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Matching the Availability of N Mineralised from Green-Manure Crops with the N-Demand of Field Vegetables

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Abstract

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This work assesses the possibilities of reducing N-losses from green-manure crops in cropping systems with iceberg lettuce and leek, by matching the availabilty of N mineralised from green.manure crops with N-demand of field vegetables. The influence of the choice of green-manure species (A), combination of species (B) and time of incorporation (C) was examined by analysing the temporal pattern of N-mineralisation from green-manures, and the N-uptake and root growth of the vegetable crops. In one of two field experiments, the effect of autumn and spring incorporated Persian clover, white clover and yellow-sweet clover was examined (A, C). In the other field experiment, the effect of inter-row red clover strips incorporated at different times during the cropping period was investigated (B). Net N-mineralisation from a mixture of perennial ryegrass and red clover was evaluated in an incubation experiment (C).

Uptake of N by perennial green-manure species kept N protected in the green-manure tissues until incorporation into soil and thus prepared the way for a match between N-availability and N-demand. The amount of N incorporated differed with green-manure species. However, because the chemical composition influenced the percentage of N mineralised, no effect of species could be observed in the temporal pattern of N-mineralisation or crop yields. Different combinations of species in the incubation experiment and time of incorporation in the field did, however, influence the temporal pattern of N-mineralisation. Combining red clover with rye grass resulted in net N-immobilisation followed by a net N-mineralisation rate that temporarily exceeded that of clover alone. However, a similar pattern was not observed when inter-row red clover strips of different ages were incorporated into the soil. The change in temporal pattern of N-mineralisation from red clover was instead proportional to the intervals with which the red clover strips were incorporated. This synchronisation effect was counteracted by uptake and transfer of N in crop rows by the clover strips between rows. In treatments with the latest time of incorporation the competition between the vegetable crop and clover strips together with low intensity and lateral spread of vegetable roots contributed to low N-uptake.

Key words: field vegetables, green-manure species and combinations, N-availability, N-demand, root development, time of incorporation

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Contents

Appendix

The thesis is based on the following papers which are referred to by their Roman numerals:

I. Ögren E., Båth B. & Rämert B. 1998. First and second year nitrogen effects of autumn and spring-incorporated green-manure crops in field vegetable production. *Swedish Journal of Agricultural Research, 28: 137-146.*

II. Båth B. Nitrogen mineralisation and uptake in leek after incorporation of red clover strips at different times during the growing period. (Accepted in *Biological Agriculture and Horticulture*.).

III. Båth B. The influence of perennial ryegrass (*Lolium perenne* L.) on the time course of net N mineralisation from a green-manure crop with red clover (*Trifolium pratense* L.). (Submitted to *Nutrient Cycling in Agroecosystems*).

IV. Båth B. & Kling M. Root development of a leek crop in a cropping system with red clover. (Submitted to *Journal of Horticultural Science & Biotechnology*).

Introduction

Of the anthropogenic loadings of nitrogen (N) in Sweden 1995, 45% originated from agriculture (Swedish Board of Agriculture -Jordbruksverket-,1999). According to Swedish statistics (Statistiska Centralbyrån, 1999) the surplus of N in 1997 was 70 kg ha^{-1} at the farm gate level. For arable land, the difference between input and output gave a surplus of 44 kg N kg ha^{-1} of which about 50% was lost by leaching. In many field vegetable crops, the potential leaching risk is higher because more N is left in the soil profile after harvest (Neeteson, 1995).

The integration of N_2-fixing species in farming systems enables a reduction in N-fertiliser use and therefore a decrease in the use of the non-renewable resources needed in fertiliser manufacturing (Ledgard & Giller, 1995). The use of N_2-fixing crops as N sources may, however, also create problems. Volatile emissions will increase both due to the use of more fossil fuels in the cropping system and as a result of emissions from the N_2-fixing crops (Mattsson, 1999). In addition, leaching may be a greater problem than if mineral fertilisers are used.

Background

Green-manure crops utilising biological N_2-fixation are an important N-source in organic farming systems with field vegetables. The amount of N in green-manure crops may be considerable and varies with stage of development and between species. The species used in this work - red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L), yellow-sweet clover (*Melilotus officinalis* Lam.) and Persian clover (*Trifolium resupinatum* L.) - have been shown to accumulate 150 – 300 kg N ha^{-1} in above-ground biomass during a growing season (Kirchmann, 1988; Kauppila, 1989; Höök, 1993; Dahlstedt & Wivstad, 1994; Stout et al., 1997). This can be compared with N uptake in field vegetables. Leek (*Allium porrum* L.) and iceberg lettuce (*Lactuca sativa crispa* L.), the crops used in this work, have an N-uptake between 75 and 150 kg ha^{-1} but more N-consuming crops such as white cabbage (*Brassica oleracea* L.) may take up three times as much N (Jackson et al., 1994; Jordbruksverket, 1999). However, the N-demand does not depend solely on N-uptake. The N-efficiency of the crop, i.e. uptake of added N, which varies between 80-90% in white cabbage and 30-40% in leek, is also of importance (Greenwood & Draycott, 1989; Thorup-Kristensen & Sørensen, 1999).

