The dry matter yield of Italian ryegrass grown after grain legumes in a crop rotation

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Abstract

The potential of grain legumes to maintain soil fertility and soil characteristics was determined in a spring sown trial during the 1996/97 growing season at Lincoln University, Canterbury, New Zealand (43°S) on a Wakanui silt loam soil. The area had previously been fallow. Plots were sown to barley (*Hordeum vulgare* L. cv. Liberty), lentils (*Lens culinaris* Medik. cv. Titore), narrow leafed lupins (*Lupinus angustifolius* L. cv. Fest), peas (*Pisum sativum* L. cv. Allure), or were left in fallow. At crop maturity, plots which contained plants either had all above ground vegetation removed, had seed only removed, or had no vegetation removed and residual vegetation was soil incorporated. The fallow and barley plots (all vegetation removed) were top-dressed with 0, 50, 100, 150 or 200 kg/ha of N as urea. The trial area was sown to a winter active cultivar of Italian ryegrass (*Lolium multiflorum* Lam. cv. Grasslands Moata). The ryegrass plots were sampled for dry matter (DM) accumulation at 190 days after sowing. Ex-lupin plots (where all lupin DM was soil incorporated) yielded considerably more ryegrass DM (19.2 t/ha) than fallow plots which had received 200 kg N/ha (16.3 t/ha). Even when only seed was removed, ex-lupin plots still produced as much ryegrass DM as fallow plots with 200 kg N/ha. Ex-pea plots gave a ryegrass DM yield (13.8 t/ha) equivalent to that from 150 kg N/ha. After the removal of all above ground DM, all ex-legume plots still gave more ryegrass DM than fallow plots, and considerably more than barley plots without nitrogen. The results of this experiment confirm that it is possible to maintain soil fertility and to improve soil physical characteristics by growing grain legumes in cropping systems.

Additional key words: *barley, crop rotation, Italian ryegrass, lentil, lupin, pea, soil nitrogen, residual effects, soil fertility,* Hordeum vulgare, Lens culinaris, Lolium multiflorum, Lupinus angustifolius, Pisum sativum.

Introduction

Inclusion of grain legumes in cropping systems often has a beneficial effect on the growth and/or yield of succeeding crops, not only by providing nitrogen (N), but through non-N effects such as reduced soil erosion, control of weeds, insects, or pathogens, or improved soil structure and soil moisture relations (Reeves *et al.*, 1984; Rowland *et al.*, 1988, 1994). Crop residue management is a key consideration when attempting to optimize fertility in sustainable agriculture and proper recycling is important to maintain or improve soil fertility (Reganold *et al.*, 1990). Major factors affecting the impact of crop residues on nutrient availability include the species, chemical composition of the residue (e.g., C:N ratio), residue placement, and the amount of residue and seeds (Schoenau and Cambell, 1996). In Canterbury, crop residues are primarily disposed of by burning or removal, and are not recycled. This practice depletes the soil of essential plant nutrients and soil organic matter (Palm and Sanchez, 1991). Crop residues help to improve soil both chemically and physically by adding organic matter to the soil (Ladd and Amato, 1986).

In New Zealand, there is little published comparative information on the consequences of incorporation of crop residues from legumes on the production of following crops. In particular the place of lentils, lupins and peas in a crop rotation after their harvest for seed has not been studied. This experiment was established to determine the effect of incorporation or removal of barley, lentil, lupin and pea dry matter (DM) and different rates of N fertilizer, on the DM yield of a following crop usingItalian ryegrass as the bioassay crop.

Materials and Methods

Site

The trial was sown into a Wakanui silt loam soil at Iverson Field, Lincoln University, Canterbury, New Zealand (43°S; mean annual rainfall 586 mm) on 1 November 1996. The area had previously been in fallow and had a pH of 6.3 and a C:N ratio of 10.5:1.

Experimental design

Initially, the trial consisted of five treatments (four preceding crops and fallow), each replicated four times in a randomized complete block design. Plot size was 6.3 m by 30 m. Later, the plots were divided into 6.3 m by 10 m sub-plots, as a randomized complete split block design with four replicates to implement the different incorporation treatments. In all replicates, part of the fallow plots and barley plots in which all above ground DM had been removed were further subdivided into five 6.3 m by 2 m sub-sub-plots for N treatments.

