Dry matter accumulation and nitrogen partitioning between shoot and root of pea (*Pisum sativum* L.) cultivars

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Abstract

Dry matter and nitrogen (N) accumulation of three field pea cultivars having different morphological characters were compared under different levels of nitrogen in a field trial conducted in 1996/1997. The cultivars used were Allure (semi-leafless, semi-erect), Beacon (conventional, determinate) and Whero (conventional, indeterminate and scrambling). The N rates were 0, 30 and 60 kg/ha applied at 26 days after sowing (DAS). Shoot growth was measured at fortnightly intervals beginning from the initiation of the N treatments, while roots were sampled at 26, 40, 54 and 82 DAS. Cultivar differences in shoot growth were usually significant while N application had no influence on shoot dry matter accumulation. Throughout most of the growing season, Allure produced the highest shoot dry weight. Application of N did not affect root dry matter content at any stage for all cultivars. Beacon produced the lowest root weight at 26 and 40 DAS. However, at later stages (54 and 82 DAS) there were no significant differences among the cultivars. Allure had higher shoot to root ratios than the other cultivars. Nitrogen had no significant effect on either shoot or root N accumulation. However, cultivar differences were observed in N concentration and total N content of shoots. Allure had a lower N concentration than the other cultivars throughout most of the experimental period. Initially Beacon contained a significantly lower N content in the shoot compared with the other two cultivars. However shoot N gain in Beacon increased gradually and approached that of Allure at later growth stages. The N partitioning between shoot and root of peas was not affected by either cultivar or N application during the growing period.

Additional key words: conventional cultivars, N accumulation, nitrogen use efficiency, semi-leafless cultivars.

Introduction

Field peas are an important crop in Canterbury, with nearly 20,000 ha grown annually. They serve as a cash crop, disease break crop and help to maintain soil nitrogen (N) levels. Many pea cultivars are grown, ranging from leafless erect types to conventionally leaved scrambling types. Growth habit has been shown to affect many aspects of growth and physiology of field peas including: light interception, water use efficiency and yield capacity (Wilson *et al.*, 1981; Zain *et al.*, 1983; Heath and Hebblethwaite, 1985; Armstrong and Pate, 1994; Fettell and Carpenter, 1997). Long duration indeterminate varieties may have a higher yield potential than short duration types, but are prone to lodging. Semi-leafless types with reduced plant height have better standing ability with the support of extensively grown tendrils which are considered to offset inherent photosynthetic disability due to absence of leaflets (Armstrong and Pate, 1994). Tall conventional cultivars have the ability to successfully continue vegetative growth, flowering and pod formation in dry seasons.

The partitioning of assimilates between shoot and root is obviously important in crop production. Partitioning of a high proportion of assimilates into leaf tissue is important for maximum dry matter production. However, the required dry matter should be supplied to the rest of the plant to support the leaves in an efficient way and to supply sufficient mineral nutrients and water. Cultivar differences in dry matter partitioning exist in peas (Armstrong and Pate, 1994). If N limits growth of higher plants, shoot growth rate decreases more than root growth and hence shoot:root ratio decreases (Hilbert, 1990). The shoot:root ratio is positively and linearly related to tissue N concentration in legumes under NO_3^- nutrition (Hirose, 1986; Andrews *et al.*, 1995).

In the present study dry matter and N accumulation were determined for three morphologically different pea cultivars. The objective was to determine the influence of the cultivar and N application on shoot:root ratios and N accumulation.

Materials and Methods

Field site

The field experiment was conducted from October 1996 to February 1997 at Lincoln University Research Farm. The soil was a Wakanui silt loam of pH 5.2 containing 0.32% total nitrogen as determined by the semi-micro Kjeldahl method (Gehrke *et al.*, 1972).

Cultivar

Three pea cultivars of contrasting morphology were selected for the study. Cv. Allure is a semi-leafless white field pea type of medium vine length and semi erect growth habit. Cv. Beacon is a conventionally leaved small blue pea with determinate growth, but may lodge badly at mid pod filling stage. Cv. Whero, is a maple pea, conventionally leaved, tall with indeterminate growth, and of a markedly prostrate and scrambling growth habit. Allure is of French origin and Beacon and Whero were bred by the former Crop Research Division of the DSIR, New Zealand.

