RESEARCH TOPIC REVIEW: Combinable protein crop production

Author: Isobel Wright, Abacus Organic Associates

1. SCOPE AND OBJECTIVES OF THE RESEARCH TOPIC REVIEW:

This research topic review aims to summarise research knowledge and observational experience of combinable protein crop production in organic farming systems for the UK. European research on peas, faba beans and lupins is included; considering their role in the rotation, nitrogen fixation, varieties, establishment, weed control, yields, problems experienced and intercropping with cereals.

2. SUMMARY OF RESEARCH PROJECTS AND THE RESULTS

2.1 Grain legumes in organic farming

Grain legumes such as pea, faba bean and lupins are rich in protein compared to cereal grain crops. They provide an alternative to imported soybean meal from North and South America. Besides being a valuable protein and energy source legumes are also beneficial to the agro-ecosystem due to their nitrogen fixation ability. In addition, they are also known to have positive effects in the crop rotations, via recycled N-rich crop residues and the break-crop effect in cereals rich rotations. In arable systems the insertion of a grain legume into a rotation may help to extend the period before the next fertility building.

Grain legume yields do not depend on applied nitrogen (N) as manure or fertiliser. As in all legumes, nitrogen is supplied from root nodules in which Rhizobium spp. bacteria convert soil atmospheric nitrogen into a form usable by the plant. The amount of nitrogen fixed in the roots of grain legumes has been estimated at 150-200 kg/ha, most of which is removed in the grain of the crop (Fisher, 1996). The majority of N will be fixed when soil temperatures are 2-3+ deg C, when Rhizobia are active. This is more likely during the late autumn and from spring onwards. N fixation during the winter period will be much reduced. Because soil organic matter break-down and nitrate mineralisation continue during crop growth, there remains a residue of nitrogen in the soil, greater than after non-legumes. This is equivalent to 40-50 kg/ha N, and is an important contribution to maintaining soil fertility in organic systems, particularly in stockless rotations (Cormack, 1997).

However, yield variability in grain legumes is well known and often related to intolerance to water stress and harvest difficulties either because of lodging or late maturity. Grain legume seeds also vary in quality, mainly due to environmental conditions and together with a weak competitive ability towards weeds and pathogen attack like e.g. Ascochyta spp. they may be less favoured in organic crop rotations.

There is a general need to increase organic grain legume protein production in Europe to meet an increasing demand. From 31st December 2011 all feed used in animal production must be organically produced according to EU regulations. In the interim, tighter annual limits on dry matter intake of feeds from conventional sources have been specified. In that perspective evaluation of the potential for increased protein production via the growing of grain legumes in organic cropping systems is urgent.

2.2 Value of nitrogen from grain legumes in organic rotations

In typical organic farming systems nitrogen is accumulated during a fertility building phase of a rotation, from leguminous green manures or leguminous cash crops, where N accumulates in the soil and in unharvested crop residues. Although recycled plant residues and animal manures help to maintain the overall nutrient balance on the farm, the only true import of nitrogen (to compensate for removal in sold products and losses to the atmosphere and in leaching) is from fixation of atmospheric N_2 by legumes (Briggs et al 2005).

Nitrogen in legumes comes from the uptake of both soil N and fixation of N from the atmosphere. The amount of N fixed by different legumes is determined by how well the symbiotic association is functioning between the N-fixing bacteria (rhizobia) and the legume host. The efficiency with which N is fixed will depend on the crop's growing conditions (e.g. soil, temperature, climate, disease), crop management and length of time for which it is grown. Consequently, the influence of all of these factors means that a wide range of values have been reported. However, for a particular legume species there is usually a close relationship between yield and the quantity of N fixed. Figure 1 indicates the range of fixation estimates quoted for a number of leguminous crops, including some grain legumes.

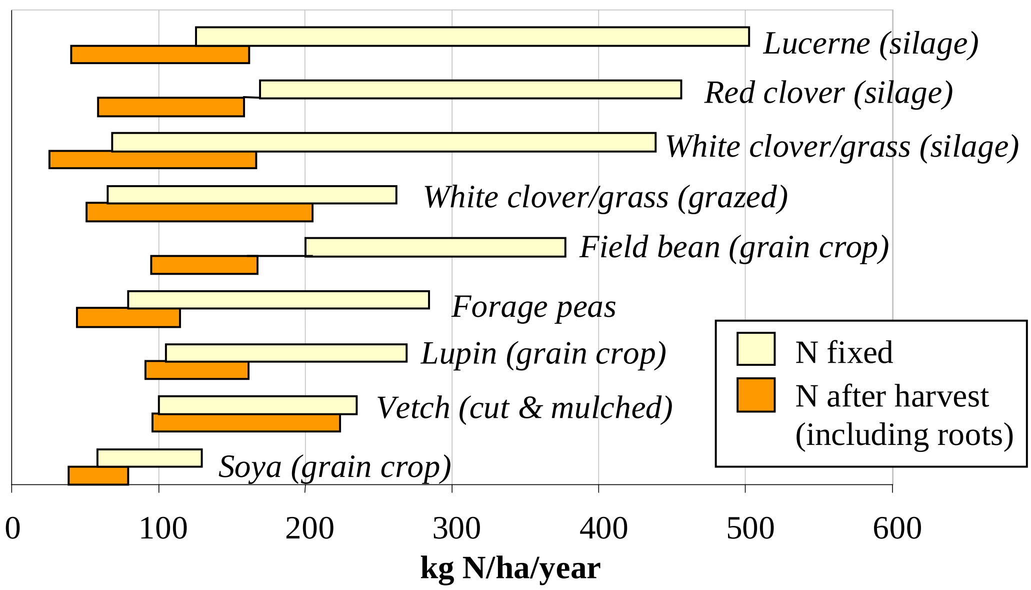

Figure 1 *Ranges for quantities of N fixed and remaining after harvest (Briggs et al 2005)*

Growing a leguminous cash crop, such as field beans or peas may obtain a small supplementary boost of N during the fertility-depleting phase. However harvesting the forage or grain will remove much of the fixed N and reduce the benefit to following crops (see Figure 1). The benefit will be further reduced if straw and other crop residues are removed from the field. In environments with surplus precipitation during autumn and winter this may result in NO_3 leaching. This problem can be managed by early sowing of the subsequent winter cereal or by N catch cropping (Jensen ES 2002).

Paffrath (2005) examined the effect of field beans, grain peas, bush beans and red clover-grass compared with the control spring wheat on the following crop potato in field trials (2001-2004). Yield of potato following the cultivation of all legumes was on average significantly higher (13 – 16 %) than the previous crop spring wheat. No differences could be seen between the four legumes, but year effects were apparent.

2.3 Value of grain legumes as a break crop on weed levels in subsequent crops

This has been looked at in research funded by Defra (Defra 2002a) In trials, weed levels in the subsequent cereal were measured following nine different break crops including beans and lupins. The data is very hard to interpret – weeding took place at different times in the preceding breaks and there was site variation. It is highly likely that weeds in the following cereals were affected not only by preceding break crop, but also by the efficiency and timing of hand weeding in the preceding break crop.

2.4 AGRONOMY OF GRAIN LEGUMES

2.4 Variety selection

2.4.1 Beans

Taylor and Cormack (2002) report that the most important considerations for organic growers in the choice of field bean varieties are straw height, earliness of ripening, disease resistance and yield. As in other organic crops, yield will be more influenced by growing conditions than by variety and organic growers should select for agronomic characteristics before yield.

Earliness of ripening is more important in beans than in many other crops. Late maturing varieties are harvested in cooler weather when drying of the crop in the field is slow. Normally beans stand well, and although brackling may occur it is unlikely to result in seed loss. Pod splitting and bird damage only occur if harvest is delayed considerably. On heavy soils, late maturing varieties increase the chance of damage to soil structure from heavy harvesting machinery as soils become wet in autumn.
Tall varieties compete better with weeds than short varieties. Although early crop vigour is the most important feature in competition with weeds, final height gives an indication of competitive ability. The recommended lists of field bean varieties suggest an inverse relationship between final straw height and earliness in beans which may be because of the indeterminate growth habit, so variety choice is a compromise.

