IMPLICATIONS OF ACCOUNTING FOR BELOW-GROUND N ON THE CALCULATIONS OF RESIDUAL RETURNS OF FIXED N FOR COMMERCIAL FABA BEAN CROPS

I.J. Rochester[1], M.B. Peoples[2], R.R. Gault[2] and G.A. Constable[1]

[1]CSIRO Cotton Research Unit, Narrabri, NSW 2390
[2]CSIRO Plant Industry, Canberra, ACT 2601

Abstract.

Nitrogen associated with nodulated roots and below-ground legume N released into soil during growth was determined experimentally for field-grown faba bean and soybean crops using ^{15}N shoot feeding techniques. The relative amounts of below-ground legume N were calculated to be similar for both crops and represented close to 40% of the total crop N. This figure was subsequently used to evaluate the potential contribution of below-ground N to the N-economy of commercial faba bean crops. Shoot growth, N_2 fixation and yield of were monitored in 35 partially irrigated crops grown in rotation with cotton over 3 years in northern New South Wales. Estimates of N_2 fixation using the ^{15}N natural abundance technique indicated a direct relationship between shoot biomass and amounts of N_2 fixed. On the basis of solely shoot-based calculations of N_2 fixation, almost 25% of all crops surveyed would have been considered to have failed to fix more N than was removed in seed. However, if the amounts of residual fixed N remaining after seed harvest were recalculated to include estimates for below-ground contributions, nearly all of the 35 faba bean crops examined were determined to be in positive N balance, with most crops fixing twice as much N (mean 177 kg N/ha) as was removed in grain (mean 64 kg N/ha). From these data it would appear that below-ground legume N can be playing an important but hidden role in the N dynamics of rotational systems, and that commercial pulse crops are likely to be contributing fixed N to soil N reserves far more frequently than previously believed.

Key words: On-farm measures, faba bean, Vicia faba, N_2 fixation, residual N

Irrigated cotton (*Gossypium hirsutum*) may require up to 200 kg fertiliser N/ha to achieve maximum yield (1). Legumes currently comprise about 10% of the rotation crops grown within cotton farming systems. In the Namoi valley of northern New South Wales in recent years, up to 10,000 ha have been sown annually to faba bean (*Vicia faba*) after cotton. As well as being valuable cash crops, legumes can also enhance lint yields of following cotton crops (3).

The contribution of fixed N by commercial legume crops to the systems in which they grow has rarely been studied. A few surveys have provided limited information on amounts of N_2 fixed by commercial soybean (*Glycine max*), lupin (*Lupinus angustifolius*), chickpea (*Cicer arietnum*) and faba bean crops (4, 6, 8). These studies provide some indication of the potential amounts of N_2 fixed and the variability that might be expected on-farm; however, this information may not be relevant to irrigated cotton cropping systems. This paper reports measurements of N_2 fixation by commercial faba bean crops growing in rotation with cotton and quantifies the contribution of below-ground N for irrigated summer and winter legume crops. Residual fixed N returned in the stubble and roots were determined to quantify the potential impact of legume cropping on the N fertility of cotton farming systems.

Materials and methods

Determinations of below-ground N

To determine the relative partitioning of legume N into shoots and below-ground we grew soybeans in 1994/5 and faba beans in 1996. Steel frames were inserted to a depth of 20 cm into the soil in an area of the field having a uniform plant stand, to demarcate an area of 0.5 m^2, enclosing 0.5 m of crop row. Plants within these frames where thinned to a uniform population (10 plants for soybean and 5 for faba bean). Four replicate frames were used on each occasion. Soybean plants were labelled by allowing individual plants to absorb through their petioles 1 mL of 0.15 M ^{15}N-enriched urea solution (0.981 mg ^{15}N excess/g

N) on 3 occasions approximately 3 weeks apart. For faba beans, 1 mL of 0.45 M ^{15}N-enriched urea solution (0.981 mg ^{15}N excess/g N) was injected into the hollow stem, once only, at mid flowering. Plant shoots were removed during late seed-filling and the soil from each microplot was removed to 25 cm, then cores were taken to 80 cm depth. Roots were recovered from the soil and all plant and soil materials were dried, weighed and milled and analysed for total N and ^{15}N. Below-ground N was determined from the relative ^{15}N enrichments of roots and soil, as described by Russell and Fillery (5).