Mineralisation of N from green-manure crops is influenced by their chemical composition and by climate and soil conditions. This makes it difficult to control and foresee their N-mineralisation pattern, but, high amounts of clover N are generally mineralised within a month following incorporation (Frankenberger & Abdelmagid, 1985; Kirchmann & Bergquist, 1989; Breland, 1994; Franzluebbers et al.1994*b*; Wivstad, 1997*b*). Early N-mineralisation may be beneficial for vegetable crops with an early uptake of N, such as Brussels sprouts (*Brassica oleracea* L. var *gemmifera* DC) (Smit et al., 1995), or for those crops with deep roots, such as white cabbage (*Brassica oleracea* L. var *capitata* L.) (Sørensen, 1993) but may be disadvantageous for vegetable crops with shallow root systems and a high N-uptake late in the cropping period (Booij et al., 1993; Jackson & Stivers, 1993; Jackson et al., 1994; Biemond, 1995; Jackson, 1995; Smit et al., 1995; Smit et al., 1996; Thorup-Kristensen & Sørensen, 1999).

The difficulties in controlling N-mineralisation from green-manure crops and differences in N-uptake pattern and N-efficiency of succeeding crops result in large variations in crop N-uptake. Uptake of N from green-manure crops by succeeding grain crops has been estimated at between 5% and 50% (Ladd & Amato, 1986; Ta & Faris, 1990; Bremer & van Kessel, 1992; Janzen & Schaalje, 1992; Wivstad, 1996). Ekbladh (1995) found that between 3% and 50% of N incorporated with yellow sweet-clover was taken up by a succeeding leek crop and Thorup-Kristensen (1993*a*) measured the apparent N-recovery by carrots (*Dacus carota* L. spp *sativus* Hoffm.) grown after catch crops to be between 8% and 33%.

Low crop uptake of mineralised N increases the potential risk of N-losses. In crops with shallow roots and late N-uptake, heavy rains or irrigation early in the cropping period promote leaching of mineralised N below the rooting depth and hence, an increased risk of losing mineralised N to ground water. Total N-losses from green-manure crops were estimated at 26 % by Müller (1987), 34 % by Harris & Hesterman (1990) and 24 % by Bremer & van Kessel (1992). Not all N mineralised from green-manures is subjected to losses. During decomposition, some of the N in green-manure crops is incorporated into soil organic matter with low turn-over rates (Stevenson, 1986). The amount of N retained in soil organic fractions incorporated with green-manure crops has been estimated at 31-38 % after eight years by Ladd et al. (1985), and at 38-54 % after six months by Harris & Hesterman (1990).

The amount of N incorporated with green-manures has a great impact on the amount of N mineralised and thus on growth of the following crop (Ladd & Amato, 1986; Groya & Sheaffer, 1985). However, if the availability of N mineralised from the green-manure crops and the N-demand of the succeeding crop could be better matched, smaller amounts of green-manure N might produce comparable crop yields. At the same time the risk of N losses would decrease. With better matching, production of green-manures would require less land in the crop rotation, which would place farmers with limited access to land at less of an economic disadvantage.

Factors affecting matching

Matching the availability of N mineralised from green-manures with the N-demand of field vegetables involves both a time factor and a spatial factor (Fig. 1).

- Synchronisation implies that two or more events are timed to occur simultaneously, asynchronisation that there is a time gap between the events.

- Synlocation, the spatial component of matching, means that two or more factors are located to the same place, while asynlocation means the opposite.

The prerequisite for synchronisation in cropping systems is availability of mineralised N at times of crop demand. In cropping systems where the main source of N is mineralisation from green-manures, synchronisation depends on such factors as the chemical and morphological composition of the green-manure crop, the spatial distribution of the plant material and the protective ability of the soil. However, the availability of mineralised N also depends on factors that influence synlocation such as soil type, precipitation and root proliferation. Mineral N may be leached below the rooting zone or lost by volatile emissions. Thus the risk of asynlocation will be higher on sandy soils in places with high precipitation and in crops with slow and low root proliferation.

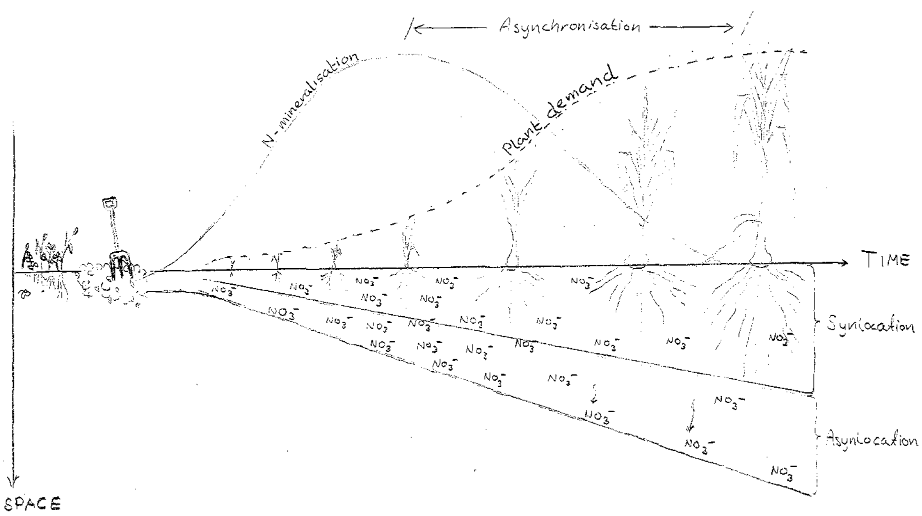

Fig. 1. Asynchronisation and Asynlocation in cropping systems with shallow rooted vegetables with late N-uptake and, green-manures incorporated in spring.

In the literature synchronisation and synlocation often merge together into one concept. This is only natural because asynlocation in a cropping system is often a result of asynchronisation even though there are examples of independence between the two factors. For example, asynlocation is independent of synchronisation when a crop cannot reach N mineralised between rows due to a narrow root system.