Cultural practices

The Wakanui silt loam site had been in chicory from 1992 until 1996 and in oats immediately prior to this experiment. Cultivation was standard farm practice, with trifluralin applied at 2 l/ha and soil incorporated six days prior to sowing. Superphosphate at 200 kg/ha was broadcast and incorporated by cultivation, immediately before sowing. Plots of 2.1 by 18 m were sown with the appropriate cultivars on 16 October 1996. The target population was 100 - 110 plants/m^2. Nitrogen was applied as ammonium sulphate at 26 days after sowing (DAS) at 0, 30 and 60 kg N/ha. Quick lime was applied on 23 November 1996 at the rate of 3 t/ha, to try and increase the soil pH from the initial level of 5.2.

Shoot biomass

Plants were harvested at fortnightly intervals after the nitrogen application for shoot biomass determination until 96 DAS. At each harvest quadrats (0.2 m^2) of the above ground biomass were cut to include the two scale nodes at the stem base (Knott, 1987). Plant samples were oven dried at 70°C to constant weight.

Root biomass

Roots were harvested at 26, 40, 54 and 82 DAS. Roots were sampled by hammering a 4.5 cm soil auger into the soil. Three cores were taken from a plot, one directly over the stem base and other two to include one in between the plants in a row and one in between the rows. Progressive sampling at 10 cm intervals at each coring position was done to recover all visible root material. The total coring depth depended upon the time of harvest. Roots were washed free of soil on a 2 mm sieve, oven dried and weighed. Dry weight was calculated on a ground area basis.

Nitrogen determination

Dried shoot and root samples were ground (<0.5 mm) and the total N content was determined from a subsample of about 3 - 5 mg, using a Europa Scientific Roboprep mass spectrometer (Goh *et al.*, 1996). Nitrogen use efficiency (NUE) was defined as follows:

$$NUE = \frac{shoot\ dry\ weight\ (g)}{shoot\ N\ content\ (mg)} \tag{1}$$

Results

Shoot and root growth

Nitrogen application did not alter shoot or root dry matter accumulation at any stage of plant growth. Shoot (Fig. 1) and root biomass, averaged over all N levels, closely followed a linear pattern of growth over the measurement period. Until 82 DAS Whero had the lowest shoot growth rate ($P<0.001$) of about 10.8 g/m^2/day. However, from 82 - 96 DAS Whero had the fastest growth rate ($P<0.01$) of 39.2 g/m^2/day. Shoot growth rate of Beacon varied only slightly from 18.5 to 21.8 g/m^2/day for the 40 to 96 DAS period. Allure grew at the same rate as Beacon early on, but had a peak growth rate of 30.4 g/m^2/day at 68 - 82 DAS. By the final harvest date all the cultivars attained similar shoot dry weights. Beacon lodged fully and was at maturity at final harvest (96 DAS), while Allure attained maturity about a week later. Whero was still producing flowers at that stage. Heavy rain fell during January and caused the soil under Beacon and Whero to maintain high moisture percentages (>30%). This caused lower leaves to decay and powdery mildew symptoms to occur. Hence measurement for shoot dry weight was stopped at 96 DAS.

Root growth of Beacon was about 40 and 20% lower than the other cultivars at 26 and 40 DAS but by 54 DAS there was no difference (data not presented). Root growth rates ranged between 1.4 - 1.7 g/m^2/day for the three cultivars between 54 and 82 DAS.

Shoot : root dry weight ratios increased from a value of around 1 at 26 DAS to about 11.6 at 82 DAS (Fig. 2). Allure, the semi-leafless cultivar maintained a significantly higher shoot : root ratio than the other two cultivars from flower initiation (54 DAS) until maturity.

N content

The N concentration in the shoot dry matter declined from 4.6% N (range 4.5 - 4.7) during early vegetative growth to 2.3% N (range 2.1 - 2.5) at 96 DAS (Fig. 3). Allure had a significantly lower N% than the other two cultivars at most sampling dates. While root N% ranged from about 1.9 - 2.8% for the 40 to 82 DAS period, there were no differences among the cultivars (data not presented). Application of N at either level at 26 DAS significantly ($P<0.01$) increased the N concentration (N%) of roots (range 2.5 - 2.9) and shoots (range 4.4 - 4.8) at 40 DAS. Application of N at 60 kg/ha resulted in a higher N concentration in shoots (range 2.7% - 3.1%) at 68 DAS. Roots were not measured at this sampling date.

