Röbäcksdalen meddelar

Pea and pea-grain mixtures as whole crop protein silage for dairy cows

Tomas Rondahl

SLU Rapport 4:2004

Institutionen för norrländsk jordbruksvetenskap
Department of Agricultural Research for Northern Sweden
Swedish University of Agricultural Science

1 Abstract
In this review the use of pea and pea/grain mixtures as whole crop protein silage for dairy cows is discussed. An introductory discussion concerns the ensilage process and protein degradation and effects of different silage additives. To minimise protein loss, prewilting time should be kept short. An acid additive will reduce respiration and thereby reduce protein degradation. The main part of the review discusses nutritional and botanical changes during development as well as results from both in vitro and in vivo experiments. The crude protein content of pea crops is relatively stable throughout development; therefore the cereal crop frequently determines optimal time of harvest. The choice of crop variety is important. The pea crop should have a not too high content of condensed tannins and high content of protein. Furthermore the pea crop should be of a semi-leafless variety with short and stiff stem. The cereal crop can preferably be stiff stalked oat that develops at a similar rate to the pea variety. Several production trials have shown that whole-crop pea silage is highly palatable for cows and can be consumed in large quantities due to the low NDF content in combination with a high rumen passage. Furthermore, whole-crop pea silage has a good balance between protein and energy, and appears to have a concentrate-saving capacity in feed rations.

2 Svensk sammanfattning
I denna litteraturöversikt diskuteras förutsättningarna för att använda helärt och ärt/grönfoder blandningar som proteinrikare helsädsensilage till mjölkkor. Inledningsvis diskuteras ensileringsprocessen och proteinnedbrytningen under denna samt effekten av olika tillsatsmedel. För att minimera proteinförluster bör eventuell förtorkningstid vara så kort som möjligt. Tillsats av syra minskar respirationen och därmed proteinförluster, dessutom erhålls en effektivare ensilering. Huvuddelen av översikten handlar om näringsmässiga förändringar och förändringar i botanisk sammansättning under grödans mognad, samt de resultat som erhållits i ett flertal försök. Resultat från både laboratorieförsök och produktionsförsök diskuteras. Vad gäller råproteinhalten är ärtor relativt okänsliga för skördetidpunkt, därför är det vanligen spannmålsgrödan i grönfoderblandningen som avgör optimal skördetidpunkt. Sortval är viktigt, ärten bör ha måttlig tanninhalt och hög proteinhalt, samt vara en bladlös, kortvuxen variant med styv stjälk för att minimera fältförluster. Spannmålsgrödan är lämpligen styvstråig havre som mognar i ungefär samma tidsintervall som ärtorna. Flera produktionsförsök visar att ärtensilage har hög smaklighet för mjölkkor och kan konsumeras i stor mängd tack vara låga halter NDF (neutral detergent fiber) i kombination med en hög passagehastighet genom vommen. Ärtensilage har en god protein:energi balans och verkar ha en koncentratsparande kapacitet i foderstater.

3 Introduction

Peas (Pisum sativum L.) are a protein crop which have increasingly been grown in Sweden and other countries in recent years as a replacement for expensive protein supplements, such as imported soya bean, in animal feeds. At the same time, an increased cultivation of peas improves crop rotation, reduces the need for N-fertilization and diminishes the overproduction of cereals. Nitrogen in grass crops for conservation comes predominantly from ammonium nitrate fertilizers, and fertilizer may represent 76% of the variable costs of the growing crop. Perhaps the cost could be reduced and chemical energy saved if a similar yield of dry matter (DM) and protein could be obtained by other means. Peas have N-fixing capabilities, enabling them to produce substantial yields without any requirement for nitrogenous fertilizer (Faulkner, 1985), and making them attractive as break-crops in an arable rotation. Unfortunately, predation by birds and pod opening with consequent seed losses at maturity can reduce the pea yield significantly. If harvested prior to maturity the unripe peas are difficult to recover and dry, and whole-crop peas can be a suitable alternative. Utilization of the whole crop also increases the yield of organic matter (OM) and can raise protein quality, however, protein content and digestibility of feed is reduced. Selection of an optimal harvest date, appropriate harvest and processing techniques and an optimal utilization of nutrients in whole-crop peas will require a better understanding of the botanical and chemical changes which occur during maturation and of the feeding value of the crop at different stages of development (Åman & Graham, 1987).

In Northern Sweden peas mixed with oats or barley and harvested for silage can be grown as a nurse crop for grassland reseeds. Peas produce a more protein-rich forage and require less nitrogenous fertilizer than cereals. There are difficulties, however, in exploiting the benefits of peas to the full. When peas are sown as a major component in a mixture, the crop may lodge severely, becoming very difficult to handle and smothering any undersown grasses. Therefore, peas should be grown with a companion cereal, especially if they are to be a nurse crop, and the choice of variety is especially important (Faulkner, 1985; Salawu *et al.*, 2001a). Furthermore, peas grow poorly in cold wet soils (Faulkner, 1985). One anticipated advantage of feeding bi-crop silages of cereal and legumes is the improvement in the efficiency of nutrient utilization due to a possible synchronous supply of readily fermentable energy and protein in the rumen (Salawu *et al.*, 2002). Cereal/legume bi-crops have been reported to compete well with conventional grass silages because they are comparatively cheaper to produce and have consistently resulted in higher intake of N, digestible protein and digestible DM (Kristensen, 1992; Adesogan *et al.*, 2000; Salawu *et al.*, 2002b). A major problem with whole-crop forages is establishing the best time to harvest to give optimum nutritive value without compromising yield. An appropriate measure of forage quality is the level of potentially digestible nutrients. This measure is however difficult to use with bi-crops because of the lack of information about their potential intake and digestibility. A common practise is to use the agronomic stage of growth as an indicator of quality and harvest schedules. In addition, useful information about the forage quality ca be obtained by combining the stage of growth with chemical composition, especially cell wall concentration and composition (Salawu *et al.*, 2001a).

4 Ensilage process and protein degradation

Until recently, legumes were regarded as being unsuitable for ensiling as the fermentation was invariably dominated by clostridia, leading to butyrate-type silage. This has been attributed to three factors; legumes are highly buffered, tend to have low water soluble carbohydrate content (WSC), and are often of low DM content. Now the disadvantages of legumes in terms of ensiling characteristics have been overcome with pretreatments such as wilting and the use of additives. During ensilage, water-soluble sugars are transformed to lactic acid by Lactic Acid Bacteria (LAB) in an anaerobic environment until approximately pH 4. The faster the process runs the less DM is lost. In order to speed up the process fresh matter (FM) must be chopped and consolidated in the silo. During the silage process the crop harvested undergoes considerable nutritional changes. In particular the protein fraction is transformed into soluble N fractions (McDonald *et al.*, 1991).

The amount of moisture present in the ensiled crop affects the total bacterial count and rate of fermentation. Wilting delays bacterial multiplication in grass silage, while addition of water to herbage initially stimulates the growth of bacteria, especially lactobacilli and Gram-negative organisms. In wet crops with very high soluble carbohydrate levels the LAB are extremely active, and the result will be low pH silage of high lactic acid content (McDonald *et al.*, 1991). If a stable pH has not been achieved in silage, usually because of a deficiency of WSC or the presence of excessive amounts of moisture, a clostridial fermentation is likely to occur. This results in catabolism of lactic acid to butyric acid, and extensive breakdown of amino acids to a range of products including ammonia, carbon dioxide and amines. Wilting the crop prior to ensiling, or the application of chemical additives such as formic acid or formaldehyde, will inhibit clostridial development. The breakdown of proteins, amino acids and other nitrogenous compounds during ensilage is currently recognised as particularly important in the subsequent utilisation of silage by the ruminant (Ohshima &McDonald, 1978).

In silages where clostridia have dominated the fermentation, catabolism of amino acids is likely to be extensive. The major amino metabolites in such silages are α- and γ-amino butyric acids, histamine, tyramine, cadaverine and putrescine. δ-Aminovaleric acid has also been found in large amounts in some clostridial silages. β-Alanine and β-amino isobutyric acid have been found in only trace amounts. As a result of these changes, the ammonia-N will be high, > 20 % total N, and this measurement is a useful indicator of amino acid degradation (Ohshima & McDonald, 1978).

Whole crop cereals and legumes with 300 to 500 g kg^{-1} DM are generally easy to ensile. The requirement for WSC to obtain efficient lactic acid fermentation is inversely proportional to the DM content, therefore WSC content is always high enough. Pure crops of legumes sometimes need to be wilted in order to obtain 300 g kg^{-1} DM, but cereals are always direct harvested (Kristensen, 1992). Fraser *et al.* (2001) suggests that 48 h wilting of peas is enough for effective fermentation. Fraser *et al.* (2001) concludes that pre-wilted pea crop harvested 10, 12 and 14 weeks after drilling fermented satisfactorily. However, pH and ammonia-N concentration indicated that fermentation could be improved by adding an inoculant. Hart *et al.* (2003a) noticed that a greater proportion of the total N in beans was broken down during the ensiling process compared to the peas with averages of 87 g kg^{-1} total N vs. 60 g kg^{-1} total N. They concluded that the higher crude protein (CP) and DM of the whole crop pea forage would seem to indicate that this crop has more potential for inclusion into ruminant diets than whole crop bean forage (Hart *et al.*, 2003a).

Proteolysis during ensilage does not proceed to completion, even when the pH is not inhibiting. It has been stated that the amount of protein hydrolysed during ensiling is dependent largely on two factors, the rate of acidification and the ”proteolytic potential”, i.e. the total protease activity, and the substrate availability and susceptibility.

When herbage is ensiled, either directly or after wilting, proteolysis continues and within 24 hours after start of fermentation, the protein content may fall from about 800 g kg^{-1} total N to less than 600 g kg^{-1} total N. By the end of ensilage this may have decreased to 300 g kg^{-1} total N or less. This change is brought about by plant enzymes, as determined by ensiling microbe-free herbage (McDonald *et al.*, 1991). The activity of plant enzymes declines rapidly after ensiling to a non-measurable level within 2 to 5 days, when vigorous microbial fermentation occurs resulting in changes to the amino acids and other nitrogenous compounds (Ohshima & McDonald, 1978).

