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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

I declare that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

There is evidence that yield response to nitrogen in blackcurrants is dominated by its effect on flower number and there appears to be more scope for refining nitrogen applications by taking account of soil mineral nitrogen than by the use of leaf or sap analysis.

Summary of the project and main conclusions

This project presents a worldwide literature review of nitrogen (N) requirements of blackcurrant processing crops, with the following scope: effect of N application on growth, yield and processing fruit quality; effect of alleyway grass swards and irrigation on N requirements; the potential for use of soil mineral N measurements and leaf and sap analysis as a basis for N fertiliser recommendations; effect of N application timing and formulation on potential leaching and volatilization losses; and the present and proposed legislative framework for N use in field crops in the UK.

There are few reports of work in which effects of N on blackcurrant growth, development or yield have been investigated independently of other nutrients in well-designed experiments.

There is evidence that yield response to N is dominated by its effect on flower number, indicating that yield was predominantly limited by the sink for photoassimilate. However, there may also be some degree of source limitation. It is important to understand source and sink limitations to yield to help guide fertilisation strategies. For example, if it is established that sink limitation of yield dominates, then maximisation of berry number should be a priority over increasing leaf area.

In redcurrant, effects of N have been shown to vary between varieties, and influence fruit quality. It is likely that this is also the case for blackcurrant.

Blackcurrant roots can explore alleyway areas for nutrients. However, if there is adequate N supply within the row, then any competition for N between alleyway vegetation and blackcurrant plants is likely to be of minor importance.

Any effects of irrigation on N requirement are likely to be through effects of irrigation on N leaching, or through effects of irrigation on canopy size and therefore N demand. In both cases, irrigation would increase N requirement.

The extent of leaching caused by irrigation is related to the amount of soil drainage (excess water applied above that required for the soil to reach field capacity). Usually irrigation is applied when there is a soil moisture deficit, and then does not lead to N leaching, unless rainfall falls unexpectedly. However, some plantations receive frost protection irrigation during April, which is likely to leach a proportion of previously applied N.

Irrigation may increase growth and yield (Niskanen *et al.,* 1993; Rolbiecki *et al.,* 2002) and so increase N requirement of foliage and N offtake. This contention is supported by work sponsored by GlaxoSmithKline Nutritional Healthcare (Horticulture LINK project MRS/003/02).

Although good relationships between leaf N concentration and N requirement have been found within individual experiments, there is insufficient evidence for a relationship that is stable between sites, soil types, management methods, varieties, climates, and levels of disease. Despite this, leaf N concentration may offer a good means of checking that N supply is not substantially sub-optimal.

Judging soil N supply is the most crucial, yet the most uncertain, element of judging fertiliser N requirements. The best method involves field analysis of soil. Generally, crops recover slightly more soil N than is measured as soil mineral N in February.

Greatest risk of leaching in blackcurrant crops occurs in spring and late autumn. There is a high risk in a spring with high rainfall, or where frost protection irrigation is applied during April. The autumn risk relates to “over supply” of N during the growing season, leaving high N residues in the soil after the period of growth and N uptake.

For environmental and economic reasons it is important to time and quantify the application of N so that there is a reduced risk of N leaching. Wasted fertiliser N through spring leaching could lead to decreased crop yields if the N losses are not recognised and corrected later. We recommend that N applications are split, as in current commercial practice, with an application in March or April, followed by another application in May when further soil drainage is unlikely. The actual rates should be determined by a qualified agronomist, taking into account the time course of N demand (e.g. Larsen, 1964) and RB209 fertiliser recommendations.

Nitrous oxide (N_2O) emissions are dependant upon soil wetness, temperature and the presence of sufficient mineral-N in the soil. Losses are greatest under warm, wet conditions. Highest nitrous oxide emissions tend to come from the application of ammonium nitrate or calcium ammonium nitrate. However, it is not considered practical to change the timing of N fertiliser application to avoid N losses to atmosphere, because plants need available N during growth.

Nitrogen fertilisers are also available in controlled release formulations which in some situations could reduce the risks of loss by leaching and volatilization. There have not been any studies reported on the use of controlled release fertiliser (CRF) N in blackcurrants and these products are not currently used on blackcurrants in the UK. At present there is no evidence to determine whether the higher cost of CRF N is justified for blackcurrant production by improved yields and/or reduced N leaching.

Bouwman *et al.* (2002) estimated the global ammonia volatilisation loss from N fertilisers, in a valuable review based on over 148 research papers. The mean emission factors that they found were 21% for urea, 16% for ammonium sulphate, 6% for ammonium nitrate and 3% for calcium ammonium nitrate.

In a series of experiments to compare the total N losses to water from the application of ammonia nitrate and urea, MacDonald *et al.* (2006) found no consistent differences in total N loss between ammonium nitrate and urea.

The current legislative framework for N use is outlined. Recommendations are made for further work.

LITERATURE REVIEW

Introduction

Background

Generally in plants, canopy size (green surface area) is related to N uptake, but not necessarily to N applied. Increase in biomass is related to the amount of solar energy intercepted by the canopy (Monteith, 1977). In blackcurrant, a perennial plant, the yield of berries will be related to increase in biomass and the way in which the biomass is partitioned between parts of the plant (e.g. shoots, roots, leaves, berries). Nutrient uptake can influence this partitioning (e. g. through effects on flower production changing the size of the sink for photosynthesis products), and therefore berry yield. Nutrient uptake can also change fruit quality (Lee and Kader, 2000). Thus, the effects of nutrient uptake on crop yield and quality are complex and interacting.