Treatments

In the first phase, on 1 November 1996, the entire experiment was sown with four crops, barley (*Hordeum vulgare* L. cv. Liberty) (300 seeds/m^2), lentils (*Lens culinaris* Medik. cv. Titore) (240 seeds/m^2), lupins (*Lupinus angustifolius* L. cv. Fest) (118 seeds/m^2) and peas (*Pisum sativum* L. cv. Allure) (120 seeds/m^2). All crops were sown at a 15 cm row spacing. A fallow control treatment was included and barley was used as a reference non-legume crop. A basal dressing of superphosphate at 200 kg/ha was added but no N fertilizer was applied. The fallow plots were maintained vegetation free by applying Glyphosate (Isopropylamine salt) at 1 l/ha as required throughout the experiment. Weekly irrigation was imposed according to a soil water balance. The herbicide Sencor (250 g/ha) was sprayed to control weeds in the lentil plots

The second phase of the experiment began five months after the start of the first phase. The legumes and the barley were harvested at maturity with a Walter/-Wintersteiger Plotheader harvester. Because the lupins started to re-grow they were desiccated with Diquat at 1.5 l/ha before harvest. Plots were harvested in three ways: all tops and seeds were removed leaving roots only (R); seeds only were removed (HR); or nothing was removed (HRS). These harvests allowed the following incorporation treatments: HRS which was when all above ground DM was incorporated, HR when all DM (including pod valves) but excluding seed was incorporated, and R when all above ground DM was removed and only roots were incorporated. To avoid shifting incorporated crop residues, after the second phase the area was rolled and rotary hoed to incorporate the DM into the soil. This was followed by disc ploughing to incorporate the DM to a depth of 12 cm. In each replicate, part of the fallow plots and the barley plots where only barley roots were incorporated were divided into five sub-sub-plots and 0, 50, 100, 150 or 200 kg of N/ha was applied as urea. After all the above incorporation treatments had been applied, the plots were sown to an annual Italian ryegrass (*Lolium multifolorum* Lam. cv. Grasslands Moata) at 1,120 seeds/m^2 over the entire area on 15 May 1997.

Measurements

Shoot and root dry weights were estimated just before crop maturity (at 50% pod formation or boot stage). In each crop, a random sample of 1 m^2 was taken. Seed yield and seed losses during mechanical harvesting were estimated by sampling from a 0.1 m^2 quadrat. The N content of roots and shoots of the barley, lentils, lupins and peas was estimated by the Micro Kjeldahl method. Ryegrass DM production was measured by taking random samples using a 0.1 m^2 quadrat from different crop residue incorporated plots and N treated plots, at 120 and 190 days after sowing (DAS). Samples were dried at 60°C to constant weight and dried samples were analyzed for N. Soil was analyzed for organic carbon (OC), mineral nitrogen (NH_4^+ and NO_3^-), cation exchange capacity (CEC), bulk density (BD), and soil aggregate stability (>2 mm) before and after sowing the legumes and barley.

Statistical analysis of data used the Statistical Analysis System (SAS) (SAS Institute Inc., 1989). Comparisons among treatment means were made based on least significant difference (LSD) at 5% probability.

Results

Climate and irrigation

Mean monthly rainfall was 37 mm, which was well below the normal average of 50 mm (Fig. 1). In January 1997, 55 mm fell but the maximum after that was 30 mm in March, May and August. The trial was irrigated with 64 mm to maintain soil moisture at or near field capacity throughout the experiment. The mean weekly soil temperature (at 0.1 m depth) was higher in summer 1998 compared to 1997. Mean air temperatures the two summers were similar. The average photoperiod was 15.8 h/day.

