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NITROGEN FIXATION FACT SHEET

GRDC Grains Research & Development Corporation
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SOUTHERN AND WESTERN REGIONS

NITROGEN FIXATION OF CROP LEGUMES: BASIC PRINCIPLES AND PRACTICAL MANAGEMENT

Nitrogen fixation by crop legumes reduces the need for fertiliser nitrogen (N) and emissions of nitrous oxide. Benefits from legumes can be maximised by using high-yielding legume varieties that are not constrained by poor management, insects, disease, weeds or nutrient deficiencies.

KEY POINTS

- Growing crop legumes in rotation with cereals substantially reduces the need for fertiliser N inputs, often by 40 to 80kg N/ha, and improves productivity.
- Crop legumes fix about 100kg N/ha on average. Nitrogen fixation is suppressed by soil nitrate.
- An estimated 167,000 tonnes of N with a nominal value of $270 million was fixed by crop legumes in 2012.
- Adequate nodulation is important.

Lupins (left) and field peas (right) contribute significant amounts of soil N through N_2 fixation.

Growing legumes as ley pastures or rotation crops helps growers spread risk and manage disease, weeds and pests.

Oilseed legumes (soybeans and peanuts) and many pulses are high-value crops in their own right.

The ability of legumes to form a mutually beneficial (symbiotic) association with rhizobia (a soil bacteria) and fix atmospheric nitrogen gas (N_2) makes them self-sufficient in nitrogen (N), enabling them to grow in almost any soil without inputs of fertiliser N.

Legumes also supply N to the cropping system, with mineral N, released from legume residues as they decompose, taken up by following crops.

The value of legumes in agricultural systems is strongly influenced by how well they grow and fix N_2. High grain and

Legume trends

Crop legumes – pulse, feed and oilseed crops – were grown on approximately 1.75 million hectares across Australia's 25,000 grain farms in 2012.

Narrow-leafed lupin was the most widely grown crop legume for many years but in 2012 the area of lupins fell to 450,000ha and chickpeas were the most widely grown crop legume. The total area of chickpeas nationwide was 565,000ha, with about 80 per cent of that area in the GRDC's northern region (northern NSW and Queensland).

The popularity of chickpeas in the northern region is not surprising. They are a high-value crop ($400 to $600 per tonne), are well adapted to the neutral to alkaline clay soils typical of the region and have proved their value as a component of northern wheat, barley and sorghum-dominant production systems (see Useful Resouces).

biomass yields mean high economic returns and potentially more N added to the system via N-rich legume residues. Benefits are greater in soils low in plant-available mineral N because nodulation and N_2 fixation are suppressed by high levels of available soil N.

Amounts of N

Nitrogen fixation by crop legumes has now been estimated in many studies. Average amounts of N fixed range from 60 kilograms N per hectare for lentils to 130kg N/ha for lupins (see Table 2, page 3).

Australia's two major crop legumes, lupins and chickpeas, together fixed close to 100,000 tonnes of N in 2012, with another 70,000t fixed by other crop legumes.

In terms of fertiliser N equivalence, the 1.74 million hectares of crop legumes grown in 2012 are estimated to have fixed a total of 167,000t of N, which can be valued at $270 million. This is based on 167,000t of N at $1300 per tonne (cost of fertiliser N) and 80 per cent efficiency of fertiliser N to plant-available N (see Table 2).

TABLE 1 Terms used to describe legume N_2 fixation and N-cycling in farming systems.