2.4.2 Peas

Factors in variety choice for combining peas include seed colour, straw length, leafed or semi-leafless characteristics, earliness of ripening and disease resistance. Peas frequently lodge severely before harvest so resistance to lodging and ease of combining are also important; semi-leafless varieties lodge later and less completely than normal-leaved varieties. This has implications for how fast the crop dries in the field, how readily weeds grow through the lodged crop and how easily the crop can be combined. Straw height is not necessarily associated with susceptibility to lodging, and analysis of SAC data indicates a positive correlation for straw strength and plant height (Taylor and Cormack 2002). Tall varieties will compete more effectively with weeds than shorter ones, however the semi-leafless varieties afford less competition against weeds.

Grevsen (2000) in Denmark found significant differences between pea cultivars in weed suppression. The most competitive types were larger peas, and not semi-leafless. A fuller leaf structure is more commonly found in the maple pea types than the human consumption and micronising types.

2.4.3 Time of sowing, seed rate and drilling

It is difficult to establish any absolute recommendations as to the optimum seed rate for arable crops grown in organic systems, since there have been relatively few studies that have considered this question directly.

Field beans may be autumn (winter) or spring sown. Winter beans have large seed (500-600g/1000) and are sown from late October to mid November in the UK. Earlier sowing may increase weed populations, although it is generally advised that in the UK early October may be preferred for winter beans for weather reasons where soil types are heavy, and generally in northern and western regions (Davies et al 2002). Winter beans can be sown to a depth of 8 to 10 cm but establishment can be conveniently done by broadcasting and ploughing-in the seed to a depth of 12 to 15 cm in order to establish about 25 plants/m^2 (Lampkin et al, 2006), aiming for an ultimate plant population of 17-18 plants/m^2.

For spring sowing of both beans and peas, allowing time for a stale seedbed approach assists in reducing weed problems in the crop. Delayed drilling into warmer soils after a weed strike can be beneficial on many sites. Otherwise it is difficult to avoid weed emergence with the crop. (Davies et al 2002).

Spring beans should be sown as soon as soil conditions allow in February or March, although later sowings, up to early April, can still give acceptable yields. They have smaller seed (350-500g/1000) and the target plant population is 40-50 plants/m^2. Spring beans are sometimes regarded as a risky crop, requiring a dry period for sowing in February/March followed by wetter conditions for germination, adequate moisture for growth, and a dry late summer for ripening and harvest. They branch less than winter beans and in order to achieve a rapid, uniform establishment they should be sown and not ploughed in. The relatively large seed of both winter and spring beans may require modifications to the seed drill, such as special feed wheels, to avoid cracking the seed. (Taylor and Cormack 2002).

Combining peas are less common than field beans in organic rotations, mainly due to concerns about lodging and weed control, especially with regard to late developing weeds which can swamp crops. Winter peas are rarely sown in the UK. Spring combining peas are sown in March or early April. Seed size varies from 150 to 350g/1000 seeds, and seed is normally sown with a cereal drill to establish 60 to 80 plants/m^2 on medium soils, less on lighter soils (Lampkin et al 2006).

Grevsen (2000) in Denmark found that increasing seed rate of pea cultivars from 90 to 150 seeds m/^{2} reduced the dry weight of weed plants by 40%. Seed weight and leaf type were important, as was early growth vigour of cultivars.

Elers (2001) experimented with pea seedrates in 1998 and 1999. Four varieties were trialled in each year (Bohatyr, Eifel, Profi and Duel, with Grana replacing Bohatyr in the second year) at four planting densities (60,80,100 and 120/m^2). Yield and weed growth was monitored. Conclusions were that the recommended plant density of 80 seeds/m^2 is sufficient for yield and less weed growth. For weed growth the chosen variety is more important than the plant density. Stability till harvest was considered the most important characteristic of variety for reducing weed growth.

2.4.4 Spatial arrangement

Sow spring peas at 20 cm and spring beans at 17 to 35 cm rows (Defra 2002). This will allow inter-row cultivation. Winter beans are established either by broadcasting and shallow ploughing or drilling into a coarse seedbed. Drilling winter beans and spring beans/spring peas does offer the potential to inter-row hoe (see weed management below).

2.4.5 Weed management

Data from crop:weed competition studies suggest that it is the weeds that emerge with or shortly after the crop that are the ones that pose the most significant threat for crop yields (Cousens et al., 1987).

Amongst the pulses, field beans, once early weed competition is controlled, tend to grow over later emerging weeds and smother them out. (Davies et al 2002).

Beans are relatively slow to emerge despite their large seed size. This, and the low densities at which they are sown compared to other arable crops, leaves bean crops open to potentially damaging weed competition in the early stages of growth. Using a harrow comb on the emerged crop may be possible or the crop may be sown in wide rows to allow inter-row cultivations (Rasmussen et al., 2000).

Peas, being much shorter than beans, are more likely to succumb to weeds. The semi-leafless nature of many modern varieties allows more light to penetrate through to the weeds. Because peas may lodge severely, allowing weed growth in the crop before harvest, good weed control is essential under organic conditions where pre-harvest chemical desiccation is not possible. Peas, like beans, are relatively widely spaced, are slow to emerge, and are not good at suppressing early weed growth. Winter peas are unlikely to be grown organically since weed control may be especially difficult since soil conditions after sowing are unlikely to be suitable for mechanical weeding. In spring, mechanical methods of weed control such as cultivation with a harrow comb in the emerged crop may be successful, although limited evidence is available from the UK. The PGRO have done some work looking at weed control by comb harrowing in peas.

Wherever possible, combining peas should be sown in fields where weeds are not a problem. Other cultural methods of weed control, such as increased seed rate, will reduce early competition from weeds, but may exacerbate crop lodging (Taylor et al., 1991). In favourable areas spring varieties are harvested in August; three to four weeks earlier than field beans. Under conventional conditions yields are similar from spring and winter sown combining pea crops, and may be expected to exceed those from beans. (Taylor and Cormack 2002)

Relatively little is known about the mechanisms of weed kill and the detailed interaction between the cultivator blade, the weed and the soil. This is particularly important with the new automated guidance equipment that allows weeding at high forward speeds (Defra 2002). The efficacy and efficiency of mechanical weed control could be improved if the underlying science was better understood. The timing and frequency of inter-row hoeing has received very little scientific attention. The optimum weed control timings are based on small-plot crop:weed competition studies and need to be verified under field scale management with inter-row hoeing equipment (Defra 2002).

It may in addition be necessary to control weeds later in the growing season to prevent them from shedding seed. For pea crops, mechanical weeding cannot be continued after the tendrils have met across the rows as crop.

There has been some Danish work on varietal differences to weeds amongst pulses. Grevsen found significant differences between pea cultivars in weed suppression. The most competitive types were larger peas, and not semi-leafless (Grevsen, 2000). The Maple types which have more leaf compared to the semi-leafless blue types tend to afford better competition against weeds.

None of the research reviewed looked at the contribution of peas and beans towards the long term build-up of perennial weeds such as couch and docks. Undoubtedly a poorly established pulse crop offers opportunity for significant build-up and it should be borne in mind that significant perennial weed numbers can threaten the viability of arable oriented organic rotations.

By way of anecdotal evidence for the difficulty of producing good pea crops, observation plots were sown at three sites in the UK as part of the Defra funded Organic Crop Demonstration Project in 2005. On two of the sites they established but were grazed out by birds. At the third site (in Yorkshire) peas established reasonably well (Nitouche, 80 plants/m^2) but ultimately were smothered by weeds and were mulched in.

