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Cotswold Seeds Ltd
The Cotswold Business Village
Moreton in Marsh,
Gloucestershire GL56 0JQ

Legume Root Nodules

Lance Mytton of the Institute of Grassland and Environmental Research (IGER) describes how the legume system works.

Legumes and soil fertility
We do not know who first observed that legumes enrich, rather than deplete the soil. Certainly the ancient Greeks knew it. The philosopher Theophastus (370-285 BC) observes in his *Enquiry into Plants* ‘of the leguminous plants the bean best reinvigorates the ground, even it is sown thick and produces much fruit’. Cato, the earliest of the great Roman agriculturalists advises farmers in *De re rustica* to ‘sow for feed for cattle, clover, vetch, fenugreek, field bean and pulse. Sow these crops a second and third time’. He also says ‘lupins, field beans and vetches manure corn land’. These statements encapsulated the principles of sustainable rotations.

Legumes enhance soil fertility, non-legumes reduce it but agriculture had to wait a thousand years to understand the reasons for this. When, in the late seventeenth century, the fledgling arts of alchemy eventually matured into the science of chemistry the tools of modern science began to reveal the secrets of plant nutrition. Nitrogen (N), phosphorus (P) and potash (K) were identified as major nutrients essential for plant growth. The soil was shown to be the source of P and K but dispute raged through most of the nineteenth century on whether plants could absorb nitrogen from the air or had to extract it as soluble compounds from the soil. The confusion arose because it was clear that some plants acquired more nitrogen than could be accounted for in the soil.

In the 1881 the pre-eminent German agriculturalist, Schultz-Lupitz, known as the ‘father of green manuring’ called non-leguminous plants ‘Stickstofffresser’ or nitrogen consumers, and the leguminous plants ‘stickstoffsammler’ or nitrogen accumulators. Two important facts were now revealed: firstly, plants needed more nitrogen than any other soil nutrient and secondly, legumes were in some way able to accumulate large amounts of this vital nutrient. The mystery was finally unravelled in 1886 by another German scientist, Hellreigel. He proved beyond doubt that the legume root-nodules were responsible for converting nitrogen gas in the air into soluble nitrogenous compounds and that leguminous plants differed in this respect from all other crops. We now know that this marvellous piece of natural chemistry is done by a unique symbiotic association between leguminous plants and a soil bacterium called

Rhizobium.

Legume root-nodules, nitrogen fixation and Rhizobium
Soluble nitrogen is one of the largest and commonest soil nutrient deficiencies. The overwhelming importance of nitrogen to agricultural production is reflected in annual fertiliser use statistics. Yet the supply of nitrogen for plants presents a paradox. The air contains vast volumes of nitrogen gas but green plants cannot use this directly. Nitrogen must first be chemically combined with other elements before plants can exploit it for growth. Microbes are the only living organisms that can make this transformation naturally and the most important of these is Rhizobium. This common soil bacterium enters the roots of legumes where it stimulates the plant to form nodules. Inside the nodule the plant switches on genes in the Rhizobium that enable it to convert nitrogen gas into nitrogenenous compounds. This process is called nitrogen fixation. The plant and the bacteria live in symbiotic harmony. The plant supplies Rhizobium with sugars and Rhizobium gives the plant soluble nitrogen. Until the early years of this century this was by far the most important source of nitrogen for agriculture. This changed when, in 1909, Fritz Harber discovered a chemical process for synthesising ammonia, which Carl Bosch subsequently developed into an industrial process. This opened the way for commercial production of nitrogen fertilisers. As fertiliser use increased, legumes and their place in rotational agriculture declined. Legumes, however, could still supply more than enough nitrogen for most systems if they were called upon to do so.

How much nitrogen can a legume crop fix?
It is difficult to generalise but a good crop will get somewhere between 70% and 90% of its nitrogen from the air. The amount fixed will relate directly to the total amount of plant material. Here at IGER we have harvested over 12 tonnes per annum of Lucerne dry matter averaging 3.5% N, at least 75% of which was derived from fixation. So this crop had fixed over 300kg of nitrogen per hectare. We have measured even larger inputs from carefully managed Field Bean crops. The best crops in the best years have exceeded 400kg nitrogen fixed per hectare. Clover can fix well over 200kg nitrogen per hectare. The extent of soil enrichment depends on how the crop is used. Some nitrogen leaks directly from the legume roots but this is only a small fraction of the total. Most nitrogen comes through re-cycling. Roots and nodules release their nitrogen through decay but most of the nitrogen is in the plant tops. If the crop is grazed then the bulk of this nitrogen is also returned to the soil in dung and urine. Nitrogen in harvested crops will only recycle if animal or plant residues derived from them are efficiently composted and returned to the soil.

The characteristics of good root nodules
Farmers and growers are well aware of the value of good seed produced from high quality cultivars and this awareness is reflected in the current high levels of commercial investment in plant breeding and in seed production. However, no matter how good the cultivar or the seed, the productivity of a legume crop

depends on the effectiveness of the Rhizobium population in the soil. Well-nodulated plants are essential to good yield. Good nodulation generally occurs early in the development of the seedling and nodules are therefore present high up on the root. The best ones are relatively large and pink. The colour comes from haemoglobin which us necessary for nitrogen fixation. Numerous small white nodules are indicative of a poor symbiosis. Complete absence of nodules obviously suggests major problems.

Generally speaking most of our soils contain large Rhizobium populations which readily nodulate common legumes such as peas, beans and clovers but there are situations in which the production of well-nodulated plants can be difficult. Some crops need different Rhizobium species which may not be present in all soils. For example, the rhizobia which nodulate Lucerne are often absent from UK soils. Alternatively, the soil may contain strains of rhizobia the fix little nitrogen. Large plants are produced by a good Rhizobium strain with nodules clustered on the root crown. A poorer strain produces smaller plants with nodules lower down the root. The difference in growth reflects the different amounts of nitrogen fixed by these strains. Such problems can generally be overcome by mixing specially selected Rhizobium cultures in with the seed at sowing. This seed treatment is called inoculation. Other factors which can also inhibit nodulation are moisture stress, low soil pH and trace element deficiencies. Large amounts of soluble nitrogen in the soil will also prevent nodulation.

What makes a good inoculant?

A good inoculant contains two basic components, firstly a dense Rhizobium population capable of producing numerous nodules which fix plenty of nitrogen. Secondly, an inert medium which allows the Rhizobium to be packaged and distributed, which gives the product a good shelf-life and which maintains cell viability when the inoculant is mixed with seed.

The ultimate test of any inoculum is whether it produces an economic response in the field. IGER has been investigating the legume-Rhizobium symbiosis for many years. Research shows that the native Rhizobium populations in UK soils frequently fix significantly less nitrogen than plants need. It is possible to ‘breed’ strains which fix more nitrogen but they often fail in the field because they do not compete with the native strains or they do not survive in sufficient numbers to have much impact on productivity. As a result of recent Government sponsored research new strains of clover inoculants are now available which are capable of improving nitrogen fixation over a wider range of environments than was previously possible. Field trials have demonstrated improvements in nitrogen fixation of up to 40% at some locations. These inoculants can also be incorporated into commercially pelleted seed. This relieves the grower of the messy task of mixing inoculant with the seed before sowing.

Inoculation is not a panacea for poor legume growth and there are many more locations where the Rhizobium populations fix plenty of nitrogen. However, there are also a surprising number of locations where inoculation improves both establishment and yield. Where legume yields are disappointing or where they have not been grown previously it may be prudent to incur the small additional expense of using inoculants rather than risk a poor crop.

Lance Mytton of the Institute of Grassland and Environmental Research (IGER)

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