THE EFFECT OF GRAIN LEGUMES ON SOIL FERTILITY

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ABSTRACT

To investigate the effect of grain legumes on subsequent crop yields, two trials were conducted on a Templeton silt loam soil at Lincoln College, using either Tama ryegrass or wheat as indicators of fertility change. On a low fertility site, a total of three harvests of Tama ryegrass yielded after the following crops: lupins, 3300; fallow, 2810; garden peas, 2670; field peas, 2650; and barley, 1860 kg DM/ha. Wheat yields after the same crops followed a similar trend with yields after barley 1100 kg/ha less than after legumes.

On a higher fertility site, one harvest of Tama ryegrass sown after field peas yielded 2950, lupins, 2600 and wheat, 2330 kg DM/ha. Greater soil nitrogen removal by cereals compared with grain legumes was responsible for the reduction in subsequent ryegrass and wheat yields. The use of grain legumes to maintain soil fertility in intensive cropping systems is discussed.

Additional Key Words: Rotation, nitrogen, Leguminosae: Lupinus angustifolius, lupin; Pisum sativum, pea; translocation, Gramineae: Triticum aestivum, wheat; Hordeum vulgare, barley; Lolium multiflorum, ryegrass

INTRODUCTION

By far the most important grain legume grown in New Zealand is peas *(Pisum sativum)* although small areas of other grain legumes such as lupins *(Lupinus* sp.*)* and tick beans *(Vicia faba)* are also grown. Over three quarters of these grain legumes are grown in Canterbury, where they are used in rotations with wheat, barley and herbage seeds. Research in New Zealand has concentrated on agronomic aspects to improve the yield of these crops but little attention has been given to their effect on soil fertility and subsequent crop yield. Douglas *et al.* (1972) found that maize grown in rotation with soybean gave higher yields than continuous maize. The beneficial effect of autumn-sown, legume forage crops on subsequent cereal yield has been reported by Janson and Knight (1980) and Piggot and Cooper (1980). Overseas work has shown that grain legumes can improve soil physical conditions (Sharma and Singh, 1970), soil nitrogen status (Wild, 1972) and subsequent crop yield (Ellington *et al.*, 1979; Doyle and Herridge, 1980; Russell, 1980; Ahlawat *et al.*, 1981).

With the development of intensive cropping systems and a reduction in the frequency of pasture in crop rotations, greater reliance may be placed on grain legumes to increase soil nitrogen levels. The work reported in this paper was initiated to supply information on the effects of grain legumes on soil fertility under Canterbury conditions.

MATERIALS AND METHODS

Trial 1

The trial was conducted on a Templeton silt loam at Lincoln College, Canterbury, where soil fertility had been depleted by cropping and large yield responses in wheat had been recorded following application of fertiliser nitrogen (Dougherty *et al.*, 1979). A randomised block design, with four replicates was used. Plot size was 15 x 12 m. Treatments were: field peas cv. Huka, garden peas cv. Puke, lupins cv. Uniharvest, barley cv. Manapou and fallow, each at two levels of nitrogen (0 and 80 kg/ha).

Seed and serpentine reverted superphosphate at 300 kg/ha were sown into a cultivated seedbed on September 24, 1978. Sowing rates for Huka and Puke peas, lupins and barley were 170, 310, 250, and 160 kg/ha respectively. Lupin seed was slurry inoculated and barley and pea seed treated with Orthocide fungicide.

Nitrogen as calcium ammonium nitrate was applied to appropriate plots on November 14, 1978. Atrazine at 1.0 kg/ha was applied pre-emergence to lupins, and terbutryn at 0.4 kg/ha to peas at the five to six node stage. Dicamba plus MPCA at 0.1 and 0.6 kg/ha respectively was applied to barley at tillering. Diquat at 0.8 kg/ha and later glyphosate at 1.4 kg/ha were applied to fallow plots.

Puke peas were harvested at the green pea stage and other crops at maturity. Seed yield from a 5.4 m^2 quadrat was obtained before plots were header harvested. Barley and lupin residues above header height, and all pea residues were removed.

Ryegrass

Half of each plot was cultivated and on March 10, 1979, 'Grasslands Tama' ryegrass was sown at 40 kg/ha with superphosphate at 500 kg/ha. Nitrogen as ammonium sulphate at 0, 25, 50, 100 and 200 kg/ha was applied on April 22 to sub-plots on the fallow treatment. Three permanent sampling areas, each $1m^2$, were randomly located on sub-plots and on all other non-fallow plots. Tama ryegrass was harvested for DM yield on June 14 and regrowth cut on August 31 and again on September 26, 1979.

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Wheat

The remaining area of plots not sown with ryegrass was cultivated and superphosphate at 250 kg/ha applied prior to sowing wheat cv. Kopara at 150 kg/ha on July 27, 1979. On September 24, wheat was sprayed for annual weeds with terbutryn at 1.0 kg/ha. Wireweed was not controlled effectively and bromoxynil (0.2 kg/ha), ioxynil (0.2 kg/ha), and mecoprop (1.1 kg/ha) were applied on October 24.