On-farm survey of shoot N accumulation, amounts of N_2 fixed, and N removed at harvest

Plant samples were collected at each on-farm site by removing all shoot material from 1 m^2 at 4 locations within each field. Similarly, N removal in grain was assessed by taking 4 replicates of 1 m^2 samples at crop maturity and threshing the grain. Most crops were irrigated to ensure even establishment; further irrigations were applied depending on the availability of water and the anticipated seed yield of the crops.

Nitrogen fixation was determined using the ^{15}N natural abundance technique (7) on 35 commercial faba bean crops growing in rotation with cotton throughout the main cotton-growing regions of northern NSW during the winter growing seasons of 1994, 1995 and 1996. Weeds growing adjacent to the area of legume crop sampled were used as non-N2-fixing reference plants to allow ^{15}N-based estimates of N_2 fixation (6).

Results and discussion

The importance of below-ground legume N The N present in nodulated roots is usually ignored in most N_2 fixation studies since roots recovered from field crops often represent only 10-15% of the total plant N [*eg.*Unkovich *et al.* (8)]. Consequently, roots are generally considered to play only a minor role in the overall N-economy of legume crops. However, recent studies applying ^{15}N shoot-feeding techniques to lupin grown in soil columns have indicated that only 35% of the total root material may be physically recoverable from soil (5). Their data suggested that considerable quantities of N (91 kg N/ha, equivalent to 28% of total crop N) may be associated with nodulated roots and released into the soil during growth.

The microplot data in the current field experiment indicated that during pod-filling the nodulated root systems of both summer and winter crops (soybean and faba bean) comprised a similar proportion of the total crop N. For soybeans, 38.6% $\pm$ 1.4 of total crop N was calculated to be below-ground; for faba beans the value was 41.0% $\pm$ 6.3. Calculations of crop N data and N_2 fixation determinations in the following sections were modified to account for the N in the below-ground fraction of each faba bean crop (estimated to be 40% of total crop N). We have presented data with and without this adjustment to illustrate the impact of including below-ground N on the contributions of fixed N to this system.

N_2 fixation by faba bean crops

In the crops surveyed, biomass and yields were closely correlated with water supply, with about 1 t grain/ha being produced for each irrigation (approximately one ML) during the drought year of 1994. The faba bean crops were well nodulated when the seed was inoculated with rhizobia prior to planting, although, we did observe some poorly nodulated crops where faba bean followed failed or over-fertilised cotton crops. The estimates of amounts of N_2 fixed (Fig. 1) were closely related to shoot dry matter (DM) production. A mean of 105 kg fixed N/ha was calculated to be present in the shoots of the 35 crops examined (Fig. 1a). However, this estimate increased to 177 kg N/ha when corrected for N contained in below-ground parts (range from 10 to 350 kg N/ha, Fig. 1b).

About 2 t shoot dry matter (DM) /ha was required before substantial N_2 fixation was evident and regression analysis indicated that N_2 fixation was maximised with about 11 t DM/ha. Over the range 2 to 7 t DM/ha, an average of 22 kg fixed N was present in the shoot for every t of shoot accumulated, 37 kg fixed N/t when adjusted to account for below-ground contributions. This level of N_2 fixation was similar to the measure of 20 kg N/t shoot DM determined by Evans *et al.* (2) for dryland pulse crops grown over a range of environments and soil types in eastern Australia.

