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Early growth and final yield of autumn sown *Vicia faba* L cultivars given different forms of fertiliser N over winter

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Summary Between 3 Nov. 1983 and 9 Apr. 1984, six applications of fertiliser N (ammonium, nitrate or urea) were given to four autumn sown (26 Oct. 1983) *Vicia faba* L cultivars, Banner Winter (BW) and Maris Beagle (MBg), cold tolerant cultivars normally sown in the autumn, and Herz Freya (HF) and Maris Bead (MBd), cold sensitive cultivars more commonly sown in the spring. The effects of additional N were determined by comparison with plants given zero-N (controls).

Application of N, regardless of form, had no effect on % emergence at the first sampling (15 Dec. 1983); > 90% for BW, MBg and HF, but only 40–60% for MBd. At this time the dry weight, carbon content and nitrogen content of all cultivars was approximately 20% less than that of the seed on planting. No more plants emerged after 15 Dec. 1983. Between 15 Dec. 1983 and 20 Feb. 1984, all cultivars, regardless of N treatment, showed little change in dry weight, carbon content and nitrogen content but the proportion of total plant dry weight, carbon content and nitrogen content in the cotyledons decreased while the proportions in root, stem and leaf tissue increased. On 20 Feb. 1984 there were no N effects. All cultivars but especially BW and MBg, showed progressive increases in dry weight, carbon content and nitrogen content during the period 20 Feb. 1984 to 8 May 1984. Pooled results for all four cultivars indicated that on 8 May 1984, plants given ammonium and urea had a greater dry weight, carbon content and nitrogen content than controls.

At harvest (1–3 Sep. 1984), BW and MBg outyielded (g dw seed m^{-2}) HF and MBd. Pooled results for all cultivars indicated that application of N regardless of form gave increased yield and an increased N concentration (mg N g^{-1} dw) in the seed.

Introduction

Depending on sowing date and pre-winter temperatures, autumn sown *Vicia faba* L may or may not produce fully differentiated nodules before the spring[2]. However, even if functional nodules are formed, rates of N fixation are very low at temperatures below 10°C[3] and there is the possibility, that between autumn and spring, plant growth is N limited.

At 6°C in the laboratory, a range of uninoculated *V. faba* cultivars show progressively improved growth as applied nitrate or urea concentration is increased from 1 to 20 mol m^{-3} N[1] (unpub.). Urea often gives substantially greater growth than nitrate[1]. Plants show poorer growth with ammonium than with nitrate or urea and, at concentrations of 4 mol m^{-3} or greater, display symptoms of ammonium toxicity and no benefits are obtained with increased concentration (unpub.).

This paper reports the findings of a preliminary experiment to test the effects of additional nitrogen (ammonium, nitrate and urea) on growth of *V. faba* at low temperatures in the field.

Materials and methods

Field site, plant material and experimental design

Field work was carried out at the Scottish Crop Research Institute (SCRI), Mylnefield, Invergowrie (National Grid Reference NO 339301) in free drained sandy loam 12″ over gravelly sandy loam. To confirm that soil N levels were low before commencement of the experiment, ammonium and nitrate concentrations were determined on twelve random soil samples using the methods described in Mackereth, Heron and Talling[5]. The ammonium level, expressed relative to the water content of the soil for comparison with laboratory work[1], was estimated at $0.2 \pm 0.1\,\mathrm{mol\,m^{-3}}$ from a distilled water extract and $0.8 \pm 0.2\,\mathrm{mol\,m^{-3}}$ from a 5% TCA extract: variance quoted = SE. Both extracts gave similar values for the nitrate concentration $1.1 \pm 0.1\,\mathrm{mol\,m^{-3}}$ (distilled water) and $1.2 \pm 0.1\,\mathrm{mol\,m^{-3}}$ (5% TCA).

