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Master thesis

INFLUENCE OF BOTANICAL COMPETITION ON BIOMASS PRODUCTION AND NUTRITIVE QUALITY OF THREE GRASSLAND CROP SPECIES

Untersuchung ausgewählter Grünlandpflanzen hinsichtlich Ertrag, Qualität und Konkurrenz

eingereicht von

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A Perennial ryegrass

AREC Agricultural Research and Education Centre Raumberg-Gumpenstein

B Chicory

C Red clover

DM Dry matter

J Joule

MJ NEL Mega joule net energy for lactation

MJ ME Mega joule metabolizable energy

NFC Non-fiber carbohydrates

NIRS Near-infrared spectroscopy

SD Standard deviation

WG1 Annual meadow grass

WG2 Common bent

WG3 Red fescue

WH1 Dandelion

WH2 Chicory

WH3 Caraway

WL1 Common vetch

WL2 Tufted vetch

WL3 Black medic

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1 Introduction

Grassland forms the basis for the nutrition of ruminating livestock in many parts of the world and it can be used in many ways. The simplest form of using grassland and its plants as animal feedstuff is a system involving pasture. In order to preserve forage, grassland can be cut and conserved in form of hay or silage to be fed to the animals. To assure precise calculation of the animal's diet, it is of great importance to have an understanding of the nutritive quality of the feedstuff (Gruber 2009).

Generally grassland consists of several plant species, which form diverse grassland mixtures that are known to be better in productivity and resource efficiency than pure stands with only one plant species (see e.g. Helgadóttir *et al.* 2008, Lüscher *et al.* 2008, Picasso *et al.* 2008). Including legume species into grassland mixtures has shown to have positive influence on the nitrogen availability in the sward due to the symbiotically fixed nitrogen by the legumes (Lüscher and Suter 2003, Nyfeler *et al.* 2009).

Little information is available on how competition with other plants influences the nutritive quality of grassland crop species. It has been shown that some changes in quality can occur in grass-legume mixtures (Lehmann and Meister 1982, Opitz von Boberfeld and Biskupek 1995).

The objective of this study was to test if grassland crop species result in different plant biomass yields and quality parameters when they are combined with weed species in binary mixtures in comparison to pure stands. The influence of weed species on the productivity of three grassland crop species was investigated in an outdoor pot experiment. It was hypothesized that the total mixture yields (addition of crop and weed yields in mixtures) would increase as compared to the pure stand yields of the respective plant species, although the individual species yields would be lower in mixtures.

Furthermore, it was examined if the combination of crop species and weed species has effects on the nutritive value of the crop species in terms of digestibility of the organic matter and net energy content. It was hypothesized that the nutritive value of the three crop species would not be influenced by the competition with weed species.

2 Literature review

2.1 *Forage in ruminant nutrition*

Forage from grassland is of high importance in ruminant nutrition (Pötsch 2009) and has been the main nutrient source for ruminating mammals since their development (Gruber 2009). Due to the specifics in the ruminant digestive tract, these animals are able to digest fibrous plants, which monogastric animals are not capable of. A symbiosis with microorganisms in the rumen helps to degrade fibrous plant parts, for which the animal itself has no enzymes (Gruber 2009).

2.2 *Nutritive value of forage*

An efficient animal production with ruminants calls for precise knowledge of the quality of the forage used for animal nutrition. The nutritive value of forage is influenced by the plant composition in the grassland sward, harvesting frequency, site conditions and fertilisation level (Pötsch and Resch 2005). These factors have an effect on the nutrient concentration, minerals, vitamins, digestibility and energy content of the forage as well as on hygiene, palatability and feed intake by the animal (Buchgraber and Resch 1997).

2.2.1 Digestibility of the organic matter

The digestibility of the organic matter is important when analysing and evaluating the nutritive quality of forage. It gives information about the total digestible nutrients in the feed that can be used as energy by the ruminant (Schubiger *et al.* 2001a). The content of net energy for lactation (NEL) can be calculated by means of the digestible organic matter, as there is a strong correlation between energy content and digestibility (DLG 1997, Forschungsanstalt für viehwirtschaftliche Produktion 1994, Resch 2009).

The type of grassland and how it is managed and harvested has major influences on the digestibility of the forage. Buchgraber and Resch (1997) showed that the digestibility of the organic matter was higher for intensively used grassland than for grassland with a lower harvest frequency and fertilisation rate in alpine regions. Intensively used grassland had a digestibility of 80 % at the vegetation stage “shooting”, which was 5 to 8 % higher than the respective values for alpine grassland. With prolonging maturity the digestibility decreases, irrespective of the type and use of grassland (Buchgraber and Resch 1997).

Similar aging processes can be observed for grassland species grown in pure stands, as shown in an experiment by Schubiger *et al.* (2001a). Grasses had a high digestibility at the beginning of the first growth in spring with values higher than 80 %. With advancing stages of phenological development, a decrease in digestibility by 5.1 to 7.4 % per week was observed in this experiment. Red clover (*Trifolium pratense*) and lucerne (*Medicago sativa*) showed less reduction in digestibility than grassed did, whereas white clover (*Trifolium repens*) and dandelion (*Taraxacum officinale*) could maintain their digestibility on a high level throughout the whole experiment. In the following re-growths, the decrease in digestibility was slower for all species than what was observed in the first growth, which explains why the herbage from these growths can be used more flexibly over time.

The determination of the digestibility of the organic matter can be done by several processes, either in animal experiments (in vivo) or in the laboratory (in vitro) (Schubiger *et al.* 2001b). In vivo method provides precise results but can only be performed by a limited number of samples due to the time-consuming process. In vitro methods include the two-stage-technique by Tilley and Terry (1963), the 'Hohenheimer Futterwerttest' (Menke *et al.* 1979) and methods using cellulase to replace rumen liquor that is needed in the other two techniques (Schubiger *et al.* 2001b).

2.2.2 Energy content

Energy content in grassland plants is strongly correlated with the digestible organic matter and is subjected to stage of maturity and number of growth (Schubiger *et al.* 2001a). Grasses have the lowest energy contents (5.85 ± 0.92 MJ NEL/kg DM) when compared to legumes and herbs, but with strong variability within grass species. Perennial ryegrass has the highest energy contents in both first and regrowths whereas meadow foxtail (*Alopecurus pratensis*) showed the lowest energy contents, as demonstrated in grassland experiments with pure stand grassland species by Daccord *et al.* (2002). The mean net energy for lactation contents of legume species was 6.10 ± 0.74 MJ NEL/kg DM of which white clover had the highest and lucerne the lowest values. Herbs contained on average relatively high values of 6.45 ± 0.34 MJ NEL/kg DM with only little variation between the species (dandelion, cow parsley (*Anthryiscus sylvestris)* and common hogweed (*Heracleum sphondylium*)) (Daccord *et al.* 2002). Similar to the processes for the digestibility of the organic matter, the influence of the physiological age of the plants in the first growth explains the changes in the energy content. Some grass species have a slow reduction in energy content, as it is seen in Italian ryegrass (*Lolium multiflorum*) with 0.37 MJ NEL/kg DM per week, whereas energy content decreases faster in other grass species like meadow foxtail (0.54 MJ NEL/kg DM/week) (Daccord *et al.* 2002). The age factor is less stronger in the following re-growths where the decline of energy is slower.

2.2.3 Protein content

Crude protein content in forage is decreasing with increasing physiological age of plants. Buchgraber and Resch (1997) described the development of crude protein content of forage from different grassland types and stated that protein contents declined from about 200 g/kg DM at the vegetation stage “shooting” to 70 to 90 g/kg DM for mature forage.

Legumes provide high crude protein contents as shown by Jeangros *et al.* (2001). They reported mean crude protein contents in the first growth of 205, 249 and 225 g/kg DM for legume species red clover, white clover and lucerne, respectively. These species had lower protein contents in the re-growths than in the first growth, a situation that is different for grasses. Grass species had higher crude protein contents in the re-growth than in the first growth, which is mainly caused by the changing ratio between stems and leaves. Mean crude protein values for cocksfoot (*Dactylis glomerata*), perennial ryegrass, meadow foxtail and Italian ryegrass were 135, 114, 130, 96 g/kg DM in the first growth and 140, 142, 155, 122 g/kg DM in the re-growths, respectively.

Some plants like chicory, sainfoin (*Onobrychis viciifolia*) and bird’s foot trefoil (*Lotus corniculatus*) are known to have moderate contents of condensed tannins (Scharenberg *et al.* 2005). Condensed tannins are assumed to have an effect on the protein degradability in the digestive tract of ruminants (Häring *et al.* 2008, Min *et al.* 2003, Scharenberg *et al.* 2005). The condensed tannins form pH-reversible bindings with the protein, which influence the degradation of the protein in the rumen. The total amount of microbial protein that is synthesised is not reduced by this (Min *et al.* 2003). Other benefits of condensed tannins have been shown in forage plants (bird’s foot trefoil and sulla (*Hedysarum coronarium*)), where increased milk production, increased wool growth of a higher quality, ovulation rate and lambing percentage were observed in sheep (Min *et al.* 2003). High concentrations of condensed tannins (> 55 g/kg DM) might have negative effects on intake and digestibility of the feedstuff (Min *et al.* 2003). Scharenberg *et al.* (2005) report that sainfoin was preferred over bird’s foot trefoil and chicory by sheep, although having the highest concentration of condensed tannins (110 g/kg DM for silage). Chicory has low concentrations of condensed tannins when compared to the other plants mentioned above (Arrigo and Scharenberg 2008, Häring *et al.* 2008).

2.2.4 Cell wall content

Forage plants can have a cell wall content of between 30 % and 80 % (Daccord *et al.* 2001a), which can be used by the ruminants due to their specific digestive tract (Gruber 2009). The parts of the cell wall can be subdivided into cellulose, hemicelluloses, pectin and lignin (Daccord *et al.* 2001a), which are overall analysed as crude fibre.

Plant species, the age of the plants, type of grassland and the number of harvests have great consequences on the cell wall contents of forage (Buchgraber and Resch 1997, Daccord *et al.* 2001a). During the aging process of grassland, the crude fibre content increases from 170 to 190 g/kg DM up to 310 to 320 g/kg DM from “shooting” to “end of flowering”, respectively. When comparing different types of grassland managed at different intensity levels, the crude fibre content varies only little between these grassland types (Buchgraber and Resch 1997). Similar mechanisms have been studied by Daccord *et al.* (2001a) for pure stands of grassland plants. Mean crude fibre content was highest for grasses and lowest for herbs, legumes had values in between the other two groups of plants. Within the grasses, the increase in crude fibre with advancing age of the plants was highest for cocksfoot with 31 g/kg DM per week and lowest for Italian ryegrass with 17 g/kg DM per week. In red clover the crude fibre content increased by 24 g/kg DM per week.

Schubiger *et al.* (2001b) mentioned strong correlations between the fibre content of grassland plants and the digestibility of the organic matter. When comparing legumes with grasses at same digestibility values, legumes showed lower crude fibre contents than grasses had. Hence, it is important to know the clover content in grass-clover mixtures when determining their nutritive value.

2.2.5 Mineral content

Minerals have essential structural and physiological roles in animals (Daccord *et al.* 2001b). The mineral content in forage is mainly determined by the site conditions (geology and soils), the type and quantity of fertilisation, the plant community and the time of harvest (Buchgraber and Resch 1997).

The potassium content in forage, which should not exceed 30 g/kg DM, is thought to be connected to the intensity of fertilisation of the grassland and has been under discussion. Buchgraber and Resch (1997) analysed the potassium content in differently managed grasslands and concluded that only grassland cut 4 to 6 times per year could show potassium contents higher than the desired values. Grass-clover mixtures more often have higher potassium contents. Daccord *et al.* (2001b) evaluated the mineral content of grasses, legumes and herbs and concluded that both grasses and legumes had high potassium contents of over 30 g/kg DM and that herbs had contents of even more than 45 g/kg DM. Potassium contents exceeding 35 g/kg DM can lead to metabolic disorders. In most of the investigated grassland species the potassium content declines with time, exceptions are white clover and dandelion where potassium increases during the first growth.

