Alternative methods of estimating crop nutrient requirements can be informed by sufficient soil sampling. Soil sampling for nutrient availability is essential before planning any fertiliser applications. It is beneficial to test for both soil mineral nitrogen (SMN) and anaerobic mineralizable nitrogen (AMN) to assess the availability of nitrogen over the course of the season, especially in soils with a high organic matter. Samples should be taken at 0-30 cm depth in representative rows (Craighead et al., 2007), although it may be beneficial to sample at greater depths (30-60cm) to test whether nutrient availability varies within the soil profile. Given the potential carryover of low mobility nutrients (e.g. phosphate) and the strong influence of seasonal factors on yield, annual soil testing is unlikely to offer any greater benefit compared with testing at two or three year intervals (Atwood, 2010). All growers surveyed for this review reported the use of soil analysis for planning nutrient applications, although this varied between sampling annually to every two to three years. There was also belief that sampling at different depths may improve the understanding of the availability of low mobility nutrients (e.g. potassium/phosphate) and that wider soil mapping could be used to aid the precision application of these nutrients.

Besides soil testing, several other techniques can be utilised to develop an understanding of the nutrient status of plantations. Of the growers surveyed, several reported the use of foliar analysis to determine the nutrient status of the crop and diagnose specific deficiency problems. Foliar analysis may be of particular importance for micronutrient content, with strong correlations reported between manganese and boron in pre-bloom and summer leaf levels (Wójcik & Filipczak, 2018).

Estimates of crop offtake can be produced using yield values, with one grower reporting the use of this method. Crop nutrient uptake of 6.0 kg N, 3.3 kg P and 4.5 kg K per tonne of fruit have been reported (Craighead *et al*., 2007). However, margins of error in this approach may be prohibitively large, especially as any variation in the proportion of fruit to vegetative material (e.g. with cultivar or changes in growth habit due to cultivation) may affect the partitioning of nutrients. Analysis of nutrient content of sap flow in the early spring has been utilised to inform nutrition status in some crops (e.g. tomato) but the lack of sufficient laboratory services and reference values for blackcurrant are likely to be significant barriers to wider uptake.

Knowledge gaps

Nutrient applications

A recurring finding when undertaking this review was the scarcity of current research relating to the nutrient requirements of modern cultivars, and how best to apply the required nutrients. This is most pronounced with nitrogen – the findings of the grower survey that standard industry practice is to apply less than the current recommended rate of nitrogen is indicative that rates could be reduced, particularly if banded applications are commonplace. Furthermore, split applications (most commonly in three equal applications over the season) are typical. Splitting nitrogen applications may allow for lower rates of overall application due to reduced leaching, but a shift towards single-dose application in the autumn as indicated by Craigshead et al. (2008) may further interact with total nitrogen applications.

The interaction between nutrition management and other aspects of production (e.g. bud break) or the integration of innovative ways of growing (e.g. use of methods to stimulate bud break) are also liable to interact with nutrient provision. Recent trials have been reported internationally (as discussed above) but the relevancy of this work to the UK may be limited due to the specific combination of climate, soil, cultivar choice and product requirements seen in the UK sector. Whilst this is likely to be a difficult area to explore, particularly due to difficulties in linking nitrogen application with yield over successive seasons due to interaction with other conditions (e.g. climate), this should be a priority area for future work. Whilst this could accommodate other aspects of nutrient management that could benefit from further elucidation (e.g. fertigation approaches), successive trialling of nitrogen responses in blackcurrant over three to five seasons would be beneficial.

Cultivar effects

There is strong potential for nutrient management approaches to be adapted to specific cultivar needs, particularly in controlling the growth of more vigorous cultivars, and this approach was reported by several growers surveyed for this review. Reduced nitrogen applications in more vigorous cultivars was reported, particularly in the early season applications in April and May. Other growers reported that they did not vary applications due to lack of information and time/labour constraints preventing varied application. Vigorous spreading cultivars such as Ben Hope are likely to be good candidates for reduced nitrogen input. Strong cultivars like 'Ben Lawers', 'Ben Klibrek' and 'Ben Starav' may also benefit from reduced nitrogen inputs after establishment on some soil types. Conversely, weaker cultivars like ‘Ben Gairn’ may require greater applications to promote sufficient growth.