2.4.6 Disease

In Denmark, most organic farmers use organically propagated cereals and legumes for sowing, and all seed lots are tested for seed borne pathogens before sowing. About 50% of all seed lots are discarded based on this assessment, but huge differences occur between year and crop, which makes planning of seed production difficult. Some years up to 90% of the seed lots of a crop may be discarded e.g. peas in year 2000 (aschochyta spp.) (Borgen, 2002)

Diseases of field beans include chocolate spot (Botrytis fabae and B.cinerea), downy mildew Peronospora viciae) and Ascochyta leaf and pod spot (Ascochyta fabae). The most likely of these to trouble an organic crop is chocolate spot, which cannot be controlled by rotation. Chocolate spot is influenced by season and location and affects winter beans more than spring beans. Comparative data for this disease is not available, though casual observations suggest that there are differences between varieties (Taylor and Cormack 2002). Downy mildew should not be a problem where a good rotation is practised and resistant varieties are used. Ascochyta is controlled through seed health standards.

The main diseases for growers of organic combining peas to consider are downy mildew (Peronospora viciae), leaf and pod spots (Ascochyta pisi, Mycosphaerella pinoides and Phoma medicaginis), botrytis (Botrytis cinerea), and pea bacterial blight (Pseudomonas syringae). Downy mildew is potentially a serious disease of pea crops. It is soil borne and may be avoided by rotations that allow at least four years between pea crops, and by using resistant varieties. Botrytis affects peas after flowering, and is most serious in humid weather. (Taylor and Cormack 2002).

It is therefore important to consider adequate break periods for grain legumes such as pea and beans in the same rotation. Some fertility building green manures such as vetch are also of the pea family, and could act as hosts of disease if grown too close in the rotation.

2.4.7 Pests

Inadequate sowing depth of peas and beans can result in serious bird damage as they dig up the seed (Defra 2002a). This can be to the point where crops are lost. Game birds can be a problem on some farms, peas and beans should be avoided when in close proximity to woodland and especially rookeries. Rabbits and deer can be a major problem, especially for peas. . Pea and bean weevil may cause damage.

2.4.8 Harvesting

Taylor and Cormack (2002) have reviewed organic pulse production. Field beans are normally harvested later than cereals. Winter-sown varieties mature earlier than spring varieties in southern parts of the UK and may be harvested from early/mid August onwards. Where adequate moisture is available to maintain slower growth in northern areas, harvest may be delayed until mid or late October, making winter beans an unsuitable choice for Scotland. Spring varieties reach maturity in late August or early September in the southern UK, but a month later in the north, where they are combined before winter beans. Unlike combining peas, field beans generally remain standing until harvest; they are less affected by wet weather and less likely to shed than peas if harvest is delayed. NIAB data would suggest that yields of non-organic winter beans may be above those of spring beans in the south but are unlikely to exceed spring beans in the north. Since winter beans are also more likely to suffer from the chocolate spot disease than spring beans, there would appear to be little advantage in organic situations from winter beans that provide very little winter ground cover against erosion, weed development or nutrient loss. However, locally the higher susceptibility to drought and aphids in spring beans may indicate a preference for winter beans.

Date of ripening in peas is important in northern areas and Scotland. Differences in maturity of a few days in the south are multiplied three or four times in the north. Only relatively early varieties of combining peas are recommended in Scotland. Delays in harvest under organic conditions, especially where weeds are not completely eliminated, can lead to slow combining, damage to machinery, and a wet, discoloured sample, with a high admixture. (Taylor and Cormack (2002).

2.5 Yields

Yield of beans can be very variable. In one Defra funded research programme, of seven sites, only two produced an economically viable bean crop, although yields were very high (over 7t/ha) in comparison to average organic yields at those sites. The trials at four sites failed due to pest and or disease problems (Defra 2002a). At ADAS Terrington, a site with very fertile soil, the yields of spring beans over a 4 year period are shown in table 1 (Defra 2002c)

***Table 1**. Saleable crop yields (t/ha), ADAS Terrington (Defra OF0301)*

Crop	**1998**	**1999**	**2000**	**2001**
Spring beans	3.16	4.96	4.15	3.46

Recent trials in France comparing the performance of organic pulses found that Faba bean was shown to have slightly higher grain yield and amount of grain N than pea. In most sites, lupin was the least efficient species in terms of DM and N accumulation as well as for weed control. Two mechanisms could explain the lowest weed DM in pea: a faster development of above ground plant parts at early growth stages and a better soil N uptake. A shorter crop duration for pea, on average 29 days less than for lupin, may also have limited weed development. Pea, lupin and faba bean were equally limited by weeds despite differences in weed biomass. Yield loss was found to be mainly defined by the type of weeds, i.e. more or less competitive. Consequently grain legume yield improvement will largely depend on choosing plots free of highly competitive weed species. The grain legume species has finally a greater impact on yield performance and on weed biomass at crop maturity (Dibet et al, 2006).

In 2000 a trial (HDRA, funded by PGRO) was conducted on a relatively fertile field in Lincolnshire to identify any problems that growers might have when growing combinable peas. The yield obtained on the central area of the field (4.2 t/ha) was considered to be good but on the margins soil compaction led to poor crop growth and weed competition. Plant establishment was excellent and pests and diseases were not a real problem. The crop was weeded twice with an Einbock weeder; this operation was successful with little damage to the peas.

2.6 Phosphate availability, lupins and field beans

In Germany Steffens et al (2005) investigated rock phosphate mobilization by summer wheat, white lupin, and faba bean in a crop rotation. In organic farming rock phosphate is used as a mineral P fertilizer, although the agronomic efficiency is limited. The objective of this study was to investigate in field and pot experiments the mobilization of rock phosphate by P-efficient plants (white lupin and faba bean) and the P availability for P-inefficient plants (spinach and maize) during a crop rotation in 2002/2003 and 2003/2004. The P uptake of spinach was higher in a crop rotation with white lupin and faba bean than in a crop rotation with summer wheat. In pot experiments the application of new basic slag phosphate (CaHPO4) resulted to a higher P uptake of the plants than rock phosphate.

2.7 Intercropping peas and beans with cereals

Until recent years little research has been published on the results of intercropping grain legumes with cereals, although historically it had been a common practice. Unpublished data suggested that intercropping legumes with cereals could result in greater grain yields than each constituent cropped individually, less weed competition and less disease. Plant growth factors such as light, water and nutrients are more completely utilised and converted to crop biomass. Mixes that have been tried include barley with peas, and wheat with beans or lupins. While being combine harvested together it is a fairly simple operation to separate the crop components by cleaning with a crop dresser fitted with sieves with appropriate sizes. Hauggaard-Nielsen et al have researched the results from intercropping peas with barley in Denmark (Hauggaard-Nielsen org eprint122 (2002b) , Hauggaard-Nielsen Orgprint 101(2002).

Crop species mixtures may have a number of advantages in organic farming including reductions in pest and disease levels, improved weed control and provision of nitrogen where legumes are used in continuous systems. Wheat and beans do not compete for nitrogen when grown together such that higher protein levels may be achieved in wheat grown with beans than in wheat alone (Bulson et al., 1997). Results on agronomic performances of evaluated intercropping series in European agricultural research indicated pea-barley mixture as a profitable technique in organic farming (Monti et al 2006).

Intercropping is being examined in recent research through the EU FP 5 project "Intercrop" carried out in five European regions including England. Pea barley and wheat bean intercrops were investigated. Preliminary results are available (Jensen et al 2006). In interviews with organic farmers (n=63) within five countries, farmers quoted yield stability, weed suppression and fodder qualities as the three most important reasons for intercropping. Problems in mechanical weeding and unequal maturation of the IC components were quoted as the major problems.

The combined grain yields of spring-sown pea- barley intercrops were greater than both SC or yields were similarly to the higher yielding sole crop. The Land Equivalent Ratio (LER) based on grain DM yields showed that the yield advantage, due to intercropping varied between 4 and 43% with an average of 21% (LER=1.21) for the five sites in the 3 years. The relative advantage of intercropping varied between sites with the greatest LERs found in the UK.