Yield of the legume and barley crops

All four preceding crops produced total DM that ranged from 5.4 to 31.4 t/ha (Table 1). Shoot DM production in lupins (24.1 t/ha) was significantly higher than in barley, lentils or peas. Lentils produced a seed yield of 0.7 t/ha only, as this crop was damaged by the herbicide Sencor. Lupins produced 4.1 t/ha root DM which was twice as much as in barley and peas. The

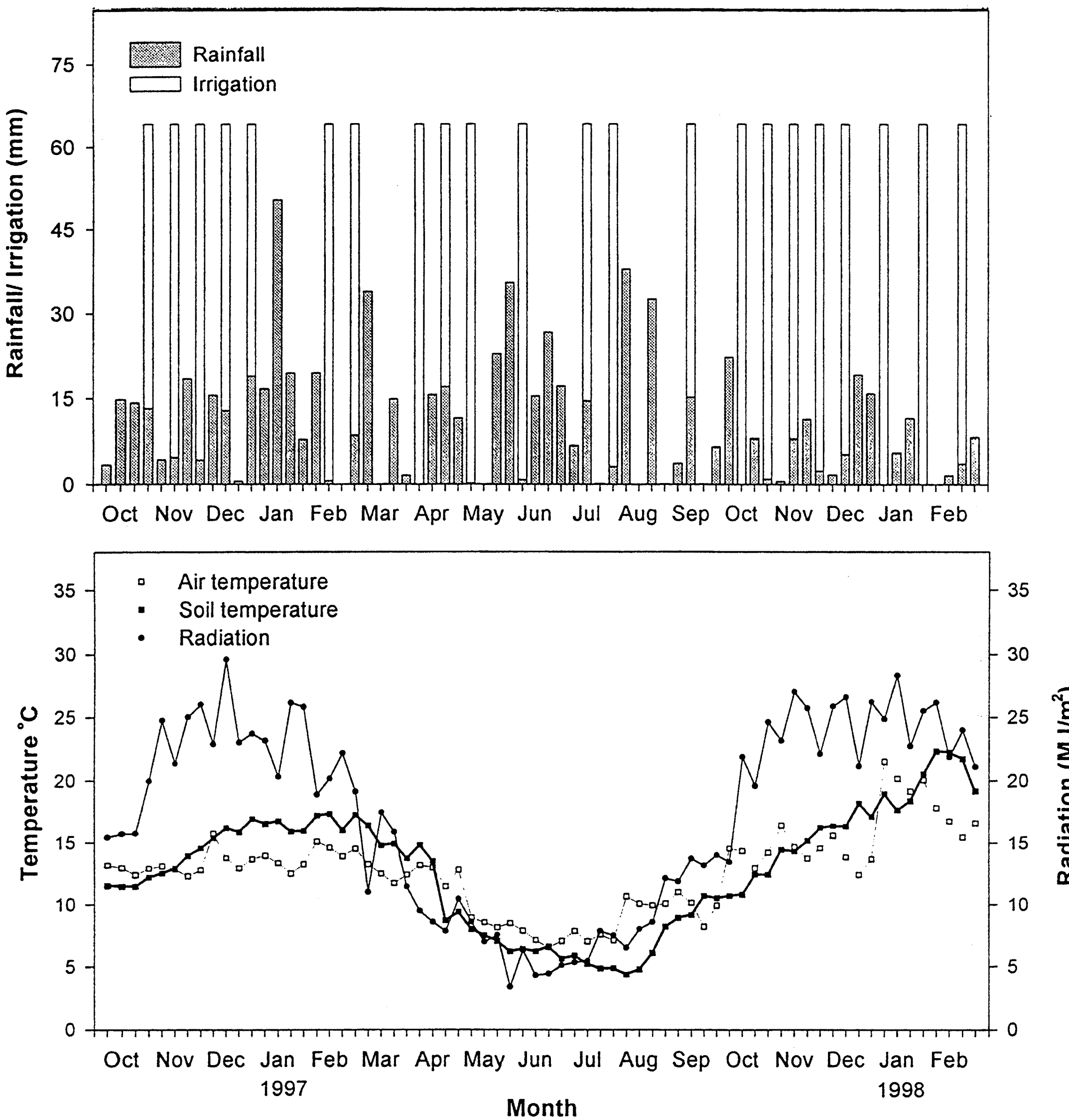

Figure 1. Top: weekly rainfall and fortnightly irrigations of 64 mm when needed. Bottom: mean weekly air and soil (0.1 m depth) temperature, and weekly means of daily radiation totals during the field experiment (October 1996 to February 1998).

Table 1. Dry matter and seed yield of the legumes and barley crops (t/ha).

