GRAIN LEGUMES IN SUSTAINABLE CROPPING SYSTEMS: A REVIEW

J.G.H. White

Plant Science Department
Lincoln College
Canterbury, New Zealand

ABSTRACT

The importance of nitrogen fixation and nitrogen addition to soils is discussed and the effects of different grain legume species and other factors on nitrogen fixation are reviewed. The addition of nitrogen to soil and its availability following crops is also discussed. The importance of grain legumes as break crops, and the positive effects of other crops on grain legumes in sustainable systems is described.

Additional Key Words: *break crop, chickpeas, crop rotation, faba beans, grain legumes, lentils, lupins, nitrogen fixation, peas,* Phaseolus *beans, sustainable systems*

INTRODUCTION

In New Zealand, grain legumes are grown in rotations with crops such as wheat, barley, grass seed, and white clover seed. In recent years there has been a strong emphasis on high input-high yield systems, although New Zealand cropping farmers have not moved as far towards capital-intensive continuous cropping systems as have farmers in countries such as the United States and Great Britain.

Concern about the sustainability of such intensive systems caused the United States Congress to pass an act in 1985 to provide authority to conduct research and education programmes into alternative farming systems, now known as LISA, or Low-Input Sustainable Agriculture. These systems seek to maintain high land productivity, but to use techniques that minimise the use of pesticides, fertilisers, and off-farm purchases through appropriate rotations, biological weed, pest, and disease control, integration of livestock with crops, and minimum tillage systems.

In 1988 a major research and extension effort commenced in the United States to provide information on such systems to reduce costs, control erosion, and abate pollution from heavy fertiliser and pesticide use and from monoculture cropping systems.

In New Zealand there is also increasing interest in lower input sustainable agricultural systems on cropping farms, particularly from the economic view, to reduce the costs of production.

At the same time there is increasing public concern about the possibility of undesirable chemical residues from farming affecting ground water and streams, or of chemical residues on the saleable produce. However, present New Zealand arable farming systems produce fewer of the problems which occur overseas although major problems of wind erosion in the 1987-89 drought are causing cropping farmers to seek improved soil management practices and greater efficiency of water use.

Lower input sustainable systems do not mean that we should return to agricultural practices of the 1940's, or that we should change to organic systems where chemicals are not used at all. Rather, low input sustainable systems require a farmer to understand more about the biological effects of a crop or management systems and how this information can be used cheaply and effectively in farm programmes, e.g., integrated pest management.

Grain legumes are of particular importance in such systems, as they are capable of fixing nitrogen or breaking cycles of diseases and pests which affect other crops.

CONTRIBUTION OF GRAIN LEGUMES TO LOW-INPUT SUSTAINABLE SYSTEMS

The main objective in growing a grain legume crop is to obtain a high net return, but in the process several positive contributions can be made by this crop to the following crops in the systems.

***Nitrogen fixation and nitrogen addition to soil*:** Most grain legume crops fix significant amounts of nitrogen symbiotically, thus obviating the need to supply fertiliser nitrogen. Some species also add sufficient nitrogen to the soil to supply part of the nitrogen needs of a following crop.

The rate of nitrogen fixation is slow during early vegetative growth, when soil mineral nitrogen sources may be sufficient for crop requirements, but increases later parallel with the crop growth rate. Maximum rates are reached during flowering and early pod fill, and may continue for some time at this level if these processes are prolonged e.g. in indeterminate cultivars. A rapid decline in nitrogen fixation coincides with decreased crop growth rate, decreased green leaf area, lodging, and the initiation of translocation of N from vegetative organs to seed (Rhodes *et al.*, 1982; Askin *et al.*, 1986; Zapata *et al.*, 1987; Jensen 1989).

