Dinitrogen fixation and residue nitrogen of different managed legumes and nitrogen uptake of subsequent winter wheat

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Summary

Fixed nitrogen accumulated by legumes is the main nitrogen source for organic farming systems. Knowledge about the amount of fixed nitrogen, its pathways into forage yield, crop residues, soil-N and yield formation of the following crop is needed for designing crop rotations.

Two field experiments were conducted in Northern Germany with differently managed (cut, mulched) legumes (red clover, alfalfa, white clover) in pure stands and various mixtures with two companion grasses (*Lolium multiflorum*, *Lolium perenne*) have been grown to determine N_2-fixation, residue nitrogen and N-uptake of subsequent crops.

Cropped grass/legume reached higher N_2-fixation than mulched. While green manure grass/legume left up to 280 kg ha^{-1} of N in mulch, stubble and roots on the field, most cropped grass/legume mixtures left less than 110 kg N ha^{-1} in crop residues. Pure legume swards or legume rich mixtures showed higher N_2-fixation than grass rich mixtures. N-uptake in late autumn and at maturity of the subsequent wheat was strongly correlated to the legume content in DM-yield.

Introduction

Symbiotically fixed nitrogen accumulated by legumes is the main nitrogen source for organic farming systems. In crop rotations forage legumes like red clover (*Trifolium pratense*), alfalfa (*Medicago sativa*) and white clover (*Trifolium repens*) show higher nitrogen fixation than grain legumes like peas or faba beans (Larue and Patterson, 1981; Hagmeier, 1986). Forage legumes are self sufficient with nitrogen, their N_2-fixation can cover the nitrogen demand of several subsequent non-N_2-fixing crops (McBratney, 1981; Bowley et al., 1984).

In Northern Germany red clover mixed with perennial ryegrass (*Lolium perenne*) or Italian ryegrass (*Lolium multiflorum*) is the main forage legume grown in crop rotations. Red clover/grass is usually cut 3 times for silage for winter forage or grown as green manure on set aside land with the possibility to receive EU-subsidies. Grazing ley clover/grass-mixtures is seldom, because German farms usually have a high proportion of permanent pasture and the average stocking rate on German organic farms is low. As the EU does not pay subsidies for growing grass/clover for forage use and the subsidies for set aside land are low, especially arable farmers try to build up crop rotations where fixed N by legumes is used efficient to keep the percentage grass/clover in the crop rotation as low as possible.

There are two pathways for the nitrogen fixed by forage legumes to meet the N-demand of the following crops:

- direct by mulch, stubble and roots,
- indirect by slurry or stable manure after feeding the conserved ensiled legume herbage.

For designing crop rotations with a high nitrogen use efficiency, knowledge about the amount of fixed nitrogen, its pathways into forage yield, crop residues, soil-N and yield formation of the subsequent crops for different managed legumes is necessary. For this reason the following field experiments have been designed.

Material and methods

The two field experiments were conducted on a sandy, loamy cambisol (14% clay) at the experimental station Hohenschulen near Kiel in Northern Germany (9°37'E, 54°21'N). Results are presented mainly from the growing seasons of 1994 to 1998. Annual precipitation was 905, 638, 522, 685 and 987 mm in 1994, 1995, 1996, 1997 and 1998 respectively. The following annual mean temperatures have been recorded: 9,2°C (1994): 8,7°C (1995), 7,1°C (1996) 8,8°C (1997) and 8,8°C (1998).

Experiment 1

The aim of experiment 1 was to determine the effect of forage legume species, seed mixture and management on yield, N_2-fixation, residue nitrogen and preceding crop value of legume/grass mixtures.

The experiment includes the following factors:

1. Management (form of use)
   4 x cropped (forage production)
   2 x mulched (green manure)
2. Legume species

white clover	(cv. 'Milkanova')
red clover	(cv. 'Maro')
alfalfa	(cv. 'Planet')

3. Seed mixture

pure sown legume	white clover: 6 kg ha^{-1}, red clover: 12 kg ha^{-1} or alfalfa: 24 kg ha^{-1}
legume/grass mixture	white clover: 4 kg ha^{-1}, red clover: 8 kg ha^{-1}or alfalfa: 16 kg ha^{-1} in mixture with perennial ryegrass: 20 kg ha^{-1} (cv. 'Mandat')
pure sown grass	perennial ryegrass: 30 kg ha^{-1} (cv. 'Mandat') as reference crop for measurement of N_2-fixation

All swards have been established in mid August in each of the following years: 1996, 1997 and 1998 in open sowing in four replications. Plot size was 9 m x 10 m. No fertiliser was applied, all swards were hand weeded. After one growing season the swards were ploughed without stubble breaking at two different dates (end of September/end of October). Winter wheat (cv. 'Orestis') was sown immediately afterwards with a rate of 290 seeds m^{-2} (end of September) or 350 seeds m^{-2} (end of October).

