RESEARCH TOPIC REVIEW: The role and management of whole-crop forage for organic ruminants

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1. Scope and objectives of the research topic review:

The objectives of this review are to summarise the findings of the results of research funded by Defra and other relevant research programmes, and to identify the practical implications these results may have for the practice of organic farming. The review takes account of published research from the UK & Europe. Research work has been the basis for the review although technical publications, levy funded material and some anecdotal evidence have also been used. Although the majority of the material does not specifically relate to organic practice, all material was screened for organic relevance and included in the review where the methodology and results were considered relevant and useful to organic practice.

Background

For the purpose of this review, whole crop forage is defined as the harvest and conservation of an annual crop or annual crop mixture. Perennial crops such as grass mixtures and lucerne have not been included in this review as they are generally considered an ensiled forage as opposed to an alternative use of an annual crop. Maize has also not been included, although there is a wealth of research on the use of maize as an ensiled whole crop; and indeed a research review solely on this subject would not do it justice. However the use of maize as whole crop is rare in UK organic production due to technical issues relating to weed control and fertility requirements. The harvesting of cereals and/or legumes as whole crop as opposed to combined is not a new practice nor is it confined to organic production. It allows greater flexibility of harvest date of high dry matter yields of good quality forage within one harvest window in contrast to multi cuts of grass silage. By choosing an earlier harvest date it allows the growing of cereals in wetter locations where climate may make combining problematic. Whole crop can complement grass silage well being relatively high in starch and lower in protein than grass silage. Inclusion of a legume to create a mixture will tend to increase the otherwise low protein of whole crop cereals. For farmers who are converting their holdings to organic production and significant re-seeding of pastures is required, whole crop forage has been used to great advantage as a nurse crop to an under-sown clover rich ley Weller et al (2004). The yield of the whole crop forage can provide a significant offset to loss in forage associated with a complete re-seed while offering an effective weed suppressing entry crop in an arable rotation. There is evidence that both under sowing legumes and including legumes in the forage mixture can also improve the efficiency of nitrogen uptake by the cereal component of the mixture. While not appearing to increase milk yield or live weight gain as a straight feed (Keady et al 2007, Chamberlain & Wilkinson 1998, Dawson 2006, Park et al 2005), whole crop can improve intake when fed as a supplement to grass silage.

Under the old cereals support regime an arable payment could still be claimed on arable area payment scheme (AAPS) eligible land. Under the current Single Payment Scheme (SPS) this issue is no longer relevant. Due to technical difficulties in growing maize silage in organic systems (weed control and fertility requirements) whole crop continues to be a popular alternative choice by converting and converted organic livestock farmers.

Whole crop forage can be conserved with an alkaline additive (typically urea or ammonia) at higher dry matters (Tetlow 1992), or as fermented silage with or without inoculants once the growing crop has reached 35 – 45% dry matter. Fermented whole crop is nutritionally distinct from alkaline whole crop being lower in starch and protein and has less aerobic stability when conserved. . Only enzymes, yeast or bacterial inoculants are permitted in organic farming (Defra 2006) and where alkaline preserved whole crop forage research material has been cited, it has been included in this review where the results are considered relevant for organic farming.

Due to the low protein content of cereal whole-crops they are rarely fed to ruminants alone which can make their feeding complicated in some situations. Recent research has looked at bi-cropping whole crop cereals with a variety of mixtures including legume species to increase the protein content to overcome this problem.

2. Summary of Research Projects and the Results

This section identifies key research projects and their conclusions allocated by subject headings below.

