BREEDING FOR IMPROVED NITROGEN USE EFFICIENCY IN OILSEED RAPE

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Abstract
Oilseed rape has a high requirement for nitrogen (N) fertiliser relative to its seed yield. This paper uses published and unpublished work to explore the extent to which the N use efficiency (seed yield ÷ N supply) of oilseed rape could be improved without reducing seed yield. It was estimated that if the concentration of N in the stem and pod wall at crop maturity could be reduced from 1.0% to 0.6%, the root length density increased to $1 cm/cm^3$ to 100 cm soil depth and the post flowering N uptake increased by 20 kg N/ha then the fertiliser requirement could be reduced from 191 to 142 kg N/ha and the N use efficiency could be increased from 15.2 to 22.4 kg of seed dry matter per kg N. Genetic variation was found for all of the traits that were estimated to be important for N use efficiency. This indicates that there is significant scope for plant breeders to reduce N use efficiency in oilseed rape.

INTRODUCTION

Oilseed rape has a high requirement for nitrogen (N) fertiliser relative to its seed yield. In the UK winter oilseed rape receives an average of 191 kg N/ha and has an average seed yield of 3.2 t/ha at 91% dry matter. This compares against winter wheat which receives 184 kg of fertiliser N and has an average yield of 8 t/ha at 85% dry matter. Oilseed rape seed has a high content of energy rich oil, but even after accounting for this it is clear that oilseed rape is not very efficient at using fertiliser N since the average energy content of the harvested seed is 387 MJ/kg of fertiliser N compared with 666 MJ/kg of fertiliser N for winter wheat. N fertiliser represents a large cost to the grower which usually amounts to more than half of the variable costs of growing oilseed rape. Furthermore only about 90 kg N/ha are removed in the harvested seed leaving N rich crop residues in the field which result in a high risk of nitrate leaching during the following winter. The high N fertiliser requirement also causes significant green house gas emissions to be associated with growing the crop. These factors reduce the viability of oilseed rape for food production and biodiesel. In the UK oilseed rape crops often remain photosynthetically active for 10 to 11 months of the year and it is clear that the crop has great potential to produce a significant amount of dry matter and utilise N efficiently. This paper uses published and unpublished work to explore the extent to which the N use efficiency (seed yield ÷ N supply) of oilseed rape could be improved without reducing seed yield. The key traits which must be improved are identified and the scope for plant breeders to control these traits is investigated.

CROP TRAITS TO IMPROVE N USE EFFICIENCY

N use efficiency may be improved by 1) minimising the amount of N that is required in the crop to capture the majority of the radiation and to use this efficiently to produce dry matter, 2) increase the efficiency with which the crop is able to acquire N that is mineralised from organic residues or from applications of inorganic fertiliser and 3) increasing yield without increasing fertiliser N requirement.

Minimising N requirement: Oilseed rape crops take up N rapidly up to the end of flowering after which the rate of N uptake decreases significantly or stops altogether. During stem extension the N is partitioned between the leaves and the stems. After flowering the N is remobilised primarily from the leaves, but also from the stems, into the pod walls. During seed filling N remobilised from the pod walls and stems into the seed. At harvest the concentration of N in the plant tissue is typically 3% in the seed and 1% in the stems and pod walls. The seed contains a high concentration of N and the rape-meal produced after oil extraction is a valuable feed product due to its high protein content. The nitrogen harvest index (ratio of seed N to total N) ranges between 0.50 and 0.65. At crop maturity the concentration of N in the stems and pod walls has been measured as low as 0.6%, which indicates that there is scope for crops remobilise a significantly greater proportion of the N in the stems and pod walls to the seed. If remobilisation can be improved to leave a concentration of N in these tissues of 0.6% rather than 1.0% then the amount of N required in the stems and pod wall could be reduced by a total of 30 kg N/ha without reducing the amount of N remobilised to the seed. Reducing the stem and pod N by this amount would mean that these tissues would contain about 56 kg N/ha and 83 kg N/ha respectively during early grain filling. From the following calculations it is estimated that these amounts of N would be sufficient for the crop to capture light and photosynthesise optimally. A green area index (GAI) of 3.5 has been shown to be sufficient for intercepting the majority of radiation (Stokes *et al*., 1998). At mid seed filling the green canopy comprises an approximate projected pod area index of 1.5, stem area index of 1.0 and a leaf area index of 1.0 (Stafford, 1996). The optimum amount of N per unit area of green tissue is dependent on the light intensity experienced by the green tissue (Grindlay, 1998). A greater concentration of N of more than 2 g/m^2 of tissue is required at the top of the canopy where the light intensity is greatest compared with about 1 g/m^2 at the bottom of the canopy (Gammelvind *et al*., 1996). The minimum amount of N required for optimum photosynthesis has been estimated by using a relationship for the optimum specific tissue N at different light levels (Critchley, 2001), assuming an extinction coefficient of 0.75 and average incident radiation in the UK at 52^oN in June. The true surface area of the pods and stems has been used in the calculation by assuming that these tissues are cylindrical. It has been estimated that the photosynthetic N required in the pods, stems and leaves is 82 kg N/ha, 43 kg N/ha and 10 kg N/ha respectively (Figure 1). It has been estimated that a further 14 kg N/ha is required in the stem for essential ‘support’ functions by assuming that an amount of N equivalent to 0.3% of stem dry matter is required for support (Critchley, 2001). It therefore seems feasible that the amount of N that crop must take up could be reduced by 30 kg/ha from a typical value of 226 kg N/ha without reducing the crops ability to photosynthesise or the amount of N redistributed to the seed.