Four *V. faba* cultivars were used: Banner Winter (BW), Maris Beagle (MBg), Herz Freya (HF) and Maris Bead (MBd). BW and MBg are cold tolerant cultivars which are normally sown in the autumn while HF and MBd are cold sensitive cultivars which are more commonly sown in the spring. With the exception of HF which was obtained from Mr R. Thompson (SCRI) all seed was purchased from the National Seed Development Organisation Ltd., Cambridge.

The four cultivars received each of four N-treatments. On 26 and 27 Oct. 1983 individual seeds were sown by hand in a twice replicated split plot design. Excluding guard rows, each plot measured $76.6\,\mathrm{m^2}$. The plots were split by polythene "walls" 1 m deep inserted on 25 and 26 Oct. 1983. Half of each subplot was sown with graded seed within ± 10% of the mean seed dry weight and half sown with unselected seed. Sowing density was 53.3 seeds $\mathrm{m^{-2}}$. Gramoxone ($2.8\,\mathrm{l\,ha^{-1}}$) and Cesatop ($2.3\,\mathrm{l\,ha^{-1}}$) herbicides were applied to both plots on 28 Oct. 1983. The four N-treatments were $200\,\mathrm{kg\,N\,ha^{-1}}$ as potassium nitrate, ammonium sulphate or urea and O additional N (control). Potassium ($558\,\mathrm{kg\,K\,ha^{-1}}$ as K_2SO_4) was applied to the control, ammonium and urea subplots to balance the additional potassium in the nitrate (KNO_3) treatment, and phosphorus ($76\,\mathrm{kg\,P\,ha^{-1}}$ as superphosphate) was added to all plots. All treatments were applied in solution (trickle irrigation or manually if soil temperatures were low) as six split dressings on 3 Nov. 1983 ($50\,\mathrm{kg\,N\,ha^{-1}}$), 19 Dec. 1983, 6 Jan. 1983, 13 Feb. 1984, 8 Mar. 1984 ($25\,\mathrm{kg\,N\,ha^{-1}}$ in all cases) and 9 Apr. 1984 ($50\,\mathrm{kg\,N\,ha^{-1}}$). The dates of N, P, K application encompassed the period of the year when values for daily solar radiation (Fig. 1A), air temperature (Fig. 1B), grass minimum temperature (Fig. 1C) and soil temperature (Fig. 1D) were lowest. In comparison to mean values for the previous twelve years, irradiance levels were for the most part similar although between late Apr and early Aug values were higher. From mid-Jan. to early Feb. air, grass minimum and soil temperatures were below the mean for the previous 30 years with values of −15.5°C and 0°C being recorded for grass and 10 cm soil depth minima respectively.

Sampling of plants, tissue analysis and measurement of yield

On six occasions between 15 Dec. 1983 and 8 May 1984 random sampling of whole plants was carried out from the half subplots containing graded seed. If no plant was found in the position indicated by the random coordinates, as was often the case for MBd, the closest plant was sampled. The number of plants sampled at each time ranged from 4 to 16 (equal numbers from the replicate plots) depending on sampling date and is given in the text. Plants were separated into leaves, stem plus petioles, roots and cotyledons, dried at 70°C for 96 h and on cooling reweighed. At four harvests, four or six plants of each cultivar were selected from each treatment and their organs grouped in pairs or threes then ground. Two or more subsamples (0.5 to 1.0 mg) were taken from all pooled tissues and analysed for C and N content in a Carlo Erba elemental analyser (Model 1106) using an atropine calibration standard.

At the end of the experiment, 1–3 Sep. 1984, a count was taken of the numbers of plants and pods in the innermost area of each cv × N subplot which had originally contained 100 ungraded seeds. Total seed from fifty pods from each treatment was weighed, then fifty of these seeds were weighed individually. Single determinations for C and N content were carried out on six seeds of each cultivar from each treatment. An analysis of variance was carried out on all data obtained. Ranking of cultivars or N-treatments was obtained by carrying out the T-test for paired comparisons. All effects discussed have an F ratio with a probability $P < 0.05$.

