Nitrogen fixation in mungbeans - expectation and reality

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Summary. Mungbean crops frequently fix less nitrogen (N) than is removed *as* seed protein. An important objective should therefore be to ensure crops fix as much of their N as possible. However, the expectation that grain legumes should be both high yielding and make net contributions to soil N is unrealistic. Genetic gains in mungbean yields have been achieved more through improved harvest index than increases in total biomass production. Consequently, nitrogen harvest index has increased rather than the total pool of dinitrogen (N_2) fixed, making a net N deficit more likely. While N *as* seed protein remains more valuable than soil N, however, N returned in stubble should be seen more as a failure to realise potential yield than a source of satisfaction.

Introduction

Grain legumes have become increasingly popular as components of crop rotations due both to attractive prices and to agronomic benefits resulting from their inclusion in cereal-based cropping systems. The latter derive primarily from their N_2 fixation capacity, and the opportunities for breaking the disease cycles and for controlling the weed populations that develop in cereal-only sequences (5). As a consequence, grain legumes can be significant in sustainable production systems (1, 5). Consistent with the Conference theme, 'Looking Back-Planning Ahead', we examine the N_2 fixing performance of a tropical grain legume, mungbean, *V igna radiata,* and ways to enhance that role in the future. We also explore some of the changes that have occurred in mungbean through the development of improved cultivars for mechanised agriculture, and some of the implications therein in terms of breeding for high yield potential while maintaining their role *as* contributors of N in sustainable agriculture.

Results and discussion

For a grain legume crop to make a net N contribution to the cropping system, it must fix more N than is removed as seed protein. In effect, the proportion of total crop N that is fixed symbiotically (P_r) must exceed the proportion of total N that is removed as seed (i.e., the nitrogen harvest index, NHI). A survey of N_2 fixation by commercial mungbean crops in Queensland, using the '^{5}N natural abundance method (8), indicated that, depending on season, most crops fixed only a small amount of their total N requirement (3). The relationship between P_r and 'apparent' NHI at crop maturity (i.e., excluding N in roots and senescent leaves) for 24 non-droughted crops on the Darling Downs in 1989-90 is shown in Figure 1. The diagonal line

= NHI represents the 'break-even' situation where fixation just meets crop needs for seed N. It has been adjusted downwards by 10% to reflect the fact that the apparent NHI overestimates actual NHI to the extent that N in roots and senescent leaves is not recovered. Detailed studies of mungbean (4) suggest that as little as 7% of total plant N at maturity may be in roots and senescent leaves, although some N may well be lost prior to that time through root decomposition. However, even if 30% of total plant N was in roots and senescent leaves, the interpretation of Figure 1 would be little altered.

Only about one-third of the crops surveyed fixed more than half their total N requirement (P f>0.50) (Fig. 1). More than half did not fix enough N to meet their demands for seed N (those below the "break-even" line), and so were not likely to make a net contribution to soil N, assuming the crop was efficiently harvested. Of these, about half (sector B) had a reasonable demand for seed N (i.e., the NHI was >0.60). The other half (sector D) had both low P_r and low NHI. Most tellingly, most of those crops that fixed more N than was required for seed (sector C) did so because NHI was low, that is, because HI (and so seed yield) was reduced below potential by environmental and/or management factors. In effect, they were *as* much cover as seed crops. Only three crops (12.5%) had both high 1', and high NHI (sector A), and met the expectations of a 'successful' grain legume crop.

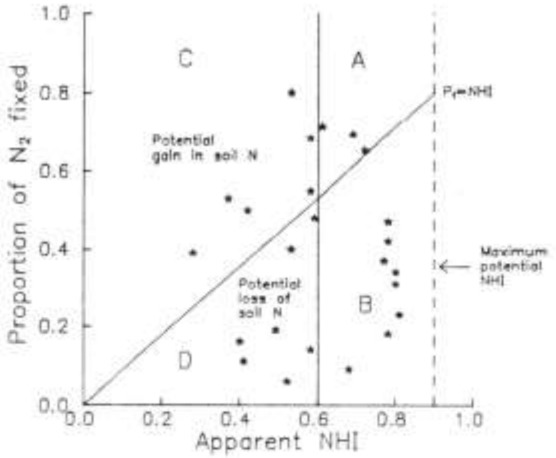

Figure 1. Relationship between the proportion of N_2 fixed (P_r) and the proportion of total N removed *as* seed (NHI), for non-droughted commercial mungbean crops grown on the Darling Downs, south-east Queensland, 1989-90.

Interestingly, there was no overall relationship among crops between P_r and seed yield, *as* indicated by NHI (Fig. 1). P_r was correlated however with the amount of N_2 fixed (r = 0.86**). In turn, the amount of N_2 fixed was correlated with total biomass and total N accumulated (r = 0.51**). Seed yield was proportional to the total biomass (r = 0.71**), total N (r = 0.66**) accumulated and to the partitioning of that DM (r = 0.57**) and N (r = 0.62**) to seed. Conversely the amount of N remaining in the vegetative stubble, a measure of the potential contribution of N to a following crop, was negatively related to NHI and HI (r = -0.62''). That is, the N available for return to the soil was least in those crops that efficiently partitioned their N into the seed.

