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Potential of Green Manure Species in Recycling Nitrogen, Phosphorus and Potassium

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ABSTRACT

Green manures can be grown as catch or cover crops which occupy the land briefly between two main crops and serve to recycle nutrients and protect the soil. Such a role is important as it prevents nutrient leaching, especially nitrogen, with the consequent pollution of underground water. Recycling is also one of the objectives in biological husbandry which differs from conventional agriculture in its manner of nutrient supply. In such systems nitrogen is made available through the mineralisation of organic materials, hence the importance of avoiding any N losses.

This paper reports the results of a greenhouse investigation of the N, P and K uptake potential in six green manure species. Six more species were compared for their dry matter accumulation and nutrient content. Rye and mustard had the fastest growth rate and highest nutrient uptakes, followed by ryegrass and the legume fenugreek. Overall, lucerne had the highest dry matter production and N accumulation. Vetch, trefoil and red clover were similar. The non-legumes had become nitrogen-limited which restricted their growth and nutrient uptake. The suitability of the various species is discussed.

INTRODUCTION

Green manuring, a practice known to the ancient Chinese and the Romans, has been defined as an enrichment of the soil by incorporating fresh plant material other than just plant residues (Pieters, 1927). Many effects have been associated with it, the most important being yield increases in the following crops (e.g; Mahler & Auld, 1989). Others include the suppression of weeds (Dyke *et al.*, 1976), the protection against pathogens such as Take-All (Garrett & Buddin, 1947; Lennartsson, 1987) and long-term effects such as the increase of soil organic matter (Chen & Wang, 1987; Maillard & Vez, 1988) and the improvement of soil structure (MacRae & Mehuys, 1987).

Another important role of green manures is to provide a cover crop which prevents nutrient losses through leaching and surface run-off. Leaching, with its consequent pollution of ground waters, could be important especially after the incorporation of materials rich in N such as leguminous residues, animal slurries or the ploughing of leys. This is quite a common practice among biological farmers referred to as alternate husbandry or ley farming, consisting of the alternation of herbal leys and arable crops. The older the leys, the larger the amount of mineral N released (Cameron & Haynes, 1986; Jenkinson, 1986) unless this is prevented by timely cultivation and by the presence of growing crops (Gustafson, 1987).

The effectiveness of green manures in the uptake of nutrients has been illustrated on a sandy soil in Germany where N losses were reduced from 86 to 39 kg/ha/year (Last *et al.,* 1981). American farmers in the southern states were advised to follow a summer legume crop by a rye crop in autumn (McKee, 1931). More recently a rye crop scavenged residual N in an Illinois soil (Keeney, 1982).

Of the other major nutrients, phosphorus is not leached although it could be lost in surface run-off. In topsoils a large proportion of the P present may not be available for uptake by plants even when it is supplied in water soluble forms (de Haan, 1986). Some plant species, however, have been shown to obtain P from insoluble forms such as rock phosphate (Mengel & Kirkby, 1987). Hence P removed by a green manure could be made more readily available upon incorporation into the soil and subsequent mineralisation. Such an effect of green manuring has been accepted as beneficial (e.g.; Joffe, 1955).

In biological farming systems, the only sources of N being of organic origin, it is essential not only to fully utilise all the N by application of organic amendments but also to minimise losses. On the other hand, there is an increasing role for green manuring following the necessity for intensification as a substitute for alternate husbandry. So far it has been restricted mainly to small holdings in British agriculture (Lampkin, 1985) while it is more frequent in continental Europe (Vine & Bateman, 1981; Kahnt, 1983; Vogtmann, 1986). There is scope for increasing the practice and also for including species beyond the traditional vetch and mustard in heavy and light soils respectively (Fream, 1892; Lockhart & Wiseman, 1978). From the practical point of view, the properties of the most promising species have been reviewed by Wyartt, 1982.

The following study dealt with the potential of green manure species in providing cover crops and recycling nutrients. The selected species were among the traditional and the newly introduced with the emphasis on the comparison between legumes and non-legumes.