Efficient use of fertiliser N requires an understanding of crop N uptake, which is influenced by many factors, including:

- potential losses due to leaching and volatilization,
- application timing,
- fertiliser formulation,
- alleyway management,
- irrigation.

Currently we believe half of the UK plantations are managed with overall herbicide and the other half has grassed alleyways. Less than half have facilities for irrigation, normally overhead with a raingun or solid set sprinklers, rather than trickle.

Most growers apply N in two dressings, one in March and the other in May. The aim is to avoid putting too much on early, otherwise it can be leached away before it can be taken up by the crop.

Most growers use ammonium nitrate, or urea or a compound probably containing ammonium or potassium nitrate.

Controlled release fertilisers (CRF) are available but are relatively expensive for common usage on field crops. The CRF products that are applied to field crops normally contain N in the form of sulphur-coated urea e.g. Agroblen® supplied by The Scotts Company (UK) Ltd (Wilson, pers. comm.). Sulphur-coated urea products are the cheapest form of controlled release N, with at typical price of £3.43 per kg N for Agroblen® Base. Nutrient release is influenced by water more than temperature and there is a higher initial release than with the resin-coated products normally used in soil-less media.

Calcium ammonium nitrate is also sometimes used and has similar leaching properties to ammonium nitrate. However, it is more bulky to store and transport due to the lower N content per kilogram of product.

It has long been known that fertilisers can be applied to and taken up by foliage (e.g. Archer, 1985). Foliar feeding is especially useful as a remedy for crops that are suffering from a nutrient deficiency. Repeated applications are required, especially for major nutrients, because uptake per application tends to be low relative to seasonal crop requirement. It would be expected that leaching losses of nutrients would be low because the nutrients are applied when the crop needs them, and large soil reservoirs of nutrients are avoided. However, losses through volatilisation could be of greater importance. We are not aware of commercial use of foliar fertilisers, or any research on use of foliar nutrients in blackcurrant crops.

For nutrients to be taken up, they must enter through stomata or the epidermal cuticle, and for this reason young foliage generally takes up nutrients better than older foliage.

There is potential for use of soil mineral N measurements and leaf and sap analysis as a basis for N fertiliser recommendations in blackcurrants. Soil mineral N measurements are not used. A very few growers (<10%) sometimes use leaf or sap analysis to help determine N requirement.

Most growers use the “Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209) (Anon., 2000) to determine N application rates. This gives fertiliser recommendations that aim to maximise economic return and are acceptable for use within nitrate vulnerable zones (NVZs).

Although rates of up to 160 kg/ha N are recommended for blackcurrants in RB209 (Anon., 2000), in practice most growers apply less – normally using in the range of 60 to 120 kg/ha, without appearing to compromise crop yield. Modern cultivars such as Ben Hope can become excessively leafy and prone to fruit *Botrytis* infection if over-fertilised.

Scope

This project presents a worldwide literature review of N requirements of blackcurrant processing crops. The literature reviewed has included research reports, scientific literature, and internet searches.

The scope of the literature searching comprised the following:

- Effect of N application on components of growth, yield and processing fruit quality in blackcurrants (reference will also be made to other *Ribes* crops where appropriate).
- Effect of alleyway grass swards and irrigation on N requirements
- The potential for use of soil mineral N measurements and leaf and sap analysis as a basis for N fertiliser recommendations in blackcurrants.
- Effect of N application timing on potential losses due to leaching and volatilization in blackcurrant plantations.
- Effect of N application formulation on potential losses due to leaching and volatilization in blackcurrant plantations.
- The present and proposed legislative framework for N use in field crops in the UK.

The literature search was widened to include other related species (e.g. redcurrant) to increase the information available.

Methods and sources of information

The literature searches included a wide range of possible sources, including MAFF/Defra/HDC reports, scientific literature, and internet websites. Information was interpreted to identify key findings and the relevance of these to the industry. We have made recommendations for future applied or strategic research and development.

Two types of approach were taken to deliver the science review.

1. Literature search. This covered the scientific and technical knowledge relating to N requirements of blackcurrant processing crops.

   The outcome of previous studies has been summarised, rather than a comprehensive description of the work undertaken.

2. Analysis. The information gathered was drawn together and expert analysis was undertaken to identify key findings and the relevance of these to the industry. We have recommended areas for future research and development considered the most fruitful based on current knowledge.

Effect of N application on growth, yield and fruit quality

Responses to N application in controlled experiments

There are few reports of work in which effects of N on blackcurrant growth, development or yield have been investigated independently of other nutrients in well-designed experiments.

A study in which multiple levels of N application were made independently of other nutrients is reported by Bould and Parfitt (1972). Six levels of N (range: 10 to 20 mequiv. NO_3/L; 140 to 280 mg/L of nitrate N) were applied in combination with four levels of phosphorus. The plants were grown in containers over two seasons, so the treatments cannot be related to field application rates of N. There was no effect of N on shoot growth (assessed in the first season), but early (mid-April) N application in the first season increased flower number in the second season, with accompanying increases in fruit number and crop yield. The effect on flower number was almost linear, from 195 to 223 flowers on a sample of shoots. Berry weight (g/100 berries) also increased over the N application range of 10 to 14 mequiv. NO_3/L (140 to 196 mg/L of nitrate N), and thereafter decreased. Thus the yield response was dominated by effects on flower number, indicating that yield was predominantly limited by the sink for photoassimilate[1], but berry size was also a factor, indicating some degree of source limitation[2]. Applications of N after flower initiation (July, actual date not given) did not affect flower number per truss, but did give a further yield increase in the following season probably by increasing secondary growth in the first season, and therefore number of trusses in the second season. The response to N interacted with response to P and was greater at higher levels of P.

