THE ROLE OF FISH MEAL IN DAIRY COW FEEDING

TECHNICAL BULLETIN

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by

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SUMMARY

With a world surplus of milk, farmers in the Economic Community and in the U.S.A. are likely to face further production cuts. More emphasis is likely on getting lower production costs, balancing milk supplies with demand, and meeting quality requirements. In this connection, the price for milk received by the farmer is expected to increasingly reflect protein content, with further falls in the value placed on the fat content. Indeed, some countries now base production quotas on milk fat yield. Emphasis on increasing yields per cow, but reducing numbers of cows is likely to continue.

Fish meal has been shown to increase milk production, milk protein content and dairy cow fertility, to play an important role in reducing the cost of milk production and improve milk quality. The extensive research work which has been done world-wide on fish meal (there are over 60 literature citations to fish meal work) gives an insight into its mode of action in the dairy cow's diet and the effect it has on productivity. Reports of this research are reviewed in this Technical Bulletin.

Fish meal can stimulate rumen fermentation. There is evidence that in some situations it may improve protein production and cellulose digestion in the rumen. The prolonged release of peptides, amino acids and ammonia from fish meal in the rumen improves fermentation, growth of micro-organisms being improved.

Fish meal also provides undegraded dietary protein which is highly digestible beyond the rumen. In this respect it is superior to most other proteins fed to ruminants. It is a high quality protein, rich in amino acids, especially lysine and methionine, which are likely to be limiting performance of cows fed practical diets. Compared with synthetic rumen protected amino acids, the fact that fish meal provides undegradable amino acids in peptide form is advantageous.

Trials to study the effect of fish meal on milk yield are numerous. Most showed positive responses, though responses were variable.

With high forage diets, fish meal improved milk protein content. There appeared to be no effect on milk protein where forage:concentrate ratios were low.

In some trials, milk fat content was depressed. This tended to occur where high starch diets, particularly corn silage diets, and high levels of fish meal (over 0.75kg per day) were fed, in the absence of rumen buffers. By restricting fish meal feeding to not more than 0.75kg per day and using rumen buffers, milk fat depression can be avoided.

Fish meal feeding can improve fertility - particularly conception rate. An improvement was seen in trials with both high and low yielding cows, and with diets with high and low forage:concentrate ratios. Based on UK prices in 1990, savings due to improved fertility were worth £120 per cow.

The combined responses in milk yield, milk protein content and fertility make fish meal, particularly ruminant grade products, a very cost effective supplement for all dairy cows in lactation. This overall improvement in fertility and milk production was estimated to produce a benefit of around £160 per cow on the basis as above. Fish meal can make a major contribution reducing milk production costs through better feed utilisation and improved productivity, and still keep milk's image as a natural food.

CONTENTS

1. INTRODUCTION

Total world milk production rose in the eighties, reaching a surplus situation. Since then milk production has started to fall. This has come about through falling cow numbers, even though individual milk yields are rising. In the EU, for example, milk quotas and schemes to encourage farmers to move out of dairying have reduced production.

Rising cow yields are being achieved through improved breeding and husbandry practices. In some areas yields will be further boosted by the use of hormones. Use of bovine somatotropin hormone (BST) is now permitted in the USA. Other countries are likely to follow with hormone use, though not the EU for the foreseeable future. Keeping down production costs will be paramount, as will meeting consumer demands. In developed countries the emphasis is increasingly away from high fat milk - consumption of butter and full-fat milk is falling. Milk payments increasingly reflect protein rather than fat content of the milk.

1.1 Feeding Strategy - Optimising Complementary Feeds

With the cow's ability to utilise high fibre feeds, which in most situations offer the cheapest feed source, emphasis on optimising use of forages is likely to continue. Complementary feeds offered with the forage should achieve the following:

- complement the forages, enhancing rather than sub stituting or depressing forage intake and digestion
- supplement the energy, protein, minerals and vita mins provided by the basal feed up to the amount required for optimum production and health
- control or manipulate metabolism in the rumen and at a tissue level to give the desired end products in terms of quantity and quality, and in particular meet the more exacting nutrient requirements of the very high yielding cows
- provide supplementary nutrients at a minimum cost to achieve the above.

1.2 Fish Meal in Dairy Cow Feeding

For fish meal to be used in dairy cow feeding it must reduce the cost of milk production-reducing production costs has become the key to new strategies for feeding dairy cows in the USA and the EU against a background of quotas (Miller & Pike, 1985). Extensive research over the past 15 years has shown that fish meal has a role in these strategies because it can:

- increase milk yield
- increase milk protein content
- reduce the amount of supplementary concentrate needed to optimise forage use
- improve fertility.

To understand how these changes are brought about, some fundamental aspects of dairy cow feeding will be considered briefly, followed by an outline of trials conducted.

Fish meal feeding of dairy cows in the UK started to increase in the early eighties, and it is now believed that over 50,000 tonnes per annum are used for this purpose. Much of the earlier work was undertaken in the UK. Considerable interest has been generated in the USA, and many trials have been completed there. These and other reports from world-wide sources are reviewed.

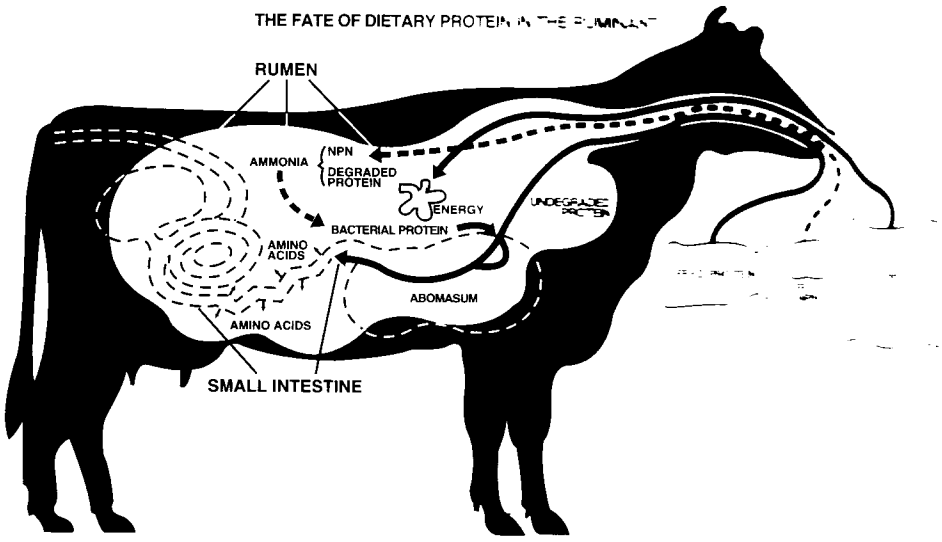
2. FEEDING THE DAIRY COW - MEETING PROTEIN REQUIREMENTS

2.1 Function of the Rumen

The ruminant has the unique ability to utilise cheap high fibre feeds, especially forages, which would generally be poorly utilised by pigs and poultry. When the ruminant is fed, it is the micro-organisms in the rumen that first digest the feed. The rumen is a vast continuous fermenter which typically has a volume about the same as a 50 gallon (220 litre) oil drum. The volatile fatty acids produced in the fermentation, the micro-organisms themselves, and the feed residues leaving the rumen in turn become the cow's source of nutrients. This is illustrated diagramatically in Figure 1. Points which are of interest in connection with the function of fish meal will be highlighted.

In feeding the dairy cow, and indeed any other ruminant, the aim is usually first to optimise fermentation within the rumen and then to complement the end products of this fermentation. In broad terms, to optimise fermentation a continuous abundance of fermentable energy matched by a continuous supply of nitrogen is required. Peaks and troughs in energy release in the rumen should be avoided if possible, particularly if the nitrogen supply does not show corresponding changes. It is not just the amount of energy and nitrogen supplied to the rumen but their rate of release is also important in optimising yield of micro-organisms.

