Effect of forage type and cottonseed supplementation on the production of dairy cows

by

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Thesis

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Supervisor: Dr. J. Coetzee

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously, in its entirety or in part, submitted it at any university for a degree.

14/11/97

Date

Abstract

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The type of forage seems to influence the production response of dairy cows receiving supplements of whole cottonseed. Literature indicated that supplementation of whole cottonseed in diets with maize silage as the only dietary forage resulted in improved milk yields but depressions in the milk fat content. It was also indicated in the literature that milk fat depression was alleviated when 10 to 20% of the maize silage were substituted with lucerne hay. Oat silage is the main source of forage for large numbers of lactating dairy cattle in the Western Cape. The question that needs to be answered is whether this depression in milk fat is a property of maize silage, or also of oat silage. Diets containing approximately 7% fat (DM), mainly from whole cottonseed, and approximately 3% fat (DM) were used to evaluate the *in sacco* degradability of oat silage, maize silage and lucerne hay. The degradability of the samples in the rumen was fitted on the exponential equation $p = a + b(1 - e^{-ct})$. Effective degradation of DM, OM, NDF and ADF was calculated for each treatment by introducing fractional outflow rates of 0.02, 0.05 and 0.08/h. There was no difference in the degradability of the three forages within the same diet. Effective degradability of DM, OM and ADF did not differ in effective degradability between the two diets. The effective NDF degradability was lower ($p < 0.05$) in the cottonseed supplemented diet at an outflow rate of 0.08/h. The oat silage in six commercial diets was substituted at different rates by lucerne hay. Diets contained either whole cottonseed supplemented at 18% of DM or no inclusion of cottonseed. Twelve lactating dairy cows were used in a change-over experimental design. The inclusion of whole cottonseed did not affect milk yield, improved ($p < 0.05$) milk fat percentage from 3.09 to 3.33% and decreased ($p < 0.05$) milk protein percentage from 2.84 to 2.75%. Dry matter intake was significantly lower ($p < 0.05$) on the whole cottonseed diets (17.8 vs. 18.2 kg/cow/day). As expected, the inclusion of whole cottonseed shifted the fatty acid composition of milk fat from short chain fatty acids to more longer chain fatty acids. It was difficult to quantify this change in fatty acid composition due to interactions between the levels of forage and the cottonseed inclusion. The inclusion levels of oat silage and lucerne hay were compliments of each other. Significant differences could therefore be due to the increasing levels of lucerne hay or the decreasing levels of oat silage. An increase in the amount of lucerne included in the diets led to significant differences in almost all the production responses measured. Milk fat percentage being the only exception. Even milk fat percentage showed an increase, although not significant. Whole cottonseed can be included in diets with oat silage as the only dietary forage. The price of whole cottonseed, the milk price structure of the milk buyer and the genetic potential of the cows will determine the economic viability of whole cottonseed inclusion.

(Key words: whole cottonseed, fat, forage, degradability)

Samevatting

Invloed van ruvoertipe en die aanvulling van katoensaad op die produksie van melkkoeie