Farming practices that influence synchronisation and synlocation between green-manures and vegetable crops are among others: Choice and combination of species, cutting intervals and time of incorporation. Simultaneous incorporation of an N-immobilising material and the green-manure crop is another way to influence N-mineralisation at farm level, as is soil management which includes mechanical measures which that increase the oxygen concentration of the soil and irrigation. In the green-manure crop, the difference in chemical composition between plant parts may influence N-mineralisation, as will the presence of substances such as phenols, which interfere with decomposition of the plant material. Redistribution of N in the cash crop builds time bridges between gaps in crop-available N in soil and crop demand for maximal growth. At periods with an excess of N in soil, crop uptake may exceed the actual demand. In times of shortage, this "luxury" N-uptake may secure crop growth. Economic efficiency involves finding a balance between the urge to produce maximum amounts of N from green-manures and the limited access to land for cash crop production.

In this work I have examined three of these factors concerning farming practices: Choice of species, combinations of species and time of incorporation as a means to improve the availability of N mineralised from green-manures with respect to the N-demand of field vegetable crops. The methods for measuring the influence of the factors examined have been to analyse the temporal pattern of N-mineralisation from the green-manures and, the N-uptake and root growth, both of which are important factors for the N-efficiency of vegetable crops.

Objectives and experimental procedures

The main objective was to design a cropping system with green-manures that could combine good growth of the vegetable crops with minimised N-losses.

The specific objectives of the work were to study:

- differences in the temporal pattern of N-mineralisation between green-manure species (Paper I).

- the influence of time of incorporation on the temporal pattern of N-mineralisation and N-uptake in field vegetables (Papers I and II).

- the influence of combining legumes and non-legumes on the temporal pattern of N-mineralisation (Paper III).

- the influence of green-manures on root growth of field vegetables (Paper IV).

Two field experiments and one incubation experiment were carried out. A brief description of materials and methods is given below. For further details the reader is referred to Papers I-IV.

Field experiment 1

The first field experiment (Paper I), carried out in two successive series, aimed to assess the influence of time of incorporation and green-manure species on soil mineral-N and on N-uptake in successive crops. Persian clover, white clover and yellow-sweet clover, incorporated either in autumn (mid-November) or spring (mid-May), were grown before iceberg lettuce and leek.

Field experiment 2

The second field experiment (Papers II and IV) aimed to assess the possibilities of synchronising N mineralised from red clover with N-demand of leek. Red clover was sown at mid-summer and remained as a catch crop during winter. During the following spring, leeks were planted in rows made in the clover crop. The strips of red clover left between the leek rows were incorporated either at planting, or 2 or 4 weeks after planting. Two row distances, 0.5 and 0.7 m, were used in the experiment. This cropping system was thought to combine high mineral-N values in the crop rows during the establishment phase with high mineral-N values between rows later in the cropping period (Fig. 2).

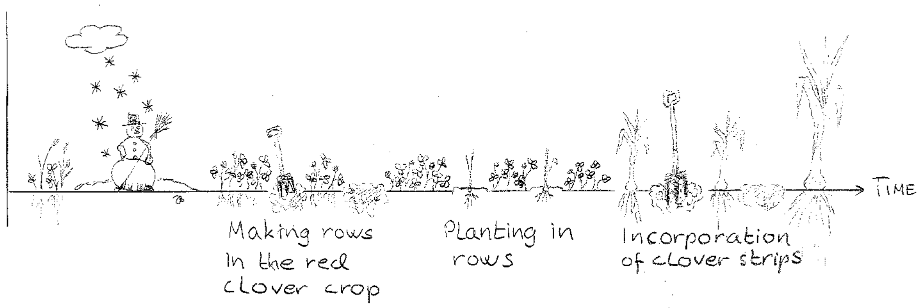

Fig. 2. The cropping system in field experiment 2.

Two ^{15}N studies were carried out in treatments with incorporation of red clover strips 4 weeks after planting. In one study, the uptake of ^{15}N from labelled red clover incorporated between leek rows was measured. In the other, uptake of ^{15}N injected between rows was measured on three occasions at four-week intervals, starting with the incorporation of the clover strips between leek rows. On the same occasions, leek root proliferation was measured in minirhizotrons in the treatment with 0.7 m row distance and in the control. At harvest, root biomass was measured by soil coring in all treatments.

Incubation experiment

To evaluate the influence of perennial ryegrass (*Lolium perenne* L.), grown with 400 or 100 mg N, on net N-mineralisation from a green-manure crop with red clover, an incubation study was set up using fresh plant material. Red clover roots and tops were cross-wise labelled with ^{15}N so that N mineralisation from each fraction could be followed separately. The experiment was carried out at constant temperature of 15°C and lasted for 84 days.

Results and discussion

The temporal pattern of N-mineralisation from green-manures

To synchronise net N-mineralisation from green-manures incorporated into soil with N-demand of vegetable crops with shallow roots and late N-uptake, a delay of the peak in net N-mineralisation is necessary. This means that the temporal pattern of net N-mineralisation must be changed. The delay must be significant, yet both the peak and decline in net N-mineralisation must take place before crop harvest to avoid losses. Low initial net N-mineralisation or net N-immobilisation from green-manures can be obtained by using plant species or combinations of species with high concentration of available C or with high concentrations of cell-wall material (lignin, cellulose and hemicellulose) (Frankenberger & Abdelmagid, 1985; Marstorp & Kirchmann, 1991; Thorup-Kristensen, 1994; Jensen, 1997; Wivstad, 1997*b*). For example, combining grasses with legumes could be expected to delay net N-mineralisation due to net N-immobilisation in the presence of an available C source (Quemada & Cabrera, 1995). However, in most cases, low net N-mineralisation or net N-immobilisation at the start of decomposition is accompanied by a small proportion of mineralised N, which will influence growth of the succeeding crop. Thus, the initial stage of low net N-mineralisation or net N-immobilisation should, ideally be followed by a corresponding increase in net N-mineralisation at the time of increasing crop demand (Fig. 3).

