Legume Futures

Legume-supported cropping systems for Europe

Legume Futures Report 1.6

Effects of legume cropping on farming and food systems

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Legume Futures

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Contents

1. INTRODUCTION

Nitrogen is generally the first limiting nutrient for plant growth. Until the invention of synthetic nitrogen fertiliser, early in the 20th century, legumes, with their capacity for biological nitrogen fixation (BNF) in symbiosis with bacteria of the *Rhizobiaceae*, were the main source of agricultural nitrogen. As nitrogen fertiliser became cheap, its use expanded and has continued to grow, with the result that there is now considered to be too much reactive N in the biosphere (Rockström et al. 2009), with associated problems of nitrate leaching into water and nitrous oxide emission into the atmosphere. Legume crops offer a great deal more to agricultural systems than BNF alone, and the Legume Futures project has explored many of these effects. This report presents a synthesis of the effects of agricultural legumes in rotations. It refers to other Legume Futures reports, in preparation at the same time, for greater depth on some issues.

2. LEGUMES IN FARMING SYSTEMS

Pre-crop effects in arable systems

The effect on the yield of subsequent crops in the rotation has been reviewed in detail by Luetke-Entrup et al. (2003), Kirkegaard et al. (2008) and Peoples et al. (2009a). The pre-crop effect can be split into the 'break-crop effect' and the 'nitrogen effect', which typically act in a combined manner (Chalk 1998). In contrast to the 'nitrogen effect' described below, the 'break crop effect' is not specific to legumes, but occurs when sequences of similar crops, typically cereals in much of Europe, are 'broken' by an alternative crop, usually broad-leaved or a ley, although by some definitions a spring-sown cereal counts as a break (Robson et al. 2002). By reducing the potential for pests, diseases and weeds and positively affecting soil fertility, dicotyledonous break crops are reported to increase subsequent cereal yields by 15 to 25% (Kirkegaard et al. 2008). Much of the yield benefit of legumes in some experiments was attributed to reduced leaf and root disease incidence in the following cereal crop (Prew and Dyke 1979, Stevenson and van Kessel 1997). Some of the other aspects of the pre-crop effect of legumes are attributed to the production of hydrogen gas as a by-product of BNF and, in turn, its effect on soil microbiology (discussed below in the section on "soil organic carbon").

The nitrogen effect

In addition to the break crop effect, provision of nitrogen derived from BNF to the subsequent crops ('nitrogen effect') increases yields especially where subsequent crops receive low or moderate levels of fertiliser. The nitrogen effect has been reviewed in detail by Jensen (1997), Chalk (1998), Giambalvo et al. (2004), Peoples et al. (2009b) and Köpke and Nemecek (2010), and is illustrated following these authors in Figure 1. Extensive research on the N contributions of legumes (Figure 1, steps a to e) has revealed considerable difficulties in accounting for the below-ground plant N, plant N that is mobilised over time, site- and management-specific factors, and alternative paths of N take-up such as ‘pool substitution’, wherein the labelled legume N is immobilised by soil bacteria and older N from the soil nutrient pool is mineralised and taken up by the subsequent crop instead. Therefore, these measurements do not adequately explain the high amounts of increased N uptake (e) in subsequent crops, which results from uptake of N from BNF or through ‘pool substitution’, as well as enhanced root health, root growth, and mineralization (Kirkegaard et al. 2008, Peoples et al. 2009a). This was shown in experiments where direct uptake of ^{15}N-labeled legume-N was only a fourth of the additional N uptake of the subsequent crop (Huber et al. 1989, Khan 2000 cited in Peoples et al. 2009a). In European experiments, increased N uptake of crops after grain legumes reached up to 61% or 36 kg ha^{-1} for a vetch-barley rotation in Cyprus (Papastylianou 2004). This N effect appears to be generally lower in Europe than in North America or Australia, where the increase is up to 112% or 55 kg ha^{-1} (Evans et al. 2003).

Forage legumes take a larger proportion of their N from BNF than grain legumes (Carlsson and Huss-Danell 2003), and fix more N in total due to their high biomass production and longer growth period, but this is countered by the fact that they are seldom grown in pure stands and generally comprise the lesser part of a mixture with grasses. Average annual BNF for clover-grass mixtures (>60% clover) and pure stands of red clover in Germany were 221 and 306 kg ha^{-1} of N, respectively (KTBL 2009). In pure stands, forage legumes derive a similar proportion of N in their shoot biomass from BNF as grain legumes (ca. 70% of nitrogen is derived from the atmosphere (Ndfa), Stein-Bachinger et al. 2004). In mixtures compared with pure stands, total N fixation per hectare is lower, but N efficiency is increased to 80-95% Ndfa (Stein-Bachinger et al. 2004).

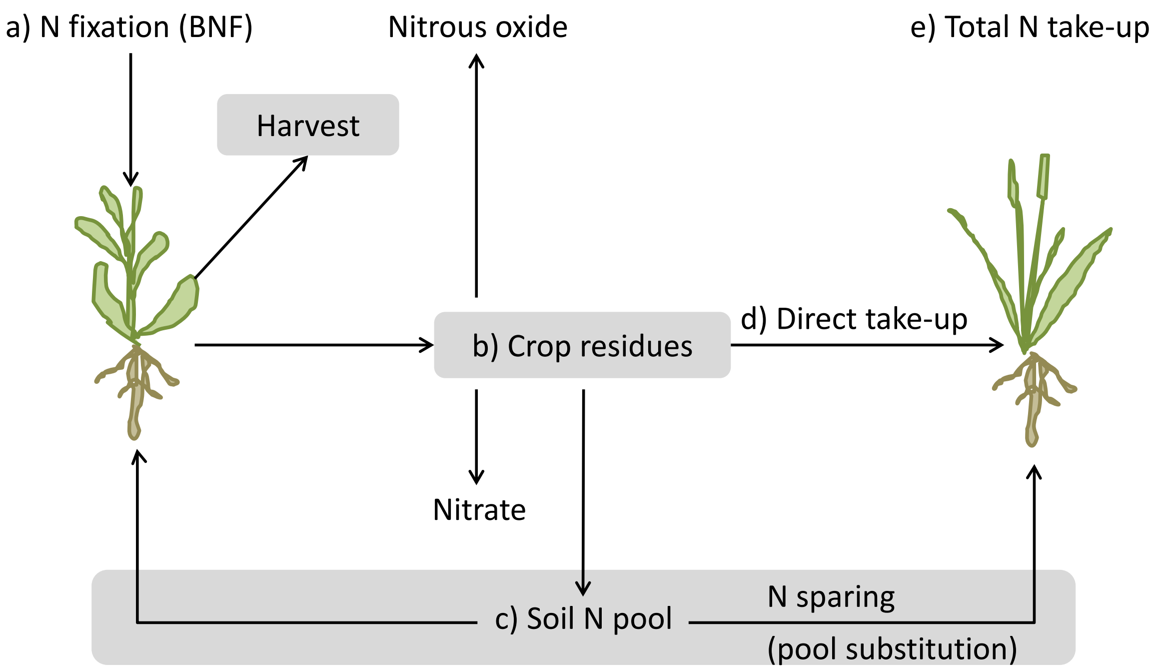

Figure 1. The nitrogen effect of legume pre-crops on subsequent crops

Fertiliser savings

Legumes require almost no N fertiliser and the pre-crop effect enables farmers to reduce fertiliser use in following crops. A grain legume may save some 150-200 kg ha^{-1} of N fertiliser compared to a cereal or rapeseed crop, as well as some 20-50 kg in the subsequent crop. Where an unfertilised legume-grass ley replaces one of pure grasses, forage legumes save 150-300 kg ha^{-1} of N fertiliser by covering their own nitrogen requirements as well as those of the grass component (Peyraud et al. 2009), along with leaving 20-50 kg ha^{-1} for the subsequent crop. In generated 3- to 6-year crop rotations in five case studies across Europe, models showed that 21 and 88 kg ha^{-1} of N fertilisers could be saved on average in grain and forage legume rotations compared to rotations without legumes (Bues et al. 2013; Legume Futures report 1.4). N fertiliser savings were very variable across sites.

Higher savings can be achieved in the subsequent crops after legumes but are not fully utilised in current farming practise. This was shown by surveys among farmers and experts, which estimated that 20-35 kg ha^{-1} fertiliser are saved (Alpmann et al. 2013; Legume Futures Survey reported in Table 1). Only when fertiliser costs relative to product prices are high or there are limitations on fertiliser use, such as in organic farming or in environmental schemes, are farmers likely to reduce fertilisation after legumes to more fully exploit the nitrogen carryover effect.

Table 1: Fertilisation practices for major protein crops and winter wheat in five case study regions across Europe[1]

Crop	Yield (t ha^{-1})	Regional average mineral fertiliser applied (kg ha^{-1})			Experts view of mineral N fertiliser saved in farm practice in succeeding wheat (kg N ha^{-1})
		N	P	K	
Faba bean (DE, IT, SC, SE)	1.6-5	0	15-20	25-45	0-20
Pea (all countries)	1.2-4	0	15-20	25-40	0-20
Lupins (DE)	2.5-3	0-30	15-35	30-35	0-20
Forage legumes, dry matter	6-15	0-65	0-15	0	0-20
Winter wheat	3.2-8	135-200	25-30	20-60	0

[1] Location and soil type: Scotland (Eastern, grade 3), Italy (Calabria, loam), Sweden (Västra Götalands, silty clay loam), Germany (Brandenburg, sandy clay loam) and Romania (Sud-Muntenia, Chernozem) Source: Legume Futures survey in five case study regions across Europe.

Yield benefits of grain legumes

The yield benefits of legumes for subsequent cereal crops, in comparison to continuous cereal cropping, has been estimated at 49% for Australia and 37% for tropical systems, without taking account of fertilisation levels (Evans and Herridge 1987, Peoples and Craswell 1992, both cited in Kirkegaard et al. 2008). Another review of Australian data quantified yield benefits compared to pure cereal sequences at 40-50% for low N levels and 10-17% for high N levels (Angus et al. 1991). However, under European conditions where higher yields prevail, more intensive management, and different climatic factors affecting N dynamics, the yield benefits appear to be lower, especially since high inputs of N are generally used in spite of the fertiliser savings potential after legumes. Experimental data from temperate Europe show that cereals yield on average 17 and 21 % more after grain legumes than after cereals under usual and moderate fertilisation levels, respectively (for example Prew and Dyke 1979, Jensen and Haahr 1990, Panse et al. 1994, Maidl et al. 1996, Charles and Vuilloud 2001, Dachler and Köchl 2003, Jensen et al. 2004). The yield benefit is smaller and less certain in comparison to other broad-leaved pre-crops (for example Dyke and Slope 1978, Dachler and Köchl 2003, Kaul 2004) and in Mediterranean climates where water availability limits yield (e.g. López-Fando and Almendros 1995, Giambalvo et al. 2004, Kraljević et al. 2007). Rapeseed and potatoes also benefit from grain legume pre-crops (for example Jensen and Haahr 1990, Charles and Vuilloud 2001).

Productivity in grasslands and leys

In grassland, forage legumes can improve economic performance at the farm level through fertiliser savings and improved animal productivity. N fertiliser costs can be a significant factor for farm economic performance of temporary leys and permanent grassland. A high legume content in permanent pastures can save 136-400 kg N ha^{-1} (Humphreys and Phelan 2013), and in a Dutch experiment fertilisation was reduced by 210 kg N ha^{-1} (Schils et al. 2005). Herbage and milk production from a perennial ryegrass/white clover pasture have been shown to be similar to that from perennial ryegrass receiving 200 kg N ha^{-1} yr^{-1} and around 70% of that of perennial ryegrass with 350–400 kg N ha^{-1} yr^{-1} (Andrews et al. 2007). Increased reliance on nitrogen from white clover and reduction in N fertilisation can improve economic performance at the farm level when fertiliser prices are moderate or high and milk prices are low or moderate (Humphreys et al. 2012), and reduce the impact of N fertiliser price increases and fluctuations observed in the last decade (Fuchs and Hoffmann 2013).

In pasture-based dairy systems, animal productivity was higher with utilisation of white clover and reduced stocking densities during the grazing period, but comparable during the housing period when animals were fed silage of either grass or grass/clover (Schils et al. 2000). Productivity per hectare was reduced due to the reduced stocking densities. Several studies confirm that clover improves sward nutritive value, herbage intake rates, and milk production per cow when grazed or fed as fresh matter, hay or silage (Harris et al. 1998, Dewhurst et al. 2003, 2009, Moorby et al. 2009). There is also increasing evidence of the value of alternative legumes such as birds-foot trefoil in increasing the productivity of dairy cows compared with traditional forages such as red clover or alfalfa (Hymes-Fecht et al. 2013). Ad-libitum grazing of clover-rich pastures can lead to increased risk of bloat, so high clover contents may not be feasible in extensive grazing systems, compared with pastures are paddocked (Schils et al. 2000). Bloat risk and nutritive value differ between legume species, due to the positive effect of secondary plant compounds such as tannins (Kleen et al. 2011, Patra and Saxena 2011).