MATERIALS AND METHODS

Experiment 1: N, P and K uptake

The potential of six green manure species as nutrient recyclers was assessed under greenhouse conditions. The non-legume species were: white mustard (*Sinapis alba* L.), grazing rye (*Secale cereale* L.) cv. Lovaspatonai, and Italian ryegrass (*Lolium multiflorum* Lam.). The legumes were: fenugreek (*Trigonella foenum graecum* L.), red clover (*Trifolium pratense* L.) and trefoil (*Medicago lupulina* L.).

The soil was a silty loam belonging to the Charity series (Soil survey, 1973). It had a pH of 7.9 (in water), 4.72 mM (146 ppm) of extractable phosphorus and 11.71 mM (457 ppm) of exchangeable potassium (M.A.F.F., 1986). After collection by the first half of March, partial air-drying to about 15% moisture content, the soil was sieved (2.8 mm mesh) and mixed with sand grit on a 2/1 ratio (v/v).

The species were sown from seeds in 15 cm diameter pots and subjected to a minimum temperature of 17°C at day and 12°C at night. No extra light was provided as the experiment was started on March 16. After the first sampling the plants were thinned to one per pot.

Four pots of each species were harvested at 4, 6, 9 and 11 weeks after the sowing date. The plants were dried at 65°C for at least 48 hrs. Shoots and roots were weighed separately then mixed and ground in a ball mill grinder.

Experiment 2: N, P and K contents

For the comparison of nutrient contents, seven species were tested in addition to the previous six. The non-legumes were: phacelia (*Phacelia tanacetifolia*) a member of the Hydrophyllacea newly cultivated in Europe and forage rape (*Brassica napus*); while the legumes were: birdsfoot trefoil (*Lotus corniculatus* L.), lucerne (*Medicago sativa*) cv. Euver, common vetch (*Vicia sativa*) and white clover (*Trifolium repens*) cv. Kent Wild. A second cultivar of red clover was also included: Altaswede red clover, a late flowering cultivar grown in high latitudes or altitudes (Spedding & Diekmahns, 1972). The experimental conditions were as previously, except for one harvest of six replicates at week 11.

Analytical techniques

A single digestion was used for the three elements (Thomas *et al.*, 1967). To 0.15 g of plant material 4.5 ml of lithium sulphate (4% w/v) and concentrated sulphuric acid mixture was added. For younger plants nitrate was included by addition of salicyclic acid to the digestion mixture in which the samples were soaked overnight. To these sodium salicylate was added before proceeding with the digestion. This consisted of heating the samples to 200°C for one hour then to 250°C for two hours, cooling them, adding 1 ml of 30% (w/v) hydrogen peroxide to each sample and reheating until the digests were clear. This solution was then used for the following determinations.

Total nitrogen reduced to ammonium was determined using a Technicon autoanalyser. The sodium salicylate/hypochlorite method was used (A.O.A.C., 1984). The colour was read at a wavelength of 660 nm.

Total phosphorus was determined by the method of Murphy & Riley (1962). P forms a complex in the presence of acid ammonium molybdate and antimony potassium tartrate which is then reduced by ascorbic acid to form a blue colour. The blue complex was read at a wavelength of 712 nm. As this method is very sensitive to the pH, it was necessary to neutralise the samples then reacidify them using 4-nitro-phenol as indicator.

Total potassium was determined using a flame photometer.

The organic carbon contents of some oven-dried plant materials were determined on a Carlo-Erba C.H.N. analyser type 1106 (University of Kent at Canterbury). The samples were chosen to cover different species and plant ages.

Statistical analyses were done using the analysis of variance. In experiment 1 it was necessary to normalise some of the data by transformation into natural logarithms.

RESULTS

Experiment 1: N, P and K uptake

Plant growth

The non-legumes, mustard and rye, grew faster in the first six weeks (Table 1). Ryegrass was not different from rye plants by the third harvest. Of the legumes, fenugreek was the fast growing species and its growth compared well with ryegrass but could not outperform the fastest species. Both mustard and fenugreek had set seeds by the ninth and eleventh weeks respectively. For annual species the onset of flowering ends the exponential phase of growth. This was not the case for rye and ryegrass because this process was hindered by the lack of nitrogen as will be discussed in the next paragraph.