2.1 Choice of species, variety and mixture.

2.1.1 Species

All spring and winter sown cereal species can be used as whole crop forage although wheat and barley are the most commonly used (Sinclair McGill 2000). A national whole crop cereals survey carried out by Weller (1990) looked at the practices of 53 conventional farms conserving 63 crops of which 20 were conserved fermented and the majority were winter wheat varieties. R.F. Weller et al (2004) also looked at a number of varieties of oats (cv. Bullion), spring barley, (cv. Riviera and Dandy), triticale (cv. Purdy) and forage pea (cv. Canis.) to determine the best species and variety with respect to dry matter (DM) yields, and suitability as a nurse crop for organic production. They found that barley yielded the highest dry matter forage when cut as silage, was most suitable as nurse crop to the under sown ley and had a higher proportion of grain in the final yield. The oats and triticale varieties were the greater suppressors of the consequent under sown ley. The forage pea was least suitable as pure nurse crop. No significant difference was found in the clover levels in the subsequent spring ley in all species grown. A barley/forage pea mixture was the most common choice of arable silage on 12 selected farms as part of a study looking at nitrogen supplied by fertility building crops carried out by IGER & ADAS (2004). Kristensen (1992) reports from Denmark that the most important species used for whole crop forage was pure spring barley stands or barley/pea mixtures. Pure legume stands of peas or beans were considered difficult to ensile although when conserved successfully had higher digestibility and feed values than cereal based whole crops. The Danish study found wheat was used to a lesser extent due to later optimum harvest dates although higher yields of dry matter were obtained. In a survey carried out by ADAS, Harvey (1992) compared wheat, triticale and winter oat varieties to determine a practical method of optimum harvest stage for conserving as whole crop. In addition to the more traditional use of cereals, the Organic Studies Centre (OSC) (2005a, b) has carried out initial field research and analysis on a number of species and mixtures for whole crop forages, including various varieties and mixtures of lupin, peas and millet. Both the pure legume stands and cereal legume mixtures were found to have higher crude protein content than cereals alone with pure lupins having the highest. Starch content was found to be extremely variable between similar mixtures and different species. Faulker (1985) carried out a comparison of beans and forage peas as whole crop forage and (Sheldrick et al 1980) made an early initial evaluation of lupins as a potential whole crop species, while Potts (1980) also carried out early work on forage peas. A more recent study by Koivisto et al (2003) has investigated the forage potential of grain pea varieties and Hauggaard-Nielsen (2001) looked at pea and barley cultivars in respect of differing levels of N availability. In a recent Welsh survey of organic farmers, by Hitchins et al (2007), of 913 ha crops grown, 50 % was harvested as whole crop. Cereals grown as mixtures for whole crop was found to be the most common arable choice (356 ha), while wheat and barley being the next most common, 165 ha and 145 ha respectively.

2.1.2 Varieties

Most commercially available small cereal and pulse varieties are results of conventional breeding programs looking at maximising grain yield under conventional conditions (i.e. use of fertilisers and pesticides is assumed) (Keatinge 2004). This is important for their use as whole crop as the portioning of grain in the crop will contribute significantly to the ultimate yield and nutritional quality of the harvest. However organic seed availability and variety performance data have been noted by organic farmers as being major constraints to organic cereal production (Pearce 2006). Wolfe (2002) noted the technical difficulties associated with attempting to breed forage mixtures due to the wide range of varieties and mixtures that are possible. An internet based database has been set up to improve technical information transfer project known as the Centre for Organic Seed Information (COSI) the Soil Association (2007) , but a search of this database revealed few varieties that have been tested under organic conditions. In a European wide study looking at the benefits of intercropping (mixtures of crops), Hauggaard-Nielsen et al (2001) looked at the characteristics of 6 pea and 5 barley cultivars to determine the optimum intercropping mixture. They found that variation between pea varieties were larger than for barley varieties, and that for peas, the determinate varieties demonstrated better characteristics for intercropping. Adesogan et al (2004), in an animal performance study, found a short straw variety of pea (v. Setchey) improved performance of dairy cows when compared to a more traditional forage pea variety (v. Magnus). As good portioning of grain is still a key objective in forage mixtures, it is assumed that grain yield performance under low input conditions will still factor high, when making a variety choice for the organic producer. Characteristics such as good disease resistance, good competition to weed populations and ability to make use of soil nutrients in limiting conditions will be paramount. However, due to the restricted use of inputs, it is noted by Taylor & Cormack (2002), that yield will be influenced to a greater extent by growing conditions in organic growing, than by choice of variety. There is nothing to suggest that this is not also the case when growing a crop or mixture for whole crop forage.

Table 1 Suitable variety choice for organic cereal production

Wheat	Barley	Oats	Triticale	Beans	Peas	Lupins
Winter Varieties						
Deben Claire	Pearl	Solva Gerald Jalna Millenium		Clipper Bourdon Punch Striker		
Spring varieties						
Axona Chablis Imp	Riviera Ego Hart Dandy Westminster	Melys Banquo Firth Winston	Ego Taurus Purdy Olympus	Lobo Victor Quattro Mars	Grafila Cooper Nitouche Eiffel Pidgin	Wodjil

2.1.3 Mixtures

As noted in 2.1.1, mixtures of cereals and legumes appear to be the most common planted crop utilised as whole crop. The higher protein content of the legume supplements well the higher starch value of the cereals chosen. In a European study combinations of both beans and cereals and peas and cereals were studied to determine a number of positive factors in subsequent crops (Jensen 2006). Typical mixtures found to be popular in the UK are barley and peas, wheat and peas and oats and vetch mixes. Lupins are beginning to make an appearance but yields are notoriously variable. Faulkner (1985) compared pure stands of forage peas and field beans with the same species mixed with cereals. He found that the beans had the highest dry matter yields and had a more favourable effect on the subsequent undersown crop than pure stands of peas or mixtures of peas. Both species were found to produce high levels of dry matter forage without the use of nitrogen fertiliser, suiting them to organic conditions. In a comprehensive review Keatinge (2004) suggests that peas are a better option as a mixture with barley than beans. Keatinge quotes another Canadian study where pea-cereal mixtures out-yielded the cereals grown alone. Keatinge noted that few workers reviewed had found advantages to sowing the mixtures in relation to total yield, but the legume mixtures were beneficial in improving the overall protein quality of the forage produced.