Moreover, forage legumes can positively affect the nutritional and sensory quality of animal products. Higher levels of desirable polyunsaturated fatty acids and essential amino acids in milk are known to be associated with feeding both red and white clovers (Dewhurst et al. 2003, Moorby 2009, Baars et al. 2011). This is also reflected in consistent differences between organic and conventional milk where there are more legumes fed within the organic diet (Ellis et al. 2006). The sensory characteristics of cheese are affected by the production system, and botanical composition of the sward is one part of the 'terroir' effect (Whittington 2006, Wood et al. 2007) that links food to its place of origin (Martin et al. 2005, Moloney et al. 2008). Feeding red clover can also increase aspects of the nutritional quality of red meat compared with grass (Scollan et al. 2006).

Soil structure and organic matter

Legumes can improve soil structure, water holding capacity, humus content, and organic carbon content (SOC) of soils (Leithold et al. 1997, Jensen et al. 2011), and reduce soil compaction by providing a continuous network of residual root channels and macropores in the subsoil, penetrating soil hardpans (especially by vigorous tap-rooted species) (Jensen and Hauggaard-Nielsen 2003, Peoples et al. 2009b). Legumes can increase SOC in several ways. First, they supply biomass, organic C, and N; this is especially the case for forage legumes and accounts for the negative effects on SOC of low dry matter producers such as lentil and pea, and the positive effects of certain non-legume, high dry-matter producers such as maize (Castro and Logan 1991 in Cederberg and Flysiö 2004, Lemke et al. 2007, Garrigues et al. 2012b). Secondly, they produce hydrogen gas as by-product of BNF, which supports the growth of bacteria in the rhizosphere of the legume nodule (La Favre and Focht 1983). Thirdly, legumes indirectly improve soil properties and SOC by enabling reduced tillage measures, namely a 2-3 year tillage break in ley-arable rotations, and reduced tillage after the legume in pure arable rotations due to the fast break-down of legume residue (Nemecek et al. 2008, Köpke and Nemecek 2010, Alpmann et al. 2013). In a survey of 75 grain-legume producers in Germany, 64 respondents stated that they applied direct seeding after a legume pre-crop, and 30 reduced tillage on the whole farm (Alpmann et al. 2013). There are also experiences with direct seeding of faba bean including in rainfed Mediterranean conditions with herbicide application (López-Bellido et al. 2003), or in areas with low pressure from perennial weeds (Köpke and Nemecek 2010).

The effect of soil carbon sequestration is more clearly shown for forage legumes than for grain legumes, with the highest impact in permanent pastures with perennial legume species (Jensen et al. 2011). Many studies report higher soil organic matter contents under grass-legume mixed swards than in pure grass swards (Ruz-Jerez et al., 1994; Mortensen et al., 2004). A number of models suggest that the conversion of short-term N-fertilised grass leys into grass-legume mixtures could sequester C into soil organic matter (Soussana et al., 2004). Absolute values will depend on species mixtures and cutting and grazing management as well as soil and climatic conditions. Gregorich et al. (2001) showed that 35 years of a lucerne/maize rotation provided about 20 t ha^{-1} more soil carbon than continuous maize. Mixtures of grasses and legumes have been shown to sequester more carbon than the corresponding monocultures (Fornara and Tilman 2008). In contrast, grain legumes cultivated under conventional tillage cannot always balance the losses of SOC through the tillage measure (Jensen et al. 2011). The legume effect on SOC was not detected in a comparison of continuous wheat with a wheat-faba bean rotation in a Mediterranean system (Lopez-Bellido et al. 2010).

Through facilitating reduced tillage systems, the soil-improving effect of legumes has a directly detectable effect for farm economic performance. Conservation tillage has been shown to reduce production costs more significantly when the change in tillage is combined with the diversification of the crop rotation by including a legume. Luetke-Entrup et al. (2006) registered cost savings of 21% when switching from a ploughed, cereal-dominated rotation to a conservation tillage rotation including a legume, compared to cost savings of 12.5% when only the tillage system was changed but the cereal-dominated rotation was maintained.

Nutrient conservation

N-losses via leaching

Nitrate leaching has been found to occur in both legume-supported and fertilised cropping systems (Crews and Peoples 2004). A limited number of studies report lower N leaching rates in legume-supported systems compared to fertilised systems (Crews and Peoples 2004).

In arable systems, the amount of nitrogen leaching is the result of two counteracting processes as has been shown by calculations for life-cycle assessments (Nemecek et al. 2008). Nitrate emissions to water from the normally unfertilised legume crop itself are low, but emissions in the subsequent crop are frequently reported to be higher. The greatest risk of leaching loss from legume-supported rotations exists after the legume harvest and in the first growing phase of the subsequent crop when the crop demand for mineral N is low (Fillery 2001; Peoples et al. 2009b). In addition, in temperate climates, grain legumes are often spring sown resulting in over-wintering fallow. The risk for nitrate leaching during the winter fallow before the legume is sown has led to unfavourable assessment of spring-sown legumes in some LCAs, but it can easily be minimized by cover cropping. Some very deep rooting legume crops such as lupins potentially reduce nitrate leaching by taking up nitrates from deep layers of soil (Dunbabin et al. 2003).

The risk of leaching after grain legume harvest can be minimized by several strategies. These include the use of catch and cover crops (e.g. Justus and Köpke 1995), cereal-legume intercropping (Pappa et al. 2012, Jensen and Hauggaard-Nielsen 2003, Justus and Köpke 1995) and early sowing of winter crops after the legume such as rapeseed. Catch crops can be stubble seeded or undersown in the grain legume crop and take up nitrate and other nutrients until they are frost-killed or tilled. Justus and Köpke (1994) showed that undersown brassicas were more efficient in reducing leaching than ryegrass and intercropping with cereals without reducing the legume grain yield.

In forage-based systems, reliance on white clover reduces leaching by 45-101 % compared to fertiliser-based systems (Haas et al. 2001, Thomassen et al. 2008, Dolman et al. 2012). These reductions are mainly an effect of lower fertiliser application and lower nitrogen surpluses. However, higher N losses associated with less efficient utilisation of dietary N and increased urinary N output with legumes compared to grasses may occur. Legumes with higher tannin content such as birdsfoot trefoil are valuable in terms of reduced N output (Dewhurst et al. 2003, 2009). In legume-grass mixtures, the grass component receives N from the legume (Pirhofer-Walzl et al. 2012) that could potentially be leached in sole cropping. The largest risk of N losses from forage legumes in ley/arable rotations occurs after the ley is tilled (Davies et al. 2001, Watson et al. 1993) although ley age, composition (Eriksen et al. 2004)) and time of ploughing (Borgen et al. 2012) impact on losses. .

Soil erosion

Legume crops often reduce the potential for erosion by water through reducing soil erodibility via improving soil structure, improved water infiltration, and water holding capacity (Bruce et al. 1987, Jensen and Hauggaard-Nielsen 2003, Peoples et al. 2009b, Jensen et al. 2011), and by enabling reduced tillage (see section 2.3). Perennial forage and (legume) cover crops grown before spring-sown crops reduce water erosion further through permanent soil cover (Peoples et al. 2009b). Major soil erosion models (USLE, Wischmeier & Smith 1987, and RUSLE2, Renard and Ferreira 1993) often do not reflect this positive impact because they do not take into account the effects of crops on soil erodibility, so estimate that grain legumes lead to increased soil erosion simply because they cover the soil for less time than autumn-sown crops (Garrigues et al. 2012a, Garrigues et al. 2012b, Núñez et al. 2012).

Efficient utilisation of phosphorus

Phosphorus requirements of forage legumes are comparable to those of pure grassland. A major distinction between legumes and non-legumes is legumes are generally able to solubilise soil phosphates through root exudates (Nuruzzaman et al. 2005), and the deep rooting of some species contributes to efficient nutrient utilisation (Jensen and Hauggaard-Nielsen 2003). Roots of most legumes release carboxylic acids that solubilise phosphate ions from bound forms such as calcium and iron phosphates that are otherwise unavailable to plants and immobile in the soil. The process is to an extent self-regulating: the lower the phosphorus concentration in the soil, the more acid is released, and depending on the species, up to 8 acids are released (Egle et al. 2003). This also benefits the phosphorus uptake of a cereal grown in mixture with the legume (Li et al. 2007) and cereals grown after a legume crop (Nuruzzaman et al. 2005). One side-effect of the release of acids by legume roots is a gradual acidification of the soil, usually countered by periodic applications of lime, and partially countered by the alkalinity of the crop residues.

Legumes efficiently utilize P (and potassium) surpluses in many European soils, thereby reducing the risk of losses of these nutrients. Many European soils are over-saturated with P, either due to high historic P fertilisation levels or because fertilisation with animal manures provides more P (and potassium) than required by cereals (Hooda et al. 2001).

Nutrient recycling

Legumes play a key role in integrating livestock and crop production by increasing the recycling of nutrients on and between farms and thus potentially reducing nutrient losses considerably (Granstedt 2000). Spatial separation of livestock and feed production between continents and regions, e.g. that which characterises pig and poultry production in north-western Europe, results in high P losses that are likely to increase further (Larsson and Granstedt 2010). Smaling et al. (2008) also highlighted the effects of the decoupling of livestock production from the land resource base on worldwide nutrient fluxes with respect to nitrogen flows in the Brazilian soybean chain. The potential for nutrient conservation through on-farm feed production, including from on-farm legume production, is illustrated by a comparison of a conventional with an “environmentally optimised” Swedish pig farm (Cederberg and Flysiö 2004). Compared with conventional pig production with substantial quantities of purchased feeds, production based on on-farm feed production offers opportunities to conserve the use of P and K substantially. Local grain legume production facilitates such resource-conserving systems.

3. ENVIRONMENTAL AND RESOURCE IMPACTS

Legume-supported farming systems have multiple impacts on the sustainability of farming in terms of resource use and effects on the environment. Several reviews have described the processes and environmental effects in detail (Nemecek et al. 2008, Peoples et al. 2009a, 2009b, Köpke and Nemecek 2010, Jensen et al. 2010, 2011). In this report, we will take on a different perspective by analysing the environment and resource impacts over the life-cycle of agricultural production, especially relating to the impacts on climate change and biodiversity loss – the areas in which human interventions have most strongly exceeded the boundaries that have been proposed as safe operating space (Rockström et al. 2009).

Life Cycle Assessments (LCA) consider the environmental effect of processes within a production system and provide a means for comparing the environmental impacts and resource use of commodities, products and processes throughout their life-cycle, from ‘cradle to grave’ (Brentrup 2004). Table 2 compiles comparative LCA studies of legume crop products versus other European crops, feed ingredients or feed formulas, the latter taking account of the different feed values of protein sources. Comparisons of crop rotations further take account of the effects of grain legumes on subsequent crops and on the choice of crops that are replaced by grain legumes.

As most of the grain legume commodity is used in animal feeds, Table 3 compiles LCAs that demonstrate the effect of increased grain legume inclusion in feed formulas on the environmental performance over the life cycle of animal products based on such feeds. In such studies, inclusion of starchy pea or faba bean in feed formulas partially replaces cereals as well as soya. Table 4 compiles LCA studies relating to ley- and pasture based animal production with relevance to forage legumes. Such assessments also depend on the different feeding values of the components and associated changes in feed composition, effects on animal productivity, and effects on excretions of nitrogen compounds. Feed crop production accounts for the major part of environmental impacts in the life-cycle analyses of animal products:

50-75% of energy consumption,
47-88% of greenhouse gas emissions,
50-98% of eutrophication,
28-98% of acidification, and

>96% of land use (for references see Table 3).

Differences in transport have generally minor effects on the overall environmental impacts of end products[1], but transport-related environmental impacts can in some cases be significantly reduced by replacing imported soya bean meal with European grain legumes (Baumgartner et al. 2008), especially when these are produced on the farm (Table 3).

Legumes and their potential for climate change mitigation

The agricultural contribution to climate change has been estimated at 13.5% of worldwide greenhouse gas (GHG) emissions (CO_2 equivalents) (De Klein et al. 2006). Legume-supported systems have a high potential for mitigating climate change through significantly reducing fossil energy use and GHG emissions and maintaining positive soil carbon balances, and their increased diversity holds potential for adapting to climate change although little empirical knowledge is available on the latter.

Energy use

Through the savings in nitrogen fertilisers, improved soil structure and potentially reduced tillage intensity (Section 2.5), legume-supported systems require less energy for fertiliser manufacture and machinery fuel. This effect is especially large for ley/arable rotations, but also exists for grain legumes in arable rotations, for which reduced overall energy use has been shown by LCA studies (Table 2). Grain legumes reduce energy use by up to 35% compared to other European crops, by more than 60% compared to imported soya bean meal and cake, and by up to 31% in four case studies comparing crop rotations. However, the results for cropping systems were greatly affected by the assumptions about the crop being replaced. For example, energy use for grain drying dominated the positive effect of replacing grain maize by pea/soya bean in a Swiss study, whereas in a case in Spain, pea replaced an unfertilised sunflower crop leading to zero or negative effects on the rotation's energy use.