deur

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Ruvoertipe het 'n invloed op die produksierespons van lakterende melkkoeie wat aanvullings van heel katoensaad ontvang. Die literatuur dui aan dat die aanvulling van heel katoensaad in mieliekuilvoer gebaseerde diëte aanleiding gee tot verhoogde melkproduksie, maar verlaagde bottervetpersentasie. Hierdie daling in bottervetpersentasie word volgens die literatuur opgehef wanneer lusernhooi 10 to 20% van die mieliekuilvoer vervang. Hawerkuilvoer word in groot hoeveelhede in die Wes-Kaap as ruvoerbron aan melkkoeie gevoer. Die vraag ontstaan of hierdie daling in bottervet wat tydens die voer van mieliekuilvoer ontstaan ook 'n kenmerk van hawerkuilvoer is. Die *in sacco* degradeerbaarheid van hawerkuilvoer, mieliekuilvoer en lusernhooi is in rumenomgewings met (ongeveer 7% vet as % van DM) of sonder heel katoensaad (ongeveer 3% vet as % van DM) ondersoek. Die degradeerbaarheid van die monsters is op die model $p = a + b(1 - e^{-ct})$ gepas waarna effektiewe degradeerbaarheid by drie verskillende deurvloeitempo's (0.02, 0.05, 0.08/h) bereken is. Geen verskille is waargeneem in die degradeerbaarheid van die drie ruvoertipes binne dieselfde rantsoen nie. Die effektiewe degradeerbaarheid van DM, OM en ADF van die drie ruvoere het nie verskil tussen die rantsoene met of sonder heel katoensaad nie. Die effektiewe NDF-degradeerbaarheid van mieliekuilvoer was laer ($p < 0.05$) in die heel katoensaad gesupplementeerde rantsoen by 'n deurvloeitempo van 0.08/h. Kommersiële rantsoene waarin hawerkuilvoer as enigste ruvoerbron stapsgewys deur lusernhooi vervang is en wat met (18%) of sonder heel katoensaad insluiting geformuleer is, is in 'n oorskakelproef aan 12 Holsteinkoeie gevoer. Heel katoensaadinsluiting het geen effek op melkproduksie gehad nie, maar het bottervetpersentasie verhoog van 3.09 na 3.33% ($p < 0.05$) en proteïenpersentasie verlaag van 2.84 na 2.75% ($p < 0.05$). Droëmateriaalinname is ook beïnvloed en het gedaal van 18.2 na 17.8 kg/koei/dag ($p < 0.05$). Soos verwag, het die insluiting van heel katoensaad ook die vetsuursamestelling van die bottervet verskuif van korter kettingvetsure na langer kettingvetsure. Dit was egter moeilik om die verandering in vetsuursamestelling te kwantifiseer omdat daar interaksies tussen die vlakke van ruvoer- en die heel katoensaadaanvulling was. Die interpretasie van die resultate word bemoeilik omdat die vlakke van hawerkuilvoer en lusernhooi komplimente van mekaar was. Betekenisvolle verskille kon wees a.g.v. die afname in hawerkuilvoer of die toename in lusernhooi in die onderskeie diëte. Verhoogde luserninsluiting het beduidende verskille in alle produksiekenmerke tot gevolg gehad. Die enigste uitsondering was die bottervetpersentasie, waar die neiging hoër was, maar nie betekenisvol nie. Die insluiting van heel katoensaad in diëte met hawerkuilvoer as die enigste bron van ruvoer het geen nadelige effekte op die produksie-eienskappe van lakterende melkkoeie nie. Die prys van heel katoensaad, die melkprysstruktuur van die koper en die genetiese potensiaal van die koeie gaan bepaal of dit ekonomies geregverdig is.

(Sleutelwoorde: heel katoensaad, vet, ruvoer, degradeerbaarheid)

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Contents

Chapter 1

General Introduction

The inclusion of fats in diets for high producing dairy cows has become practice for many dairy farmers in South Africa. Variation in responses obtained with the inclusion of fat in some feeding programs created uncertainty about the correct use of fats. The performances of lactating dairy cows appear to be influenced by the type of forage and fat included in the diets.

The most common type of fat used in diets of dairy cows in South Africa is most probably whole cottonseed (WCS). The results of feeding WCS to lactating dairy cows appear to be influenced by the type of forage in the diet. Staples *et al.* (1991) reviewed five experiments where corn silage was the primary dietary forage and reported that the inclusion of WCS increased milk yield but decreased milk fat percentage. Smith and Harris (1992) reported the same tendency towards a decreased milk fat percentage when they summarised nine experiments where WCS was supplemented to corn silage as the primary dietary forage. Average daily milk yield was unchanged at 25 kg per cow for both control and WCS supplemented diets. Average milk fat percent, however, decreased with 5.9% from 3.58 to 3.37 %. Milk protein percent was unchanged. They concluded that their results do not support the inclusion of WCS in diets for lactating dairy cows when corn silage is the only dietary forage, except when economics dictate.

The same authors summarised six experiments in which WCS was included at an average level of 18 % of dietary dry matter (DM), with lucerne hay as the primary dietary forage. Daily milk production was unchanged, but average milk fat percent and 4% fat corrected milk (FMC) production increased 11.4 % from 3.42 to 3.81 and from 23.3 to 24.9 kg/day, respectively. These results support the inclusion of WCS in dairy cow diets with lucerne hay as the primary dietary forage, especially to increase milk fat percentage.

The inclusion of WCS in diets containing corn silage as the primary forage and lucerne hay or bermudagrass hay as the secondary forage did not change average daily milk production, but increased (9.1%) milk fat percent from 3.41 to 3.72 (Smith & Harris, 1992). According to the authors it appears that the inclusion of 10 to 20% hay in corn silage based diets alleviates the fat-induced milk fat depression caused by the inclusion of WCS.