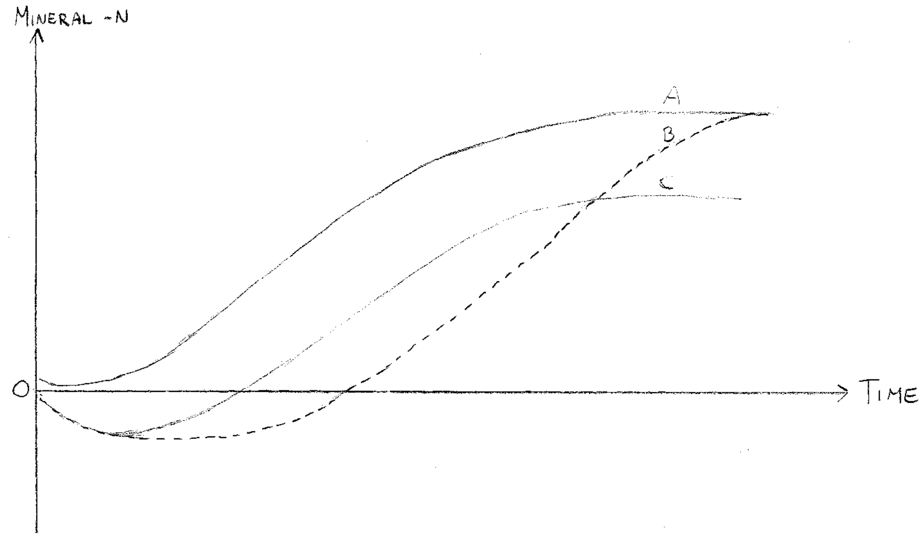

Fig. 3. Schematic diagram of the N-mineralisation pattern generally found in incubation experiments without a crop, after incorporation of green-manures into soil. With (C) and without (A) net N-immobilisation, and (B) the ideal curve.

Plant species and combinations of species

Plants are not homogenous in their chemical composition. Stems and roots usually have a lower concentration of N and a higher concentration of lignin than leaves (Yadvinder-Singh et al., 1992). In an experiment by Wivstad (1997*a*) the concentration of cell-wall material was higher in stems and roots than in leaves of yellow-sweet clover and red clover. This difference, also noted by Amato et al. (1984), Frankenberger & Abdelmagid (1985), Franzluebbers (1994*b*) and Quemada & Cabrera (1995), influenced the proportion of N mineralised. Mineralisation was highest from leaves and lowest from stems (Wivstad, 1999). In the present work, an incubation experiment was carried out (Paper III) to see if the differences in chemical composition between red clover roots and tops influenced the temporal pattern of N-mineralisation from the plant as a whole. The proportion of N mineralised from red clover roots and tops was at the same level but their N-mineralisation pattern differed. However, because the root fraction constituted only a small part of the incubated material, the N mineralisation pattern of roots had little effec on the overall mineralisation pattern. Under field conditions the root/top ratio of red clover would probably be higher and the roots would have a much greater effect on total mineralisation (Bowren et al., 1969).

The differences in chemical and morphological composition between plant parts influence the proportion of N mineralised from green-manure species (Frankenberger & Abdelmagid, 1985; Quemada & Cabrera, 1995). The species used in field experiment 1 (Paper I) - white clover, Persian clover and yellow-sweet clover - were analysed for C and N. In an parallel pot experiment, white clover had a higher N concentration, a lower concentration of cell-wall material, especially lignin, and a higher proportion of leaves than the other species. The lower C:N ratio in white clover agreed with measurements in field experiment 1 and resulted in a higher proportion of N being mineralised in the field. In treatments with white clover, the soil mineral-N values and yields of leek and iceberg lettuce were as high as in treatments with Persian clover or yellow-sweet clover where higher amounts of N were incorporated.

In contrast to the percentage of N mineralised, the temporal pattern of N mineralisation in soil was not affected by differences in chemical and morphological composition between green-manure species in field experiment 1 (Paper I). This somewhat contradicts results from laboratory experiments where the peak in net N-mineralisation was delayed due to initial net N-immobilisation, and where the subsequent decline in the net N-mineralisation rate also differed between species. For example, in an experiment by Frankenberger & Abdelmagid (1985), Egyptian clover (*Trifolium alexandrinum* Fahl.) initially released N more slowly than soybeans (*Glycine max* L.), but after this initial stage there was a shift in the N-mineralisation rate between species so that eventually the same amount of N was mineralised in both species. In another experiment carried out by Ranell & Wagger (1996), a result resembling that of Frankenberg & Abdelmagid (1985) was obtained by mixing rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth). These differences in the temporal pattern of N-mineralisation obtained in the laboratory would probably not have been evident in the field due to environmental factors masking the delicate interplay between plant parts. In the incubation experiment of the present work (Paper III), the changes in the N-mineralisation pattern were more pronounced. In the mixed treatments, especially in the treatment with a high C:N ratio, N-immobilisation was followed by a net N-mineralisation rate which temporarily exceeded that of the clover treatment and thus resembled the ideal mineralisation pattern as illustrated in Fig. 3. This large increase in net N-mineralisation rate was not obtained in the clover treatment, although plant parts with different N-concentrations and C:N ratio were mixed together.