Common mixtures typically available commercially are Oats/Pea, Barley/Pea, Barley/Vetch/Pea (Olivers 2007). More novel mixtures including lupins and triticale are offered by some suppliers Soya UK (2007) and are summarised below.

Table 2 Novel Whole crop mixtures (Soya UK 2007)

Whole crop option	Mixtures	Status
Flexi Mix	Vetch & Triticale	New
Avon Mix	Spring Triticale & White Lupins	Well proven
Trent Mix	Spring Wheat & White Lupins	Well proven
Clyde Mix	Spring Triticale & Yellow Lupins	New
Cherwell Mix	Spring Oats & Blue Lupins	New/ experimental
Hamble Mix	Spring Barley & Yellow Lupins	New
Humber Mix	Spring Barley & Peas	Well proven

Pure stands of cereals for whole crop have been reported to outperform mixtures on yield of dry matter alone, however the inclusion of legumes in the mixture can improve the "D" value without serious penalties on yield if chosen carefully according to site and mixture (Olivers 2007).

2.2 Management of whole crop forage

Whole crop forage management differs from that of cereals in general, in that plant target populations are generally lighter due to allowing compatibility in the mixture and so as not to smother an undersown crop; a typical practice in organic production. If a mixture includes legumes, then attention to lime status as well as other major soils nutrients is necessary with the exception of lupins which can tolerate lower pH than other legume species. Whole crop forages can occupy a similar place in the rotation to first or second cereals depending on crop rotation requirements and fertility. A common practice is to undersow whole crop forages (spring sown crops only) and in effect the whole crop will act as a nurse crop for the consequent grass crop. Seed rates may be reduced in this case to avoid a smothering effect to the undersown forage.
Harvesting for fermented whole crop will typically be up to 6 weeks prior to normal harvesting date for combining. As whole crop forages are not required to harvest dry, the harvesting window is typically longer than combined crops and the sowing date for spring crops in particular are more flexible.
Conservation for fermented whole crop can be with or without an additive but dry matter must not be allowed to rise above 45% to ensure adequate consolidation, sufficient water soluble carbohydrates (WSC) and stability in the clamp.

2.2.1 Soil

Cereals can be successfully grown on most soil types although poor drainage and low fertility will impair yields (Sinclair McGill 2000). Most legumes will require pH of 6 or above, although lupins will tolerate more acidic soils and indeed most varieties will not tolerate alkaline conditions. In common with other crops, soil profiles ideally should allow deep rooting. Fertility levels should be medium to high for successful crops i.e. soils index 2 or above (Lockhart & Wiseman 1978). Autumn sown crops can be left cloddier while spring sown seedbeds should be prepared rather finer (Wibberly 1989). Choice of cultivation technique will depend on previous crop, soil type, time available between crops and timing of sowing. Lighter soils will establish with minimal cultivation assuming the weed burden is under control. Heavier soils may need the more traditional approach of ploughing for weed control and secondary cultivations. An excellent review of soil conditions effecting cereal establishment is covered by Blake et al (2003). Factors such as planting depth, temperature, soil structure and aggregate size all contributed to successful crop emergence. Planting depth was found to be detrimental to establishment below 80mm. Blake et al (2003) found that crop emergence was inhibited if sown below a soil temperature of 4 degrees centigrade but emergence was below 10 days if sown between temperatures of 10 and 20 degrees C. Aggregate structure was also found to be important in relation to drainage and oxygen availability to the seed. The optimum seed bed aggregate size was noted as 1mm – 3mm in diameter. Higher percentages of aggregates above this size were found to inhibit germination although aggregate shape was also found to be important.

2.2.2 Establishment

Sowing can be either drilled or broadcast. Drilling is recommended for cereal mixtures containing large seeded legumes due to increased danger of pest predation if broadcast. Pure cereal crops can use target plant populations as advised for combining unless under-sowing. Spink et al (2000) recommends 325 – 400 seeds/m^2 for winter sown crops and a general target spring plant population of 275 plants/m^2. When planting mixtures then plant populations are more difficult to predict and sowing rates (kg/ha) are more typically quoted, with the mixture made up as a percentage of the total. Commercial quoted rates are between 65 – 70 kgs/acre (170 kg/ha) for Barley/Pea mixtures, with the barley making up between 35 – 50% of the mixture. A trial by Fychan & Jones (1997) used a range of cereal/pea mixtures all at a rate of 80kg cereal to 120 kg peas per hectare. Sinclair McGill (2007) quotes a commercial mixture at a suggested rate of 100 kg cereal to 120 kg peas. Lupins are recommended to be planted at 85 – 110 seeds/m^2 (40 – 50 kgs/acre) or as a 50/50 mix with triticale at 70 kgs/acre. Typically seeds rates should be reduced by 15% if undersown (Olivers 2007). Potts (1980) carried out trial work on forage peas and found that the earliest sowings (longest growth to harvest) with the highest seed rates gave the highest yields suggesting that warm sites are most suitable for this species. The highest seed rate used was in the trial 200kg/ha. Commercial rates for forage peas as a pure stand are quoted ranging from 200kg/ha to 100kg/ha (Lampkin & Measures 2006). Gilliland and Johnston (1992) in a study compared differing seed rates for cereal/pea mixtures and the subsequent effect these had on the under-sown grass crops. They concluded that overall mixture rates of below 100kg/ha are too low for effective weed suppression and optimum rates to balance the objective of good yields and good nurse crop characteristics was 120 – 160kg/ha for the barley component and 50 – 60kg/ha for the pea component of the mixture.