FIGURE 1



2.2 Fish Meal in the Rumen

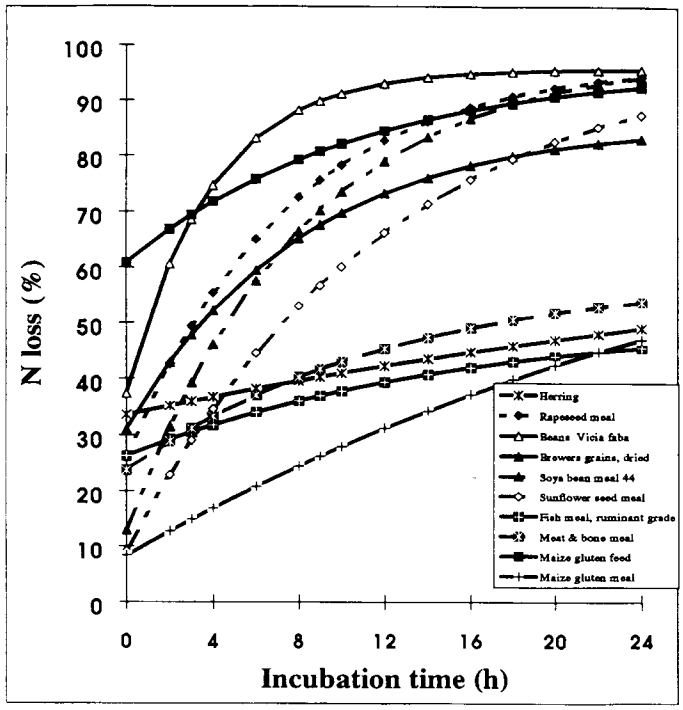
It has been known for some time that the protein in fish meal is generally relatively resistant to degradation by micro-organisms in the rumen. The rate of nitrogen loss with time from protein feeds incubated in polyester bags in the rumen of sheep are shown in Figure 2. The degradation of protein at a ruminal outflow rate of 0.08 ("*p*" value) is given in Appendix Table 1. Heat denaturation of the protein in the processing of fish to produce a dried product is one factor in reducing degradability. This heating is gentle, and has been shown to have little effect on the digestibility of the proteins in the small intestine (see Appendix Table 2). The possibility exists that the lipids in fish meal afford some protection to fish protein, to enable it to largely escape degradation, since solvent extracted fish meal is more extensively degraded *in vitro* (Hoover *et al*, 1989). The undegraded protein will pass to the small intestine to be digested.

Protein that is degraded in the rumen, as shown in Figure 1, was believed to be broken down to simpler forms of nitrogen and ultimately ammonia which is then utilised by micro-organisms producing microbial protein. However, work undertaken at the University of Nottingham in the U.K. labelled the protein in fish meal with isotopic hydrogen (tritiated - ^{3}H) leucine and traced its fate during in vitro rumen fermentation (Yhokha and Buttery, 1986). It was shown that a high proportion of preformed amino/peptide units were incorporated directly into microbial protein without being broken down to ammonia. Dawson *et al* (1988) showed that microbial protein synthesis increased in efficiency as a result of supplementing a basic grass silage diet with fish meal (from Provimi British Fish Meals Limited) from 30.8gN/kg apparently digested organic matter to 54.3gN/kg. It has also been shown that rumen micro-organisms grow faster with preformed amino acids and peptides (Argyle and Baldwin, 1988). Rapidly degraded proteins are unlikely to provide a continuous supply whereas those that are slowly degraded, such as fish meal, should give a supply of these and of ammonia over a longer period to stimulate growth. It has also been shown that a supplement of fish meal can improve cellulose digestion in the rumen (McAllan & Griffiths, 1987; Ortigues *et al*, 1989; Stritzler *et al*, 1992) by stimulating cellulolytic organisms. Fish meal degradable protein provides a prolonged release of ammonia, amino acids and peptides which would appear to stimulate growth of micro-organisms. It is suggested that fish meal stimulates bacteria that break down cellulose by exerting its affect on those intimately related to the fibre and not the whole bacterial population (Stritzler *et al*, 1992).

In some trials inclusion of fish meal has reduced microbial protein production, thereby negating the advantage of extra undegradable protein from the fish meal (Mercer *et al*, 1980; Zerbini *et al*, 1988; Hussein *et al*, 1991). In these trials fish meal was included at high levels in an attempt to more accurately measure its effects. Zerbini *et al* (1988) fed diets of 15.5% crude protein in which menhaden meal supplied 54% of the protein to lactating cows. Intake of fish meal was 2.05 kg/day or 11.5% of diet dry matter. Mercer et al (1980) fed lambs concentrate diets containing 7.8% Peruvian fish meal and Hussein *et al* (1991) fed lambs diets containing 9.7% menhaden meal. The negative effects on microbial protein production efficiency in these trials may be due to excessive supply of highly unsaturated fish lipids in these diets (see 2.2.2). To avoid such adverseeffects it is recommended that dairy cows are fed not more fish meal than 1.75 kg day.

FIGURE 2

DISAPPEARANCE OF FEEDSTUFF N FROM POLYESTER BAGS SUSPENDED IN THE RUMEN OF SHEEP.



N disappearance from samples (except meat & bone meal, maize gluten and maize gluten feed) incubated in polyester bags (43μm pore size) suspended in the rumen of sheep fed a standard diet at Cambridge. Meat & bone values from Ørskov et al. (1983); maize gluten meal and maize gluten feed values from MAFF, (1990)

From IAFMM Technical Bulletin No5; see also Appendix Table 1

2.2.1. Factors affecting the proportion of fish meal protein escaping rumen degradation

Though the proportion of the protein in fish meal escaping degradation in the rumen is generally high, it is variable (see Appendix Table 1). Factors affecting degradability have been investigated by Mehrez *et al*, 1980. They found that the freshness of raw fish and the proportion of solubles added back in the process affect degradability. This was also confirmed by Yoon *et al* (1990).

As fish spoil, protein is broken down to peptides, amino acids, amines and ammonia. The non-protein nitrogen not already broken down to ammonia is believed to be more readily attacked by micro-organisms in the rumen. As much of this non-protein nitrogen fraction, along with some of the more soluble protein pass into the solubles separated in the fish meal process, limiting the proportion of solubles returned to the meal will result in a high proportion of undegradable protein.

2.2.2 Effect of fish lipids on rumen function

Fish lipids contain relatively large amounts of highly unsaturated long chain (n-3) fatty acids. They have a tendency to oxidise readily in fish meal, but this is reduced if antioxidants have been added during manufacture (see IAFMM Technical Bulletin No 22). Whilst unsaturated fatty acids tend to be hydrogenated in the rumen, fish lipids appear to be resistant to biohydrogenation. Working with the CSIRO in Australia, Ashes *et al* (1992), have shown that long chain fish oil fatty acids (C20 and C22) escaped hydrogenation in an artificial rumen (in vitro) (Ashes *et al*, 1992). A similar finding has been made by Offer (1994) working with bags suspended in the rumen of cattle *(in sacco)*. Further evidence that these fatty acids escape hydrogenation in the rumen is provided by data from Dawson *et al* (1991). The fatty acid composition of muscle phospholipids from beef cattle fed fish meal showed the presence of the unsaturated n-3 fatty acids with C20:5 and C22:6 (eicosapentaenoic and decosahexaenoic) reflecting fish lipid fatty acids.

Fish lipids can interfere with rumen fermentation. When a normal and a defatted fish meal were added to an artificial rumen maintained at normal pH (6.2), the former depressed digestion of fibre and protein, and acetate:propionate ratios in the rumen were reduced (Hoover *et al*, 1989). The amount of fish meal added, 6% of the diet, and its high lipid content (12%), provided the equivalent of 120g to 150g of fish lipid to the dairy cow. This is considered excessive - not more than 100g has been recommended (Opstvedt, 1985).

In some trials, generally those where a high level of fish meal feeding was used (1kg per day or more giving 100g or more fish lipids) a depression of milk fat has occurred (see section 3.3). The use of rumen buffers can prevent this. Vandersall *et al* (1989) fed 1.4kg per day menhaden fish meal with a corn:corn silage diet. Inclusion of the buffers sodium bicarbonate (1%) and magnesium oxide (0.5%) raised milk fat from 2.98% to 3.41%.

2.3 Supplementing Microbial Protein - Fish Meal as a Source of Undegraded Protein

The role of undegraded proteins is to bridge the gap between the animal's requirement for amino acids beyond the rumen, and those supplied by microbial proteins. Generally speaking, microbial proteins are of high quality. So, too, is fish protein. In Figure 3, the amino acid composition of microbial protein and fish meal protein have been compared with milk protein. Although details of the amino acids required by the lactating dairy cow are not yet known, lysine, methionine, tryptophan and possibly histidine are likely to be the more limiting. Relative to milk protein, fish protein has a very favourable content of these amino acids. This would not be true of other proteins. For example, Figure 4 shows the content of undegraded amino acids which are digestible in the small intestine provided by a number of feedstuffs (on equal weight basis). These figures are arrived at from the amino acid composition of the proteins, the degradability (see Appendix Table 1) and the digestibility of the undegraded protein (see Appendix Table 2).

