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Identifying oilseed rape varieties with high yield and low nitrogen fertiliser requirement

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ABSTRACT

Reducing the fertiliser nitrogen (N) requirement of oilseed rape (*Brassica napus* L.) whilst maintaining yield will be beneficial for both growers and the environment. The aim of this paper was to identify differences in fertiliser N requirement between varieties and investigate simple in-field methods to rapidly identify varieties that can maintain high yield whilst requiring lower optimal N rates ('HYLO' varieties) to aid breeding for lower N fertiliser requirement. Four field experiments were conducted in the UK during seasons 2011-12 or 2012-13 on a range of soil types. Each experiment included 21 elite open pollinated and hybrid varieties. Each variety was grown at seven levels of N fertiliser ranging from zero to super-optimal (340 or 400 kg N/ha). Measurements of seed yield and seed oil content were combined to calculate gross output yield, i.e. seed yield adjusted for oil content. Linear plus exponential yield response curves were fitted to calculate the economically optimum N rate (Nopt) of each variety and the associated nitrogen use efficiency (NUE) was calculated at the Nopt. Across varieties, gross output yield responses to optimum N fertiliser, compared with yields at nil N rates, were significant, ranging from 1.3 to 2.7 t/ha between sites. Nopt ranged from 117 to 286 kg N/ha between sites giving experimental average yields at Nopt (Yopt) of 3.0 to 4.6 t/ha. Varietal yield ranges at Nopt within each experiment ranged from 0.6 to 1.7 t/ha, and there was a positive trend for yield to increase with date of variety introduction by 0.24 t/ha per decade. Significant variety x N fertiliser rate interactions were measured for gross output yield in two out of four experiments and significant varietal differences in Nopt were measured in one experiment ranging from 195 kg N/ha to 296 kg N/ha. There was no correlation between Nopt and Yopt indicating that improving varietal yield potential will not necessarily increase N requirement. Significant varietal differences in NUE were measured at Nopt ranging from 13.5 to 15.9 kg of gross output yield per kg of N supply from soil residues and fertiliser. Seed with low N and high oil content, and high biomass harvest index could be useful indicators of high NUE. However, no single trait correlated consistently with varietal variation in NUE. The yield difference between sub- and super-optimal N rates was positively correlated with Nopt. Further research is required to develop new experimental approaches for measuring yield at more than one N level on small experimental plot areas and to investigate a wider range of genotypes.

1. Introduction

Inorganic nitrogen (N) fertilisers are of major economic importance for oilseed rape production, often doubling crop yields (Berry and Spink, 2009; Sylvester-Bradley and Kindred, 2009). These yield increases are important as they help to meet the food demands of a growing global population, diminish expansion in the arable area and decrease associated negative impacts on the environment (Snyder et al., 2009). However, use of N fertilisers is also associated with environmental concerns. Fertiliser N can be responsible for over 75% of the GHG emissions associated with crop production (Mahmuti et al., 2009; Berry et al., 2010a) and is also a significant source of water and air pollution (Davies and Sylvester-Bradley, 1995; Misselbrook et al., 2000). Therefore, having an ability to increase crop yields without increasing (and ideally by reducing) fertiliser N use will be highly desirable. Improving productivity at a given level of N fertiliser is particularly important for OSR which has been shown to have one of the lowest N use efficiencies of temperate agricultural crop species (Sylvester-Bradley and Kindred, 2009).

N fertiliser use can potentially be reduced, or yield increased at a

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given N application rate, either by improved N management or by genetic crop improvement. Good N management principally involves estimating the requirement that the crop has for fertiliser N and applying the N at optimal timings, in addition to taking account of crop growth, weather and soil conditions (Berry et al., 2011b; Berry and Spink, 2009).

A crucial route to reduced reliance on N fertilisers in arable cropping is the development of varieties that have high yields but low optimum fertiliser N requirement, or 'HYLO' varieties as described by Kindred and Sylvester-Bradley (2010). In general, crop varieties must have a high yield to be commercially viable. For example an OSR variety yielding just 10% (0.5 t/ha) less than a standard variety would have an N fertiliser requirement of approximately 25% (50 kg N/ha) compared to a standard variety, for a similar gross margin over N fertiliser costs to be achieved. Lower yielding varieties are also undesirable as they are likely to result in a greater cropped area to meet demand for food.

The N requirements of crops in the UK are generally defined as rates of fertiliser N that maximise profitability for the grower; these are predicted by recommendation systems (e.g. Nutrient Management Guide, 2017). The N requirement or economically optimal N rate is the rate at which any further increase in N rate will result in greater N fertiliser costs than the value of the additional crop yield produced. This is therefore dependent on the relative price of the yield and N fertiliser, or the breakeven ratio (BER): the amount of crop yield (kg) required to pay for one kg of fertiliser. In order to calculate the economically optimum N rate it is necessary to mathematically describe the response of crop yield to N fertiliser. The relationship between applied N and yield is complex and usually typified by a rapid increase in yield at low N rates, followed by a levelling off of the yield response, and often a reduction of yield at super-optimal N rates due to factors such as lodging. A linear plus exponential (LpE) function was chosen as being best at describing the range of N responses of UK cereals (George, 1984) and it has remained the standard for 30 years; it has four fitted parameters a, b, c & r which approximately (because they are strongly correlated) describe respectively the asymptote, the effect of omitting N, the slope of the asymptote, and the curvature of the response. In order to fit a LpE function information about the effects on crop yield of five to seven levels of N spanning sub- and super-optimal N rates is required.