There is also potential for rates of application to be linked with plantation age. Cultivars such as ‘Ben Finlay’ that have weak initial growth may require more nitrogen during establishment, but this could be reduced later to manage growth in more mature conditions. Whilst this may be of primary focus on nitrogen, this may also be relevant to other nutrients. For example, one grower surveyed reported phosphate deficiency issues with ‘Ben Gairn’ which was addressed through supplementary foliar fertilisers. While there is significant potential for growers to vary their nutrient management for differing cultivars, there have been no recent UK nutritional trials on which to base such decisions, so for now growers will need to rely upon their own experiences. Given there is likely to be significant interaction between application rates, climate, crop age and past history, this is a complex area that would greatly benefit from deeper exploration.

Adopting alternative growing methods

There has been limited uptake of alternative growing methods, such as the use of fertigation, controlled release fertiliser and mulches. Whilst these may not see wide-scale uptake, they are likely to offer a range of benefits to growers in terms of nutrient and water management. Furthermore, new technological solutions will enable growers to better monitor the condition of their crops (including leaf analysis and local weather monitoring), and this could be used as a foundation for ongoing modification of nutrient inputs. The use of foliar feeds is also widespread, although these may often be used without sufficient manufacturers’ guidance and therefore key evidence is missing as to the best practice approaches for these products. Whilst there are some existing recommendations for these approaches, these are liable either to be linked with obsolete cultivars (e.g. linkage with rainfall) or adopted from other sectors (e.g. fertigation) and may not represent the best practice approach for modern blackcurrant cultivars. Further development of these areas is likely to provide the evidence needed by growers that are seeking to adopt new approaches.

Conclusions and future research requirements

The nutrition of blackcurrants is a complex issue and one for which there is a significant scarcity of information relevant to modern commercial production in the UK. Basing the growth of modern cultivars and modern growing techniques on nutritional guidance that was developed 50 years ago is unsatisfactory and needs to change. Whilst there has been some limited international research on blackcurrant nutrition in the intervening period, it is difficult to find any clear recommendations suitable for implementation in UK plantations.

The grower survey carried out as part of this review demonstrated a trend towards reduced nitrogen use relative to long-standing recommendations. There are significant knowledge gaps regarding the optimum nitrogen requirements and how it should be applied, taking account of cultivar differences and local effects of weather conditions. The need to further refine nutrition of blackcurrants will increase as growers seek to minimise their environmental impact and aspire to meeting carbon net zero targets.

This review of nutrient management in blackcurrant has highlighted gaps in our knowledge and where future research is urgently required:

- The impact of nitrogen applications on yield across multiple seasons should be studied, and links between nitrogen requirements and crop history (including yield, climate and past management) should be identified. This will enable growers to consider the requirements of their plantation in the longer term, rather than each season and a standalone period.

- The relationship between measurable nutrient indices (e.g. soil, leaf, fruit or stem sampling) and crop requirements and/or likely offtake should also be evaluated – if a tool can be generated which links required applications with easily determinable figures will provide growers with additional confidence when planning nutrient applications.

- The impact of climate variation, growth, yield and nutrient requirements would also benefit from a longer-term exploration over several seasons. As noted above, grower awareness of changing nitrogen requirements with water availability has not translated into practice due to a lack of evidence to support the judgement process, and this should be addressed through targeted examination.

- Research to refine the nutritional needs of modern cultivars, particularly nitrogen, would help growers to improve fertiliser use efficiency, reduce adverse effects on the environment and optimise plant growth and fruit quality. This would also be in reference to the points identified above to test the relationship between cultivar and changes in the growing environment.
- The optimum application timing, frequency and dosage of foliar feed products needs to be assessed to help growers who are employing this method of nutrition.
- Improving our understanding of optimum soil health for blackcurrant production could also be investigated as part of a wider movement to provide a holistic approach to nutrient management in blackcurrant in the UK.

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