This approach assumes that the protein left following the changes that occur in the rumen is of similar nutritional value to the original. Work by Mathers *et al*, 1979, demonstrated that with fish meal there was little difference in the nutritive value of the original and that remaining in the rumen (undegraded protein) in terms of the growth rate of rats receiving the proteins, and the protein efficiency ratio, whereas with sunflower meal, the by-pass material was markedly inferior (Figure 5). Further confirmation of this is seen from data comparing herring meal protein before and after 24 hour exposure in the rumen - the difference in amino acid composition was small - the concentration of most amino acids actually increased (Opstvedt 1993) (see Appendix Table 3).

When grass silage fed twice daily to growing cattle, initial weight 120 kg, was part substituted with 150g fish meal per kg total dry matter, equivalent to an average intake of 622g fish meal per day, there was a marked increase in flow of amino acids to the small intestine, corresponding to 65% of the fish meal N passing the rumen undegraded, together with a small, non-significant increase in efficiency of microbial protein production from the reduced amount of silage (Beever *et al*, 1990). At a lower supplementation rate of 50g fish meal/kg dry matter intake (206g fish meal per day) there was no increase in amino acid flow to the small intestine; although 72% of the fish meal N was determined as passing to the intestine, this was offset by reduced microbial amino acids due partly to less silage consumed at equal dry matter intake and partly to a non-significant decrease in efficiency of microbial protein synthesis (see Figure 6). In a parallel study with the same silage but with fish meal added as a supplement at the rate of 150g/kg silage dry matter, and the mixture fed hourly, marked increases in amino acid flow to the small intestine due to 70% of the fish meal protein escaping degradation together with a 32% increase in microbial N flow (Dawson *et al*, 1988). A marked increase in the flow of amino acids to the small intestine as a result of supplementing pasture with fish meal, has also been shown in Australia by Hynd (1989).

Recent work at the Hannah Research Institute in Scotland (Choung & Chamberlain, 1992) suggests that beyond the rumen the dairy cow has limited capacity to utilise free amino acids. Infusing proteins beyond the rumen (into the abomasum), they compared casein, soya protein and soya protein plus amino acids to equate its amino acids to those in casein. In neither soya treatment did milk production match that from casein. They believe that amino acids in peptide form (as in casein) behave differently to free amino acids which are less effectively utilised.

A trial at the Rowett Research Institute in Scotland compared the flow of non-ammonia nitrogen to the small intestine of ewes and its digestibility after feeding soyabean meal, fish meal and blood meal. Non-ammonia nitrogen (NAN) utilisation and digestibility were highest for fish meal (see Table 1).

FIGURE 3

ESSENTIAL & SEMI-ESSENTIAL AMINO ACID PATTERNS MICROBIAL PROTEIN AND FISH MEAL COMPARED WITH MILK

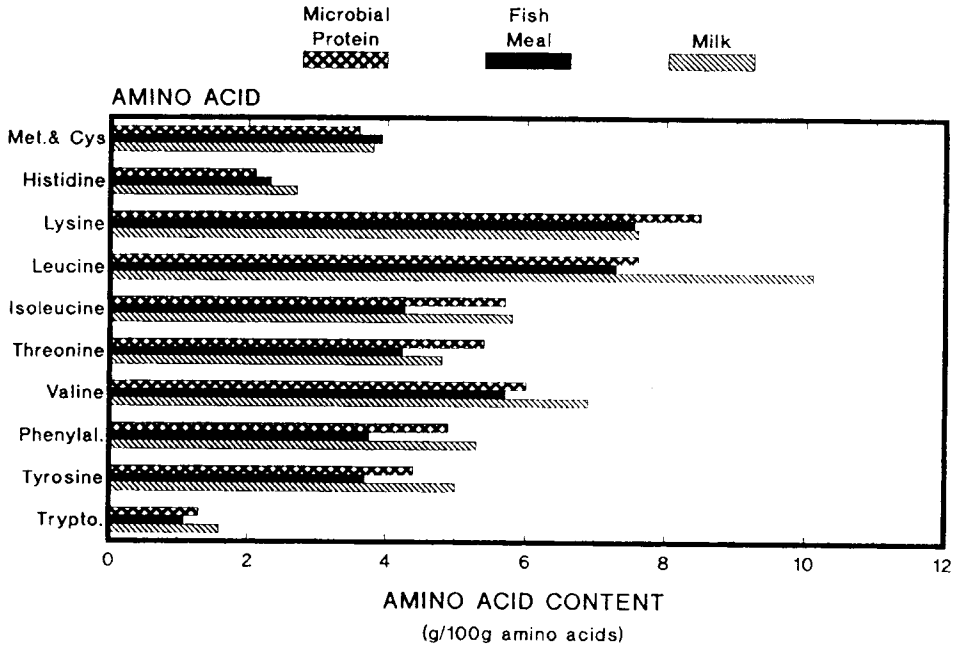
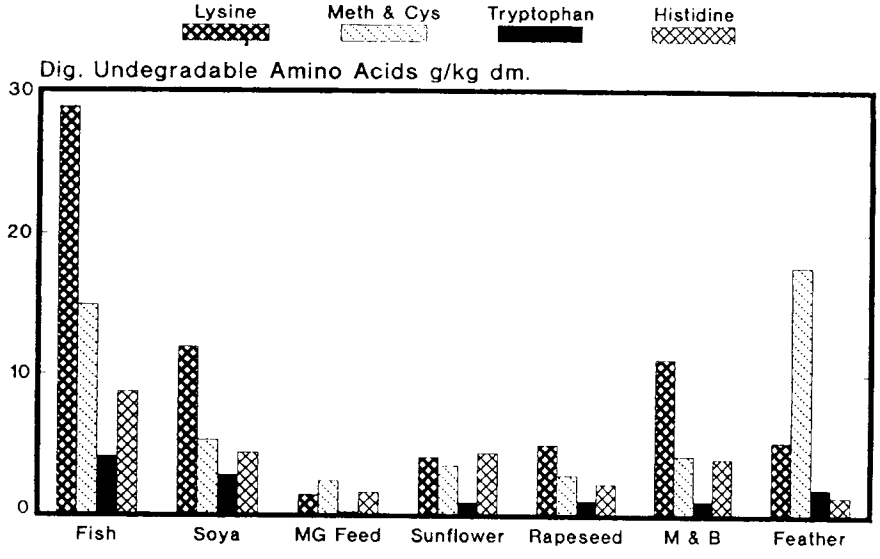


FIGURE 4

COMPARISON OF PROTEIN SOURCES (1) - SUPPLY OF DIGESTIBILE UNDERGRADABLE AMINO ACIDS FOR RUMINANTS



(1) as meals. MG – maize gluten; M & B – meat and bone meal

See also Appendix Table 2

TABLE 1

POST-RUMINAL UTILISATION OF NITROGEN BY LACTATING EWES - COMPARISON OF SOYA, FISH AND BLOOD MEALS

(Ngongoni *et al*, 1989)

	Soyabean Meal	Fish Meal	Blood Meal
Intestinal digestibility[1]	0.82	0.88	0.75
NAN utilisation[2]	0.58	0.61	0.48

1 Truly digested non-ammonia nitrogen (NAN) in small intestine

2 Efficiency of utilisation of truly digested NAN-average values for 3 experiments.

A group of research workers with INRA in France (Station de Recherches sur la Vache Laitiere) has shown that the composition of amino acids entering the small intestine tends to reflect the composition of feed proteins. For example, diets with high contents of maize and/or maize silage were found to give an amino acid flow beyond the rumen that was deficient in lysine (Rulquin and Verite, 1993 - see later, Section 3.2).

Fish meal was found to give one of the highest digestibility figures. Because it contains no carbohydrate, digestibility is not as sensitive to the degree of heating as with other proteins that are heated. The work reported was mainly with regularly dried fish meals. A special product made with more gentle drying may have higher digestibility.

To conclude, fish meal if it is specially produced for a high content of undegraded protein and fed at a level which does not result in excessive levels of fish lipids in the rumen (for example, 0.75kg per day to the dairy cow), will in some cases stimulate digestion of fibre and microbial protein production in the rumen, whilst at the same time provide a high quality source of by-pass protein. The resultant flow of amino acids into the small intestine, their digestion and utilisation will be enhanced, more so because the increased supply from fish meal will be in peptide form.