The Western Cape region of South Africa receives almost all its rain during the four winter months (May – August). The dairy farmers in the majority of this region are dependent on winter crops to provide forage for their dairy animals throughout the year. Because of the fact that the area is mainly a wheat-producing region, the forage crops must be species suited for alternate husbandry (to eliminate the transfer of certain wheat diseases) and provide the opportunity to exterminate broad-leafed plants. The most common forage is therefore oats that is harvested mostly for silage.

The objective of this study was to determine if the feeding of WCS would impair oat silage fibre digestion and hence depress milk fat percentage in diets where oat silage was the primary dietary forage. Furthermore if the feeding of lucerne hay as a secondary dietary forage would provide any responses. In order to achieve the above mentioned, two trials were conducted. Firstly, to determine if the feeding of WCS would impair the fibre digestibility of oat silage, maize silage and lucerne hay during an *in sacco* digestibility trial in diets with or without WCS. Secondly, to examine the production responses on diets containing oat silage as the primary forage supplemented with WCS and the substitution of different amounts of oat silage with lucerne hay in these diets.

Due to the difference in price of oat silage and lucerne hay, and the difference in milk composition expected when WCS are fed, an economic evaluation was included in the results.

Chapter 2

Effect of type of forage on the performance of lactating dairy cows supplemented with oilseeds

2.1 Literature review

The increased genetic potential of dairy cows for milk yield has exceeded their ability to meet their energy needs from diets high in cereal grains. Thus, feeding dietary fats to lactating cows has become routine on many dairy farms. Because of the variation in responses obtained with the inclusion of fat in feeding programs, there is still uncertainty about the correct use of fats in diets for high producing dairy cows. The type of roughage as well as the type of fat included in the diet influences the production of dairy cows.

The difficulty in satisfying the energy requirements of dairy cows during early lactation led to the inclusion of fat sources to the diets of high producing dairy cows to improve their energy status (Palmquist & Jenkins, 1980; Laarveld *et al.*, 1981; Coppock, 1985; Casper *et al.*, 1990). Fats contain on average 37 MJ/kg gross energy that is available as digestible energy and of which approximately 80% (29.6 MJ/kg) is available as net energy (Thornton & Tume, 1984). Smith & Harris (1992) acknowledge these high values, but concludes that fats probably do not contain more than 24.4 MJ NE*l*/kg. One unit of fat has approximately 2.25 times the energy of one unit of carbohydrate (Palmquist, 1989). The addition of supplemental fat to dairy rations may improve the energy status of cows, but the net result depends on the effects of supplemental fat on dry matter intake, fatty acid digestibility and milk production.

With increasing levels of dietary fat in diets for high producing dairy cows, ruminal cellulose fermentation was depressed (Palmquist, 1984, 1987a). Rumen micro-organisms can only tolerate 3 to 5% unprotected dietary fat (Palmquist & Jenkins, 1980; Palmquist, 1984). Fat supplementation above 5% must be rumen inert. The mechanism by which fat affects rumen fermentation is not clearly established. Devendra and Lewis (1974) summarised four theories to explain these effects:

- physical coating of the fibre with fat and thereby preventing microbial enzyme activity,
- modification of the rumen microbial population due to possible toxic effects of fat on certain micro-organisms,
- inhibition of microbial activity from surface active effects of fatty acids on cell membranes and
- reduced cation availability from formation of insoluble complexes with long chain fatty acids.

The benefits of fat inclusion in dairy diets may be offset by the detrimental effects of dietary fat on rumen fermentation (Palmquist & Jenkins, 1980; Chalupa *et al.*, 1984; Jenkins & Palmquist, 1984;

Chalupa *et al.*, 1986; Palmquist *et al.*, 1986). These negative effects of fat on rumen fermentation may, however, be diminished or eliminated by feeding rumen inert fats (Palmquist & Jenkins, 1980).