Calcium contents in grassland species are low for grasses with 3.7 g/kg DM and higher for legumes and herbs with 15.1 g/kg DM and 13.7 g/kg DM, respectively (Daccord *et al.* 2001b). There exists only little variation of the calcium content between the different growths. With increasing age of the plants, the calcium content slightly decreases for grasses, which can be explained by changes in the leaf/stem ratio, but increases for clover and dandelion. Forage that is rich in herbs and legumes can result in too high calcium contents and can thus lead to health problems for dry cows (e.g. post-parturient hypocalcaemia).

Both grasses and legumes show similar phosphorus contents (3.6 g/kg DM and 3.4 g/kg DM, respectively), while herbs have slightly higher contents (4.9 g/kg DM). There is a strong correlation between phosphorus and potassium content in the forage. Phosphorus content decreases with time, a very rapid decline can be observed for grasses (-0.4 g/kg DM per week). Usually the phosphorus requirements of dairy cows with 20 kg milk production per day can be met by the phosphorus content in forage (Daccord *et al.* 2001b).

All three functional plant groups contain small amounts of magnesium with low values for grasses (1.7 g/kg DM) and the highest values for herbs with 3.2 g/kg DM. These contents are normally sufficient to meet the requirements of dairy cows. The low contents in grasses in the first growth can increase the risk of hypomagniesemic tetany (grass tetany) (Daccord *et al.* 2001b).

2.3 Forage production with mixtures

2.3.1 Benefits of mixtures

When producing animal feed with grassland plants it has been shown that plant mixtures are more productive than pure stands. The potential of grassland mixtures has been intensively used in agriculture up to the second half of the 20^{th} century. High mineral N- fertilizer practice and productive grass monocultures have reduced the value of mixtures in recent decades in many parts of Europe (Helgadóttir *et al.* 2008, Lüscher *et al.* 2008).

Recent research emphasised the positive effect of grassland mixtures in species-rich and unfertilised systems (Cardinale *et al.* 2007) and in grassland communities under commercial farming conditions (Helgadóttir *et al.* 2008, Kirwan *et al.* 2007). A common interest of many biodiversity experiments is the evaluation of the development and stability of biomass yield

production. It has been stated that increasing number of species in a mixtures leads to a greater biomass production than in monocultures (Lüscher *et al.* 2008). Fundamental differences between nutrient-poor and nutrient-rich systems do not allow a transfer of the findings from one system to the other, but research has shown that benefits of mixtures also occur under fertile agricultural conditions (Nyfeler *et al.* 2009).

Besides the positive influence on yield, other benefits of mixtures have been investigated in a number of studies. Not only total biomass production is positively affected by increasing diversity, the yield of mixtures was more stable over time in many cases (Helgadóttir *et al.* 2008) and spatial stable (Weigelt *et al.* 2008). The incidence of unsown species is reduced by mixtures when compared with monocultures (Helgadóttir *et al.* 2008, Picasso *et al.* 2008) and N-leaching can be reduced. Furthermore, mixtures have shown to be of high value as habitats for other organisms like insects (Joshi *et al.* 2004 by Lüscher *et al.* 2008).

Including legumes in grassland mixtures can lead to a reduced N-fertiliser use without a deduction in yield (Lüscher *et al.* 2008, Lüscher and Suter 2003). It has been shown that legumes positively influence the yield of mixtures due to their ability to fixate nitrogen. However, these effects also occur in highly N-fertilised grasslands and it can thus be concluded that other mechanisms besides nitrogen availability are influencing the productivity of mixtures (Lüscher *et al.* 2008).

It can be said that mixtures provide increased resource-use efficiency compared with monocultures. A reason for this effect is that plant communities with higher species richness are more successful in utilising available resources due to positive inter-specific interaction and species niche complementarity (Nyfeler *et al.* 2009).

2.3.2 Forage production in mixtures

Besides other functions of more diverse ecosystems, the biomass yield of mixtures is of high importance for agriculture. Very productive monoculture grass species can produce high biomass yields of 12 to 17 t/ha per year under intensively fertilised conditions (Daepp *et al.* 2000). It is often stated that mixtures produce more forage yield what than could be expected when comparing the performance of all species in pure stands (Helgadóttir *et al.* 2008, Picasso *et al.* 2008). The results from a common COST experiment at 28 European sites using mixtures with four commonly used forage species (two legumes and two grasses) confirmed this relationship on agricultural grassland (Kirwan *et al.* 2007). At the Swiss experimental site of this project, four-species mixtures including perennial ryegrass, cocksfoot, red clover and white clover produced up to twice the yield of the average of the four monocultures (Nyfeler *et al.* 2009). This is described as over-yielding, which occurs in a situation where the mixture biomass yield is greater than the average yield of the involved species in pure stands. This seldom occurs in mixtures of two grass species grown together (Donald 1963 by Soussana and Lafarge 1998), whereas in grass-legume combinations it can be seen that the mixture outyields the pure stands (Haynes 1980). To be the most efficient system, a mixture would have to be better than the most productive species in pure stand, which is then called transgressive over-yielding (Lüscher *et al.* 2008, Trenbath 1974). Nyfeler *et al.* (2009) described transgressive over-yielding in their experiments where mixtures were up to 57 % more productive than the most productive pure stand. It is remarkable that these effects occurred in mixtures with different species proportions and at two low levels of nitrogen fertilisation. Different levels of nitrogen fertilisation were tested in this experiment and mixtures with legume proportions of 50 to 70 % receiving low amounts of nitrogen fertiliser (50 kg N/ha/year) could produce yields comparable to grass monocultures fertilised with 450 kg N/ha/year (Nyfeler *et al.* 2009). In a field experiment Pötsch and Resch (2006) showed significant differences in dry matter production between different grass and legume mixtures and pure stands. Including white clover, red clover and bird's foot trefoil in combination with perennial ryegrass led to an increase in biomass production when compared to grass monoculture. These mixtures were tested within two cutting systems (3 cut vs. 5 cut) and the most productive and stable mixture was perennial ryegrass with white clover, regardless of the cutting frequency. Legume species, which are sensitive to frequent defoliation like red clover and bird's foot trefoil, could not show their advances in dry matter production in the 5 cut regime due to the high utilization frequency and the conditions at this particular experimental site.

2.3.3 Competition in forage mixtures

Competition between grassland species in mixtures has effects on the plants involved in this process and on the species-richness and evenness within the swards (Huber-Sannwald 2001). Plant morphology and performance can be changed due to competition (Carrère *et al.* 2006, Huber-Sannwald 2001).

Competition for light leads to a change in allocation of biomass in the above ground organs (Huber-Sannwald 2001), which has also been shown by Carrère *et al.* (2006) where grass sheats and lamina were increased in size when competing with other grasses. Plants form leaves with a higher specific leaf weight (g/m^2) when they are exposed to light, whereas shading results in decreased branching and increased height growth.

Complementarity among species can result in better access to resources or niches (Picasso et al 2008).

2.3.4 Influence of competition on nutritive value

The influence of inter-specific competition between plants in grassland communities on the nutritive value of the involved plant species has been studied in a small number of scientific studies. Some research has focussed on the competition between grasses and clover in mixtures (Jahns *et al.* 1999, Lehmann and Meister 1982, Opitz von Boberfeld and Biskupek 1995), whereas the competition between grasses has been investigated by Carrère *et al.* (2006). The influence of competition between grasses and legumes on the biomass yield has been known for long time (Nesheim and Boller 1991), whereas the consequences for the nutritive value have been scarcely treated in scientific research (Opitz von Boberfeld and Biskupek 1995). Lehmann *et al.* (1978 by Opitz von Boberfeld and Biskupek 1995) described a strong influence of clover on the nutrient content of the companion grasses in mixtures, whereas there was only a slight effect of grasses on clover nutrient contents. The results from Opitz von Boberfeld and Biskupek (1995) suggest that there is only a little influence of competition with red clover on the net energy for lactation content of the companion grass in grass-clover mixtures. The grasses, Italian ryegrass and cocksfoot, had a smaller energy content when grown in mixtures with Red clover compared to grass pure stands, especially in low fertilised swards. In mixtures, grasses have more nitrogen available than in grass monocultures, which can be a reason for the reduced content of net energy (Deinum 1984 by Opitz von Boberfeld and Biskupek 1995). Clover plants have lead to shading of the grass plants, which is mentioned to reduce the energy content. The content of net energy of red clover was only marginally influenced by competition, which has been stated by other research (Lehmann *et al.* 1978 by Opitz von Boberfeld and Biskupek 1995, Lehmann and Meister 1982). The results from Pötsch and Resch (2006) show a significant impact of the companion legume on the quality of perennial ryegrass. The digestibility of the organic matter was higher for ryegrass in mixtures than in monoculture ryegrass, and net energy concentration was increased as well.

Inter-specific competition influences the crude protein contents of grasses due to the reduced requirement of legumes for soil nitrogen as well as nitrogen transfer from decomposed clover biomass (Opitz von Boberfeld and Biskupek 1995). Important for a successful transfer of nitrogen from legumes to grasses is a close spatial distance between the plants. Lehmann and Meister (1982) found an influence of increasing clover proportion in mixtures with perennial ryegrass on the protein content throughout several harvesting times. Crude protein content of red clover can decline with increasing proportion of grass in the mixture, as reported by

Lehmann and Meister (1982) and Opitz von Boberfeld and Biskupek (1995). Nesheim and Boller (1991) stated that competition with grasses and white clover lead to an increasing proportion of clover-nitrogen deriving from symbiosis and that temperature is essential for the nitrogen fixation of white clover. The symbiosis-nitrogen was less at low temperatures, where clover plants will have to compete with grasses for soil nitrogen, more than they would have to do at higher temperatures (Nesheim and Boller 1991). A reason for the increase in nitrogen derived from symbiosis in case of competition is the uptake of mineral nitrogen by grass plants resulting in a lower mineral nitrogen content in the soil.

The content of non-fibre carbohydrates (NFC) in forage has an influence on the nutritive value of the feedstuff. The influence of companion grasses on the NFC content of red clover has been studied by Jahns *et al.* (1999). The two grasses used in this experiment, perennial ryegrass and Italian ryegrass, had different effects of the NFC contents. Italian ryegrass tended to be faster in establishment and could thus reduce the clover content in the swards. Red clover had less NFC in mixtures with Italian ryegrass than in mixtures with perennial ryegrass, which was significant for the first growth. Less influence was reported for the clover content in the mixtures.

Forage mixtures without legumes were studied by Carrère *et al.* (2006) who compared binary mixtures of cocksfoot and five other grasses. The competition between these plants led to an increase in size of the above ground organs like tiller, sheat and lamina, which was associated with higher NDF contents. Consequently, the digestibility of the grasses was significantly reduced by competition when compared with grasses in monoculture. In this experiment, small grass species like red fescue (*Festuca rubra)*, smooth meadow-grass (*Poa pratensis*) and golden oat-grass (*Trisetum flavescens*) were affected by competition to a greater extent than larger species.

The content of minerals in the plants is affected by inter-specific competition but with different patterns for the various elements (Lehmann and Meister 1982). Grasses that have been grown in mixtures with clovers or that have been fertilised showed higher sodium and potassium contents than grasses from pure stands. This can be explained by the fact that plants with higher nitrogen uptake have increased uptake of these ions as well. On the other hand, potassium and sodium contents in clover were not altered by competition with grasses (Lehmann and Meister 1982, Opitz von Boberfeld and Biskupek 1995). Calcium and magnesium contents in the plants were only slightly influenced by legumes (Lehmann and Meister 1982) or showed unsteady reactions, which made the results difficult to interpret (Opitz von Boberfeld and Biskupek 1995). Opitz von Boberfeld and Biskupek (1995) mentioned a strong influence of competition on the mineral content of grasses and clover, which were dependent on the growing conditions and the proportions of the respective species in the mixtures. Phosphorus content in grasses is increased when competing with clover. An explanation for this is that legumes or microorganisms solubilise phosphorus in the soil, which can then be taken up by the root system of the grasses better than by clover. Clover plants had less phosphorus when grown in mixtures compared to pure stands (Opitz von Boberfeld and Biskupek 1995).

2.4 Summary

Grassland plants that are grown in a plant community react differently in their performance than plants in pure stands do. It has been shown that biomass productivity and plant morphology can be influenced by interspecific competition. Above ground plant organs like sheat, tiller and lamina can increase in size. Forage production with mixtures of different plant species can positively affect the yield, which is of great importance for agricultural purposes. Several scientific studies emphasize the importance of including legumes together with grasses in mixtures for forage production.