When soya-based animal feeds were substituted by pea- or faba bean-based ingredients, the effects of feed production were less significant than other main energy-using processes involved, but reductions up to 9% were achieved (Table 3). In animal production, reductions in transport and partial replacement of highly fertilised cereals by pea starch in feeds were the main contributors to energy-use reductions. A more systematic shift to largely integrated production with on-farm feed production achieves the largest energy-use reductions up to 19%.

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[1] Transport contributes 4-27% of energy demand, 2-15% of GHG emissions and around 18% of acidification in the studies listed hereafter.

Nevertheless, energy savings and other environmental benefits of grain legumes on a per unit product basis are constrained by currently low yields (see also the contrasting impacts on land use, Tables 2 and 3). Low yields led to non-significant effects on energy use and negative effects on GHG emissions per kg product in a Swiss case (Nemecek et al. 2005). In the comparisons of crop rotations, such yield differences are not factored into the assessment but reduced environmental benefits due to low yields have also been noted (Nemecek and Baumgartner 2006, Baumgartner et al. 2008).

Reduced greenhouse gas emissions

Significant reductions in global warming potential, specifically of the greenhouse gases CO_2 and N_2O, are a logical consequence of reduced fertiliser and energy use in arable systems with legumes. Fertiliser production leads to estimated CO_2 emissions of 300 Tg from fossil energy sources worldwide (Jensen et al. 2011). N fertiliser savings of legume-supported rotations across Europe (Legume Futures report 4.2) are equivalent to 66 and 277 kg ha^{-1} of CO_2 savings per year on average across rotations for grain and forage legume rotations, respectively (1 kg N = 3.15 kg CO_2, Jensen et al. 2011). Although CO_2 emissions from nodulated roots of legumes can be higher than from other crops and fertiliser production, this C is considered not to affect CO_2 concentrations in the atmosphere since it has been captured by recent photosynthesis (Jensen et al. 2011).

In addition to carbon dioxide, nitrous oxide (N_2O) emissions to the atmosphere tend to be lower in grain and forage legumes compared to N-fertilised crops and pastures (Rochette and Janzen 2005; Lemke et al. 2007; Dusenbury et al. 2008; Jensen et al. 2011). In contrast to earlier assumptions, there is no direct association between N_2O emissions and the process of BNF (Jensen et al. 2011), and emissions from the residue depend not on the crop family but on whether straw is exported or mulched (De Klein et al. 2006, Lemke et al. 2007, Jensen et al. 2011). In a review of studies, Jensen et al. (2011) reported average direct N_2O emissions from legume fields to be less than half of those from non-legume crops (1.29 kg N_2O–N ha^{-1} compared to 3.22 kg N_2O–N ha^{-1}, respectively). However, data on N_2O emissions vary widely. Besides different rates of N inputs, climatic, soil and management conditions, differences between legume species and cultivars contributed to the variability (Pappa et al. 2011). Furthermore, it has been proposed that N_2O emissions relate to N balance rather than N application (Wiltshire et al. 2012). Pappa et al. (2011) highlighted the potential of legumes to further reduce N_2O losses when grown in legume-cereal intercropping systems. Furthermore, the inhibiting effect of some rhizobia and other bacteria on denitrification in the root zone of some plants can reduce N_2O emissions (Henry et al. 2008, Sameshima-Saito et al. 2006).

The current guidelines for national greenhouse gas inventories of the IPCC (Intergovernmental Panel on Climate Change 2006) exclude BNF of legumes as an input for calculating emissions. However, many studies still apply previous IPPC guidelines where BNF is calculated with the same emission factor as N fertilisers (1.25%) leading to an overestimation of the N_2O contributions from legume-supported systems (Tables 2-4).

When only studies with the current method are considered, global warming potential is more than halved by grain legumes compared to other crops or soya products, reduced by about 12% in legume-based rotations and by more than 20% by legume-based animal products. In a sensitivity analysis for one case study, Nemecek and Baumgartner (2006) found that the change in methodology reduced the estimate of total N_2O emissions of the legume by 47%, gaining a 4.6% reduction of global warming potential of the crop rotation instead of a 3% increase with the old methodology. Thus it is reasonable to assume that the results of LCAs for global warming potential would be in all cases positively to very positively affected by legumes with the current methodology. Exact estimations of grain legume emissions of N_2O would further require taking weather patterns into account (Goglio et al. 2012).

Most studies also considered the impact of land-use change through Latin American soya production. Topp et al. (2012) found no greenhouse gas effect of European pea- or bean-fed pork compared to pork fed with imported soya-based feed per unit of meat product, but when land-use change (deforestation and destruction of grasslands in South America) was incorporated into the LCA, the European-grown protein diets had an advantage over the soya-based diets in terms of GHGs (Topp et al. 2012).

Global warming potential of ley and pasture based farming systems

In ruminant farming systems, methane emissions from the animals form the major part of GHG emissions, and are still the majority of total GHG emissions when measured across the whole EU livestock sector (Lesschen et al. 2011). Hence the environmental impacts of ruminant production show little effect of soya replacement and of the fertiliser savings potential of forage legumes, as shown for French beef production systems (Nguyen et al. 2012) (Table 4). Nevertheless, comparisons of grassland farming systems based on white clover or synthetic fertilisation show that increased feed self-sufficiency, reduced fertilisation, changes in animal productivity and soil carbon sequestration together significantly reduce energy demand and global warming potential. One aspect of this is the reduced N_2O emissions of clover-based pastures (Li et al. 2011).

Clover-based leys and pastures have the potential to greatly reduce the global warming potential by supporting higher animal productivity at lower stocking rates (see section 2.2), thereby reducing methane emissions per unit area. This strategy has a trade-off with productivity per area, but where larger areas of less fertilised pastures are required, there can be clear benefits to grassland biodiversity and carbon sequestration. The link between increased animal productivity, lower stocking density and reduced greenhouse gas emissions per hectare or per kg milk or meat has been shown in several studies (Hermansen and Kristensen 2011, Clarke et al. 2012, Guerci et al. 2012). Furthermore, clover is an important component for extensive and organic farming systems with reduced fertilisation requirement and increased feed self-sufficiency.

Soil carbon sequestration
Beyond the estimation of global warming potential in most LCAs, legume-supported cropping systems can mitigate climate change by sequestering carbon in the form of soil organic matter (see Section 2.3). In arable systems, the carbon sequestration potential greatly depends on legume species and tillage management and is not taken into account by the compiled LCAs. In grassland systems, soil carbon sequestration can have a major impact on the comparison of different farms with different shares of pasture-based forage and arable crop-based silages and concentrate feeds.

Legumes and biodiversity

Crop diversity
As minor crops in European agriculture, grain and forage legumes increase the planned biodiversity of crops in arable rotations. Legumes enable temporal diversification of the agro-ecosystem through crop rotation and spatial diversification through mixed cropping, e.g. of grain legumes with cereals, cereals undersown with forage legumes, and leys comprising mixtures of grasses, different legume species and cultivars, and forbs. This diversification affects the associated diversity of wild flora, fauna, and soil microbes (Peoples et al. 2009a, Köpke and Nemecek 2010, Collette et al. 2011) and results in 'potentially more dynamic and sustainable systems' (Peoples et al. 2009a).

Associated diversity
Agricultural areas represent a habitat and foraging ground for associated plants and animals. The choice of crop rotation, crop management and the presence of extensively utilized and semi-natural habitats influences this associated diversity (Nemecek et al. 2005). Two of the reviewed LCAs (Nemecek et al. 2005, Nemecek and Baumgartner 2006) attempted to estimate the effect of crops on associated diversity by the SALCA-biodiversity method for Switzerland (Jeanneret et al. 2006). The results were inconclusive with respect to the role of legumes, as they depended largely on the rating of the catch crop before spring-seeding and on the rating of the replaced maize crop in the rotation. Methods for estimating biodiversity effects in LCAs are being developed and debated by many researchers, but so far none has been widely applied (Corsons and van der Werf 2012).

Where legumes are spring-sown, they have the potential to diversify winter-crop dominated arable systems: e.g., winter crops cover 59% of arable land in Germany and 62% in England and Wales, with proportions above 70% in some regions (calculated from Defra and AHDB 2012 and Bundesministerium für Ernährung und Landwirtschaft 2013). Spring-sown legumes provide an opportunity for retaining crop stubble during winter before spring seeding, which is a rare practice outside agri-environment schemes. Over-wintered cereal stubble provides combined forage and cover for small mammals, birds and insects that is not found in low-growing winter cereal crops (Potts 2003, Evans et al. 2004, Gillings et al. 2005). Outside such schemes, undersown leys are the most important crop for ensuring the availability of winter feed for farmland birds of conservation interest (Potts 2003, Evans et al. 2004). During the growth phase, spring-sown crops benefit biodiversity compared to autumn-sown crops as has been shown for cereals: They support other weeds and arthropods, with highest abundance at different times than autumn-sown cereals, and thereby provide forage to ground-feeding farmland birds at critical times (Berg et al. 2002, Dicks et al. 2013). Some of these benefits may also apply to the spring-sown grain legumes, but this depends strongly on weed management.

By providing nectar and pollen, the mass-flowering of grain and forage legumes contributes to the maintenance of populations of wild and domesticated bees (Westphal et al. 2003, Köpke and Nemecek 2010). For example, faba bean flowers provide nectar to bumblebees with a long proboscis, such as *Bombus hortorum, B. pascuorum* and *B. ruderatus*, and other large-bodied wild bees such as *Eucera numida* in Spain (Stoddard and Bond 1987, Palmer et al. 2009). Faba bean and lupin flowers are an important source for pollen for honeybees (*Apis mellifera*) that is used for feeding the brood, but agricultural lupins are considered to lack nectar (Green et al. 1980) and that of faba bean is inaccessible to honeybees (Stoddard and Bond 1987). Jeanneret et al. (2006) argued that crop fields are not suitable for the mostly ground-nesting wild bees due to regular soil disturbance, application of biocides and the dense shading of the soil surface, and (unusually) concluded that the effect of grain legumes on bees was quite negative. The importance of clover flowers in grasslands for insect populations has been demonstrated for organic systems (Haas et al. 2001, Power and Stout 2011) and may be presumed to apply as well to non-organic clover. The relevance of clover as a source of nectar for honeybees is also indicated by the wide availability of clover honey on the market.

Increases in population size and diversity of decomposer invertebrates such as earthworms and collembola have been noted under perennial forage legumes (Eisenhauer et al. 2009, Sabais et al. 2011) and the Legume Futures project is assessing whether the same happens under annual legume crops (Legume Futures reports 3.6 and 3.8). Hydrogen gas, as a by-product of BNF, supports the growth of hydrogen-fixing bacteria in the rhizosphere of the legume nodule which again support populations of soil fauna (La Favre and Focht 1983, Köpke and Nemecek 2010). Increases in populations of collembolan feeding on soil bacteria as well as earthworm and nematode populations have been reported in H_2-treated soils (Dong and Layzell 2002).

Clover-grass leys represent an important breeding habitat for farmland birds, including skylark (*Alauda arvensis*), corn bunting (*Emberiza calandra*), yellow wagtail (*Motacilla flava*) and whinchat (*Saxicola rubreta*), but nesting can be disturbed by farming operations, particularly the timing and cutting height of harvesting (Stein-Bachinger and Fuchs 2012). Fuchs (2010) found that legume-grass leys were the most attractive habitat for the European hare (*Lepus europaeus*) on an arable organic farm in north-eastern Germany, but reproductive success was reduced due to harvesting operations, which could be altered by modifying cutting (Fuchs 2010). In contrast, Kopij (2008) noted that there was little change in the bird fauna from a zone in southwestern Poland where faba bean and clover disappeared from cultivation.

Forage legumes are critical components of especially diverse grassland farming systems, such as around 15 M ha in Mediterranean grassland ecosystems where native legumes are an important component (Ledda et al. 2000). They play a role in agroforestry systems, e.g. in silvoarable systems where trees such as olive or carob are combined with mixed ley-arable rotations (Eichhorn et al. 2006). Another example is the Spanish 'dehasa' silvopastoral system that covers about 4 M ha with trees of predominantly *Quercus* species and a grassland community known as 'majadal' (*Poetalia bulbosae*). Intensive and continuous livestock grazing (Olea and Miguel-Ayanz, 2006) creates and maintains a high representation of several legume species such as subterranean clover (*T. subterraneum*), and many self-sown legumes (e.g., 29 species in the Madrid region, González Bernáldez 1991). Legume-based grasslands with little or no fertiliser can also support more above- and below-ground biodiversity. In a study of 94 grasslands in Germany Birkhofer et al. (2011) showed that the feeding activity of soil fauna was enhanced by legume species richness and Piotrowska et al. (20130 also noted the positive impact of legumes on earthworm populations. The value of legumes such as Trifolium species in field margins is well known for attracting bumblebee species into agricultural landscapes (Backman and Tiainen 2002, Pywell et al. 2005)

Legumes are the backbone of organic farming systems, which are often considered of high value for the conservation of farmland biodiversity (Bengtsson et al. 2005, Hole et al. 2005, Gomiero et al. 2011). Organic farming often has positive effects on species richness and abundance, but its effects are likely to differ between organism groups and landscapes (Bengtsson et al. 2005).