The main products of protein breakdown during ensilage are amino acids and ammonia, the proportion of each depending on the extent of further amino acid breakdown. The total amino acid composition of herbage is consistent regardless of species but although proteolysis is uniform the further breakdown is not. In many studies the absence of ammonia has been taken to mean that deamination has not occurred. However, this may not be the case as any ammonia formed could combine with α-oxoglutarate to produce glutamate, or with glutamate or aspartate to form their respective amides, and it would thus not be detected as free ammonia (Ohshima & McDonald, 1978; McDonald *et al.*, 1991). Increases in amide concentration may take place during wilting, but during ensiling the amide concentration generally decreases and is difficult to detect if transient amide formation has occurred. It should be noted that many papers have been published where ammonia production has been referred to as a measure of proteolysis[1] (McDonald *et al.*, 1991). The combined effects of both plant and microbial enzymes result in extensive changes to the nitrogenous fractions during ensilage. In unwilted lactate silages, residual protein-N levels are usually between 300 and 450 g kg^{-1} total N with most of the non-protein N (NPN) present in the form of amino acids (Table 1). The extent of amino acid degradation in these low pH silages depends mainly upon the degree to which clostridial activity has been suppressed, and this appears to be related to the rate of lactic acid production and pH fall. Ammonia-N levels in lactate silages are usually less than 100 g kg^{-1} total N, the ammonia being derived mainly from the deamination of arginine, serine and amides and the reduction of nitrate by the LAB (Ohshima & McDonald, 1978). Adding lactobacillus inoculants to pea/wheat bi-crop forage gives no significant effects on WSC, total N, ammonia N and NDF compared to no additive, formic

Table 1. Nitrogen components of herbages and lactate silages (% total N) (Oshima & McDonald, 1978)

<table>
<tr><th></th><th colspan="2">P. ryegrass</th><th colspan="2">P. ryegrass</th><th colspan="2">Red clover</th></tr>
<tr><th></th><th>Herbage</th><th>Silage</th><th>Herbage</th><th>Silage</th><th>Herbage</th><th>silage</th></tr>
<tr><td>Period (d)</td><td>-</td><td>147</td><td>-</td><td>90</td><td>-</td><td>80</td></tr>
<tr><td>PH</td><td>-</td><td>3.9</td><td>-</td><td>3.95</td><td>-</td><td>4.23</td></tr>
<tr><td>NH_3-N</td><td>0.5</td><td>3.0</td><td>0.5</td><td>10.0</td><td>1.0</td><td>14.4</td></tr>
<tr><td>Amide-N</td><td>5.0</td><td>2.2</td><td>5.3</td><td>2.2</td><td>7.5</td><td>trace</td></tr>
<tr><td>Amino-N</td><td>5.0</td><td>20.6</td><td>3.9</td><td>26.4</td><td>4.3</td><td>25.0</td></tr>
<tr><td>Peptide-N</td><td>1.7</td><td>1.9</td><td rowspan="2">85.7</td><td rowspan="2">43.1</td><td>4.4</td><td>0</td></tr>
<tr><td>Protein-N</td><td>81.8</td><td>40.8</td><td>76.0</td><td>43.9</td></tr>
<tr><td>NO_3-N</td><td>n.d.*</td><td>n.d.</td><td>n.d.</td><td>n.d.</td><td>2.5</td><td>1.0</td></tr>
</table>

*n.d. not determined

[1] This is an incorrect assumption as it is an indication of further amino acid breakdown only. Intensive proteolysis can occur without there being any significant increase in ammonia content (McDonald *et al.*, 1991).

acid additive or tannin additive. Lactic acid and acetic acid are the main fermentation products, and all the treatments gives high concentrations of acetic acid, indicating a heterofermentative pathway (Salawu *et al.*, 2001b).

4.1 Factors affecting proteolysis

4.1.1 Respiration

There is a general agreement that the extent of proteolysis is increased by extending the wilting period, and more importantly by wilting under humid conditions. The main products of protein hydrolysis during wilting are peptides, free amino acids and amides. Wilting under good conditions does not appear to have much effect on the overall decrease in protein after ensilage but may reduce further amino acid metabolism, especially deamination (McDonald *et al.*, 1991). The direct application of formaldehyde, and to a lesser extent formic acid, can be expected to inhibit proteolysis and reduce deamination (Ohshima & McDonald, 1978). It has been shown that application of acids reduces production of nonprotein N due to their inhibitory effect on respiration, Figure 1 (Broderick, 1995).

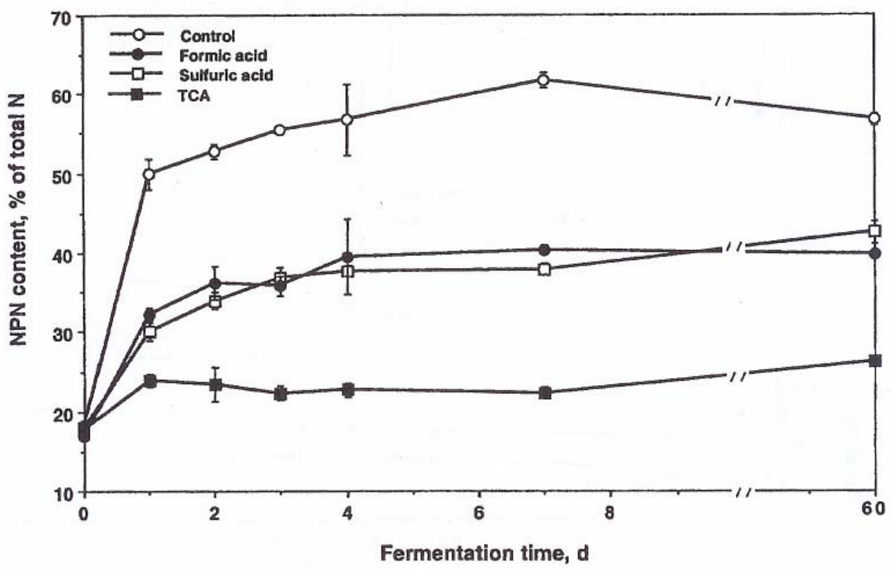

Figure 1. Formation of nonprotein N (NPN) with time after ensiling of untreated alfalfa silage (Control) and alfalfa forage adjusted to pH 4.0 at ensiling using formic acid, sulphuric acid, or trichloroacetic acid (TCA) (Broderick, 1995).

4.1.2 Dry matter

During wilting, since there is little change in pH, any reduction of proteolysis depends on reaching a high enough DM. In fact, lightly wilted material may show increased levels of proteolysis due to the inhibition of acidification (McDonald *et al.*, 1991). In conditions in which a rapid wilt to 250-300 g kg^{-1} DM is possible, this will be beneficial, as it will reduce effluent production without having a significant effect on the nutritive value of the silage. Under good weather conditions the DM increases and the sugars are concentrated in the DM, but under poor weather conditions the DM content may increase very little, if at all, and if the wilting period is extended over several days soluble carbohydrates will be lost, protein-N contents may be reduced and deamination of amino acids may increase. If this occurs the silage is likely to have a high ammonia-N content even with the application of an effective additive. It is generally accepted that well-preserved silage should have an ammonia-N content less than 80 g kg^{-1} total N (Henderson, 1993).

The wilting of crops prior to ensiling does not appear to inhibit plant protease activity, even though clostridial activity will be inhibited and some reduction in growth of the LAB can be expected. As a result, ammonia-N levels will be rather lower than in unwilted lactate silages (Ohshima & McDonald, 1978).

4.1.3 Temperature

Since plant proteases have high temperature optima, a rise in temperature in the silo will tend to increase their activity. The degree of heating is controlled by respiration, therefore it is important that the herbage should be well compacted and the silo filled rapidly and well sealed to prevent entry of air (McDonald *et al.*, 1991).

4.1.4 pH

It is well known that the rate of fall of pH is important in determining the extent of proteolysis, and during a slow decrease in pH more protein will be broken down. This was the theory behind the early AIV-process (adding mineral acids diluted with water) by Virtanen: immediately reach a pH to about 3.6 and thereby prevent proteolysis during ensiling, i.e. the breakdown of protein to NPN (soluble-N) compounds. However, many studies have shown that even direct acidification to a pH below 4 will reduce but not prevent proteolysis. Optimum pH for plant leaf proteases is 5.0 to 6.0, but many proteases are active at pH 3.6 (McDonald *et al.*, 1991). The rate of protein loss and the rate of fall of pH in the attainment of pH 4.3 during ensilage prevent further proteolysis (Ohshima & McDonald, 1978). The rate of pH decrease is more important than the finally achieved pH, given that the final pH is below 4 (Table 2) (McDonald *et al.*, 1991).

Table 2. Effect of formic acid on protein-N and ammonia-N contents of ryegrass-clover ensiled for 50 days (McDonald *et al.*, 1991).

	pH		Total-N	Protein-N	Ammmonia-N
	Initial	After 50 days	(g kg^{-1} DM)	(g kg^{-1} TN*)	(g kg^{-1} TN*)
Original grass	5.85	-	19.3	819	-
Silages					
Control	5.85	3.87	18.2	265	95
Formic acid (g kg^{-1})					
0.4	5.40	3.77	17.8	285	79
1.0	4.90	3.67	18.5	325	59
2.0	4.45	3.81	19.3	358	46
4.1	4.05	3.88	19.2	401	12
7.7	3.50	3.80	18.6	462	12

* TN = total N

5 Silage additives

The first essential objective in preserving crops by natural fermentation is the achievement of anaerobic conditions. The second main objective is to discourage the activities of undesirable microorganisms such as clostridia and enterobacteria (McDonald *et al.*, 1991).

Silage additives can be classified into five main categories according to Table 3.