Preformed fatty acids of dietary origin can be incorporated directly into milk, thereby sparing energy for other productive functions in the mammary gland. The key to mammary metabolic efficiency is the utilisation of long chain fatty acids, rather than acetate, for milk fat synthesis (Kronfeld, 1976). Although the energy obtained from the oxidation of long chain fatty acids may be relatively small, the yield of adenosine triphosphate (ATP) from the oxidation of long chain fatty acids is 10% more efficient than from the oxidation of acetate (Palmquist, 1988a). Several researchers have indicated that the efficiency of milk production was maximised when long chain fatty acids constituted 16 to 20% of the total metabolizable energy intake (Kronfeld, 1976; Brumby, *et al.*, 1978; Palmquist, 1988a). Maximum efficiency of milk production is achieved when diets for lactating dairy cows contain 7 to 8% total fat or 5% supplemental fat (Kronfeld, 1976; Brumby *et al.*, 1978; Palmquist, 1988a).

Dietary fat in lactating dairy cow diets has certain properties that make them attractive to dairy cattle nutritionists:

(i) Increased caloric density without compromising fibre (Palmquist & Jenkins, 1980; Coppock, 1985). The energy density of fats is greater than the ingredients they replace.

(ii) This permits increased energy intake for higher milk yield during early lactation when cows fail to consume sufficient feed (Coppock, 1985).

(iii) Increased efficiency of energy utilisation (Bines & Hart, 1882; Brumby *et al.*, 1978; Kronfeld, 1976; Kronfeld *et al.*, 1980). Long chain fatty acids (C16-C22) from supplemental fat are used with a high efficiency for lactation because they can be transferred directly to milk fat.

(iv) Enhanced lipogenic : glucogenic ratio (Kronfeld, 1976; Kronfeld *et al.*, 1980).

(v) The maintenance of fibre intake while increasing energy density leads to improved reproductive performance, greater persistency in milk yield and less ketosis (Coppock & Wilks, 1991).

The desired mammary response to fat is not always observed (Schneider *et al.*, 1990), and this inconsistency is only partly explained in terms of fat type and amount. Other dietary, endocrine and genetic factors may be involved (Kronfeld, 1976; Canale *et al.*, 1990; Chow *et al.*, 1990; Schneider *et al.*, 1990).

Shaver (1990) listed the following factors that should be considered when deciding which fat source to be used:

- the forage program and supplemental nutrient needs,

- the facility constraints in ingredient handling, storage and feeding,
- the feeding system constraints on palatability of the fat supplement,
- rumen inertness and digestibility of the fat supplement,
- milk yield and composition response and
- the cost of the fat supplement

2.2 Classification of fat sources for lactating dairy cows

Fat supplements can be divided in three main categories:

- oilseeds,
- rendered animal fats that may be blended with vegetable oils or acidulated soapstocks from the oil refining industry and
- granular fats (Ruminally-inert fats).

Stevens (1990) classified ruminant feed fats as liquid fats, whole oilseeds and protected dry fats. Protected dry fats can be sub-divided into physically protected and chemically protected fats.

The oilseeds together with animal fats are referred to as commodity fats while ruminally-inert fats are referred to as speciality fats (Shaver, 1990).

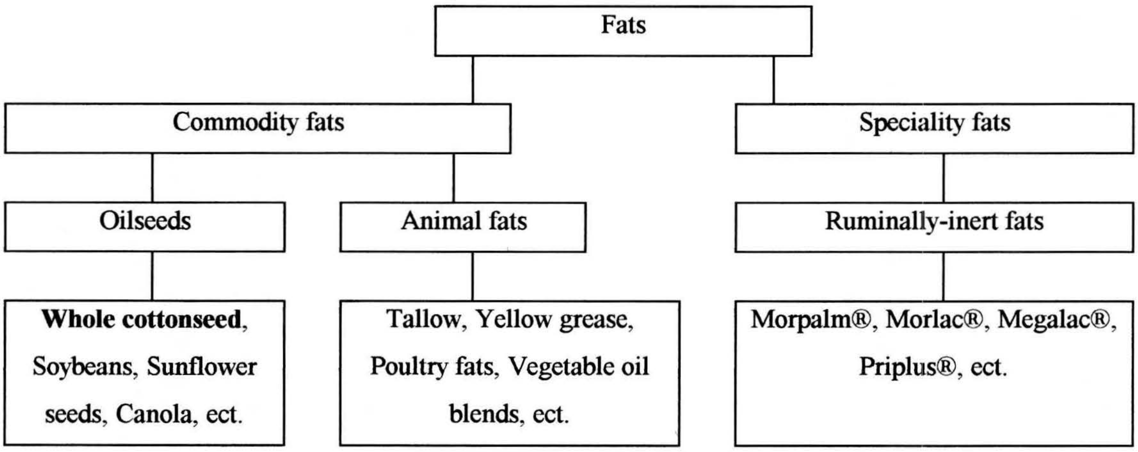

Figure 2.1 Diagrammatic display of the classification of different fat sources.