Nitrogen fixation by different grain legume species : Grain legumes vary widely in their ability to fix atmospheric nitrogen due both to species differences and the field conditions under which they are grown. However, clear trends are apparent in Table 1 with lupins and faba beans fixing the highest amounts of nitrogen, followed by peas and lentils, chickpeas, and soya beans. Peas, our main grain legume have not been measured to fix more than 75 kg/ha in New Zealand (Askin, 1983). However, field peas grown under irrigation in Canada have fixed double this amount (Rennie & Dubetz, 1986), while high yielding pea crops in Denmark (5.0 t/ha) fixed a mean of 208 kg N/ha over four years of experimental work (Jensen, 1986, 1989).

There are less data available on nitrogen fixation by lentils and chickpeas than for other grain legumes. Soya beans only fix half their total plant nitrogen, while *Phaseolus* beans are generally poor at nitrogen fixation due to poor symbiosis and often a low genetic ability to fix nitrogen (Graham, 1981; Pika & Munns, 1987). Early maturing bush types are weakest, and indeterminate climbers are best.

Most *Phaseolus* beans grown for processing in New Zealand receive fertiliser nitrogen as their main source of this nutrient, and few or no nodules are found on their roots.

Table 1: Estimates of nitrogen fixed by different grain legume species.

Legume species	Amount fixed (kg/ha)	Source
Lupins	175	Rhodes (1980)
	252	Herridge (1982)
	60	Smith *et al.* (1987)
	217-225	Herridge & Doyle (1988)
	193-247	Larsen *et al.* (1989)
Faba beans	235	Day *et al.* (1979)
	216 (179-252)	Rennie & Dubetz (1986)
	80	Smith *et al.* (1987)
	209	Zapata *et al.* (1987)
	160	Bremer *et al.* (1988)
	230	Jung *et al.* (1989)
Peas	17-69	Mahler *et al.* (1979)
	65	Rhodes (1980)
	75	Askin (1983)
	185 (174-196)	Rennie & Dubetz (1986)
	60-80	Smith *et al.* (1987)
	105	Bremer *et al.* (1988)
	208	Jensen (1989)
Lentils	10-129	ICARDA (1983)
	176 (162-190)	Rennie & Dubetz (1986)
	80	Smith *et al.* (1987)
	75	Bremer *et al.* (1988)
Chickpeas	14-120	ICARDA (1983)
	54 (24-84)	Rennie & Dubetz (1986)
	10	Smith *et al.* (1987)
Soya beans	75-90 (50 % of total N)	LaRue & Patterson (1981)
***Phaseolus* beans**		
	24-65 (37-68 % of total N)	Ruschel *et al.* (1982)
	40-125 (50 %)	Rennie & Kemp (1983)
	20-115	Graham & Temple (1984)
White clover seed		
	220	Whelan & White (1985)

For all grain legumes except for lupins and faba beans, these estimates of nitrogen fixation are on average much lower than those reported for white clover in a grazed pasture (Hoglund & Brock, 1978) or grown as a seed crop (Whelan & White, 1985).

Factors affecting the level of nitrogen fixed within a species: The circumstances where grain legumes are likely to fix high levels of symbiotic N are well known, and it is important to create these conditions in the field wherever possible.

A fundamental requirement is the presence of effective strains of *Rhizobium* and for a number of legumes in New Zealand it is necessary to add these as inoculum on seed, e.g., soya bean, and chickpeas. Although *Phaseolus* beans are not inoculated in N.Z. there is now a realisation that both strains of rhizobia and cultivars of beans need to be selected with improved *Rhizobium* strain-host symbiosis and increased nitrogen fixing ability (Graham, 1981) so that reliance on fertiliser nitrogen can be reduced or eliminated.

Grain legumes will use soil mineral nitrogen or fertiliser nitrogen if it is available, in preference to fixing their own. Consequently, fixation of N is likely to be greatest when the legume follows a soil N depleting crop such as wheat, barley, or ryegrass seed, and lowest when following pasture or a clover seed crop. In fact, where soil mineral N levels are very high the grain legume may obtain almost all its requirements from the soil and virtually none from fixation, resulting in a net reduction in total soil nitrogen. Faba beans are more tolerant of soil mineral N than other species and will still fix large quantities of N when mineral N is present (Roughley *et al.*, 1983). This is because faba beans have a lower N fertiliser utilisation efficiency (Chalifour & Nelson, 1988) together with a high potential to accumulate nitrogen.