TABLE 1

Plant dry weights (mg) of six green manure species between weeks 4 and 11.

	Week 4	Week 6	Week 9	Week 11
Fenugreek	94.4 ^{c}	612.5^{b}	1920^{b}	3840^{ab}
Mustard	254.8 ^{ab}	1412.5^{a}	2280^{b}	2610^{c}
Red clover	11.8^{f}	102.5^{c}	900^{c}	2890^{bc}
Rye	154.82^{bc}	1380.0^{a}	3980^{a}	5430^{a}
Ryegrass	48.72^{d}	600.0^{b}	3757^{a}	5353^{a}
Trefoil	23.95^{e}	162.5^{c}	2100^{b}	4850^{a}

Within each column, values followed by the same letters are not significantly different. Statistical analysis done on the transformed data.

N uptake and content

Nitrogen concentrations of the non-legumes showed a sharp decrease between weeks 6 and 9, in parallel to a reduction in their growth rate (Table 2). These observations indicate N limitation following the exhaustion of the soil available N.

The plant dry matter was the most important parameter in determining the total N for the legumes (Fig. 1) as this varied to a larger extent than the N concentrations. The shortage of N for the non-legumes caused a levelling-off of the total N despite higher dry matter. By week 11 fenugreek had twice as much N as either rye or ryegrass indicating an almost 50% contribution through biological fixation. In trefoil still at the vegetative stage, this was at 65%.

P uptake and content

Similarly to the nitrogen content, the parameter which primarily affected the phosphorus content was the plant dry weight (Fig. 2). By the third harvest, rye had still the highest content which could be related to higher P concentration until the third harvest (data not shown).

K uptake and content

Like N and P, K content closely followed the dry matter at the early stages (Fig. 3). The plateau reached by the non-legumes later, is similar to that for the N contents, although less pronounced. This is a consequence of N limitation.