Table 3. Classification of silage additives (McDonald *et al.*, 1991)

Fermentation stimulants		Fermentation inhibitors		Aerobic deterioration inhibitors	Nutrients	Absorbents
Bacterial cultures	Carbohydrate sources [Ψ]	Acids	Others			
Lactic acid bacteria	Glucose Sucrose Molasses Cereals Whey Beet pulp Citrus pulp Potatoes Cell wall degrading enzymes	Mineral acids Formic acid Acetic acid Lactic acid Benzoic acid Acrylic acid Glycolic acid Sulphamic acid Citric acid Sorbic acid	Formaldehyde Paraformaldehyde Glutaraldehyde Sodium nitrite Sulphur dioxide Sodium metabisulphite Ammonium bisulphate Sodium chloride Antibiotics Carbon dioxide Carbon bisulphide Hexametylenetetramine Bronopol Sodium hydroxide	Lactic acid bacteria Propionic acid Caprioic acid Pimaricin Ammonia	Urea Ammonia Biuret Minerals	Barley Straw Sugar beet pulp Polymers bentonite

[Ψ] Most substances listed under carbohydrate sources can also be listed under nutrients.

Fermentation stimulants and inhibitors are concerned with fermentation control and act either by encouraging a lactic acid fermentation (stimulants) or by inhibiting partially, or completely, microbial growth (inhibitors). Aerobic deterioration inhibitors are aimed primarily at controlling the deterioration of silage on exposure to air. The fourth category nutrients is added to crops at the time of ensiling in order to improve the nutritional value of the silage, and the fifth group absorbents is added to low DM crops to reduce loss of nutrients and pollution of watercourses by effluent.

Silage additives have been reviewed frequently (McDonald *et al.*, 1991, Henderson 1993, Bolsen *et al.*, 1995 and Bolsen *et al.*, 1996). A different grouping of silage additives has been suggested by Henderson (1993), as described in the following text.

5.1 Carbohydrate sources

Carbohydrate-rich materials such as sugar, molasses, whey, citrus pulp and potatoes are added to silage crops to increase the supply of substrate[2] for the LAB. Molasses is the most frequently used carbohydrate source. If the objective is to achieve maximum effect it should be used in crops low in soluble carbohydrates (i.e. legumes) and it must be used in relatively high concentrations (about 40-50 g kg^{-1}). If the treated crop has a very low DM content, a considerable proportion of the added carbohydrate may be lost in the effluent during the first few days of ensilage (Henderson, 1993).

5.2 Acid-based additives

By lowering the pH of the herbage, acids inhibit the activities of the respiratory and proteolytic enzymes. Whether acid additives act as stimulants or inhibitors of LAB depends upon the concentration of the active ingredient or ingredients in the commercial product and upon the rate at which the product is applied to the crop. Acid salts are less effective than the

[2] Wilting is an alternative to substrate silage additives. Especially WSC carbohydrates will increase in concentration when amount of water is reduced.

equivalent acid and therefore they must be applied at higher rate to obtain a similar effect (Henderson, 1993).

5.2.1 Mineral acids

Mineral acids lower the pH of the herbage, which inhibits the activity of undesirable bacteria such as enterobacteria and clostridia, and stimulates LAB to grow on the available substrate and lower the pH further. In crops in which substrate is in short supply this can be beneficial. Sulphuric acid is cheaper than organic acids, but may have negative effects on animal health (Henderson, 1993). According to Woolford (1978) mineral acids as hydrochloric, orthophosphoric and sulphuric acid appears to act by acidification only during ensilage.

5.2.2 Organic acids and acid salts

Organic acids, in particular formic acid, have an antibacterial action trough a hydrogen ion concentration effect and a selective bactericidal action of the undissociated acid. Woolford (1975) concluded that organic acids as formic, acetic and propionic acid seem to have the dual function of acidification and discrimination against spore-bearing bacteria. However, yeasts are particularly tolerant of formic acid, and high counts have been noted in silages treated with this additive applied at the recommended rate. Under anaerobic conditions yeasts obtain energy from the fermentation of sugars with the production of ethanol and loss of DM. In situations where treatment with formic acid has improved silage fermentation (intermediate application may inhibit LAB), positive effects on digestibility and intake of silage have been obtained, reflected in enhanced animal performance. However, acid additives can increase effluent production on young grass by up to a third depending on the level applied. When formic acid is applied at high level (5 l t^{-1} FM or more) much of the WSC is retained in the silage, and the acid content and buffering capacity are much lower than those of untreated silage from the same sward. Use of organic acids is connected with risks. Corrosive action against machinery and healthy risks towards man has resulted in focused attention on alternatives such as acid salts (Henderson, 1993).

5.3 Biological additives

Biological additives are safe to handle. They either provide additional substrate for the indigenous population of microorganisms or increase the population of homofermentative LAB. In some products, the LAB is added with substrate or with enzymes to provide additional substrate (Henderson, 1993).

5.3.1 Bacterial inoculants

The ideal inoculum should grow fast (>10^6 CFU g^{-1} FM), be active in a wide pH range and ensure a fast pH-drop to at least 4.0, due to lactic acid production. Most inoculants are homofermentative to fulfil the later criteria. Many inoculant preparations include at least two stems of LAB to be reliable in this aspect; they may also include a supply of carbohydrate material, which would serve as an immediate substrate for the added microorganisms. An alternative is a combination of LAB and enzymes that produce additional fermentable sugars from cell walls or cell contents (McDonald *et al.*, 1991). Furthermore, freshly cultured LAB is as effective as formic acid treatment with 3 l ton^{-1} FM in reducing ammonia-N content in wet white-clover-rich silage (Cussen *et al.*, 1995).

In silages made from young and moist peas, the pH was not reduced significantly from inoculum treatment; only combination, inoculum and enzymes were effective in this respect. In pea silage (PS) harvested at the early podding stage pH were reduced significantly compared to no treatment (control). In peas harvested at full podding instead, there was no effect on pH reduction (Weinberg *et al.*, 1993).

5.3.2 Cell wall degrading enzymes

The use of cellulolytic and hemicellulolytic enzymes as silage additives has been considered from two points of view; first, to increase the content of WSC as substrate for the LAB, and, second, as a method of improving the digestibility of the OM of the crop (McDonald, *et al.*, 1991). Enzyme preparations, like plant cell wall degrading enzymes, are most active in immature, low-DM silages and less active in wilted and mature silages. When poorly fermentable grass is ensiled, the application of enzymes does not prevent butyric acid fermentation. Enzymes applied at commercial dosages do not appear to liberate sufficient additional sugar during the onset of silage fermentation. Many commercial inoculants contain some cell wall degrading enzymes but, as optimum pH of enzymes is 4-5, it is unlikely that they produce sugar at a sufficiently early stage to be effective or that they are present in sufficient quantities to be effective at a later stage of fermentation (Henderson, 1993).

5.4 Aerobic deterioration inhibitors

As yeasts play an important role in the aerobic deterioration of grass silages, potential deterioration inhibitors must act against yeasts (Woolford, 1990). Yeasts increase in number during wilting and when oxygen infiltrates the silage during the storage period.

5.4.1 Acids

Propionic acid inhibits most but not all of the organisms responsible for silage deterioration, but only when applied to crops in relatively high concentrations. Similarly high levels of formic acid may delay the onset of deterioration (Henderson, 1993). Woolford (1975) claims that propionic acid is the most effective antimycotic agent of the short chain fatty acids. Added to crops in where pH will be reduced to 4, propionic acid will not only restrict growth of yeasts and moulds but also that of LAB, and thereby produce silage with little fermentation (Woolford, 1975).

5.4.2 Bacterial inoculants

Some indications exist that inoculum of LAB can restrict the development of yeasts and make the silage more stable than untreated crop. Generally the opinion is that stability have been reduced by inoculants; if stability shall be retained yeasts must be kept under the threshold of 10^5 g^{-1} silage under a minimum of air inlet (Henderson, 1993). Filya et al (2000) demonstrates that inoculants can have different effects on aerobic stability in whole crop wheat silage. Furthermore, some inoculants primarily protect silage during aerobic exposure (Filya *et al.*, 2000; Weinberg *et al.*, 2002).

5.4.3 Bacterial inoculants-chemicals

Salts in combination with LAB inoculants develop an antimicrobial effect with increasing acidity in the silage. These silages contain less lactic acid, fewer clostridial spores and are more stable than corresponding untreated silages (Henderson, 1993).

5.4.4 Nutrients

These include molasses, cereals and whey, which also act as fermentation stimulants.

5.4.5 Absorbents

Where there is a risk of pollution, additives, such as enzymes or formic acid, which increase effluent flow or alter the pattern of effluent flow, should be avoided, and the use of absorbents should be considered. Of the absorbents tested, fibrous by-products such as sugar beet pulp or distillers dried grain appear most promising (Henderson, 1993).

5.5 Feed out and storage stability

Weinberg *et al.* (1995) investigated the effect of cellulase and hemicellulase plus pectinase on the aerobic stability and fibre analysis of peas and wheat silages. All treatments were enriched with LAB inoculum (10^4 CFU g^{-1}). The NDF and ADF contents decreased with increasing enzyme level, more so in the PS than in the wheat. The component that was most strongly affected by the enzymes was cellulose (ADF-ADL), which decreased by about 15% in both silages. However, enzyme treatments resulted in enhanced aerobic deterioration in both pea and wheat silages (Weinberg *et al.*, 1995). Further on Weinberg *et al.* (1993) noticed that inoculated wheat silage was very unstable upon aerobic exposure. They concluded that inoculated silage lost more DM compared to other treatments (control, enzymes, inoculum + enzymes). The enzyme treatment alone had no apparent effect on pH during the initial stages of ensiling. In pea and wheat silage made at flowering stage, the combination of inoculum and enzymes resulted in lower pH throughout the ensiling period, as compared with the inoculum treatment only (Weinberg *et al.*, 1993). Inoculants have also been shown to protect wilted wheat silage from yeast and moulds upon aerobic exposure, but this was not observed for fresh wheat silage (Filya *et al.*, 2000). Formic acid treatment gives the most aerobically stable silage compared to control and tannin-treated silage. However, the control and tannin-treated silages did not heat up by more than 1˚C during the first six days of exposure to air (Salawu *et al.*, 2001b).