Increasing N uptake efficiency: On average oilseed rape crops have been measured to take up about 73% of the combined mineral N in the soil at the beginning of March and applied fertiliser N (unpublished data). It should be noted that this estimate does not account for the net mineralision/immobilisation that may occur after March. Measurements of rooting have shown that the root length density of oilseed rape is greater than 1cm per cm^3 of soil within the top 40 cm of soil and averages 0.74 cm/cm^3 below 40cm depth (Blake *et al*., 2006). Studies on wheat have shown that a root length density of 1cm/cm^3 is required for the roots to extract all available water from soil (King *et al.*, 2004). If this is the same for oilseed rape then its root system is generally not dense enough below 40 cm depth to extract all of the mineral N. If the root length density below 40 cm could be increased to 1cm/cm^3 then it is estimated that oilseed rape could take up an additional 8 kg N/ha using assumptions described in King *et al.* (2004) and a typical mineral N content below 40 cm depth of 30 kg N/ha.

Increasing yield: In the UK plant breeders have increased the potential yield of new oilseed rape varieties by 0.05 t/ha per year (Berry and Spink, 2006). However, greater yield potential has been associated with greater optimum rates of fertiliser N, which may counter its effect on N use efficiency. A possible mechanism of increasing yield without increasing the requirement for fertiliser N is to increase the amount of N taken up after the end of flowering. This would help to delay senescence by slowing the rate at which N is relocated from the pod wall to the seed. The potential to increase post flowering N uptake depends on what determines post flowering uptake. If it is supply driven then agronomic methods may be best for increasing post flowering N uptake. If it is demand driven then there may be scope to improve this genetically. It has been suggested that the reduction in uptake after flowering may be triggered by the production of hormones in response to flowering (Rossato *et al.*, 2001). This may indicate that there is scope to manipulate this trait genetically. If post flowering N uptake could be increased by 20 kg N/ha then this may result in a yield increase of up to 0.6 t/ha if all of the additional N is used to build seed yield.

METHODS

In 2006-7, field experiments were carried out at six sites in the UK to investigate the growth of oilseed rape varieties with nil N fertiliser and the recommended rate of N fertiliser. Thirty varieties were investigated at four plant breeding stations and the growth of ten varieties were investigated in more detail at two ADAS sites. At the ADAS sites the treatments were arranged in a split-plot design with N treatment as the main plots and variety fully randomised within the sub-blocks. The plot dimensions were 3.5m x 24m and each treatment was replicated 4 times. At each Plant Breeding stations two variety trials were grown adjacent to each other. One trial received the recommended N rate and the other trial received the nil fertiliser N. Within each trial the varieties were fully randomised in a complete randomised block design. Each variety was replicated 3 times in plots measuring 2m x 12m.