3. EFFECT OF FISH MEAL ON MILK PRODUCTION

3.1 Milk Production Trials

A review of the trials feeding fish meal is given in Appendix 1 and Appendix Table 4. The trials were grouped based on the forage fed. Average responses in milk yield found were as follows:

Forage	Response to Fish Meal (kg/head/day)
Maize silage	+ 1.6
Alfalfa haylage	+ 1.3
Grass silage	+ 0.5
Hay	+ 0.6

Although bigger responses were seen with maize silage and alfalfa haylage, this may reflect the generally higher yields of these cows rather than a nutrient interaction between fish meal and the forage. For example the higher starch content of maize silage would be expected to provide more fermentable energy than from grass silage, more microbial protein, and thereby reduce the amount of undegraded protein needed. The latter would be higher with high yielding cows even though more microbial protein may be supplied from the rumen.

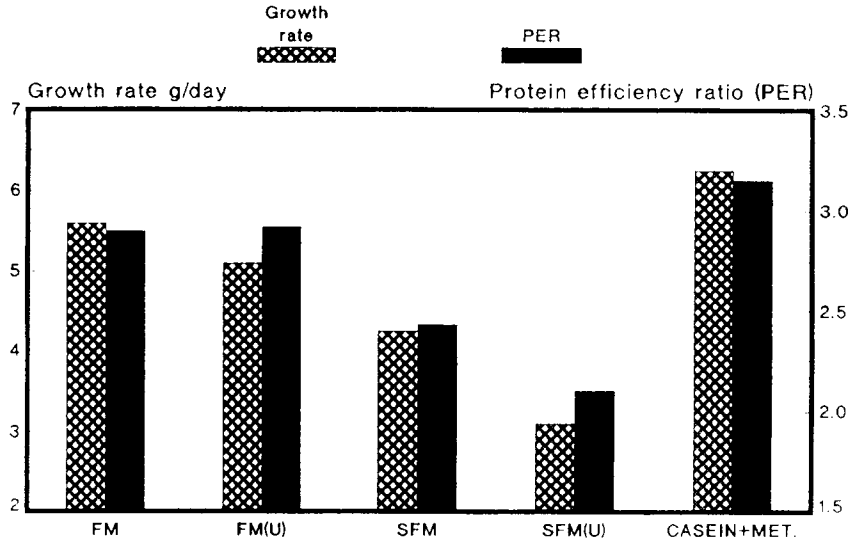
A comparison of a low soluble protein fish meal (LSFM) and a high soluble one (HSFM) has been undertaken by Broderick *et al*, 1991. Working with high yielding cows they compared these fish meals (LSFM and HSFM) with soyabean meal. The HSFM gave a small milk production response over soyabean meal; LSFM gave a further response over the HSFM. How the different degradabilities were achieved is not stated.

In conclusion, most of the yield responses were positive, though they were variable. Factors likely to affect the response in milk yield are as follows:

(i) High forage diets, where forage:concentrate ratios are greater than 1:1, are expected to give greater responses to fish meal feeding. This was demonstrated by ørskov et al (1981) where he used diets differing in forage concentrate ratio but similar in other respects. Although the results summarised in Appendix Table 2 do not show the same trend, this is believed to be due to other factors being conounded with forage: concentrate ratio, particularly milk yield.

FIGURE 5

NUTRITIVE VALUE OF FISH MEAL & SUNFLOWER MEAL COMPARISION OF ORIGINAL & RUMEN UNDEGRADED FED TO RATS

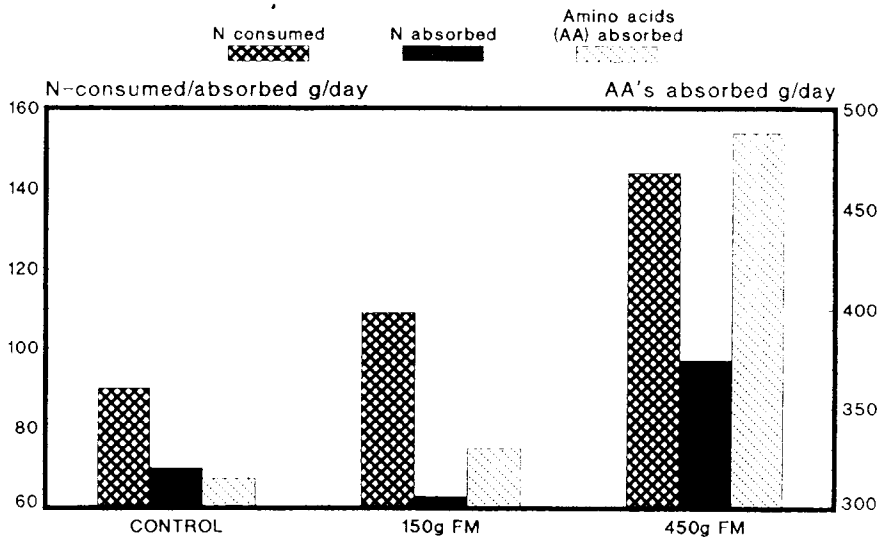


FM=fish meal;SFM=sunflower meal:U=undegraded;met=methionine

From Mathers, J.C., 1979

FIGURE 6

FISH MEAL SUPPLEMENT TO GRASS SILAGE FED CATTLE -EFFECT ON AMINO ACIDS ABSORBED



From Beever et al, 1990

(ii) The size of the milk yield response did not appear to be related to the yield. Responses were as great in low as high yielding cows where high levels of forage were fed, but low yielding cows fed highlevels of concentrate, particularly if they received maize silage with high starch content, tended to give smaller responses or no response.

(iii) There is some evidence that responses may have been greater in early lactation, especially from the large co-ordinated multi farm trials by Miller et al, (1982).

(iv) Although yield responses were greatest with maizesilage diets and least with grass silage, the comparison is confounded by other factors, the moreimportant being forage: concentrate ratios andmilk yield. As the grass silage and hay fed cows were generally lower yielding, this would haveresulted in a smaller overall protein requirement.

(v) Fish meal solubility - it should be kept low by using fresh fish and returning little, if any, solublesin the processing.

Fish meal offers a "natural" way of increasing milk yield without compromising the perception of milk as a "natural" food from healthy cows.

3.2 Effect of Fish Meal Feeding on Milk Protein Content

The concentration (%) of protein in milk is influenced by both non-dietary and dietary factors. The former include breed, stage of lactation, age of the cow and seasonal changes. Dietary factors include energy, protein and amino acids.

Of the dietary factors energy supply has the greatest influence on milk protein concentration, followed by protein and amino acids. Infusion of protein and amino acids into the small intestine prove that milk protein concentration can be improved by increased balanced amino acid supply for absorption. Because fish meal enhances the intestinal supply of amino acids, particularly methionine and lysine, an increase in both milk protein concentration and milk protein yield can be expected.

This potential has been revealed in a review of the effects of using protected methionine and lysine as supplements in maize silage based diets (Rulquin & Verite, 1993). Responses in terms of increased milk protein % to the protected amino acids were greatest when the supplementary proteins were low in lysine (groundnut meal) intermediate when the proteins were moderate sources of lysine and/or methionine (maize gluten meal, protected soya bean meal, protected rapeseed meal) and least when the diet included fish meal. Thus including fish meal appears to have supplied sufficient of these amino acids to meet milk production needs in this situation. A different situation appears to apply where the diets are based on grass silage. Girdler *et al* (1988) found protected methionine and lysine had no effect when added to a silage-barley or to silage-soya bean meal diet but increased milk protein % when added to a silage-fish meal, blood meal and meat and bone meal blend. Here the grass silage with barley or soya bean meal would appear to be supplying inadequate amounts of amino acids other than methionine and lysine. The addition of the high undegraded protein source then corrects this deficiency and allows response to the protected amino acids.

In five out of sixteen trials with grass silage as the basal forage, fish meal significantly increased milk protein % (see Appendix Table 5). Responses were obtained where moderate levels of concentrates were used (forage:concentrate ratios 2:1 to 1:1). In three out of four trials with alfalfa silage as forage, fish meal gave a significant increase in milk protein %. In each case the forage:concentrate ratio was in the range 70:30 to 50:50. One trial with a very high forage:concentrate ratio did not give a positive response. In two out of five trials with hay as forage significant improvement in milk protein % was obtained. Trials not giving a response had either low energy (high forage:concentrate ratio) or very high energy from concentrates. In 13 trials where maize silage was the forage there was no significant increase in milk protein %. However, in seven of these there was a non-significant trend to increased milk protein %. Further trials with maize silage based diets are warranted to delineate conditions where responses may be expected.

In their review of nutritional factors influencing nitrogen composition of milk DePeters & Cant (1992) found response to fish meal variable. The explanation they proposed was that the additional fat in the fish meal tended to depress milk protein. In some situations this offset the milk protein enhancement resulting from an improved flow of amino acids beyond the rumen from the undegraded protein in the fish meal.