The interest of this study lies with whole cottonseed as an oilseed and therefore only the oilseeds will be discussed further.

2.2.1 Oilseeds

The world oilseed production for 1996-97 was anticipated at 256.3 million tons, up one million tons from the previous year. Nearly all the gain was in U.S crops. Soybean crops were reduced world-wide, while sunflower seed and rapeseed increased slightly (Brown, 1996).

Several hundreds of plants produce oilseeds, but only twelve are produced commercially (Gurr, 1984). Table 2.1 summarises information on eight commercially important oilseeds. In almost all of these the fatty acid, linoleic acid ($C_{18:2}$), predominates. According to Gurr (1984) the only exception is the very high (57%) linolenic acid ($C_{18:3}$) content of linseed oil. Soybean oil also contains significant amounts of linolenic acid ($C_{18:3}$) (Palmquist & Jenkins, 1980).

Table 2.1 Information on certain commercially important oilseeds (Gurr, 1984)

Seed	Oil content (%)	Important fatty acids	Important usage's
Soybean *(Glycine hispida)*	13-20	C9: C12-18:2	Margarine, cooking oil, salad oil, ice-cream, paint, soap
Peanut *(Arachis hypogaea)*	45	C9: C12-18:2	Margarine, cooking oil, salad oil, ice-cream
Coconut *(Cocos nucifera)*	63	C12:0	Margarine, cooking oil, soap, lubricants
Sunflower *(Helianthus anuus)*	40	C9: C12-18:2	Margarine, cooking oil, salad oil, paint, soap
Oilpalm *(Elaeis guineensis)*	50	C16:0, C9-18:1, C12:0	Margarine, biscuit fat, ice-cream, soap
Cotton *(Gossypium hirsitum)*	15-23	C9, C12-18:2, C9-18:1	Margarine, cooking oil, salad oil
Linseed *(L. usitatissimum)*	30-40	C9, C12, C15-18:3	Paint, varnish and other industrial usage
Canola (rapeseed) *(B. campestris)*	40-45	C18:1, C18:2, C18:3	Margarine, cooking oil

Free vegetable oils should not be used in ruminant diets as free fats inhibit rumen cellulose fermentation (Palmquist & Jenkins, 1980). This inhibition is minimised when full fat seeds are fed, probably due to the slow release of the fat from the cellular structure of the seed (Steele, 1984) with subsequent biohydrogenation to more saturated, less inhibitory fatty acids. The fatty acid compositions of the four most important oilseeds are given in Table 2.2.

Table 2.2 Fatty acid (FA) composition of typical oilseeds (Palmquist & Jenkins, 1980; Palmquist 1988a, 1991; Coppock & Wilks, 1991)

	FA content (mg/g)	Fatty acid content (g/100g fatty acid)						
Fatty acids		**14:0**	**16:0**	**16:1**	**18:0**	**18:1**	**18:2**	**18:3**
Cottonseed	-	1.0	25	0.8	3	17	54	0.2
Soybean	-	0.1	11	0.2	4	24	54	7
Canola	380	0	4.3	0.3	1.7	59.1	22.8	8.2
Sunflower	347	0.1	5.5	0	3.6	21.7	68.5	0.1

2.2.1.1 Whole cottonseed

In 1981/82 cotton oilseed production held second place in the world oilseed production (USDA Foreign Agriculture Circular, August 1981) and probably still does. Cottonseed production increased steadily over the last few years with India and China being some of the main contributors (Brown, 1996). Whole cottonseed (DM basis) contains a high level of energy (96% TDN, 16.0 MJ ME/kg, 9.30 MJ NE*l*/kg), protein (25%) and fat (23.8%) (NRC, 1989). The nutrient composition of whole cottonseed according to the NRC (1989) is given in Table 2.3. Whole cottonseed is therefore an excellent and unique ingredient and frequently used in diets for high producing dairy cows.

Whole cottonseed must be ruminated to release the fat (Palmquist, 1984). The linters help to distribute the seed in the rumen mat that in turn ensures that it is regurgitated with the fibrous portion of the feed and ruminated. Fatty acids in whole cottonseed are 71% unsaturated (Palmquist, 1988a). Whole cottonseed probably has little effect on rumen function and is highly valued as a feed energy source (Coppock *et al.*, 1987).