Experiment 2

The aim of experiment 2 was to determine the impact of companion grass species, seed rate and management on yield, N_2-fixation and preceding crop value of red clover/grass.

The experiment included the following factors:

1. Seed mixture:

100 % red clover	(cv. 'Maro') 12 kg ha^{-1}	
67 % red clover + 33 % grass	8 kg ha^{-1}	+10 kg ha^{-1}
33 % red clover + 67 % grass	4 kg ha^{-1}	+20 kg ha^{-1}
100% grass		30 kg ha^{-1}

2. Companion grass:

Italian ryegrass (cv. 'Malmi') (representing a very high competitive companion grass)
perennial ryegrass (cv. 'Mandat') (with a lower competitiveness than Italian ryegrass)

3. Seeding date /Duration of ley / Management (form of use) :

august 1993 / 2-years / 1994/95: 4/4 cuts (forage production)
august 1994 / 1-year / 1995: 4 cuts (forage production)
august 1994 / 1-year / 1995: 2 mulching cuts (green manure)

The swards have been established in each years in open sowing in four replications. Plot size was 9 m x 12 m. No fertiliser was applied, all swards were hand weeded. After one/two growing season(s) swards were ploughed without stubble breaking at two different dates (end of September/end of October 1995). Winter wheat (cv. 'Orestis') was sown immediately afterwards with a rate of 290 seeds m^{-2} (end of September) or 350 seeds m^{-2} (end of October).

Determined parameters

In both experiments the following parameters have been determined:

- crop yield and clover content of each cut,
- organic matter of stubble, roots (depth 0 - 30 cm) and mulch before ploughing,
- forage quality parameters of herbage, N-content of all plant material,
- $CaCl_2$-extractable mineral and organical soil-N (depth 0 - 90 cm) before ploughing,
- N_2-fixation (Total-N-difference method (Hardy and Holsten, 1975) based on the N-amounts in harvested plant material, crop residues and the $CaCl_2$-extractable soil-N fractions with the pure grass swards as reference crops),
- grain yield, total dry matter before winter in autumn and at maturity of winter wheat,
- N-content/crude protein concentration in wheat vegetative tissue material and grain.

Results and discussion

In experiment 1 the different combinations of the factors legume species, seed mixture and management showed highly significant effects on production of dry matter, harvested N, N in crop residues and N_2-fixation of swards with forage legumes. Also grain yield of the subsequent winter wheat was influenced by these factors. The chosen factors had no effect on grain protein content of winter wheat.

Figure 1 shows the effect of different combinations of legume species, seed mixture and management on DM-production, harvested N-yield and the N-amount in crop residues. Under both managerial systems grass/legume-mixtures showed higher production of dry matter than pure legume stands. In all mixtures and managerial systems white clover reached significantly lower yields than alfalfa or red clover. Under both managerial systems the red clover/grass mixture achieved the highest dry matter production.

While in the green manure system the whole plant material after mulching remained on the field, at least 250 kg N ha^{-1} were harvested from each of the cropped legume stands. The swards with white clover showed significantly lower N-yields than the swards with alfalfa or red clover. Pure red clover and pure alfalfa as well as the red clover/grass mixture gave highest yields.

After one growing season the cropped swards left about 105 kg N ha^{-1} on average in crop residues (roots and stubble) on the field. There were no significant differences between the cropped stands. The green manure swards left at least 210 kg N ha^{-1} in form of mulch, roots and stubble on the field. Due to a very well developed, by the first mulching cut not negatively affected net of stolons, the mulched swards with white clover left higher nitrogen amounts than the swards with alfalfa or red clover.

Figure 2 shows the highly significant interactions of legume species, seed mixture and management on N_2-fixation calculated with the Total-N-difference method based on the N-amounts in harvestable plant material, mulch and crop residues under consideration of the $CaCl_2$-extractable soil-N fractions. All cropped swards fixed higher amounts of N than the mulched ones. With an average of 330 kg N ha^{-1} the cropped swards with alfalfa or red clover fixed at least 50 kg N ha^{-1} more than the cropped swards with white clover. In the mulched system the stands with white clover reached higher fixation rates than the swards with the other two legume species.