2.2.3 Weeds & Disease

Both cereals and legumes will be subject to similar diseases that affect them when grown for combining. As harvesting occurs earlier in the case of whole crop harvesting some diseases will not be as progressed as for combined crops. If weed suppression is required by a given strategy this would be counterproductive to development of the under-sown species. Trials that are not specifically targeted at organic production will typically use chemical weed and disease control as appropriate as this approach would normally be available to commercial growers (Potts 1982). In an organic study comparing two pea-barley mixtures with sole crops for their capacity to reduce weeds Dibet & Hauggaard-Nielsen et al (2006) found that that the weeds were better controlled in barley sole crops and intercrops than in peas grown as a sole crop. The study highlighted the role that soil N had in relation to crop competition with weeds. The presence of barley effectively reduced soil N levels and consequently reduced weed levels. In another study under organic conditions, disease levels were monitored in pure stands and barley mixtures with lupins, beans and peas. Levels of net blotch (Pyrenophora teres), brown rust (Puccinia recondita) and powdery mildew (Blumeria graminis f. sp. hordei) were found to be lower in the mixtures than in pure stands of barley. Ascochyta blight (Ascochyta pisi) on peas was also found in reduced levels in the mixtures (Kinane and Lyngkjær 2002).

2.2.4 Harvesting

It is in the harvesting of whole crop forages that differs from the traditional combine harvesting of cereals and pulses as dry grain crops. This report considers fermented whole crop silages (FWC) only as preservation of alkaline treatments such as Urea (UWC) are prohibited by organic farming standards (Defra 2006). Fermented whole crop silages have both advantages and disadvantages over urea-treated method of preservation. Heron (1996) summarises these in the table below:

Table 3 Pros and cons of fermented whole crop forage.

Advantages	Disadvantages
Any cereal or mixture can be used	Fermentation losses at lower dry matters
Earlier harvest	Can be aerobically unstable in the clamp
Better control of weeds in the crop	Acidic material with low buffering capacity (cereals only)

Wider harvest window	Legume inclusion will lift buffering capacity
Lower field losses of grain	Short chop is essential for better consolidation in the clamp
No excess non protein N in the diet	Fermented silages can attract vermin and birds
Additives can be cheaper than for Urea	Low in crude proteins as earlier harvested (can be lifted if legumes are included in the mixture)
Can be fed up to 100% as forage in the ration	
Undersown crops do not effect the fermentation	
Compliments higher dry matter grass silages	

After Heron (1996)

Cereals and cereal mixtures harvested as FWC should be harvested before dry matters reach over 55% to avoid poor consolidation and reduced stability in the clamp. Target dry matters for wheat based forages is 40 – 40% or at the “soft cheddar” grain stage, for barley targets are 35 – 40% due to a less digestible kernel (Sinclair McGill 2000, Heron 1996). Bastiman & Pullar (1993) sampled fermented wheat crops at 37 % (brie stage) in and experiment comparing FWC and UWC. The crop colour at the recommended Zadoks (1974) growth stage (GS 71 – 85) is changing from green to yellow and the texture of the grains has changed from watery to cheesy (soft Cheddar) (Cushnahan 2007). For forage peas Olivers (2002) recommend harvesting at no more than 30%. Above this dry matter the digestibility as measured by the “D” value, declines. A study by Fraser et al (2001) looking at the optimum harvest time between peas and beans showed this to be 12 weeks (flat pod stage) for peas but 14 weeks for beans (pod fill GS 207). Both crops had a more beneficial fermentation by the addition of an innoculant. A study by ADAS (2001), forage lupins were successfully ensiled, with a lactic acid fermentation, however, due to low dry matter at harvest the workers concluded that in-field wilting of the crop was desirable for a more stable ensilage process. George (2004) recommends that the crop is harvested for wholecrop at 15-18 weeks after sowing. Harvesting takes place while the crop is still green but after pod fill is complete. Lupins are typically mown and wilted before chopping through a forager at 2 – 5 cm length. In a further study into the silage potential of two lupin varieties (v.Nelly & v.Arthur), Fraser et al (2005), reported the optimum growth stage for harvesting for both varieties occurred at 16.5 weeks after sowing. Although there were differences in fresh matter yield, the dry matter (DM) yield was similar at 59%. In a bi-cropping study looking at the potential for organic farming of lupins and cereals, white lupin mixed with spring wheat or triticale was the most successful mixture and harvesting at a minimum of 50% DM and about 116 days from sowing ensured a high quality and stable silage (Azo et al 2006). Raising the cutting height can increase the quality of whole crop cereals as the grain/straw ratio is increased. This however will inevitably lead to a reduction in overall yield (Keatinge 2004).