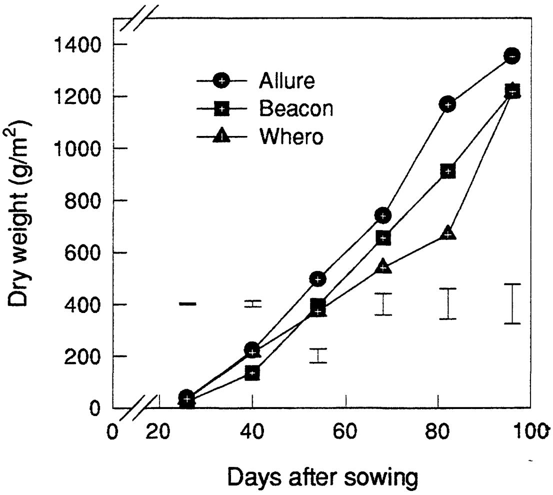

Figure 1. Effect of cultivar on shoot dry matter accumulation. (Bars = ±SEM).

Allure and Whero maintained higher N contents in the shoots than Beacon up to 40 DAS but then were slowly surpassed by Beacon (Fig. 4). By 96 DAS the shoots of all cultivars contained almost similar total N contents at around 29 g/m^2. The total N content in roots did not differ among cultivars except for minimal difference at 40 DAS and averaged 0.65 g/m^2 at 26 DAS, 1.4 g/m^2 at 54 DAS and 2.0 g/m^2 at 82 DAS.

Nitrogen application rate did not alter either the total N content in shoots or roots up to 96 DAS.

Neither cultivar nor N application affected the N partitioning between shoots and roots over the experimental period. Shoot N : root N ratios for 26, 40, 54 and 82 DAS were 2.3, 8.1, 11.6 and 11.4 respectively.

N use efficiency

Nitrogen use efficiency was affected by both cultivar and nitrogen levels. From 54 DAS Allure had a significantly higher N use efficiency for shoot biomass

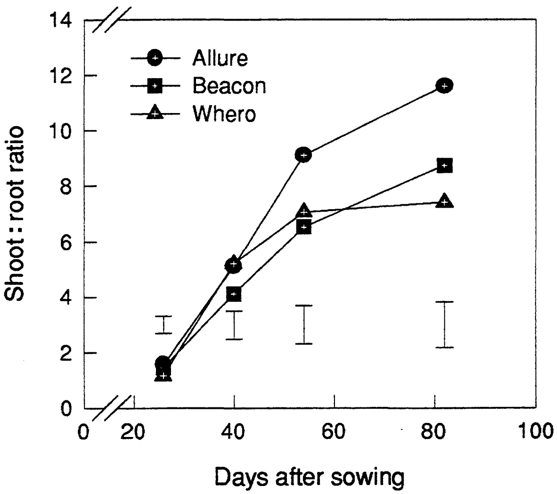

Figure 2. Effect of cultivar on shoot:root ratios. (Bars = ±SEM).

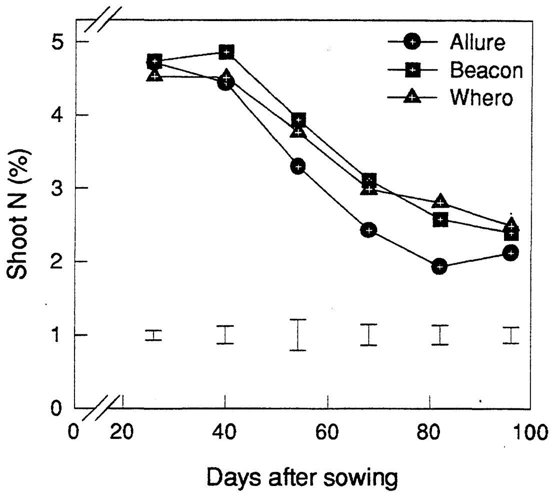

Figure 3. Effect of cultivar on shoot nitrogen percentage. (Bars = ±SEM).

production (Fig. 5). The difference was greatest at 82 DAS when Allure was about 30% more efficient at using N for shoot growth than were the other two cultivars. Application of N reduced nitrogen use efficiency at 40 and 68 DAS by about 14%.

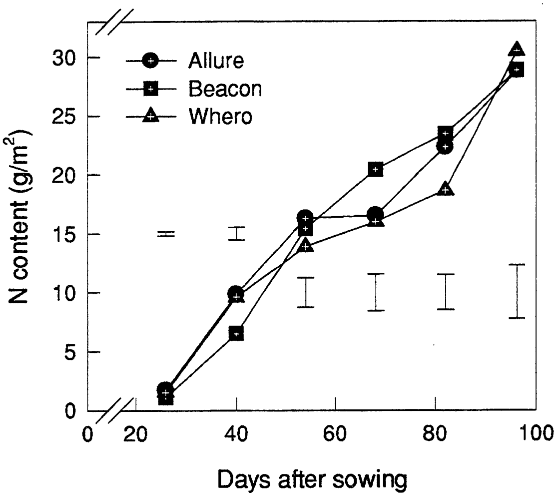

Figure 4. Effect of cultivar on shoot nitrogen content. (Bars = ±SEM).