6 Nutritional and botanical changes during development in pea (cereal) intercrops

6.1 **Peas**

Peas generally have high feeding values, PS being about 11.5 MJ ME kg^{-1} DM. The digestible organic matter (DOM) measured in sheep is about 800 g kg^{-1} OM for PS. Peas generally have a very low fibre content, high digestibility and feeding value (Kristensen, 1992). Peas have higher CP and DOM digestibility but lower NDF and ADF than wheat (Salawu *et al.*, 2001a). Potts (1980) recorded low DM contents for forage peas, and suggested wilting plus an effective additive for satisfactory ensilage.

The choice of harvesting method affects yields when harvesting pea crops, and should be carefully considered. Fraser *et al.* (2001) comments that yields from large round-bales were lower than those achieved with a Haldrup harvester. They presumed this was a reflection of greater field losses. The crimper mower was anticipated to cause less damage than a conventional conditioner mower, but the process of cutting together with the passage through the rollers of the baler led to loss of leaves and pods. This is a significant problem since these plant parts have the highest nutritional value, and their loss decreases the protein and starch concentrations of the resultant silage. Whole crop legumes harvested as silage generally give high yields at harvest. Kristensen (1992) reported hectare DM yields from experiments of 7 to 10 tonnes for peas.

Levels of CP remain relatively uniform in peas after an initial increase. Cell wall constituents and ADF values vary with dates of sampling but lignin remains relatively constant at 5% (Brundage & Klebesadel, 1969). Faulkner (1985) pointed out that the CP contents of pea and bean forages are similar, and both are much higher than that of whole-crop oats. In pea plants the pods and seeds decreases in protein and sugar concentration with advancing maturity but gains starch, cellulose and hemicellulose. Leaves and stems loose protein, sugars and starch and gained cellulose, hemicellulose and lignin. The leaves made the dominant contribution to the total plant dry weight at the first harvest (early pod-filling) and the pods with seeds at the final harvest (most pods ripe) (Trevino *et al.*, 1987). Pea filling is a rapid exponential phase (Åman & Graham, 1987). During this process dramatic changes occur in the botanical composition of the whole crop and nutrients, especially carbohydrates and protein, are translocated from the vegetative parts of the plant to the peas. Fully developed peas constitute around half the whole crop. However, the gross chemical composition of the whole crop remains remarkably constant, with exception of the transformation of soluble sugars to starch and the increased content of cell walls (Åman & Graham, 1987). The use of coloured flowered or variegated peas, containing tannin, may lead to increase in rumen escape protein. Degradation of pea protein in the rumen may depend on variety of pea. Results from *in sacco* degradation on ruminally-cannulated wethers suggest lower degradation of DM and protein in the rumen of the coloured flowered variety of pea (Hart *et al.* 2003c). This may be a caused due to the presence of condensed tannin (Hart *et al.*, 2003c; Min *et al.*, 2003). It has been shown that an increased tannin content decreases the proportion of soluble nonprotein N, Figure 2 (Broderick, 1995).

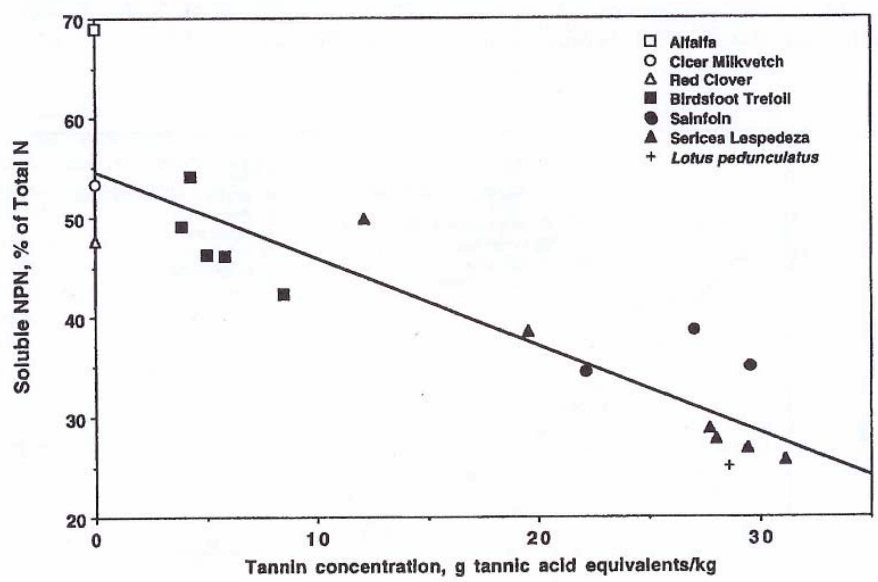

Figure 2. Regression of soluble nonprotein N (NPN), as a proportion of total N (Y), on condensed tanning concentration (X) 45 d after ensiling samples of seven legume forage species. Y = 54.8 – 0.875; $r^2 = 0.799$, $P < 0.01$ (Broderick, 1995).

6.2 Cereals

Whole crop cereals harvested as silage generally give high yields at harvest. Kristensen (1992) reports hectare DM yields from experiments of 8 to 12 tonnes for spring barley and 9 to 17 tonnes for winter wheat. Levels of CP decline continuously in oats but cell wall constituents and ADF values vary with dates of sampling and are consistently higher in oats than in peas. Lignin increases to 50 g kg^{-1} DM in oats by early milk stage of maturity (Brundage & Klebesadel, 1969). Barley separated from mixture plots, intercropped with peas, has a higher protein content than barley grown in pure stand at the same N rates (Lunnan, 1989). Khorasani *et al.* (1997) harvested cereal grain from barley, triticale, barley/triticale and oat as silages. Generally CP and nitrate concentrations of all crops decreased with increased maturity. Further on, NDF, ADF, and cellulose concentrations of all crops initially increased and then decreased with advancing maturity whereas acid detergent lignin (ADL) concentrations increased with advancing maturity. During growth phase, oats and triticale had higher NDF and ADF concentrations, but by harvesting these differences had disappeared. Leaf DM as percentage of total DM and leaf: stem ratios were higher and the stem DM as percentage of total DM was lower for the barley/winter triticale mixture compared with the cereal monocrops. Cereal forages were ranked in order of decreasing quality as barley, barley/winter triticale, triticale, and oats (Khorasani *et al.*, 1997).

6.3 Bi-crops

Investigations have shown that adding pea to wheat, oat or barley improves forage quality, i.e. not only increases forage CP concentration but also decreases NDF and ADF (Brundage & Klebesadel, 1969; Chapko *et al.,* 1991; Salawu *et al.*, 2001a). It has been shown that pea-wheat bi-crop silages can replace moderate-quality grass silage in dairy cow rations, but their role as alternatives to high-quality forages requires additional investigation (Salawu *et al.*, 2002a). Furthermore, pea-wheat bi-crops give high yields and provide good quality forage for ruminants. The optimum forage quality for such bi-crop is obtained when the wheat is at early to soft dough stage and the peas at yellow wrinkle stage (Salawu *et al.*, 2001a). Inclusion of oats in seeds mixture reduces lodging but also decreases OMD and CP concentration compared to peas alone. However the “stubble” left by the cereal component probably reduces risk of soil contamination if swathing and wilting is practised (Potts, 1982). Pea-oat forage mixtures are probably more palatable and more readily consumed by livestock than pea-barley mixtures because the awn fragments of barley may irritate the mouths of livestock. Pea-oat mixtures have significantly lower NDF- and higher CP-content than pea-barley mixtures, although the latter generally produces more forage (Chapko *et al.,* 1991). Pea rich mixtures increase the protein content of DM by about 50 g kg^{-1} compared with barley. The amount of biologically fixed N is highest in monoculture peas, but appreciable quantities are fixed in the mixtures even at N rates of 80 kg ha^{-1} (Lunnan, 1989).

Less forage is produced by intercrops when the cereal component is sown at half the sole-crop rate. In contrast, forage yield is not affected by the pea-seeding rate, whilst CP concentration increases with increasing seeding rate of peas in three out of four years. Forage N yield is unaffected by intercropping. This indicates that the cereal component of a pea-cereal intercrop contributes more to forage yield than the pea component. By increasing the relative proportion of pea seed to cereal kernels sown in a mixture, forage CP concentration can be increased without affecting forage N yield. Therefore, the cereal component in pea-barley and pea-oat mixtures should be sown at a sole-crop or greater seeding rate for maximum forage production (Carr *et al.*, 1998). In contrast, Potts (1982) states that inclusion of oats in seeds mixture has no marked effect on DM yield. Furthermore, the mean CP concentration in the total herbage, 169 g kg^{-1}, was at the lower end of the range, 140-240 g kg^{-1}, observed in previous years for peas alone (Potts, 1982). Similarly, Faulkner (1985) found that inclusion of a cereal raised forage DM contents but lowered CP content. Mixtures with peas and barley will give intermediate values on yields and feeding compared to those of pure barley and pea crops. Increasing the proportion of peas above 400 g kg^{-1} of the total forage DM, the CP content is increased but overall forage quality is only marginally increased (Salawu *et al.*, 2001a). In most years, sowing rates of between 120 and 160 kg ha^{-1} for barley and a maximum of 60 kg ha^{-1} for peas provides the best compromise between attaining good arable silage yields and avoiding excessive dangers of damage of undersown grass re-seeds (Gilliland & Johnston, 1992).

Cultivar selection can influence forage yield of cereal-pea intercrops (Carr *et al.*, 1998). Barley germinates and develops leaf area faster than peas. The forage pea ‘Timo’ competes better with the barley than the white-flowered cultivars 'Bodil' and 'Tammi', but lodges heavily late in the growth period (Lunnan, 1989). Faba beans mixed with cereals yielded less than beans alone, but peas with cereals yielded slightly more than peas alone (Faulkner, 1985). When intercropping with barley, sowing in separate rows can increase competitiveness for some pea varieties and be important for the content of composite yields (Lunnan, 1989). Salawu *et al.* (2001a) point out that the choice of wheat variety must match the pea variety in order to support the peas from lodging. In other words long-straw pea varieties with dense foliage must be avoided.