Reduced ecotoxicity by biocide application and ozone formation

The diversification of cereal-dominated cropping systems with legumes enables pesticide savings, especially of specific fungicides, in rotations (von Richthofen et al. 2006). Cederberg and Flysiö (2004) calculated for a resource conserving pigmeat production scenario that in total the application of active substances could be reduced by 58% per kg of pork, of which 10% was due to reduced use of imported soya and 48 % to diversified crop rotation and integrated, partly mechanical weed control instead of exclusive reliance on herbicides. However, the high application rates of biocides, especially insecticides, in conventional grain legume production (Kirkegaard et al. 2008) off-sets this benefit, such that the terrestrial ecotoxicity potential assessed within an LCA of crop rotations was either not improved or the improvements were not consistent over different assessment methods (Nemecek and Baumgartner 2006). In addition to biocides, reduced ozone formation due to reduced fertiliser use has the potential to mitigate toxic effects on plants in ecosystems and agricultural production (Table 2).

Eutrophication and acidification of vulnerable ecosystems

Farming activities indirectly affect biodiversity in non-agricultural ecosystems through emissions to air and water that cause eutrophication. Depending on catch-crop management, legumes in arable systems can have slightly positive to very negative effects on nitrate leaching. On the other hand, they can strongly reduce gaseous N emissions – an effect that is not detectable from the impact category "eutrophication" in LCAs which is dominated by the leaching effects. Therefore both processes shall be discussed separately here.

Agricultural emissions of N and P compounds are a significant source of freshwater nutrients and are detrimental to biodiversity in aquatic ecosystems through eutrophication (Nemecek et al. 2005, European Environment Agency 2012b). Since leaching effects are the result of two counteracting processes (see section 2.4), the outcome of comparisons of grain legumes to other crops range from very positive to very negative, and the comparisons of crop rotations and animal products reveal non-significant to somewhat negative effects of including grain legumes (Tables 2-3). However, in all except one study (Cederberg and Flysiö 2004), grain legumes were not combined with winter catch crops before spring sowing or after their harvest. Nemecek and Baumgartner (2006) found in a sensitivity analysis for a German rotation, that inclusion of a catch crop changed the leaching effect of the legume rotation from a 4% increase to a 7% decrease compared to the non-legume rotation. In the estimations of Cederberg and Flysiö (2004), where catch crops were included before spring-sown crops, nitrate leaching decreased by 12% per ha farmland and, in combination with a higher feed efficiency, by 28% per kg of pork. Where grain legumes produced on-farm replace imported protein feeds, the combined eutrophication impacts are positively to very positively affected by grain legumes.

In forage-based systems, reliance on legumes combined with extensification or conversion to organic farming has the potential to reduce nitrogen leaching by more than half, but this is linked to lower productivity per unit area (Table 4).

Gaseous emissions of N compounds are dominated by ammonia, of which more than 93% comes from agriculture (European Environment Agency 2012a). These emissions cause nitrogen deposition to terrestrial ecosystems, leading to eutrophication and soil acidification (Galloway et al. 2004, Clark et al. 2013, WBA and WBD 2013). Evidence has shown a curvilinear decline of species richness in European acid grasslands with increasing N deposition (Stevens et al. 2010). In UK grasslands, plant species richness declined by one species per 4-m^2 quadrat for every 2.5 kg ha^{-1} $year^{-1}$ of chronic nitrogen deposition (Stevens et al. 2004).

Introducing grain legumes into crop rotations strongly reduces gaseous emissions, which are separately represented in Nemecek and Baumgartner (2006) and Cederberg and Flysiö (2004) and reflected in the impact category "acidification". Grain legume crops do not emit ammonia, leading to about 25% ammonia emission reduction on a rotation scale where fertilised crops are replaced, and reduce emissions of nitrous and nitrogenous oxides by about 10% on a rotation scale (Nemecek and Baumgartner 2006). For the same reasons, Table 2 shows that in 8 out of 10 case studies, grain legumes lead to favourable or very favourable impacts on acidification compared to other crops or rotations, even though many studies overestimate N_2O emissions of legumes, as previously described. For animal production, changes in feed or pasture composition have overall low effects on both eutrophication and acidification, only on-farm feed production with legumes significantly reduces both impacts. Use of domestic pea in feeds in combination with air filters in stables in one case study reduced ammonia emissions by 60% per kg meat (64% per ha) and nitrogenous oxides by 50% (Cederberg and Flysiö 2004).

Land-use change and biodiversity

Since the yield of grain legumes is currently much lower than that of cereals in the most productive regions of Europe, there is a risk that their environmental benefits will be countered by the need to use more land, with possible adverse effects on natural habitats and biodiversity. However, Cederberg and Flysiö (2004) estimated that increased cultivation of the domestic protein sources, rapeseed and pea, increased cereal yields to a degree that overall land use was slightly reduced. Mueller et al. (2013) showed that the mere area of land occupation in dairy farming systems is not a good indicator for biodiversity impact, as the lower biodiversity impact of land occupation in organic systems balanced their larger area occupation.

Mueller et al. (2013) also highlighted the large impact of land transformation in regions of soya production on biodiversity. Worldwide, soya demand is a major driver for deforestation and cultivation of savannahs in Brazil, although policies have been successful in reduce deforestation in recent years (Morton et al. 2006, Macedo et al. 2012, Barretto et al. 2013). Bickel & Dros (2003) highlighted the biodiversity value and insufficient protection of the Cerrado savannah in Mato Grosso. Sala et al. (2000) estimated that land use will be the major impact on biodiversity in the 21st century. Swiss LCA data estimated that 3.2 % of the soya crop area is transformed from rainforests or savannah in Brazil, and 1.6 % in Argentina (Baumgartner et al. 2008).

4. CONCLUSIONS

Increasing legume cultivation in Europe would bring benefits for the environment and resource use at a range of scales, from the field to the global. Their pre-crop effect, nitrogen provision, and potential to improve nutrient conservation and soil structure add to the sustainability of farm productivity while saving resources and reducing emissions. However, the effects may be reduced by the frequently low yields and by associated changes in cropping systems at the global scale.

Climate change

Existing LCAs show the potential for legumes to mitigate to climate change, but underestimate their true potential by mostly underestimating GHG reduction potential due to older methodology and not taking into account carbon sequestration. Furthermore, information on forage legumes in ley/arable rotations, with a likely much higher impact, is lacking. In animal production, grain legumes as replacement of soya feed can significantly reduce product life-cycle greenhouse gas emissions, but this effect is most pronounced where imported soya is replaced with feed produced either on the farm or in the region. Inclusion of legumes in forage-based systems has the greatest potential effects on GWP of animal products, and effects of partially replacing concentrate feeding by forage may be even higher when the greater carbon sequestration of grassland, compared to arable fields, is taken into account.

Moreover, through diversifying current cropping systems in European agriculture by growing more legumes, there is potential to reduce the vulnerability of these systems to climate change. However, little research has focused on climate change adaptation so far. A review on the adaptation of grain legumes to climate change (Vadez et al. 2012) focused on semi-arid and tropical conditions, and highlighted the complexity of adaptation challenges because of changes in temperature, water availability and distribution of insect pests and diseases. Similar research is lacking for European farming systems.

Biodiversity

The effects of crops on the diversity, richness and abundance of species and threats to vulnerable ecosystems are highly complex and cannot be fully represented by a simple indicator in LCAs. Grain legumes can increase crop and associated diversity of arable farming systems, but their biodiversity effect depends mainly on management in terms of applied pest and weed control and prevention of nitrate leaching through catch crops. Our compiled information is insufficient to conclude about the biodiversity benefits of leys in rotations and legume-based pastures, but there are indications that associated farmland biodiversity is high.

Replacing some of the EU feed soya import may have the greatest biodiversity benefits, but the effect of higher grain legume production in Europe on imports may be negligible due to the vast amounts of soya imported and increasing demand from the livestock sector. European production of protein crops, even if it were significantly increased, can satisfy only a small share of the European feed demand at current levels of crop yield, animal production and consumption.

Farming and food system effects

The analyses show that legumes are not a silver bullet, but a key component for a wider shift in agricultural production and consumption that reduce environmental impacts. They reduce environmental impacts of crop and animal production, but to achieve high reductions, further optimisations of livestock systems with respect to environmental impacts are required. On-farm feeding of home-grown legumes increases benefits further, although an on-farm feed producer may not achieve the efficiency of animal feed manufacturers, leading to higher feed costs and lower animal performance from farm-produced feeds. Grassland-based ruminant production systems may have lower impacts associated with feed production. Improved nutritional qualities (through plant breeding) of grain legumes would reduce environmental impacts from manure management. Baumgartner et al. (2008) suggested that feed optimisation models (defining the most cost-effective feeds) should be extended with environmental optimisation criteria, which would require research into the development of such models.[2] European-grown grain legumes can also provide environmental benefits in other end-uses in feeds for farmed fish (partially replacing soya feeds or fish meal), discussed in more detail in Legume Futures Report 1.3.

Furthermore, the analyses show that optimized production methods may not be sufficient to outbalance the high environmental impacts of animal production at current high levels of production and consumption. European average meat consumption would have to reduce by 62% to meet climate goals (stabilize GHG emissions from food sector at 2000-2005 level) and by 19% to meet health goals (reduce risks for cancer, obesity etc.) (Hallströmand Börjesson 2012).

[2] Models that take the environmental effects of feedstuff production into account do not seem to exist. Castrodeza et al. (2005), Dubeau et al. (2011) and Oishi et al. (2011) described feed formulation models that enable an optimized nutrient composition that reduces N and P excretion. Lara (1993) developed a feed formulation model that aims not only at low cost, but also at a maximised inclusion of the ingredients available in the farm.

Grain legumes may have a very significant environmental role to play in supporting diets with reduced animal protein. González et al. (2011) showed that in relation to energy use, grain legumes were the most efficient protein sources with 41-77 g protein per MJ energy use, and few cereals reached that range of efficiency (barley, rye, oats with 41-57 g protein per MJ). The efficiency was even greater in relation to global warming potential: grain legumes produced 246-505 g protein per kg CO_2-equivalent emissions, and only two cereals reached that range (rye and oats with 283 and 359 g protein per kg CO_2-eq.). The protein efficiency of most vegetables, fruits and animal products in relation to energy and GHG was below 10 g MJ^{-1} and 100 g kg^{-1}, respectively. A meal with potatoes, vegetables and a pea burger reduced all environmental impacts (GWP, eutrophication, acidification) by 34-78 % compared to a meal with a pork chop, even though all retail and household transport, losses, processing and home cooking were considered (Davis et al. 2010).

Such diets would have several health benefits. Grain legume seeds contain protein, fibre, micro and macronutrients, vitamins and numerous bioactive phytochemicals (Strohle et al. 2006), such as flavonoids and other antioxidants (Scalbert et al. 2005). Replacing animal products in the diet with plant products such as soya bean provides benefits in cardiovascular health (Sirtori et al. 2009) through lowered cholesterol (Harland and Haffner 2008) and reduced hypertension (Harland and Haffner 2008). Consumption of both soya bean and lupin decreases cholesterol in animals (Sirtori et al. 2004, Marchesi et al. 2008) and in humans (Sirtori et al. 2012) and grain legumes may also be useful in managing diabetes (Bertoglio et al. 2011).

Table 2. Resource (R) and environmental (E) effects of legumes arising from key agroecological processes operating at four levels of scale.

Process	Protein crop	Farm	Agri-food system	Global
Biological nitrogen fixation (BNF)	R: No N fertiliser required. E: Reduced N_2O emissions. E: Below ground biodiversity changes.	R: Reduced N fertiliser requirement.	R: Reduced fossil energy (natural gas) use. E: Reduced CO_2 emissions from industry.	E: Reduced global GHG emissions.
Grain protein synthesis	R: Lower crop yield (compared with cereals) due to resource demands of protein synthesis.	R: Increased on-farm supply of protein.	R: Increased diversity of 'protein' crop commodity supplies.	R: Reduced demand for globally traded soya. E: Reduced direct land-use change pressures.
N transformations in soil	E: Reduced N_2O emissions.	E: Effects in both directions on nitrate leaching.		E: Reduced global GHG emissions .
Soil development		R: Improved water infiltration, reduced cultivation energy, increased crop yields.		
Phosphorus transformations	R: Increased mobilisation of soil P.	R: Reduced optimum levels of plant-available P.		R: Reduced mining of phosphate rock (minor effect).
Soil carbon transformations	R: Positive soil carbon balance.	R: Increased soil organic matter, higher and more stable crop yields.		E: Increased soil carbon sequestration (minor effect).
Weed, pest and disease development		R: Increased cropping system yield. E: Reduced emissions of pesticides to water.		
Species interactions	E: Increased pollen and nectar provision. Increased soil fauna diversity.	E: Larger population of insects supporting wider wildlife.		