Whole cottonseeds are high in neutral detergent fibre (NDF, 44%) and are an excellent source of "effective" fibre in lactating cow diets despite the short fibre length. It is difficult to separate fat - and fibre effects when evaluating the production and digestion responses to whole cottonseed supplementation in research trials, because the addition of whole cottonseed generally increases neutral - and acid detergent fibre and lowers non-fibre carbohydrates, which can have a positive impact on rumen fermentation. Fibre in cottonseed was recently demonstrated to be as effective as the fibre in lucerne silage in promoting milk fat tests (Clark & Armentano, 1992). The production responses of feeding whole cottonseed to lactating cows appear to be influenced by the type of forage in the diet (Smith & Harris, 1992).

Table 2.3 Nutrient composition of whole cottonseed according to the NRC (1989)

Nutrient	Cotton seeds with lint	Cotton seeds without lint
TDN %	96.0	96.0
MJ ME/kg	16.0	16.0
MJ NE*l*/kg	9.3	9.3
Crude protein %	23.0	25.0
Fibre %	24.0	17.2
NDF %	44.0	37.0
ADF %	34.0	26.0
Cellulose %	24.0	12.0
Lignin %	10.0	14.0
Ether extract %	20.0	23.8
Ash %	4.8	4.5

The pigment glands of cottonseed contain gossypol, a polyphenolic toxin. Ruminants are considered to be relatively tolerant to gossypol. This is ascribed to the binding of gossypol in the rumen to the *e*-amino group of lysine (Reiser & Fu, 1962), iron (Jonassen & Demint, 1955), calcium, sodium, potassium (Berardi & Goldblatt, 1969) and certain amines, especially octylamine (Singleton & Kratzer, 1973).

2.2.1.2 Soybeans

Soybean oilseed production holds first place in world oilseed production (USDA Foreign Agricultural Circular, August 1981) primarily owing to the high demand for edible oils (Akerne & Kennelly, 1982). U.S. oilseed production for 1996-97 was forecast at 73.5 million tons of which 63.9 million tons were soybeans (Brown, 1996).

Raw or heat treated soybeans are excellent sources of protein for high producing dairy cows. Interest in production of soybeans in South Africa increased during 1988/1989 due to the high prices paid for protein sources. The annual crop of 30 000 tons (1987) had trebled to 89 000 tons (1989) (Erasmus, 1989). Raw soybeans (DM basis) have a high energy (91% TDN or 15.1 MJ ME/kg or 8.8 MJ

NE*l*/kg), high protein (42.8%), low fibre (5.8%), low acid detergent fibre (10.0%) and a high fat content (18.8%) (NRC, 1989) (Table 2.4). Soybeans contain 85% unsaturated fatty acids (Palmquist, 1988a).

Soybeans are heated to destroy the trypsin inhibitor, inactivate urease activity, destroy enzymes (mainly lipase) which cause fat deterioration, increase the amount of "bypass" protein and improve palatability (Barmore, 1988). Trypsin inhibitors are destroyed in the rumen, although the maximum detoxifying ability of the rumen is not known (Chubb, 1982). It is not known whether the feeding of moderate levels of urea, especially with whole raw soybeans, will cause insufficient utilisation of urea or urea poisoning. It is recommended that urea not be included in diets with raw soybeans (Schingoethe, 1984).

Palmquist (1991) recommends that whole soybeans be roasted and cracked, not extruded or finely ground, as the latter processes release highly unsaturated oils which are too rapidly available in the rumen (Steele, *et al.*, 1971).

Table 2.4 Nutrient composition of soybeans according to the NRC (1989)

Nutrient	Raw soybeans	Heat treated soybeans
TDN %	91.0	94.0
MJ NE*l*/kg	8.8	9.1
MJ ME/kg	15.1	15.6
Crude protein %	42.8	42.2
Fibre %	5.8	5.6
NDF %	-	-
ADF %	10.0	11.0
Ether extract %	18.8	20.0
Ash %	5.5	5.1

Only 25% of the crude protein in raw soybeans is undegradable intake protein (UIP). Relative to soybean meal, soybeans are lower in crude protein (42 vs. 50%) and in the case of heat-treated soybeans higher in "bypass" protein (45-55 vs. 35% UIP). Heat treated soybeans work best in diets for high producing, early lactation cows needing additional "bypass" protein (Barmore, 1988).