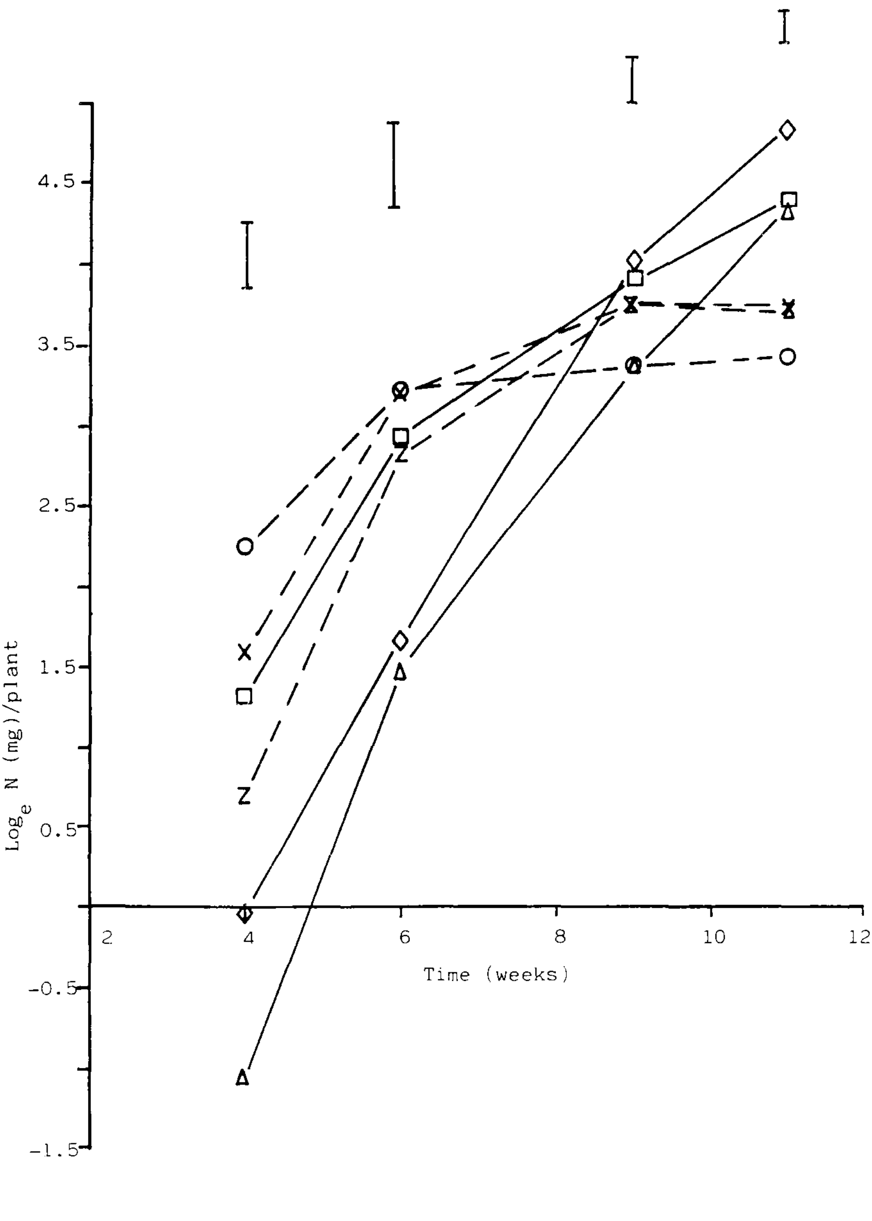

FIGURE 1. Total nitrogen uptake by plants of three legume (———) and three non-legume (----) species of green manure over eleven weeks. X–rye; O–mustard; Z–ryegrass; □–fenugreek; ◇–trefoil; Δ–red clover. Bars represent LSD at $p<0.01$.