Only little influences on the nutritive quality of forage by competition have been observed by several scientific studies. Slight changes can be expected for the energy content of single plants in communities with other plants whereas mineral content and protein content can be altered to a greater extent due to competition. The strength of the influence depends on the plant communities and the species involved. Legumes can positively influence the nutritive value of grasses, whereas there is only a little effect on the quality of grasses.

3 Material and methods

Grassland species from three different functional groups (grass, deep-rooted herb and legume) were sown in binary mixtures with weed species from the same functional groups. Grassland species perennial ryegrass (*Lolium perenne* cultivar 'Helmer'), chicory (*Cichorium intybus* cultivar 'Grasslands Puna') and red clover (*Trifolium pratense* cultivar 'Ares') and weed species annual meadow-grass (*Poa annua*), common bent (*Agrostis capillaris*), red fescue (*Festuca rubra*), dandelion (*Taraxacum officinale*), chicory (*Cichorium intybus*), caraway (*Carum carvi*), common vetch (*Vicia sativa*), tufted vetch (*Vicia cracca*) and black medic (*Medicago lupulina*) were chosen for this experiment. Weed species curled dock (*Rumex crispus*) and cow parsley (*Anthriscus sylvestris*) had been the first choice for weed herbs but had to be excluded from the experiment due to unsuccessful germination results.

3.1 Plant material

3.1.1 Crop species

Grass species are able to produce high biomass yields with high stability and create dense swards in grassland. Furthermore, they show a good ability to be conserved as silage or hay with less biomass losses than herbs or legumes have (Meister and Lehmann 1988). Legume species are very essential parts of grassland communities in many parts of the world (Lüscher and Suter 2003). Reasons for the great value of forage legumes are their ability to fixate molecular nitrogen, their high nutritional value, greater feed intake and better distribution of biomass production over the growing period (Lüscher and Suter 2003). It has to be mentioned that the low stability of legume swards leads to fluctuations in yield.

Perennial ryegrass

Perennial ryegrass (*Lolium perenne*) can be described as one of the most important grasses in temperate grassland with respect to biomass production and nutritive value (Lenuweit and Gharadjedaghi 2002). Perennial ryegrass forms rhizomes, which produce dense swards that make it highly suitable for grazing. It prefers mild sites with average temperatures between 6.5 and 9 °C and it is sensitive to drought and frost (Dietl *et al.* 1998). Perennial ryegrass can be used in permanent grassland as hay and silage and as pasture grazed by animals, where it can be intensively managed. A combination of perennial ryegrass and white clover is a suitable mixture for cut and grazed leys (Dietl *et al.* 1998).

Table 1. Nutrient content and digestibility (based on dry mass) of perennial ryegrass (*Lolium perenne*). Modified after DLG, 1997

1st growth vegetation stage	DM (g)	Ash (g)	OM (g)	CP (g)	Fibre (g)	DOM (%)	nXP (g)	RNB (g)	ME (MJ)	NEL (MJ)
shooting	160	117	883	240	177	83	162	+12	11.56	7.10
begin of heading	170	109	891	197	197	82	156	+7	11.60	7.12
heading	180	115	885	191	221	81	151	+6	11.16	6.81
begin of flowering	210	107	893	157	256	77	142	+3	10.56	6.36
flowering	230	101	899	135	295	75	139	0	10.27	6.15
after flowering	280	108	892	117	349	68	127	-2	9.23	5.42

Chicory

Chicory (*Cichorium intybus*) is a perennial plant belonging to the composite plant family (*Compositae*) (Dietl and Jorquera 2003). In agriculture, chicory was frequently categorised as a weed because it commonly grows along roadsides and waste areas (Li and Kemp 2005). The cultivar ‘Grasslands Puna’ was the first forage chicory that was released in New Zealand in 1985 (Rumball 1986 by Li and Kemp 2005). Research has shown that forage chicory is a valuable perennial herb for pastures in the USA (Sanderson *et al.* 2003), in New Zealand (Rumball 1986 by Li and Kemp 2005) and in other continents including Europe and Asia (Barry 1998) due to the good productivity under dry summer conditions. According to Scharenberg *et al.* (2005), chicory is used in Swiss pasture mixtures. It has a high feeding value for ruminants (Li and Kemp 2005) and could positively contribute to the nutritional profile of mixed species pastures, whereas the lack of persistency in the sward has to be taken into account (Sanderson *et al.* 2003). Kusmartono *et al.* (1996 by Barry 1998) reported that the in vitro digestibility of the organic matter of vegetative chicory plants remains relatively constant at 85 % throughout the growing season. These values correspond with the findings of Sanderson *et al.* (2003), who showed an average digestibility of chicory of 86%. Chicory has a higher digestibility when compared to perennial ryegrass irrespective of the season (Min *et al.* 1997, Barry 1998). Due to the higher mineral content in chicory than in perennial ryegrass or red clover, Barry (1998) reported greater amounts of ash (149, 105, 104 g/kg DM for chicory, perennial ryegrass and red clover, respectively). Li and Kemp (2005) stated even higher ash contents of chicory of 188 g/kg DM. Energy content of vegetative chicory (in MJ ME/kg DM) is equivalent to that of vegetative red clover but higher than that of vegetative perennial ryegrass (11.7, 11.0, 12.0 MJ ME/kg DM for chicory, perennial ryegrass and red clover, respectively) (Barry 1998). The crude protein in chicory with values ranging from 134 to 244 g/kg DM is lower than in legumes but higher than in perennial ryegrass (Crush and Evans 1990 by Li and Kemp 2005). Chicory root can be used in pig nutrition where it is known to positively effect the digestion (Dietl and Jorquera 2003). Similar effects occur in ruminants, where condensed tannins in chicory reduce the protein degradation in the rumen.

Red clover

Red clover (*Trifolium pratense*) can be seen as one of the major forage legumes in temperate grassland in Europe and North America. In northern regions, such as Sweden, it is the main legume species and the second most important legume after lucerne in the USA. The high nutritive value and the ability to fixate molecular nitrogen had been responsible for the cultivation of red clover. Mineral nitrogen fertilisation and the variable herbage production lead to a decline in the use of red clover in forage mixtures in some European countries (Frame 1998).

Table 2. Nutrient content and digestibility (based on dry mass) of red clover (*Trifolium pratense*). Modified after DLG, 1997

1st growth vegetation stage	DM (g)	Ash (g)	OM (g)	CP (g)	Fibre (g)	DOM (%)	nXP (g)	RNB (g)	ME (MJ)	NEL (MJ)
before budding	140	105	895	227	158	79	164	+10	11.27	6.87
bud emergence	160	100	900	193	213	76	152	+7	10.68	6.44
begin of flowering	220	93	907	161	261	70	138	+4	9.82	5.82
flowering	250	89	911	150	296	66	135	+2	9.34	5.47
after flowering	280	83	917	141	333	63	128	+2	8.95	5.18

3.1.2 Weed species

Grasses

Three grasses were used as weed grasses in this experiment, although not all of them are classified as weed species in all European countries.

Red fescue (*Festuca rubra*) is an important species of less intensively managed meadows and permanent pastures where it forms dense swards. Especially on alpine sites, red fescue is a valuable forage grass (Dietl *et al.* 1998), whereas on pastures this grass is sometimes rejected by grazing livestock (Klapp and Opitz von Boberfeld 2006). If other grasses like perennial ryegrass or smooth meadow-grass are repressed due to reduced fertilisation, red fescue can spread in the sward and affords changes in management and fertilisation (Klapp and Opitz von Boberfeld 2006).

Annual meadow-grass (*Poa annua*) grows on nutrient-rich, compacted soils and along roads and paths. The nutritive value of annual meadow-grass is low and unlike other meadow-grasses, forage is rejected by animals due to the mouldy odour (Dietl *et al.* 1998). It colonises empty patches in the sward but is low yielding and not resistant against drought. According to Klapp and Opitz von Boberfeld (2006), sowing of annual meadow-grass in agricultural grassland is not desired.

Common bent (Browntop bent) (*Agrostis capillaris*) can be found on less frequently harvested, nutrient poor grassland. In meadows and pastures this grass has only a low nutritive value, whereas it is appreciated in alpine swards (Dietl *et al.* 1998, Klapp and Opitz von Boberfeld 2006).

Herbs

Dandelion (*Taraxacum officinale*) is a perennial herb belonging to the composite plant family (*Compositae*) that forms deep roots of up to 200 cm length. It preferably grows on nutrient-rich soils, which are heavily fertilised with slurry or liquid slurry. Incomplete swards offer open gaps for germination of dandelion (Dietl and Jorquera 2003).

Caraway (*Carum carvi*) builds deep taproots and can grow on humid sites as well as on compacted soils. It can also be found in pastures and meadows, which have a lack of intensively useable grasses like meadow foxtail and perennial ryegrass. Even though herbage and seeds of caraway are rich of energy and protein and have high mineral contents, too much of it in the sward should be repressed by grazing and reseeding of grasses (Dietl and Jorquera 2003).

Legumes

Common vetch (*Vicia sativa*) is an annual legume plant that can be used as an intermediate crop (Dietl and Jorquera 2003).

Tufted vetch (*Vicia cracca*), a perennial legume, is a valuable forage plant in temperate grassland that can be found on nutrient rich sites and in less frequently used meadows (Dietl and Jorquera 2003).

Black medic (*Medicago lupulina*) can form up to 50 cm long taproots. It can be grown at nutrient poor sites in the lowland as well as at alpine sites. It can be characterised as a valuable forage plant that is repressed by fertilisation (Dietl and Jorquera 2003). Black medic prefers calciferous soils but can also grow at sandy sites. This legume is primary used as green manure or in mixtures with other clover species and ryegrass (Freyer *et al.* 2005).

3.2 Methods

The different species were sown on July 10 and 11, 2009 in rectangular pots (27x17x14 cm, LxWxH) in an enclosed outdoor area located in Uppsala, Sweden. Each weed species were sown with each of the grassland species in binary mixtures, which resulted in 27 different treatments. Additionally all species were also sown in pure stands. These 39 treatments were replicated three times. Potting soil was used to fill the pots with each 5.5 l. Before sowing the pots were watered to achieve a compact substrate for sowing. To avoid stagnant moisture the pots had little holes in the bottom for water drainage. The established sward should finally consist of 21 grassland species plants and 8 weed species plants per pot. Due to uneven germination rates more seeds were sown and surplus plants were removed after their emergence. Seeds were covered with 0.25 l of soil which resulted in a 0.5 cm thick layer on top of the seeds. Extra seeds were cultivated on sand in Petri dishes to fill up empty spaces in the pots due to the risk of uncompleted germination. Pots with mixtures were surrounded by cover pots containing perennial ryegrass. In addition to natural rainfall, water was added when needed. Pots were divided into three blocks, representing the three replicates and were randomly distributed over the total experiment area.

3.2.1 Harvest

Plants were harvested block-wise from August 24 to September 5, 2009 at an age of seven to eight weeks. A harvest protocol defined the exact procedure for harvesting the different species. Plants were cut with a solid pair of scissors at soil surface level. If necessary, soil particles were removed from the plants to avoid contamination. Yields were separated in the two species of each pot containing a mixture.

Drying and weighing
All plants were dried at 50 °C for 48 hours in a dryer using aluminium cups. After drying, the weight of the dry mass of each species was determined.

Packing and transportation
Dried samples of crop plants were packed in paper bags and tagged with labels indicating date and description of the treatment. These bags were then sent to Austria by mail and stored at room temperature until further processing.

3.2.2 In vitro analysis of nutritive value

The digestibility of the organic matter of the forage samples was evaluated according to the method of Tilley and Terry (1963). At the Agricultural Research and Education Centre (AREC) Raumberg-Gumpenstein, a modified analysis method is used (Resch 1991). The process of digestion was simulated in the laboratory in two main stages similar to the real procedure in the animal.

Plant samples were milled to a particle size of 1 mm. Exactly 500 mg (± 0.5 mg) was added to a 100 ml Erlenmeyer flask. During the first 48 hours rumen liquor and inorganic buffer solution was added to the feed sample to achieve a degradation of parts of the nutrients like carbohydrates and protein. Rumen liquor was collected from two fistulated oxen to be able to reduce the animal influence on the quality of the liquor. The relatively large volume of buffer solution (40 ml) added to the samples ensured an adequate pH-level in the rumen so the acid production does not exceed the one in the animal (Tilley and Terry 1963). The processes in the abomasum of ruminants were simulated with pepsin and hydrochloric acid for again 48 hours. The remaining feed sample was then dried and weighted. To know the amount of organic matter in the sample, the ash content was analysed by incinerating in a muffle furnace, and the value obtained was then used to calculate the organic matter content. The dry matter content of the plant samples was analysed by near-infrared spectroscopy (NIRS) using a Zeiss Corona 45 Visnir spectrometer, which was necessary for the calculation of the dry matter that was weighted in.