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[1] Flowers are sinks for photoassimilates produced in leaves, so if yield increases when flower number increases the implication is that yield was limited by the total size of the sink for photoassimilates.

[2] Increased yield through an increase in berry size indicates that the photoassimilate source (foliage) has increased output independent of changes to the size of the photoassimilate sink (number of flowers), so size of photoassimilate source had previously limited yield.

Toldam-Andersen and Hansen (1993) support the view of Bould and Parfitt (1972), that blackcurrant is not strongly source limited. They studied effects of light and leaf-shoot removal on growth distribution and fruit drop. Nitrogen nutrition was not studied, but this work is relevant because of the importance of N for canopy growth and light interception. It is also important to understand source and sink limitations to yield to help guide fertilisation strategies. For example, if it is established that sink limitation dominates, then the strategy should be to maximise berry number by increasing flower number and/or fruit set, rather than leaf area.

Craighead et al. (2007) reported an effect of N treatment on fruit set, but this was not consistent between seasons. There were also indications that confounding factors (e.g. water stress) may have influenced fruit set in the same experiments. Bould and Parfitt (1972) reported effects of N treatments on flower number, but not on percentage fruit set.

Nitrogen availability could influence fruit set directly (perhaps by changing flower quality), or in several other ways. For example, leaf area is changed by N nutrition, and would affect both assimilate supply and shading of flowers. Canopy density could also influence pollination, through sheltering flowers from wind and pollinating insects. Thus, the effect of N availability on fruit set would be very difficult to study in a field environment.

It is not clear from these studies how source and sink limitations to yield balance over a number of seasons of perennial growth. Perennial plants store photoassimilate, e.g. in roots and stems, and it may not be apparent from studies over a period of one or two seasons, how photoassimilate storage is changed and has cumulative effects over multiple seasons.

In contrast to these results, a field study, reported by Goode and Hyrycz (1970) showed that yield of berries did not respond to N application (two rates of 78 and 157 kg/ha, both applied as split applications in February and April). Interestingly, water requirement was also not affected by N, indicating that canopy size was probably not affected. This was despite leaf N concentration being below a target level, raising questions about the usefulness of leaf analysis to provide fertiliser recommendations.

In another field study, Sandvad (1964, cited in Bould and Parfitt, 1972) found no effect of N on flower number per cluster or berry size, but concluded that N increased yield by increasing shoot growth and therefore number of flower buds.

More recent work sponsored by GlaxoSmithKline Nutritional Healthcare (Horticulture LINK project MRS/003/02) supports many of the findings of the older studies discussed above. Nitrogen increased yield up to a maximum at a supply rate of 152 kg/ha N, but decreased ascorbic acid content of berries. Fruit removal resulted in larger berries indicating some degree of source limitation, but increases in light interception and canopy growth gave only small increases in fruit yield, suggesting that there was some degree of sink limitation. It was concluded in the LINK project that excess N supply can lead to excessive vegetative growth, which could shade fruit, thereby reducing fruit ascorbic acid concentration (Lee and Kader, 2000; Ma and Cheng, 2003).

Time pattern of N uptake

Timing of N application is likely to affect availability for uptake. The implications for leaching and volatilisation are discussed below in another section, but timing of plant demand is also an important consideration. Larsen (1964) showed that uptake increased rapidly after bud burst and remained high until end of July. Thus, the period April to July is when applied N should be made available to the plant.

Nitrogen offtake from a crop of 10 t/ha of fruit yield has been estimated as 20 kg/ha N (Langford). Craighead *et al.* (2007) report a similar value for N offtake in fruit, and state that a 10-12 t/ha blackcurrant crop is likely to remove 55-65 kg/ha N including N offtake in new shoot growth and foliage. These reports suggest that N fertiliser requirement is not likely to be high compared with other many other crops. These data do not directly indicate N fertliser requirement because uptake of fertiliser N is inefficient (55% to 70% efficiency depending on soil type; Anon., 2000) and some N is supplied from the soil.

Effects of N confounded with other nutrients

There are reports of effects of N application that are confounded with effects of other nutrients or other factors, such as irrigation. These reports have limited value with respect to effects of N nutrition.

An example of this is given by Reckrühm *et al.,* 1990: fertiliser increased yield compared with a control (no fertiliser), but the amount applied did not have an effect. However, several nutrients (N, P, K, Ca) were applied together, so effects were mutually confounded. Other reports have also shown no effect of increasing fertiliser application rates (Clanciara and Smolarz, 1983 cited in Reckrühm *et al.,* 1990), whereas dose responses have been reported by others. Kongsrud and Nes (1999) and Nes *et al.,* 2002 reported a dose response to increasing fertiliser application rates, but the nutrients N, P and K, and irrigation, were confounded.

Bradfield (1969) showed that an increase in frequency of nutrient application increased production of fruiting wood in the year of application, and yield of fruit in following year, but the fertiliser included many elements.