6.4 Time of harvest

With grasses and leguminous forages like clover, lucerne and lotus, quality forage can be obtained by management strategies that are directed towards cutting when leaf to stem ratio is high. Thus, grasses are harvested at boot stage and legumes at the beginning of flowering. A decrease in the leaf to stem ratio and a decline in the nutritive value of the stem component has been shown to be responsible for the decline in forage quality with age. When whole-crop cereals (i.e. wheat, barley, oats or maize) and pulses (i.e. peas or beans) or the bi-crops are to be used as forage, the management strategies differ. This is because, in addition to selection for leaf to stem ratio with cereals, the grain and pod yields of pulses are important (Salawu *et al.*, 2001a).

The choice of time of harvest affects the methods available for harvesting. In general, peas must be handled with some care; mechanical manipulation increases the risk of not only soil contamination but also field losses. In whole crop pea forage, fully developed peas constitute around half the DM content, Figure 3 (Åman & Graham, 1987). If the peas are harvested at

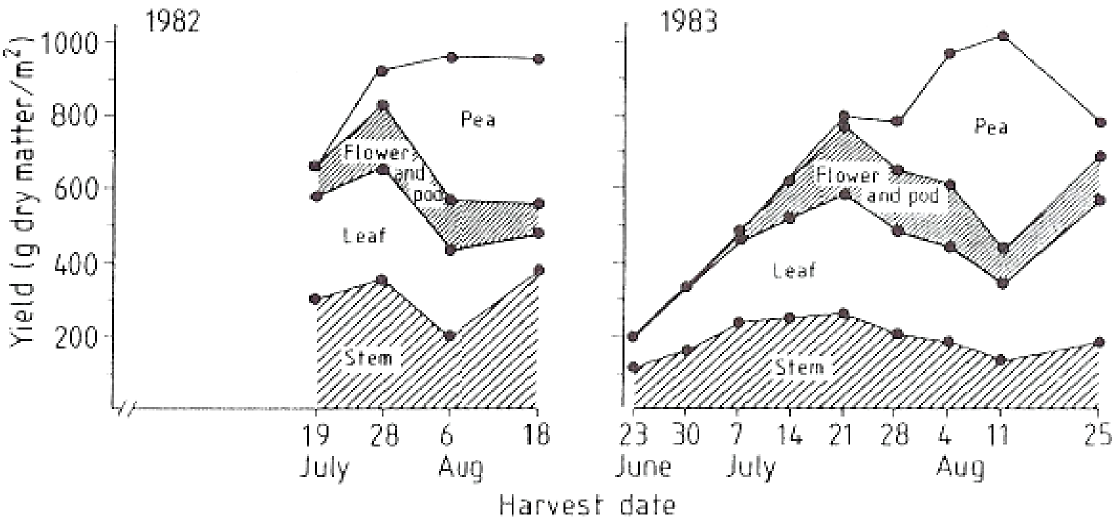

Figure 3. Growth curves of botanical fractions of whole-crop peas harvested during 1982 and 1983 (Åman & Graham, 1987).

maturity stage flat pods or later, a disc mower with conditioner is less suitable but often used (Rodhe & Thylén, 1991). It is not advisable to use rotating discs, since there is an increased risk for shattering peas and increasing field losses. Furthermore, lodged crops should be cut against the lodging direction at low rpm speeds to decrease field losses (Kindesjö, 1984; Rodhe & Thylén, 1991).

Potts (1980) suggests that the peak yield of forage peas is obtained 100 d after sowing, when the lower pods have formed, but have not yet begun to swell. This growth stage corresponds to 12 weeks after sowing in studies by Fraser *et al.* (2001), where FM yields for forage peas at 10 and 12 weeks after sowing are significantly higher than FM yield 14 weeks after sowing. However, the later harvest had a higher DM content, and DM yields were similar for each harvest occasion. The lower FM yields for the later harvest was caused by lodging of the crop. Intercropping peas with a cereal can decrease this, as is discussed in other parts of this review. Furthermore, since the quality of peas remains stable with maturity, it is possible to use the stage of maturity of wheat only as the index of the ideal time to harvest pea-wheat bi-crop for conservation as forage for ruminants. However, this applies only in e.g. absence of lodging, infections or senescence in peas (Salawu *et al.*, 2001a). Considering yield, Lomakka (1993) suggests that in unfavourable years both pure barley and pea/barley mixtures should be harvested 7 weeks after inflorescence (barley), and in years with favourable weather conditions, 8-9 weeks after inflorescence. At these times yield ha^{-1} of both ME and CP are highest (Lomakka, 1993). In years with worse weather conditions, the increase in ME in grain cannot compensate for the simultaneous decrease of ME in the straw wherefore barley containing whole crop must be harvested at an earlier time point after inflorescence (Lomakka, 1993).

Dry matter yields of pea-wheat bi-crops generally increase with maturity and the average bi-crop DM yields. For both peas and wheat, the DM, CP, starch, NDF and DOM digestibility (DOMD) at harvest were higher in the second cut (15 weeks after planting) than in the first cut (13 weeks after planting). The DM yield, CP, starch, WSC, NDF, ADF content of the bi-crops and their DOMD yields were all influenced by the stage of maturity and the proportion of peas to wheat in the bi-crops. The optimal harvesting stage of pea-wheat bi-crops appears to be when wheat is at early to soft dough stage and peas at yellow wrinkle pod stage (Salawu *et al.*, 2001a). Similarly, Salawu *et al.* (2002a) consider that the higher digestibility, positive N balance and better aerobic stability at 14 weeks post drilling are good indicators of the optimal stage for harvesting pea-wheat bi-crops. Bi-crop silages have less acidic pH-values, higher concentrations of starch, CP and ammonia, and lower concentrations of NDF compared with grass silage (Salawu *et al.*, 2002a). There were similar, moderate, concentrations of fermentation acids in all silages, though the pea-wheat bi-crop silages had lower concentrations of lactic acid and higher concentrations of acetic and propionic acids (Salawu *et al.,* 2002b). As regards CP concentration, there are reports of marked decline by the time the crops are harvested, and CP concentration of oat/pea forage was reduced from 200 g kg^{-1} on June 22 to 130 g kg^{-1} on July 6 (Jaster *et al.*, 1985). Furthermore, protein solubility decreases at later developing stages, Figure 4 (Åhman & Graham, 1987).

6.5 Nutritional value of pea silage

The feeding value of whole-crop cereals may vary between 9.4 and 10.7 MJ ME kg^{-1} DM, while that of field beans is about 10.5 MJ ME and that of peas about 11.5 MJ ME kg^{-1} DM (Kristensen, 1992). Salawu *et al.* (2002a) consider that the intake and digestibility of pea-bi crop (pea/wheat) silages is moderate when the proportion of peas in the sward is less than 200 g kg^{-1}. They also concluded that DOM intake was not affected by maturity stage.

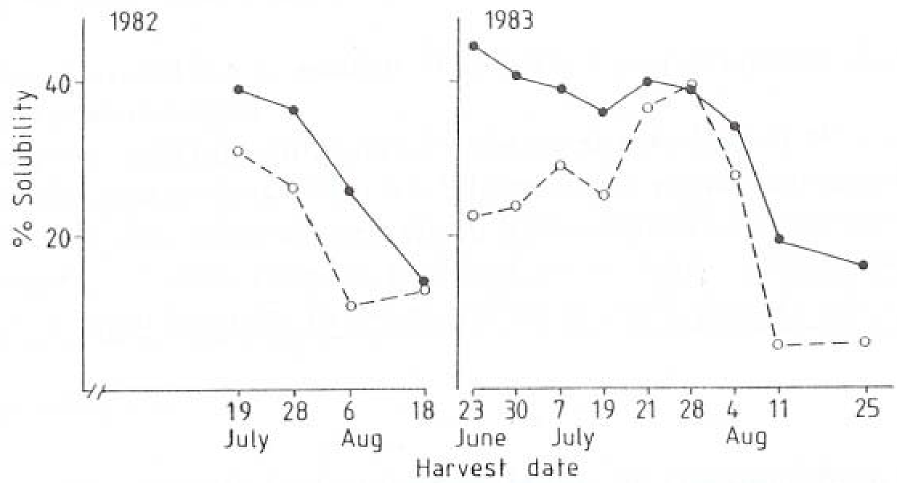

Figure 4. Solubility in 80% ethanol and chloroform of DM (•) and CP (o) in whole-crop peas at different harvest dates during 1982 and 1983 (Åman & Graham, 1987).

7 *In vivo* results

7.1 Forage intake

The voluntary intakes of legumes have long been recognized to be higher than that of grasses of equal digestibility (Thornton & Minson, 1973). Heifers consuming pea silage has greater DM intake and DM digestibility than those consuming other silages such as oatlage, barley/pea, and oat/pea. Lignin is more constantly associated with DM digestibility while other components, particularly NDF, ADF, and CP, are related to DM intake (Jaster *et al.*, 1985). Dairy cows have a higher consumption of whole-crop pea (WCP) silage than of bi-crop silages (pea/wheat). The higher intake of WCP silage compared to bi-crop silages is probably due to its faster rate of degradation and higher CP content, ruminal degradability and total tract digestibility (Salawu *et al*, 2002a). Forage intakes were higher when bi-crops were fed (10.3 to 11.4 kg DM d^{-1}) than when grass silage (GS) was fed (8.6 kg DM d^{-1}). Total DM intake was similar among cows fed bi-crop silages together with low concentrate (6 kg) diet and GS with high concentrate (9 kg) diets, but intakes for GS with low concentrate were at least 1.7 kg DM/d lower (Salawu *et al.*, 2002a). Feeding intercrop silages to dairy cows instead of GS with the same amount of concentrates increased forage intakes (Adesogan *et al.*, 2004).