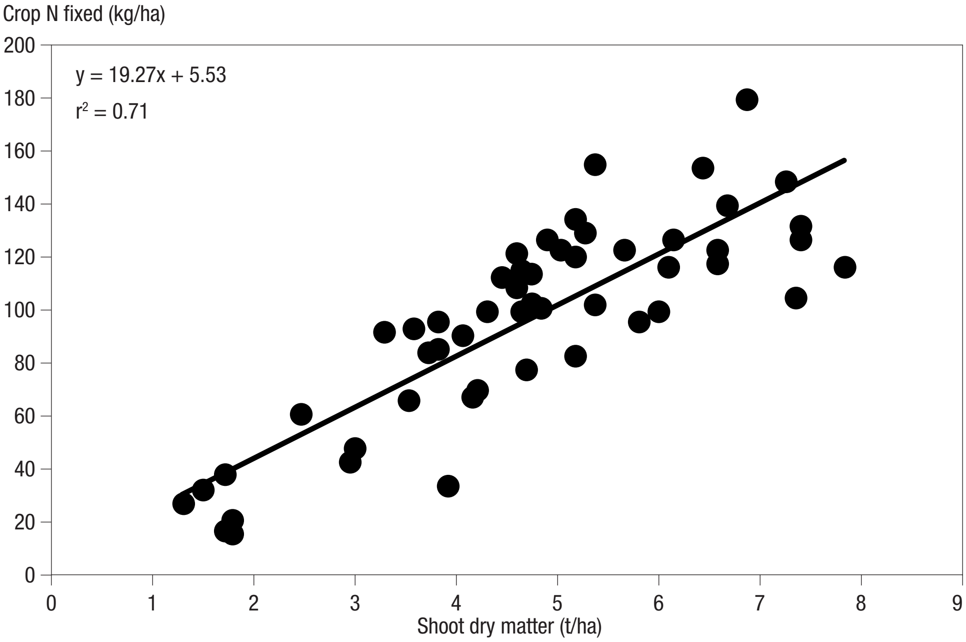
Term	Meaning
N_2 fixation	The reduction of atmospheric nitrogen gas to ammonia (NH_3). Nitrogen fixation in legumes is a biological process in which root nodule bacteria (rhizobia) fix N_2 via the enzyme nitrogenase.
Total crop N fixed	The total contribution of N_2 fixation to legume biomass, including above-ground vegetation and below-ground roots and nodules. In legumes, 30 to 50 per cent of total crop N is in the below-ground portion of the plant.
Crop N balance	The difference between N inputs and N outputs. N inputs are N_2 fixation and fertiliser N (if applied). Outputs are the N in harvested grain or hay/fodder plus N lost through volatilisation and leaching.
Nitrate-N benefit	The extra nitrate N available after a legume; best described as the difference between soil nitrate N when the legume was sown and nitrate N at sowing of the following crop.

Pasture legumes

Pasture legumes, mostly annual and perennial clovers and medics, provide most of the N_2 fixation in Australia's farming and grazing systems, with the 1.7 million hectares of crop legumes dwarfed by more than 20 million hectares of pasture containing legumes. The area of legume pasture could be as high as 50 million hectares, depending on the definition used.

This lack of definition, plus the lack of data on legume biomass produced each year, makes it almost impossible to accurately define how much N is fixed by legume-based pastures Australia-wide, but a ballpark figure would be 1.7 to 2.5 million tonnes of N annually.

FIGURE 1 Increasing legume productivity increases N_2 fixation for faba beans.



This graph shows the relationship between shoot dry matter and N_2 fixation for faba beans.

SOURCE: NSW DPI LONG-TERM ROTATION TRIALS IN NORTHERN NSW

Nitrogen fixation drivers

Legumes must be well nodulated for maximum N_2 fixation and soil N benefits. In most situations, growers will need to inoculate at sowing to ensure good levels of nodulation. For guidelines on legume inoculation see Useful Resouces.

Provided nodulation is adequate, legume N_2 fixation is strongly and positively linked to productivity, and suppressed by soil nitrate.

The faba bean data in Figure 1 clearly shows how the amount of N fixed increases with the productivity of the legume. The equation of the line of best fit shows that an extra 19.3kg N/ha is fixed for every extra tonne of shoot dry matter produced. This linear relationship between legume productivity and N_2 fixation is fairly typical of all crop legumes.