Figure 2 also presents the effect of various combinations of legume species, seed mixture and management on grain yield and crude protein content of winter wheat following forage legume stands. Wheat following mulched grass/legume swards showed higher grain yields than wheat after cropped swards. A reason for this may be the higher amounts of N in the not harvested plant parts of the green manure stands. The grain yield of winter wheat after mulched swards was not significantly affected by the choice of preceding legume species or seed mixture. With a cropped sward as preceding culture the grain yield was nearly 1 t ha^{-1} higher with white clover than with red clover or alfalfa as preceding legume. As all preceding cropped swards left the same amounts of residue nitrogen on the field, a reason for grain yield differences may be different C/N ratios or N concentrations in the crop residues of the different swards.

Without additional fertilisation none of the different combinations of legume species, seed mixture and management reached the crude protein content of baking wheat. After a calculation of the amount of N removed from the field with wheat grain based on grain yield and crude protein content, 100 kg N ha^{-1} will be removed after green manure, while after cropped grass/legume 80 kg N ha^{-1} were removed from the field. A comparison of the removed N in grain with the N inputs through roots, stubble and mulch of the preceding legume sward showed a higher nitrogen use efficiency after cropped than after mulched swards.

The high nitrogen input from green manure of at least 210 kg N ha^{-1}, and the difference between N-input and N-output after these swards of at least 110 kg N ha^{-1} indicates an increased leaching risk after green manure incorporation as well as after grain harvest.

In experiment 2 all factors affected the considered variables significantly. The different variables influenced by various combinations of seed mixture and management are presented in Figure 3 and 4 as an average of the two considered companion grass species perennial and Italian ryegrass. Figure 3 shows that the dry matter production in 1995 was mainly affected by the management. Cropped swards with clover reached higher dry matter production than the mulched ones. Cropped leys with clover in production year two achieved higher dry matter and N-yields than the swards in the first production year. Contrary to the DM-yields of seed mixtures with clover, pure grass showed the highest DM-yields in the mulched system and the lowest DM-yields in year two of forage production. While in each of the two cropped systems there was no effect of the seed mixture on the DM-yields of swards with red clover, an increase of seed mixture clover content led to an increase of N-yields.

According to the residue N both experiments had comparable results. On average the mulched variants with clover in the seed mixture left approximately 200 kg N ha^{-1} as mulch, stubble and roots while comparable mixtures in the cropped systems left about 110 kg N ha^{-1} in crop residues on the field. While there was no difference in residue N between the different seed mixtures with clover in the cropped system, an increase of red clover content in the seed mixture led to an increase of the N amount in the not harvestable plant parts.

Figure 3 also shows the effect of seed mixture and management on the N-concentration in the not harvesteable plant parts. In this case the variation between 0.9 % of OM and 2.8 % of OM is mainly caused by the variation of red clover content in the seed mixture. An increase of seed mixture clover content led to an increase in nitrogen content.

All cropped swards with red clover in experiment 2 achieved higher clover contents in DM-yield and N-fixation than the mulched ones. With an average of more than 400 kg N ha^{-1} the cropped swards in the second growth period were more effective than both one year old swards. Clover contents in DM-yield of swards in the second production year were higher than in both one year old swards. In all sward types clover rich seed mixtures reached higher clover contents and N-fixation than seed mixtures with a lower clover content.

Figure 4 shows the influence of seed mixture and management of red clover/grass on grain yield, crude protein content and on nitrogen uptake at different stages of subsequent wheat. Clover content in the seed mixture accounted for most of the occurring variation of the variables considered in the subsequent wheat. A high seed mixture clover content led to high grain yields and also to a high N-uptake before winter as well as at maturity. An increased clover content in the seed mixture increased also the amounts of N that can be removed with the grain.

The mulched pure red clover sward with its very high amount of N in crop residues reached the highest grain yield, N-uptake and grain protein content in the subsequent winter wheat. Only the wheat following this sward achieved baking quality without additional fertilisation, but it is noteworthy that this economically desirable grain yield and quality only was achieved through an input of 260 kg N ha^{-1} in form of an incorporation of very lightly mineralisable plant material with an N-concentration of 2.8 % of OM which may lead to leaching losses of nitrogen. A comparison of clover content in DM-yield and the occurring variation of the variables considered indicates a correlation between clover content in DM-yield and N-yield, N_2-fixation, N-concentration in not harvesteable plant parts as well as grain-yield and N-uptake of the subsequent crop.