Considerable use is now made of added fat or high fat whole oilseeds. However such diets almost always result in a reduction in milk protein %. DePeters & Cant, 1992. These authors suggested that because dietary fat enhances synthesis of non-nitrogenous components of milk rather than milk protein, the latter

is depressed by dilution. In three trials supplementing such diets with fish meal, or fish meal blends, partially prevented the depression in milk protein %. The combination of protected fat with fish meal may improve peak yield, maintain milk persistency, maintain milk protein % and improve reproduction. This combination deserves further investigation.

Work in Ireland (Murphy & O'Mara, 1993) has shown that fish meal generally increases milk protein concentration. The trials reported in this review would have used high forage diets (forage dry-matter intake over half total dry-matter intake).

In conclusion, the use of fish meal, with or without protected fat, together with a reduced input of concentrate such that the forage concentrate ratio is between 70:30 and 50:50, depending on the quality of the forage, allows greater reliance on forages and helps to maintain, and in many situations increase the milk protein % in the face of reduced cereal consumption. In the trials reviewed, milk protein concentration increased by around 0.1% in diets where concentrates did not exceed 50% of the dry matter. Restricting the fat from fish meal (to below 100g per cow per day) may also help to improve milk protein content in some situations.

3.3 Effect of Fish Meal Feeding on Milk Fat Content

The effect of fish meal on milk fat content has been variable. Earlier trials with grass silage in the UK resulted in little if any change in milk fat content whereas several trials in the USA with maize silage:maize diets showed a significant drop, e.g. Wohlt *et al* (1991), Spain *et al* (1990) & Blauwiekel *et al* (1990). In these trials the amount of fish meal fed was high (Wolt 1.35kg; Spain 1.4 and 2.6kg; Blauwiekel 1kg) using menhaden fish meal with around 10% lipids which were highly unsaturated. In contrast, trials in Wisconsin with alfalfa haylage, Broderick (1991) and Dhiman and Satter (1991) showed no significant drop in milk fat content. It appears that the drop was associated with high starch diets.

In conclusion, on the basis of work on the effects of fish lipids on ruminants (Opstvedt, 1985) and work by Vandersall et al (1989) the following advice is appropriate:-

(i) If adverse effects of fish lipid are to be avoided in the rumen, the total content of fish lipid fed in the form of fish meal should be below 100g per day, and preferably below 75g for the lactating dairy cow.

(ii) Rumen buffers should be used when feeding high starch diets to avoid low rumen pH.

(iii) Whilst there may be some marketing situations where it could be desirable to reduce milk fat content, it is not recommended that fish meal is used at a high level for this purpose. A high level of fish lipid (over 100g per day) is likely to reduce the efficiency with which fibre in the diet is utilised.

4. FISH MEAL FEEDING AND FERTILITY

High levels of rumen ammonia arising when feeding high protein diets and/or diets with inadequate rumen fermentable energy, limiting the capacity of micro-organisms to utilise the ammonia, can give rise to fertility problems (Kaufmann & Lüpping, 1982). Working in Israel, this group showed that treating the protein with formaldehyde to reduce rumen ammonia levels also improved fertility. Other results of trials investigating rumen ammonia levels and fertility support Kaufmann's results and are given in IAFMM Flyer No 19.

There is now published evidence from trials in Israel (Bruckental *et al* 1989) and Northern Ireland (Armstrong *et al*, 1990) that fish meal improves fertility of dairy cows.

In the Israeli trial, conception rate improved from 48% on a low protein containing diet and 43% in a high protein diet (both based on soyabean meal) to 52% on a high protein fish meal diet. In the Northern Ireland trial conception rate improved from 44% with a vegetable protein based diet to 64% with a fish meal containing diet.

In the Israeli trial, milk yield increased as a result of fish meal feeding from 40.0 to 40.8kg per day for cows and from 31.2 to 33.4kg for heifers; in the trial in Northern Ireland it increased from 22.5 to 23.4kg over the 90 day trial and from 20.6 to 21.9kg over the last 21 days of this period.

A further trial in Ireland in which grazing cattle had their diets supplemented with sugar beat pulp (an energy source) or fish meal combined with a small amount of sugar beet pulp as a carrier (undegraded protein) also showed improved fertility with fish meal - conception rates for fish meal, beet pulp and control (unsupplemented) were 76, 63 and 58% respectively (Diskin *et al*, 1993).

The improvement in fertility should give the following benefits:-

(i) Higher milk production because of a longer period of peak lactation with a shorter "tail off" period and shorter dry period.

(ii) Less slip in calving pattern, enabling greater exploitation of incentives for seasonal milk production.

(iii) Improved income from more calves.

(iv) Reduced culling rate.

(v) Reduced vet charges and insemination costs as a result of fewer services needed.

It is not yet clear why fish meal feeding improves fertility. One possibility is that the improved supply of amino acids (peptides) beyond the rumen corrects negative nitrogen balance in early lactation - microbial and tissue amino acid requirements are met with less production of toxic ammonia; hormone production may be stimulated as a result, to the benefits of fertility. Another possibility is that the long chain omega 3 unsaturated fatty acids from fish meal escaping changes in the rumen, (see earlier section 2.2.2) through the eicosanoid mechanism favourably affect fertility, though this is only conjecture at the moment.

5. QUALITY CRITERIA FOR RUMINANT GRADE FISH MEAL

A fish meal produced specifically for ruminants will meet the following criteria:

(i) it is produced from fresh raw material - as fish spoils its solubility, and hence degradability will increase;

(ii) only a small proportion of solubles, if any, will have been returned to the meal - the soluble nitrogen content will be not higher than 22%. Meals without solubles are known as press-cake meals.

(iii) the lipid (fat) content will not exceed 9% and it will be antioxidant treated.

Through (i) and (ii) the fish meal will provide protein, a high proportion of which (60 to 70%) will escape rumen breakdown, but providing a proportion of degraded protein part of which will slowly release in the rumen. This will contribute towards the requirements for ongoing fermentation of structural carbohydrates of the forage in particular, for which a continuous nitrogen source is needed. The lipid limit should avoid excessive levels in the rumen (see section 2.2.2) and the antioxidant treatment minimises oxidation of unsaturated fatty acids.

6. COST BENEFITS FROM FISH MEAL FEEDING

The benefits of fish meal feeding which will improve milk profitability are as follows:-

(i) Higher milk yields.

(ii) Increased milk protein content in some situations.

(iii) Improved fertility.

These benefits have been costed for a situation prevailing in the U.S.A. (Wisconsin) in 1991 and in the UK in 1990. The results are as follows:-

FISH MEAL AND REPRODUCTIVE PERFORMANCE -ECONOMIC BENEFIT IN U.S. (WISCONSIN)[1] SITUATION

Decrease in calving interval	$1.50-3.50 per cow, per day
(11 days x $1.50)	= $16.50
saving per 100 cow herd	= **$1,650**
Culls	$600/head
(11 fewer culls in 100 cow herd)	x 11
Saving per 100 cow herd	= **$6,600**
Cost per service	$15/head/year
reduction in services - 0.69 per cow saving	= $10.35
saving in 100 cow herd	= **$1,035**
Veterinary cost saving	$1 per cow
saving in 100 cow herd	= **$100**
TOTAL	**$9,385 per 100 cow herd or approximately $100 per cow per laction**

[1]Costings by R Shaver, University of Minneapolis

As the main forage in Wisconsin is alfalfa haylage, for which the overall milk yield response was found to be

1.3kg per cow per day, the value of the extra milk from 100 cows daily (130kg) would be $31.4. This is estimated at an increase of 312kg for an average lactation yield of 8,000kg - worth $75 per cow per lactation or $7,500 for a 100 cow herd. The extra return from improved fertility and milk yield ($9,385 plus $7,500) for a 100 cow herd would be $16,885. There would be a further small extra return in those situations where forage feeding was at least 50% of the diet from an increase in milk protein content.

For the UK situation, based on conception rate improving from 44% to 64% (as in the Northern Ireland trial) these cost benefits amount to around £120 per cow per lactation, based on costings by R Esselmont of Reading University.

Feeding fish meal to high yielding cows in early lactation has been shown to increase milk yield. Alternatively, yield can be maintained and cuts made in concentrate feeding. The cost benefits resulting are £45 and £40 per cow per lactation respectively. This takes into account the extra cost of feeding fish meal.

The combined cost benefit of improved fertility and improved production efficiency are calculated at £160-£165 per cow per lactation.