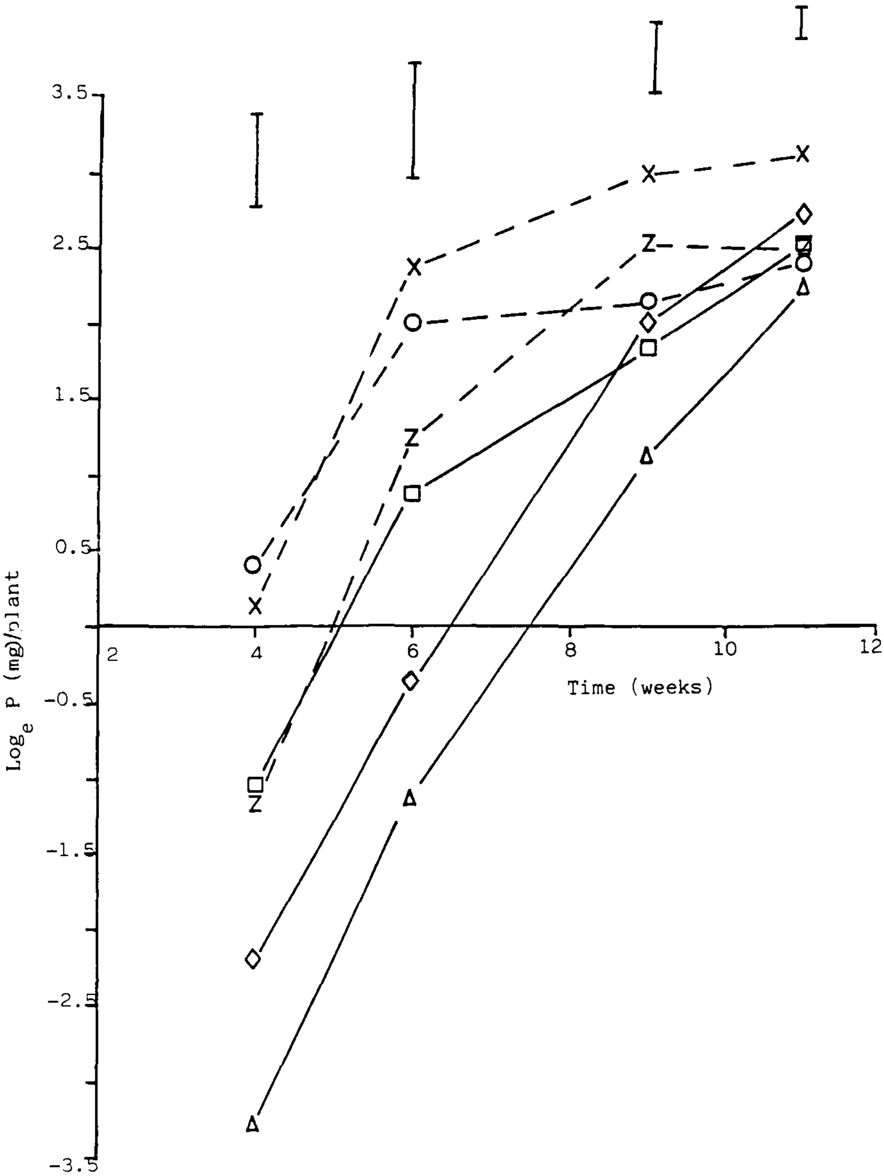

FIGURE 2. Phosphorus uptake by three legume (———) and three non-legume (----) species of green manure over eleven weeks. Key as in Figure 1.