Intercrops used the nitrogen sources (soil N and N2 fixation) 20-30% more efficiently than sole crops. However, the largest amounts of N fixed occurred in the pea sole crop. The proportion of fixed N in pea was greater in intercropped pea than sole cropped pea, due to the competition for soil N from barley. Analysis of weed growth showed that intercropping pea with barley significantly reduced the weed growth and nitrogen accumulation with factors 2 to 4 compared to SC pea in all European sites. The lowest weed development was observed in the barley SC.

Monitoring of plant diseases showed that diseases e.g. powdery mildew, rust and net blotch in barley was significantly reduced if diseases occurred at the sites.

Analysis of grain quality showed that the intercropped cereals (barley and wheat) N and S concentrations were significantly increased compared to sole cropped cereals. The increase in wheat quality improved the baking quality of the grain.

The stability (expressed as %CV on average grain yields over 3 yrs) of intercrop yields relative to especially the grain legume sole crop yields shows that intercropping is a promising technology for securing yield and enhancing local organic feed protein production on organic farms within the EU. Intercropping of cereals and grain legumes in organic farming across Europe has the potential to increase the resource use, grain yield, stability and plant health. Intercropping may be especially valuable for production of protein on land with weed problems and for enhancing the grain protein concentration in cereals to levels, which was only likely to be obtained otherwise with high levels of animal manure. (Jensen et al 2006).

LER (Land Equivalent Ratio) has been questioned as a measure for calculating the cropping advantage of intercrops over sole crops as too simple: neglecting weed suppression, yield reliability, grain quality, and minimum profitable yield, which are all relevant factors from a farmer's perspective. For farmers an intercrop becomes interesting when the net returns of that crop are better than those of one of the sole crops. Next to economics, weed suppression, reliability of yield and grain quality are other important indicators for farmers. (Prins et al 2006) Prins and de Wit investigated intercropping in Holland. For Dutch organic farmers poor weed suppression in grain legumes is the main reason for not growing grain legumes at all. Adding a cereal to the grain legume highly improves the weed suppression abilities of the crop. However, compared to a sole cereal crop, weed suppression is at best comparable, but often less in an intercrop (Hauggaard-Nielsen 2001a). As the cereal is the main weed suppressor in the intercrop, cereals should be sown at sufficient levels (see table 2).

Intercrop Barley Kg/ha	Pea	Sand Yield T/ha	Weed seeds Kg/ha	Light clay Yield T/ha	Weed seeds Kg/ha
5	200	1.8	408	5.9	38
20	190	2.5	372	6.2	26
40	180	3.1	230	6.4	25

Table 2*. Grain yields and weed seed yield in three barley –pea intercrop mixtures sown in different ratios in 2003 (Prins et all 2006).*

For intercrop mixtures the yield reliability is often still considered too low to convince farmers. Pea-barley mixtures in particular are highly variable in yield due to possible damage by pigeons directly after sowing and during ripening. Prins et al (2006) examined yields of pea/barley over 4 years and yield varied from 1.8t/ha on sandy land in 2005 (of which 49% was legume grain) to 6.4t/ha in 2003 (53%). Legume grain % varied through the 4 years from 2002 to 2005 and on sand and light clay land from 10% (after heavy rain in 2004 on light clay) to 53%. Field bean/wheat intercropping was established in 2004 and 2005 and resulted in less variation (sand; 2004, 4.3t/ha, 74% legume; 2005, 5.7t/ha, 57%; light clay; 2004, 4.2t/ha, 56%; 2005, 6.4t/ha, 47%). The wrong choice of cereals and grain legumes causes a great risk of loss of yield and reduction in grain quality. Combining an early ripening crop like barley or pea, with a late ripening crop like wheat or faba bean does increase the risk considerably as the early crop can loose its grains while waiting for the late crop to ripen. But even when two crops theoretically match, an extra uncertainty is introduced compared to sole cropping. Even a slight delay in harvest of a cereal crop due to the fact that the grain legume hasn't fully ripened, can cause a drop in grain quality due to bad weather. So intercropping cereals with grain legumes does not automatically give an improvement of yield reliability. This can only be reached by carefully choosing the right crops and varieties for the mixtures. Of the different intercrops, an early ripening faba bean with a late ripening wheat seem to give the highest yield reliability as both crops are hardly prone to lodging and grain loss.

In both experiments with pea-barley and faba bean-wheat Prins et al found a considerable heightening of the protein content in the cereal grains when intercropped with a grain legume (table 3).

	2004	2005
Wheat sole crop	11.2%	10.2%
Wheat intercrop	13.0%	12.5%

Table 3 *Average protein content (%) in wheat grown as a sole crop or intercropped with faba beans. (Prins et al, 2006)*

The heightening of the protein level of roughly 2% is not much from a feed value point of view, but large and possibly decisive for a distinction between animal feed and milling wheat. Obtaining the same protein levels in sole organic wheat crops has been proven to be very difficult. Anecdotal evidence from mixing winter field beans with winter wheat has suggested increased grain protein content in the wheat making it better suited as a bread making sample. This technique has been adopted by a number of farmers who produce bread making cereals for their own milling operations.

Prins et al concluded that of the different intercrops, pea-barley mixtures are still considered to be too risky to cultivate (low yield reliability). Faba bean-wheat mixtures seem to be the most reliable and economically viable option. The biggest benefit of intercrops can be expected in arable rotations, where the percentage of nitrogen fixing legumes is lower and where the heightening of the protein level in the cereals can be made to profit in the production of baking wheat. In the livestock sector dairy farmers may favour intercropping as a lower cost per tonne way of introducing home grown proteins. However they may prefer sole crop cereals where there is the benefit of highly fertile soils from the previous grass clover swards.

Kasyanova et al (2006) conducted field experiments in three successive growing seasons (2002/03 to 2004/05) at different sites within Europe. Treatments included wheat intercropped with faba bean in both replacement and additive designs, both autumn and spring sowing, and at one site, wheat intercropped with pea. Irrespective of design, sowing season, site, or grain legume used, intercropping increased the N and S concentration, and the N:S ratio in wheat grain. The rheological (deformation and flow) properties of doughs made from wheat flour, and hence the characteristics of many wheat-based products, are strongly influenced by the amount and type of storage proteins in wheat endosperms. The crude protein concentration (e.g. N x 5.7) of wheat grain is, therefore, a commonly used quality criterion for marketing wheat. Achieving sufficient N concentration in organic wheat can be a challenge in high yielding areas of Europe (Gooding et al. 1999) as it is heavily dependant on nitrogen availability, particularly during grain filling. Sulphur is also an important component of wheat proteins and provides the inter- and intra-chain disulphide bonds that help maintain gluten functionality. Thus, in the UK, loaf quality can be more closely correlated with S than with N concentration (Zhao et al. 1999). Intercropping cereals with grain legumes is known to increase the N concentration in the cereal grain (Hauggaard-Nielson et al. 2006, Prins et al 2006), but little is known concerning the implications for S concentration. The experiments confirmed that intercropping cereals with grain legumes can increase the cereal grain N concentration, and demonstrated that similar effects occur on S concentration. The work also showed, however, that intercropping is consistently, more beneficial to N, than to S such that N:S ratio increases. Despite this, intercropping improved loaf quality (data was not presented).

The combination of field pea (Pisum sativum L.) and wheat (Triticum sativum L.) have also been trialled to consider effects on wheat baking quality (Hauggaard-Nielsen et al 2006). Peas and wheat were either sole cropped or intercropped in a complete design of five relative proportions and five density levels to determine the effects of interspecific interaction in an intercrop on wheat baking quality. The research shows how pea interspecific competitive ability for factors such as light and water results in an increase in wheat protein content without reducing other important quality parameters. Density and relative crop frequency can be used as “regulators” when specific objectives such as bread making quality are wanted.