The clear message from Figure 1 is that while mungbean nodulates freely with a wide range of bradyrhizobia, including native strains (2), and can fix all of its N requirement when conditions demand (2, 4), it is frequently not achieving that potential under commercial conditions. The surveys suggested that part of the problem was associated with poor nodulation. Both P_r and the amount of N fixed were correlated with nodulation rating (r = 0.55** and r = 0.52**, respectively). A surprisingly large proportion of crops were poorly nodulated. For example, some 46% of 50 non-droughted crops sampled during 1988/89 in the Dawson-Callide Valley, and 31% of 36 sampled on the Darling Downs in 1989/90 were rated as having sparse to zero nodulation. Many of these crops were on land that had not grown mungbeans before, suggesting that perhaps soil populations of bradyrhizobia were too low. Another factor associated with poor nodulation was high soil N level. Nodulation rating, P_r and the amount of N fixed were all negatively affected by the application of fertiliser N to the crops (r = -0.49**, r = -0.58**, r = -0.50**, respectively). Nodule rating was also reduced by the use of wide row spacings (r = -0.55**), perhaps because of a relatively more favourable supply of soil N early in seedling growth.

While further detailed work is needed, the results to date suggest that a number of management practices require closer attention if mungbean is to adequately fulfil its role as a N_2 fixing crop. Firstly, the crop needs to be grown in situations with relatively low soil N so that maximum pressure is placed on N_2 fixation. Thus for example, the crop should preferably follow a cereal, and not another legume or a fallow. Where practicable, the crop should be grown solid-seeded rather than in rows, so that available soil N is removed rapidly, favouring early establishment of the symbiosis. Under no circumstances should the crop be fertilised with N, even as a 'starter' application. Secondly, while mungbean nodulates freely with a wide range of native bradyrhizobia, and it is difficult to obtain overt responses to inoculation experimentally (2), the relatively low P_r and poor nodulation in 'first-crop' fields suggest that there may be benefits from an initial inoculation. Selection of cultivars that nodulate more readily under a range of adverse conditions, including the presence of soil N could be profitable.

While there is scope for manipulating the potential of the mungbean crop as a N contributor by manipulating P_r, analysis of the changes in mungbean during its development for mechanised agriculture suggests that future crop improvement will if anything exacerbate the situation shown in Figure 1. Modern cultivars differ greatly from either landrace or wild varieties in their accumulation and partitioning of DM and N (4, 7). Improved yield potentials have been achieved through high HI (and consequently, high NHI). Thus, higher yielding cultivars tend to remove more N *as* seed than is accumulated through fixation unless the crop is fixing a large proportion of its N. For example, in a glasshouse study comparing the recently-released cv. Satin with a photoperiod-sensitive landrace variety from India, and a wild accession from south-east Queensland that has not been the object of any artificial selection, the absolute HI, that is, including roots and senescent leaf, ranked in the order Satin (0.54) > wild accession (0.33) > landrace variety (0.23). Satin, typical of modern cultivars, is earlier maturing, shorter statured, less branched and has greater synchrony of seed production than either of the other lines. N_2 was fixed during vegetative growth and continued for a short time during podfilling but seed development also depended upon remobilisation of resources from vegetative structures. At the other extreme, the wild accession produced seed continuously after flowering and fixed N_2 and remobilised resources throughout growth.

Breeding for higher seed yield has produced a relatively small, unbranched plant, with increased seed production being dependent upon greater HI rather than greater total biomass accumulation. On a per unit area basis, the latter is manipulated by changing plant density. These changes are consistent with experience in other crops that breeding for increased yields under mechanised agriculture has converged crop plants towards a similar generalised morphotype (6), the key features of which include a strictly annual habit and synchronous reproductive growth, erect thickened stems, reduced branching, fewer but larger leaves, non-dehiscent pods, larger seeds and larger HI. At a seed N concentration of 4.3% and a HI of 0.54, the absolute NHI of Satin was 0.84 (or an 'apparent' HI, excluding roots and senescent leaves, of 0.90). There is therefore only limited opportunity for further productivity improvement through genetic increases in NHI (and by implication HI, unless seed protein concentration is to be lowered) above that of Satin. Nonetheless, it is clear from Figure 1 that there remains a substantial gap between potential NHI and that routinely achieved in the field.

In this context, we would argue that excessive N recycled through the crop stubble to the soil represents failure to maximise yield potential and thus the full economic potential of the grain legume crop. An analysis of the potential value of that N as seed protein compared with its value as soil N for a subsequent crop, supports this view. A tonne of mungbean seed, containing *circa* 42-45 kg of N is currently worth $400-500 depending on quality, or *circa* $9-12 per kg of N. Even if the efficiency of utilisation of the legume N by the subsequent crop were several times that of fertiliser N, at $0.78/kg N, it would still be much cheaper to apply the latter. The contrast is even sharper when losses are considered on an area basis. The survey of commercial mungbean crops on the Darling Downs during 1989/90 showed that, had a NHI of 0.8 been uniformly obtained by all crops, between 7-47 kg/ha (mean 28 kg/ha) more plant N would have been removed as seed. At an average $400/t of seed, that represented losses of *circa* $65-440, compared with gains in soil N of $6-37. We suggest that analogous arguments apply with other grain legumes. Thus unless and until the price of fertiliser N changes relative to the value of seed, gains in soil N following the grain legume should therefore be seen as lost opportunity rather than a source of satisfaction.

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