Although generally it is not recommended to feed fish meal with high fat levels (100g fish oil equivalent or more per day) to depress milk fat, in some situations this could be advantageous. For example, in Holland, quotas are based on milk fat production; a reduction in milk fat concentration would allow more milk to be produced within the quota. The economic benefits of this would have to be weighed against reduced fibre digestion that might occur.

7. RECOMMENDED FEEDING OF FISH MEAL

It is recommended that during lactation 0.75 kg of fish meal is fed. This should be ruminant grade. Fish meal feeding should continue for at least the first half of lactation; it should be introduced gradually prior to calving - for example 10 days before, increasing to at least 0.5 kg per day before calving. It can be included in either total mixed rations or in compounded feeds. The rate of incorporation should be sufficient to provide between 0.5 and 0.75 kg per cow per day. Mixtures of fish meal plus sugar beet pulp e.g. 50:50, can be fed out of parlour. They can also be sprinkled on silage - or fish meal can be sprinkled on directly. For direct feeding, more gradual introduction may be necessary.

8. ACKNOWLEDGEMENTS

The contributions to the financial evaluation from fertility improvements resulting from fish meal feeding by Dr. Richard Esslemont of Reading University and Dr. Randy Shaver of the University of Minneapolis are gratefully acknowledged. Helpful comments from Dr. J. Opstvedt, SSF, Bergen, Professor J.P.H. Wessels, FIRI, Cape Town and P Sandbøl, Esbjerg Fiskeindustri AmbA are also acknowledged. Thanks are due to Mrs Jeanne Pike for her painstaking proof reading.

9. APPENDIX

9.1 APPENDIX 1

EFFECT OF FISH MEAL ON MILK PRODUCTION - MILK PRODUCTION TRIALS

Those trials with fish meal which are believed to show how the fishmeal is utilised by dairy cows are discussed below. Other trials are summarised in Appendix Table 4.

It is almost 15 years since the Association first planned a large scale milk production trial to test fish meal in dairy cow feeding in the U.K. At that time, it was unusual for dairy farmers to feed fish meal. Because the better commercial herds were achieving higher yields than herds on experimental units, a trial involving 12 large commercial farms in the West Country (UK) was carried out (Miller *et al*, 1982).

The high yielding cows in the herds were chosen for the trial on the basis of stage of lactation and previous milk yield and lactation number (number of reproductive cycles). They received their normal farm diet, believed to be adequate in protein, with or without an additional 0.75kg of fish meal. These two treatments were imposed according to a double reversal design. An increase of 2.7 litres per day or around 9% was found as the response to this intermittent feeding of fish meal in early lactation (see Appendix Figure 1). There was a slight improvement in the percentage fat in the milk, and the percentage protein remained unchanged as a result of fish meal feeding.

This trial demonstrated that in diets which were considered adequate in protein, there was a response to fish meal. The protein sources in the diet, namely grass silage plus a mixture of proteins in the concentrate (proprietary feeds were given) would appear to have provided inadequate quantities of undegradable protein.

Another trial carried out in the U.K. demonstrated the yield that could be obtained from cows fed on silage only, and how this changed feeding either a compounded feed with 18% crude protein, or a protein supplement. Appendix Figure 2 shows that a yield of 4,000kg per lactation was possible from grass only, with cows yielding around 16kg per day of milk. With a protein supplement, or a compound feed with 18% protein, this was boosted to about 21kg per day giving a lactation yield of around 5,200kg. This daily increase in milk of around 5kg was achieved through the feeding of either 5kg of concentrate or 0.45kg of fish meal plus 1.3kg of soyabean meal, the yield increase being a very cost-effective response (Reeve, 1987). This trial demonstrates that with grass silage diets fed alone, protein may be more limiting than energy.

A marked response of dairy cows fed forage to a fish meal supplement was demonstrated by Dhiman and Satter (1991) at the U.S.D.A. Dairy Forage Research Centre in Wisconsin. An additional supplement of corn with the fish meal gave a further milk yield response (see Appendix Figure 3). This work demonstrated that a forage diet which might be considered limiting in energy was limiting in both energy and protein. Interestingly, there was practically no depression of milk fat in this trial despite the fact that 1.2kg per day of fish meal (which is 0.6kg of fish lipid) were fed. The protein content of the milk was boosted by the supplements.

In Canada, protein/urea supplements were compared to a basal diet consisting of soyabean meal plus grass silage (negative control). Supplements of additional soyabean meal or fish meal were compared with or without additional urea added to the grass silage (Erfle, *et al*, 1983). There was a response in milk yield to the additional soyabean when urea was added, though there was a response to soyabean meal alone (see Appendix Figure 4). The biggest response was obtained with the supplement of fish meal and urea. There was no response to fish meal alone. The explanation for these results may be that soyabean meal provided excessive levels of degradable protein -hence the failure to get a response when additional urea was added, whereas the fish meal provided inadequate levels of degradable protein - hence the good response when fish meal and urea addition were combined. The fish meal depressed milk fat compared with the soyabean meal.

In a trial of the supplements of either urea, fish meal, or formaldehyde protected soya, were compared added to grass silage. Milk yield was increased by the protein supplements, compared with the urea treatment. The highest yield was achieved with the fish meal supplement. Formaldehyde treatment of the soya did not have any effect (Broster *et al*, 1981). The low digestibility of formaldehyde treated protein beyond the rumen (see Ingalls *et al*, 1992) may account for the lack of response in contrast to the previous trial. Either way, the fish meal increased the fat content of the milk. Although the amount of fish meal fed was not stated in Oldham's work, it is believed that it did not exceed 1kg per day and that the fish meal fed was not more than 75g per day.

Appendix Table 4c

APPENDIX TABLE 4
MILK RESPONSE TO FISH MEAL - GRASS SILAGE DIETS

REF NO.[2]	F:C RATIO	CONTROL YIELD KG[3]	RESPONSE	REF.	COMMENTS
1. (i)	ad lib silage:10-13kg	26.6	1.0	Miller et al 1982	
2. (ii)	ad lib silage:10-13kg	26.0	1.3	Miller et al 1982	
3.	ad lib silage:16kg	42.1	0.6	Pike et al 1984	
4.	ad lib silage:12kg	26.1	1.4	Pike et al 1984	
5.	ad lib silage:15kg	22.9	(-0.1)	Pike & Miller 1986	Concentrate reduced 2kg with fish meal feeding
6. (i)	ad lib silage:8kgDM	23.1	1.6	Thomas et al 1985	
(ii)	ad lib silage 8kg DM	23.1	3.4	Thomas et al 1985	Yield increased with increasing fish meal-control, low level of fish meal
7. (i)	ad lib:9kg conc.	23.7	1.0	Oldham et al 1985b	Fish meal v soya
(ii)		23.4	2.6		Fish meal v soya (higher levels)
8. (i)	ad lib:9kg conc.	23.6	0.4		
(ii)	ad lib:9kg conc.	25.7	-0.6		
9. (i)	ad lib silage:9kg conc.	27.7	0.5	Strickland et al 1985	
(ii)	ad lib silage:9kg conc.	28.5	-1.4	Strickland et al 1985	
10. (i)	ad lib silage:9kg conc.	27.3	-0.3	Strickland et al 1985	
(ii)	ad lib silage:9kg conc.	30.3	-2.9	Strickland et al 1985	
11. (i)	8.3:9.3	26.1	0.2	Sloan et al 1988	
	8.6:9.3	26.1	0.7	Sloan et al 1988	
12. (i)	9.35:6.83	26.2	0.1	Small & Gordon 1985 & 1990	
(ii)	9.35:6.83	26.2	0.0		
13.	9.5:6.5	25.9	0.2		
14. (i)	9.0:0.8	16.2	1.9	Gordon & Small 1990	
(ii)	9.1:4	20.7	2.2	Gordon & Small 1990	
15.	8.3:7.0	23.0	0		
	8.7:7.0		0.6	Cody et al 1990	
16. (i)	12.1:1.5	21.3	(-1.2)		
(ii)	12.1:1.3	21.3	(-0.4)	Rae et al 1986	Fish meal and soyabean meal replaced a larger amount of concentrate.
17. (i)	10.6:3.7	15.4	-0.1	Hecheimi et al 1989	
(ii)	11.0:4.1	15.3	0	Hecheimi et al 1989	
18. (i)	ad lib silage:10	24.3	(0.7)	Volden & Harstad	Comparison of high v low degradability fish meal for cows in lactation nos 1 & 2
(ii)	ad lib silage:10	29.0	(-0.5)	Volden & Harstad 1991	As above with older cows
	12.8:3.0	21.0	1.8	Davis 1992	Comparison of high protein v low protein diet with 750g v 150g fish meal per cow per day
		AV RESPONSE 0.5[1]			

des comparisons of with and without fish meal where concentrate feeding is the same. Other comparisons, in brackets, have been excluded.