Further evidence that intercrops offer the opportunity to manipulate product quality was produced by Hauggaard-Nielsen et al (2002). Greater N content in the barley grains comparing SC and IC was recorded. It is usually difficult to increase the protein content of sole crop cereals because increased N-supply generally will increase also the dry matter yield and “dilute” the increased N uptake. One solution could be to supply N after flowering, but that is almost impossible using organic fertilizers. It was found that barley had a greater competitive ability for soil N than pea. Thus, it may result in a more than proportionate share of the soil N sources in legume-cereal IC systems because the relative increase in barley protein content is enhanced relatively more than the dry matter production. As a consequence protein content is increased.

Early pea growth is important for providing quicker, greater and more extensive soil coverage and thus improves pea competitive ability towards for growth resources. However, in order to withstand a large degree of complementary N use in the intercrop an improved pea growth should not compromise cereal N use, yield level and stability. One solution could be to create a better basis for selecting the most suited cultivars for intercropping. Breeding programs for sole cropping are not suitable to adapt a crop to growth in association with relatively different companions. Another solution may be to change the sowing strategy from sowing intercrop components at the same time in the same row to e.g. using relay intercropping strategies and/or non-regular spatial distribution of crops using newer sowing technologies. The key is how to improve early tillering growth in pea to improve the competitive ability towards weeds with an increased DM accumulation, increase N demand and thereby evolve a stronger sink increasing SNF. Normal-leafed cultivars seem to be the most suited for intercropping in low-input systems, the choice of barley cultivars was less important.

The experiments demonstrated several potentials of reintroducing pea-barley intercropping to European cropping systems when including current problems that conventional, specialised farms are increasingly confronted with. However, there is a lack of suitable cultivars and knowledge about key parameters determining co-existence and complementarity in intercropping systems. (Haugggaard-Nielsen et al 2002).

2.7.1 <u>Legume-cereal intercropping as a weed management tool</u> (Hauggaard-Nielsen et al, 2003)

Weed density and biomass is often markedly reduced in intercrops (IC) compared to the respective sole crops (SC) (Hauggaard-Nielsen et al., 2001a). Liebman and Dyck (1993) explained such IC-weed control advantages by either (i) Weed-suppression; a more effective use of resources by IC or suppressing weed growth through allelopathy compared to SC or (ii) Weed-tolerance; use of resources that are not exploitable by weeds or convert resources to harvestable material more efficiently than SC.

Calculation of pea-barley IC Land Equivalent Ratios (LER) showed that plant growth factors were used up to 30-40% more efficiently by IC than by SC (Hauggaard-Nielsen et al., 2001a; Jensen, 1996). LER indicate a more complete exploitation of environmental growth resources probably influencing the weeds competitive ability. This is supported by another study showing that pea-barley IC caused a deeper barley root system and a faster lateral root development by both species as compared to SC (Hauggaard-Nielsen et al., 2001b) indicating a potential improvement in the search of soil water and nutrient sources. Utilization of soil N sources was shown to influence weed biomass production. In a field study weeds accumulated about 55 kg soil N ha-1 in aboveground plant parts during spring in a pea SC compared to around 20 kg soil N ha-1 in a pea-barley IC (Hauggaard-Nielsen et al., 2001a). Furthermore, 46 days after emergence about 30 kg more inorganic soil N ha-1 was found under pea SC compared to pea-barley IC supporting weed growth.

A higher degree of interspecific competition combined with a certain complementarity between intercropped species improves the crop stands competitive ability towards weeds. The weed-suppression approach from Liebman and Dyck (1993) are the most likely to ex-plain the present pea-barley IC findings.

2.8 Lupins

New lupin varieties offer growers a pulse crop with significantly higher protein content than peas or beans, however growers need to match the variety to their particular situation, since certain varieties can be later maturing, or sensitive to alkaline soils (PGRO, 2007). See the table 4 for typical lupin feed analysis compared to peas and spring beans (George R. 2005).

	Field Peas	Spring Beans	White Lupins	Blue Lupins	Yellow lupins
Protein (%)	22.5	25	36-40	31-35	34-42
Oil Content (%)	1.9	1.8	10.0	6.0	4.0
Energy ME (MJ/kgDM)	13.5	12-13.5	15.5	13.5	13
Yield t/ha	3.5	2.8	3.5	2.5-3	2.5-3
pH tolerance	5.9-6.5	6.5-7.5	5.0-7.9	4.0-7.0	4.8-7.0

Table 4. *Typical Lupin Feed Analysis Compared To Peas And Spring Beans (George R. 2005).*

Trump (2004) summarised organic lupin issues as follows. Three types of lupins are available to be grown in this country, white (Lupinus albus), yellow (Lupinus luteus) and blue or narrow leaved (Lupinus augustifolius). Flower colour has no bearing on lupin type. Choosing the correct lupin type is very important to ensure a reasonable crop. Blue varieties are determinate and so will mature when grown across the UK. The yellow and white types are indeterminate and so require the warmth of a more southerly climate to mature. Even so, harvesting will be late - into mid September. Soil pH is an important determinant of which type is suitable. White varieties will tolerate soil pH of up to about 7.8 whilst yellow varieties prefer pH below 6.8 and are happy below 5. Blue types prefer a range between 5 and 6.8. The level of Calcium Carbonate in the soil is an important determinant in which cultivar should be grown and how lupins will develop. This should not be confused with the soil pH. It is very important to check the level of free calcium in the soil, high levels severely restricting lupin crop performance (Lampkin et all, 2006).) White types also have higher oil content and possibly more stable protein yield and provide a taller plant with palmate leaves offering greater shading potential. Given these attributes perhaps favours white types on all but the most acidic soils. All types are spring sown, (with winter sown varieties not well suited to organic conditions (Lampkin et al, 2006).

Establishment is critical and a fine un-compacted seedbed is required with seeds planted on usual row spacing at 3 - 5 cm depth. Seed should be inoculated prior to drilling to ensure good nodulation and effective nitrogen fixation. Pests and diseases are no more significant than for other crops. There are no problematic invertebrate pests but some can be a hazard at establishment. The worst disease is Anthracnose (Colletotrichum acutatum) which is a seed borne problem and seed testing is vital to reduce the incidence of the problem (PGRO 2006). Rotation design is also important and lupins should have a 5-year minimum interval between crops. Sclerotinia can infect the crop and therefore due consideration should be given to planning rotations with other host crops, that include peas and beans (PGRO 2006). Weed competition is the major difficulty and so a clean seedbed is beneficial. The possibility of wide row spacing and inter row cultivations might be a useful technique for those embracing that system. The need to use clean land to reduce weed burden perhaps brings the crop forward in the rotation. Lupins will yield approximately 1.75 - 2.5 t/ha.

Seed size varies considerably between varieties and seed rate should be calculated using thousand seed weight and percent germination. Target populations are 35 plants/m2 (white), 60-75plants/m^2 (branching types) up to 100 plants/m^2 (non branching types). A 10-15% allowance should be made for losses at establishment. Drilling date of the spring varieties should be as early as conditions allow, with an optimum time of mid to late March (PGRO 2006).

Lupins were grown with mixed success for the Defra funded Organic Crop Demonstration Programme in 2005 at 2 sites in England (S Briggs, Abacus Organic Associates, personal communication, 2006). On one site they established but died back – apparently due to high free calcium levels in the soil. At the second site (Yorkshire) five varieties established but ultimately were smothered by weeds, mainly fat hen, and were mulched in.

The spring sowing theoretically offers an ideal opportunity for stale seedbeds. Growers have tried comb harrowing narrow row drilled crops and inter row hoeing wide drilled crops. Hand rogueing may be required. Avoid mechanical weeding from shortly before germination to the four leaf stage to prevent crop damage at this susceptible stage (Lampkin et al 2006).

Lupins certainly have problems in terms of weed management but they are a crop with potential and one which should improve as more is grown and techniques develop (Trump, 2004).

Defra funded research has looked at weed levels in the subsequent cereal following lupins (Defra 2002a). Data was limited but the limited areas of lupin plots which did produce a good crop indicated that weed suppression may be taking place in the lupin and following cereal. This phenomenon is not reflected in the results, but was supported in subsequent pot trials and studies by other workers and may therefore be worth further investigation (Robson, 2002).