2.2.5 Conservation

Conservation of FWC forages are reported as being easier to ensile but more unstable at feed out than UWC treated forages (Leaver & Hill 1992). Fermented whole crops are harvested earlier than alkali or urea treated crops. At this earlier stage of growth, dry matter is lower and water soluble carbohydrates (WSC) and starch are higher. This leads to a lactic acid fermentation of sugars similar to that when ensiling grass silage (Tetlow 1992) although due to the higher proportion of WSC’s and higher dry matters at harvest when compared with grass, whole crop cereals are twice as unstable (Kristensen 1992) once ensiled. Aerobic stability once the clamp is opened can be a problem if the clamp face is too wide and new material is not removed regularly enough. Good consolidation and quick filling of the clamp is recommended as is double sheeting and a well weighted clamp head. When opening the clamp to feed, a clean, ideally sheared face should be maintained (Heron 1996).

Baling is an alternative to clamping, however the higher dry matter of cereal based whole crops when compared with grass based, can damage wrapping film allowing aerobic spoilage and secondary fermentation within the bale. Extra wrapping is therefore recommended.

Additives permitted within organic production are those based on acids (preservatives) or enzymes and bacteria (inoculants). No genetically modified organisms (GMO) can be included in these products. The use of acids in the production of silage is only permitted when weather conditions do not allow for adequate fermentation (Defra 2006, Soil Association 2005, Organic Farmers & Growers 2006). The inclusion of legumes in a whole crop mixture complicates the fermentation process by the high buffering capacity of legumes in general. This quality counteracts the requirement to lower pH sufficiently in the silage to achieve stability. Adesogan and Salawu (2002) compared bacterial inoculants with formic acid and salt based preservatives on different mixes of Pea/wheat bi-crops. The study concluded that it is misleading to assume that a given additive will have consistent effects on the fermentation and aerobic stability of all pea/wheat bi-crops. Formic acid achieved best stability and resulted in a better quality nutritional product in the study. This was true for the mixtures that had high pea/wheat ratios. Lower pea ration mixtures could be ensiled successfully without inoculants.

Inoculation was found to increase the lactic acid concentration and reduce the pH and ammonia-N and acetic acid concentrations in a comparison of Pea and Bean silages carried out by Fraser et al (2001). A later study gave similar results comparing two lupin varieties carried out by the same authors (2005).

2.3 Production

The production of whole crop forage is measured in their performance on the basis of yield and quality. With fermented whole crops forages, the feeding value is highly dependent on achieving the optimum balance between the increasing starch level in the ripening grain and the decreasing digestibility of the straw (Cushnahan 2007). Most trials have been carried out using barley and wheat crops using crop maturity, yield and quality as performance parameters. Large variations in the yield of whole crop cereals are attributed to differences in soils and site conditions (Keatinge 2004). Weller et al (1995) found there was not a correlation between maximum yield and dry matter in a study involving ten different varieties of winter wheat. Adegosan *et al* (1998) detected large differences in water-soluble carbohydrate and starch contents, but not in crude protein when analysing two varieties of whole-crop winter wheat at different stages of growth and Keatinge (2004) suggests that these factors should be taken into account when selecting a variety.

As mentioned, including legumes in a cereal mixture can increase the feeding quality of the final harvest but does not necessarily increase the overall yield. As FWC cereals are generally lower in protein than that required by ruminants' inclusion of a legume is clearly advantageous.

2.3.1 Yield

Yields of FWC cereals vary between species and as a result of site variation. Tetlow (1992) recorded yields of between 15 – 18.1t DM/ha for winter varieties of wheat, barley, oats and triticale, with triticale giving the highest and barley the lowest in the conventional study. Spring varieties recorded yields of between 10 – 12t DM/ha in the same study. Large variations in yield were confirmed by Kristensen (1992) in a summary of Danish research over 17 years into production and feeding of whole crops showed that the yield potential of winter wheat was 9 – 17 t DM/ha, spring barley 6 – 11 t DM/ha and peas or field beans 6 – 9 t DM/ha. Jones et al (1998) found that total dry matters yields were found to be similar between oats and barley at 8 – 9 t DM/ha, despite the oats yielding more on a fresh weight basis. In a report from a study on organic dairy conversion Weller (2006) used barley and triticale/vetch mixtures as nurse crops for undersown leys. Average yields of 10.3 t DM/ha for the barley and 11.8 t DM/ha were recorded. In a forage crop experiment Ghanbari-Bonjar and Lee (2003) compared sole crops of wheat and field beans with a mixture of the two species and found that the wheat and bean intercrops were higher in total forage dry matter (DM) yield than either wheat or bean grown as sole crops. The plots in the experiment did not receive any pesticides or fertilisers.