Heat treated soybeans respond well when included in lucerne silage based diets (Faldet, 1989) because lucerne protein is highly degradable in the rumen. It is difficult to separate fat and protein effects when evaluating the production response to soybeans in research trials since addition of soybeans generally alters protein degradability of the diet.

2.2.1.3 Sunflower seeds

Whole sunflower seed (DM basis) has a high energy (83% TDN or 8.0 MJ NE*l*/kg), high protein (17.9%), fibre (31.0%), acid detergent fibre (39.0%) and a high fat content (27.7%) (NRC, 1989). Whole rolled sunflower seeds were reported to be a satisfactory fat supplement when incorporated at 10% of diet DM in lactating dairy cow diets (McGuffey & Schingoethe, 1982; Rafalowski & Park, 1982).

Sunflower seed production in Europe increased slightly from 1981. This, however, was not enough to secure its place as the fourth largest oilseed production in the world (Brown, 1996). Sunflower oils are highly valued for their stability at high temperatures (Akerne & Kennelly, 1982).

2.2.1.4 Canola (Rapeseed)

Canola (*Brassica campestris*) is an oilseed containing 40 to 45% lipid and roughly 21% protein. Rape oilseed production ranked fifth in world oilseed production (USDA Foreign Agriculture Circular, August 1981), but has since moved into the fourth place mainly because of high oilseed crops in Canada (House, 1996). High wheat, barley and oats prices caused Canadian canola farmers to switch back to cerial grains, resulting in a drop in canola production from 77.3 million tons in 1995 to 60 million tons in 1996 (House, 1996).

The first varieties of rapeseed contained high levels of glucosinolates and erucic acid. Hydrolysis of glucosinolates result in the production of a number of goitrogenic compounds including thiocyanate. Feeding high glucosinolate varieties of rapeseed has been shown to increase the thiocyanate concentration and reduce the iodine concentration of milk (Kennelly & Fenton, 1982).

The limitations imposed by glucosinolates in rapeseed meal and erucic acid in rapeseed oil have provided a major incentive for plant breeders to develop varieties of rape with reduced amounts of these compounds. In 1992 at least six commercially available low-glucosinolate rapeseed cultivars (*Brassica napus*: Tower, Regent, Altex, Andor; *Brassica campestris*: Candle, Tobin) were available. Such rapeseeds are now called canola seeds and consistently yield meals with total glucosinolate levels of 1 to 3 mg/g meal. None of the above mentioned were commercially grown during 1996 in South Africa and were replaced by improved varieties (*Brassica napus*: Springfield, CRN045, Hyola 42, Rainbow, Oscar, Narendra, Karoo, Dunkeld; *Brassica campestris*: Monty) with *campestris* being the more drought tolerant (C. Muller, SSK, P.O. Box 12, Swellendam, 6740, personal communication, October, 1996). Wiesen *et al.* (1989) have shown that processed whole canola are a potential energy source for lactating dairy cows.

The lipid fraction of canola seed contains the following fatty acids (Handy & Kennelly, 1983):

Palmitic (C16:0)	3.8%
Palmitoleic (C16:1)	0.2%
Stearic (C18:0)	1.4%
Oleic (C18:1)	51.3%
Linoleic (C18:2)	25.2%
Linoleic (C18:3)	13.5%

Varieties of canola with low glucosinolates (20 *u*mol/g fat free DM) and low erucic acid (0.1% of fatty acid) have been used in a research trial by Kennelly & Fenton (1982) to examine the influence of canola meal and whole canola seed on milk thiocyanate levels. Lactating dairy cows were fed diets containing soybean meal or a combination of canola meal and whole canola seed. Milk thiocyanate levels were approximately five times higher for cows fed canola meal or whole canola seeds than those fed soybean meal. Whole canola seed at inclusion levels of 6%, 12% and 18%, and canola oil at 5% inclusion, had milk thiocyanate levels of 3.2, 3.3, 3.1 and 2.8 ppm, respectively. Soybean meal at a 8% inclusion level had thiocyanate levels of 0.6 ppm in milk and canola meal at 15% inclusion level 3.6 ppm. A review of literature would suggest that the consumption of milk with these levels of thiocyanate is unlikely to have an inhibiting effect on iodine metabolism in humans (Kennelly & Fenton, 1982).