Crop	Root	Shoot	Seed	Total
Barley	2.0	8.3	3.7	14.0
Lentil	1.4	3.3	0.7	5.4
Lupin	4.1	24.1	3.1	31.4
Pea	1.9	8.7	4.6	15.3
$LSD_{P<0.05}$	0.3	0.9	0.5	

Table 2. The root, shoot, and seed N (%) content, the amount of N (t/ha) added to the soil after residue incorporation, and the herbage C:N ratio.

Crop	Root	Shoot	Seed	Added N	C:N ratio
Barley	0.99	0.36	1.40	0.1	79.4:1
Lentil	3.88	3.47	3.49	0.2	18.8:1
Lupin	3.81	4.68	5.43	1.5	21.4:1
Pea	3.44	3.10	3.51	0.5	19.7:1
$LSD_{P<0.05}$	0.21	0.13	0.10	0.03	3.1

highest seed yield of 4.6 t/ha was from the peas. There was no significant difference in seed yield of barley or lupins (3.7 and 3.1 t/ha).

N content of the legume and barley crops

Among the three legumes the shoot N content was highest in lupins (4.68%) and the root N content was significantly higher in lentils (3.47%) and lupins (3.81%) compared with peas (3.10%) (Table 2). Lupin had a seed N content of 5.43% compared with 3.51% for peas and 3.49% for lentils. Barley had lower levels of root, shoot and seed N than all the legume crops. The total incorporation of lupin (HRS) added significantly more N (1.5 t/ha) to the soil via residue soil incorporation than the other crops (Table 2). Peas (0.5 t/ha) and lentils (0.2 t/ha) added more N to the soil from their residues than the barley (0.1 t/ha). The C:N ratio of barley was significantly higher than for lentils, lupins and peas (Table 2).

Changes in soil chemical and physical properties

Soil chemical and physical analysis showed that there was an increase in soil pH in all legumes and barley plots compared with the fallow plots (Table 3). After barley and legumes the OC content had almost doubled compared to that of the fallow plots. The soil NO_3^-, NH_4^+ and CEC were significantly higher in ex-legume plots than the barley plots. Soil bulk density (BD) was significantly reduced after the growth of all crops (1.00 g/ml) compared with the fallow plots (1.54 g/ml). The lupin plots contained 72% (2 mm) water stable aggregates.

DM yield of Italian ryegrass

Total ryegrass DM yield was significantly affected by the various preceding crops and the amount of their DM incorporated (Table 4). Among the barley and legumes, the lowest and the highest ryegrass DM yields were from

Table 3. Soil chemical and physical properties before the experiment and after growing legumes and barley crops (sampled at 0-12 cm depth).

Treatments	pH	OC %	NO_3^- Kg/ha	NH_4^+ Kg/ha	CEC me/100g	BD g/ml	% Agg.[1] (2 mm)
Before Cropping	6.3	18.1	27	4	6.7	1.57	25
After Cropping							
Barley	6.2	24.3	10	4	12.1	1.02	49
Lentil	6.6	29.5	34	10	11.5	1.03	55
Lupin	6.5	33.0	55	15	13.4	1.00	72
Pea	6.3	26.9	36	9	11.6	1.00	29
Fallow	6.0	18.5	26	7	10.0	1.54	23
$LSD_{P<0.05}$	0.1	1.2	4	2	0.4	0.04	5

[1] Agg. - soil aggregates at a depth of 12 cm

barley and lupins respectively. Pea and lentil plots produced similar DM yields at each harvest.

Dry matter yield of ryegrass was initially highest following HRS incorporation but did not differ from HR at 190 DAS (Table 4). The HR incorporation plots produced significantly more DM than the R incorporation plots. At all harvests the significant interaction between incorporations and species was due to the yield reductions in the barley HRS incorporation treatment, and the yield increases in all legume HRS treatments (Fig. 2). Lupin HRS incorporation (19.2 t/ha) and HR incorporation (16.9 t/ha) produced more DM than all the other treatments. The yield for peas following HRS (10.8 t/ha) was significantly higher than that for lentils. Barley plots gave the lowest ryegrass DM yields.