From the commercial perspective Olivers (2007) have carried out their own trials and propose yields of a barley/pea/vetch mixture of 9 – 10 t DM/ha with 7 – 9 t DM/ha for a mixture of barley and peas only. The same commercial supplier quotes up to 10 t DM/ha for their barley/oats/pea mixture and up to 7 t DM ha for a triticale/lupin mixture.

2.3.2 Quality

Fermented whole crop cereals are characterised as high energy/low protein forages. The energy density is typically lower than for maize silage (Keatinge 2004). The energy density of whole crop wheat, oats and triticale is lower than that of Barley (Olivers 2007). In common with grasses and other crops, the stage of maturity at harvest has an effect on the nutritional value of the final crop.

Leaver and Hill (1992) looked at the feeding value of both UWC and FWC and that both methods of conservation produced crops with energy levels of between 9 – 10.5 ME (MJ per kg DM) although the UWC produced higher yields. Heron (1996) quotes a typical range of feed values for FWC of 9 -11.5 ME, "D" (%) values of 60 – 70, crude protein (% DM) of 9– 11 and starch (% DM) of 15 – 30. Dry matter ranged from 35 – 50%.

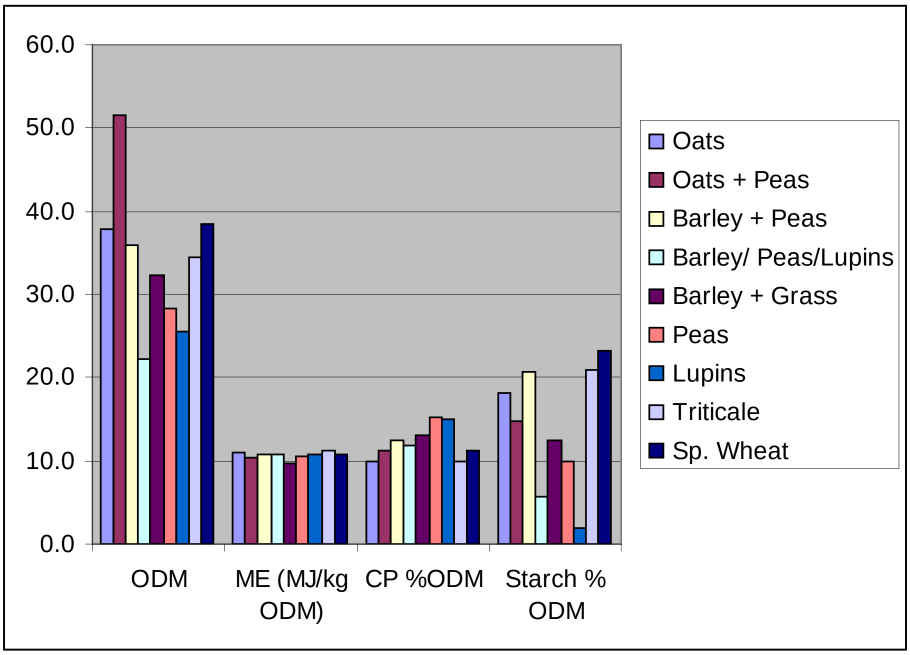
When harvested as a legume mixture, proteins and energy density (due to higher digestibility of the cell wall in legumes) in the final feed will increase but overall yield will tend to be reduced. Kristensen (1992) showed that by including beans into a barley crop as a mixture this raised the CP % from 8.3 to 12.6. In a survey of organic farm practice, carried out by the Organic Studies Centre (2005b) analysed a large variety of whole crop forages and recorded the cropping experiences from the participating farmers. The results are averaged and displayed in figure 1. This shows that while there was little difference found in energy values, protein values were affected positively by the inclusion of peas or lupins by up to 5%. Starch values were found to be very variable with the lupins and lupin mixtures showing the lowest levels and wheat and triticale the highest.

Bax (1998) records relative ME yields of 126, 107 and 89 GJ/ha and yields of crude protein of 1080, 945 and 1490 kg/ha for whole crop wheat, barley and forage peas respectively.

In their trials comparing oats and barley as baled silage in an organic system, Jones et al (1998), found that barley had significantly higher WSC than oats at two different harvest dates although satisfactory fermentation was achieved for both species.

In the lupin study, Fraser et al (2001) prepared silages from two different varieties and recorded crude proteins in the range of 20.9 – 22.9 %, and WSC of 12.2 - 16.3%. Sinclair McGill (2000) promote lupin silages with ME potential of 10 – 10.5 and crude proteins of between 17 – 22%.