The results show that dry matter production, N-yield, residue nitrogen and N-fixation of legume/grass mixtures can be influenced by various combinations of legume species, seed mixture, management and duration of ley. The same factors also influenced grain yield, N-uptake and protein content of subsequent winter wheat. The named factors have to be considered while planning crop rotations.

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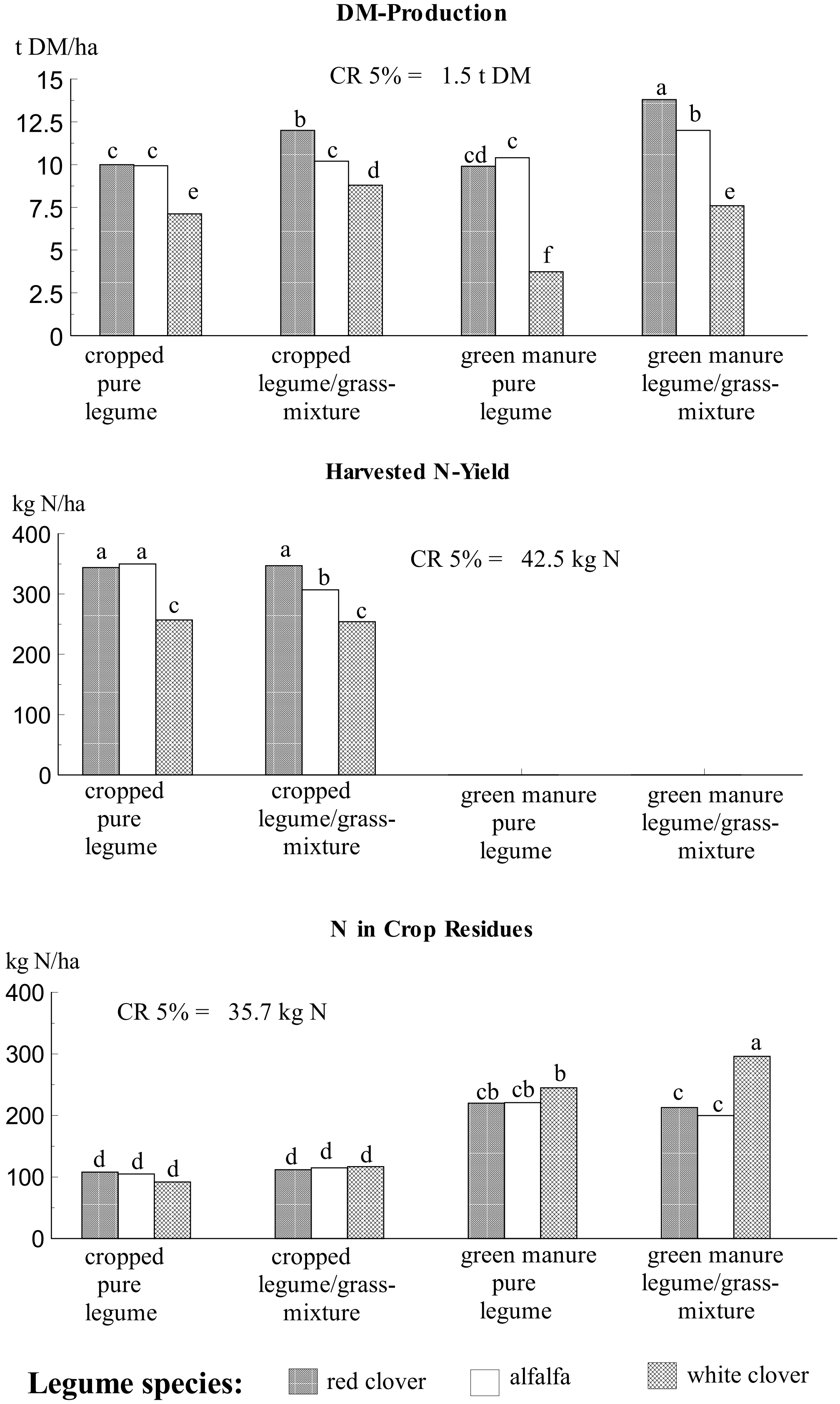
Tables and figures

Figure 1. Effect of management on dry matter production, harvested N-yield and N in crop residues of three legume species in two different seed mixtures (Hohenschulen 1997).