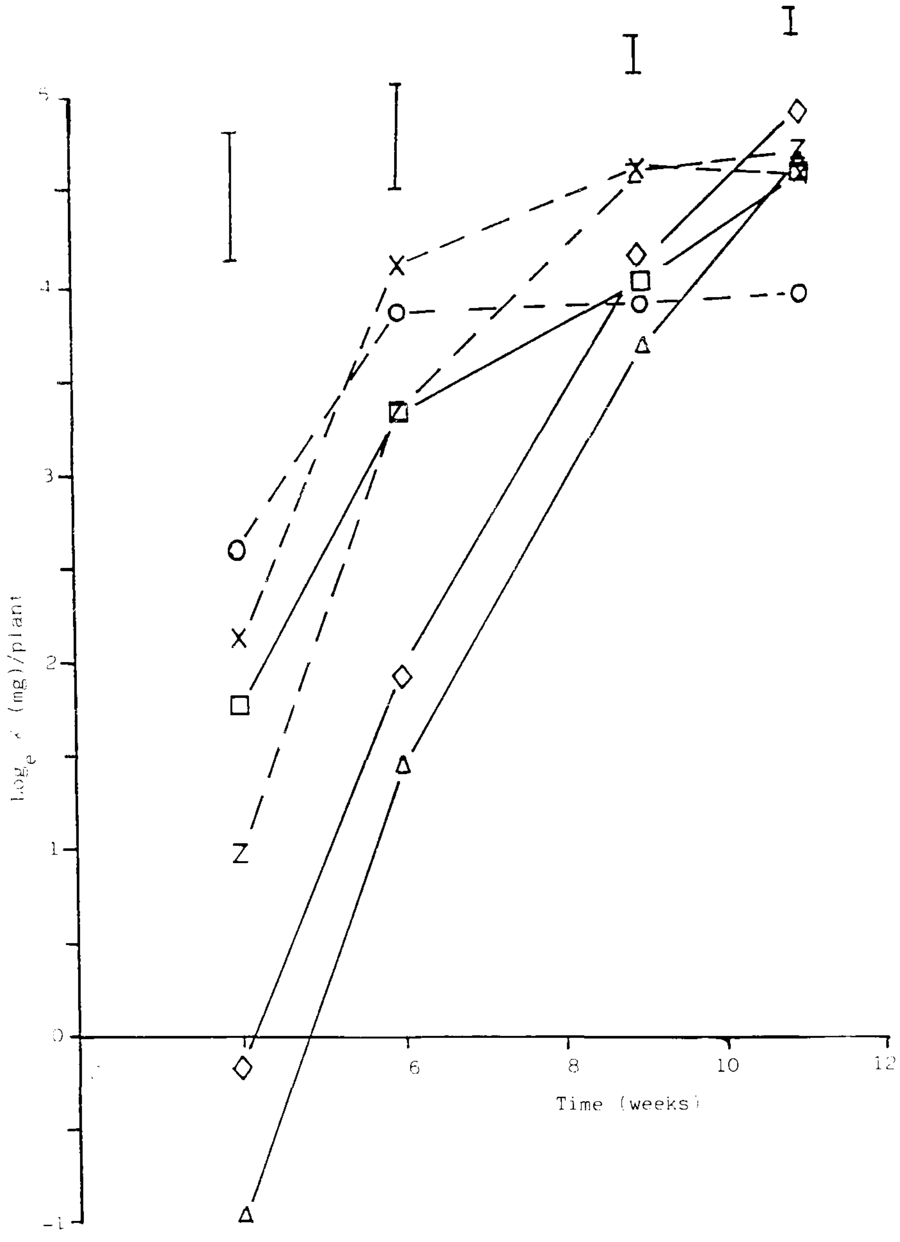

FIGURE 3. Potassium uptake by three legume (———) and three non-legume (----) green manure species over eleven weeks. Key as in Figure 1.

TABLE 2

Nitrogen concentrations (%) in six green manure species between weeks 4 and 11.

	Week 4	Week 6	Week 9	Week 11
Fenugreek	3.94[a]	3.12[b]	2.59[b]	2.09[b]
Mustard	3.8 [a]	1.78[c]	1.3 [c]	1.18[c]
Red clover	3.11[b]	4.43[a]	3.23[a]	2.61[a]
Rye	3.34[b]	1.76[c]	1.09[c]	0.79[d]
Ryegrass	4.15[a]	2.92[b]	1.15[c]	0.75[d]
Trefoil	4.02[a]	3.5 [b]	2.75[b]	2.63[a]
LSD ($p < 0.01$)	0.42	0.66	0.31	0.24

Within each column, values followed by the same letters are not significantly different.

Experiment 2: N, P and K contents

A large difference was found between the smallest N concentration in legumes (fenugreek: 2.09%) and the highest in non-legumes (rape: 1.19%) (data not shown). As the concentration decreases with the accumulation of dry matter, this is balanced by a larger biomass and consequently higher N contents in the most productive species.

This was the case for the legumes (Table 3) with lucerne being the most productive followed by trefoil, altaswede red clover, vetch and white clover. The development of red clover was slow and uncharacteristic compared to white clover and to the slower altaswede cultivar.

In the previous experiment, the non-legumes were hindered in their development by lack of nitrogen.

Phosphorus content (Table 3) was equally determined by the P concentration (data not shown) and the plant dry matter. Rye, rape and phacelia had higher P content due to high concentration for the last two. Under the experimental conditions, however, it is not possible to separate the effects of N limitation from the ability of these species to remove phosphorus from the soil. All the legumes behaved similarly.

The K content (Table 3) was similar to that of P, determined by the dry matter and the concentration. The latter was related to the growth and indirectly to the presence of nitrogen.

Relatively speaking, C content showed a smaller variation (coefficient of variation: 4.11%) between species and the age of the samples than N concentrations which had a coefficient of variation of 33.83%. The relationship between the C/N ratios (y) and the N concentrations (x) was curvilinear following the equation:

$$y = 39.23\ x^{-1.002}$$

TABLE 3

Plant dry weights and N, P and K contents in green manures at week 11.

Species	Plant wt (g)	mg N/ plant	mg P/ plant	mg K/ plant
Lucerne	6.378[a]	154.68 [a]	15.728[bc]	125.51[a]
Rye	5.536[ab]	43.683[c]	22.828[a]	101.45[b]
Ryegrass	5.353[ab]	40.228[c]	12.185[bc]	112.52[b]
Trefoil	5.138[b]	135.47 [a]	16.00 [b]	152.83[a]
Altaswede	4.45 [bc]	122.61 [a]	11.234[bc]	159.27[a]
Fenugreek	3.851[cd]	80.47 [b]	12.298[bc]	100.33[b]
Vetch	3.71 [cd]	101.02 [a]	14.488[bc]	132.76[a]
Birdsfoot trefoil	3.47 [cd]	74.21 [b]	10.742[d]	118.06[a]
Phacelia	3.442[cd]	39.1 [c]	17.127[ab]	83.05[b]
Rape	3.37 [cd]	40.127[c]	17.23 [ab]	73.91[c]
Red Clover	3.038[d]	79.355[b]	9.98 [d]	114.65[b]
White Clover	3.005[d]	83.265[b]	11.1 [d]	110.23[b]
Mustard	2.615[d]	30.85 [c]	11.13 [cd]	53.92[c]
LSD ($p < 0.01$)	1.265	0.539	0.338	0.343

Within each column, values followed by the same letters are not significantly different.