Hughes (1966) and Kawecki and Tomaszewska (1993) reported that farmyard manure increased yield, and N nutrition may have been a causal factor. However, these experiments are not helpful in understanding responses to N.

Studies with related species

Evidence from work with redcurrant (*Ribes rubrum* L.) shows that the effect of N on yield varies with variety (Papp *et al.,* 1984). There were four N application rates (0, 50, 100, 200 kg/ha) and in cv Jonkheer van Tets yield increased from 17.1 t/ha (0 kg/ha N) to 24.5 t/ha (200 kg/ha N), but in cv Red Lake the equivalent yields were 14.0 t/ha and 15.5 t/ha (Table 1). In the same study there was a tendency for berry sugar content to decrease with increasing N application.

Tromp *et al.* (1994), working with redcurrant in polythene tunnels reported that N fertilisation had no effect or only minor effects on fruit set and effective pollination period (ovule longevity minus the time between pollination and fertilisation). They suggested that mineralisation of N in the soil, enhanced by high soil temperature under polythene tunnels, met plant demand.

Conclusions

There is evidence that yield response to N is dominated by effects on flower number, indicating that yield was predominantly limited by the sink for photoassimilate. However, there may also be some degree of source limitation. It is important to understand source and sink limitations to yield to help guide fertilisation strategies. For example, if it is established that sink limitation dominates, then maximisation of berry number should be a priority over increasing leaf area.

In redcurrant, effects of N have been shown to vary between varieties, and influence fruit quality. It is likely that this is also the case for blackcurrant.

Table 1. The effect of N application rate on yield, leaf N content, and berry quality, for two redcurrant varieties (adapted from Papp *et al.,* 1984).

Treatments	Yield (t/ha)	Leaf N content (%)	Soluble solids in berries (%)	Total acid content of berries (%)	Total sugar content of berries (%)
			Jonkheer van Tets		
0 kg/ha N	17.1	2.61	10.18	2.460	7.09
50 kg/ha N	19.6	2.88	9.57	2.503	6.83
100 kg/ha N	22.9	3.02	9.42	2.456	7.81
200 kg/ha N	24.5	3.08	9.28	2.456	6.49
			Red Lake		
0 kg/ha N	14.0	2.58	11.06	1.912	9.06
50 kg/ha N	14.7	2.75	10.26	1.871	9.08
100 kg/ha N	15.7	2.84	10.37	1.895	8.61
200 kg/ha N	15.5	2.96	10.47	1.948	8.57

Effect of alleyway grass swards on N requirement

Lindhard Pedersen (1997) found that alleyway cover crops (natural weed cover or white clover) did not compete for nutrients in established blackcurrants. The same author also reported work with leguminous cover crops grown in the alleyway in organic blackcurrant crops (Lindhard Pedersen, 2002). There was no control treatment (no cover crop), but leaf analysis results suggested that all treatments had adequate N supply and there were no differences between alternative cover crop treatments. Root growth assessments within the row (the area with no cover crop) showed that blackcurrant roots were present at a distance of 1.5 m from the row centre, which was the boundary between the alleyway (with cover crop) and the row (no cover crop). This result suggests that blackcurrant roots could explore alleyway areas for nutrients, especially as the alleyways in this study were wider than in UK commercial practice. However, if there is adequate N supply within the row, then any competition for N between alleyway vegetation and blackcurrant plants is likely to be of minor importance. It should be noted that in the UK it is common practice to apply compound fertilisers broadacre in mature plantations regardless of alleyway cover, except where fertigation is used. The majority of growers, however, apply subsequent N top dressings as a band application (Saunders pers. comm.). There may be scope for savings in fertiliser use by all growers targeting applications to the row; this is an aspect that could be further investigated.

Effect of irrigation on nitrogen requirement

There are reports of increases in growth and yield of blackcurrant in response to irrigation (e.g. Niskanen *et al.,* 1993; Rolbiecki *et al.,* 2002), but we have not found any reports that show effects of irrigation on N requirement, except that Goode and Hyrycz (1970) found no interaction between N application rate and irrigation.

Any effects of irrigation on N requirement are likely to be through effects of irrigation on N leaching, or through effects of irrigation on canopy size and therefore N demand. In both cases, irrigation would increase N requirement.

Effects of irrigation on N leaching

We have found no literature that provides information on the effects of irrigation on N leaching in blackcurrant or other similar fruit crops. However, effects of soil drainage in general on N leaching have been studied. Leaching occurs mainly in winter, when it will not affect immediate N fertiliser requirement (there is no N demand). In exceptional weather N can be leached in summer, and then may increase N requirement. Leaching can also occur in summer on cracking clay soils when there is high rainfall following a period of dry weather. Irrigation will prevent cracks forming and so prevent this risk.

The extent of leaching caused by irrigation is related to the amount of soil drainage (excess water applied above that required for the soil to reach field capacity). Usually irrigation is applied when there is a soil moisture deficit (the difference between actual soil water content and the soil water content at field capacity), and the irrigation will not lead to N leaching. However, some plantations receive frost protection irrigation during April, and such irrigation is likely to leach any previously applied N as water application rates will put the soil well in excess of field capacity. In some seasons there will be a period in April when the plants require N but frost protection irrigation or excess rainfall could lead to large losses if N has already been applied.

We recommend that N applications are split, with a lower application in March/April, followed by a larger application when further soil drainage is unlikely. The actual rates should be determined by an agronomist, taking into account the time course of N demand (e.g. Larsen, 1964) and RB209 fertiliser recommendations.