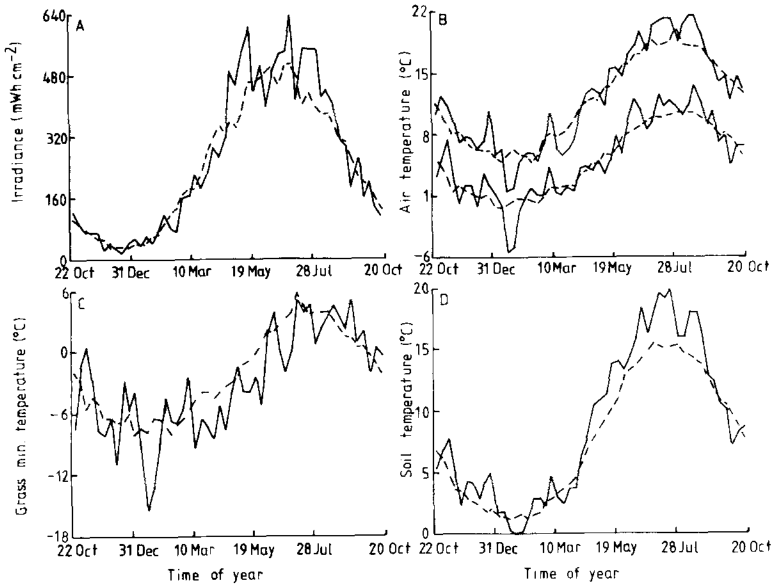

Fig. 1. Weekly mean values for **A**, daily solar radiation, **B**, minimum and maximum daily air temperature, **C**, grass minimum temperature and **D**, soil temperature at 10 cm depth. *Unbroken lines* give values during the year of study, *broken lines* give mean values for the previous ten years in the case of A, and the previous 30 years in the case of B, C, D. All data were supplied by the Scottish Crop Research Institute, Mylnefield, Invergowrie.

Results and discussion

Emergence and early development

Regardless of N-treatment, > 90% of BW, MBg and HF, but only 40–60% of MBd had emerged at the first sampling date, 15 Dec 1983. At this time the dry weight (Fig. 2), carbon content (Fig. 3) and nitrogen content (Fig. 4) of all cultivars was approximately 20% less than that of the seed on planting and non-cotyledonary dry weight (*i.e.* root + stem + leaves) for the cultivars decreased in the order BW = HF > MBg > MBd. No more plants emerged after 15 Dec 1983. In the laboratory MBd achieves < 10% emergence at 6°C but > 90% emergence at 15°C whilst BW, MBg and HF achieve > 90% emergence at both temperatures (unpub.). It is concluded that it is likely that poor establishment of MBd in the present study is a low temperature response.

Between 15 Dec. 1983 and 20 Feb. 1984 nodulation did not occur and all cultivars showed little change in dry weight, carbon content and nitrogen content. However, the proportion of total plant dry weight, carbon content and nitrogen content in the cotyledons decreased while the proportions in root, stem and leaf tissue increased. Plant sampling on 27 Dec. 1983 and 12 Jan. 1984 (data not shown on Figs. 1,2,3) showed this to be a gradual change throughout the winter. On 20 Feb. 1984 approximately 25% of the dry weight of all cultivars was still in the cotyledons: BW and MBd had respectively the greatest and least non-cotyledonary dry weight while values for HF and MBg were now not significantly different. Pooled results for all cultivars indicated that additional N regardless of form had no effect on the total plant dry weight, carbon content and nitrogen content at this sampling.