Appendix Table 4d	APPENDIX TABLE 4 MILK RESPONSE TO FISH MEAL - GRASS SILAGE DIETS				
REF NO.	**F:C RATIO**	**CONTROL YIELD KG[3]**	**RESPONSE KG[3]**	**REF.**	**COMMENTS**
1. (i)	4:6	20.1	0.8	Ørskov et al '81	
(ii)	4:6	28.9	-1.3	Ørskov et al '81	
(iii)	4:6	28.9	0.5	Ørskov et al '81	
(iv)	5:5	26.3	-0.3	Ørskov et al '81	
(v)	7:3	21.2	2.7	Ørskov et al '81	
2. (i)	6:11	22.5	1.3	Garnsworthy '89	
(ii)	7.5:10	23.4	0.6	Garnsworthy '89	
			AV RESPONSE 0.6		

APPENDIX TABLE 5

Increment in Milk Protein (g/kg) With Fish Meal in Paired Treatment Comparisons

A. ISONITROGENOUS SUBSTITUTION

i) Grass Silage Based Diets

REF NO.[1]	REFERENCE	DIET FORAGE:CONCENTRATE RATIO	RESPONSE (C&G)	COMMENTS
7	Oldham et al, 1985b	Ad lib:9kg/d	-0.8	
7	Oldham et al, 1985b	Ad lib:9kg/d	-0.9	
8	Oldham et al, 1985b	Ad llib:9kg/d	+0.2	
8	Oldham et al, 1985b	Ad lib:9kg/d	+0.5	
9	Strickland et al, 1985	Ad lib:9kg/d	-0.3	
9	Strickland et al, 1985	Ad lib:9kg/d	+0.7	
10	Strickland et al, 1985	Ad lib:9kg/d	-0.8	
10	Strickland et al, 1985	Ad lib:9kg/d	+0.2	
11	Sloan et al, 1988	8.6:9.2	+0.2	
12	Small & Gordon, 1985	9.35:6.8	+0.8	
12	Small & Gordon, 1985	9.35:6.8	+0.7	
13	Small & Gordon, 1990	9.5:6.5	+1.4	P<0.001
15	Cody et al, 1990	8.3:7.0	+0.5	Lower response to increased UDP P<0.05
15	Codey et al, 1990	8.3:7.0	+1.3	
17	Hecheimi et al, 1989	10.6:3.9	-0.1	
17	Hecheime et al, 1989	11.1:4.3	-0.2	
18	Volden et al, 1991	Ad lib:0.4kg/kg milk (10 kg)	+0.5	1st & 2nd lactation P<0.05
18	Volden et al, 1991	Ad lib:0.4kg/kg milk (11.6kg)	0	
Mean			+0.22	±0.157 NS
Mean trials 12,13,15,17		Forage:Concent. >50:50	+0.63	±0.235 P<0.05

[1] These reference numbers correspond to those in Appendix Table 2

APPENDIX TABLE 5 CONTINUED
Increment in Milk Protein (g/kg) With Fish Meal in Paired Treatment Comparisons
A. ISONITROGENOUS SUBSTITUTION
ii) Hay

REF NO.[1]	REFERENCE	DIET FORAGE:CONCENTRATE RATIO	RESPONSE (G/KG)	COMMENTS
20	Ørskov et al, 1981	40:60	+2.6	v. urea P<0.001
21	Ørskov et al, 1981	40:60	+1.2	
21	Ørskov et al, 1981	40:60	+0.6	
22	Ørskov et al, 1981	50:50	+2.5	P<0.05
22	Ørskov et al, 1981	70:30	0	
23	Garnsworthy, 1989	6:11	-0.7	
23	Garnsworthy, 1989	7.5:10	+0.4	
Mean			**+0.94**	±0.469 NS

APPENDIX TABLE 5
Increment in Milk Protein (g/kg) With Fish Meal in Paired Treatment Comparisons
B. FISH MEAL INCREASES CRUDE PROTEIN CONTENT OF DIET
i) Grass Silage Based Diets

TRIAL NO.	REFERENCE	DIET FORAGE:CONCENTRATE RATIO	RESPONSE (G/kG)	COMMENTS
1	Miller et al, 1982	Ad lib:10-13kg/d	-0.1	
2	Miller et al, 1982	Ad lib:12.75kg/d	-1.2	
6	Thomas et al, 1985	Ad lib:8kg	+0.4	
6	Thomas et al, 1985	Ad lib:8kg	0	
7	Oldham et al, 1985b	Ad lib:9kg	0	
7	Oldham et al, 1985b	Ad lib:9kg	0	
8	Oldham et al, 1985b	Ad lib:9kg	+0.8	
8	Oldham et al, 1985b	Ad lib:9kg	-0.5	
9	Strickland et al, 1985	Ad libL9kg	+1.0	
10	Stricland et al, 1985	Ad lib:9kg	+0.5	
10	Strickland et al, 1985	Ad lib:9kg	+0.5	
11	Sloan et al, 1988	8.3:9.3	-0.5	
14	Gordon & Small, 1990	9.3:0.8	+0.6	Main effect P<0.01
14	Gordon & Small, 1990	8.5:4.0	+2.5	F:C x FM interaction
14	Gordon & Small, 1990	8.1:7.2	+0.9	was NS
15	Cody et al, 1990	7.8:6.9	+1.2	Increase in UDP P<0.05
16	Rae et al, 1986	11.4:0	+2.4	P<0.05
16	Rae et al, 1986	11.4:0	+2.2	P<0.05
Mean			**+0.59**	±0.238 P<0.05
Mean trials 6,14,15,16		F;C>50:50	**+1.27**	±0.344 P<0.01

APPENDIX TABLE 5 CONTINUED
Increment in Milk Protein (g/kg) With Fish Meal in Paired Treatment Comparisons
B. FISH MEAL INCREASES CRUDE PROTEIN CONTENT OF DIET
(ii) Hay Based Diets

No trials				
		iii) Alfalfa Silage Based Diets		
26	Dhiman & Satter, 1989	98.2:1.8	+1.7	P<0.05
27	Dhiman & Satter, 1991	75:25	+0.1	
		iv) Maize Silage Based Diets		
31	Bruckental et al, 1989	25:75	+0.3	
32	Bruckental et al, 1989	25:75	+0.2	
33	Wohlt et al, 1991	50:50	-2.0	
35	Erfle et al, 1983	60:40	+0.8	
		v) Maize4 Silage Plus Alfalfa Hay Based Diet		
42	De Peters & Palmquist, 1990	45:55	+0.7	Main effect P<0.06
42	De Peters & Palmquist, 1990	45:55	+1.3	

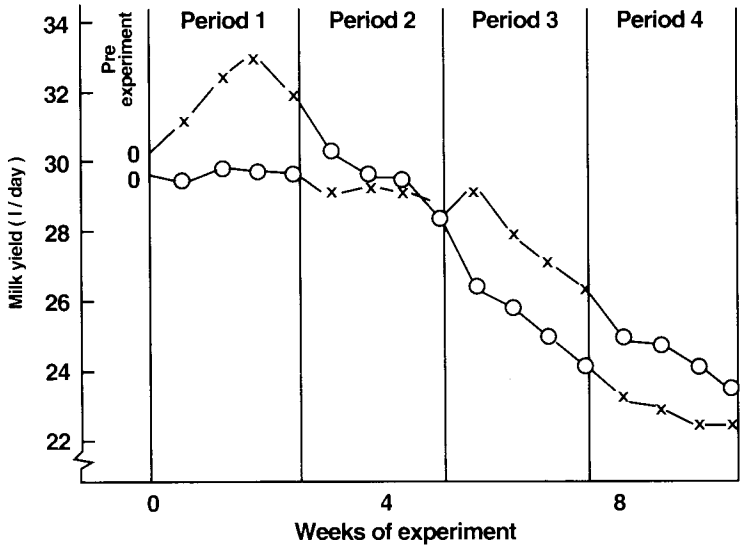
APPENDIX TABLE 5
Increment in Milk Protein (g/kg) With Fish Meal in Paired Treatment Comparisons
C. FISH MEAL WITH REDUCED CONCENTRATES
i) Grass Silage Based Diets