At maturity, components of yield were measured from twenty heads sampled at random from $0.3m^2$. A $2.25m^2$ area was cut to ground level and seed yield determined.

Trial 2

The trial was situated on an area which had grown two wheat crops after lucerne. A randomised block design with four replicates was used. Plot size was 9 x 22 m. Treatments were: wheat cv. Oroua with nitrogen at 0 and 85 kg N/ha, field peas cv. Huka and lupins cv. Unicrop. Lime (5 t/ha) and superphosphate (400 kg/ha) were broadcast prior to drilling. Wheat at 170 kg/ha and peas and lupins at 200 kg/ha were sown into a cultivated seedbed on September 14, 1979. Nitrogen as sulphate of ammonia was applied to wheat on October 10, 1979. Bromoxynil (0.2 kg/ha), ioxynil (0.2 kg/ha) and mecoprop (1.1 kg/ha) were applied to wheat on October 26, 1979. Metribuzin (0.2 kg/ha) and methabenzthiazuron (0.7 kg/ha) were applied to peas on October 16, 1979, and chloroxuron (0.5 kg/ha) plus Citowett at 0.5% v/v to lupins on October 26, 1979.

At crop maturity, plots were header harvested and grain yield measured from two 1.5 x 22 m areas within each plot. All remaining vegetation was removed. The trial area was cultivated prior to sowing 'Grasslands Tama' ryegrass at 40 kg/ha on March 20, 1980. Ryegrass was harvested from ten 0.1 m^2 quadrats cut to ground level on August 2, 1980.

RESULTS

Trial 1

Crop yields

Barley seed yields were increased by fertiliser nitrogen but there was no significant effect on legume yields and values for the no nitrogen treatments only are presented (Table 1). Seed yield from Uniharvest lupins was higher than for Huka peas but harvest index was lower. Nitrogen harvest index was higher for lupins, and lupin seed had a higher nitrogen concentration (4.6%) compared with peas (2.9%). The green pea yield of Puke peas at a TR of 109 was 2590 kg/ha. On a dry matter basis, this was 470 kg/ha, which was considerably less than the seed yield of Huka peas at maturity. The harvest indices were also lower (Table 1).

TABLE 1: Seed yields, harvest index and nitrogen harvest index.

Crop	Seed yield (kg DM/ha)	Harvest index	Nitrogen harvest index
Huka peas	2260	0.66	0.86
Puke peas	470*	0.23	0.44
lupins	3430	0.49	0.92
barley	1410	—	—
barley + N	2380	—	—
LSD 5%	570	0.05	0.07

*Puke green pea yield 2590 kg/ha (TR = 109)

Ryegrass

Ryegrass yield after pea cultivars was similar to that for fallow but yield after Uniharvest lupins was higher (Table 2). Ryegrass production after barley was lower than after legumes or fallow particularly where no nitrogen had been applied to the barley crop. Nitrogen applied to ryegrass increased yields up to the highest rate applied (Table 3).

TABLE 2: Tama ryegrass yields (Trial 1).

Treatment	Ryegrass yield (kg DM/ha)
fallow	2810
Huka peas	2650
Puke peas	2670
lupins	3300
barley	1860
barley +N	2290
LSD 5%	400

TABLE 3: Effect of autumn applied nitrogen on Tama ryegrass yield, fallow treatment.

N applied (kg N/ha)	Ryegrass yield (kg DM/ha)
0	2810
25	3340
50	3860
100	4970
200	5960
LSD 5%	510

Wheat

Colour differences were obvious by late tillering, with plots previously sown to barley a paler green than others.

The analysis of variance of final harvest results (Table 4) incorporated single degree of freedom tests on four orthogonal comparisons, which were: cropped versus fallow; barley versus legumes; Puke versus Huka; and peas versus lupins. Total biomass and seed yields were low, with a large difference in seed yield between barley and legumes. The relatively large amount of straw present in the barley plots was reflected in the harvest index of 0.28 which was significantly different to the legumes ($P < 0.05$). Spikelets per ear were unaffected by previous treatments, with a mean of 16.5. The reductions in both ears/m^2 and 1000 grain weight had a large effect on the yield difference between barley and legumes.

TABLE 4: Wheat grain yield, components of yield and harvest index.