RESULTS & DISCUSSION

If the concentration of N in the stem and pod wall at crop maturity could be reduced from 1.0% to 0.6%, the root length density increased to 1cm/cm^3 to 100cm soil depth and the post flowering N uptake could be increased by 20 kg N/ha then it is estimated that the fertiliser requirement could be reduced from 191 to 142 kg N/ha and the N use efficiency could be increased from 15.2 kg of seed dry matter per kg N to 22.4 kg of seed dry matter per kg N (Table 1). Statistically significant differences were observed between varieties grown without fertiliser N for the key crop traits that have been predicted to affect N use efficiency. Across the two ADAS sites the differences between the 10 varieties for the concentration of N in the stems at maturity ranged from 0.70% to 0.86% and the concentration of N in the pods ranged from 0.68 to 0.90% ($P<0.01$). Varieties with low tissue N at maturity tended to have remobilised a greater quantity of N. The total amount of N taken up ranged from 141 to 173 kg N/ha and much of this variation was positively correlated with the amount of N taken up after flowering which ranged from 33 to 61 kg N/ha. These results indicate that there is genetic variation in the amount of N taken up after flowering which can be exploited. This analysis indicates that genetic variation for traits that affect N use efficiency have the potential to have a large effect on the crop's requirement for N fertiliser. A combined analysis of the yields with and without fertiliser N from the breeding station trials showed that there was a significant interaction between N level and variety ($P<0.001$), but these interactions were not always consistent between the sites as illustrated by a significant N x variety x site interaction. Nonetheless, the rankings of several varieties appeared to increase with nil N fertiliser compared with the fertilised plots at several sites which may indicate that these varieties have a lower requirement for fertiliser N. Further work will assess the most contrasting varieties at a wider range of fertiliser N rates in order to investigate whether the optimum N rate varies between varieties.

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Table 1. Effect of changing crop traits on N use efficiency

	Typical crop	Ideal crop	Ideal crop plus late N uptake
Total N requirement (kg/ha)	226	196	216
Crop uptake by March (kg/ha)	50	50	50
Soil N in March (kg/ha)	50	50	50
N uptake efficiency	73%	76%	76%
Fertiliser N (kg/ha)	191	142	142
Yield (t/ha)	3.2	3.2	3.6
Fertiliser N use efficiency (kg seed dry matter/kg fertiliser N)	15.2	20.5	24.3

Data from Growhow UK Ltd is gratefully acknowledged

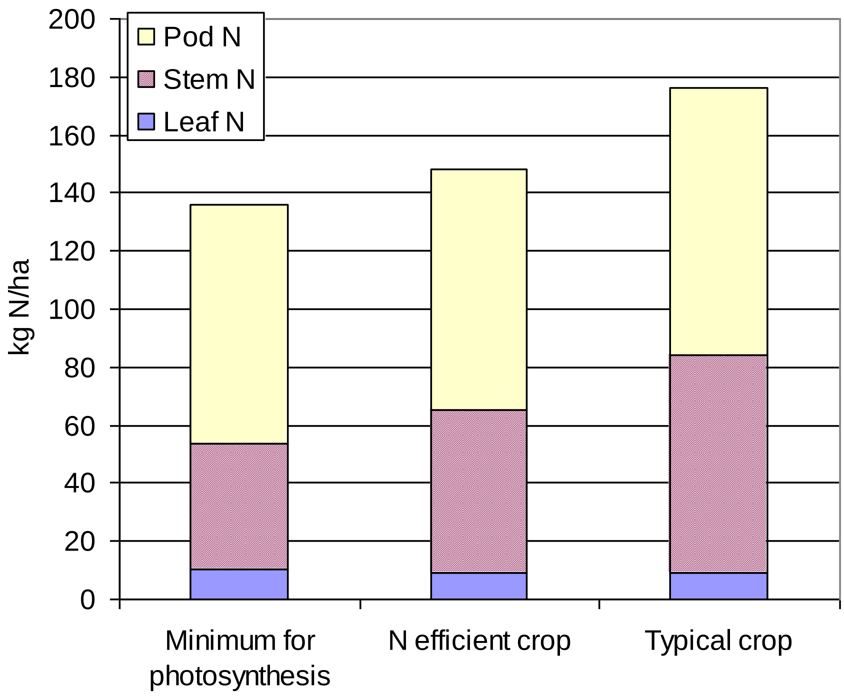

Figure 1. Estimated N required for photosynthesis and support for an ‘N efficient crop’ and the amount of N measured in a ‘Typical’ oilseed rape crop.