In commercial situations a proportion of the crop is whole crop foraged, or crimped for livestock feeding. This can be a practical option in poor harvesting years. Lupin straw is very coarse and probably only suitable for bedding material.

There is limited independent data on lupin performance. In a Defra funded trial in 2000, lupins were grown on three sites. There were no significant differences in the yields recorded between two sites which produced an organic lupin crop of average yield, (Aberdeen 2.2t/ha and Ceredigion, 2.0t/ha 2000). The crop failed to emerge at the third site in Warwickshire (2000) due to soil capping immediately following sowing.

A major Defra funded research project is underway to test lupins in an organic situation LISA, LK0950 Lupins in Sustainable Agriculture. Studies on the agronomy and husbandry of spring sown lupins are being conducted at a range of geographical sites overseen by PGRO, TAG, Newcastle University and IGER. Detailed nutritive value and utilisation of lupins will be assessed in both ruminant studies with sheep at IGER and in non ruminants with pigs at the University of Newcastle. Environmental impact of nutrient leachate from spring sown lupins will be conducted at the IGER North Wyke site in Devon and potential emissions of greenhouse gases from ruminants fed a lupin diet will be investigated using laboratory based batch culture technology. Introduction of lupins and peas into long term farm systems (5 years) will be conducted at the Organic Duchy Highgrove Estate, Cirencester overseen by TAG and also at the IGER Aberystwyth and Brecon sites which will allow nutrient supply to and leached from the legume crops to be assessed. Contribution of N and P from the legume crop will be estimated in terms of yield and quality of follow on cereal crops.

The development of a more competitive, reliable lupin crop and systems for its optimal utilisation will bring a number of benefits to farmers, the feed industry, the environment and consumers. Early indications of research in organic situations are that establishing higher plant populations gives better suppression and yield. (http://www.lupins.iger.bbsrc.ac.uk/ProjectInformation/detailed_trial_info.htm)

2.9 <u>Grain legumes in poultry rations</u>

Defra funded a desk study to look at the suitability of home-grown organic legumes to underpin protein supply for poultry Defra (2002b).

3. ANALYSIS AND CONCLUSIONS

3.1 Value of grain legumes

- Grain legumes, that is, winter or spring beans, spring sown peas and spring sown lupins, are beneficial in organic agriculture in terms of their nitrogen fixation ability. In addition, they have positive effects in the crop rotations, via recycled N-rich crop residues and the break-crop effect on disease in cereal rich rotations. Field beans are more commonly grown organically than either peas or lupins.
- Whist not being competitive with weeds, grain legumes offer growers different timings for weed control and in the case of spring sown legumes, stale seedbed opportunities. However a poorly established grain legume can severely aggravate long term weed problems and so field selection is vital and weedy fields should be considered risky for peas and lupins. It will be important to have available good mechanical weeding options.
- Grain legumes are particularly susceptible at establishment to poor soil conditions, pests such as birds and co-establishing weeds
- Grain legumes should be treated as nitrogen neutral with only a small amount of nitrogen left after grain harvest for following crops. Research indicates nitrate leaching being about 0–20 kg N/ha greater after pea than after cereals.
- In selecting a break crop, the practical and direct financial implications must be considered along with the agronomic requirements and effects. The break crop may require specialist machinery and/or labour inputs (the large size of bean seed for example may require modifications to the drill). Marketing must be considered at an early stage. The organic market is fluid, therefore the market should be established before each cash crop is grown. To assess the realistic return to the farm through the inclusion of the different crops in the rotation, net margins need considering. As well as the usual gross margin costs and any applicable subsidies, the calculation included field operations, ground preparations, weeding and harvesting based on contractor charges. Even using net margin figures, the direct financial return does not provide a complete economic picture, because the agronomic effects of the crops may be reflected in improved yields of subsequent crops in the rotation (Defra 2002a). The financial implications of potentially having a poor or indeed no crop need to be considered along with the risk of worsening weed situations.
- Lupins and field beans may improve soil phosphate availability for following crops. Adequate phosphate and potash levels are required for successful grain legume growth.

3.2 Field beans

- Field bean provides good economic returns if average or better yields are obtained. However crop failure and crop losses do occur due to pest and disease damage, therefore it should be considered a risky organic crop on some sites.
- Allow at least four years, preferably more, between bean crops, and consider sclerotinia and other disease susceptible crops in the rotation.
- Variety selection should be based on agronomic characteristics before yield since these and growing conditions will have a greater effect on yield in an organic situation than

varietal differences in yield. Selection criteria should include straw height, earliness of ripening and disease resistance.

- Winter beans have large seed (500-600g/1000) and should generally be sown from late October to mid November in the UK. Sowing in early October may be preferable in northern and western regions and where the soil type is heavy for weather reasons, but at the potential expense of weed control.
- Winter beans can be sown to a depth of 8 to 10 cm but establishment can be conveniently done by broadcasting and ploughing-in the seed to a depth of 12 to 15 cm in order to establish about 25 plants/m^2.
- Spring beans should be sown as soon as soil conditions allow in February or March, although later sowings, up to early April, can still give acceptable yields. They have smaller seed (350-500g/1000) and the target plant population is 40-50 plants/m^2. Spring beans should be sown to allow weeding and also to achieve a rapid, uniform establishment. Sow spring beans at 17 to 35 cm row width. This will allow inter-row cultivation and at the wider spacing offers the potential to possibly undersow.
- For spring sown beans allow time for a stale seedbed to reduce weed emergence with the crop.
- Weeds that emerge with or shortly after the crop pose the most threat for crop yields. Beans are relatively slow to emerge despite their large seed size. Use a harrow comb on the emerged crop or in the case of drilled crops consider also inter-row cultivations. Winter beans can be harrowed hard in the spring and will tiller. Spring beans do not tiller much so more care should be taken to preserve plant population. Once early weed competition is controlled, beans tend to grow over later emerging weeds and smother them out
- A sulphur spray may be required for mildew control. There are no direct control measures for chocolate spot.
- Ensure that aphid predators are encouraged in field margins etc on the farm.

3.3 Peas

- Peas are risky crops to grow unless the chosen site is likely to have very low levels of weeds. Nevertheless they offer the benefits of the break crop and a useful protein source. Lodging and weed control are the main concerns, but bird damage can be crop threatening on some sites.
- Avoid growing peas more than one year on six to seven to avoid soil-borne disease.
- Factors in varietal choice for combining peas include seed colour (for sale), leaf structure, straw length, earliness of ripening and disease resistance. Peas frequently lodge severely before harvest so resistance to lodging and ease of combining are also important; semi-leafless varieties lodge later and less completely than normal-leaved varieties. This has implications for how fast the crop dries in the field, how readily weeds grow through the lodged crop and how easily the crop can be combined. Tall varieties will compete more effectively with weeds than shorter ones. Ideally a variety would be tall and also normal leaved so a compromise may be necessary.
- Allow time for a stale seedbed approach to assist in reducing weed problems in the crop. Otherwise it is difficult to avoid weed emergence with the crop.
- Spring combining peas are sown in March or early April. Seed size varies from 150 to 350g/1000 seeds, and seed is normally sown with a cereal drill to establish 60 to 80

plants/m^2 on medium soils, less on lighter soils. Sow spring peas at 20 cm row width to allow for inter-row weeding. Consider bird scaring tactics

- Good weed control is essential. Following a stale seedbed use post- emergence mechanical weeding. Do not weed from just before crop germination to the three leaf stage to avoid unacceptable crop damage. It may in addition be necessary to control weeds later in the growing season to prevent them from shedding seed. Mechanical weeding cannot be continued after the tendrils have met across the rows.
- Ensure that aphid predators are encouraged in field margins etc on the farm. Peas are usually able to grow through pests such as weevils