Figure 1. Average of surveyed whole crops (Organic Studies Centre 2005b)



ODM = Oven dry matter.

In a study by ADAS (2001) forage lupins were successfully ensiled and shown to have very low DM (~15%) and high CP contents (~ 20%). The solubility of the CP fraction was very high.

2.3.3 Role in ruminant nutrition

Whole crop cereals and cereal bi-crops can be successfully fed to lambs, beef and milking cows. If low in protein (< 10 %) they are typically fed as a supplement to grass silage. In the review by Keatinge (2004) he reports that inclusions of fermented whole crop wheat silage of between 33 % and 40% have been recommended by different workers. While different workers report increased feed intake in dairy cows as a result of inclusion of FWC in the diet, no conclusive increases in animal performance were recorded. Keady et al (2006) fed steers alternative diets of grass and maize or grass and whole crop wheat. While intakes were marginally higher for the grass + whole crop ration, the grass + maize diet resulted in better live weight gains and final carcase weights. The results for the grass only ration differed little from the whole crop ration. All treatments resulted in similar carcass composition and meat eating quality. In a feeding experiment using both dairy cows and sheep Sinclair et al (2003) found no significant differences in production when a fermented whole crop wheat and grass silage diet was compared with grass silage alone. Pea silage as a whole crop silage was used to feed lambs as one of a number of alternatives to ryegrass silage in a study by Marley et al (2007). The Pea treatment was discontinued due to very low lamb live weight gains. Pullar (1993) also found that FWC wheat had the lowest protein content when compared with UWC wheat and grass silage. When fed to dairy cross heifers the FWC wheat resulted in live weight gains of 0.54 kg/day compared with 0.6 & 0.65 kg/day for grass and UWC wheat respectively. Feed conversion efficiency was consequently the lowest for the FWC wheat treatment. Another study using lambs looked at the animal performance from fermented whole crop barley (WCB) and whole crop oats (WCO) to determine their potential as winter feeds. Adesogan and Jones (2000) found that after the 20 day feeding trial all treatments had live weight losses with 78g/day for oats and 128g/day for the barley whole crop. This was despite the better nutritional quality (digestibility, starch and protein) of the barley crop. In research undertaken in N.Ireland, Dawson (2006) reports similar findings when feeding whole crop wheat to finishing beef. When compared to grass alone as a ration, intakes increased for both grass/maize and grass/WCW rations offered. However both carcase weight and carcase gain only increased for the maize ration and was not significantly affected by the inclusion of whole crop wheat. This is summarized in Table 4.

Table 4. Effect of including maize and whole crop wheat on beef cattle performance

Factors	**Grass silage only**	**Grass silage + maize silage**	**Grass silage + whole crop wheat**
Forage intake (kg/day)	5.0	5.8	5.8
Carcass gain (kg/d)	0.51	0.60	0.50
Carcass weight (kg)	326	340	324

Source: Dawson L 2006

Rondahl (2007), in a review of the how cereal silage mixtures including peas might affect milk production, concluded that few workers had found that inclusion had a positive effect on milk production, despite increasing voluntary feed intake. However his PhD study on the use of pea/oat silages for milking cows concluded that this type of silage can be used in diets to both intermediate- and high-yielding cows and can replace high-quality grass-clover silage. The most beneficial ration mix was pea-oat bi-crop and grass-clover silage 0.50:0.50 on a DM basis which had a concentrate saving effect of up to 3kg/cow/day. Salawu et al (2002) showed that when compared with grass silage, a pea (v. Magnus)/wheat silage had a slight concentrate-sparing effect and also gave marginal improvements in milk production.

Adesogan (2004) noted that, whereas several studies have evaluated the potential of legumes to provide dietary protein for ruminants, few have focused on the benefits of including cereal-legume silages in livestock rations. In this important study, he looked further at improving the milk yield and concentrate saving opportunities of different pea/wheat silages using 2 different pea varieties, one long straw (v. Magnus) and one short straw (v. Setchey) in the mixture. He found the short straw pea variety mixture (SW) resulted in higher intakes and milk yields (+ 3 kg) when fed to milking cows and also resulted in a saving of around 4kg of concentrate was achieved when compared with feeding grass silage alone. The improvement in performance was attributed to the higher pea/wheat ratio in the SW ration.

Table 5. Feed intake, milk yield, and milk composition of dairy cows fed pea/wheat intercrop silages differing in pea variety or grass silage with 2 levels of concentrate (Adesogan 2004)

	Treatment[1]				
	GS8	**GS4**	**MW4**	**SW4**	**SED[2]**
Forage DMI (kg/d)	10.7	11.8	14	15.8	0.5
Total DMI (kg/d)	17.5	15.4	17.2	19.3	0.71
Milk yield (kg/d)	24.5	20.1	20.8	24	0.81

[1] GS8 = Grass silage with 8 kg/d concentrates; GS4 = Grass silage with 4 kg/d concentrates; MW4 = Magnus pea/wheat intercrop silage and 4 kg/d concentrates; SW4 = Setchey pea/wheat intercrop silage and 4 kg/d concentrates.