(Means with the same letter are not significantly different)

Figure 2. Effect of management, legume species and seed mixture of legume/grass on N_2-fixation (Hohenschulen 1997) and on grain yield and grain crude protein content of subsequent wheat (Hohenschulen 1998).

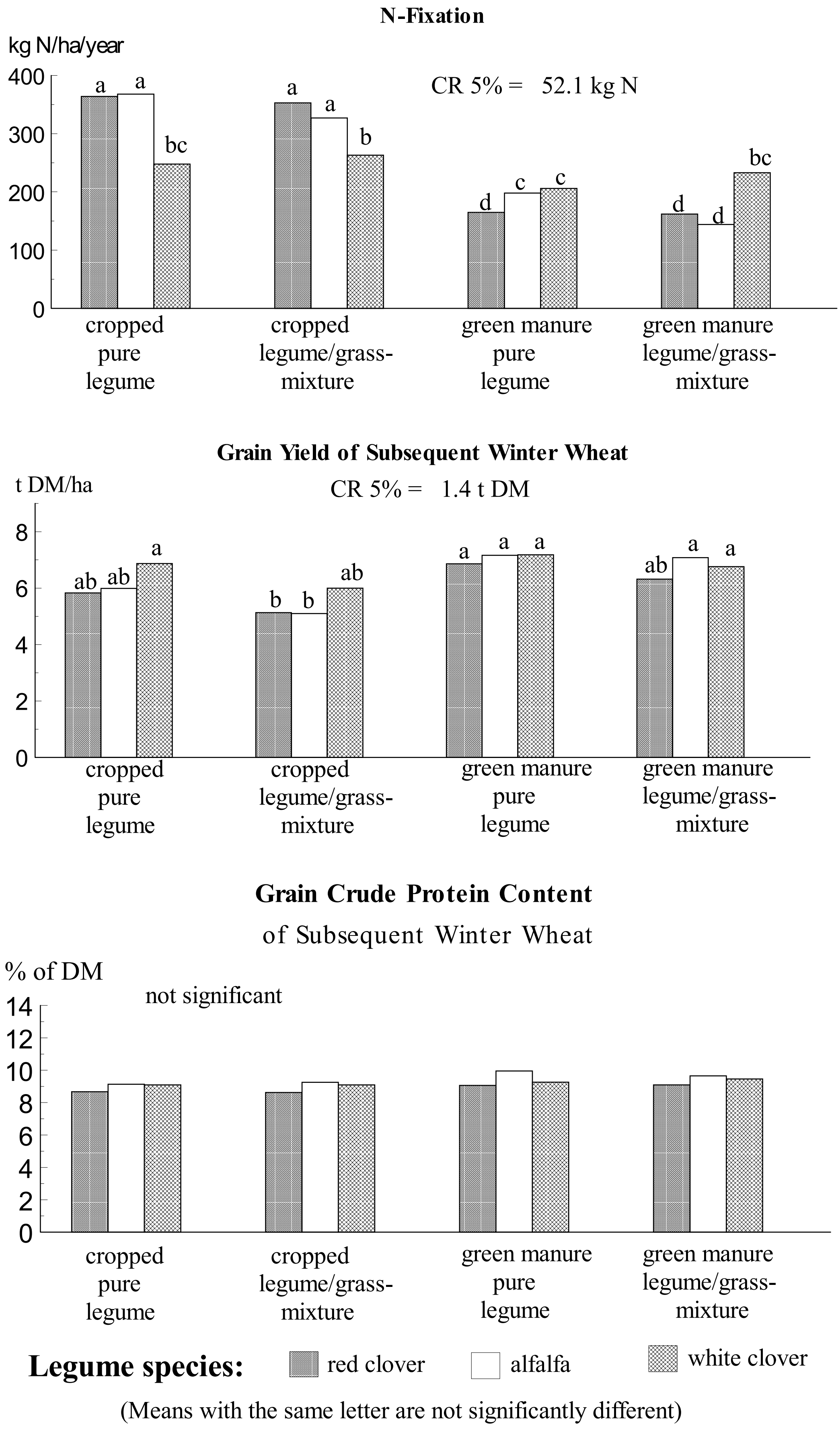


Figure 3. Effect of management of different red clover/grass seed mixtures on dry matter production, clover contend, harvested N-yield, N in plant residues, N-concentration in plant residues and N_2-fixation (Hohenschulen 1995).