The difference in influence of chemical composition between plant parts of red clover compared to mixtures of red clover and ryegrass may have been due to different mineralisation patterns of N and C, and thereby restricted N-immobilisation. The ryegrass in the mixture with red clover had a high C:N ratio, but the C may have been more readily available - due to fewer lignin structures - than the C in stems or roots of red clover (Whitehead et al., 1979). High availability of C in ryegrass would have promoted synchronisation of N and C-mineralisation and thus N-immobilisation in the mixed treatment (Handayanto et al., 1997). Prevention of N-immobilisation by asynlocation could explain the results obtained by Handayanto et al. (1994). In their work, the N-mineralisation pattern differed in pots compared to in litterbags and leaching tubes. In the pot experiment, a low but long-lasting net N-immobilisation from legume tree prunings with high concentrations of polyphenols and lignins was followed by a large increase in the net N-mineralisation rate. The authors explain the difference between experimental techniques by differences in leaching of polyphenols which have a protein-binding capacity (Harborne, 1997). A prerequisite for the N-mineralisation pattern obtained in the pot experiment by Handayanto et al. (1994) and in the incubation experiment of the present work is a mixture of plant materials with high concentrations of easily available N and C substances. The presence of a large number of secondary compounds with low C:N ratio and easily available C would, in turn, favour high remineralisation of N (Elgersma & Hassink, 1997) due to net N-immobilisation and internal cycling of N (Jansson & Persson, 1982), or to chemical bindings as suggested by Handayanto et al. (1994). However, the restricted N-immobilisation caused by leaching og polyphenols in the litterbags and leaching tubes shows that this N-mineralisation pattern might not have been obtained in the field situation.

In a field situation it may also be difficult to achieve the same proportion between clover and grass as in the incubation experiment (Paper III). The amount of ryegrass in the incubation experiment, 50% of total plant DW, was higher than that commonly found in first-year leys with low inputs of fertiliser-N (Frankow-Lindberg 1982; Humphreys et al., 1998). In a field experiment by Wivstad (1996) the high percentage of clover in a one-year-old mixed ley resulted in similar soil mineral-N values and yield of the following grain crop as when a pure clover sward was the preceding crop. However, with a higher seed rate it might be possible to increase the grass component.

Another complication with mixed green-manure crops is a lower N-concentration, and thus lower amounts of mineralised N compared to monocultures of clover. This may be a problem when the succeeding crop has a high N requirement and an inefficient N-uptake. However, inter-cropping with N_2-fixing and non-fixing plants generally gives a higher total biomass production than monocultures (Chang & Shibles,1985; Ta & Faris, 1987) due to a more effective exploitation of available resources in the soil. This could to some extent compensate for the effect of a low N-concentration in mixed green-manures. Mixtures may also increase the percentage of fixed-N in the legumes as observed by Colwell et al. (1989), but if the total amount of N is low the amount of fixed N may still be low. This is supported by Jørgensen et al. (1999) who observed higher amounts of fixed N in pure white clover swards than in mixed swards with white clover and perennial ryegrass, in spite of higher DM yields in the grass-clover mixture.

Time of incorporation

Time of incorporation affected the temporal pattern of N-mineralisation in both field experiments 1 and 2 (Papers I and II). In field experiment 1, the influence varied between years. In the first year there was no difference between incorporation in autumn and incorporation in spring with respect to the temporal pattern of N-mineralisation but in the next year, autumn incorporation resulted in an earlier mineral-N peak. In field experiment 2, incorporation of red clover strips between rows at different intervals resulted in a corresponding delay in N-mineralisation (Fig. 4). After incorporation of red clover strips, mineral-N in the top-soil increased within two weeks. This rapid N-mineralisation is in agreement with Jackson et al. (1993) who observed a large increase in mineral-N immediately following the incorporation of cover crops.

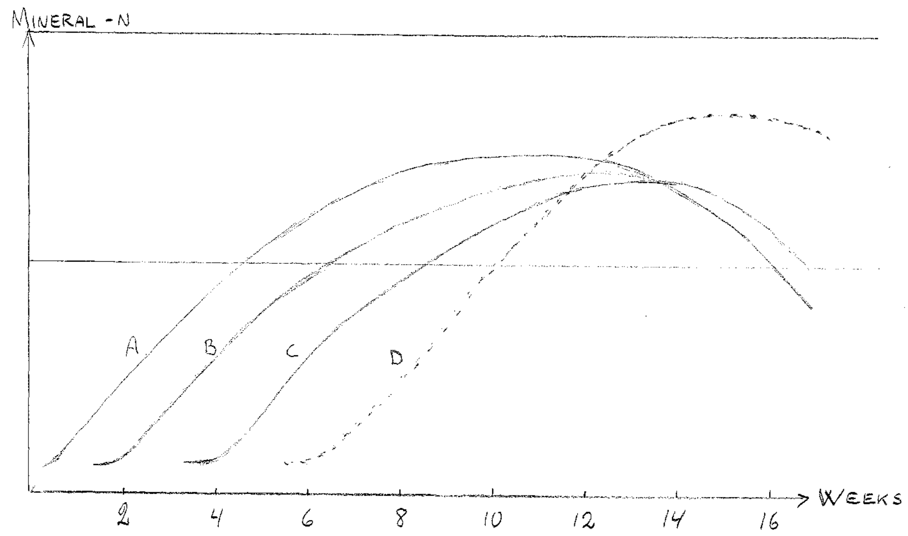

Fig. 4. The mineral-N values between rows in treatments with row distance 0.7 m. (A) = incorporation of clover strips at planting, (B) and (C) = incorporation of clover stips 2 and 4 weeks after planting respectively. D represents the ideal curve.