No trial	REFERENCE	DIET FORAGE:CONCENTRATE RATIO	RESPONSE (g/kg)	COMMENTS
3	Pike et al, 1984	Ad lib:16kg/d	-0.1	
4	Pike et al, 1984	Ad lib:12kg/d	-0.2	
5	Pike & Miller, 1986	Ad lib:15kg/d	0	
16	Rae et al, 1986	10.4:4.4	+1.2	
		II) ALFALFA SILAGE BASED DIETS		
28	Petit & Veira, 1991	12.4:10.4	+0.7	

9.3 APPENDIX FIGURES 1-4

APPENDIX FIGURE 1

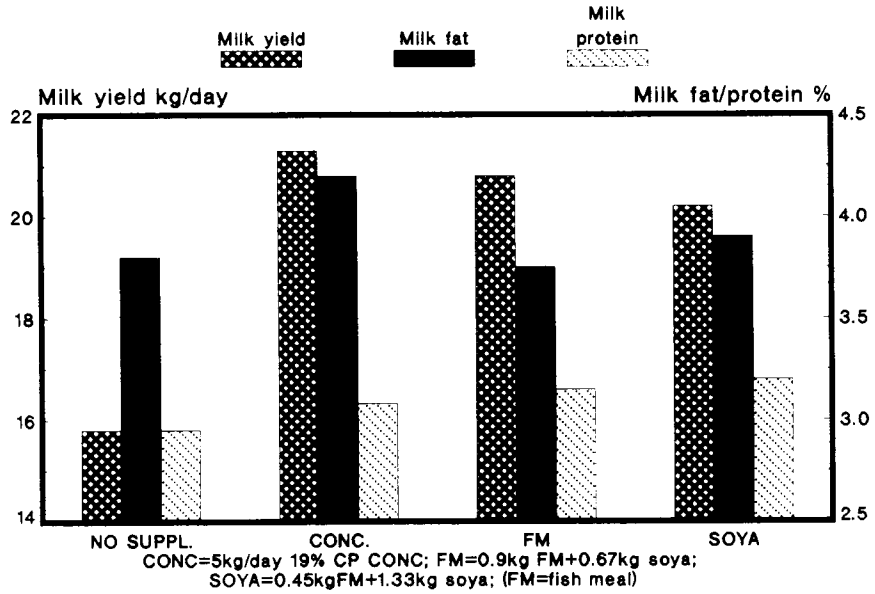
MILK YIELD OF COWS FED DIETS WITH AND WITHOUT FISH MEAL



Responce to supplemental fish meal in alternating four-week periods averaged over 13 herds: X, plus fish meal; O, normal diet.
Data from Miller et al. (1982).
(From IFAMM Technical Bulletin No 14)

APPENDIX FIGURE 2

COMPARISON OF SUPPLEMENT FOR GRASS SILAGE FED COWS -RESPONSE TO CONCENTRATE V FISH SOYA MEAL COMBINATIONS

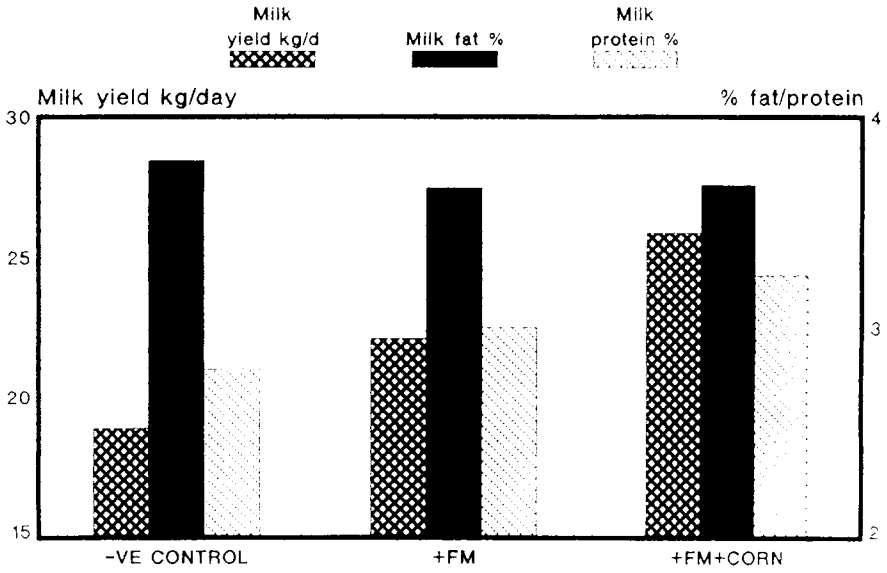


CONC=5kg/day 19% CP CONC; FM=0.9kg FM+0.67kg soya;
SOYA=0.45kgFM+1.33kg soya; (FM=fish meal)

From Reeve, A., 1987

APPENDIX FIGURE 3

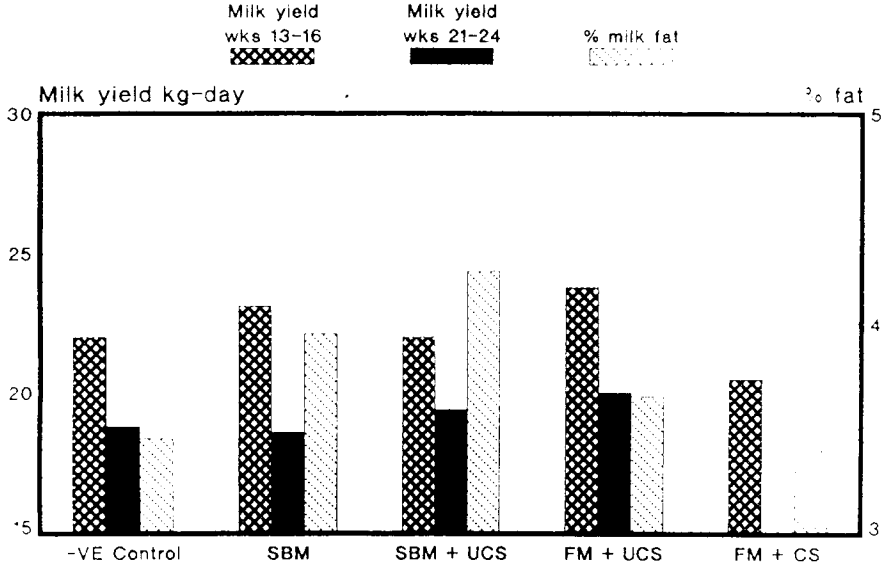
HIGH FORAGE DIETS FOR DAIRY COWS -EFFECT OF FISH MEAL (FM) OR FISH MEAL + CORN



From Dhiman and Satter, 1991

APPENDIX FIGURE 4

EFFECT ON MILK PRODUCTION OF FISH MEAL -WITH UREA/CORN SILAGE



From Erfle et al., 1983

SBM=soyabean meal; UCS=urea corn silage; FM=fish meal

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TECHNICAL BULLETIN NUMBER 27 - ERRATUM SLIP

I regret to say that in the printing of Technical Bulletin number 27, three errors have occurred in the setting up of the tables.

In Appendix Table 1 (page 13) the Blood meal figure under the "dup" column should read "0.81" not 0.18.

Figures in the first and third row of Appendix Table 4b (page 16) have been transposed one column to the right. These have been moved across in a correct version given below.

On page 18, the heading of Appendix Table 4d, "Milk Yield Response to Fish Meal" refers to "Hay Diets" and not Grass Silage Diets.

APPENDIX TABLE 4

Appendix Table 4b. MILK YIELD RESPONSE TO FISH MEAL - ALFAFA HAYLAGE DIETS					
REF NO.	F:C RATIO	CONTROL YIELD KG	RESPONSE KG	REF.	COMMENTS
24. (i)	70 : 30	36.0	1.1	Broderick 1988 & 1989	
25. (i)	56 : 44	35.7	0.6	Broderick 1991	Regular menhaden meal
(ii)	56 : 44	35.7	0.9	" "	Sea Lac ruminant grade menhaden meal
26. (i)	91.2 : 88	18.8	3.4	Dhiman & Satter 1989	Low yielding cows on forage only with FM
(ii)	61.2 : 38.8	18.8	(7.0)	" "	Low yielding cows on forage + corn with FM
28.	12.4 : 10.4	32.2	0.7	Petit & Veira 1991	
			Av response 1.3		
Fish meal with blood meal with/without protected fat:					
27. (i)	75 : 25	29.6	6.1	Dhiman & Satter 1991	Response to 0.38 kg FM 0.13 kg blood meal
(ii)	75 : 25	31.0	2.5	" "	Response to 0.38 kg FM 0.13 kg blood meal
(iii)	75 : 25	4.4	4.4	" "	Response to glucose infused into abomasum - no fat