All cultivars showed progressive increases in dry weight, carbon content and nitrogen during the period 20 Feb. 1984–5 May 1984: increases were greater for winter cultivars than for spring cultivars. The slower growth rate of the spring cultivars may be due to their low-temperature sensitivity. For example, both cultivars, but HF especially, were chlorotic in the spring regardless

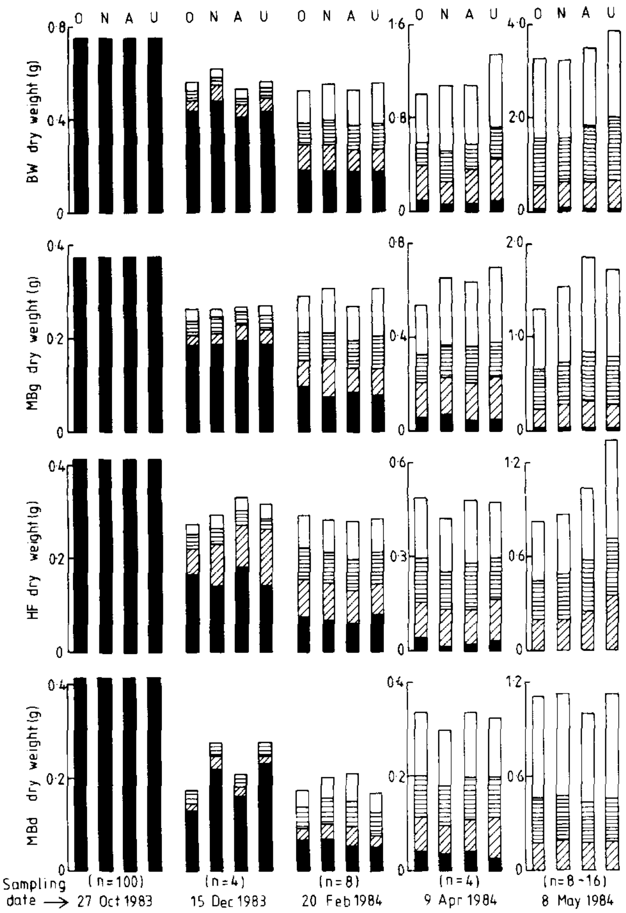

Fig. 2. Late autumn, winter and early spring dry weights of cotyledons ■, root ▨, stem ▤ and leaves □ of four *Vicia faba* L cultivars Banner Winter (BW), Maris Beagle (MBg), Herz Freya (HF) and Maris Bead (MBd) given O, no additional N, N, 200 kg N ha^{-1} as nitrate, A, 200 kg N ha^{-1} as ammonium and U, 200 kg N ha^{-1} as urea.

of N treatment and did not turn fully green until May. Thus, they may have been incapable of the rates of photosynthesis achieved by the green, cold tolerant BW and MBg and photosynthesis may have a greater limitation on growth than N-assimilation. Evidence in support of this proposal is the finding that, on 22 Feb. 1984 and 9 Apr. 1984 both spring cultivars had a greater tissue N concentration (mg N g^{-1} dw) than the two winter cultivars while their carbon concentration was less (Figs. 1,2,3). Such increases in N relative to C are commonly shown by laboratory grown plants given increased concentrations of applied nitrogen at a fixed low irradiance level[1,7]. On 9 Apr. 1984 cotyledonary tissue constituted ~ 15% of the total plant dry weight, carbon content and nitrogen content of all cultivars. Non cotyledonary dry weight, carbon content and nitrogen content decreased in the order BW > MBg > HF > MBd. At this time nodules were not visible. On 8 May 1984 all cultivars had little or no cotyledonary tissue, the total plant dry weight for the cultivars decreased in the order BW > MBg > HF = MBd and all cultivars were nodulated. Pooled results for all four cultivars indicated that on 8 May 1984 plants given ammonium and urea had a greater