Each plant sample was analysed in three replication in two different runs. Standard feed samples with a defined in vivo digestibility were analysed in order to compare the results of the in vitro experiment with the in vivo values. Blanks containing only rumen liquor were used to find out the indigestible part of the rumen liquor.

3.3 Statistical analysis

The data were analysed with the SAS programme 9.2 using a general linear model. The statistical model included the replicate and the treatment, i. e. mixture or pure stand of the plant species.

Figures and tables were created with the Excel programme.

4 Results

4.1 Crop yield

4.1.1 Perennial ryegrass

The biomass yields of the different treatments, including crop, weed and total pot yields (crop + weed) are shown in figure 1. The bars shown represent mean values of three replicates together with the associated standard deviation.

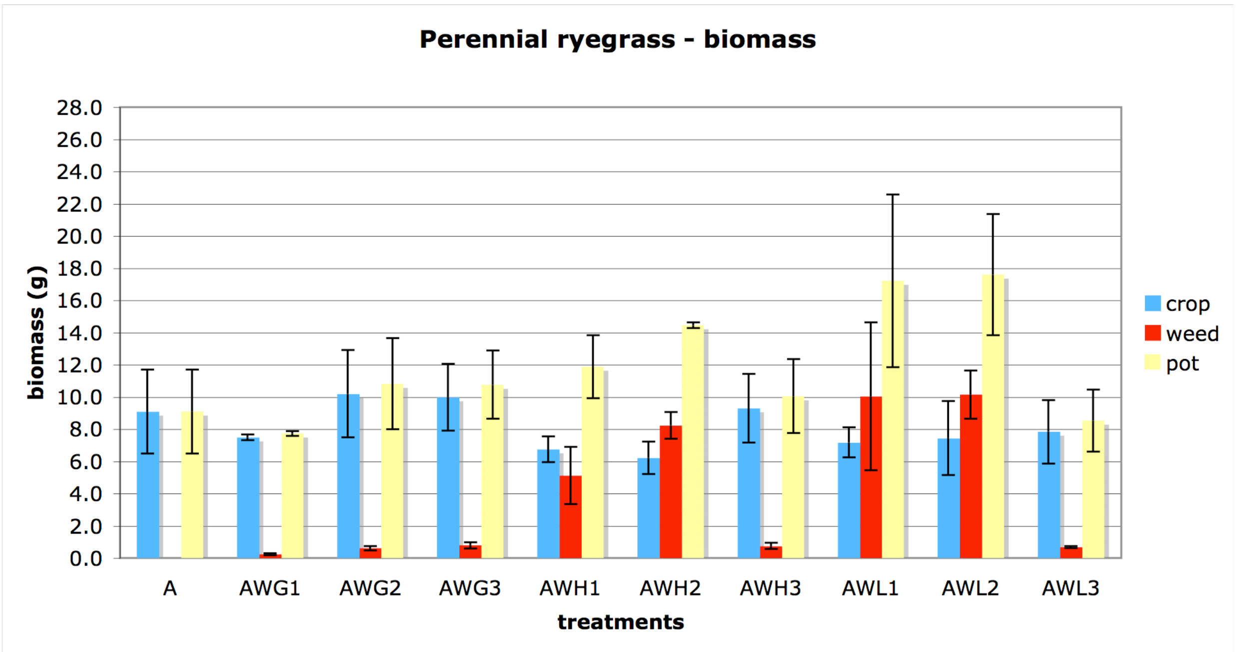

Figure 1. Biomass yield ±SD per pot (in g DM) of treatments including ryegrass yields, weed yields and total pot yields, n=3

Table 3. Biomass yields per pot (in g DM) of crop species perennial ryegrass and the companion weed species. Means with the same letter are not significantly different (p<0.05)

crop	mean	SD	min	max	**weed**	mean	SD	min	max	**crop +weed**	mean	SD	min	max
A	9.1^{ab}	2.6	5.4	11.0	-	-	-	-	-	A	9.1^{ab}	2.6	5.4	11.0
A	7.5^{ab}	0.2	7.3	7.7	WG1	0.2^{a}	0.1	0.2	0.3	AWG1	7.7^{b}	0.1	7.5	7.8
A	10.2^{a}	2.7	6.5	12.9	WG2	0.6^{b}	0.1	0.5	0.8	AWG2	10.8^{ab}	2.8	7.0	13.7
A	10.0^{ab}	2.1	7.4	12.5	WG3	0.8^{b}	0.2	0.6	1.0	AWG3	10.8^{ab}	2.1	8.0	13.2
A	6.8^{ab}	0.8	5.8	7.8	WH1	5.1^{c}	1.8	3.7	7.6	AWH1	11.9^{abc}	2.0	9.5	14.3
A	6.2^{b}	1.0	4.9	7.2	WH2	8.2^{c}	0.8	7.4	9.3	AWH2	14.5^{ac}	0.2	14.2	14.6
A	9.3^{ab}	2.1	6.4	11.5	WH3	0.8^{b}	0.2	0.6	1.0	AWH3	10.1^{ab}	2.3	7.0	12.5
A	7.2^{ab}	0.9	5.9	7.9	WL1	10.0^{c}	4.6	5.1	16.2	AWL1	17.2^{c}	5.4	11.0	24.1
A	7.5^{ab}	2.3	4.3	9.7	WL2	10.2^{c}	1.5	8.3	12.0	AWL2	17.6^{c}	3.8	12.6	21.6
A	7.8^{ab}	2.0	5.8	10.5	WL3	0.7^{b}	0.1	0.6	0.7	AWL3	8.5^{ab}	1.9	6.6	11.1

Table 3 shows the biomass yields of perennial ryegrass and the companion weed species with their average biomass yield of three replicates, the minimum and maximum value and the standard deviation.

The yields of perennial ryegrass (*Lolium perenne*) (A) in monoculture and in mixtures do not differ significantly, except two treatments. The amount of ryegrass biomass produced per pot is in a range between 6.2 g and 10.2 g for the lowest and highest yielding treatment respectively. Treatment A with only crop species perennial ryegrass yielded on average 9.0 g. The yields of ryegrass in mixtures with weed grass species common bent (*Agrostis capillaris*) (AWG2) and red fescue (*Festuca rubra*) (AWG3) tended to be higher than pure stand ryegrass, although these differences were not significant. Low amounts of ryegrass biomass were found for broad-leaved weed herb species dandelion (*Taraxacum officinale*) (AWH1) and chicory (*Cichorium intybus*) (AWH2) but unexpectedly also for all three weed legume species. Ryegrass in treatment including common bent (AWG2) produced significantly more biomass than ryegrass in the treatment with chicory (AWH2).

The biomass yields for the weed species sown in binary mixtures with perennial ryegrass are shown in the same figure. Due to the various species involved, the yields range from 0.2 g (WG1) to 10.1 g (WL2). Very low biomass yields can be observed for all three weed grass species, for herb caraway (*Carum carvi*) (WH3) and for legume black medic (*Medicago lupulina*) (WL3). The broad-leaved herb species dandelion and chicory produced 5.1 g and 8.2 g biomass per pot, respectively. The highest biomass yields for weed species in mixtures with ryegrass are those of legume species common vetch (*Vicia sativa*) (WL1) and tufted vetch (*Vicia cracca*) (WL2) with 10.0 g and 10.1 g, respectively. The broad-leaved weed herbs and the Vicia species had significantly higher yields than the other weed species. In treatments with chicory (AWH2), common vetch (AWL1) and tufted vetch (AWL2), the weed species produced higher biomass yields than ryegrass did.

No weed species grown in mixture with crop species perennial ryegrass could significantly influence the yield of ryegrass when compared to monoculture, whereas two treatments differed from each other in their biomass yield. Weed grass species produced very low amounts of biomass and no influence on the yield of ryegrass can be noticed. High amounts of weed biomass tended to reduce the yield of ryegrass as seen in treatments with dandelion (WH1) and chicory (WH2), whereas these effects are not significant. Although weed legumes WL1 and WL2 produced the highest amounts of biomass for treatments with ryegrass, their influences on perennial ryegrass can be regarded as similar as the influence of weed herbs WH1 and WH2 on ryegrass yield. Weed legume species WL3 produced little amount of biomass, but the yields of perennial ryegrass were similar to the ones of WL1 and WL2, i.e. ryegrass yields are nearly the same for all three weed legume treatments (AWL1, AWL2, AWL3), although the yields of the companion weed species differed widely.

Figure 2 describes the correlation between crop and weed biomass yield for perennial ryegrass when values for crop yield are plotted against weed yield. The yield of ryegrass was lowered due to high weed biomass production.

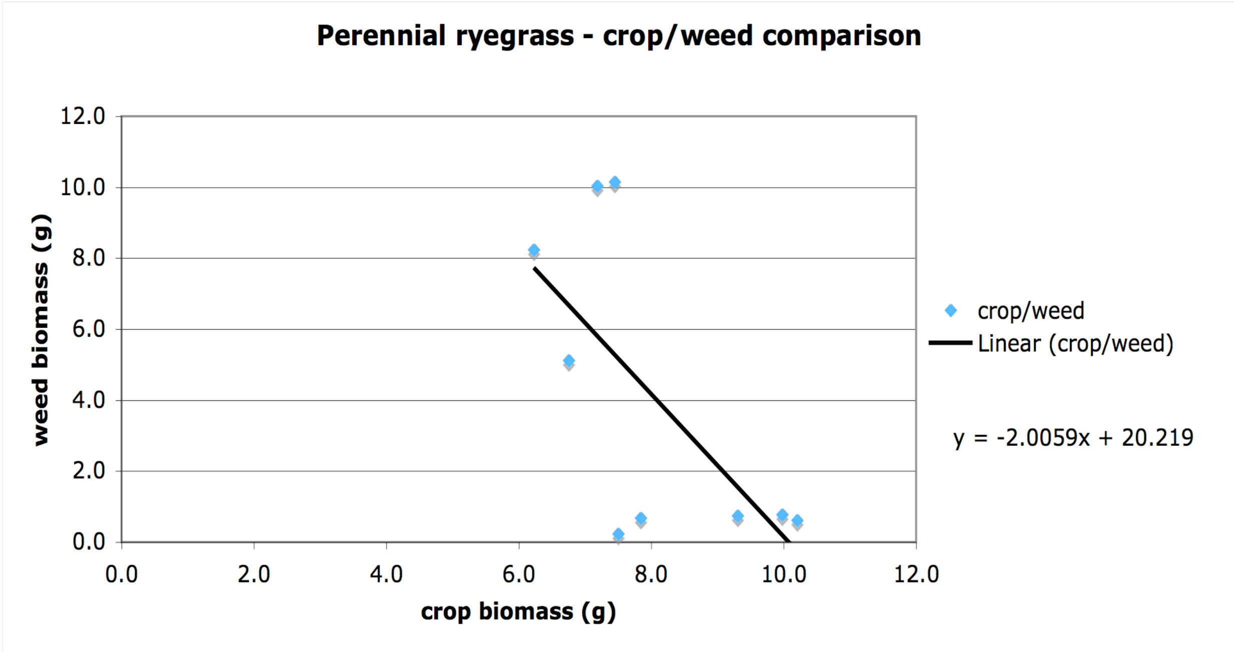

Figure 2. Comparison of crop and weed biomass yields per pot (in g DM) for treatments including crop species perennial ryegrass

4.1.2 Chicory

The biomass yields of the different treatments, including crop, weed and total pot yields (crop + weed) are shown in figure 3. The bars shown represent mean values of three replicates together with the associated standard deviation.