In the field, time of incorporation of green-manure crops will influence several variables. The chemical composition and amounts of incorporated plant material will change with time, as will the climatic conditions for decomposition and losses of N. When a plant ages, the N-concentration decreases while the concentration of cell-wall material increases (Kirchmann & Bergquist, 1989; Franzluebbers et al., 1994*a*; Wivstad, 1997*a*). Mineralisation of N from young plant tissue will therefore generally, be faster than that from old tissue (Müller & Sundman, 1988). In agreemant with Kirchmann & Bergquist (1989), there were only small differences in N-concentration and C:N ratio between plants incorporated at different ages, in field experiment 2. However, both in the experiment by Kirchmann & Bergquist (1989) and in field experiment 2, a decrease in N-mineralisation in proportion to input was observed. In the former case this was probably due to an increased lignin concentration. In field experiment 2, a decreasing proportion of N in leaves and an increasing proportion in stems and flower stalks - plant parts which usually have a higher lignin concentration than leaves - may explain the smaller proportion of N mineralised from red clover after the last time of incorporation. This is in agreement with Wivstad (1997*a*) who observed that the leaf proportion of the above-ground biomass was strongly correlated to the concentration of N and cell wall material and thereby to N-mineralisation. In other words, the higher proportion of leaves, the higher the percentage of N mineralised.

The lack of influence of differences in chemical and morphological composition of red clover in field experiment 2 (Paper II) on the temporal pattern of soil mineral-N may be due to several factors. Low degree of contact between plant parts may be one, as observed by Jingguo & Bakken (1989), and asynchronicity of N and C-mineralisation another. Decomposition of leaves, which are rich in N, may have followed the same pattern as red clover incorporated at earlier stages of development, while decomposition of stems, flower stalks and roots with a higher C:N ratio was probably delayed (Frankenberger & Abdelmagid, 1985; Quemada & Cabrera, 1995). In a field situation, leaching of N as well as uptake of N by the leek crop may have increased the influence of asynchronicity between N and C-mineralisation. The protective capacity of the soil, including physical protection of metabolites and biomass, adsorption to soil particles and the fixing of ammonium in clay minerals as observed by Amato & Ladd (1992), Sørensen & Jensen (1995), Sørensen (1996) and Thomsen et al. (1996), is still another factor that may have increased the influence of asynchronicity between N and C mineralisation.

N-efficiency of vegetable crops

Besides the temporal pattern of N-mineralisation, the N-efficiency of the vegetable crop is of importance for matching N-availability to N-demand. The uptake and assimilation of N require energy and thus vary with carbohydrate supply and distribution between plant parts. Effective assimilation and redistribution of carbohydrate will promote root growth and thereby the uptake of N, which in turn will improve shoot growth. This interaction between shoot and root growth contributes to more proliferating root systems in vegetable crops under climatic conditions that favour shoot growth. Root growth is also governed by soil conditions, as well as by genetic factors (Engels & Marschner, 1995). The depth, density and lateral proliferation of the root system will in turn affect how efficiently a vegetable crop may explore and deplete soil N, and thus, the potential risk of N-losses.

N-uptake and root growth

In agreement with Groya & Sheaffer (1985), Harris & Hesterman (1990) and Tiffin & Hesterman (1998), green-manure species and time of incorporation did not influence N-uptake of leek or lettuce in field experiment 1 (Paper I). In field experiment 2 (Paper II), the difference in N-uptake was small between treatments with incorporation of red clover strips between rows at planting and 2 weeks after planting. At the latest time of incorporation the N-uptake was lower, approx. 80% of the highest N-yield in the experiment, because the effect on synchronisation obtained by the delayed incorporation was counteracted by uptake and transfer of N by the clover strips (Fig. 5).

Fig. 5. Assimilation and transfer of inherent soil-N and N mineralised from red clover incorporated in the leek row, by red clover strips between leek rows.

The inter-row clover strips assimilated and transferred inherent soil-N as well as N mineralised from red clover incorporated in the leek rows. This kept mineral-N values in the 0-0.3 m soil layer at a low level, both within and between plant rows, until time of incorporation. This effect was especially pronounced and prolonged in treatments with the latest time of incorporation, where the time factor allowed for more uptake of N by clover strips, and contributed to a low growth rate in this treatment. Low growth rate made it difficult for the leek crop to explore N mineralised between rows and thus decreased N-uptake. This effect of early growth and plant size is in agreement with Benjamin (1984) and Gray & Steckel (1990). The uptake of N from the soil probably also influenced the N-fixing efficiency of the clover strips between leek rows. So, although the amount of N incorporated into soil was higher with the latest time of incorporation, the contribution of fixed N to the crop rotation might have been lower than in treatments where the clover strips were incorporated at an earlier stage of development. In addition, to compensate for the greater uptake of N from the soil, the amount of N mineralised from red clover strips incorporated at the latest date had to be higher than from clover strips incorporated at earlier stages of development. As discussed earlier, the changes in chemical and morphological composition worked in the opposite direction. A smaller proportion of N was mineralised at the latest time of incorporation and, in view of N-uptake and soil mineral-N values during the cropping period, the total amount of N mineralised was at the same level as with earlier incorporation (Fig. 6).