The period over which a crop grows also affects the amount of nitrogen fixed. Autumn or winter sown legumes generally fix more N than spring-sown crops because they are growing for longer, and often in moister soil conditions which are better suited to optimum N fixation (Askin, *et al.*, 1986; Keatinge, *et al.*, 1988; Wery, *et al.*, 1988). Peas harvested for vining fix less than the same cultivar when taken for seed because the crop is taken while fixation is still continuing (Askin, 1983).

The nutrition, soil physical conditions, and moisture regime of the crop also influences N fixation, and crops that are adequately fertilised, and with good soil aeration and adequate soil moisture will fix nitrogen at a higher level or over a longer period. Canadian work has shown that nitrogen fixation by lentils, peas and faba beans declined by an average of 5.3, 7.6 and 10.5 kg N/ha for every 10 mm reduction in moisture use. Under drought-stressed conditions peas and lentils were more efficient in nitrogen fixation than faba beans (Bremer, *et al.*, 1988).

Genetic differences exist among cultivars in their ability to fix N. Generally, indeterminate cultivars fix more N than those with a determinate growth habit, e.g., climbing beans (Pika & Munns, 1987), Austrian winter pea (Smith *et al.*, 1987). In New Zealand, Askin, *et al.* (1986) found that field peas, particularly Maple peas, had higher rates of nitrogen fixation than garden peas. They suggest that this was genetic in origin and that there may be scope in plant breeding to exploit these differences.

Addition of nitrogen to the soil and availability to the following crop: Grain legumes generally leave the soil in a higher state of soil fertility than cereal crops, particularly in terms of the amount of soil mineral nitrogen available to following crops (Rhodes, 1980; Askin, *et al.*, 1986; Jensen, 1989) (Table 2). However, there are large differences in the amounts made available by grain legume species or by different management systems.

Table 2: Nitrogen uptake in winter ryegrass (Rhodes, 1980) and winter barley (Jensen, 1989) succeeding peas or a cereal.

Preceding crop	Nitrogen uptake (kg N/ha) Winter ryegrass	Winter barley
Peas	66	89
Cereal	36	43

As grain legumes mature there is a rapid translocation of nitrogen from stems, leaves, and pods into the seed. Large amounts of nitrogen are removed when this seed is harvested, in many cases equalling or exceeding all of the N which is fixed (Tables 2, 3). In peas, lentils and chickpeas, all that can be expected is that the amount of N fixed is equal to that removed in the grain (Table 4). Where nitrogen fixation is suboptimal in these crops, the balance is obtained from soil mineral N which will deplete total soil nitrogen. Crops of soya beans and *Phaseolus* beans will almost always result in a net loss of soil nitrogen. It is only in lupins and faba beans where fixation normally exceeds the amount removed in seed (Table 5).

Table 3: Nitrogen removed in seed from an average grain legume crop.

Species	Yield (t/ha)	N in grain (%)	Total N removed (kg/ha)
Dry peas	3.5	3.5	123
Green peas (vined)	6.0	5.0 (on DM basis)	50
Lentils	2.0	4.0	80
Lupins	3.5	5.5	193
Faba beans	4.0	4.0	160

Lupins are widely used in crop rotations in Australia as a significant and sometimes the only sources of nitrogen for following wheat crops. Increases in yields of cereals grown after lupins range from 30 - 100 % when compared to wheat monoculture (Rowland, *et al.*, 1986).