Bigger legume crops also mean bigger N and yield benefits for the following cereal crop. For example, in 167 experiments conducted in Western Australia between 1974 and 2007 to examine the rotational benefit of narrow-leafed lupins and field peas for subsequent wheat crops, the greatest benefits were provided by high-yielding legume crops grown in high-rainfall areas. A simple analysis of these results suggests that a doubling of legume grain yield doubles the yield benefit in the following crop.

Management

Good management can increase legume productivity and N_2 fixation.

- Choose the most appropriate legume for the soil type and environment and varieties that are robust and produce large amounts of biomass.
- Optimise nutrient inputs such as phosphorus.

TABLE 2 Crop legume areas and estimates of N_2 fixation.

Crop	Area sown (ha)[1]	Average per cent Ndfa[2]	Average crop N fixed (kg/ha)[3]	Total crop N fixed (tonnes)[4]
Chickpeas	565,000	41	70	39,600
Lupins	450,000	75	130	58,500
Field peas	280,000	66	105	29,400
Faba beans	180,000	65	110	19,800
Lentils	165,000	60	60	9,900
Others[5]	100,000	50	100	10,000
Total	1,740,000	60	96	167,000

1 Statistical data for 2012. ABARES Crop Report, December 2012.
2 %Ndfa = % legume N derived from atmosphere, i.e. N_2 fixation. Values from nearly 500 measurements of %Ndfa. Source: Unkovich et al. 2010.
3 Calculated using data from Unkovich et al. (2010) on legume shoot DM, N and root:shoot ratios of 1:1 (chickpeas), 0.5:1 (soybeans) and 0.4:1 (remainder).
4 Calculated as legume area x average crop N fixed.
5 Others include soybeans, mung beans etc.

- Use lime to improve the pH of acid soils.
- Effectively manage weeds, disease and insects.
- Aim to maximise soil water accumulation ahead of seeding.
- Use no-tillage or reduced tillage to improve water infiltration and reduce soil moisture loss.
- Sow on time and establish the appropriate plant density.

Soil nitrate inhibits legume nodulation and N_2 fixation. At low soil nitrate levels (less than 50kg N/ha in the top metre of soil), legume N_2 fixation is generally high (see Figure 2). As soil nitrate levels increase, legume nodulation is reduced and N_2 fixation declines. At nitrate levels of more than 200kg N/ha, nodulation and N_2 fixation will be close to zero.

However, not all crop legumes are equally affected by soil nitrate levels. Faba beans, for example, are less affected by nitrate levels than crops such as chickpeas and field peas.

Aggressive cultivation, heavy use of nitrogenous fertilisers and long pre-crop fallows all increase soil nitrate levels.

Capturing the benefits

Legume N_2 fixation can significantly reduce fertiliser N costs.

Figure 3 (see page 4) shows the amounts of N available to a cereal crop after a legume and after an N-fertilised wheat crop.

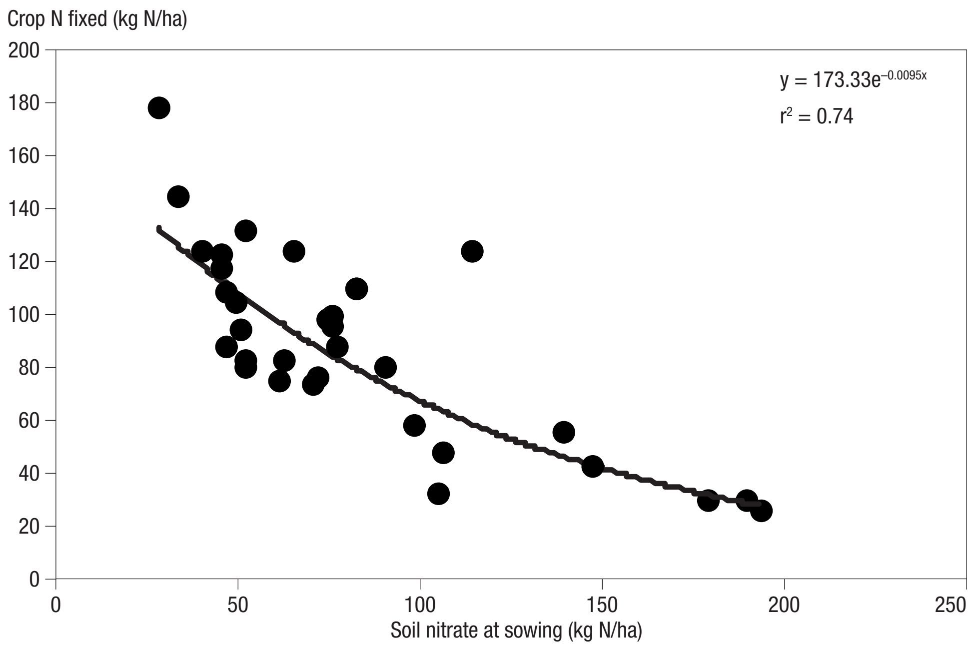
The values in Figure 3 are for a low to medium-fertility clay soil in northern New South Wales, with the legume (chickpeas) yielding 2t/ha and the N-fertilised wheat 3t/ha at 11 per cent grain protein. The actual values are a combination of experimental data and simulated estimates for a particular set of circumstances, but the principles are universal.

