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Nitrogen fertilizer and the efficiency of the sugar beet crop in late summer

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Abstract

This study investigated whether nitrogen (N) fertilizer is necessary to maintain the efficiency of sugar beet foliage in late summer or whether the crop can continue to operate effectively on N mineralized from the soil. Three field experiments were carried out at Broom's Barn in 2000, 2001 and 2002. The treatments were early doses of N fertilizer (0, 80 or 160 kg N ha^{-1}) without and with a late N fertilizer application (60 kg N ha^{-1}) made as soon as the foliage reached 85% cover of the ground. The late N fertilizer dose increased the N concentration in the plants and canopy size in late summer, but canopy size still declined throughout autumn. The late N application increased chlorophyll concentration in the leaves but had no significant effect on radiation use efficiency (RUE) in late summer and autumn. In consequence, late N application increased foliage dry weight at final harvest but failed to have a positive effect on sugar yield. This occurred on a soil which should mineralise no more N during summer than any other soil used for growing beet in England. Therefore, nitrogen from fertilizer is not necessary to maintain canopy efficiency and seems to be necessary solely to stimulate the rapid growth of the canopy in early summer.

Keywords: Sugar beet; Canopy; Radiation use efficiency; N fertilizer response; Soil mineral N

1. Introduction

There is strong evidence that the role of N in the generation of the foliage canopy is a central mechanism governing the yield of healthy and disease-free sugar beet crops (Malnou et al., 2006). After emergence, sugar beet crops with adequate nutrients and water need approximately 900 °C days above a base temperature of 3 °C to achieve 85% canopy cover, almost a closed canopy (Malnou et al., 2006; Werker and Jaggard, 1997). This amount of canopy cover is equivalent to a leaf area index (LAI) of 3 (Andrieu et al., 1997): sugar beet needs to contain 0.04 g N cm^{-2} of leaf, which corresponds to an uptake of 120 kg N ha^{-1} to reach 85% cover (Jaggard and Qi, 2006). This N needs to be available for rapid uptake in order to produce a closed canopy as early in the growing season as possible.

Too little N retards leaf growth (Milford et al., 1985), gives pale green foliage due to low chlorophyll concentration (Draycott and Christenson, 2003), accelerates leaf senescence (Bürcky and Biscoe, 1983) and therefore reduces the amount of incident solar radiation intercepted and consequently the dry matter yield. However, this yield loss is partly compensated by an increase in the proportion of assimilates stored as sugar (Scott et al., 1994).

Too much N induces over-production of dark green leaves and a shift in dry matter distribution at the expense of storage root and sugar yields (Milford et al., 1988): the extra leaves seem to provide little benefit in terms of additional intercepted radiation (Scott et al., 1994). Sugar extraction is also affected adversely as surplus N increases the concentrations of α-amino N compounds within the storage root (Pocock et al., 1990) which significantly reduce the proportion of the sugar which can be crystallized (Dutton and Huijbregts, 2006).

It is clear that beet crops require adequate N to expand the canopy rapidly and this N often comes from recently applied fertilizer. However, once the canopy has been produced, the crop may increase in dry weight three fold and in N uptake by at least 100 kg ha^{-1} (Last et al., 1983; Armstrong et al., 1986; Malnou et al., 2006). Does the crop require a N fertilizer source for this or can N be absorbed in sufficient quantity and sufficiently rapidly

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from soil sources to maximize yield? Once a large canopy has been produced, can the soil supply enough N (a) to maintain canopy size so that light interception is optimized and (b) so that the foliage remains an efficient converter of light energy into dry matter and sugar?

Scott and Jaggard (1993) showed an example where N fertilizer had a large effect on the amount of radiation intercepted, but did not seem to affect the conversion coefficient from light to dry matter (1.67 and 1.6 g MJ^{-1} with or without fertilizer, respectively).

The study described in this paper aims to determine whether N fertilizer is necessary to maintain the efficiency of sugar beet foliage in late summer or whether the crop can continue to operate effectively on N mineralized from the soil.

2. Materials and methods

2.1. Experimental sites

Three experiments were carried out at Broom's Barn, UK (52°16′N 00°34′E, 75 m above sea level). The experiments were all grown in soil which is naturally well-drained and with a sandy loam texture at the surface over chalky drift at depth, Barrow series (Hodge, 1991). The crops of the cultivar Roberta were grown in 2000, 2001 and 2002 under conditions of optimum husbandry (Jaggard et al., 1995) apart from the nitrogen treatment, which ranged from 0 to 220 kg N ha^{-1}.