Salawu *et al.* (2001b) compared feeding value of pea and field bean silages when fed to lambs. Voluntary DM intakes were similar on all treatments, despite the apparent digestibility of the forage PS being significantly higher than that of the field bean silages. According to Hart *et al.* (2003b), lambs fed forage mixtures tended to perform better on diets containing pea forages when comparing PS and GS or a sole GS diet, both supplemented with the same concentrate.

7.2 Milk yield and composition

When fed to dairy cows in early lactation, PS can be used to replace barley silage without affecting milk yield or composition. Pea silage can also replace alfalfa silage (AS) with no effect on short-term milk yield (Mustafa *et al.*, 2000). In a study by Salawu *et al.*, (2002a) no large differences were found between the bi-crop silages in their effects on feed intake, milk production and composition, and blood metabolite concentrations. This supports the assumption that bi-crop silages have a wide harvest window as well as a wide range of pea-to-wheat ratio over which the nutritive value remains similar (Salawu *et al.*, 2002a). Moreover, feed intake, milk production and live weight change were higher with pure legume silages than with barley or a mixture of barley and field beans. The highest production was obtained with peas. The differences observed in feed intake and milk production were in accordance with differences in the energy intakes of the cows (Kristensen, 1992). Salawu *et al.* (2002a) found that milk yield tended to be similar for cows fed a cut 2 bi-crop and GS high concentrate diets, and these values were at least 1.7 kg higher than those for cows fed on other treatments. Generally, the bi-crop diets resulted in higher milk fat contents and lower polyunsaturated fatty acid contents. Milk protein content was highest for cows fed the high concentrate diet (Salawu *et al.*, 2002a). Mustafa *et al.* (2000) reports that dairy cows fed AS diet had lower ($p< 0.05$) milk urea N than cows fed the barley silage (BS) diet. However, feeding PS did not affect milk urea N relative to feeding AS or BS. Blood urea N was lowest for cows fed AS diet, intermediate for cows fed the PS diet, and highest for cows fed the BS diet ($P < 0.05$). This even though cows fed the BS consumed less CP than cows fed the PS and AS diets. Other researchers have reported that milk urea N is related more to the ratio between CP intake and energy intake than to the absolute CP intake (Hof *et al.*, 1997; Jonker *et al.*, 1999). Hof *et al.* (1997) suggested that a surplus of protein digested in the small intestine relative to energy available for milk protein synthesis is a major factor responsible for high milk and blood urea N levels in dairy cows. Milk composition was similar for cows fed PS or BS; cows fed PS produced milk with a higher fat and a lower protein percentage than those fed the AS (Mustafa *et al.*, 2000). Pea bi-crop diets resulted in higher milk fat contents and lower polyunsaturated fatty acid contents. Cows fed high concentrate diet and GS gave more milk and higher milk protein concentrations than all the bi-crop silages except the high pea (second cut) bi-crop diet (Salawu *et al.*, 2002a). Adesogan *et al.* (2004) concluded that similar milk yield and milk composition can be obtained by feeding pea/wheat bi-crop (Pea variety: Setchey) and 4 kg of concentrates, when compared with that obtained with GS and 8 kg of concentrates.

7.3 Rumen degradability

Mustafa *et al.* (2000) concluded that PS was more degradable in the rumen than BS. This was mainly due to higher ruminal degradability of CP and NDF of PS relative to those of BS. The main difference in ruminal degradability between PS and AS was in NDF degradability, which was higher in AS than PS. However, the difference in NDF degradability between PS and AS was not reflected in ruminal degradability of DM, which was similar for the two silages (Mustafa *et al.*, 2000). The effective rumen degradability of DM and the N loss after 48 h were higher for cut 1 silages than for cut 2 and cut 3 silages. However, the starch loss after 48 h increased ($P<0.05$) with maturity (Salawu *et al.*, 2002b). The addition of *Lactobacillus* inoculants to pea/wheat bi-crop silage increases the rate of N and NDF degradation in the rumen, whilst formic acid and tannin additives reduces both the effective and potential degradation of N (Salawu *et al.*, 2001b). The choice of cereal combined with pea may be of great interest for the nutritive value of the bi-crop but this is not easy to prove. According to Khorasani *et al.* (1993), dairy cow consumption of a TMR diet is lower when oat and triticale is included as compared to barley, but overall milk production was not significantly affected by consumption. Digestibilities of DM, OM, CP and ADF were highest for AS, intermediate for barley, and lowest for diets based on oat and triticale. Even though oat and triticale silage had higher dietary NDF content compared to barley this consumption-limiting factor did not have any significant impact on cow performance when silage were fed ad libitum. These cereals harvested at an early stage of maturity can therefore be favourably used in dairy cow rations (Khorasani *et al.*, 1993).

7.4 Protein stability and N retention

Feeding intercrop silages to dairy cows instead of GS with the same amount of concentrates increased N-retention, and microbial protein synthesis (Adesogan *et al.*, 2004). Nitrogen retention was higher for lambs offered forage PS. Application of an inoculant was found to have negative effect on the amount of N retained, indicating the necessity for more detailed investigations in proteolytic activity within these crops during the fermentation process (Salawu *et al.*, 2001b). This effect of was also observed by Fraser *et al.* (2001), who found that adding inoculant decreased N retention by lambs' offered pea and field bean silage. The protein value of GSs fed to sheep was determined in a study by Verbič *et al.* (1999), who concluded that hay has better protein value than silage, and wilted silage is better than unwilted silages ensiled without an additive. However, the protein value of unwilted silage is increased by adding 85 g kg^{-1} formic acid diluted 1:1 in water at a rate of 5 kg t^{-1} FM prior to ensiling (Verbič *et al.*, 1999). According to Broderick (1995), pea varieties that contain condensed tannins decreases degradation rate, Figure 5, and could therefore improve protein utilisation in legumes.

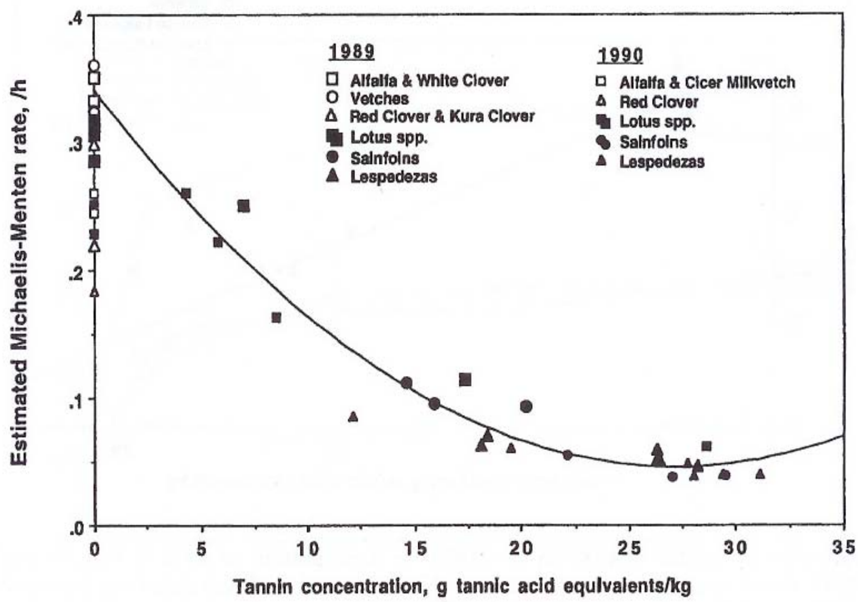

Figure 5. Quadratic regression of estimated Michaelis-Menten degradation rates (Y) on condensed tannin concentrations (X). Michaelis-Menten rates estimated for accessions from 11 species of legumes from 2 years (1989 and 1990). $Y = 0.340 – 0.021 X^2$; $r^2 = 0.924$; $P < 0.01$. Estimated Michaelis-Menten rate was minimal (0.048/h) at 27 g of tannic acid equivalents/kg DM (Broderick, 1995).

8 Discussion

The general conclusion in this review concerns the combination of different factors contributing to the final quality and digestibility of silage. It appears that the choice of variety of both peas and cereals is of central importance, as well as the proportions of these in the seeding rate (Lunnan, 1989; Chapko *et al.*, 1991; Carr *et al.*, 1998; Salawu *et al.*, 2001a). Field peas may be classified into white-flowered leafless or semi-leafless and variegated with dense foliage. The latter contains higher levels of condensed tannins that can be advantageous when feeding ruminants because of their reducing effect on protein degradation in the rumen (Hart *et al.*, 2003 c; Min *et al.*, 2003). Another important characteristic of pea plants is their tendency to lodge in later developing stages, since this influence the amount of field losses and the choice of harvesting technique (Kindesjö, 1984; Rodhe & Thylén, 1991; Fraser *et al.*, 2001). Long-straw pea varieties with dense foliage should be avoided to decrease risk of lodging. Cultivating peas in pure stand increase the risk of heavy lodging at harvest if the developing stage is later than pod swell (Salawu et al., 2001a; 2002b). Therefore intercropping is preferable in most cases and the pea plants tendency to lodge influences the choice of cereal variety. A pea variety that tends to lodge should be intercropped with a more rigid variety of cereal. The choice of cereal to use as bi-crop with peas is subject to extensive discussion. Oats, barley, and wheat are the most often used cereals in bi-crops (Brundage & Klebesadel, 1969; Chapko *et al.,* 1991; Salawu *et al.*, 2001a). Often, the NDF and ADF content of the cereal are used to determine the choice of cereal. Comparing the nutritional value, inclusion of cereal will more or less lower the CP and DOMD content and increase NDF and ADF value (Salawu *et al.*, 2001a). However, different studies present different results, sometimes claiming that barley has lower NDF content than oats, making the barley a better bi-crop (Khorasani *et al.*, 1993), other times the opposite (Chapko *et al.*, 1991). It appears therefore that it can be the choice of cereal variety rather than the choice of cereal that is important when looking at NDF and ADF content. Other important parameters in choice of cereal variety are time to harvest maturity, competitiveness with pea plants, disease susceptibility and so on. Barley appears to have an efficient initial growth period with risk of suppressing pea plant growth at early stages (Lunnan, 1989) making barley less suitable for intercropping when the drilling of both cultivars is done simultaneously in the same rows. This is the most practical form of drilling for most on-farm applications. Furthermore, the awn fragments of barley may irritate the mouths of livestock (Chapko *et al.*, 1991). Wheat appears to give good quality bi-crop silage with peas that can replace moderate-quality GS in dairy cow rations (Salawu *et al.*, 2001a). However, wheat is not a good choice for intercropping in northern Sweden since they have a long growth period. Oats are less competitive than barley when drilled simultaneously with the peas, and several varieties are suitable for growing in northern Sweden. These varieties that are especially adapted for growth in northern Sweden may mature faster than the peas and are therefore not suitable. Furthermore, pea-oat mixtures appear more palatable and more readily consumed by livestock than pea-barley mixtures (Chapko *et al.*, 1991).