3.4 Lupins

- Lupins, like peas are risky to grow unless on a very weed free site. Nevertheless they offer the benefits of the break crop and a useful protein source. Experience of growing the crop and managing weeds is still limited in Britain and yields expected to be less than peas. Crop failure in trials is not uncommon.
- Consider rotation and have at least 5 years between lupin crops, but also bear in mind other sclerotinia susceptible crops.
- Variety selection should be based on latitude, pH, free calcium level and market place. Seed should be inoculated.
- Seed testing is vital for anthracnose (Colletotrichum acutatum) to reduce the incidence of the problem.
- Drilling date of the spring varieties should be as early as conditions allow, with an optimum time of mid to late March. Allow for a stale seedbed and weed strikes.
- Establishment is critical and a fine uncompacted seedbed is required with seeds planted on usual row spacing at 3 - 5 cm depth. Seed rates vary according to variety (see 2.8 above).
- Take measures against birds and rabbits
- Weed competition is the major difficulty and so a clean seedbed is beneficial. The possibility of wide row spacing and inter row cultivation might be a useful technique. Avoid mechanical weeding from shortly before germination to the four leaf stage to prevent crop damage at this susceptible stage. Hand weeding later in the season may be needed. Avoid fields with deadly nightshade.
- In commercial situations a proportion of the crop is whole crop foraged, or crimped for livestock feeding

3.5 Intercropping grain legumes with cereals

Intercropping could be a tool to overcome the problems of unreliable yield, weed threat and difficult harvest since grain legume intercropping shows clear annual benefits for weeds, diseases and quality. Further evaluation is needed to clarify the long-term nitrogen effects, yield stability and farm income, development of improved varieties for intercropping situations and knowledge of the required proportion of cereal and legume for yield and quality.

3.6 Current and future grain legume research

In recognition of the importance of grain legumes to the future of European farming, the European Union has agreed to co-fund the Grain Legumes Integrated Project (GLIP). This four-year project brings together a large group of European scientific research institutions (and beyond) currently involved in tackling the fundamental problems of improving grain legume production.

Module 2 of GLIP examines Economic and Environmental Impact, to use legumes to develop healthy and sustainable agriculture. Grain legume crops are sources of protein for animal feed and they require low levels of synthetic fertilisers and pesticides. Their increased contribution in European arable cropping systems could be of significant benefit to European farmers, the environment and society within a sustainable framework. Agronomists and agro-ecologists will evaluate new approaches to enhance and assess the performance of grain legumes in production systems and the related impact on the environment, in terms of agronomic, economic and ecological criteria.

In the course of the IOTA Arable Workshop (15th November 2008) the following research priorities were identified:

Long term monitoring of weeds in grain legumes and their effect on yield is required together with the development of effective control techniques.

Legume/cereal mixtures (bi-cropping) offer good potential for optimising yield and weed control; there is a need for development of the technique. The unreliability of grain legumes is a major problem for maximising cropping on arable farms and supplying the UK animal feed market; there is a need to develop more reliable agronomy.

4. REFERENCES

Borgen, Anders (2002) Control of seed borne diseases in organic cereals and legumes. Paper presented at The 4th ISTA - PDC seed health symposium: Healthy seeds, the asis for sustainable farming, Wageningen, The Netherlands, 29th April-1th May 2002; Published in Proceedings of The 4th ISTA - PDC seed health symposium: Healthy seeds, the basis for sustainable farming, page 18. ISTA. Org Print 1032

Bowerman P & Cook SK (1991) Winter beans – effect of sowing date, plant population and method of establishment on two soil types. Aspects of Applied Biology 27, 85-88.

Briggs S.R., Cuttle S, Goodlass G, Hatch D, King J, Roderick S & Shepherd M (2005) Soil Nitrogen Building Crops in Organic Farming – Defra research project OF0316

Bulson, H.A.J., Snaydon, R.W. and Stopes, C.E. (1997) Effects of plant density on intercropped wheat and field beans in an organic farming system. J. agric. Sci., Cambs, 128, 59-71.

Cormack, W.F. (1997). Testing the sustainability of a stockless arable rotation on a fertile soil in Eastern England. In Resource Use in Organic Farming (eds J. Isart and J.J. Llerena), Proceedings of the 3rd ENOF Workshop, Ancona 4-6 June 1997. pp.127-135.

Cousens R, Brain O, O'Donovon JT & O'Sullivan A (1987) The use of biologically realistic equations to describe the effects of weed density and relative time of emergence on crop yield. Weed Science 35, 720-725.

Davies, D.H.K. and Welsh, J.P. (2002) Weed control in organic cereals and pulses, in Younie, D.; Taylor, B.R.; Welch, J.M. and Wilkinson, J.M., Eds. Organic cereals and pulses. Papers presented at conferences held at the Heriot-Watt University, Edinburgh, and at Cranfield University Silsoe Campus, Bedfordshire, 6 and 9 November 2001, chapter 5, page pp. 77-114. Chalcombe Publications Org Print 8162

Defra 2002 A Review Of Knowledge: Inter-Row Hoeing And Its Associated Agronomy In Organic Cereal And Pulse Crops OF0312

Defra (2002a) Advantages and disadvantages of different break crops in organic grass/arable rotations OF0143

Defra (2002b) Desk study – Optimising the synergism between organic poultry production and whole farm rotations, including home grown protein sources OF0163

Defra (2002c) Testing the sustainability of stockless arable organic farming on a fertile soil OF0301

Dibet, Audrey; Corre-Hellou, Guénaëlle; Aveline, Anne and Crozat, Yves (2006) Performance of pea, lupin and faba bean, in organic cropping systems in France. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. Org print 7442.

Elers, Barbara (2001) Einfluß der Sorte und Bestandesdichte auf Ertrag und Unkrautbesatz bei Futtererbsen [Influence of variety and plant density of peas on yield and weed growth].

Paper presented at 6. Wissenschaftstagung zum Ökologischen Landbau - Von Leit-Bildern zu Leit-Linien, Freising-Weihenstephan, 06.-08.03.2001; Published in Reents, Hans Jürgen, Eds. Von Leit-Bildern zu Leit-Linien: Beiträge zur 6. Wissenschaftstagung zum Ökologischen Landbau, Freising. Verlag Dr. Köster, Berlin. Org print 2201

Fisher, N.M. (1996). The potential of grain and forage legumes in mixed farming systems. In Legumes in Sustainable Farming Systems (ed. D. Younie),. Occasional Symposium No.30, British Grassland Society, Aberdeen 2-4 September 1996. pp.290-299.

George R 2005 Organic Lupin Production, Briefing Paper December 2005, Soil Association

Grevsen, K (2000). Competitive ability of pea (Pisum sativum L) cultivars against weeds. Proceedings 13th IFOAM Scientific Conference, 179.

Gooding, M.J., Canon, N. D., Thompson, A. J. and Davies, W. P. (1999). Quality and value of organic grain from contrasting breadmaking wheat varieties. Biological Agriculture and Horticulture 16: 335-350

Hauggaard-Nielsen H., Ambus P. and Jensen E.S.(2002) Reintroducing grain legume-cereal intercropping for increased protein production in European cropping systems. Org Print 101

Hauggaard-Nielsen H., P. Ambus and E.S. Jensen (2001a); Interspecific competition, N use and interference with weeds in pea-barley intercropping; Field Crops Research 70; p. 101-109

Hauggaard-Nielsen, Henrik (2002b) Grain legumes in organic cropping systems. [oral] Presentation at Grain Legumes for Sustainable Agriculture, Strasbourg, France, 26-28 September 2002. Org Print 122

Hauggaard-Nielsen, H.; Jensen, E.S.; Aveline, A. and Crozat, Y. (2004) Grain legumes and nitrate leaching: significance and prevention. [oral] Presentation at Legumes for the benefit of agriculture, nutrition and the environment, Palais de Congrès, Dijon, France, 7 -11 June 2004. Org print 3108

Hauggaard-Nielsen, Henrik; Jørnsgaard, Bjarne and Jensen, Erik Steen (2003) Legume-cereal intercropping as a weed management tool. Paper presented at 4th EWRS workshop: Crop/Weed competitive interactions, Universitá Tuscia, Viterbo, Italy, 10-12 April; Proceedings and presentations from 4th EWRS workshop: Crop/Weed competitive interactions. European Weed Research Society.
Org Print 1349

Hauggaard-Nielsen H., Ambus P., Jensen E.S. 2001a. Interspecific competition, N use and interfer-ence with weeds in pea-barley intercropping. Field Crops Research 70, 101-109.