Table 2: Comparison of the results of LCA studies of grain legume products compared to other crops (%)

Region	% change in environmental impact					
	Energy demand	Global warming[11]	Ozone formation	Eutrophi-cation	Acidi-fication	Land use
Comparison of European-grown grain legumes to other crops [9] (per kg produce)						
Sweden, pea[1]	-27					
Sweden, pea[2]	-25	-7		91	2	
Switzerland, pea[4]	-3	11	25	-52	-48	29
Switzerland, faba bean[4]	-5	13	17	-56	-62	31
Switzerland, soya bean[4]	18	76	50	38	6	65
Finland, pea [6]	-25	-55*		-24	-37	-2
Finland, faba bean [6]	-7	-53*		124	-36	-11
Comparison of European-grown grain legumes to imported soya meal/cake (per kg produce)						
Sweden, pea [1]	-70					
Sweden, pea [2]	-78	-57		-50	-87	
France, pea[3]	-64	-44		-17	-67	-58
Austria, protein substitute with faba bean [7]		-74*				
Comparison of feed formula with European-grown grain legume to soya-based formula (per kg feed)						
Germany, feed formula[5] [10]	-5-10	-4-8	-4-8	-4-7	-5-12	
Comparison of crop rotations with grain legumes to those without (per ha land)						
Germany[5]	-14	-12	-10	-2	-17	
France[5]	-11	-8	-6	-6	-18	
Switzerland[5]	-31	-9	-15	10	-14	
Spain[5]	4	13	6	15	4	
France, winter pea [8]		-13*				
France, spring pea [8]		-12*				

Colour coding[5]	very favourable	favourable	n.s., not significant	unfavourable	very unfavourable

Source: Calculations based on data from: [1] Cederberg and Flysiö (2004), [2] Eriksson et al. (2004), [3] van der Werf et al. (2005) [4] Nemecek et al. (2005), [5] Nemecek and Baumgartner (2006), [6] Saarinen et al. (2012), [7] Hörtenhuber and Zollitsch (2010), [8] Hayer et al. (2012)

[9] other crops: average of wheat, barley, rapeseed

[10] range of feed formulas for different fattening stages

[11] most values are likely to be underestimated because in contrast to current IPCC 2006 guidelines, it was estimated that BNF caused N_2O emissions

* values estimated with current IPCC 2006 guidelines assuming no direct N_2O emissions caused by BNF

Table 3: Comparison of results of LCA studies of animal products produced using different feed compositions (%)

Region, product (main feed protein source)	% change in environmental impact: Energy demand	GWP excl. LUC	GWP incl. LUC	Ozone formation	Eutrophi-cation	Acidi-fication	Land use
Comparison between domestic legume-based feed and feed using imported soy (per kg end-product)							
Germany, pork[3] (pea)	-1		-5	-2	-7	-2	2
Germany, pork[3] (pea+SAA)	-1		-6	-2	-7	-2	1
Spain, pork[3] (pea)	-6		-2-11[7]	6	17-19[8]	-2	32
UK, pork (pea)[4]		-5*	-22*		-1	-33	
UK pork (bean)[4]		-2*	-22*		7	-17	
Sweden, pork chop[5] (pea)	-1		-3	0	-4	-3	2
Spain, pork chop[5] (pea)	-2		-1	1	12	-1	28
France, chicken meat[3] (pea+faba bean)	-6		-10	-2	5	-2	2
France, chicken meat[3] (pea+ faba bean+SAA)	9		-9	-3	-2	-3	-10
France, eggs[3] (pea)	-4		-10	-5	6	0	0
UK, milk[3] (pea)	-9		-4	-3	2	-1	3
UK, milk[3] (pea, energy optimized feed)	-7		-7	-4	-5	-8	-3
Comparison farm-produced legume-based feed and feed based on imported soy (per kg end-product)							
Germany, pork[3] (pea)	-19		-16	-25	-19	-10	-3
Sweden, pork[2] (pea, typical organic formula)	-19	-10			2	8	24
Sweden, pork[2] (pea+SAA)	-13	-7			-15	-21	17
Sweden, pork[1] (pea+faba bean) [6]	-16	-13		n.s.	-31	-40	-8
Comparison between pulse- and meat-based human meal (per one meal)							
Sweden, pork chop (pea) or pea burger[5]	-9		-53	-20	-59	-78	-64
Spain, pork chop (pea) or pea burger[5]	-16		-34	-27	-58	-54	-55

Colour coding[6]	very favourable	favourable	n.s., not significant	unfavourable	Very unfavourable

Source: Calculations based on data from: [1] Cederberg and Flysiö (2004), [2] Eriksson et al. (2005), [3] Baumgartner et al. (2008), [4] Topp et al. (2012), [5] Davis et al. (2010), [6] Nemecek and Baumgartner (2006)

[6] comparison of a conventional with a resource optimized farming system scenarios

[7] increased when biomass burning of land transformation of savannahs was included

[8] increased when technical improvements of manure handling were introduced for both feed alternatives

* values estimated with current IPCC 2006 guidelines assuming no direct N_2O emissions caused by BNF

Table 4: Comparison of LCA studies of animal production systems with forage legumes (%)

Region, product (main feed protein source)	FU	% change in environmental impact					
		Energy demand	GWP	GWP incl. C sequ.	Eutrophi-cation	Acidi-fication	Land use
Optimisation of beef cattle rearing in France							
… reduce grassland fertilisation[8]	kg carcass	-3	-2*	-2*	-11		
… partially replaced soya in winter feed by lucerne hay[8]	kg carcass	0	0*	0*	-1		
Comparison of dairy farms with fertilised and white clover-based pastures							
Ireland[1]	kg ECM	-15	-11-23				
Netherlands[2]	ha			-18			
	kg ECM			-10			
Comparison of intensive dairy farms with those with forms of extensification and increased feed self-sufficiency							
Ireland[3], Agri-environental schemes	kg live weight gain		-6				
	ha		-18				
German Allgäu region[4], Agri-environental schemes	ha	-54	-26		-13	-42	
	t milk	-52	-23				
Netherlands[5], 'Internal nutrient cycling' farms	kg FPCM	-15	-7*	**	-16	-9	-7
	ha				-6	1	
Italy[6], extensive farm clusters	kg FPCM	-21	-8*		28	6	5
Comparison of intensive dairy/cattle farms with organic ones							
Ireland[3]	kg live weight gain		-15				
	ha		-57				
German Allgäu region[4]	ha	-69	-33		-21	-75	
	t milk	-56	0				
Netherlands[7]	kg FPCM	-38	7*		-36	14	38

[1] Yan et al. (2013), [2] Schils et al. (2000), Schils et al. (2005), [3] Casey and Holden (2006), [4] Haas et al. (2001), [5] Dolman et al. (2012), [6] Guerci et al. (2012), [7] Thomassen et al. (2008), [8] Nguyen et al. (2012)
* GWP estimated according to current methodology De Klein et al. (2006), which estimates no direct N_2O emissions from BNF.
** C sequestration increased by 22% per ha
In general, the extensive farms reduced N fertiliser use up to 77% (except organic farms?), consequently had an up to 39% lower grassland yield and had up to 58% lower stocking density, whereas milk yield per cow was in most cases comparable and only negatively affected in two organic situations.

5. REFERENCES

Agreste, 2013. Des rendements proches d'une année moyenne pour les céréales à paille, mais inférieurs pour les cultures de printemps. In: Agreste conjoncure - Infos rapides. Mountreuil sous Bois: pp: 5.

Alpmann, D., J. Braun and B.C. Schäfer, 2013. Analyse einer Befragung unter erfolgreichen Körnerleguminosenanbauern im konventionellen Landbau. Erste Ergebnisse aus dem Forschungsprojekt LeguAN. In: DLG Wintertagung, Im Fokus: Heimische Körnerleguminosen vom Anbau bis zur Nutzung. Berlin: pp: 20.

Andrews, M., Scholefield, D., Abberton, M.T., McKenzie, B.A., Hodge, S. and Raven, J.A. 2007. Use of white clover as an alternative to nitrogen fertiliser for dairy pastures in nitrate vulnerable zones in the UK: productivity, environmental impact and economic considerations. Annals of Applied Biology 151, 11–23

Angus, J.F., A.F. van Herwaarden and G.N. Howe, 1991. Productivity and break crop effects of winter-growing oilseeds. Australian Journal of Experimental Agriculture, 31: 669-677.

Aslaksen, M.A., Kraugerud, O.F., Penn, M., Svihus, B., Denstadli, V., Jorgensen, H.Y., Hillestad, M., Krogdahl, A., Storebakken, T., 2007. Screening of nutrient digestibilities and intestinal pathologies in Atlantic salmon, *Salmo salar*, fed diets with legumes, oilseeds, or cereals. Aquaculture 272:541–555.

Ayaz, S., B.A. McKenzie, G.D. Hill and D.L. McNeil, 2004. Variability in yield of four grain legume species in a subhumid temperate environment i. Yields and harvest index. The Journal of Agricultural Science, 142: 9-19.

Baars, T., Wohlers, J.,Kusche, D. & Jahreis, G. 2011. Experimental improvement of cow milk fatty acid composition in organic winter diets. Journal of the Science of Food and Agriculture 92: 2883-2890.

Bäckman JC, Tiainen J (2002) Habitat quality of field margins in a Finnish farmland area for bumblebees (Hymenoptera: Bombus and Psithyrus). Agric Ecosyst Environ 89:53–68

Ball, B.C., Watson, C.A., Crichton, I., 2007. Nitrous oxide emissions, cereal growth, N recovery and soil nitrogen status after ploughing organically managed grass/clover swards. Soil Use and Management 23: 145-155.

Barretto, A.G., G. Berndes, G. Sparovek and S. Wirsenius, 2013. Agricultural intensification in Brazil and its effects on land-use patterns: an analysis of the 1975-2006 period. Global Change Biology, 19: 1804-1815.

Baumgartner, D.U., L. de Baan and T. Nemecek, 2008. European grain legumes - Environment-friendly animal feed? Life cylce assessment of pork, chicken meat, egg, and milk production. In: Final Report WP2.2, Grain Legumes Integrated Project. Agroscope Reckenholz-Tänikon Research Station (ART), Zürich: pp: 112.

Bengtsson, J., J. Ahnström and A.-C. Weibull, 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. Journal of Applied Ecology, 42: 261-269.

Berg, Å., M. Jonsson, T. Lindberg and K.-G. Källebrink, 2002. Population dynamics and reproduction of Northern Lapwings *Vanellus vanellus* in a meadow restoration area in central Sweden. Ibis, 144: E131-E140.

Bertoglio, J.C., M.A. Calvo, J.L. Hancke, R.A. Burgos, A. Riva, P. Morazzoni, C. Ponzone, C. Magni and M. Duranti, 2011. Hypoglycemic effect of lupin seed γ-conglutin in experimental animals and healthy human subjects. Fitoterapia, 82: 933-938.

Bickel, U. and J.M. Dros, 2003. The Impacts of Soybean Cultivation on Brazilian Ecosystems. J. Runkel (Ed.). WWF Forest Conversion Initiative: pp: 33.

Birkhofer, K., Diekötter, T., Boch, S., Fischer, M., Müller, J., Socher, S.. and Wolters, V. 2011. Soil fauna feeding activity in temperate grassland soils increases with legume and grass species richness. Soil Biology and Biochemistry 43, 2200-2207.

Borgen, S.K., Lunde, H.W., Bakken, L.R., Bleken, M.A. and Breland, T.A. 2012 Nitrogen dynamics in stockless organic clover–grass and cereal rotations. Nutrient Cycling in Agroecosystems 92, 363-378Bruce, R.R., S.R. Wilkinson and G.W. Langdale, 1987. Legume effects on soil erosion and productivity. In: The Role of Legumes in Conservation Tillage Systems, J. F. Power, (Ed.). Soil Conserv. Soc. Am., Ankeny, IA: pp: 127-138.

Bues, A., Preissel, S., Reckling, M., Zander, P., Kuhlman, T., Topp, K., Watson, C.A., Lindström, K., Stoddard, F.L. & Murphy-Bokern, D. 2013. The environmental role of protein crops in the new Common Agricultural Policy. European Parliament, Directorate General for Internal Policies, Policy Department B: Structural and Cohesion Policies, Agricultural and Rural Development IP/B/AGRI/IC/2012-067. 112 pp. http://www.europarl.europa.eu/studies. ISBN 978-92-823-4521-4, doi: 10.2861/27627.

http://www.europarl.europa.eu/RegData/etudes/etudes/join/2013/495856/IPOL-AGRI_ET(2013)495856_EN.pdf

Bundesministerium für Ernährung und Landwirtschaft, 2013. MBT-0104160-0000 Vorläufige Herbstaussaatfläche für die Ernte.

Carlsson, G. and K. Huss-Danell, 2003. Nitrogen fixation in perennial forage legumes in the field. Plant and Soil, 253: 353-372.

Casey, J.W. and N.M. Holden, 2006. Greenhouse gas emissions from conventional, agri-environmental scheme, and organic irish suckler-beef units. J. Environ. Qual., 35: 231-239.

Castrodeza, C., Lara, P., Peña, T., 2005. Multicriteria fractional model for feed formulation: economic, nutritional and environmental criteria. Agricultural Systems 86:76–96.

Cederberg, C. and A. Flysiö, 2004. Environmental assessment of future pig farming systems. Quantifications of three scenarios from the FOOD 21 synthesis work. In: SIK-rapport. The Swedish Institute for Food and Biotechnology (SIK), Göteborg: pp: 54.