Effects of irrigation on canopy size and N demand

We have found no reports on this subject. However, irrigation may increase growth and yield (Niskanen *et al.,* 1993; Rolbiecki *et al.,* 2002) and so increase N requirement of foliage and N offtake. This is supported by work sponsored by GlaxoSmithKline Nutritional Healthcare (Horticulture LINK project MRS/003/02). In irrigation experiments, plants not receiving full irrigation had decreased shoot growth and optimal irrigation gave cumulative fruit yield increases. Thus, it would be expected that a crop with adequate water supply will need more N than a crop with sub-optimal water supply.

Potential for soil or plant analysis as a basis for N fertiliser recommendations

Plant analysis

Leaf N content has been studied as a method of assessing plant nutrient status and therefore N requirement. Bould *et al.* (1960) reviewed the principles of leaf analysis and concluded that the relationship between leaf composition, growth and yield is not simple, but useful methods for relating leaf analysis to plant performance had been established for a range of crops. These authors also support leaf analysis as a means of applying results of sand culture studies to field-grown plants.

However, there is conflicting information on the usefulness of leaf analysis to inform N fertiliser policy.

Bould (1955) showed that leaf N concentration of middle-aged leaves (i.e. leaves in the middle third of a shoot) declined until early June, and then was approximately constant for two to three weeks, until fruit maturity. Larsen (1964) also showed that there is a stable period of leaf N concentration late in the season, although the timing differed from that shown by Bould (1955) because the leaf samples included all leaf ages.

Selection of leaves for analysis appears to be of great importance. Bould *et al.* (1960) state that factors, other than nutrient supply, affecting leaf composition are age, leaf position, yield, injury, disease and any other factor that limits growth. Thus, the sampling protocol should be specified with any guidance on target leaf N concentration.

Some studies have shown responses of leaf N concentration to N fertiliser application rate. Papp *et al.* (1984), working with redcurrant, found that 2.5–2.9% N content of leaves indicated an adequate N supply, judged by the response of yield to N supply. Bould and Parfitt (1972), showed that average responses of leaf N concentration, and of yield, to N supply were approximately linear.

Other studies show poor agreement between leaf N concentration to N fertiliser application rate. Bradfield (1969) reported that leaf concentration of N was little affected by levels of a nutrient solution, which contained N. Aaltonen and Dalman (1993) also did not show a clear relationship between applied N and leaf N concentration.

In a field study reported by Goode and Hyrycz (1970), yield of berries did not respond to N application (two rates of 78 and 157 kg/ha, both applied as split applications in February and April), and water requirement was not affected by N, indicating that canopy size was probably not affected. This was despite leaf N concentrations being close to, or below, the minimum satisfactory range for blackcurrant given in RB209 (2.8–3.0% by dry weight; Anon. 1993), raising questions about the usefulness of leaf analysis to provide fertiliser recommendations.

The satisfactory nutrient range of N in blackcurrant leaves (fully expanded leaves on extension growth, sampled prior to harvest) given in RB209 is 2.8–3.0% by dry weight, and this is supported by two research reports by Farm Advisory Services Team Ltd to SmithKline Beecham (Cox, 1991; Anon., 1993).

Although good relationships between leaf N concentration and N requirement have been found within individual experiments, there is insufficient evidence for a relationship that is stable between sites, soil types, management methods, varieties, climates, and levels of disease. Despite this, leaf N concentration may offer a good means of checking that N supply is not substantially sub-optimal.

Soil analysis

Judging soil N supplies is the most crucial, yet the most uncertain, element of judging fertiliser N requirements. The best current method involves field by field analysis of soil to 60 or 90 cm depth; careful measurements can give a very good indication of soil N available to the crop. Figure 1 shows that, across a number of experiments, the range of crops recover slightly more soil N than is measured as soil mineral N (SMN) in February.

Sampling should be done, or directed, by a competent agronomist with knowledge of the required sampling procedure. Sampling and analysis is laborious and can be relatively expensive, so the possible contribution of the SMN level has generally been ignored when deciding on N fertilizer use in blackcurrants. However with the increasing cost of N fertilizers – currently £0.90 / kg N. - and environmental considerations, arable farmers are making more use of SMN measurements and it may be time to consider this approach for blackcurrants as well.

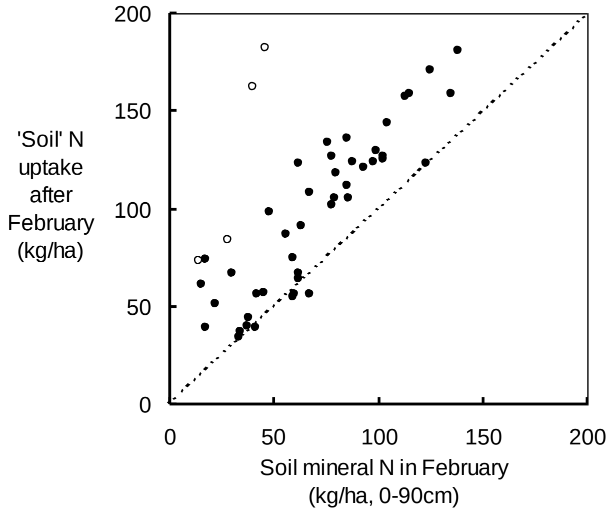

Figure 1. Relationship between soil mineral N to 90 cm in February for a wide range of crops (with different soils, previous crops, and sowing dates, over 3 seasons), and uptake of N after February from soil supplies only (i.e. with no fertiliser applied). The dotted line shows 100% recovery. The open circles are for a site where there was a history of using animal manures (Sylvester-Bradley *et al.,* 2001).