N removal in faba beans and residual fixed N

Grain yields for the survey crops averaged 2 t/ha (range 0.8 to 4.4 t/ha). Four of the 35 crops were green-manured prior to maturity and seed was not harvested. The net input of N to the soil system (residual fixed N) was calculated by subtracting the N removed in seed from the amount of N_2 fixed. Where below-ground N was not included, several crops were either deemed to have fixed less N than was harvested in grain, or the amounts of fixed N present in the shoot was in close balance with seed N requirements (Fig. 2a). Substantially higher values for residual fixed N were calculated with the inclusion of estimates for below-ground contributions and almost 80% of all crops were considered to have fixed at least twice as much N than was removed in the grain (Fig. 2b). Of the 177 kg N/ha fixed by the average commercial faba bean crop, 64 kg N/ha was harvested with seed and at least 113 kg fixed N/ha remained in vegetative tissues, nodulated roots and root derived soil N. These estimates of residual returns of fixed N are somewhat higher than comparable calculations undertaken for another similar survey of rainfed legume crops in the northern wheat-belt which also adjusted crop N determinations to include below-ground N (6). This presumably reflects the seasons when the dryland study was undertaken (the drought of 1994, and 1995), and the enhanced potential for crop growth and N_2 fixation with the supplementary irrigation on cotton farms in the present investigation.

Conclusions

Most previous estimates of N_2 fixation have not represented the true value of legume crops by failing to include the N associated with the root system. The size of the below-ground component indicated in this study has important implications for the calculation of residual fixed N returned to the soil after legume cropping. For example, the roots of the commercial faba bean crops examined in this survey could have contributed an additional 80-100 kg N/ha in excess of the amounts of N_2 fixed calculated solely on the basis of shoot N. Hence, legume crops are contributing much more to soil N fertility than has previously been recognised. On the basis of the limited survey data reported here it would appear that faba bean crops are capable of providing a valuable input of N into cotton farming systems. The flow-on benefits of legume rotation crops to cotton in terms of potential savings in N-fertiliser applications are currently being researched. Growers who use faba bean should recognise that following cotton crops are likely to require lower rates of fertiliser N to optimise cotton nutrition than traditional cropping systems.

Acknowledgments

Support from the Cotton Research and Development Corporation is gratefully acknowledged. We thank the cooperating farmers who allowed us to sample their legume crops. We are also indebted to Sue Hazlewood, Emma Hely and Gayle Williams for their technical assistance and Graham Turner for mass spectrometer analyses.

References

1. Constable, G.A. and Rochester, I.J. 1988. *Agron. J,* **80**, 498-502.

2. Evans, J., O'Connor, G.E., Turner, G.L., Coventry, D.R., Fettell, N., Mahoney, J., Armstrong, E.L. and Walsgott, D.N. 1989. *Aust. J. Agric. Res,* **40**, 791-805.

3. Hearn, A.B. 1986. *Field Crops Res,* **13**, 159-175.

4. Peoples, M.B., Gault, R.R., Lean, B., Sykes, J.D. and Brockwell, J. 1995. *Soil Biol. Biochem,* **27**, 553-561.

5. Russell, C.A. and Fillery, I.R.P. 1996. *Aust. J. Agric. Res,* **47**, 1047-1059.

6. Schwenke, G.D., Peoples, M.B., Turner, G.L. and Herridge, D.F. 1998. *Aust. J. Exp. Agric.* (in press).

7. Shearer, G. and Kohl, D.H. 1986. *Aust. J. Plant Physio,* **13**, 699-756.

8. Unkovich, M.J., Pate, J.S. and Hamblin, J. 1994. *Aust. J. Agric. Res,* **45**, 149-164.

Figure 1: The relationship between the amounts of N_2 fixed by commercial faba beans and shoot dry matter (DM) production measured at peak biomass. The (a) omission, or (b) inclusion of below-ground N in calculations substantially altered estimates of N_2 fixation.

Figure 2: The amounts of residual fixed N remaining after seed harvest of faba bean crops calculated either (a) solely on the basis of shoot N, or (b) including estimates for below-ground N. Values falling below the dashed line indicated those crops where the amounts of N_2 fixed were calculated to be less than seed N removed. Those values above the dashed line were deemed to have made a net contribution of fixed N to soil N reserves.