Chalk, P.M., 1998. Dynamics of biologically fixed N in legume-cereal rotations: A review. Australian Journal of Agricultural Research, 49: 303-316.

Charles, R. and P. Vuilloud, 2001. Pois protéagineux et azote dans la rotation. Revue suisse Agric., 33: 365-370.

Clark, C.M., Y. Bai, W.D. Bowman, J.M. Cowles, M.E. Fenn, F.S. Gilliam, G.K. Phoenix, I. Siddique, C.J. Stevens, H.U. Sverdrup and H.L. Throop, 2013. Nitrogen Deposition and Terrestrial Biodiversity. In: Encyclopedia of Biodiversity (Second Edition), A. L. Simon, (Ed.). Academic Press, Waltham: pp: 519-536.

Clarke, A.-M., P. Crosson and P. Brennan, 2012. An assessment of greenhouse gas emissions and economics of grass based suckler beef production systems In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 163-168.

Collette, L. Hodgkin, T., Kassam, A., Kenmore, P., Lipper, L., Nolte, C., Stamoulis, K., Steduto, P., 2011. Save and Grow. Rome, Italy: Food and Agriculture Organization of the United Nations.

Corson, M. S. and H. M. G. van der Werf (Eds.) 2012. Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2012), 1-4 October 2012. INRA, Saint Malo, France.

Crews, T.E., Peoples, M.B., 2004. Legume versus fertiliser sources of nitrogen: Ecological tradeoffs and human needs. Agriculture, Ecosystems and Environment 102:279–297.

Dachler, M. and A. Köchl, 2003. Der Einfluss von Fruchtfolge, Vorfrucht, Stickstoffdüngung und Einarbeitung der Ernterückstände auf Ertrag und Rohproteingehalt von Winterweizen und nachfolgender Sommergerste. Die Bodenkultur, 54: 23-34.

Davies, M., K. Smith and A. Vinten, 2001. The mineralisation and fate of nitrogen following ploughing of grass and grass-clover swards. Biology and Fertility of Soils, 33: 423-434.

Davis, J., U. Sonesson, D.U. Baumgartner and T. Nemecek, 2010. Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. Food Research International, 43: 1874-1884.

De Klein, C., R.S.A. Novoa, S. Ogle, K.A. Smith, P. Rochette, T.C. Wirth, B.G. McConkey, A. Mosier and K. Rypdal, 2006. N2O emissions from managed soils, and CO2 emissions from lime and urea application. In: 2006 IPCC guidelines for national greenhouse gas inventories, S. EgglestonL. BuendiaK. MiwaT. Ngara and K. Tanabe, (Eds.). Institute for Global Environmental Strategies,, Hayama: pp: 11.11-11.54.

Defra and AHDB, 2012. HGCA/AHDB Winter Planting Survey 2012. A. M. Intelligence (Ed.).

Dewhurst, R.J., W.J. Fisher, J.K.S. Tweed and R.J. Wilkins, 2003. Comparison of Grass and Legume Silages for Milk Production. 1. Production Responses with Different Levels of Concentrate. Journal of Dairy Science, 86: 2598-2611.

Dewhurst, R.J., L. Delaby, A. Moloney, T. Boland and E. Lewis, 2009. Nutritive value of forage legumes used for grazing and silage. Ir. J. Agric. Food Res., 48: 51-70.

Dicks, L.V., J.E. Ashpole, J. Dänhardt, K. James, A. Jönsson, N. Randall, D.A. Showler, R.K. Smith, S. Turpie, D. Williams and W.J. Sutherland, 2013. Farmland Conservation: Evidence for the effects of interventions in northern and western Europe. Exeter: Pelagic Publishing.

Dolman, M.A., M.P.W. Sonneveld, H. Mollenhorst and I.J.M. De Boer, 2012. Comparing integral sustainability performance of conventional farms with farms focussing on internal recycling of nutrients. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-

4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 76-81.

Dong, Z., Layzell, D.B., 2001. H_2 oxidation, O_2 uptake and CO_2 fixation in hydrogen treated soils. Plant and Soil 229:1–12.

Dubeau, F., Julien, P.-E., Pomar, C., 2011. Formulating diets for growing pigs: economic and environmental considerations. Annals of operations research 190:239–269.

Dunbabin, V., Diggle, A., Rengel, Z., 2003. Is there an optimal root architechture for nitrate capture in leaching environments? Plant, Cell and Encironment 26:835 –844.

Dusenbury, M.P., Engle, R.E., Miller, R.P., Lemke, R.L., Wallander, R., 2008. Nitrous oxide emissions from a northern Great Plains soil as influenced by nitrogen management and cropping systems. Journal of Environmental Quality 37:542–550.

Dyke, G.V. and D.B. Slope, 1978. Effects of previous legume and oat crops on grain-yield and take-all in spring barley. Journal of Agricultural Science, 91: 443-451.

Egle, K., Romer, W., Keller, H., 2003. Exudation of low molecular weight organic acids by *Lupinus albus* L., *Lupinus angustifolius* L. and *Lupinus luteus* L. as affected by phosphorus supply. Agronomie 23:511–518.

Eichhorn, M., P. Paris, F. Herzog, L. Incoll, F. Liagre, K. Mantzanas, M. Mayus, G. Moreno, V. Papanastasis, D. Pilbeam, A. Pisanelli and C. Dupraz, 2006. Silvoarable systems in Europe – past, present and future prospects. Agroforest. Syst., 67: 29-50.

Eisenhauer, N., Milcu, A., Sabais, A.C.W., Bessler, H., Weigelt, A., Engels, C., Scheu, S., 2009. Plant community impacts on the structure of earthworm communities depend on season and change with time. Soil Biology and Biochemistry 41:2430–2443.

Ellis, K.A., Innocent, G., Grove-White, D., Cripps, P., McLean, W.G., Howard, C.V. & Mihm, M. 2006. Comparing the fatty acid composition of organic and conventional milk. Journal of Dairy Science 89: 1938–1950.

Eriksen, J., Vinther, F.P. and Søegaard, K. 2004. Nitrate leaching and N_2-fixation in grasslands of different composition, age and management. Journal of Agricultural Science, 142, 141–151

Eriksson, I.S., H. Elmquist, S. Stern and T. Nybrant, 2004. Environmental Systems Analysis of Pig Production - The Impact of Feed Choice. The International Journal of Life Cycle Assessment, 10: 143-154.

European Environment Agency, 2012a. Ammonia (NH3) emissions (APE 003). In: Indicators. European Environment Agency: pp: 11.

European Environment Agency, 2012b. Nutrients in freshwater (CSI 020). In: Indicators. European Environment Agency.

Evans, A., J. Vickery and M. Shrubb, 2004. Importance of overwintered stubble for farmland bird recovery: a reply to Potts. Bird Study, 51: 94-96.

Evans, J., G. Scott, D. Lemerle, A. Kaiser, B. Orchard, G.M. Murray and E.L. Armstrong, 2003. Impact of legume 'break' crops on the yield and grain quality of wheat and relationship with soil mineral N and crop N content. Australian Journal of Agricultural Research, 54: 777-788.

Fillery, I.R.P., 2001. The fate of biologically fixed nitrogen in legume-based dryland farming systems: a review. Australian Journal of Experimental Agriculture, 41: 361-381.

Fornara, D.A., Tilman, D., 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology 96:314-322.

Fuchs, N. and U. Hoffmann, 2013. Ensuring food securits and environmental resilience - The need for supportive agricultural trade rules. In: UNCTAD Trade and Environment Review 2013. United Nations,, Geneva: pp: 266-275.

Fuchs, S., 2010. Feldhase. In: Stein-Bachinger, K., Fuchs, S., Gottwald, F., Helmecke, A., Grimm, J., Zander, P., Schuler, J., Bachinger, J. Gotschall, R.: Naturschutzfachliche Optimierung des Ökologischen Landbaus 'Naturschutzhof Brodowin'. Bonn-Bad Godesberg: Bundesamt für Naturschutz.

Galloway, J.N., F.J. Dentener, D.G. Capone, E.W. Boyer, R.W. Howarth, S.P. Seitzinger, G.P. Asner, C.C. Cleveland, P.A. Green, E.A. Holland, D.M. Karl, A.F. Michaels, J.H. Porter, A.R. Townsend and C.J. Vorosmarty, 2004. Nitrogen cycles: past, present, and future. Biogeochemistry, 70: 153-226.

Garrigues, E., M.S. Corson, C. Walter, D.A. Angers and H. van der Werf, 2012b. Soil-quality indicators in LCA: method presentation with a case study In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 163-168.

Garrigues, E., M.S. Corson, D.A. Angers, H.M.G. van der Werf and C. Walter, 2012a. Soil quality in Life Cycle Assessment: Towards development of an indicator. Ecological Indicators, 18: 434-442.

Giambalvo, D., L. Stringi, G. Durante, G. Amato and A.S. Frenda, 2004. Nitrogen efficiency component analysis in wheat under rainfed Mediterranean conditions: effects of crop rotation and nitrogen fertilisation. In: Mediterranean rainfed agriculture: Strategies for sustainability, C. Cantero-Martínez and D. Gabiña (Eds.). Mediterranean Agronomic Institute of Zaragoza, Zaragoza: pp: 169-173.
Gillings, S., S.E. Newson, D.G. Noble and J.A. Vickery, 2005. Winter availability of cereal stubbles attracts declining farmland birds and positively influences breeding population trends. Proc Biol Sci, 272: 733-739.
Goglio, P., C. Colnenne-David, C. Di Bene, S. Bosco, P. Laville, R. Roche, G. Ragaglini, T. Doré, M. Mazzoncini, B. Gabrielle and E. Bonari, 2012. Soil, climate and cropping system effects on N_2O accounting in the LCA of faba bean and cereals. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 76-81.
Golding, A.-L., Dong, Z., 2010. Hydrogen production by nitrogenase as a potential crop rotation benefit. Environmental Chemistry Letters 8:101–121.
Gomiero, T., D. Pimentel and M.G. Paoletti, 2011. Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture. Critical Reviews in Plant Sciences, 30: 95-124.
González Bernáldez, F., 1991. Ecological consequences of the abandonment of traditional land use systems in central Spain. In Baudry J., Bunce R.G.H. (Eds.) .Land abandonment and its role in conservation Zaragoza : CIHEAM Options Méditerranéennes : Série A. Séminaires Méditerranéens; 15:23- 29.
González, A.D., B. Frostell and A. Carlsson-Kanyama, 2011. Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation. Food Policy, 36: 562-570.
Granstedt, A., 2000. Increasing the efficiency of plant nutrient recycling within the agricultural system as a way of reducing the load to the environment - experience from Sweden and Finland. Agriculture Ecosystems & Environment, 80: 169-185.
Green, A.G., A.H.D. Brown and R.N. Oram, 1980. Determination of outcrossing rate in a breeding population of *Lupinus albus* L.(white lupin). Zeitschrift fur Pflanzenzuchtung, 84: 181-191.
Gregorich, E.G., Drury, C. F., Baldock, J.A., 2001. Changes in soil carbon under long-term maize in monoculture and legume-based rotation. Canadian Journal of Soil Science 81: 1-31.
Guerci, M., M. Zucali, A. Sandrucci, A. Tamburini, C. Penati and L. Bava, 2012. Life cycle assessment of milk production in Italian intensive dairy farms. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 659-660.
Haas, G., F. Wetterich and U. Köpke, 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agriculture Ecosystems & Environment, 83: 43-53.
Hallström, E. and P. Börjesson, 2012. Sustainable meat consumption to meet climate and health goals - implications of variations in consumption statistics In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf (Eds.). INRA, Saint Malo, France: pp: 163-168.
Harland, J.I. and T.A. Haffner, 2008. Systematic review, meta-analysis and regression of randomised controlled trials reporting an association between an intake of circa 25 g soya protein per day and blood cholesterol. Atherosclerosis, 200: 13-27.
Harris, S.L., M.J. Auldist, D.A. Clark and E.B. Jansen, 1998. Effects of white clover content in the diet on herbage intake, milk production and milk composition of New Zealand dairy cows housed indoors. J. Dairy Res.: 389-400.
Hauggaard-Nielsen, H., B. Jørnsgaard, J. Kinane and E.S. Jensen, 2008. Grain legume–cereal intercropping: The practical application of diversity, competition and facilitation in arable and organic cropping systems. Renewable Agriculture and Food Systems, 23.
Hayer, F., E. Bonnin, B. Carrouée, G. Gaillard, T. Nemecek, A. Schneider and C. Vivier, 2012. Designing sustainable crop rotations using life cycle assessment of crop sequences. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf (Eds.). INRA, Saint Malo, France: pp: 828-829.
Henry, S., Texier, S., Hallet, S., Bru, D., Dambreville, C., Chèneby, D., Bizouard, F., Germon, J.C., Philippot, L., 2008. Disentangling the rhizosphere effect on nitrate reducers and denitrifiers: insight into the role of root exudates. Environmental Microbiology 10:3082–3092.