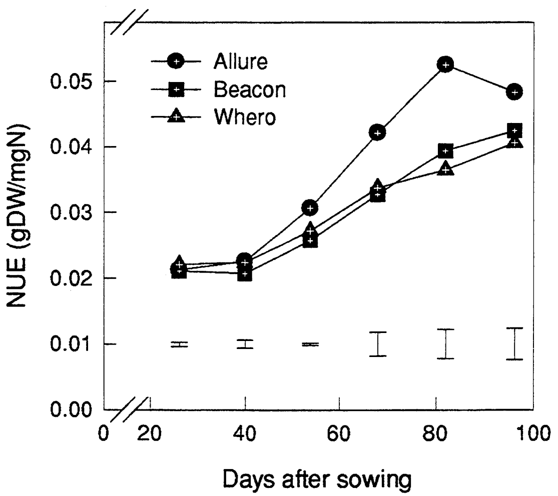

Figure 5. Effect of cultivar on nitrogen use efficiency. (Bars = ±SEM).

Discussion

Nitrogen application had no effect on either shoot or root biomass accumulation. In previous work a nil response in pea dry matter accumulation to N application was reported (Jensen, 1987) even at N levels of 100 kg/ha (Frechilla *et al.*, 1995). Mahon and Child (1979) suggested a period of N stress may last until the third week of pea growth and indicated that early stimulation of leaf area development by the addition of fertiliser nitrogen could result in greater capacity for symbiotic N_2 fixation. The nitrogen content in this soil was 0.32% at the beginning of the experiment. A range of 0.3 to 0.6% N in soil has been rated as a medium level for New Zealand soils (Kear *et al.*, 1967). This, plus the lack of response to N suggests that at this site, soil N plus N fixed by the plant were adequate for crop growth over the growing season.

Allure maintained the highest dry matter production throughout the growing season. Heath and Hebblethwaite (1985) indicated that semi-leafless peas could convert the intercepted radiation into dry matter as efficiently as leafed peas. Wilson *et al.* (1981) compared the growth of two pea cultivars and concluded that semi-leafless peas could produce more dry matter than conventional types especially under non-irrigated conditions due to more efficient water use.

Beacon maintained a stable growth rate of about 19 $g/m^2/day$ after 40 DAS. Allure and Whero had their highest growth rate during pod filling, between 68 - 82 DAS and 82 - 96 DAS period respectively. Armstrong and Pate (1994) evaluated six pea genotypes of contrasting morphology and observed disparities in crop growth rates among genotypes to be greatest during pod filling.

Even though the shoot growth rate increased at a faster rate between 82 DAS and 96 DAS in Whero compared with the other two cultivars, the root weight gain was similar for the three cultivars during this period. This observation contrasts with that of Armstrong and Pate (1994), who observed exceptionally high shoot an root growth rates,

for indeterminate cultivars late into the season in a water limited Mediterranean environment. The high soil moisture percentage of about 35% obtained by measurement with a neutron probe, under the canopy of Whero at the later stages of crop growth may have reduced the requirement for higher root growth. Allure, the semi-leafless pea, partitioned a greater proportion of its dry matter to shoots than roots compared with Beacon and Whero especially, and significantly so, after 40 DAS. The increased water use efficiency which has been shown in the past for semi-leafless peas (Wilson *et al.*, 1981), which is likely due to reduced evapotranspiration and perhaps to improved efficiency of radiation use (Zain *et al.*, 1983) could account for the improved partitioning.

There was a significantly lower N concentration in the shoots of Allure compared with the other two cultivars over most of the growing period even though Armstrong *et al.* (1994) reported similar N% for six cultivars of different morphological characters. Low N concentrations maintained throughout the growth with high shoot dry weights led Allure to record high nitrogen use efficiencies. Application of nitrogen had no effect on total N content of peas as observed by Jensen (1986). Neither cultivar nor N level affected the N partitioning between shoot and root of pea. The lack of nitrogen stress in this experiment accounts for many of the nil responses found. This experiment also included sampling based on ^{15}N fertiliser application. These samples, which were taken to determine a nitrogen balance for fixation, fertiliser and soil N may help determine why there were no differences in N partitioning. This information will be published at a later date.

Conclusions

1. Allure, the semi-leafless pea produced more biomass, higher shoot : root ratios and had a greater N use efficiency than the other two cultivars.
2. Application of fertiliser N did not affect either the shoot or root dry matter accumulation.
3. Neither cultivar nor N level affected N partitioning between shoots and roots of pea.

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