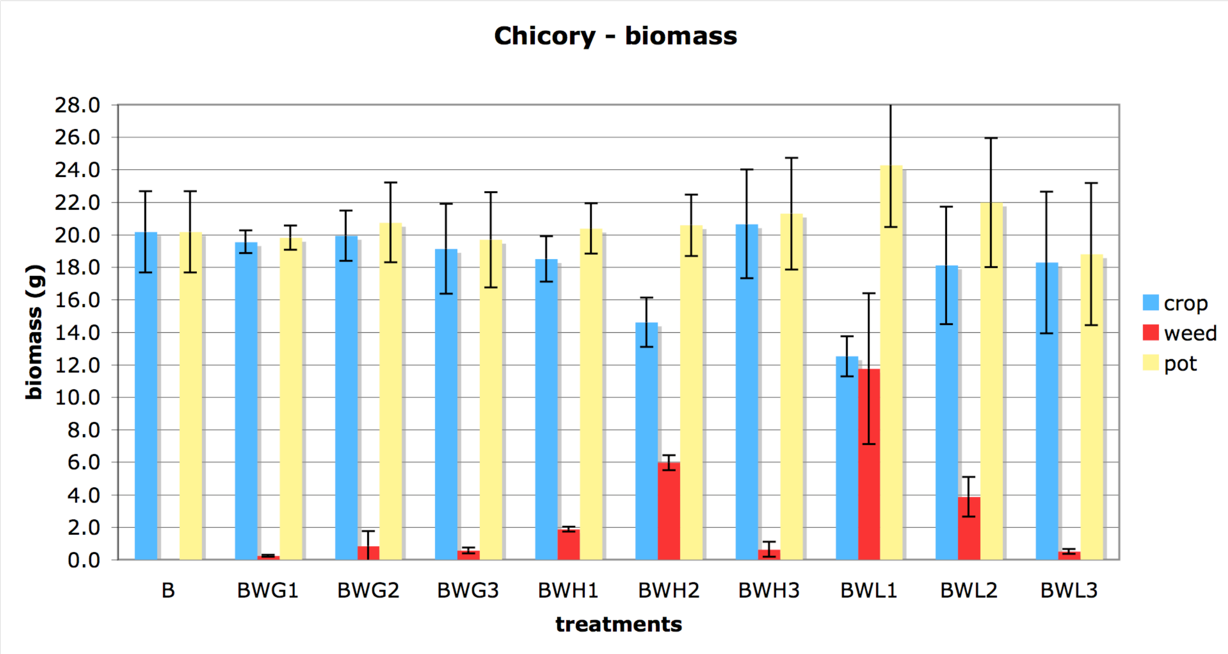

Figure 3. Biomass yield ±SD per pot (in g DM) of treatments including chicory yields, weed yields and total pot yields, n=3

Table 4. Biomass yields (in g DM) of crop species chicory and the companion weed species. Means with the same letter are not significantly different (p<0.05)

crop	mean	SD	min	max	**weed**	mean	SD	min	max	**crop + weed**	mean	SD	min	max
B	20.2^{a}	2.5	16.7	22.5	-	-	-	-	-	B	20.2^{a}	2.5	16.7	22.5
B	19.6^{a}	0.7	18.8	20.5	WG1	0.2^{a}	0.1	0.2	0.3	BWG1	19.8^{a}	0.7	19.0	20.8
B	19.9^{a}	1.5	18.5	22.1	WG2	0.8^{ab}	0.9	0.2	2.1	BWG2	20.8^{a}	2.4	18.7	24.2
B	19.1^{a}	2.8	15.2	21.3	WG3	0.6^{ab}	0.2	0.3	0.8	BWG3	19.7^{a}	2.9	15.5	21.9
B	18.5^{ab}	1.4	17.0	20.3	WH1	1.9^{bc}	0.1	1.7	2.0	BWH1	20.4^{a}	1.5	18.7	22.4
B	14.6^{ab}	1.5	12.5	16.1	WH2	6.0^{c}	0.4	5.6	6.6	BWH2	20.6^{a}	1.9	18.1	22.7
B	20.7^{a}	3.4	16.2	24.2	WH3	0.6^{ab}	0.5	0.3	1.3	BWH3	21.3^{a}	3.5	16.5	24.5
B	12.5^{b}	1.2	10.9	13.9	WL1	11.8^{c}	4.6	6.7	17.9	BWL1	24.3^{a}	3.8	19.5	28.8
B	18.1^{ab}	3.6	13.0	20.7	WL2	3.9^{c}	1.2	2.5	5.5	BWL2	22.0^{a}	4.0	16.6	26.1
B	18.3^{ab}	4.4	1.1	21.7	WL3	0.5^{ab}	0.2	0.3	0.7	BWL3	18.8^{a}	4.4	12.7	22.4

Crop species chicory (B) in monoculture produced 20.2 g of biomass over the three replicates. The crop yields range from 12.5 g for treatment with common vetch (BWL1) to 20.6 g for treatment caraway (BWH3). The yields of chicory in the three weed grass treatments did not significantly differ from pure stand yields. Crop yields in treatments with WH1 and WH3 were similar to the monoculture yields, whereas the broad-leaved weed chicory (WH2) tended to reduce the biomass yield of crop chicory. The lowest chicory biomass yield can be observed for treatment BWL1 with weed species common vetch.

Significant influences on chicory biomass yield can be observed in treatment with common vetch, where crop biomass was significantly lower than in pure stands and in the treatment with caraway (BWH3). The weed legumes tufted vetch and black medic did not significantly affect crop production and crop yields were similar, although tufted vetch produced more weed biomass than black medic did.

4.1.3 Red clover

The biomass yields of the different treatments, including crop, weed and total pot yields (crop + weed) are shown in figure 4. The figures for crop and weed yields are mean values over three replicates together with the associated standard deviation.

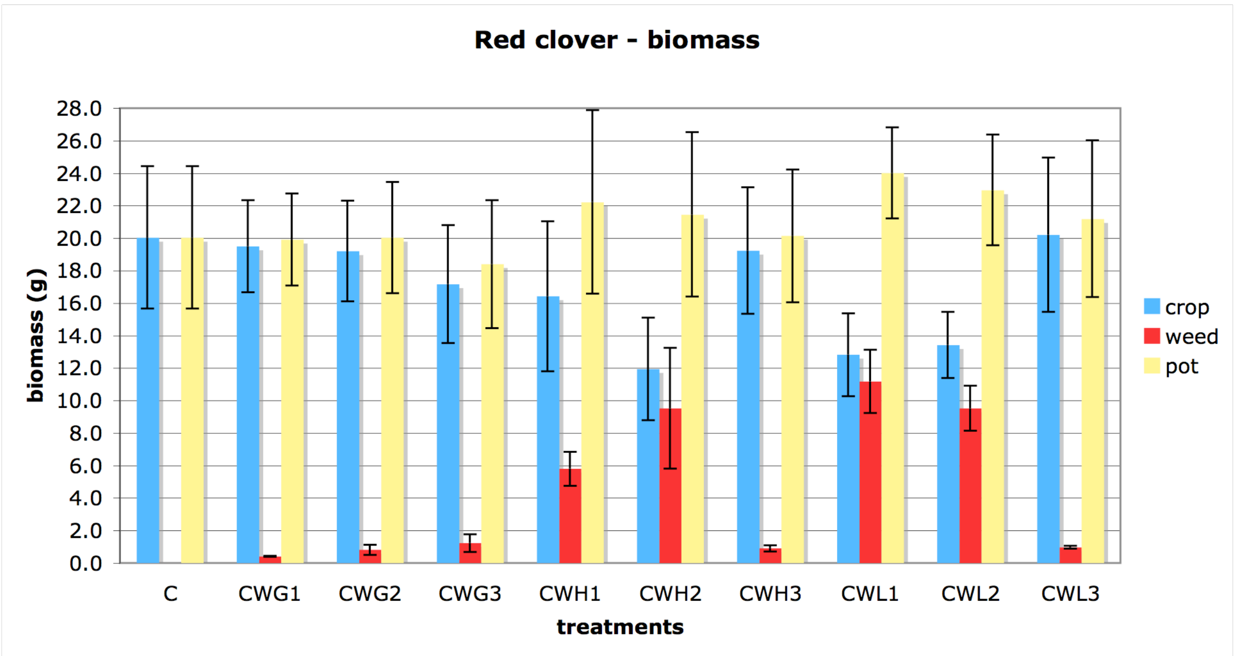

Figure 4. Biomass yield ±SD per pot (in g DM) of treatments including red clover yields, weed yields and total pot yields, n=3

Table 5. Biomass yields (in g DM) of crop species red clover and the companion weed species. Means with the same letter are not significantly different (p<0.05)

crop	mean	SD	min	max	**weed**	mean	SD	min	max	**crop+weed**	mean	SD	min	max
C	20.0^{a}	4.4	13.9	23.7	-	-	-	-	-	C	20.0^{ab}	4.4	13.9	23.7
C	19.5^{a}	2.8	15.5	21.9	WG1	0.4^{a}	0.0	0.4	0.4	CWG1	19.9^{ab}	2.8	15.9	22.3
C	19.2^{a}	3.1	14.8	21.6	WG2	0.8^{a}	0.3	0.4	1.1	CWG2	20.0^{ab}	3.4	15.2	22.6
C	17.2^{ab}	3.6	12.2	20.8	WG3	1.2^{a}	0.5	0.7	2.0	CWG3	18.4^{a}	3.9	12.9	21.8
C	16.4^{ab}	4.6	10.1	20.9	WH1	5.8^{ab}	1.1	4.3	6.6	CWH1	22.2^{ab}	5.7	14.4	27.6
C	11.9^{b}	3.2	8.6	16.2	WH2	9.5^{b}	3.7	5.8	14.6	CWH2	21.5^{ab}	5.1	14.3	25.7
C	19.2^{a}	3.9	14.0	23.4	WH3	0.9^{a}	0.2	0.7	1.2	CWH3	20.1^{ab}	4.1	14.7	24.6
C	12.8^{b}	2.6	9.5	15.7	WL1	11.2^{b}	1.9	9.0	13.7	CWL1	24.0^{b}	2.8	20.3	27.0
C	13.4^{b}	2.0	10.6	15.1	WL2	9.5^{b}	1.4	7.7	10.9	CWL2	23.0^{ab}	3.4	18.2	26.0
C	20.2^{a}	4.7	13.7	24.8	WL3	1.0^{a}	0.1	0.9	1.1	CWL3	21.2^{ab}	4.8	14.5	25.8

The crop species red clover sown in monoculture produced 20.0 g biomass per pot. Biomass yields of Red clover range from 20.0 g for treatment with caraway (CWL3) to 11.9 g for treatment with chicory (CWH2). Crop species red clover yielded on average the same amount of biomass in all three weed grass treatments, in weed herb treatment with Caraway, and in weed legume treatment with black medic. Biomass production tended to be lower for the treatment including dandelion (CWH1). Three treatments produced significantly less crop biomass than the monoculture pot of red clover, including treatments with chicory (CWH2), common vetch (CWL1), and tufted vetch (CWL2).

Low amounts of weed biomass were produced in all three weed grass treatments, in weed herb treatment CWH3 and in weed legume treatment CWL3, where crop biomass production was on a similar level as the monoculture crop yield. It can thus be assumed that the low amounts of weed biomass did not affect the growth of red clover. High amounts of weed biomass can be seen in all three treatments where crop biomass was significantly lower than in monoculture (treatments CWH2, CWL1 and CWL2).

The total pot biomass yield was significantly different between the treatments with red fescue (CWG3) and Common vetch (CWL1), but no treatment was significantly different from pure stand of red clover.

4.1.4 Weed species

The biomass yields of the different weed species are shown in figure 5, including weed yield from pure stand and weed yield from mixtures with the three crop species. The figures of weed yields are mean values over three replicates together with the associated standard deviation.