Hermansen, J.E. and T. Kristensen, 2011. Management options to reduce the carbon footprint of livestock products. Animal Frontiers, 1: 33-39.
Hernanz,J.L., Sanchez-Giron, V. & Navarrete, L. 2009. Soil carbon sequestration and stratification in a cereal/leguminous crop rotation with three tillage systems in semiarid conditions. Agriculture, Ecosystems & Environment 133: 114-122.
Hole, D.G., A.J. Perkins, J.D. Wilson, I.H. Alexander, P.V. Grice and A.D. Evans, 2005. Does organic farming benefit biodiversity? Biological Conservation, 122: 113-130.
Hooda, P.S., Truesdale, V.W., Edwards, A.C., Withers, P.J.A., Aitken, M.N., Miller, A. and Rendell, A.R. 2001. Manuring and fertilisation effects on phosphorus accumulation in soils and potential environmental implications. Advances in Environmental Research 5, 13-21.
Hörtenhuber, S. and W. Zollitsch, 2010. Greenhause gas emissions of regionally produced alternative feedstuffs rich in protein for Austrian dairy production. In: Building sustainable rural futures. IFSA, Vienna: pp: 1349-1356.
Huber, R., E.R. Keller, F. Schwendimann and A. Soldati, 1989. Biological N-fixation of fababeans and effects of the N-capacity of soils in serial crop rotations. Bodenkultur, 40: 25-36.
Humphreys, J. and P. Phelan, 2013. White clover supported forage systems in North West Europe. pp: 22.
Humphreys, J., E. Mihailescu and I.A. Casey, 2012. An economic comparison of systems of dairy production based on N fertilised grass and grass-white clover grassland in a moist maritime environment Grass Forage Sci., 67: 519-525.
Humphreys, J., I.A. Casey and A.S. Laidlaw, 2009. Comparison of milk production from clover-based and fertiliser n-based grassland on a clay-loam soil under moist temperate climatic conditions. Irish Journal Agriculture and Food Research, 48: 71-89.
Hymes-Fecht, U.C., Broderick, G.A., Muck, R.E. and Grabber, J.H. 2013 Replacing alfalfa or red clover silage with birdsfoot trefoil silage in total mixed rations increases production of lactating dairy cows. Journal of Dairy Science 96, 460-469.
IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Inst. for Global Strategies (IGES), Hayama.
Jeanneret, P., D.U. Baumgartner, R. Freiermuth and G. Gaillard, 2006. Méthode d'évaluation de l'impact des activités agricoles sur la biodiversité dans les bilans écologiques. Agroscope FAL Reckenholz: pp: 67.
Jensen, C.R., B. Joernsgaard, M.N. Andersen, J.L. Christiansen, V.O. Mogensen, P. Friis and C.T. Petersen, 2004. The effect of lupins as compared with peas and oats on the yield of the subsequent winter barley crop. European Journal of Agronomy, 20: 405-418.
Jensen, E.S. and H. Hauggaard-Nielsen, 2003. How can increased use of biological N2 fixation in agriculture benefit the environment? Plant and Soil, 252: 177-186.
Jensen, E.S. and V. Haahr, 1990. The effects of pea cultivation on succeeding winter cereals and winter oilseed rape nitrogen nutrition. Applied Agricultural Research, 5: 102-107.
Jensen, E.S., 1997. The role of grain legume N fixation in the nitrogen cycling of temperate cropping systems. Roskilde: Risø National Laboratory.
Jensen, E.S., M.B. Peoples and H. Hauggaard-Nielsen, 2010. Faba bean in cropping systems. Field Crops Research, 115: 203-216.
Jensen, E.S., M.B. Peoples, R.M. Boddey, P.M. Gresshoff, H. Hauggaard-Nielsen, B.J.R. Alves and M.J. Morrison, 2011. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agronomy for Sustainable Development, 32: 329-364.
Justus, M. and U. Köpke, 1995. Strategies to Reduce Nitrogen Losses via Leaching and to Increase Precrop Effects when Growing Faba Beans. Biological Agriculture & Horticulture, 11: 145-155.
Kaul, H.-P., 2004. Pre-crop effects of grain legumes and linseed on soil mineral N and productivity of subsequent winter rape and winter wheat crops. Die Bodenkultur, 55: 95-102.
Kirkegaard, J.A., O. Christen, J. Krupinsky and D. Layzell, 2008. Break crop benefits in temperate wheat production. Field Crops Research, 107: 185-195.
Kleen, J., F. Taube and M. Gierus, 2011. Agronomic performance and nutritive value of forage legumes in binary mixtures with perennial ryegrass under different defoliation systems. Journal of Agricultural Science, Cambridge 149: 73-84.
Kopij, G., 2008. Effect of change in land use on breeding bird communities in a Silesian farmland (SW Poland). Polish Journal of Ecology 56:511–519.
Köpke, U. and T. Nemecek, 2010. Ecological services of faba bean. Field Crops Research, 115: 217-233.

Kraljević, D., L. Šumanovac, G. Heffer and Z. Horvat, 2007. Effect of precrop on winter wheat yield. Cereal Research Communications, 35: 665-668.

KTBL [Kuratorium für Technik und Bauwesen in der Landwirtschaft], 2009. Faustzahlen für die Landwirtschaft. 14. Auflage. Darmstadt: KTBL.

La Favre, J.S., Focht, D.D., 1983. Conservation in soil of H2 liberated from N2 fixation by Hup- nodules. Applied and Environmental Microbiology 46:304–311.

Lara, P., 1993. Multiple objective fractional programming and livestock ration formulation: A case study for dairy cow diets in Spain. Agricultural Systems 41:321–334.

Larsson, M. and A. Granstedt, 2010. Sustainable governance of the agriculture and the Baltic Sea — Agricultural reforms, food production and curbed eutrophication. Ecological Economics, 69: 1943-1951.

Ledda L., Porqueddu C., Roggero P.P., 2000. Role of forage legumes and constraints for forage legume seed production in Mediterranean Europe. In : Sulas L. (Ed.). Legumes for Mediterranean forage crops, pastures and alternative uses . Zaragoza: CIHEAM, 2000. Cahiers Options Méditerranéennes 45:453-460.

Leithold, G., K.J. Hülsbergen, D. Michel and H. Schönmeier, 1997. Humusbilanzierung - Methoden und Anwendungen als Agrar-Umweltindikator. Schriftenreihe der Sächsischen Landesanstalt für Landwirtschaft 3:19–28.

Lemke, R.L., Z. Zhong, C.A. Campbell and R.P. Zentner, 2007. Can pulse crops play a role in mitigating greenhouse gases from North American agriculture? Agronomy Journal, 99: 1719-1725.

Lesschen, J.P., M. van den Berg, H.J. Westhoek, H.P. Witzke and O. Oenema, 2011. Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science and Technology, 166-167: 16-28.

Li, D., G. Lanigan and J. Humphreys, 2011. Measured and simulated nitrous oxide emissions from ryegrass-and ryegrass/white clover-based grasslands in a moist temperate climate. PLoS ONE, 6: e26176.

Lopez-Bellido, R.J., J.M. Fontan, F.J. Lopez-Bellido and L. Lopez-Bellido, 2010. Carbon sequestration by tillage, rotation, and nitrogen fertilisation in a Mediterranean vertisol. Agronomy Journal, 102: 310-318.

López-Bellido, R.J., L. López-Bellido, F.J. López-Bellido and J.E. Castillo, 2003. Faba bean (*Vicia faba* L.) response to tillage and soil residual nitrogen in a continuous rotation with wheat (*Triticum aestivum* L.) under rainfed Mediterranean conditions. Agronomy Journal, 95: 1253-1261.

López-Fando, C. and G. Almendros, 1995. Interactive effects of tillage and crop rotations on yield and chemical properties of soils in semi-arid central Spain. Soil and Tillage Research, 36: 45-57.

Luetke-Entrup, N., H. Pahl and R. Albrecht, 2003. Fruchtfolgewert von Körnerleguminosen. In: UFOP-Praxisinformation. Union zur Förderung von Oel- und Proteinpflanzen (UFOP), Berlin: pp: 20.

Macedo, M.N., R.S. DeFries, D.C. Morton, C.M. Stickler, G.L. Galford and Y.E. Shimabukuro, 2012. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. Proc Natl Acad Sci U S A, 109: 1341-1346.

Maidl, F.X., F.X. Haunz, A. Panse and G. Fischbeck, 1996. Transfer of grain legume nitrogen within a crop rotation containing winter wheat and winter barley. Journal of Agronomy and Crop Science, 176: 47-57.

Maimaiti, J., Zhang,Y., Yang, J., Cen, Y.-P., Layzell, D.B., Peoples, M., Dong, Z., 2007. Isolation and characterization of hydrogen-oxidizing bacteria induced following exposure of soil to hydrogen gas and their impact on plant growth. Environmental Microbiology 9:435–444.

Marchesi, M., C. Parolini, E. Diani, E. Rigamonti, L. Cornelli, A. Arnoldi, C.R. Sirtori and G. Chiesa, 2008. Hypolipidaemic and anti-atherosclerotic effects of lupin proteins in a rabbit model. Br J Nutr, 100: 1-4.

Martin B., Verdier-Metz I., Buchin S., Hurtaud C. and Coulon J. B., 2005. How do the nature of forages and pasture diversity influence the sensory quality of dairy livestock products? Animal Science 81: 205-212.

Moloney A.P., Fievez V., Martin B., Nute G.R. and Richardson R.I., 2008. Botanically diverse forage-based rations for cattle: implications for product composition, product quality and consumer health. Grassland Science in Europe 13: 361-374.

Moorby, J.M., M.R.F. Lee, D.R. Davies, E.J. Kim, G.R. Nute, N.M. Ellis and N.D. Scollan, 2009. Assessment of dietary ratios of red clover and grass silages on milk production and milk quality in dairy cows. Journal of Dairy Science, 92: 1148-1160.

Mortensen M.C., Schuman G.E. and Ingram L.J. (2004) Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (Medicago sativa ssp. falcata) Environmental Management 33, 475-481.

Morton, D.C., R.S. De Fries, Y.E. Shimabukuro, L.O. Anderson, E. Arai, F. del Bon Espirito-Santo, R. Freitas and J. Morisette, 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. Proceedings of the National Academy of Sciences of the United States of America, 103: 14637-14641.

Mueller, C., L. Baan and T. Koellner, 2013. Comparing direct land use impacts on biodiversity of conventional and organic milk—based on a Swedish case study. The International Journal of Life Cycle Assessment.
Nemecek, T. and D.U. Baumgartner, 2006. Environmental impacts of introducing grain legumes into European crop rotations and pig feed formulas In: Concerted Action GL-Pro. Agroscope Reckenholz-Tänikon Research Station (ART), Zürich: pp: 63.
Nemecek, T., J.-S. von Richthofen, G. Dubois, P. Casta, R. Charles and H. Pahl, 2008. Environmental impacts of introducing grain legumes into European crop rotations. European Journal of Agronomy, 28: 380-393.
Nemecek, T., O. Huguenin-Elie, D. Dubois and G. Gaillard, 2005. Ökobilanzierung von Anbausystemen im schweizerischen Acker- und Futterbau. In: Schriftenreihe der FAL, Agroscope FAL Reckenholz. Zürich: pp: 156.
Nguyen, T.T.H., M. Doreau, M. Eugène, M.S. Corson, F. Garcia-Launay, G. Chesneau and H.M.G. van der Werf, 2012. Effect of farming practices for greenhouse gas mitigation and subsequent alternative land-use on environmental impacts of beef-cattle production systems. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 601-606.
Núñez, M., A. Antón, P. Muñoz and J. Rieradevall, 2012. Regionalised method to assess soil erosion in LCA. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 519-523.
Nuruzzaman, M., Lambers, L., Bolland, M.D.A., Veneklaas, E.J., 2005. Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertiliser. Australian Journal of Agricultural Research, 56: 1041–1047.
Offermann, F., Nieberga, H. & Zander, K. 2009. Dependency of organic farms on direct payments in selected EU member states: Today and tomorrow. Food Policy 34: 273-279.
Oishi, K., Kumagai, H., Hirooka, H., 2011. Application of the modified feed formulation to optimize economic and environmental criteria in beef cattle fattening systems with food by-products. Animal Feed Science and Technology 165:38–50.
Olea, L. and San Miguel-Ayanz, A., 2006. The Spanish dehesa. A traditional Mediterranean silvopastoral system linking production and nature conservation. Grassland Science in Europe 11: 3-13.
Palmer, R.G., P.T. Perez, E. Ortiz-Perez, F. Maalouf and M.J. Suso, 2009. The role of crop-pollinator relationships in breeding for pollinator-friendly legumes: From a breeding perspective. Euphytica, 170: 35-52.
Panse, A., F.X. Maidl, J. Dennert, H. Brunner and G. Fischbeck, 1994. Yield formation in cereal-rich crop rotations and monocultures in an extensive and intensive crop-management system. Journal of Agronomy and Crop Science-Zeitschrift Fur Acker Und Pflanzenbau, 173: 160-171.
Papastylianou, I., 2004. Effect of rotation system and N fertiliser on barley and vetch grown in various crop combinations and cycle lengths. Journal of Agricultural Science, 142: 41-48.
Pappa, V.A., Rees, R.M., Walker, R.L., Baddeley, J.A., Watson, C.A., 2011. Nitrous oxide emissions and nitrate leaching in an arable rotation resulting from the presence of an intercrop. Agriculture, Ecosystems and Environment 141:153–161.
Patra, A.K. and Saxena, J. 2011 Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition. Journal of the Science of Food and Agriculture 91, 24-37.
Peoples, M.B., H. Hauggaard-Nielsen and E.S. Jensen, 2009b. The potential environmental benefits and risks derived from legumes in rotations. In: Nitrogen Fixation in Crop Production. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America,: pp: 349-385.
Peoples, M.B., J. Brockwell, D.F. Herridge, I.J. Rochester, B.J.R. Alves, S. Urquiaga, R.M. Boddey, F.D. Dakora, S. Bhattarai, S.L. Maskey, C. Sampet, B. Rerkasem, D.F. Khan, H. Hauggaard-Nielsen and E.S. Jensen, 2009a. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis, 48: 1-17.
Peyraud, J.L., A. Le Gall and A. Lüscher, 2009. Potential food production from forage legume-based-systems in Europe: an overview. Irish Journal of Agricultural and Food Research, 48: 115-135.
Piotrowska, K., Connolly, J., Finn, J. Black, A. and Bolger, T.2013 Evenness and plant species identity affect earthworm diversity and community structure in grassland soils. Soil Biology and Biochemistry 57, 713-719.