In the legume-cereal sequence, the legume crop uses most of the N_2 it fixes during the growing season (120kg N/ha out of total of 200kg N/ha), eliminating the need for fertiliser N to produce a crop. After harvest, 18kg N/ha is mineralised from the legume residues, adding to the 80kg nitrate N/ha from mineralisation of native soil organic matter and other plant-available N already in the soil.

In the cereal-cereal sequence, fertiliser N (63kg N/ha) is applied to the first cereal crop and no N is released after harvest. In fact, there is a deficit because of the high C:N ratio of the cereal stubbles, which immobilises mineral N (–21kg N/ha).

At seeding time for the following crop, there is 98kg of nitrate N/ha available after the legume, 39kg N/ha more than

FIGURE 2 Increasing soil nitrate fertility reduces N_2 fixation by legumes.



This graph shows the relationship between soil nitrate levels at sowing and N_2 fixation of chickpeas.

SOURCE: NSW DPI LONG-TERM ROTATION TRIALS IN NORTHERN NSW there is following the cereal. This is equivalent to about 50kg fertiliser N/ha (assuming 80 per cent fertiliser N ends up as nitrate N).

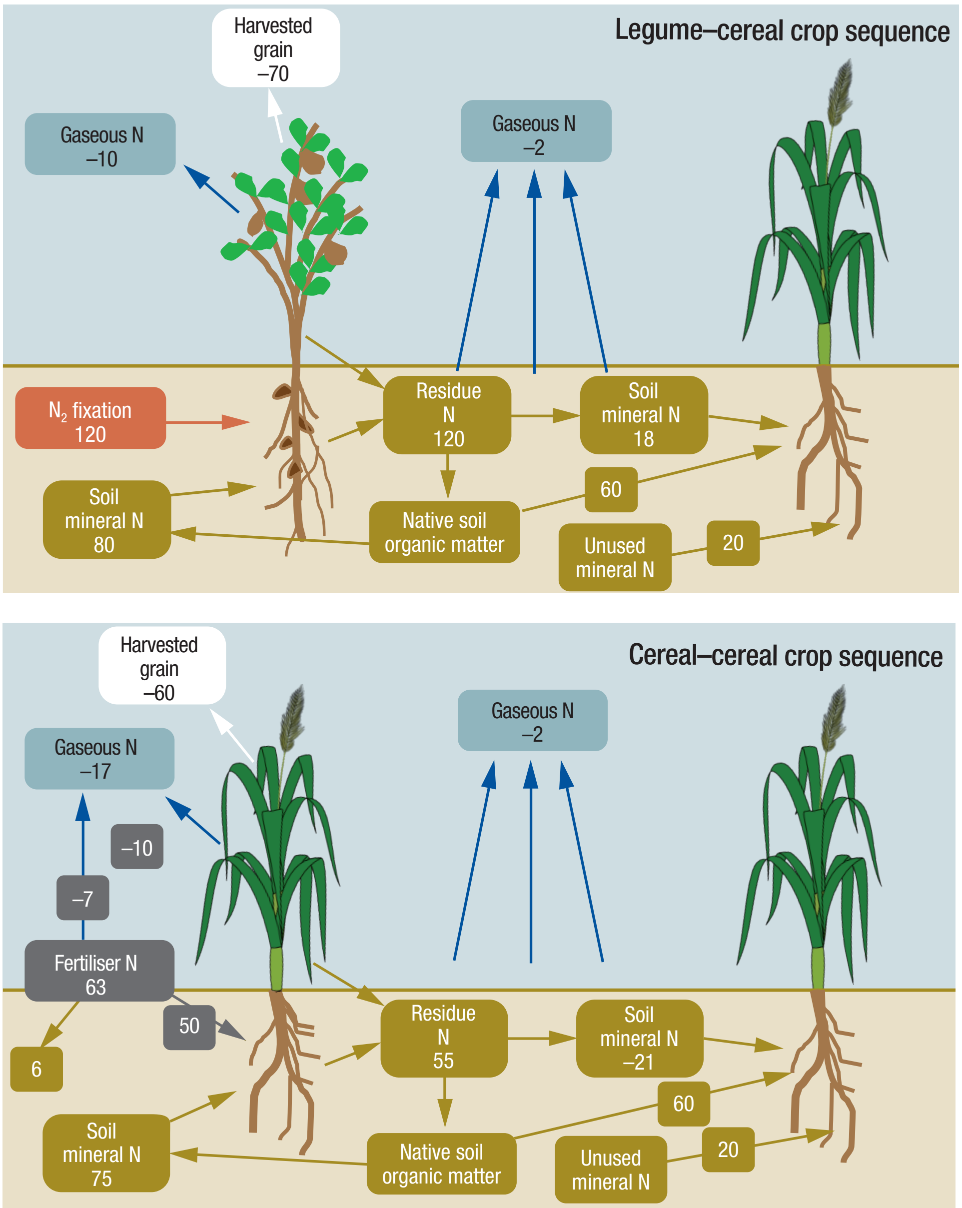
These figures show that legume N_2 fixation reduces the cost of growing a legume crop and supplies additional nitrate for the following crop.

Reduction in gaseous N losses