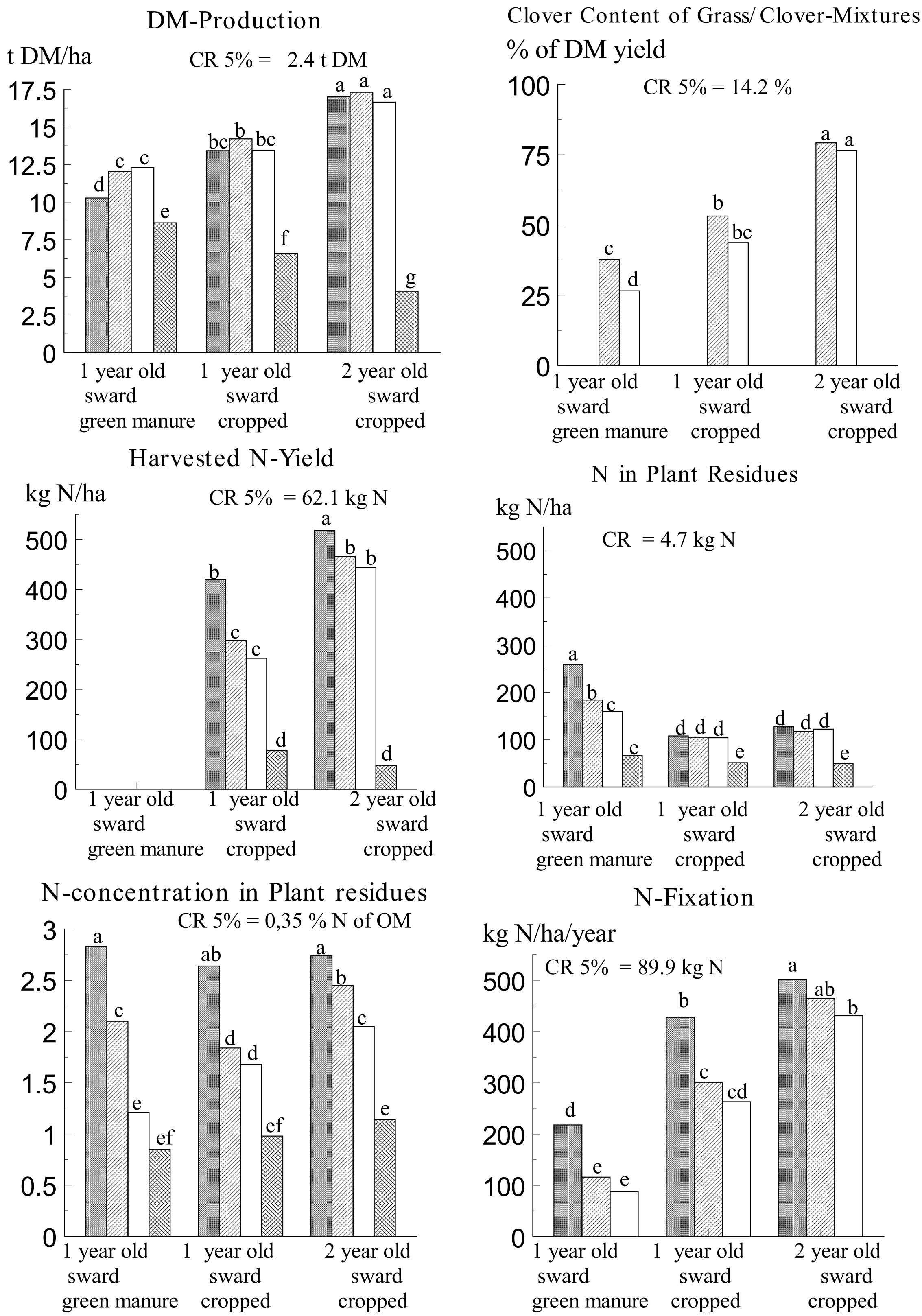


Figure 4. Effect of management and seed mixture of red clover grass on grain yield and grain crude protein content, grain N-amount and N-uptake at different stages of subsequent wheat (Hohenschulen 1996).