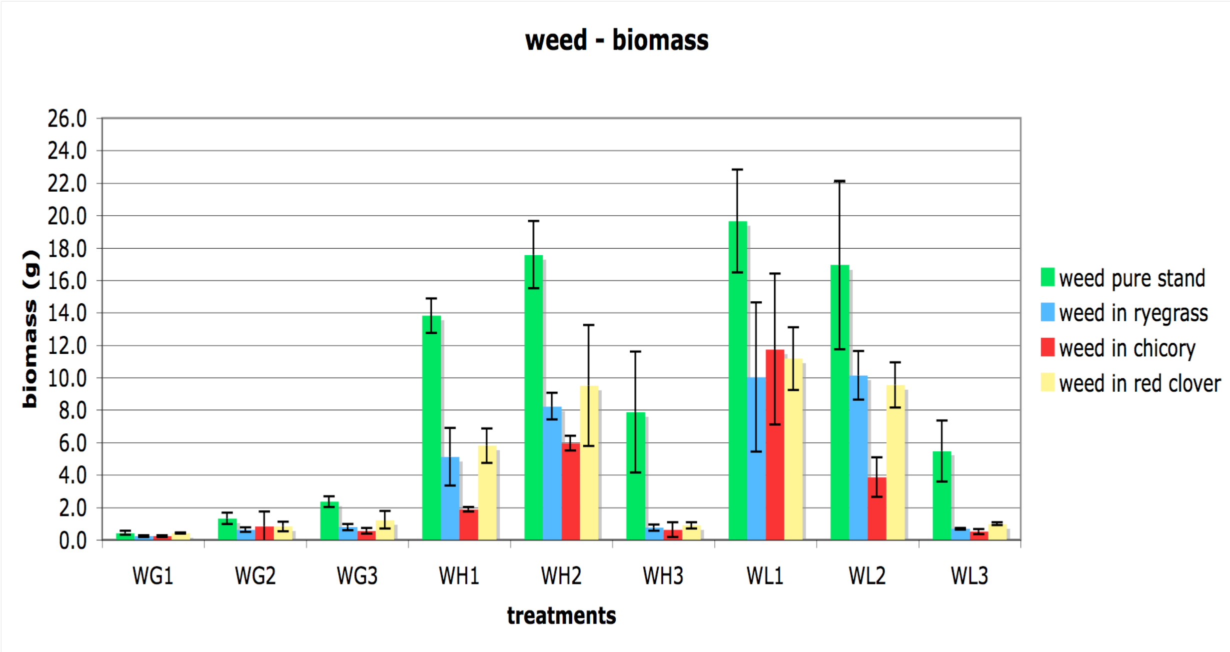

Figure 5. Biomass yields ±SD per pot (in g DM) of weed species in pure stands and in the different treatments, n=3

Table 6. Biomass yields per pot (in g DM) of weed species in pure stands and in mixtures with perennial ryegrass, chicory and red clover. The figures are mean values of three replicates. Means with the same letter are not significantly different (p<0.05)

	WG1	WG2	WG3	WH1	WH2	WH3	WL1	WL2	WL3
pure stand	0.4^{a}	1.3^{a}	2.4^{a}	13.8^{a}	17.6^{a}	7.9^{a}	19.7^{a}	16.9^{a}	5.5^{a}
perennial ryegrass	0.2^{a}	0.6^{a}	0.8^{a}	5.1^{b}	8.2^{b}	0.8^{b}	10.0^{b}	10.2^{ab}	0.7^{a}
chicory	0.2^{a}	0.8^{a}	0.6^{a}	1.9^{b}	6.0^{b}	0.6^{b}	11.8^{b}	3.9^{b}	0.5^{a}
red clover	0.4^{a}	0.8^{a}	1.2^{a}	5.8^{b}	9.5^{b}	0.9^{b}	11.2^{b}	9.5^{b}	1.0^{a}

The weed species used in this experiment produced different biomass yields when sown in pure stands. Similar biomass production can be observed for all three weed grass species which did not produce more than 1.2 g per pot, disregarding the crop partner. High biomass values can be found for the broad-leaved herbs dandelion (WH1) and chicory (WH2), which produced on average 13.8 g and 17.5 g, respectively. The highest yielding weed species was common vetch (WL1) with a biomass yield of 19.6 g per pot, and tufted vetch (WL2) which produced 16.9 g per pot in pure stands.

Significant differences in weed biomass yield between pure stands and mixtures are shown in Table 6. It can be noticed that the presence of a companion grass, herb and legume had effected the biomass yields of some of the weed species. Weed grass species annual meadow-grass (WG1), common bent (WG2) and red fescue (WG3) showed no significant changes in biomass yield when sown in mixtures when compared to monoculture yields, which were in general at a low level. Broad-leaved weed herbs in pure stands obtained high biomass production but the presence of a companion crop species significantly reduced the weed yield, despite the type of crop species, although weed biomass yields tended to be lowest for mixtures with crop species chicory. Caraway (WH3) yield was significantly higher in pure stands than in all three mixtures with other crops, similar relations can be observed for black medic (WL3). In both cases, weed biomass yields in mixtures were below 1 g per pot, whereas plants in pure stands produced 7.8 and 5.4 g per pot for WH3 and WL1, respectively.

4.2 Organic matter

4.2.1 Perennial ryegrass

The content of the organic matter of perennial ryegrass is shown in table 7.

Table 7. Organic matter (in g/kg DM) of perennial ryegrass in pure stand and mixtures

	mean	max	min	SD
A	861.3	871.6	847.5	10.2
AWG1	855.2	871.5	844.5	11.7
AWG2	870.9	879.7	859.8	8.3
AWG3	867.0	872.0	858.4	6.1
AWH1	854.2	856.0	852.4	1.5
AWH2	859.4	869.2	850.3	7.8
AWH3	861.5	868.6	853.1	6.4
AWL1	856.6	865.4	850.4	6.4
AWL2	862.7	867.4	855.1	5.4
AWL3	854.7	865.3	840.7	10.4

The content of organic matter of perennial ryegrass in pure stand is not significantly different from perennial ryegrass in mixtures with weed species. The organic matter content of perennial ryegrass in pure stands was on average 860 g/kg DM. The values range from 854.2 to 870.9 g for treatments with dandelion (AWH1) and common bent (AWG2), respectively.

4.2.2 Chicory

The content of the organic matter of chicory is shown in table 8.

Table 8. Organic matter (in g/kg DM) of chicory in pure stand and mixtures

	mean	max	min	SD
B	877.7	882.5	869.5	5.8
BWG1	874.8	882.9	865.5	7.1
BWG2	877.6	880.5	872.8	3.4
BWG3	875.9	887.0	860.6	11.2
BWH1	876.6	891.7	864.1	11.4
BWH2	879.3	891.2	869.9	8.8
BWH3	884.1	890.1	872.3	8.3
BWL1	880.9	888.1	872.1	6.6
BWL2	877.7	894.1	865.8	12.0
BWL3	879.4	890.2	868.4	8.9

The organic matter contents of chicory were on a higher level as the respective values for perennial ryegrass and differences between the treatments were not so strong. No treatment was significantly different from pure stand chicory. Values ranged between 874.8 g for treatment with annual meadow-grass (BWG1) and 884.1 g for the mixture with caraway (BWH3).

4.2.3 Red clover

The content of the organic matter of red clover is shown in table 9.

Table 9. Organic matter (in g/kg DM) of Red clover in pure stand and mixtures

	mean	max	min	SD
C	866.5	881.1	846.3	14.8
CWG1	864.4	878.7	850.6	11.5
CWG2	866.8	876.1	852.6	10.2
CWG3	855.2	871.8	846.9	11.7
CWH1	878.8	887.4	867.5	8.3
CWH2	879.4	894.2	860.3	14.2
CWH3	868.1	875.6	854.4	9.7
CWL1	872.3	877.1	865.8	4.8
CWL2	871.6	879.0	860.2	8.2
CWL3	868.2	883.2	853.0	12.3

The content of organic matter of crop species red clover ranges between 855.2 g and 879.4 g for mixtures with red fescue (CWG3) and Chicory (CWH2), respectively. No treatment was significantly different in the content of the organic matter of red clover.

4.3 Digestibility of the organic matter

4.3.1 Perennial ryegrass

The digestibility of the organic matter of perennial ryegrass in pure stands and mixtures is presented in table 10. The figures are mean values over three replicates together with the associated standard deviation.

Table 10. Digestibility of the organic matter (in %) of perennial ryegrass in pure stand and mixtures

	mean	max	min	SD
A	76.3	78.1	72.8	2.4
AWG1	76.7	77.0	76.4	0.2
AWG2	79.4	81.2	77.1	1.7
AWG3	78.3	80.0	75.9	1.8
AWH1	74.4	75.5	73.5	0.9
AWH2	78.9	80.2	77.9	1.0
AWH3	77.9	78.4	77.2	0.5
AWL1	76.5	82.3	71.2	4.6
AWL2	76.3	80.9	73.1	3.4
AWL3	75.3	78.2	71.1	3.0

The digestibility of the organic matter of perennial ryegrass in pure stands was on average 76.2 %. No significant differences in ryegrass digestibility could be found between the treatments.

4.3.2 Chicory

The digestibility of the organic matter of chicory in pure stands and mixtures is shown in table 11. The figures are mean values over three replicates together with the associated standard deviation.

Table 11. Digestibility of the organic matter (in %) of Chicory in pure stand and mixtures

	mean	max	min	SD
B	87.0	88.1	85.2	1.3
BWG1	84.5	85.5	83.6	0.8
BWG2	85.5	86.8	84.8	1.0
BWG3	84.9	86.7	83.6	1.3
BWH1	86.6	87.4	86.1	0.6
BWH2	88.2	89.9	86.8	1.3
BWH3	88.6	89.3	87.5	0.8
BWL1	86.1	87.1	84.1	1.4
BWL2	86.6	87.9	84.4	1.6
BWL3	85.5	87.9	84.3	1.7

Chicory in pure stands had on average a digestibility of the organic matter of 87.0 %. The digestibility was not significantly different between all treatments.

4.3.3 Red clover

The digestibility of the organic matter of red clover in pure stands and mixtures is shown in table 12. The figures are mean values over three replicates together with the associated standard deviation.

Table 12. Digestibility of the organic matter (in %) of red clover in pure stand and mixtures. Means with the same letter are not significantly different (p<0.05)

	mean	max	min	SD
C	71.8^{ab}	72.9	70.8	0.9
CWG1	71.4^{abc}	74.2	69.9	2.0
CWG2	73.1^{a}	74.2	71.8	1.0
CWG3	66.8^{bc}	67.7	66.2	0.6
CWH1	70.0^{abc}	71.8	67.3	1.9
CWH2	71.0^{abc}	71.1	70.7	0.2
CWH3	68.8^{abc}	69.9	67.5	0.9
CWL1	66.4^{c}	68.0	64.9	1.3
CWL2	71.0^{abc}	72.0	69.2	1.2
CWL3	69.3^{abc}	71.1	66.0	2.3

Red clover organic matter in pure stands had on average 71.8 % digestibility. Clover in the treatment with common vetch (CWL1) had a significantly lower digestibility than clover in pure stand.

4.4 Net energy content

Net energy concentrations were calculated on the basis of digestible organic matter.

4.4.1 Perennial ryegrass

Table 13 shows energy contents of perennial ryegrass in pure stand and in mixtures.

Table 13. Energy content of perennial ryegrass (in MJ NEL/kg DM); Values are means of three replicates, minimum and maximum values and the associated standard deviation

	mean	min	max	SD
A	6.03	5.53	6.29	0.35
AWG1	6.02	5.88	6.20	0.13
AWG2	6.45	6.09	6.67	0.26
AWG3	6.30	5.95	6.53	0.25
AWH1	5.76	5.66	5.86	0.08
AWH2	6.30	6.10	6.53	0.18
AWH3	6.20	6.04	6.29	0.11
AWL1	6.01	5.38	6.72	0.55
AWL2	6.04	5.74	6.58	0.38
AWL3	5.87	5.28	6.27	0.42

Mean energy values for net energy concentration of perennial ryegrass range from 5.76 to 6.45 MJ NEL/kg DM for treatments including dandelion (AWH1) and common bent (AWG2), respectively. The treatments did not differ significantly in their energy concentration at a probability level of 5 %.

4.4.2 Chicory

Table 14 shows energy contents of chicory in pure stands and in mixtures.

Table 14. Energy content of Chicory (in MJ NEL/kg DM); Values are means of three replicates, minimum and maximum values and the associated standard deviation

	mean	min	max	SD
B	7.36	7.20	7.54	0.14
BWG1	7.06	6.87	7.18	0.14
BWG2	7.19	7.06	7.36	0.12
BWG3	7.12	6.81	7.42	0.25
BWH1	7.30	7.24	7.41	0.08
BWH2	7.51	7.39	7.67	0.12
BWH3	7.61	7.36	7.75	0.18
BWL1	7.29	6.98	7.48	0.22
BWL2	7.32	7.03	7.61	0.24
BWL3	7.22	7.09	7.36	0.11

Net energy concentration for chicory was on a higher level than the respective values for perennial ryegrass and ranged from 7.06 to 7.61 MJ NEL/kg DM for treatments BWG1 and BWH3, respectively. The net energy concentration of all treatments including chicory was 7.30 MJ NEL/kg DM. The treatments with chicory did not differ significantly in their net energy concentration.