In this the C/N ratios are inversely related to the N values with a power coefficient = –1.002 very close to –1. Hence, the N component is the main variable of the C/N ratio which determines the mineralisation of the plant materials in the soil.

DISCUSSION

Nitrogen limitation in both experiments led to the hindering of development in non-legumes (Marschner, 1986) with the consequent decrease in the shoot/root ratio.

Phosphorus and potassium uptakes were affected differently by the lack of nitrogen. As P uptake is not directly related to the plant growth rate, a depression in the development can lead to an accumulation of this element. Rye had the highest "luxury uptake" of the three non-legumes in experiment 1. This could be due to the species tolerance of fairly acidic soils, conditions under which P tends to be adsorbed (Lauchli & Bieleski, 1983). Hence the survival of the species might depend on its ability to increase the availability of the nutrient.

At the early stages K uptake was not affected by the N shortage due to it being taken up earlier than P and N (Nelson, 1968). However, later on it was affected in the non-legume species.

These results illustrate the importance of N and its effect. They also show that when green manures are grown to remove residual N the best crops are mustard and rye; but when the time gap before the next crop is relatively short mustard could be preferred. Its uptake, however, will be limited to the surface layer due to its shallow rooting system; rye has more developed and deeper roots which could also stabilise the soil. Another advantage over mustard is its tolerance to low temperatures (Langer & Hill, 1982; Maillard, 1988) making it suitable as an overwintering crop.

Of the two Cruciferae, rape produced more dry matter and had a higher P concentration. The species is known to grow on poor acid soils where P is less available (Moorby, 1986) despite it being non-mycorrhizal (Gerdeman, 1975). Rape has been grown as a catch crop in Germany after the incorporation of a summer legume (Phillips & Whitehouse, 1985), and in Sweden after ley ploughing (Gustafson, 1987) and application of animal slurry (Bertilsson, 1988).

Phacelia, a new introduction in continental Europe (Maillard *et al.*, 1989), compared favourably to rape but had smaller roots. It is very sensitive to low temperatures (Maillard, 1988) hence its restriction in usage to spring or early August.

Legumes were slow starters except for fenugreek which equalled ryegrass. As a warm climate crop (Duke, 1981), despite the development of cold tolerant cultivars, it is best grown under warm weather conditions. In The Netherlands fenugreek sown in August outyielded fodder radish, forage rape, vetch and Italian ryegrass, only stubble turnip was more productive (cited by Wyartt, 1982).

If legumes are established by undersowing in the previous crop, they could be efficient scavengers of nutrients including N (Kurtz *et al.*, 1984), especially as nitrogen fixation is depressed by the presence of mineral N. Of the species studied, those with intermediate growth habits would be most suitable for undersowing, in order to avoid any outgrowth of the nurse crop. Their optimum growing conditions are, however, different; trefoil would do best on light soils (Dyke *et al.*, 1976) late-flowering cultivars of red clover on medium to heavy soils (Duke, 1981; Wyartt, 1982). Common vetch is a multi-purpose winter hardy crop (Duke, 1981) mostly sown in mixtures with rye (Elers & Hartmann, 1988; Holderbaum *et al.*, 1990).

The slower birdsfoot trefoil is suitable for acid or even highly alkaline soils (Wheeler & Hill, 1957), in neutral soils it is outyielded by lucerne (Heichel *et al.*, 1985).

On the whole legume species should be used if a significant contribution by N fixation is to be expected. Non-legumes, if allowed to grow for too long as before maize, could be N limiting causing an immobilisation after incorporation.

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