There were three early N treatments: 0, 80 and 160 kg N ha^{-1} (N0, N80 and N160), in factorial combination with two late N treatments, 0 or 60 kg N ha^{-1} (+0, +60). Nitrogen fertilizer was surface applied as solid ammonium nitrate. The early N treatments, N80 and N160, were applied as two doses of fertilizer, 40 kg N ha^{-1} immediately after sowing and the remaining early N dressing at the 2–4 leaf stage. The late N application of 60 kg N ha^{-1} was applied at full canopy cover. No organic manure was applied and the top soil in all experiments contained less than 1.5% organic matter.

The treatments were arranged in a randomized block design with five replicates. There were 30 experimental plots, each 12 m long × 3 m (6 rows) wide. All observations were confined in the central 10 m by 4 rows. An error occurred in 2000 on the five control plots with late N application: these received 40 kg N ha^{-1} at sowing (N40) instead of no N fertilizer application.

The daily global incoming solar radiation, rainfall and temperature were recorded within 400 m of the experiment each year. Thermal time, as the arithmetic accumulation of daily mean air temperature above the base temperature was calculated from sowing up to final harvest. The base temperature used was 3 °C (Gummerson, 1986).

2.2. Canopy cover

The time when the first treatment reached 85% crop cover is referred to here as TC85. The percentage crop cover was determined twice weekly up to TC85 and thereafter at intervals of 2 weeks, using a hand-held spectral ratio meter (PP Systems Ltd., Hitchin, Herts, UK). To demonstrate how late N fertilizer application contributed to the maintenance of the canopy cover in late summer, a canopy model (Werker and Jaggard, 1997) was fitted to the mean canopy cover over thermal time as described by Malnou et al. (2006) using Sigma Plot 2001 for Windows 7 (SPSS Inc.). When the ANOVA analyses showed no differences between early and late N treatment before the addition of fertilizer N in mid-season, the results were pooled as (N0, N0 + 60) (N80, N80 + 60) and (N160, N160 + 60) up to the time of late application.

2.3. Sampling and growth analysis

Soil mineral nitrogen (SMN), as NO_3^- and NH_4^+, was determined before sowing ($SMN_{initial}$) and at final harvest at three depths (0–30, 31–60 and 61–90 cm) as described in Malnou et al. (2006). Soil samples were taken from at least five positions in each block. The soil from these positions was mixed prior to analysis.

In all 3 years, sequential harvests were taken after canopy closure up to final harvest. The date, sample size and method used varied between years (Table 1). The number of plants and the fresh weights of tops and washed roots were recorded. The tops were defined as the laminae, petioles and crowns separated from the storage root immediately above the first leaf scar. Whenever the samples of roots were to be collected by a harvesting machine, samples of whole tops from 16 or 20 plants per plot were taken manually at random before the roots were lifted. These tops were immediately weighed and a sub-sample was taken from five tops. The sub-sample was weighed then oven-dried at 85 °C for 48 h and reweighed to determine dry weight. In 2000 and 2001, the laminae and petioles plus crowns were analysed separately. A sub-sample of fresh storage roots was analysed to measure sugar concentration polarimetrically and to measure amino N concentration colourmetrically using standard sugar industry protocols (Anon., 2005). A sample was oven-dried at 85 °C for 48 h to determine dry weight and total N. Sugar yield was determined as the product of clean root yield and sugar concentration.

Table 1
Date, area sampled and method used on each harvest occasion

Harvest date	Tops	Roots	
	Sample size	Sample size	Harvest method
2000			
12 July	1.5 m^2	1.5 m^2	Hand
14 August	1.5 m^2	1.5 m^2	Hand
18 September	1.5 m^2	1.5 m^2	Hand
8 November	20 tops	10 m^2	Machine
2001			
28 August	20 tops	10 m^2	Machine
24 September	20 tops	10 m^2	Machine
24 October	20 tops	10 m^2	Machine
19 November	20 tops	10 m^2	Machine
2002			
21 August	16 tops	10 m^2	Machine
17 October	16 tops	10 m^2	Machine