Previous crop	Grain yield (kg DM/ha)	Harvest index	1000 grain weight (g)	Grains/ spikelet	Ears/m²
Huka peas	2480	0.43	39.1	1.42	268
Puke peas	2660	0.43	40.6	1.60	253
lupins	2850	0.41	39.4	1.65	269
barley (no N)	1540	0.28	31.8	1.34	211
fallow	2630	0.43	39.2	1.57	259
LSD 5%	570	0.15	4.2	0.32	36
Significance of single d.f. orthogonal comparisons	barley vs legumes **	barley vs legumes *	barley vs legumes **	NS	barley vs legumes **

Trial 2
Crop yields

There was no response to nitrogen in wheat, which was severely affected by take-all *(Gaeumannomyces graminis var. tritici)*. Excellent weed control was achieved in peas but calindrinia *(Calindrinia menziesii)* and wireweed *(Polygonum aviculare)* were not controlled in the lupins, where yields were less than peas (Table 5).

Ryegrass

Tama yield after peas was greater than after wheat, but yields after lupins and wheat were similar (Table 5). There was little residual effect of nitrogen fertiliser applied to wheat.

TABLE 5: Seed and Tama ryegrass yields (Trial 2)

Treatment	Seed yield (kg/ha)	Ryegrass yield (kg DM/ha)
peas	3350	2940
lupins	1910	2600
wheat	2940	2350
wheat + N	2990	2520
LSD 5%	670	460

DISCUSSION

Peas are sensitive to poor soil aeration (Low, 1973; Wiersum, 1979), and high bulk density (Eavis and Payne, 1969; Hebblethwaite and McGowan, 1980). At the site used in trial 1, continuous cropping had caused a deterioration in soil structure, which is likely to have been responsible for the low pea yields obtained (Table 1), in comparison with those reported by Stoker (1975) and Falloon and White (1978).

Lupin yields, however, compared favourably with those reported by other workers for crops grown in Canterbury (Stoker, 1975; Lucas *et al.*, 1976; Horn and Hill, 1978). This suggests that lupins tolerate low fertility conditions better than peas, and would be more suitable for use as a break crop after successive cereal crops.

Cereal yields at both sites were low. The response to nitrogen in barley (Table 1) indicates that nitrogen deficiency limited yields in trial 1, although poor soil structure may also have been important. Take-all depressed wheat yields in trial 2 and could have reduced the effect of applied nitrogen.

The large response to nitrogen on fallow plots (Table 3) and the residual effect of nitrogen applied to barley (Table 2) indicates that ryegrass was highly responsive to nitrogen at site 1. This suggests that ryegrass yields were higher after legumes compared with barley due to differences in available nitrogen. Greater uptake of soil nitrogen by barley and removal of this nitrogen in grain and straw would have reduced subsequent nitrogen availability relative to lupins and peas and resulted in lower ryegrass yields. Similarly a reduction in the supply of nitrogen to ryegrass after wheat relative to peas would have resulted in the lower yields obtained in trial 2. The smaller difference between ryegrass yield after lupins and after wheat (Table 5) compared with that between lupins and barley (Table 2) may have been due to the removal of soil nitrogen in weeds harvested with the lupins.

In trial 1, the nitrogen stress in wheat which followed barley was first observed at late tillering and became progressively more acute. This premature leaf senescence reduced all components of yield except spikelets/ear (Table 4) and also the grain filling period, resulting in shrivelled grains. These factors resulted in the 1100 kg/ha yield difference in wheat after barley compared with wheat following legumes.

Nitrogen return from Puke and Huka peas was limited primarily to that contained in roots and nodules. Mineralised nitrogen from this source recovered by ryegrass and wheat appears to have been sufficient only to offset removal of soil nitrogen in the harvested pea grain and straw since yields after peas were similar to those on the fallow treatment. It is unlikely that the yields of subsequent crops would have been substantially higher had Huka pea residues been returned since 86% of the nitrogen present at maturity was in the seed (Table 1). Yields may have been higher with Puke pea residue return since 56% of the nitrogen at the green pea stage was contained in crop residues.

In contrast to peas, ryegrass and wheat yields were higher after lupins than after fallow. Mineralisation of nitrogen returned in roots and nodules, abscissed leaves and other crop residues appears to have compensated for soil nitrogen removal via lupin seed and could account for the higher yields.

Although these trials have shown that grain legumes, when harvested at maturity, can have a beneficial effect on subsequent crop yields in comparison with cereals, their use as fertility building crops in intensive cropping systems appears limited. Total soil nitrogen can be increased via grain legumes only where fixed nitrogen added to the soil via roots and nodules, leaf fall and crop residues exceeds losses of soil nitrogen through uptake and removal in the seed. This may occur under low soil fertility conditions where nitrogen fixation supplies most of the crop nitrogen requirement. However, the net increase in total soil nitrogen, particularly in legume crops with a high nitrogen harvest index, is unlikely to be sufficient to offset nitrogen uptake and removal in subsequent non-legume grain crops. Under high fertility conditions, where soil nitrogen uptake can account for a major proportion of legume nitrogen (McAuliffe *et al.*, 1958; Allos and Bartholomew, 1959; Gibson, 1976), the removal of soil derived nitrogen in seed may be greater than the return of fixed nitrogen, resulting in a net reduction of total soil nitrogen.

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