Craighead *et al.* (2007) showed some relationship between blackcurrant yield and soil anaerobic mineralisable N (AMN, a measure of available soil N; this is also described as "soil available N", but the analysis method is not given and it may not be the same as the term "soil mineral N" usually used in the UK to indicate available N.) plus fertiliser N applied (R^2=0.43) on the sites where N was likely to be the most limiting factor to yield. Using this relationship it required 95-100 kg/ha of N to produce a 10-12 t/ha crop. These authors state that typical soil AMN values of 80 kg/ha of N (in New Zealand), indicate that many growers would need no more than 25-30 kg/ha N, with a likely range of 0-60 kg/ha.

Interestingly, Marks (1995) reported that mean soil mineral N concentrations in winter for the row position of blackcurrants were in the range 250–320 kg/ha N. These surprisingly high values were not associated with N application rates in excess of current recommendations at that time, but suggest that N was over-supplied, especially late in the growing season. This illustrates the value of soil mineral N analysis for helping to determine N fertiliser application protocols. It would be very useful to survey blackcurrant crops under current commercial practice to determine typical soil mineral N values, in autumn and in early spring.

Effect of N application timing on potential leaching and volatilisation

Timing of N application has an important effect on the risk of N loss by leaching (ADAS, 2007). Nitrate leaching occurs predominantly during periods of soil drainage following heavy rainfall, and when there is little crop uptake of N and water, i.e. usually winter and early spring. At this time of year there is no blackcurrant crop canopy, and N uptake is minimal (Larsen, 1964). Nitrate, NO_3^-, the main N-containing anion occurring in the soil, is very soluble and moves freely through the soil profile (Anon., 1998). When rainfall is high and the soil become saturated (i.e. wetter than field capacity), nitrate is readily leached out and into streams and rivers (surface water) or through porous rock aquifers (ground waters).

In a series of experiments to compare the total N losses to water, from the application of ammonia nitrate and urea, MacDonald *et al.* (2006) found that the N losses from the application of N fertilisers to 'wet' soils in spring (crops were winter wheat or grass) were dependant upon the timing and amount of rainfall that followed application. Nitrogen losses ranged from 0.7–23% of the total N applied, this represented a worst case scenario as plots in some experiments were irrigated soon after application.

For environmental reasons it is important to time the application of N so that there is a reduced risk of N leaching, but it is also important to avoid wasting fertiliser. Furthermore, wasted fertiliser N (e.g. through leaching if the fertiliser is applied too early in spring and is followed by high rainfall) could lead to decreased crop yields if the N losses are not recognised and corrected later.

Greatest risk of leaching in blackcurrant crops occurs in spring and late autumn. There is a high risk in a spring with high rainfall, or where frost protection irrigation is applied during April. The autumn risk relates to oversupply of N during the growing season, leaving high N residues in the soil after the period of growth and N uptake.

A strategy to decrease risk of N leaching is to apply N fertiliser in two applications to reduce N leaching in the event of heavy rainfall soon after the earliest (e.g. at bud burst) N fertiliser application. A second, later application is less likely to be followed by leaching because the soil will be drier and uptake more rapid. The second application can be adjusted if leaching has occurred to ensure adequate N supply, but avoiding oversupply to minimise consequent autumn leaching.

Nitrous oxide (N_2O) emissions are dependant upon soil wetness, temperature and the presence of sufficient mineral-N in the soil. In cold dry conditions emissions factors of 0-0.2% were typical (Dampney *et al.,* 2004); however, these rose to 11% under warm wet conditions. Of the formulations tested, the highest nitrous oxide emissions factors tended to come from the application of ammonium nitrate or calcium ammonium nitrate. It is not considered practical to change the timing of N fertiliser application to avoid N losses to atmosphere, because the plants need available N during growth.

Effect of N application formulation on potential leaching and volatilisation

We have not found any literature relating specifically to blackcurrant crops. In this section we take an overview of the subject from work on grassland and cereal crops.

There are a number of different N formulations that are available for application to crops. Ammonium nitrate (in prilled form) is the most commonly used type of N fertilizer in England (Dampney *et al.,* 2003). Other formulations include urea, ammonium sulphate, calcium ammonium nitrate and urea. Organic manures also supply N to crops.

MacDonald *et al.* (2006) found no consistent differences in total N loss between ammonia nitrate and urea, but there was a difference in the balance of N loss forms to surface waters. Generally ammonium-N plus urea-N loads were 2 to 3-fold higher from urea than from ammonium nitrate, but nitrate-N loads were 3-6 fold higher from ammonium nitrate compared with urea.

Chadwick *et al.* (2005) studied the effects of N formulations on the loss of N through volatilisation. Through a series of trials on different sites it was found that ammonia emissions from ammonium nitrate applied to grassland were typically low at 2% of total N applied, compared to 27% of total N for urea. On tillage land, ammonia emissions from ammonium nitrate were typically low at 3% total N, compared with 22% of total N for applications of urea. Bouwman *et al.* (2002) estimated the global ammonia volatilisation loss from N fertilisers based on over 148 research papers. The mean emission factors that they found were 21% for urea, 16% for ammonium sulphate, 6% for ammonium nitrate and 3% for calcium ammonium nitrate.