DM yield of N fertilized Italian ryegrass subplots

Increased levels of N fertilizer increased the DM yield of ryegrass (Fig. 3). Usually fallow plots yielded more than barley R plots. In the early stages, the addition of N fertilizer did not result in any difference in the DM yield of ryegrass. However, from 120 DAS, the DM yield increase with increased amounts of N was linear. In the fallow and barley R plots, the addition of 200 kg N/ha produced 16.3 t/ha and 15.6 t/ha DM, which was significantly higher than all other N levels.

Table 4. The effect of previous crop species and residue incorporation on Italian ryegrass DM yield and herbage N content.

	DM (t/ha)		N content (%)	
Treatment	120 DAS	190 DAS	120 DAS	190 DAS
Species				
Barley	1.1	6.1	2.2	2.1
Lentil	3.6	10.1	3.9	3.0
Lupin	6.0	16.6	4.7	4.2
Pea	3.5	11.1	4.2	4.0
Fallow	2.3	7.1	2.8	2.4
$LSD_{P<0.05}$	0.3	1.0	0.5	0.4
Incorporation				
HRS	3.7	11.2	3.8	3.8
HR	3.3	10.4	3.7	3.8
R	2.9	9.1	3.2	3.2
$LSD_{P<0.05}$	0.2	0.8	0.4	0.3
Interaction	***	***	**	ns

**P<0.001, ***P<0.0001, ns – not significant

Herbage N content of the Italian ryegrass

The herbage N content (%) of the ryegrass varied with the preceding crop species and amount of residue

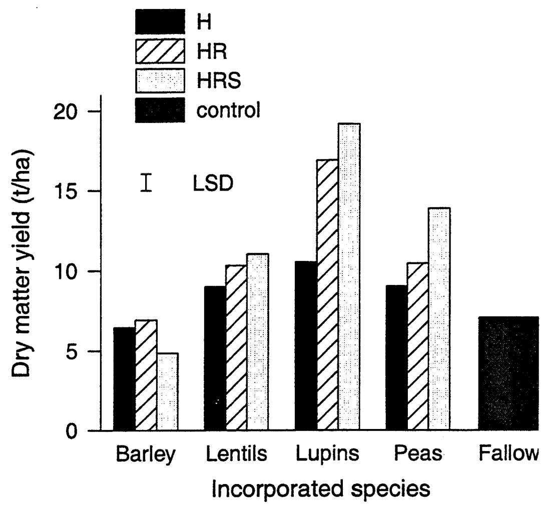

Figure 2. Interaction between incorporation method and species for Italian ryegrass DM yield compared with fallow at 190 DAS.

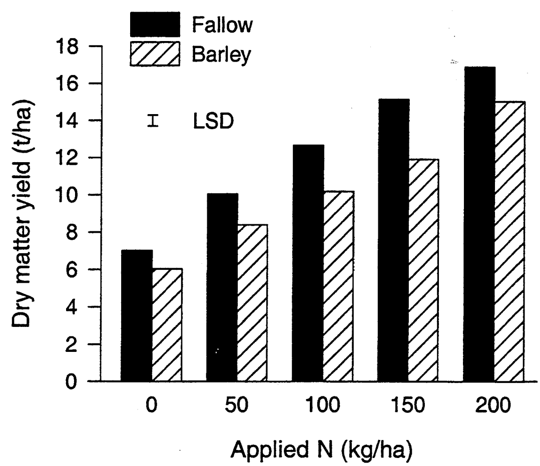

Figure 3. Italian reygrass DM yield response to levels of N-fertilizer in barley R and fallow plots at 190 DAS.

incorporation. It declined between 120 and 190 DAS (Table 4). At 120 DAS there was no significant difference in the N content of the ryegrass after lentils or peas, but the difference was significant at 190 DAS. Nitrogen % of ryegrass was always higher after lupins than after lentils and peas and the differences were usually highly significant. Ryegrass from the barley plots had the lowest N %. The N content of ryegrass in the HRS and HR residue incorporation treatments was similar. The R incorporation treatment had significantly lower % N than the HRS and HR treatments but it was significantly higher than that of fallow plots. There was a significant species by incorporation interaction for ryegrass % N at 120 DAS due to the reductions in N content in ryegrass in all barley plots.