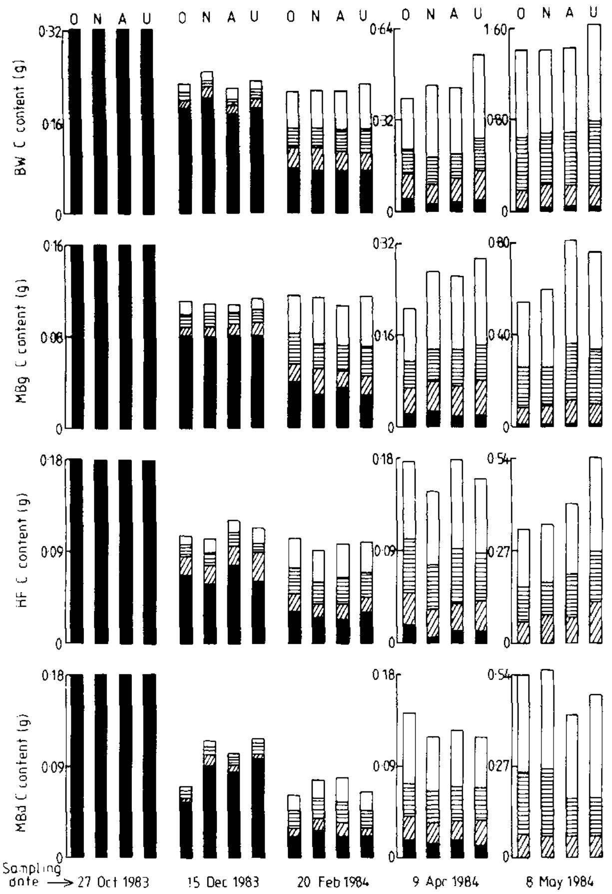

Fig. 3. Late autumn, winter and early spring carbon content of cotyledons ■, root ▨, stem ▤ and leaves □ of four *Vicia faba* L cultivars Banner Winter (BW), Maris Beagle (MBg), Herz Freya (HF) and Maris Bead (MBd) given O, no additional N, N, 200 kg N ha^{-1} as nitrate, A, 200 kg N ha^{-1} as ammonium and U, 200 kg N ha^{-1} as urea.

dry weight, carbon content and nitrogen content than controls and plants given nitrate. The finding that at low temperatures in the field, urea gives greater than nitrate, is in agreement with laboratory results[1], however, greater growth with ammonium than nitrate is contrary to findings in the laboratory (see above). Possible reasons for the different responses to ammonium in the two environments are the different buffering capacities of soil and the vermiculite/perlite substrate used in the laboratory; the probability that in the field dilution, leaching and microbial activity ensure that high concentations of ammonium do not build up and, in the field, plants given ammonium are likely to be assimilating nitrate also and thus adverse pH effects much reduced[4,6]. The finding of no N effects on 22 Feb 1984 but significant effects of N on 8 May 1984 indicate that it would be best economically to add N-fertilizer in the spring than to risk overwinter loss through leaching or volatilisation.