4.4.3 Red clover

Net energy contents of red clover in pure stands and in mixtures are shown in Table 15.

Table 15. Energy content of red clover (in MJ NEL/kg DM); Values are means of three replicates, minimum and maximum values and the associated standard deviation. Means with the same letter are not significantly different (p<0.05)

	mean	min	max	SD
C	5.59^{ab}	5.30	5.76	0.21
CWG1	5.52^{ab}	5.37	5.70	0.14
CWG2	5.73^{a}	5.63	5.94	0.15
CWG3	4.95^{b}	4.82	5.07	0.10
CWH1	5.50^{ab}	5.11	5.77	0.29
CWH2	5.62^{ab}	5.46	5.72	0.11
CWH3	5.28^{ab}	5.03	5.46	0.18
CWL1	5.05^{ab}	4.93	5.24	0.14
CWL2	5.54^{ab}	5.38	5.70	0.13
CWL3	5.33^{ab}	4.97	5.63	0.27

The lowest net energy concentration of red clover was measured for treatment CWG3 (red fescue) with a mean value of 4.95 MJ NEL/kg DM. Treatment including weed grass common bent (CWG2) had the highest energy concentration of all red clover samples with 5.73 MJ NEL/kg DM. These two values differ significantly at the 5% level of probability.

4.5 Quality yield

The quality yield (J NEL/pot) was calculated on pot level by using the biomass yield and the energy content of the respective crops.

Quality yields (in J NEL/pot) for crop species perennial ryegrass, chicory and red clover in pure stand and the different treatments are presented in figure 6.

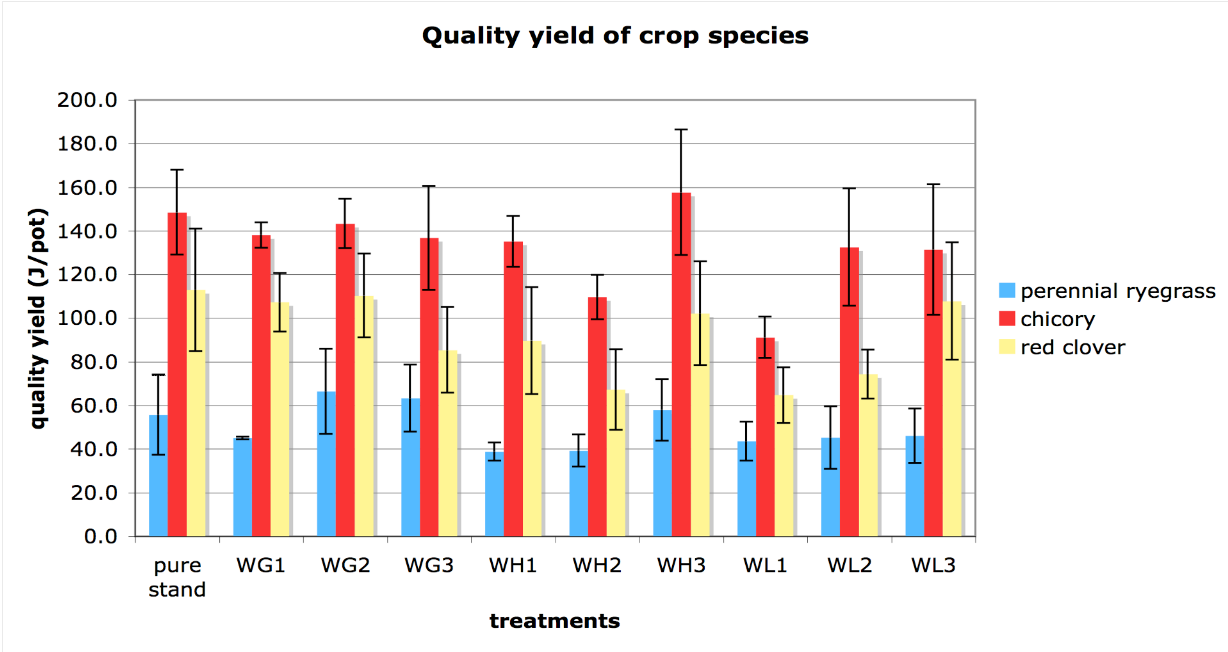

Figure 6. Quality yield ±SD (in J NEL/pot) of crop species perennial ryegrass, chicory and red clover in pure stand and the different treatments, n=3

4.5.1 Perennial ryegrass

The quality yield of perennial ryegrass in pure stands and mixtures is shown in table 16.

Table 16. Quality yield of perennial ryegrass (in J NEL/pot); Values are means of three replicates, minimum and maximum values and the associated standard deviation

	mean	max	min	SD
A	55.7	69.3	29.8	18.3
AWG1	45.1	45.8	44.4	0.6
AWG2	66.5	85.4	39.6	19.6
AWG3	63.4	81.5	44.1	15.3
AWH1	38.9	43.9	33.5	4.2
AWH2	39.4	47.2	29.6	7.3
AWH3	58.0	72.3	38.8	14.1
AWL1	43.6	53.1	31.5	9.0
AWL2	45.2	55.4	24.9	14.4
AWL3	46.0	63.6	36.6	12.5

The quality yield of crop species perennial ryegrass in pure stands was not significantly different from any of the other treatments. Ryegrass in mixtures with productive weed species like broad-leaved herbs dandelion and chicory as well as the legumes common vetch and tufted vetch tended to result in lower quality yields than in mixtures with weed grasses and caraway. Quality yield per pot was on a lower level compared to the other crop species with values ranging from 38.9 to 66.5 J NEL/pot for treatments with dandelion and common bent, respectively.

4.5.2 Chicory

Chicory quality yield of pure stands and mixtures is presented in table 17.

Table 17. Quality yield of chicory (in J NEL/pot); Values are means of three replicates, minimum and maximum values and the associated standard deviation. Means with the same letter are not significantly different (p<0.05)

	mean	max	min	SD
B	148.6^{ab}	169.7	122.9	19.4
BWG1	138.1^{abc}	146.2	133.4	5.7
BWG2	143.4^{ab}	157.9	130.4	11.3
BWG3	136.8^{abc}	157.9	103.6	23.7
BWH1	135.2^{abc}	150.8	122.8	11.6
BWH2	109.7^{bc}	120.7	96.2	10.2
BWH3	157.7^{a}	187.6	118.9	28.7
BWL1	91.3^{c}	103.8	80.8	9.5
BWL2	132.6^{abc}	157.4	95.3	26.8
BWL3	131.5^{abc}	153.9	89.3	29.9

The quality yield of chicory in pure stand was significantly different from chicory in treatments with chicory as a weed herb and legume species common vetch. Calculated per pot, chicory quality yields were ranging from 91.3 to 157.7 J NEL/pot for treatments with common vetch and caraway, respectively.

4.5.3 Red clover

The quality yield of red clover in pure stands and mixtures is presented in table 18.

Table 18. Quality yield of red clover (in J NEL/pot); Values are means of three replicates, minimum and maximum values and the associated standard deviation. Means with the same letter are not significantly different (p<0.05)

	mean	max	min	SD
C	113.0^{a}	136.4	73.6	28.0
CWG1	107.3^{ab}	117.6	88.4	13.4
CWG2	110.3^{a}	126.0	83.3	19.2
CWG3	85.4^{abcd}	105.3	58.8	19.6
CWH1	89.8^{abcd}	117.9	58.2	24.5
CWH2	67.3^{cd}	91.7	46.8	18.5
CWH3	102.2^{abc}	127.7	70.5	23.8
CWL1	64.7^{d}	77.3	47.1	12.8
CWL2	74.4^{bcd}	83.3	58.6	11.2
CWL3	107.8^{ab}	139.5	73.8	26.9

Several treatments had quality yields for red clover which were significantly different from pure stand clover. In treatments with weed herb chicory and legumes common vetch and tufted vetch, red clover quality yield was significantly lower than in pure stands. Red clover quality yields per pot were between 67.3 and 113.0 J NEL/pot for the mixture including weed chicory and for pure stand red clover.

5 Discussion

The present study was based on a plant experiment conducted in Uppsala, Sweden, during summer 2009 where the influence of different weeds on the productivity of forage crops was analysed. Plant samples from this trial were analysed at AREC Raumberg-Gumpenstein for their nutritional value in an in vitro experiment.

The unexpected large variation between the values of the three replicates of each treatment in the experiment might be due to prolonged harvesting of the swards. One replicate, which has been harvested before the other two replicates because of limited work capacity, showed values for biomass production which were lower than the respective values in the other replicates.

Other influences on the germination and development of the plants in this experiment, such as weather conditions, were not evaluated.

5.1 Biomass yield

When comparing the biomass yields of the three crop species grown in monoculture with the respective values of binary mixtures, significant differences can be observed in some cases.

Perennial ryegrass produced on average 8.2 g DM per pot in the three pure stands, which was lower compared to red clover (17.0 g DM/pot) and chicory (18.1 g DM/pot). The pure stand biomass yield was not significantly different from the values for perennial ryegrass in mixtures. The treatments including broad-leaved weed herbs dandelion and chicory and legumes common vetch and tufted vetch led to a reduction of the biomass production of perennial ryegrass more than any other weed species. The ryegrass biomass yields were significantly lower than the ryegrass yields of two of the mixtures including weed grasses. Weed biomass yields were in all cases reduced by the presence of a crop species in mixtures compared to weed pure stands. The total mixture yields show that some of the mixtures could significantly increase their total biomass production compared to monoculture stands. Especially the combination of each of the two vetch species common vetch and tufted vetch with perennial ryegrass resulted in a high total mixture yield, exceeding the one of pure stand ryegrass. These benefits of grass-legume mixtures on biomass production are well described in literature (Helgadóttir *et al.* 2008, Lüscher *et al.* 2008, Nyfeler *et al.* 2009, Pötsch and Resch 2006). The reduction of biomass yield for perennial ryegrass in mixtures with broad-leaved herbs can be due to the relatively high competitive biomass production of these weed species.

It has to be stated that even though common vetch and tufted vetch assembled high amounts of biomass, their influence on the yield of perennial ryegrass was not stronger than the one of black medic, which had very low biomass yields. It can thus be concluded that growing legumes and perennial ryegrass in mixtures in this experiment did not lead to a reduction in grass biomass yield, despite the variable legume yields under this conditions. The low yields of weed grasses could not significantly influence the biomass production of perennial ryegrass, which underlines the high competitiveness of perennial ryegrass.

Average biomass production of crop species chicory in pure stands was 18.1 g DM per pot. In the treatment of chicory with legume common vetch, a significant reduction of chicory yield could be observed. Common vetch was the highest yielding weed species in mixtures with chicory and this treatment produced the highest total pot yields, although the crop yields were the lowest. As expected, very low biomass yields were produced by the three weed grass species, black medic and caraway in combination with chicory. Within the total mixture yields, no significant differences could be observed, although the combination of chicory and common vetch tended to be the most productive mixture.

Red clover produced on average 17.0 g DM per pot in pure stands. When compared with red clover yields from mixtures, several treatments showed significant differences. The presence of weed chicory, common vetch and tufted vetch in mixtures with red clover could significantly lower the yield of red clover. These weed species were the most productive ones in mixtures with red clover and the clover biomass reduction can be explained by the high weed biomass production in these pots.

Within all crop species, the high producing weed species dandelion, chicory, common vetch and tufted vetch had influenced the biomass production of the three crop species. The legume species common vetch and tufted vetch could probably better cope with the growing conditions at the site, especially with the limited amount of soil for rooting, as they have the ability to fixate air nitrogen. Although the root systems of the investigated crop and weed species and its influence on each other has not been analysed in the present study, this might also be an explanation for the reduced crop biomass in mixtures with deep-rooting weed herbs (Huber-Sannwald 2001). Broad-leaved herbs like dandelion and chicory as well as legume species common vetch and tufted vetch with great amount of biomass lead to shading of the companion species and could thus have negatively influenced the growth of the companion plant (Huber-Sannwald 2001).

The low biomass production of all three weed grass species can be observed in the pure stands as well as in all mixtures with crops. It can be assumed that the chosen weed grass species were slow in establishment and were thus not able to compete in mixtures (Huber-Sannwald 2001).