Discussion

Climatic conditions during this trial were favourable for high DM production and seed yield of the legumes and barley crops, and for the ryegrass test crop. Lupins had produced 19.3 t/ha of DM at 50% flowering. By 120 DAS, wind had lodged most of the plants. However, final lupin shoot dry weight was 24.1 t/ha due to profuse re-growth of lodged plants. As a result seed ripened unevenly, and seed yield contributed only 11% of the total DM yield in lupin compared to 37%, 14% and 38% contributions for barley, lentils and peas respectively. In Canterbury, Herbert (1977) showed that lupins had the potential to yield 20 t/ha herbage DM under irrigated conditions. The total lupin DM yield including root, shoot and seed was 31.4 t/ha. This added 1.5 t N/ha to the soil. The total root, shoot and seed DM of pea (15.3 t/ha) added 0.5 t N/ha on soil incorporation. Lentils were damaged at the latter stage of flowering due to a herbicide (Sencor) that reduced the seed yield. From the undamaged lentil plants, a seed yield of 0.7 t/ha was estimated. Nevertheless, the damaged lentils provided substantial amounts of DM (5.4 t/ha) for soil incorporation. The barley produced 14.0 t/ha of total plant DM, but added only 0.1 t N/ha due to the much lower N content of its residues. Substantial amounts of N were also added via legume seed lost at harvest, contributing an additional 71-111 kg N/ha to the soil. Seed loss of lupins added about 50% more N than lentils or peas. The N added from barley seed was low at all times.

Growth of the barley, lentils, lupins and peas reduced soil acidity more than the fallow. The organic carbon (OC) content of the soil increased by 6-14 t/ha compared with the fallow treatment due to the considerable amount of plant material returned to the soil during leaf fall, root and nodule death. The decomposition of these materials also improved the CEC of the soil. The NO_3^- and $NH4^+$ were also increased after the growth of legume crops as biologically fixed N was added to the soil via roots, nodules, leaf fall, crop residues and seed. High NO_3^- levels ranging from 34 kg/ha to 55 kg/ha were observed after the growth of legumes compared to barley (10 kg/ha). However, the NO_3^- concentration was higher in fallow plots (26 kg/ha) than in barley plots as a result of mineralization of soil organic matter and probably due to the rapid conversion to NO_3^- that accumulated in the root zone as a result of low rainfall and no vegetation.

Generally ryegrass yields were higher after the growth of legumes than after barley or fallow. The greater uptake of soil N by barley reduced subsequent N availability for the growth of ryegrass. At the start of ryegrass growth, the N returns from the soil incorporated residues of barley, lentils, lupins and peas were limited and the immediately available N was primarily from roots and nodules. Over time, mineralization returned N to the soil from incorporated crop residues, and appears to have accounted for soil N increases and the subsequent yield increase of ryegrass. The ryegrass DM yields for the amount of residue incorporation of legumes were in the order of HRS > HR > R > fallow. This was because of the amounts of N added via the soil incorporated residues, their C:N ratio and their mineralization in the soil. For example, HRS incorporation of lupins added 1.5 t N/ha, which was the highest among the legumes, and HR incorporation added 1.4 t N/ha. A similar trend of change in N content was found for the levels of incorporation of HRS, HR and R in lentils and peas. However this order changed for barley to HR > R > HRS due to the high C content of barley seed that reduced mineralization of the crop residue. The narrower C:N ratio, especially in legume residues promotes mineralization via crop residue decomposition, and increases soil N availability for the succeeding crops (Troeh and Thompson, 1993). In this experiment the ryegrass DM yield differences between barley and legume residue incorporations were mainly due to the higher C:N ratio of barley (71.4:1) than of the legume C:N ratios (19.7:1-21.4:1). Therefore, the legume residue incorporation resulted in net N mobilization. The lupin biomass incorporated in the HRS treatment provided 1.5 t N/ha. This enabled high levels of mineralization of the crop residue by soil microbes and increased the availability of N for ryegrass growth.