The total amount of nitrogen returned in crop residues and roots is generally much greater than the amount taken up by an immediate following crop (Table 5). In many grain legumes the nitrogen harvest index (NHI), i.e. the proportion of total above-ground N which occurs in the seed, is very high, of the order of 80 - 90 % (Askin, *et al.*, 1986; Larsen, *et al.*, 1989). Crop residues may therefore only contribute a small amount of nitrogen when returned to the soil. In addition, their nitrogen content may be low (e.g. peas 1.28 % N, (Jensen, 1989)) resulting in little net mineralisation for many months. The nitrogen from these residues (< 1.3 - 1.5 % N) is not readily available for a succeeding crop but will contribute to the more stable pools of soil organic matter, thus benefiting future crops in the rotation.

It is the roots and root nodules of grain legumes which are likely to be the greatest source of N for following crops (Dyke & Prew, 1983). These plant parts are higher in nitrogen content (e.g. peas, 2.5 % N, (Jensen, 1989)) and decompose quickly, releasing mineral nitrogen in a few weeks (Askin, 1985; Jensen, 1989).

Table 4: Nitrogen balance for a pea crop (Jensen, 1989).

Parameter	kg N/ha (4 year mean)
Total crop N	283
N_2 fixation	208 (73 %)
N from soil	75
N in seed	217
N in straw (returned)	66
Soil N gain or loss	-9

Table 5: Fixed nitrogen supplied by a grain legume to a following crop.

Species	Amount supplied (kg/ha)	Source
Lupins		
	25	Rhodes (1980)
	80	Herridge (1982)
	41	Reeves *et al.* (1984)
	37	Rowlands *et al.* (1988)
	37	Doyle *et al.* (1988)
Faba beans		
	44-50	Dyke & Prew (1983)
	18	Jung *et al.* (1989)
Green manure peas		
	26	Mahler & Auld (1989)
Grazed lupins		
	76	McKenzie & Hill (1984)

Green tops of legumes breakdown similarly. For example, vining peas have a low NHI of 50 % or less because they are harvested before translocation of N to the seed is completed. When returned to the soil the green vines are a significant source of nitrogen and are mineralised rapidly.

Grain legumes may be grown as a forage for animals (Janson & Knight, 1980; Janson, 1984; McKenzie & Hill, 1984) or as a green manure, and can add large amounts of nitrogen to the soil. In either case, lupins or faba beans are likely to fix more nitrogen and add greater amounts to the soil than other grain legumes. In higher fertility soils the proportion of nitrogen derived from fixation may also be enhanced by growing the forage or green manure legume with a non-leguminous companion crop such as ryegrass or oats to utilise soil mineral nitrogen (Danso *et al.*, 1987).

Because a significant proportion of nitrogen added to the soil by grain legumes is mineralised in the few weeks following harvest, it is important to avoid losses of this nitrogen from the plant-soil system. The principal losses are through leaching of nitrate, and denitrification (Jensen, 1989). If no crop is established in the autumn and the land is left fallow until the following spring then most of this nitrogen may be lost. Autumn-winter sowings of ryegrass seed, winter wheat or winter barley will minimise these losses, but if these are not planned, then a nitrogen catch crop of greenfeed ryegrass or cereal should be used between the harvested grain legume and the spring crop (Table 6).

Table 6: The effect of white mustard as a N catch crop on grain yield and nitrogen uptake of spring barley when following peas (Jensen, 1989).

N catch crop	Barley grain yield (t/ha)	Nitrogen uptake (kg N/ha)
-	4.7	87
+	5.3	104

Break crop: Grain legumes are highly regarded as an important and beneficial break crop. They are particularly valuable in reducing disease and pest infestation of following cereals because the legume is not a host of most cereal pathogens. For example, take-all (*Gaeumannomyces graminis*) in wheat can be greatly reduced by a previous legume grain crop (Reeves, *et al.*, 1984; Gardner & McDonald, 1988; Rowlands, *et al.*, 1988), while other diseases such as eyespot (*Pseudocercosporella*) are also minimised. In Australia, a 14 % increase in wheat yield has been measured where wheat was preceded by lupins, due to reduced incidence of take-all (Gardner & McDonald, 1988).