5.2 Organic matter

The content of organic matter is linked to the crude ash concentration in the forage. High crude ash contents negatively influence the contents of organic matter. Throughout all crop species, crude ash contents of the plant samples (data not shown) were relatively high compared to the values from DLG (1997), which was responsible for the low organic matter content. For perennial ryegrass, crude ash content ranges between 117 and 101 g/kg DM within all development stages (DLG 1997). Mean crude ash content of all perennial ryegrass samples in the present study was 139 g/kg DM, which can be explained by the overall low cutting height that has been used at harvest to assure a maximum of collected biomass. This could have probably led to an increased contamination with soil particles. Mean crude ash content of chicory was 121 g/kg DM within all plant samples. After DLG (1997) red clover has crude ash contents ranging from 105 to 83 g/kg DM. The mean values in the present experiment were 130 g/kg DM, which might have the same explanation than the high contents in perennial ryegrass.

5.3 Digestibility of the organic matter

The digestibility of the organic matter is of great importance for the evaluation of forage used for animal nutrition (Schubiger *et al.* 2001b). It provides information about the concentration of digestible nutrients and how the organic matter can be used by the ruminants in their digestive tract. Many forage plants show a decrease in the digestibility with proceeding age of the plants (Schubiger *et al.* 2001b).

Crop species perennial ryegrass and chicory did not significantly differ in the digestibility of the organic matter when grown in mixtures compared to pure stands. The digestibility of perennial ryegrass in this experiment was ranging between 74.4 % and 79.4 %. When comparing these results with the values for digestibility of the organic matter of perennial ryegrass in the literature (DLG 1997), the values do not accord. After DLG (1997) perennial ryegrass in the vegetation stage “begin of flowering” and “flowering” has a digestibility of 77 % and 75 %, respectively. The plants in this experiment have been harvested at an earlier stage of development but had similar values for the digestibility. The values from DLG (1997) were evaluated under different conditions than given in this experiment. The growing conditions in small pots cannot directly be compared with field trials, which could be an explanation for the unequal values.

Red clover digestibility was ranging from 73.1 % to 66.4 %, which was again comparable to the vegetation stages “begin of flowering” to “flowering” according to DLG (1997), although plants were harvested earlier than these stages. The red clover treatment with common vetch as a weed resulted in a significantly lower digestibility of the organic matter than red clover in pure stands, which can possibly be linked to the high biomass production of common vetch and the significant reduction of clover biomass in this treatment.

The results from Pötsch and Resch (2006) from a field trial can partly be confirmed in the present study. They demonstrated a significant impact of the legume species, which resulted in an increased digestibility of perennial ryegrass in the first two years of the project. This correlation did not occur in the third year where the digestibility of ryegrass in mixtures was lower compared to pure stand ryegrass (Pötsch and Resch 2010). It has to be taken into account that the influence of plant species on each other can change with time.

5.4 Net energy content

The net energy content of all three crop species was calculated by means of the digestible organic matter (DLG 1997).

Perennial ryegrass had an average energy content of 6.03 MJ NEL/kg DM in pure stand. This value was not significantly different from ryegrass energy content in mixtures with weed species, although some mixtures showed higher net energy concentration, including mixtures with herbs chicory and caraway and weed grasses common bent and red fescue. Opitz von Boberfeld and Biskupek (1995) stated that shading of grass plants by clover plants led to a reduction in energy content. Although broad-leaved herbs dandelion and chicory formed similar leaves, their influence on the net energy content of perennial ryegrass was on an unequal level. In case of perennial ryegrass-dandelion mixtures, biomass production of ryegrass was not changed by competition, whereas the energy content was reduced. Chicory had a similar effect on the biomass yield of ryegrass where the grass energy content was increased in this treatment. Caraway produced very little biomass in mixtures with perennial ryegrass and thus the effect on the grass biomass yield was low. The energy content of ryegrass in the treatment with caraway was slightly increased when compared to pure stand ryegrass.

Opitz von Boberfeld and Biskupek (1995) stated that only a little effect of competition with legumes on the energy content of the companion species could be expected. Perennial ryegrass in mixtures with legumes common vetch and tufted vetch had similar net energy content as pure stand ryegrass. A significant reduction in net energy of ryegrass could not be shown in the present study. Deinum (1984 by Opitz von Boberfeld and Biskupek 1995) showed a reduction in energy concentration in grasses when growing in the presence of legumes due to more nitrogen available.

The results of the present study of net energy content of perennial ryegrass do not accord to the findings of Pötsch and Resch (2006) where a significant influence of the companion legume species on the quality of perennial ryegrass was shown. Again, it has to be pointed out that the growing conditions in this experiment were different from the ones in the field experiment conducted by Pötsch and Resch (2006). This positive impact of legumes on the energy content of the companioned grass could not have been confirmed during the third year of the study by Pötsch and Resch (2010), which has already been discussed for the digestibility of the organic matter.

No significant differences in net energy content of chicory between pure stand plants and mixture plants could have been observed. In mixtures with broad-leaved weed herbs dandelion and chicory, no significant differences in energy content were found.

Some of the treatments including red clover and weed species showed significant differences in net energy content of clover. Red clover from mixtures with common bent and red fescue had significantly different net energy concentrations, although red clover biomass yields and weed biomass yields were similar for these two treatments. Broad-leaved weed herbs and the two vetch species could significantly influence the biomass production of red clover but had no significant effects on the net energy content of clover. These results of the energy content of red clover correspond with the ones of Opitz von Boberfeld and Biskupek (1995) and Lehmann and Meister (1982), which reported only little influence by interspecific competition on the energy content of clover.

5.5 Quality yield

The quality yields of all three crop species corresponded with the biomass production. The decrease in biomass production of all crop species that has been due to high yielding weed species negatively influenced the quality yield as well. Contrary to this, weed species with little amounts of biomass only marginally influenced the biomass yield of the crops and thus had slightly positive effects on the quality yield of these crops. Crop species chicory had the highest quality yields of all three crop species, perennial ryegrass the lowest ones. The same weed species had similar effects on the quality yield of all crop species.

Chicory was the best yielding crop species in terms of quality yield throughout all treatments. The average chicory quality yield of all plant communities including chicory was 132.5 J NEL/pot. Although chicory and red clover had similar average biomass production, their quality yields diverge due to the different energy contents (7.30 versus 5.41 MJ NEL/kg DM for all chicory and red clover treatments, respectively). The biomass production of perennial ryegrass was on a very low level compared to the other crop species which resulted in a low average quality yield of 50.2 J NEL/pot.

For an overall evaluation of the mixture quality yield, it is necessary to include the biomass production and the energy content of the companion plant species in the calculation.

6 Conclusion

This study was set up in order to evaluate the influence of different weed species on the biomass production and the nutritive quality of three grassland crop species. The plants were both grown in pure stands and in binary mixtures with crop and weed plants in an outdoor pot experiment.

Some of the combinations of crop and weed showed higher biomass production than each of the species grown in pure stands. The benefits of growing mixtures of several species have been shown by several studies under experimental and commercial farming conditions. Some weed species showed high biomass production in pure stands and could maintain their yields on a high level when competing with each of the crop species. Mixtures containing these weeds were the most productive ones in terms of total mixture biomass yield.

The results of the evaluation of the nutritive value with regard to digestibility of the organic matter and the net energy content of the forage showed only slight influences of the weed species on the nutritive value of crop species. These findings partly correspond with results from other studies dealing with this question, which suggests that only small changes can be obtained, especially in energy content. Protein content of the crop plants has not been analysed in this study due to the little amount of harvested biomass, which did not allow further analysis than the ones that have been carried out.

Even though a significant increase in forage quality cannot be observed in the present study, as well a decline of the quality was not the case. It can thus be concluded that under the conditions of the present experiment, growing crop and weed species in binary mixtures did not lead to a decreased nutritive value of the crop species. Under commercial farming conditions, forage from mixtures is not separated into their plant components as it has been done in this study. The companion plant in mixtures will therefore also contribute to the nutritive quality of the forage.

Other studies (e.g. Pötsch and Resch 2010) have demonstrated the importance of investigating plant interactions and their influence on quality over a longer period of time, which has led to results that could not have been obtained in short-term experiment.

The findings of the present study can only be tentatively compared with the situation under farming conditions as this experiment was based on plants grown in pots under strict experimental conditions. The fact that the single harvest has taken place in the year of establishment of the plant communities might also lead to different results than what would have been seen under a long-term observation of the crop-weed interactions. Further work has to be conducted to clarify the influence of competition on the nutritive quality of grassland plants under commercial farming conditions.

7 Abstract

The objective of this study was to assess the influence of weeds in mixtures on the biomass yield of selected crop species and the effects on the nutritive quality of the crops in terms of digestibility of the organic matter and net energy content. Three grassland forage crop species including perennial ryegrass (*Lolium perenne*), chicory (*Cichorium intybus*) and red clover (*Trifolium pratense*) were grown in binary mixtures with each of nine different weed species belonging to the functional groups of grass, herb and legume in an outdoor pot experiment in Uppsala, Sweden. All plants were harvested at the same time and the produced biomass was measured for each species separately. The in vitro digestibility of the organic matter was analysed with the method of Tilley and Terry (1963) and net energy for lactation content was calculated by means of the digestible organic matter. Crop biomass was in most cases reduced due to competition with weed species when compared to pure stand crop yield, disregarding the crop species. Very productive weed species in weed monocultures could maintain their high yield also in mixtures with crops and contributed to increased total mixture yields. The digestibility of the organic matter of the crop species was not significantly changed in most of the treatments, which has been shown by other studies in the past. Net energy content was similar to the digestibility and partly corresponds with literature, which shows the greatest changes due to interspecific competition in protein content. The fact that competition with weeds did not significantly decrease the nutritive value of forage crops is of importance for the use of mixtures in animal nutrition. In permanent grassland a certain content of herbs and legumes is tolerated and desired. The results of this study can only be carefully transferred to the situation under commercial farming conditions due to the experimental approach used in this work.

8 German abstract

In der vorliegenden Arbeit wurde untersucht, wie sich interspezifische Konkurrenz zwischen Grünland-Futterpflanzen und Beikräutern auf den Trockenmasseertrag und die Futterqualität bezogen auf Verdaulichkeit der organischen Masse und Netto-Energie Gehalt der Futterpflanzen auswirkt. Die drei Futterpflanzen Englisches Raygras (*Lolium perenne*), Zichorie (*Cichorium intybus*) und Rotklee (*Trifolium pratense*) wurden mit neun Beikräutern in binären Mischungen in einem Topfversuch in Uppsala, Schweden angebaut. Alle Pflanzen pro Topf wurden zur gleichen Zeit geerntet und die Trockenmasseerträge wurden für jede Spezies separat erhoben. Die in vitro Verdaulichkeit der organischen Masse wurde nach der Methode von Tilley und Terry (1963) ermittelt und der Gehalt an Netto-Energie-Laktation mit Hilfe der verdaulichen organischen Masse errechnet. Die von den Futterpflanzen produzierte Trockenmasse wurde in den meisten Fällen durch die Konkurrenz mit Beikräutern im Vergleich zu Futterpflanzen-Reinsaaten reduziert. Sehr ertragreiche Beikräuter zeigten hohe Erträge sowohl in Reinsaat als auch in Mischungen mit den drei Futterpflanzen, wodurch sich teilweise hohe Gesamtfuttererträge ergaben. Die Verdaulichkeit der organischen Masse der Futterpflanzen wurde durch die Konkurrenz mit Beikräutern kaum verändert, eine Tatsache, die auch in anderen Untersuchungen gezeigt werden konnte. Die Energiegehalte waren ebenso schwachen Veränderungen ausgesetzt, diese Beobachtungen decken sich nur zum Teil mit anderen wissenschaftlichen Ergebnissen. Die Tatsache, dass es durch Konkurrenz zwischen Futterpflanzen und Beikräutern zu keiner Verschlechterung der Qualität der Futterpflanzen kommt, ist bei der Verwendung von Mischungen zur Futterproduktion und in Dauergrünland bedeutsam, da ein gewisser Anteil an Kräutern und Leguminosen toleriert beziehungsweise erwünscht ist. Es muss jedoch beachtet werden, dass die Ergebnisse dieser Studie nicht ohne Vorsicht mit anderen Arbeiten verglichen werden können und dass weitere Forschung in diesem Bereich die Zusammenhänge zwischen Konkurrenz und Futterqualität unter landwirtschaftlichen Praxisbedingungen betrachten soll.

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