The maturity of the cereal and the pea variety at harvest is very important and if either of the crops is too mature, the field losses during harvest will be too great to be acceptable. Also, it has been shown that for optimal silage quality, neither the cereal nor the peas should be fully mature. This is partly due to the higher DM content in mature crops. This makes the forage more difficult to consolidate adequately resulting in low-density silage with many air pockets or pores. Thereby the silage will have very poor storage stability after opening, decreasing quality and increasing losses. When determining best time for harvest, it is better to consider the maturity of the cereal component rather than the pea component. This is because the quality of pea plants remains relatively stable with and during maturity (Salawu *et al.*, 2001a). However, there will be an increased risk of pea seed losses if the plants are approaching pod fill, also the risk of lodging increases with maturity. Direct harvest methods decrease these losses; especially if care is taken to consider the direction the forage has lodged. Therefore, the pea maturity cannot be ignored. For optimal yields, pea bi-crops should be harvested when the peas have started forming lower pods, but have not begun to swell (Potts, 1980; Fraser *et al.*, 2001). This corresponds to harvest at approximately 12 weeks after sowing (Fraser *et al.*, 2001). Changes in crop maturity have little effect on chemical composition in fresh pea crop (Åman and Graham, 1987; Fraser et al., 2001) with the exception of transfer of soluble sugars to starch and an increased content of cell-wall constituents (Åman & Graham, 1987).

The choice of harvesting technique demands consideration of the chosen crops and harvest time. To reduce the field losses it is important to reduce the amount of mechanical manipulation of the crop. Direct harvest is optimally performed with a disc mover on a precision cutter in order to reduce field losses. If the forage has lodged, it should be cut towards the lodging direction (Kindesjö, 1984; Rodhe &Thylén, 1991). If direct harvest is not possible, swathing and wilting can be done. However, manipulation of the forage must be minimal during wilting, since field losses will increase due to shower down of drying cereal and pea seeds. Since there is no sward in the field, the risk of soil contamination is increased. The "stubble" left by the cereal component probably reduces this contamination risk (Potts, 1982). However, the contamination risk from vehicles is present, as well as the problem with wind-induced soil contamination in dry weather. Pea-cereal bi-crop forage can be ensiled in both big bales (Fraser *et al.*, 2001; Salawu *et al.*, 2002b) and bunker silos (Salawu *et al.*, 2002a; Adesogan *et al.*, 2004) with good results.

One of the objectives for feeding legume-cereal bi-crop silages to ruminants is to supply starch and protein, allowing minimal feeding of purchased concentrates. The bi-crop silages contained up to 180 g kg^{-1} DM starch and 165 to 187 g kg^{-1} DM CP. However, they also contained high concentrations of ammonia, indicating the occurrence of considerable proteolysis during ensiling, despite the use of the inoculant. This observation confirms the difficulties associated with conserving heterogeneous forages (Kristensen, 1992). Salawu *et al.*, (2002a) concluded that pea-wheat bi-crop silages can be used to replace moderate–quality GS in dairy cow rations, but their role as alternatives to high quality forages requires additional investigation. Cows fed high concentrate diet (9 kg) and GS gave more milk and higher milk protein concentrations than all the bi-crop silages except the high pea (second cut) bi-crop diet. Therefore, the concentrate sparing effect of the bi-crop silages that were evaluated seemed marginal, and as such they may have limited role as an alternative feed in high input systems. This problem may be related to inadequate supply of fermentable carbohydrate from the bi-crop silages, as was evident from high blood urea concentrations (Salawu *et al.*, 2002a).

During harvest and until the crop is preserved, the protein fraction is degraded, initially by crop enzyme respiration and then by unfavourable microorganisms (e.g. clostridia and enterobacteria), if the preservation process does not reach a stable pH, or if it proceeds slowly. The objective of the early AIV-process (adding mineral acids diluted with water) by Virtanen was to immediately reach a pH to about 3.6 and thereby prevent proteolysis during ensiling. However, it appears that enzymes active at acid pH predominate in many crops, and hence the widely held opinion that the achievement of pH 4.0 prevents further proteolysis during ensilage is unlikely to hold true (McDonald *et al.*, 1991). Preservation by wilting increases the time the crop respirates and will therefore in many cases lead to degradation of plant protein (McDonald *et al.*, 1991). However, it has been shown that hay has better protein value than silage, and wilted silage is better than unwilted untreated silage. But, by adding formic acid prior to ensiling, the protein value of unwilted silage is improved compared to wilted silage (Verbič *et al.,* 1999). Adding inoculants prior to ensiling improves fermentation (Fraser *et al.*, 2001; Kung *et al.*, 2003), but LAB inoculants decreases N retention in vivo in lambs (Fraser *et al.*, 2001). However, inoculants can have different effects on aerobic stability in whole crop wheat silage (Filya *et al.*, 2000). Some inoculants primarily protect silage during aerobic exposure. For instance, *L. pentosus* inhibits yeast and mould infections in wilted wheat silage (Filya *et al.*, 2000) and *L. buchneri* protects whole-crop wheat and corn silage during aerobic exposure (Weinberg *et al.*, 2002). Noteworthy is that freshly cultured LAB can be as efficient as formic acid treatment in reducing wet white-clover-silage ammonia N content (Cussen *et al.*, 1995). The addition of enzymes as a treatment can reduce both NDF and ADF content in silage, however, enzyme treatment of wheat and PS resulted in enhanced aerobic deterioration (Weinberg *et al.*, 1995).

Whole crop peas are fed either exclusively or as a bi-crop primarily to utilise forage with both high protein content and a high concentration of energy (i.e. starch) compared to whole crop cereals only (Kristensen, 1992; Salawu et al., 2001a; 2002b). Not only will this reduce the costs for concentrate (Salawu et al., 2002a; Adesogan et al., 2004), it will also reduce labour for the farmers since one harvest occasion generally yields enough forage for the season. Furthermore, peas have a high palatability for cows. In fact, DM intake of pea-wheat intercrop silage is significantly higher than DM intake of GS (Adesogan *et al.*, 2004). Also, both intake and digestibility is reduced when the pea content is less than 200 g kg^{-1} when intercropping (Salawu *et al.*, 2002b). Pea silage harvested at full pod stage can replace AS in TMR with no effect on short-term milk yield, although milk from cows fed PS had a lower protein percentage than milk from cows fed AS (Mustafa *et al.*, 2000). Conclusively, whole crop peas can be an alternative feed in low-input systems if only the protein fraction can be stabilised and the N-use efficiency increased (Salawu *et al.*, 2002a). Kindesjö (1984) suggested that the proportion between energy and protein implicated that whole crop PS can support dairy cattle of high production level.

9 Conclusion

To summarise, whole-crop pea silage has the potential to become an excellent feed in dairy production if the nutritional value of their proteins can be improved. In order to achieve this, the following points have to be considered:

- ♣ Whole crop PS has a good balance between energy and protein and appear to have concentrate-saving capacity in feed rations.
- ♣ Whole crop PS is highly palatable for cows and can be consumed in large quantities due to the low NDF content in combination with a high rumen passage rate.
- ♣ Pea protein is very soluble, and most of the protein is lost as ammonia-N and other compounds not available for the rumen microbes.
- ♣ Protein loss during ensiling can be prevented by optimising choice of variety, intercropping, harvest time and minimising the microbial activity during ensiling.
- ♣ An optimal pea variety should have not too high content of condensed tannins, high protein content, reduced foliage (i.e. semi-leafless), and be short and stiff stemmed.
- ♣ During ensiling, rate of reaching target pH and the target pH is of equal importance.
- ♣ Silage additives should alone or in combination be functional across different DM contents and effectively inhibit both clostridia and yeasts.

10 References

Adesogan A.T., Owen E. and Givens D.I. (1998) Prediction of the in vivo degradability of whole crop wheat from in vitro digestibility, chemical composition, in situ rumen degradability, in vitro gas production and near infrared reflectance spectroscopy. *Anim Feed Sci Technol* 74, 259-272.

Adesogan A.T., Salawu M.B. and Deaville E.R. (2000) The effect of the pea to wheat ratio and harvest date on the voluntary feed intake, in vivo digestibility and nitrogen retention of pea-wheat bi-crop silages by sheep. In Proceedings of the British Society of Animal Science. Edited by British Society of Animal Science U. British Society of Animal Science, Scarborough, UK. pp 81.

Adesogan A.T., Salavu M.B. and Deaville E.R. (2002) The effect on voluntary feed intake, in vivo digestibility and nitrogen balance in sheep of feeding grass silage or pea-wheat intercrops differing in pea to wheat ratio and maturity. *Anim Feed Sci Technol* 96, 161-173.

Adesogan A.T., Salawu M.B., Williams S.P., Fisher W.J. and Dewhurst R.J. (2004) Reducing Concentrate Supplementation in Dairy Cow Diets While Maintaining Milk Production with Pea-Wheat Intercrops. *J Dairy Sci* 87, 3398-3406.

Anslow R.C., Burgis P.R.H. and Sheldrick R.D. (1983) The potential value of forage peas [Digestibility, feed composition, nutritive value]. *Agric Progress* 58, 20-29.