Certain problem grass weeds in cereals can also be controlled by growing a legume in rotation. Ripgut brome (*Bromus rigidus*) is a problem weed in wheat crops in both western Oregon in the United States, and in southern Australia and cannot easily be controlled with chemicals. However, the seed survives for less than 12 months in soil, (Gleichsner & Appleby, 1989), and by rotating wheat with peas, excellent long-term control of the brome has been obtained by the use of herbicides on the pea crop (Appleby, pers. com.).

Stubbles for grazing: Compared to cereal stubbles, grain legumes stubbles are of relatively high value for grazing with livestock after harvest. This is not only the stems and leaves, but includes any unharvested grain.V ining pea stubbles are particularly valuable as the vines are relatively high in protein compared to threshed peas.

POSITIVE EFFECTS OF OTHER CROPS ON GRAIN LEGUMES

A number of other crops, if grown before a grain legume crop, can have a positive effect on grain yield or nitrogen fixation of the legume.

Reduced disease incidence: Continuous grain legume cropping is rarely practiced because of fungal diseases, particularly those that are soil borne, which can increase rapidly and cause major reduction in yield.

The root rot complex caused by the organisms *Aphanomyces euteiches* and *Fusarium solani* is economically very important in both peas and lentils. No disease resistant genotypes have yet been developed commercially (Davis & Shehata, 1986; J. Kraft, pers. comm., 1989) and control of these and other diseases such as *Ascochyta* is largely by maintaining at least a five year gap between successive pea and lentil crops.

In fact, all grain legume species should be regarded as the same crop when planning cropping sequences in order to minimise heavy loss from soil-borne pathogens (Salt & Delaney, 1986).

Recently Chan & Close (1987), at Lincoln, measured significant reductions in the incidence of *Aphanomyces* root rot in peas where cruciferous crops such as rape, mustard, fodder radish, and kale preceded the peas. Even where only roots were incorporated into the soil, disease severity was reduced by 41 %. The cause of the reduction in disease is likely to be due to sulphur-containing volatiles such as isothiocyanates which are produced on decomposition of the brassica crop and which are known to be extremely toxic to *Aphanomyces*: At the University of Idaho, in the United States, Dr D.L. Auld is breeding rapes with high isothiocyanate content which may reduce nematode as well as *Aphanomyces* levels in soil. Using brassica crops before peas or lentils in cropping rotation is thus an important way of reducing the incidence of *Aphanomyces* root rot.

Weed control: Compared to cereals, most grain legumes are poor competitors with weeds and yields are generally increased by good chemical weed control. Because the worst weeds are broadleafed, cost of control can sometimes be high, e.g., Californian thistle. The incidence of such weeds in grain legumes can be kept low by growing alternative crops such as cereals in a rotation, and using wide-spectrum cheaper chemicals for their control in those crops.

Soil physical condition: Most grain legumes suffer reduced yields if soils are compacted and poorly aerated. Vining pea yields can be reduced up to 70 % by soil compaction, which reduces seedling emergence, root growth, and water extraction of the peas (Dawkins & McGowan, 1986). Good soil structure produced by growing ryegrass seed crops or pasture before a grain legume will reduce these problems, particularly if combined with minimal and timely cultivation practices to conserve this good structure.

CONCLUSIONS

The practice of lower input sustainable agricultural systems requires a good understanding by the farmer of the effects of one crop upon another and how beneficial effects may be managed to greatest advantage but at low cost. This review summarises our present knowledge of the positive effects of grain legumes in cropping systems, particularly the nitrogen economy, and the benefits of previous crops on grain legumes. These approaches are not new, but if they are practiced in an integrated way, they will reduce the need for nitrogen fertiliser and pesticides, thus reducing costs of production, while maintaining or even increasing the yield of grain legumes.

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