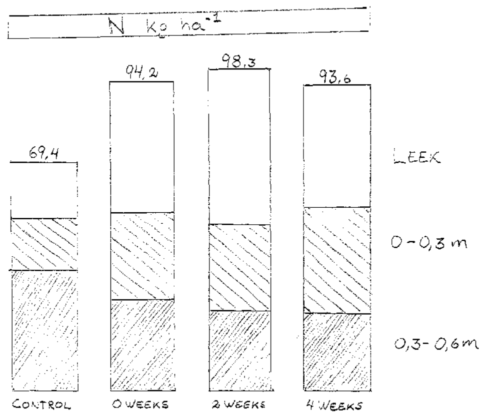

Fig. 6. Mineral-N in soil (0-0.6 m) + N-uptake in leeks (including roots) at harvest.

Low intensity and lateral root proliferation of leek in treatments with red clover strips between rows probably also contributed to reduced N-efficiency of the leek crop (Paper IV). High amounts of mineral N left between rows is in agreement with the ^{15}N experiments in field experiment 2 (Paper II) and demonstrates the difficulties for leeks in treatments with the latest time of incorporation to exploit N mineralised between rows, especially at the wider row spacing. In a partial inter-cropping system as in field experiment 2, the wider row spacing facilitates incorporation of the inter-crop but gives rise to an asynlocation between mineral N and leek root distribution which must be dealt with to avoid losses. This can be achieved by e.g. establishment of catch crops late in the cropping period (Thorup-Kristensen, 1997) and by soil immediately after incorporation of the clover inter-crop.

Because the intensity and lateral spread of leek roots were greater in the control treatment where leek yield was lower than in the clover treatment (Fig. 7) with the latest time of incorporation of clover strips between leek rows, low root proliferation was probably due to factors other than low crop-growth rate. This difference in root proliferation is in agreement with Thorup-Kristensen & van den Boogaard (1999) and may be an effect of lower soil mineral-N values in the control than in the clover treatment. It has been shown that when roots, especially from N-deficient plants, reach a zone rich in N, root proliferation is increased (Drew et al., 1973, Drew, 1975; Eissenstat & Caldwell, 1988; Burns, 1991). The difference in root intensity was greatest between rows, where N mineralised from soil organic matter could have triggered the reaction on root growth in the control treatment. Low root proliferation in the clover treatments may also have been due to creation of soil conditions and release of substances with an inhibitory effect on root growth. During decomposition of green-manure crops several factors may interfere with plant growth: Depletion of soil oxygen, release of toxic organic substances such as organic acids and isoflavonoids, accumulation of ammonia and nitrites and increased growth of damping-off fungi (Chang et al., 1969; Greenwood, 1969; Allison, 1973; White et al., 1989). Disturbance of root growth during incorporation of clover strips and compacted soil in the clover treatments are two other factors that may have contributed to low lateral root intensity in the clover treatments as shown by Wellbank et al. (1974), although a moderate soil pressure has been shown to have the opposite effect (Drew and Goss, 1974).

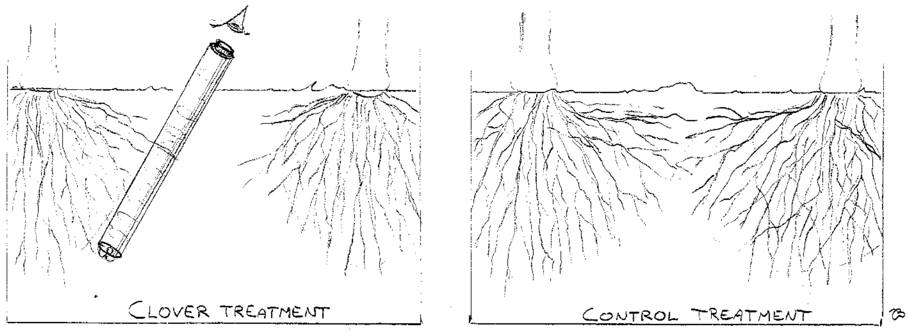

Fig. 7. Root proliferation as observed in minirhizotrones in the clover treatment with incorporation 4 weeks after leek planting and 0.7 m row distance and, in the corresponding control treatment.

In contrast to lateral root growth, differences in soil mineral-N did not influence the vertical root growth of the leek crop. This is in agreement with Drew (1975), Schenk et al. (1991), and Thorup-Kristensen & van den Boogaard (1999), but in contrast to Thorup-Kristensen (1993*b*) who observed deeper broccoli roots in treatments with larger amounts of mineral-N in the subsoil.

The potential risk for N losses

Losses of N from green-manures by nitrate leaching may be a problem if synchronisation between N-mineralisation from green-manures and crop N-demand is not achieved. Losses were not measured in this work but the soil mineral-N values give indications of the potential leaching losses.

In field experiment 2 (Paper II) uptake of N in the red clover crop kept soil mineral-N values at a low level during winter and early spring (Fig. 8). The uptake of N contributed to synlocation between mineral-N and root distribution of the following crop and prepared the way for synchronisation between N-availability and crop N-demand. However, even though N-storage in green-manure tissue is favourable if the subsequent crop has shallow roots as in crops used in the present work, it may be disadvantageous in deep-rooted crops due to pre-emptive competition (Thorup-Kristensen, 1993*a*; Thorup-Kristensen & Nielsen, 1998). In field experiment 1 (Paper I) total mineral-N values in the 0-0.9 m soil profile were lower with spring-incorporated compared to autumn-incorporated white clover, an effect also noted by Sanderson et al. (1999). There were no differences in soil mineral-N values due to time of incorporation in treatments with Persian clover or yellow-sweet clover.