Hauggaard-Nielsen H., Ambus P., Jensen E.S. 2001b. Temporal and spatial distribution of roots and competition for nitrogen in pea-barley intercrops - a field study employing P- 32 technique. Plant and Soil 236, 63-74.

Hauggaard-Nielsen, Henrik and Jensen, Erik Steen (2004) Intercropping strategies for Europe . [oral] Presentation at 5th European Conference on grain legumes: Legumes for the benefit of agriculture, nutrition and the environment, Palais de Congrès, Dijon, France, 7 -11 June 2004. Org Print 3129

Hauggaard-Nielsen, Henrik; Trydeman Knudsen, Marie; Ravn Jørgensen, Johannes and Steen Jensen, Erik (2006) Intercropping wheat with pea for improved wheat baking quality. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. Org Print 7471.

HDRA (2001) Combinable Peas: Monitoring And Evaluation Of The Feasibility Of Organic Production (Funding body: PGRO) http://www.gardenorganic.org.uk/research/ir_hortprod_vining_peas.php

IGER 2003, Research into Practice Information Sheet – Lupins 2003.

IGER 2006, http://www.lupins.iger.bbsrc.ac.uk/ProjectInformation/detailed_trial_info.htm

Jensen E.S. 1996. Grain yield, symbiotic N-2 fixation and interspecific competition for inorganic N in pea-barley intercrops. Plant and Soil 1996 Vol. 182 Nr. 1, 25-38.

Jensen E.S. 2002 The contribution of grain legumes, currently under-utilised in the EU, to a more environmentally-friendly and sustainable European. LINK. Grain legumes for Sustainable Agriculture, Strasbourg 26 September 2002. Org Print 1852.

Jensen, E S; Ambus, P; Bellostas, N; Boisen, S; Brisson, N; Corre-Hellou, G; Crozat, Y; Dahlmann, C; Dibet, A; von Fragstein, P; Gooding, M; Hauggaard-Nielsen, H; Kasyanova, E; Monti, M and Pristeri, A (2006) Intercropping of cereals and grain legumes for increased production, weed control, im-proved product quality and prevention of N –losses in European organic farming systems . Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006.Org Print 7659.

Jørnsgård, B., Raza, S., Jensen, E.S. Christiansen, J. 2001. Choice of species and varieties of grain legumes and cereals for inter- and monocropping in organic agricultural systems. Proceed-ings of 4th European Conference on Grian Legumes, pp. 350. AEP, Crakow 8-12 July 2002

Kasyanova, Dr E and Gooding, Dr MJ (2006) Intercropping with grain legumes increases N and S concentration and N:S ratios of wheat grain in European organic farming systems. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. Org Print 7484

Lampkin,N, Measures, M and Padel S. (2006), 2007 Organic Farm Management Handbook.

Liebman M., Dyck E. (1993). Crop rotation and intercropping strategies for weed management. Eco-logical Applications 3, 92-122.

Monti, Michele; Crozat, Yves; Dahlmann, Christoff; Dibet, Audrey; von Fragstein, Peter; Gooding, Mike J.; Hauggaard Nielsen, Henrik; Jensen, Erik S.; Kasyanova, Elena; Bellostas Muguerza, Natalia and Pristeri, Aurelio (2006) Agronomic performance and yield stability of pea-barley intercropping in European organic farming system.. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. Org Print 7519.

Paffrath, A (2005) Einfluss von Ackerbohnen, Körnererbsen, Buschbohnen und Rotkleegras auf die Folgefrucht Kartoffeln [Effect of field beans, grain peas, bush beans and red clover grass on the following crop potato]. Paper presented at 8. Wissenschaftstagung Ökologischer Landbau, Kassel, 01.03.2005 - 04.03.2005; Published in Heß, J and Rahmann, G, Eds. Ende

der Nische, Beiträge zur 8. Wissenschaftstagung Ökologischer Landbau. kassel university press GmbH, Kassel. Org Print 3576
PGRO, 2006, PGRO Pulse Agronomy Guide 2007.

Prins, U. and Wit, J. de (2006) Intercropping cereals and grain legumes: a farmer's perspective. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. Org Print 7297.

Rasmussen, I.A., Akegaard, M. and Olesen, J.E. (2000). Weed controlin organic crop rotation experiments for grain production. Proceedings of the 13th International IFOAM Scientific Conference, 28-31 August 2000, Basel (eds T. Alfoldi, W. Lockeretz and U. Niggli). p.182.
Robson, MC, Watson, CA, Fowler, SM, Leitch, M, Robinson, D & Litterick, AM (2002) The agronomic and economic potential of break crops for ley/arable rotations in temperate organic agriculture. Advances in Agronomy 77, 369-427.

Steffens, Prof. Dr. Diedrich; Stamm, Roland; Yan, PD Dr. Feng; Leithold, Prof. Dr. Guenter and Schubert, Prof. Dr. Sven (2005) Rohphosphatmobilisierung von Sommerweizen, Weißlupine und Ackerbohne in einer Fruchtfolge [Rock phosphate mobilization by summer wheat, white lupin, and faba bean in a crop rotation]. Paper presented at 8. Wissenschaftstagung Ökologischer Landbau 2005 - Ende der Nische, Kassel, 01-04.03.05; Published in Heß, J and Rahmann, G, Eds. Ende der Nische, Beiträge zur 8. Wissenschaftstagung Ökologischer Landbau. kassel university press GmbH, Kassel. Org Priny 3606.

Taylor, B.R. and Cormack, W.F. (2002) Choice of cereal and pulse species and varities, in Younie, D.; Taylor, B.R.; Welch, J.P. and Wilkinson, J.M., Eds. Organic cereals and pulses. Papers presented at conferences held at the Heriot-Watt University, Edinburgh, and at Cranfield University Silsoe Campus, Bedfordshire, 6 and 9 November 2001, chapter 2, page pp. 9-28. Chalcombe Publications. Org Print 8163

Taylor, B.R., Richards, M.C., Mackay, J.M. and Cooper, J. (1991). Plant densities for combining peas in Scotland. In Production and Protection of Legumes (ed. R.J. Froud-Wiliams, P. Gladders, M.C. Heath, J.F.Jenkyn, C.M. Knott, A. Lane and D. Pink), Aspects of Applied Biology, 27, 309-312.

A Trump, 2004, Elm Farm Research Centre Bulletin, 74, November 2004, Orgprint 4183

Zhao, F., Salmon, S.E., Withers, P.J.A, et al. (1999). Responses of breadmaking quality to sulphur in three wheat varieties. Journal of Cereal Science 79: 1865-1874.

5. APPENDIX

Useful background reading for Organic Advisers

PGRO, (2006), PGRO Pulse Agronomy Guide 2007.

A Trump, (2004), Elm Farm Research Centre Bulletin, 74, November 2004, Orgprint 4183

NIAB literature

Lampkin,N, Measures, M and Padel S. (2006), 2007 Organic Farm Management Handbook.

George R (2005) Organic Lupin Production, Briefing Paper December 2005, Soil Association

Soya UK, website - www.soya-uk.com

IGER website - www.iger.bbsrc.ac.uk, and
http://www.lupins.iger.bbsrc.ac.uk/ProjectInformation/detailed_trial_info.htm

COSI www.cosi.org.uk for protein crop varieties available organically

PGRO Inf. Sheet 184 Notes for growing organic pulses. Jan 2006 PGRO

http://www.grainlegumes.com The Grain Legumes Integrated Project