Pirhofer-Walzl, K., J. Rasmussen, H. Høgh-Jensen, J. Eriksen, K. Søegaard and J. Rasmussen, 2011. Nitrogen transfer from forage legumes to nine neighbouring plants in a multi-species grassland. Plant and Soil, 350: 71-84.
Potts, D., 2003. The myth of the overwintered stubble: New Government schemes are not properly designed to recover lost farm biodiversity. Bird Study, 50: 91-93.
Power, E.F. and J.C. Stout, 2011. Organic dairy farming: impacts on insect-flower interaction networks and pollination. Journal of Applied Ecology, 48: 561-569.
Preissel, S., M. Reckling, N. Schlaefke, B. Amjath-Babu and P. Zander, unpublished results. Grain legume precrop benefits and their farm-economic value in Europe – a review.
Prew, R.D. and G.V. Dyke, 1979. Experiments Comparing Break Crops As A Preparation For Winter-Wheat Followed By Spring Barley. Journal of Agricultural Science, 92: 189-201.
Pywell, R.F., Warman, E.A., Carvell, C., Sparks, T.H., Dicks, L.V., Bennett, D., Wright, A., Critchley, C.N.R. and Sherwood, A. 2005. Providing foraging resources for bumblebees in intensively farmed landscapes. Biological Conservation 121, 479–494
Renard, K.G. and V.A. Ferreira, 1993. RUSLE model description and database sensitivity. J. Environ. Qual. 22:458-466.
Ribeiro Filho, H.M.N., R. Delagarde and J.L. Peyraud, 2005. Herbage intake and milk yield of dairy cows grazing perennial ryegrass swards or white clover/perennial ryegrass swards at low- and medium-herbage allowances. Animal Feed Science and Technology, 119: 13-27.
Robson, M.C., S.M. Fowler, N.H. Lampkin, C. Leifert, M. Leitch, D. Robinson, C.A. Watson and A.M. Litterick, 2002. The agronomic and economic potential of break crops for ley/arable rotations in temperate organic agriculture. Advances in Agronomy, Volume 77: 369-427.
Rochette, P., Janzen, H.H., 2005. Towards a revised coefficient for estimating N_2O emissions from legumes. Nutrient Cycling in Agroecosystems 73:171–179.
Rockström, J., W. Steffen, K. Noone, A. Persson, F.S. Chapin, E.F. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen and J.A. Foley, 2009. A safe operating space for humanity. Nature, 461: 472-475.
Rohner-Theilen, E., 2010. Eurostat Statistics in Focus 10/2010. http://ec.europa.eu/agriculture/organic/eu-policy/data-statistics_en (Accessed 24/02/2013).
Rutter S.M., 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: Current theory and future application. Applied Animal Behaviour Science 97:17–35.
Ruz-Jerez B.E., White R.E. and Ball P.R. 1994 Long-term measurement of denitrification in three contrasting pastures grazed by sheep. Soil Biology and Biochemistry 26, 29-39.
Saarinen, M., Y. Virtanen and H. Hyvärinen, 2012. LCAs for a large repertoire of Finnish outdoor plant products. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 835-836.
Sabais, A.C.W., Scheu, S., Eisenhauer, N., 2011. Plant species richness drives the density and diversity of Collembola in temperate grassland. Acta Oecologica 37:195–202.
Sala, O.E., F.S. Chapin, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B. Walker, M. Walker and D.H. Wall, 2000. Global Biodiversity Scenarios for the Year 2100. Science, 287: 1770-1774.
Sameshima-Saito, R., Chiba, K., Hirayama, J., Itakura, M., Mitsui, H., Eda, S., Minamisawa, K., 2006. Symbiotic *Bradyrhizobium japonicum* reduces N_2O surrounding the soya bean root system via nitrous oxide reductase. Applied and Environmental Microbiology 72:2526–2532.
Scalbert, A., C. Manach, C. Morand, C. Remesy and L. Jimenez, 2005. Dietary polyphenols and the prevention of diseases. Critical reviews in food science and nutrition, 45: 287-306.
Schils, R.L.M., A. Verhagen, H.F.M. Aarts and L.B.J. Šebek, 2005. A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems. Nutrient Cycling in Agroecosystems, 71: 163-175.
Schils, R.L.M., T.J. Boxem, C.J. Jagtenberg and M.C. Verboon, 2000. The performance of a white clover based dairy system in comparison with a grass/fertiliser-N system. II. Animal production, economics and environment. NJAS - Wageningen Journal of Life Sciences, 48: 305-318.

Scollan, N., J.F. Hocquette, K. Nuernberg, D. Dannenberger, I. Richardson and A. Moloney, 2006. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. Meat Sci, 74: 17-33.

Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, W., Zhang, F., 2011. Phosporus dynamics: from soil to plant. Plant Physiology 156:997–1005.

Sirtori, C.R., M. Triolo, R. Bosisio, A. Bondioli, L. Calabresi, V. De Vergori, M. Gomaraschi, G. Mombelli, F. Pazzucconi, C. Zacherl and A. Arnoldi, 2012. Hypocholesterolaemic effects of lupin protein and pea protein/fibre combinations in moderately hypercholesterolaemic individuals. British Journal of Nutrition, 107: 1176-1183.

Sirtori, C.R., M.R. Lovati, C. Manzoni, S. Castiglioni, M. Duranti, C. Magni, S. Morandi, A. D'Agostina and A. Arnoldi, 2004. Proteins of white lupin seed, a naturally isoflavone-poor legume, reduce cholesterolemia in rats and increase LDL receptor activity in HepG2 cells. The Journal of nutrition, 134: 18-23.

Smaling, E., R. Roscoe, J. Lesschen, A. Bouwman and E. Comunello, 2008. From forest to waste: Assessment of the Brazilian soybean chain, using nitrogen as a marker. Agriculture, Ecosystems & Environment, 128: 185-197.

Soussana J.F., Loiseau P., Vuichard N., Ceschia E., Balesdent J., Chevallier T. and Arrouays D. 2004 Carbon cycling and sequestration opportunities in temperate grasslands. Soil Use and Management 20, 219-230.

Statistik Austria, 2010. AS2010 Bodenbedeckung im Winter nach politischen Bezirken. In: Agrarstrukturerhebung 2010.

Stein-Bachinger, K., J. Bachinger, L. Schmitt, T. Dewes, A. Sundrum and R. Andersson, 2004. Nährstoffmanagement im Ökologischen Landbau. Darmstadt: Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL).

Stevens, C.J., C. Duprè, E. Dorland, C. Gaudnik, D.J.G. Gowing, A. Bleeker, M. Diekmann, D. Alard, R. Bobbink, D. Fowler, E. Corcket, J.O. Mountford, V. Vandvik, P.A. Aarrestad, S. Muller and N.B. Dise, 2010. Nitrogen deposition threatens species richness of grasslands across Europe. Environmental Pollution, 158: 2940-2945.

Stevens, C.J., N.B. Dise, J.O. Mountford and D.J. Gowing, 2004. Impact of nitrogen deposition on the species richness of grasslands. Science, 303: 1876-1879.

Stevenson, F.C. and C. van Kessel, 1997. Nitrogen contribution of pea residue in a hummocky terrain. Soil Science Society of America Journal, 61: 494-503.

Stoddard, F.L., Bond, D.A., 1987. The pollination requirements of the faba bean (*Vicia faba* L.). Bee World 68:144–152.

Strohle, A., A. Waldmann, M. Wolters and A. Hahn, 2006. Vegetarian nutrition: Preventive potential and possible risks Part 1: Plant foods. Wiener klinische wochenschrift, 118: 580-593.

Thomassen, M.A., K.J. van Calker, M.C.J. Smits, G.L. Iepema and I.J.M. de Boer, 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. Agricultural Systems, 96: 95-107.

Tivy, J.,1990. Agricultural Ecology. Longman Group UK Limited, UK.

Topp, C.F.E., J.G.M. Houdijk, D. Tarsitano, B.J. Tolkamp and I. Kyriazaki, 2012. Quantifying the environmental benefits of using home grown protein sources as alternatives to soyabean meal in pig production through life cycle assessment. Advances in Animal Biosciences, 3: 15.

Vadez, V., J.D. Berger, T. Warkentin, S. Asseng, P. Ratnakumar, K.P.C. Rao, P.M. Gaur, N. Munier-Jolain, A. Larmure, A.-S. Voisin, H.C. Sharma, S. Pande, M. Sharma, L. Krishnamurthy and M.A. Zaman, 2011. Adaptation of grain legumes to climate change: a review. Agronomy for Sustainable Development, 32: 31-44.

van der Werf, H.M.G., J. Petit and J. Sanders, 2005. The environmental impacts of the production of concentrated feed: the case of pig feed in Bretagne. Agricultural Systems, 83: 153-177.

von Richthofen, J.-S., H. Pahl and T. Nemecek, 2006. Economic interest of grain legumes in European crop rotations. GL-Pro: pp: 58.

WBA and WBD, 2013. Novellierung der Düngeverordnung: Nährstoffüberschüsse wirksam begrenzen. Kurzstellunnahme. pp: 22.

Watson, C.A., Fowler, S.M. & Wilman, D. 1993 Soil inorganic-N and nitrate leaching on organic farms. Journal of Agricultural Science, Cambridge 120, 361-369.

Westphal, C., Steffan-Dewenter, I., Tscharntke, T., 2003. Mass flowering crops enhance pollinator densities at a landscape scale. Ecology Letters 6:961–965.

Whittington F.W., Dunn R., Nute G.R., Richardson R.I. and Wood J.D. 2006. Effect of pasture type on lamb product quality. In: J.D. Wood (ed.) New developments in sheep meat quality. Proceedings of the 9th Annual Langford Food Industry Conference, BSAS, Edinburgh, pp 27-32.

Willer, H., Lernoud J & Kilcher, L.,2013. The world of Organic Agriculture. Statistics and Emerging Trends 2013. FiBL, IFOAM.

Wiltshire, J., S. Wynn, R. Sylvester-Bradley, D. Kindred, N. Mortimer, A. Evans, C. Hatto and O. Mwabonje, 2012. Improving estimates of life cycle nitrous oxide emissions from cropbased food products. In: Proceedings of the 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, 1-4 October 2012, M. S. Corson and H. M. G. van der Werf, (Eds.). INRA, Saint Malo, France: pp: 163-168.

Wischmeier W.H. & Smith D.D., 1978. Predicting rainfall erosion losses – a guide to conservation planning. US Department of Agriculture, Agricultural Handbook 537. USDA Washington DC.

Wood, J.D., Richardson, R.I., Scollan, N.D., Hopkins, A., Dunn, R., Buller, H., et al., 2007. Quality of meat from biodiverse grassland. In J. Hopkins, A. J. Duncan, D. I. McCracken, S. Peel, & J.R.B. Tallowin (Eds.), High value grassland (pp. 107–116). Cirencester, Gloucestershire: British Grassland Society.

Wright, I., 2008. Research topic review: Combinable protein crop production In: IOTA Arable Workshop. Institute of Organic Training & Advice.

Yan, M.J., J. Humphreys and N.M. Holden, 2013. The carbon footprint of pasture-based milk production: Can white clover make a difference? Journal of Dairy Science, 96: 857-865.

Yau, S.K. and J. Ryan, 2013. Differential impacts of climate variability on yields of rainfed barley and legumes in semi-arid mediterranean conditions. Archives of Agronomy and Soil Science, 59: 1659-1674.

Zhang Y., Overland, M., Sorensen, M., Penn, M., Mydland, L.T., Shearer, K.D., Storebakken, T., 2012. Optimal inclusion of lupin and pea protein concentrates in extruded diets for rainbow trout (Oncorhynchus mykiss). Aquaculture 344-349:100–113.