In a study on the behaviours of different N fertilisers, Dampney *et al.* (2004) found that the gaseous emissions from both ammonium nitrate (prills) and calcium ammonium nitrate were typically less than 1% of total N applied. Urea, however had emissions of 25%, urea ammonium sulphate (on grass land) had emissions of 19%, and liquid ammonium nitrate (tillage) had emissions of 14%. They found that higher soil temperatures generally caused emission factors to rise from urea.

Dampney *et al.* (2003) found that typically 65% of the ammonium-N content of farm yard manure and 35% of the ammonium-N and uric acid-N content of poultry manure can be lost through volatilisation after application. Applied manures should be rapidly incorporated into soils to reduce volatilisation losses of N.

Nitrogen fertilisers are also available in controlled release formulations which in some situations could reduce the risks of loss by leaching and volatilization. There have not been any studies reported on the use of CRF N in blackcurrants and these products are not currently used on blackcurrants in the UK. However, there is some commercial use of CRF in newly planted apples. The products normally applied contain N in the form of sulphur coated urea e.g. Agroblen® supplied by The Scotts Company (UK) Ltd (Wilson, pers. comm.). Products can also contain P and K in resin coated form e.g Agroblen® Total, or N only e.g. Agroblen® Base. For sulphur coated urea products nutrient release is influenced by water more than temperature and there is a higher initial release than with resin coated products. Resin coated products e.g. Osmacote® Pro and Exact have a more progressive nutrient release influenced by temperature rather than moisture content. In general the sulphur coated urea products are more suitable for soil grown crops and the resin coated products for production in containers with soil-less media. At present there is not the research evidence to determine whether the higher cost of CRF N is justified for blackcurrant production by improved yields and/or reduced N leaching.

Generally, for foliar applied fertilisers, repeated applications are required, especially for major nutrients, because uptake per application tends to be low relative to seasonal crop requirement. It would be expected that leaching losses of nutrients would be low because the nutrients are applied when the crop needs them, and large soil reservoirs of nutrients are avoided. However, losses through volatilisation could be of greater importance. There is some limited use of foliar applied urea in UK blackcurrant crops but we are not aware of any research on use of foliar nutrients in blackcurrant crops.

The present and proposed legislative framework for N use in field crops in the UK

Agriculture is responsible for about 67% of the N load in surface water across Europe (Anon., 2008a). Where member states have efficient urban and industrial waste water treatment systems, the percentage attributable to agriculture is higher due to the reduced N load from these sources.

The Water Framework Directive (2000/60/EC) is the most substantial piece of EC water legislation to date (Anon., 2008b). It is designed to enhance the status and prevent further degradation of aquatic ecosystems and associated wetland. This Directive commits European Union member states to achieve good status of water bodies by 2015.

The 1980 Drinking Water Directive sets a limit of 50 milligrams per litre of nitrate in public water supplies.

The Nitrates Directive (91/676/EC) was adopted by Europe in 1991. This is an environmental measure that is designed to reduce the impact of nitrates from agriculture on water quality. This Directive requires member states to designate Nitrate Vulnerable Zones (NVZs) that cover all land that drains to waters that are affected by nitrate pollution currently 55% of England falls in an NVZ and this will increase to 70%. The distribution of NVZs in England and Wales is shown in Figure 2.

The action programme for NVZ regulations 2008 came into effect in April 2008 (Anon., 2008c). This gives a set of regulations that determine current and future practice that can occur in areas classified as NVZs. Failure to follow these regulations constitutes an offence. These regulations lay out maximum levels of N that can be applied to any one field, and on average across the farm, dependent upon crop, soil type and rainfall. They also give the closed periods during which manures or manufactured fertilisers cannot be applied to the land. These periods vary depending on soil type (for manures only) and type of land (grassland or tillage). For application of manufactured fertilisers to tillage land, the closed period is 1 September to 15 January. It is also stated that the crop requirement for N should not be exceeded. This requirement should be calculated taking into account the crop uptake, soil N supply, crop residues from previous crops and whether or not any organic manures have been used. Manure applications must not exceed 170 kg/ha of total N averaged over all non-grass land. Total N applications to a single field must not exceed 250 kg/ha N. Applications should only occur under suitable conditions, they should not occur when soils are water logged, flooded, frozen or under snow nor should it be done on steep slopes as there is a high risk of run off. Organic manures must not be applied within 10 m of a water course. All applications should be made as accurately and evenly as possible.

RB209 is a document, produced by the Ministry of Agriculture Fisheries and Food (MAFF, now replaced by Defra), which provides fertiliser recommendations for both arable and horticultural crops (Anon., 2000). Its primary aim is to maximize economic return from the use of fertilisers. It is a source of authoritative advice and provides a national standard for fertiliser recommendations. The use of RB209 is not compulsory, provided one can support alternative systems to show provision of a correct level of crop nutrition.

The Water Code (Anon., 1998) is a code of good agricultural practice that can provide information on protecting the water sources present on a farm. It gives recommendations for the storage and handling of artificial fertilisers and organic manures. This code is expected to be replaced by the Code of Good Agricultural Practice to protect water, soil and air quality, which has been subject to a recent consultation (see http://www.defra.gov.uk /corporate/consult/cogap-rev/summary%20of%20responses.pdf). The draft code is a practical interpretation of legislation and good practice which is intended to help farmers and land managers understand their environmental responsibility. The Code is intended to cover England only and will replace the three existing Codes of Good Agricultural Practice for the protection of Water, Soil and Air.