Among the different preceding crops the highest ryegrass DM was recorded for lupins HRS at 19.2 t/ha and lupins HR at 16.9 t/ha. After lupin was pea (13.8

t/ha) and then lentil (11.9 t/ha). Residue incorporation of these two legumes yielded more than that after incorporated barley (7 t/ha). These results follow the same trend as these of McKenzie and Hill (1984). In their experiment, the ryegrass DM yield was 5.5 t/ha after the lupin and was greater than after fallow (4.8 t/ha) or after barley (3.4 t/ha). The large response to applied fertilizer N on fallow and barley R plots suggests that increased ryegrass yields after legumes were mainly due to differences in available N. This is supported by the findings of Smith *et al.* (1986) who confirmed a N requirement of 400 kg N/ha for ryegrass (*Lolium multiflorum*) for a yield of 15 t/ha, and Amerziane (1984) who found an application of 300 kg N/ha produced 18 t/ha of DM. In this experiment, the addition of 200 kg N/ha yielded 16.3 and 15.6 t/ha ryegrass DM, in fallow and barley R plots respectively. The DM yield reduction in barley R was due to the greater uptake of soil N by the barley crop which reduced subsequent soil N availability relative to the fallow treatment. These ryegrass DM yields are consistent with the results of Smith (1987) and Kumar (1998) who obtained 17 to 18 t/ha DM yield from 200 kg N/ha.

The results from this experiment suggest that the ryegrass DM yield increases after lupin HRS and HR treatments were mainly due to increased soil N. The ryegrass DM yield of 19 t/ha obtained in the lupin HRS treatment was higher than yields achieved from adding 200 kg N/ha. This indicates that there were some non-N effects involved in improving the DM yield of ryegrass. This assumes that the actual response of ryegrass to fertilizer N is not linear as shown in Figure 3. Clearly, at some levels of N input, ryegrass response will begin to decline as shown by Smith (1987). The response to 200 kg/N on fallow was equivalent to the lupin HR treatment. Lupin R and pea HRS were comparable with the response on fallow plots to 150 kg N/ha.

The residues of the preceding crops added to the soil via leaf fall, root death, nodule death and seed fall and the subsequent soil incorporation of crop residues (HRS, HR and R) which improved soil chemical and physical characters by adding increased levels of organic matter (OM) to the soil (Ladd and Amato, 1986). Probably this OM also acted as a major source of organic nutrients and energy for microbial activity, providing sites for absorption of nutrients and water storage, promoted soil aggregation and root development and improved other soil physical properties as reported by Rassmussen and Collings (1991). The high amounts of added OM from residue incorporation increased the CEC of the soil and may have allowed essential cations to be absorbed on to the soil, thus decreasing leaching losses.

The preceding crops and subsequent residue incorporation reduced soil bulk density and improved the soil aggregation more than the fallow treatment. The deep root growth of the preceding legume crops reduced soil bulk density and increased soil macroporosity. These results agree with Reeves *et al.* (1984). Later, the growth of ryegrass also reduced soil bulk density via root growth and increased soil aggregation, similar to the report of Haynes and Beare (1997).

The soil chemical and physical changes after the preceding crops were due to the low C:N ratios of the legume residues. As reported by Lopez-Bellido (1993), because of the relatively narrow C:N ratio of the legume residues, microbial biomass may have been increased, giving rise to increased aggregation due to hyphal binding. In lupins, a higher root biomass results in greater rhizo-deposition of carbonaceous material. High microbial biomass usually produces carbohydrate binding agents which increase aggregate stability as found by Haynes and Beare (1997). Ryegrass root exudates, together with below ground crop residues and soil minerals, improved soil aggregation and lowered bulk density.

Conclusions

- The growing of lentils, peas and lupins in a rotation increased the DM yield of a succeeding Italian ryegrass crop by increasing soil fertility and improving soil chemical and physical properties.
- Soil incorporation of legume crop residues increased mineralization and the average N mineralization was greatest after lupins followed by peas and then lentils.
- The DM yields of the succeeding ryegrass crop in the lupin HRS and HR treatments were greater than after the application of 200 kg N/ha. This response indicated that the inclusion of lupin in a cropping system has a beneficial effect on the growth and yield of the succeeding crop by not only by providing N but also by improving soil chemical and physical properties.
- The replacement of fallow with legume crops and their residues has the potential to improve cereal production and agricultural sustainability in Canterbury.

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