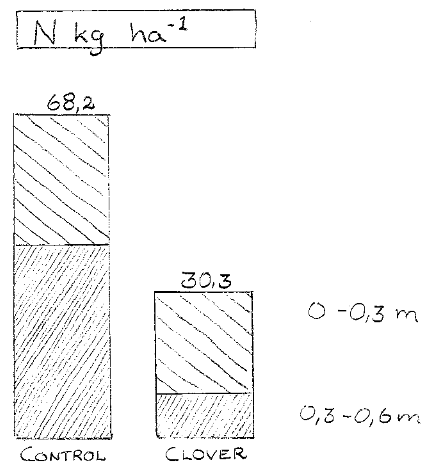

Fig. 8. Mineral-N values in soil at planting.

At harvest, the potential leaching risk was high both in field experiment 1 and 2 (Papers I and II). Between 30 and 100 kg N ha^{-1} were left in the 0-0.6 m soil layer and the amount of residual mineral N down to 0.9 m, as measured in field experiment 1, was between 50 and 130 kg N ha^{-1}, with lettuce at the higher limit. In field experiment 2, a comparison of the controls and clover treatments shows that larger amounts of mineral-N were left in the deeper soil layer (0.3-0.6 m) in the controls (Fig. 6). This was probably a result of larger residual amounts of mineral-N in the deeper soil layer at planting rather than an effect of the clover strips left between leek rows because there were no differences between clover treatments.

Losses by denitrification and ammonia volatilisation were not measured in this work, but the conditions during the growing period in field experiment 2 (Paper II) were favourable for both. Compacted soil, high precipitation and large amounts of incorporated plant material are conditions that increased the risk of denitrification (Aulakh et al., 1983; Breland, 1994). The risk of ammonia volatilisation increased with the latest time of incorporation when large amounts of red clover were left on the top of the soil for a couple of days before incorporation. However, as was shown by Whitehead et al. (1988), Whitehead & Lockyear (1989) and Marstorp (1995), ammonia volatilisation from fresh plant material is low during the first days after cutting. The losses from red clover may have been higher because it had a higher N-concentration than ryegrass used in the experiment by Whitehead et al. (1988) and Whitehead & Lockyear (1989) which showed that ammonia volatilisation increases with N-concentration.

The crop rotation perspective

Many factors influence the potential risk of N-losses from green-manure crops and the use of catch crops and combinations of fertilisers within the crop rotation are important measures to minimise N-losses. Besides the supply of N, green-manure crops influence other factors that may contribute to increased crop yield (Janzen & Schaalje, 1992). An example of this is stabilisation of the soil structure as observed by Tisdall & Oades (1982) which may facilitates root penetration and, thus, nutrient uptake. Green-manures also influence the availability of plant nutrients by changing the chemical conditions in soil.

A factor of particular importance in organic field vegetable production, where inputs of chemicals are restricted, is how the cropping system influences the frequency of pests and weeds. Decreased crop yields may be accepted if the economic result is maintained due to a high crop quality or suppression of weeds by the cropping system. Inter-cropping systems with vegetables and green-manures result in decreased cash crop yields due to competition from the green-manure, as has been shown in this work as well as in others (Nicholson & Wien, 1983; Warman, 1990; Lotz et al., 1997; Brandsæter et al.,1998; Riley & Brandsæter, 1999). However, Theunissen et al. (1992), Rämert (1996) and Brandsæter et al. (1998) reported fewer problems with weeds and pests in inter-cropping systems. The decrease in frequency of pests and weeds in these experiments was often insufficient to produce commercially viable crops, but the experiment by Rämert (1996) showed that in years with a high frequency of pests, the sorted yield in an inter-cropping system was as high as with mono-cropping.

Legume species other than red clover may be more appropriate for use as legume inter-crops. Nicholson & Wien (1983) and Brandsæter et al. (1998) showed that white clover, established in the spring, had the least negative impact on the yield of inter-cropped white cabbage. An alternative to perennial legumes may be to use a winter-tolerant species like hairy vetch, which when sown in the autumn will flower and die, or is easily killed by mowing close to the ground in the first part of the following summer (Schonbeck et al., 1993; Brandsæter & Netland, 1997; Creamer & Bennet, 1997; Netland & Meadow, 1997). From the crop rotation perspective, winter-tolerant legumes established during the later part of the cropping period may serve as catch crops during winter and supply the following crop with N (Vrabel et al., 1980; Guldan & Martin, 1996).

Conclusions

Experiences gained from this work and the literature show the difficulties that exist in matching the availability of N mineralised from green-manures with N-demand by the following crop in a field situation. Two of the methods for measuring the influence on matching in this work, the temporal pattern of N-mineralisation from green-manure crops and N-uptake by vegetable crops, were not influenced by choice of green-manure species. In minimising the potential risk of N-losses, perennial crops seem to be the better choice if the subsequent vegetable crop has shallow roots. By combining species in the incubation experiment, an interesting effect on the temporal pattern of N-mineralisation was obtained but the same effect may not have been evident in a field situation. In addition, combining legumes and grass will probably result in smaller amounts of N in the green-manure, which increases the requirement for land to supply the crop rotation with the same amount of fixed N_2, compared to when the green-manure consistes of legumes only. Time of incorporation of green-manures seems to be a more effective way to control the temporal pattern of N-mineralisation than choice of species. In this work, however, intercropping during part of the cropping period did not result in higher N-uptake by the vegetable crop throughout. On the contrary, with the latest time of incorporation the N yield was lower than with earlier incorporation, due to competition between the vegetable and the green-manure crop. If other benefits such as decreased pressure from weeds and pests and improved soil structure are taken into account, intercropping may still prove to be economically justifiable.

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