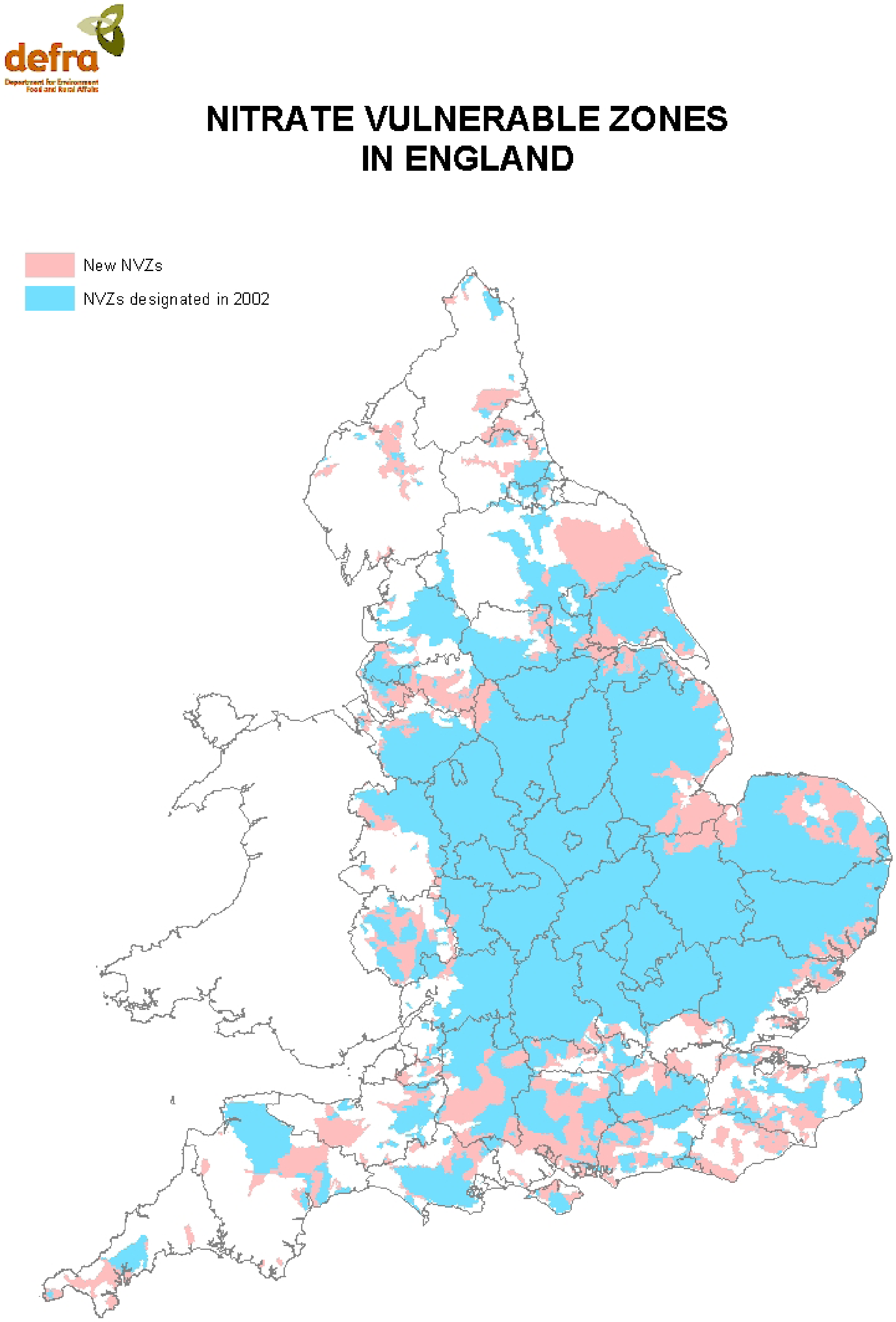

Figure 2. NVZ Action Programme (AP) designation, England and Wales.

Research recommendations

A study of the balance between source and sink for photoassimilates, and how this balance could be manipulated, would improve understanding of yield formation. Nitrogen supply could be used to change flower number (sink). Techniques for control of leaf area (source) (e.g. regulated deficit irrigation and/or partial rootzone drying) could be combined with N supply treatments to optimise fruit production and quality.

A survey of soil mineral N in blackcurrant crops would allow recommendations to be made with better knowledge of soil N supply. Values available from literature for the UK are surprisingly high and may not be representative of crops under current UK commercial growing practices.

The effect of N placement in plantations (e.g. greater use of band application), with and without alleyway cover crops, should be investigated, along with application methods and an economic appraisal.

Nitrogen response studies on a range of soil types would improve knowledge of N requirements for blackcurrant crops. Although this work would be relatively expensive there is a need to reassess the recommendations given in RB209 under modern growing systems with improved knowledge of SMN levels.

Longer-term studies of N effects on source/sink limitation to yield are needed for perennial crops such as blackcurrant. Short term studies (e.g. two seasons) do not allow bush maturity to be included as a factor. Such studies would allow characterisation of change in N requirement as plantations age.

Differences in N requirement need to be quantified for the main cultivars used.

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