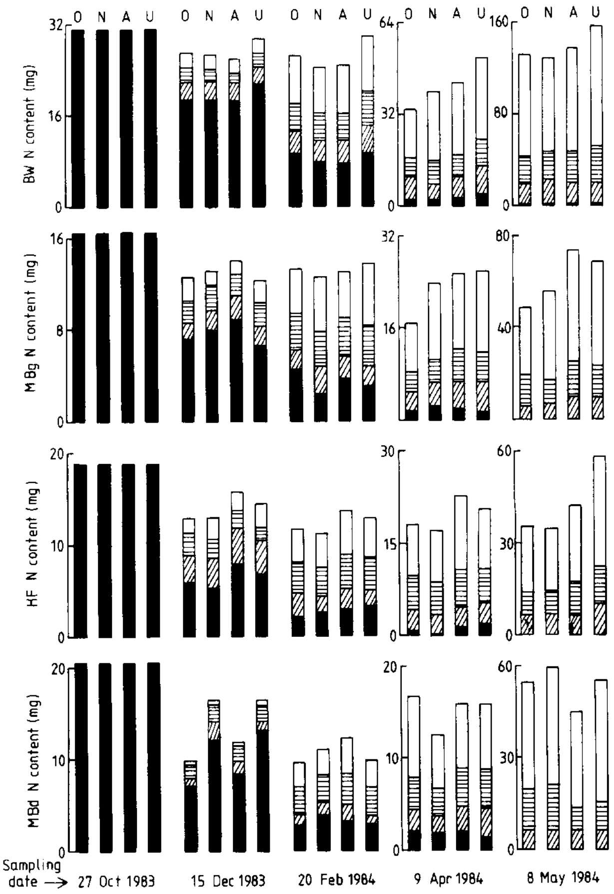

Fig. 4. Late autumn, winter and early spring nitrogen content of cotyledons ■, root ▨, stem ▤ and leaves □ of four *Vicia faba* L cultivars Banner Winter (BW), Maris Beagle (MBg), Herz Freya (HF) and Maris Bead (MBd) given O, no additional N, N, 200 kg N ha^{-1} as nitrate, A, 200 kg N ha^{-1} as ammonium, and U, 200 kg N ha^{-1} as urea.

Yield (g dw seed m^{-2}, Table 1) for the cultivars was directly related to early growth rate and decreased in the order BW > MBg > HF > MBd. Pooled results for all four cultivars indicated that application of N regardless of form significantly increased yield and N concentration (mg N g^{-1} dw) in the seed but there was no significant difference between the ammonium, nitrate and urea treatments. However, the data for the two winter cultivars suggest that in there case, application of ammonium and urea can give a greater yield than application of nitrate. It is concluded that in low N soils both cold sensitive and cold tolerant cultivars of *V. faba* grow slowly at low temperatures in the spring when nitrogen fixation is either absent or occurring at low rates, and under such conditions application of ammonium and urea can stimulate growth. This increase in growth rate plus any effect from the residual applied nitrogen can give increased yield. Residual nitrogen from overwinter and spring application of nitrate can also increase yield. Further studies are needed to assess whether these findings are reproducible year to year and if so are they of commercial importance.

Table 1. Yield and related parameters for four *Vicia faba* L. cultivars Banner Winter (BW), Maris Beagle (MBg), Herz Freya (HF) and Maris Bead (MBd) given, -O, no additional nitrogen, -N, 200 kg ha^{-1} as nitrate, -A, 200 kg N ha^{-1} as ammonium and -U, 200 kg N ha^{-1} as urea

Cv-treatment	Plants at harvest / seed sown	Pods $plant^{-1}$	G dw seed $plant^{-1}$	G dw seed m^{-2}	Av seed weight (g)	Mg C g^{-1} dw seed	Mg N g^{-1} dw seed
BW-O	0.93	5.8	9.4	476	0.67	44.1	4.16
BW-N	0.96	5.9	10.7	546	0.70	42.5	4.30
BW-A	0.95	6.9	13.9	697	0.72	43.8	4.56
BW-U	0.96	6.9	13.5	690	0.68	42.7	4.57
MBg-O	0.95	4.3	6.6	330	0.63	43.1	4.19
MBg-N	0.91	5.0	7.8	396	0.68	43.3	4.58
MBg-A	0.92	6.9	11.9	576	0.69	43.2	4.73
MBg-U	0.92	6.5	11.2	549	0.67	43.7	4.70
HF-O	0.87	5.8	6.7	310	0.39	43.1	4.56
HF-N	0.84	6.7	7.7	345	0.42	43.7	4.90
HF-A	0.84	6.7	7.9	349	0.42	43.7	4.84
HF-U	0.88	7.4	8.5	394	0.41	43.8	5.22
MBd-O	0.32	12.8	16.1	220	0.41	43.2	4.94
MBd-N	0.47	9.6	11.2	282	0.41	43.6	5.13
MBd-A	0.44	11.3	14.7	270	0.40	43.7	5.44
MBd-U	0.47	7.6	9.0	228	0.41	43.8	5.23

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