2.4 Role in Mixed farming Systems

The growth of organic production in the UK has largely occurred in the more maritime Western regions. These regions are the higher rainfall areas that supply the majority of milk, beef, lamb in the UK. While arable crops are grown on better land on organic farms, this will typically be for the feeding of livestock and only surpluses are sold off farm. Livestock feed in the form of grazed and conserved grass and forage crops, will supply typically over 90% of energy requirements for ruminants.

Supplementary proteins may be required at lambing, for finishing beef cattle and to supplement the rations of milking cows during winter and early lactation. The majority of organic livestock farm systems are dominated by permanent and temporary grassland and arable cropping is carried out where site class permits. Furthermore, the organic farm system aspires to self sufficiency and where livestock are present, bought in concentrate feeds are minimised in pursuit of this aim.

Wholecrop silages including cereals or a mixture of cereals and legumes, fit well into the mixed organic farm system, providing good opportunities for a break-crop adding diversity within the cropping season and arable rotation, as nurse crops for undersown grass re-seeds and their early harvest allows for an important opportunity for a bastard fallow for perennial weed control. Not only do they supply an alternative and comparable feed to grass silage but they can also provide a high energy, less acid silage which compliments grass silage and grazed grass, potentialy improving intakes, reducing concentrate feed requirements and enhancing digestion, cow health and performance, Bax pers.com. They can be harvested earlier in one harvest operation and with less risk than combined cereal crops in higher rainfall areas. They can provide a valuable source of home grown protein when legume species are included.

In the comprehensive European report Jensen (2006), lists the advantages of inter-cropping for harvest and forage. In particular he quotes best use of resource in one season, more stable yield response, better use of nitrogen (N), better residual fertility for the consequent crop, better weed control, some beneficial effects on pest and disease levels and enhanced feed quality for livestock. In another review of the potential of intercropping under temperate conditions, Anil et al (1998) acknowledges that although research was lacking in some areas, the use of bi-crops can be of use to both intensive and extensive and organic systems.

3. Analysis and Conclusions

There is a large base of evidence that fermented whole crop forages can be grown and conserved successfully in temperate conditions such as the UK offers. As preservatives are generally eschewed in organic production the crop is generally cut earlier in line with recommendations for fermented whole crop forages. Starch and protein levels will be lower at earlier harvest dates. This results in penalties in yield, greater losses in dry matter during fermentation and can lead to secondary fermentation when the clamp is opened to feed.

Most of the research work reviewed is based on cereal whole-crop, although there is a developing body of knowledge based on intercropping of cereals and legumes as well as crops such as kale. Much of this work is addressed at the needs of the low-input and organic producer where fertiliser inputs and purchased feeds (in particular) proteins to the farm system are minimised. The bulk of this research however, has focused on production and conservation and relatively little on feeding of the forages to livestock. This is especially the case for cereal/legume mixtures which are most interesting to the organic livestock producer. This is surprising as all production of whole crop forages either as sole crops or as mixtures are ultimately as feeds for livestock.

The nutritional quality (especially protein) can be somewhat lacking when grown as a sole cereal crop and the inclusion of a legume has been seen to partially overcome this although due to lower dry matter yields can detract from the objective of preventing forage production penalties where these crops are grown as nurse crops for grass re-seeds. Most workers agree that dry matter intakes are stimulated when offered as a feed to ruminants but few workers have found an increase in animal performance (weight gains, carcase quality or milk yields). There are however definitely opportunities to reduce reliance on purchased concentrates by growing and including, in particular legume-based forage mixtures to organic livestock. This attribute has become more important recently in the UK due to limited sources and costs of organic protein sources to purchase. On farm where re-seeding of pastures is practiced, whole crop forages can provide an excellent nurse crop and alternative feed to grass silage and help to overcome the seasonal production penalty usually associated with grass re-seeds.
The key points arising from the review can be summarised in the following list:

- The production and conservation of fermented whole crop cereals and cereal/legume mixtures is well documented
- Seed rates can vary significantly depending on variety choice
- Whole crop forages and mixtures should be chosen carefully to fit in with the overall farm system objectives (i.e. nurse crop, yields, quality requirements).
- The feed quality of whole crop cereal forages will be better when grown as a mixture with a legume than as a sole crop
- Feeding whole crop forages will not necessarily result in improved production
- Whole crop forages mixtures including legumes can make savings on the use of concentrates without loss of animal performance

Further work is required

- Feeding cereal/legume mixtures to livestock and effect on animal performance
- Identifying the best varieties to use in mixtures for cereal/legume whole crop forage

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