(12kg N/ha for legume-cereal compared with 19kg N/ha for cereal-cereal in Figure 3) is an additional benefit of reducing fertiliser N inputs by incorporating N_2 fixing legumes into farming systems.

Much of the gaseous N is emitted as nitrous oxide, a particularly potent greenhouse gas, so using a legume instead of N fertiliser to provide N also has an environmental benefit.

FIGURE 3 Contrasting N-cycling in legume–cereal and cereal–cereal crop sequence. The values for N (kg/ha) in the boxes are a combination of experimental data and simulated estimates.



USEFUL RESOURCES

Managing legume and fertiliser N for northern grains cropping. Revised 2013.
Ground Cover Direct: 1800 110 044
www.grdc.com.au/GRDC-Booklet-ManagingFertiliserN

Inoculating legumes: A practical guide
Ground Cover Direct: 1800 110 044
www.grdc.com.au/GRDC-Booklet-InoculatingLegumes

Rhizobial inoculants Fact Sheet: Harvesting the benefits of inoculating legumes
www.grdc.com.au/GRDC-FS-RhizobialInoculants

Choosing rotation crops Fact Sheet: Short-term profits, long-term payback
www.grdc.com.au/GRDC-FS-ChoosingRotationCrops-North
www.grdc.com.au/GRDC-FS-ChoosingBreakCrops-South

Rotations Fact Sheet: Good rotations – when do you need a break?
www.grdc.com.au/GRDC-FS-GoodRotations

Unkovich MJ, Baldock J, Peoples MB. 2010. Prospects and problems of simple linear models for estimating symbiotic N2 fixation by crop and pasture legumes. *Plant and Soil* 329, 75-89.

MORE INFORMATION

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