Bolsen K.K., Ashbell G. and Wilkinson J.M. (1995) Silage additives. In Biotechnology in animal feeds and animal feeding. Edited by Wallace R.J. and Chesson A. VCH Publishers Inc., Weinheim. pp 33-54.

Bolsen K.K., Ashbell G. and Weinberg Z.G. (1996) Silage fermentation and silage additives: Review. *Asian Australasian J Animal Sci* 9, 483-493.

Broderick G.A. (1995) Desirable characteristics of forage legumes for improving protein utilization in ruminants. *J Anim Sci* 73, 2760-2773.

Brundage A.L. and Klebesadel L.J. (1969) Nutritive value of oat and pea components of a forage mixture harvested sequentially. *J Dairy Sci* 53, 793-796.

Carr P.M., Martin G.B., Caton J.S. and Poland W.W. (1998) Forage and nitrogen yield of barley-pea and oat-pea intercrops. *Agron J* 90, 79-84.

Chapko, L B., Brinkman, M A., and Albrecht, K A. (1991) Oat, oat-pea, barley, and barley-pea for forage yield, forage quality, and alfalfa establishment. *J Prod Agric*. (4(4)) pp 486-491.

Cussen R.F., Merry R.J., Williams A.P. and Tweed J.K.S. (1995) The effect of additives on the ensilage of forage of differing perennial ryegrass and white clover content. G*rass Forage Sci* 50, 249-258.

Faulkner J.S. (1985) A comparison of faba beans and peas as whole-crop forages. *Grass Forage Sci* 40, 161-169.

Filya I., Ashbell G., Hen Y. and Weinberg Z.G. (2000) The effect of bacterial inoculants on the fermentation and aerobic stability of whole crop wheat silage. *Anim Feed Sci Technol* 88, 39-46.

Fraser M.D., Fychan R. and Jones R. (2001) The effect of harvest date and inoculation on the yield, fermentation characteristics and feeding value of forage pea and field bean silages. *Grass Forage Sci* 56, 218-230.

Gilliland T.J. and Johnston J. (1992) Barley/pea mixtures as cover crops for grass re-seeds. *Grass Forage Sci* 47, 1-7.

Hart K.J., Wilkinson R.G., Sinclair L.A. and Huntington J.A. (2003)**a** The ensiling profile of whole-crop pea (Pisum Sativum L.) and whole-crop bean (Vicia Faba L.) silages.

Proceedings of the 11th International Scientific Symposium Forage Conservation 102-103.
Hart K.J., Wilkinson R.G., Sinclair L.A. and Huntington J.A. (2003)**b** Utilisation of whole-crop pea (*Pisum Sativum* L.) silages by finishing lambs; effect on growth and carcass characteristics. *Proceedings of the 11th International Scientific Symposium Forage Conservation* 154-155.
Hart K.J., Wilkinson R.G., Sinclair L.A. and Huntington J.A. (2003)**c** Determination of the *in sacco* degradation characteristics of whole-crop pea (*Pisum Sativum* L.) silages. *Proceedings of the 11th International Scientific Symposium Forage Conservation* 176-177.
Henderson N. (1993) Silage additives. *Anim Feed Sci Technol* 45, 35-56.
Hof G., Vervoorn M.D., Lenaers P.J. and Tamminga S. (1997) Milk Urea Nitrogen as a Tool to Monitor the Protein Nutrition of Dairy Cows. *J Dairy Sci* 80, 3333-3340.
Jaster E.H., Fisher C.M. and Miller D.A. (1985) Nutritive value of oatlage, barley/pea, oat/pea, pearl millet, and sorghum as silage ground under a double cropping forage system for dairy heifers. *J Dairy Sci* 68, 2914-2921.
Jonker J.S., Kohn R.A. and Erdman R.A. (1999) Milk Urea Nitrogen Target Concentrations for Lactating Dairy Cows Fed According to National Research Council Recommendations. *J Dairy Sci* 82, 1261-1273.
Khorasani G.R., Okine E.K., Kennelly J.J. and Helm J.H. (1993) Effect of whole crop cereal grain silage substituted for alfalfa silage on performance of lactating dairy cows. *J Dairy Sci* 76, 3536-3546.
Khorasani G.R., Jedel P.E., Helm J.H. and Kennelly J.J. (1997) Influence of stage maturity on yield components and chemical composition of cereal grain silages. *Can J Anim Sci* 77, 259-267.
Kindesjö B. (1984) Ensilerad helärtgröda till mjölkkor. SLU, Uppsala. pp 1-26.
Kristensen V.F. (1992) The production and feeding of whole-crop cereals and legumes in Denmark. In Whole-crop cereals (2nd ed.). Edited by Stark B.A. and Wilkinson J.M. Chalcombe Publications, Kingston, Kent. pp 21-37.
Kung L., Taylor C.C., Lynch M.P. and Neylon J.M. (2003) The Effect of Treating Alfalfa with Lactobacillus buchneri 40788 on Silage Fermentation, Aerobic Stability, and Nutritive Value for Lactating Dairy Cows. *J Dairy Sci* 86, 336-343.
Lomakka L. (1993) Skördetidsförsök i norra Sverige i korn och ärtblandsäd för våtkonservering. SLU Repro UMEÅ, Umeå. pp 39.
Lunnan T. (1989) Barley-pea mixtures for whole crop forage. Effects of different cultural practices on yield and quality. *Norw J Agric Sci* 3, 57-72.
McDonald P., Henderson N. and Heron S. (1991) The Biochemistry of Silage. Marlow:Chalcombe Publ., Bucks, U.K. pp 340.
Min B.R., Barry T.N., Attwood G.T. and McNabb W.C. (2003) The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: a review. *Anim Feed Sci Technol* 196, 3-19.
Mustafa A.F., Christensen D.A. and McKinnon J.J. (2000) Effects of pea, barley, and alfalfa silage on ruminal nutrient degradability and performance of dairy cows. *J Dairy Sci* 83, 2859-2865.
Ohshima M. and McDonald P. (1978) A review of the changes in nitrogenous compounds of herbage during ensilage. *J Sci Food Agric* 29, 497-505.
Potts M.J. (1980) The influence of sowing date, harvest date and seed rate on the yield of forage peas. *Grass Forage Sci* 35, 41-45.
Potts M.J. (1982) The influence of selected agronomic factors on the yield of forage peas. *Grass Forage Sci* 37, 327-331.

Rodhe L. and Thylén A. (1991) Helärt - skörd och foderberedning. JTI, Uppsala. pp 64.
Salawu M.B., Adesogan A.T., Weston C.N. and Williams S.P. (2001)**a** Dry matter yield and nutritive value of pea/wheat bi-crops differing in maturity at harvest, pea to wheat ratio and pea variety. *Anim Feed Sci Technol* 94, 77-87.
Salawu M.B., Warren E.H. and Adesogan A.T. (2001)**b** Fermentation characteristics, aerobic stability and ruminal degradation of ensiled pea/wheat bi-crop forages treated with two microbial inoculants, formic acid or quebracho tannins. *J Sci Food Agric* 81, 1263-1268.
Salawu M.B., Adesogan A.T. and Dewhurst R.J. (2002)**a** Forage intake, meal patterns, and milk production of lactating dairy cows fed grass silage or pea-wheat bi-crop silages. *J Dairy Sci* 85, 3035-3044.
Salawu M.B., Adesogan A.T., Fraser M.D., Fychan R. and Jones R. (2002)**b** Assessment of the nutritive value of whole crop peas and intercropped pea-wheat bi-crop forages harvested at different maturity stages for ruminants. *Anim Feed Sci Technol* 96, 43-53.
Thornton R.F. and Minson D.J. (1973) The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. *Aust J Agric Res* 24, 889-898.
Trevino J., Centeno C. and Caballero R. (1987) The chemical composition of pea plant parts as related to harvesting time. *Anim Feed Sci Technol* 16, 305-309.
Verbic J., Ørskov E.R., Zgajnar J., Chen X.B. and Znidarsic-Pongrac V. (1999) The effect of method of forage preservation on the protein degradability and microbial protein synthesis in the rumen. *Anim Feed Sci Technol* 82, 195-212.
Weinberg Z.G., Ashbell G., Azrieli A. and Brukental I. (1993) Ensiling peas, ryegrass and wheat with additives of lactic acid bacteria (LAB) and cell wall enzymes. *Grass Forage Sci* 48, 70-78.
Weinberg Z.G., Ashbell G., Hen Y. and Azrieli A. (1995) The effect of cellulase and hemicellulase plus pectinase on the aerobic stability and fibre analysis of peas and wheat silages. *Anim Feed Sci Technol* 55, 287-293.
Weinberg Z.G., Ashbell G., Hen Y., Azrieli A., Szakacs G. and Filya I. (2002) Ensiling whole-crop wheat and corn in large containers with Lactobacillus plantarum and Lactubacillus buchneri. *J Ind Microbiol Biotechnol* 28, 7-11.
Woolford M.K. (1975) Microbiological screening of the straight chain fatty acids (C1-C12) as potential silage additives. *J Sci Food Agric* 26, 219-228.
Woolford M.K. (1978) Antimicrobial effects of mineral acids, organic acids, salts, and sterilizing agents in relation to their potential as silage additives. *J British Grassland Society* 33, 131-136.
Woolford M.K. (1990) The detrimental effects of air on silage. *J Appl Bacteriol* 68, 101-116.
Åman P. and Graham H. (1987) Whole-crop peas. 1. Changes in botanical and chemical composition and rumen in vitro degradability during maturation. *Anim Feed Sci Technol* 17, 15-31.

Institutionen för norrländsk jordbruksvetenskap
SLU
Dept. of Agricultural Research for Northern Sweden

DISTRIBUTION
SLU, Röbäcksdalen
Box 4097
904 03 UMEÅ
Tel. 090-786 81 00 Telefax 090-786 87 04
SLU Repro UMEÅ 2004

ISSN 0348-3851
ISRN NLBRD-M – 4:04 SE