To date, no studies have investigated genetic variation in N requirement for oilseed rape using the above method to calculate the economically optimum N rate. The vast majority of variety x N studies have only investigated two N rates (e.g. Yau and Thurling, 1987; Svečnjak and Rengel, 2006a, b; Weisler et al., 2005; Berry et al., 2010a, b; Nyikako et al., 2014; Stahl et al., 2017). These studies have been useful for proving variety x N rate interactions, but are inadequate for calculating the economically optimal N rate. It is not possible to draw reliable conclusions about which variety has a lower N requirement from experiments with two N levels. This is illustrated in Fig. 1 which shows three plausible patterns of N response for hypothetical varieties. The economic optimum N rate varies widely for these varieties; variety A (161 kg/ha), variety B (110 kg/ha) and variety C (139 kg N/ha). At high levels of applied N (> 200 kg N/ha), which would be typical of UK variety testing systems, all three varieties have a similar yield and there is no information on how the varieties vary for optimum N rate. At zero applied N variety A has a greater yield than variety C which may imply that it will have a lower N requirement if both varieties have a similar yield at high N, however the shallower N response of variety A means that it actually has a higher optimum N rate.

In addition to fertiliser N requirement, N use efficiency (NUE) is also important for quantifying the N cost of yield production, and is commonly reported in scientific literature (e.g. Sylvester-Bradley and Kindred, 2009). NUE is defined as the harvestable dry matter (DM) yield (kg/ha) divided by the supply of available nitrogen (N) from the soil and fertiliser (kg/ha) (Moll et al., 1982). A higher NUE would therefore appear favourable for reducing environmental impacts and

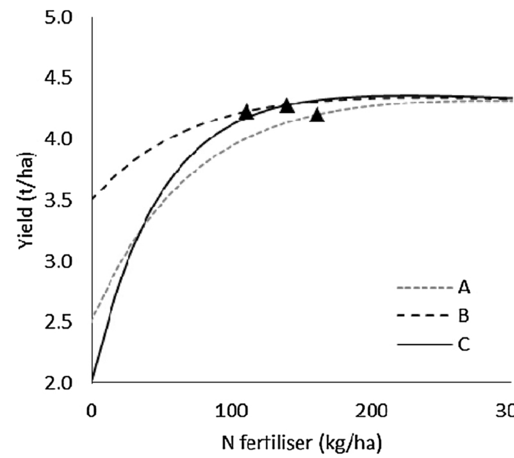

Fig. 1. The effect of fertiliser N rate on yield for a standard current OSR variety (A) and hypothetical varieties (B, C) with a similar yield at high applied N, but with either a steeper yield response to applied N or a higher yield at zero applied N. Economically optimum N rates (▲) are shown for a N:seed price ratio of 2.5 and are calculated as A) 161 kg/ha, B) 110 kg/ha and C) 139 kg/ha.

costs of N use. However, the greatest NUE is achieved at zero N rate, which also has the lowest yields. Consequently growing crops at zero N would increase requirement for cropped area and is unlikely to be profitable for farmers. The N response curves in Fig. 1 also illustrate how measuring yield at two N levels can result in misleading calculations of NUE. The lowest yields are measured at zero N, but show variation in NUE between varieties, whereas at high N all varieties have the same NUE. In contrast, at the respective optimum N requirement rates variety B has the greatest NUE as it achieves high yield with the lowest requirement for N. It is therefore important to compare NUE of varieties at the economically optimum N rate and consider this alongside the yield at the optimum N rate in order to best understand the practical and economic differences between varieties.

Given the high cost of performing variety experiments at multiple N rates it will clearly be beneficial if traits can be identified that determine the crop's optimum N requirement. Several studies have investigated N requirement traits, but it should be recognised that these have been associated with NUE at specific N rates rather than with the optimum N rate. At the simplest level the two main components of a crop's N requirement are; above ground crop N uptake and N utilisation efficiency (seed dry matter yield / crop N uptake). It has been shown that at low N supply the seed yield of OSR varieties was more closely correlated with N uptake than N utilisation efficiency (Schulte auf'm Erley et al., 2011; Nyikako et al., 2014; Berry et al., 2010b). Increasing sink capacity (seeds/m^2) has been shown to be important for increasing both N uptake efficiency and N utilisation efficiency (Berry et al., 2010a, b). High yield at low rates of fertiliser N, or high NUE, have been shown to be positively related with post-flowering N uptake (Berry et al., 2010a; Ulas et al., 2013; Bouchet et al., 2016). Positive correlations have been found between delayed leaf senescence and N efficiency (Schulte auf'm Erley et al., 2007; Bouchet et al., 2016). Genetic improvements in NUE have been shown to be related to breeding improvements in seed yield and seed oil concentration (Stahl et al., 2017). A study of two varieties with contrasting NUE grown under low N supply showed that the variety with high NUE had greater root growth after stem extension (Kamh et al., 2005) and the importance of root length was supported by Bouchet et al. (2016). High N utilisation efficiency has been associated with lower seed protein concentration (Schulte auf'm Erley et al., 2011; Koeslin-Findeklee et al., 2014). High N utilisation efficiency has also been associated with greater N remobilisation from the stem to the seed after flowering (Girondé et al., 2015), and genetic improvement in NUE has been associated with greater N remobilisation within the plant (Bouchet et al., 2016).