The inclusion of whole canola seed in early lactation diets for dairy cows may be limited due to its relatively low concentration of rumen undegradable protein and potential inhibitory effect of fat on cellulose digestion in the rumen. Jet sploding, a process using dry heat, can increase the proportion of undegradable protein in whole canola seed available to the dairy cow. Whole canola seed should undergo some form of processing (grinding or rolling) to enable the cow to utilise the seed most effectively (Handy & Kennelly, 1983).

Results from Khorasani *et al.*, (1989) suggest that up to 6% fat in the form of jet sploded whole canola seed (15% jet sploded whole canola seed) can be added to the diets of lactating dairy cows in early lactation, but no benefit from added fat was evident for dairy cows in mid or late lactation. Feeding 15% jet sploded whole canola seed increased milk production in early lactation cows (Khorasani *et al.*, 1989). Murphy *et al.*, (1987) suggested that crushed full fat canola was suitable for feeding to lactating cows when supplemented at 1 to 2 kg/day in the diet.

Protec^{R} is a protected lipid supplement available in Canada and consists of 75% whole canola seed and 25% canola meal treated with formaldehyde and has been used successfully in lactating cow diets (Khorasani *et al.*, 1989).

2.2.1.5 Heat treated oilseeds

Soybeans are by far the most common oilseed to be heat treated. The three most common methods used to heat treat soybeans are extrusion, flame roasting and popping (Barmore, 1988). Extrusion involves forcing the soybeans through a die under pressure. The friction that is generated during extrusion heat the soybeans uniformly. Fat cells are raptured, partially releasing the fat from the soybean plant cells. Flame roasting is a continuous flow process where soybeans come into direct contact with a flame. The bean is heated to temperatures in excess of 120 °C. Mechanical cooling is used to bring the soybean temperature down gradually. Popping soybeans is similar to flame roasting except that the soybeans are heated by hot air and do not come into direct flame contact. Popped soybeans are gradually heated to 160 - 195 °C and then cooled gradually (Schroeder *et al.*, 1996).

Jet-sploding is another technique of heat treatment, which utilises high temperatures for a very short time. The feedstuff is fed by gravity into a heat exchanger. Air, heated to 316 °C, is pumped through jets into the exchanger, where it rapidly heats the seed and transports it through the unit. The seed, containing very hot moisture at high pressure, leaves the unit passing through a roller which "explodes" the seed (Kennelly & De Boer, 1986).

It has been shown that heat treatment of oilseeds effectively decreases the rumen degradability of crude protein (Fox, Sniffen & Van Soest, 1981; Kennelly & De Boer, 1986). The type of treatment of soybeans also affect the dietary energy value for monogastric animals as shown in Table 2.5 (Kleyn, 1996).

Table 2.5 Influence of heat treatment on dietary energy value of full fat soya (Kleyn, 1996)

Treatment	**ME (MJ/kg) (Pig)**
Raw soya	13.50
Roasting	14.96
Micronisation	15.50
Wet extrusion	17.38
Dry extrusion	17.89

2.3 Fat supplementation to lactating cow diets

Rumen active fats (whole oilseeds or animal fat) can be used to supplement the fatty acid content in a dairy diet to a maximum of 6%. The addition of rumen active fat should not add more than 4% fat to the diet (Howard, 1988). If more than 6% fat is to be included, rumen inert fats should be used to provide an additional maximum of 3% in the diet DM. The total amount of fat in the diet should not exceed 9 to 11% (Palmquist, 1988a). Fat supplementation should meet the guideline of 16% of metabolizable energy intake to achieve maximal metabolic efficiency (Kronfeld, 1982). The amount of fat fed to dairy cows should be equally divided between conventional (tallow, animal/vegetable blend, whole cottonseed and soybeans) and inert sources of fat (Table 2.6).

Table 2.6 Combinations of fat which may be used in the dairy diet (Palmquist, 1989)

Sequence of addition	Fat source	Fat in total diet (% of DM)	Fat intake (kg/day)
1	Basal Ingredients	3	0.5 - 0.8
2	Conventional fats	2 - 3	0.5 - 0.8
3	Rumen inert fats	2 - 3	0.5 - 0.8
	TOTAL	7 - 9	1.5 - 2.5

Palmquist (1989) suggested as a rule of thumb to feed as much fat daily to a cow as the cow produces in her milk e.g. if milk production is 40 kg at 3.5% milk fat, then fat production is 1.4 kg and 1.4 kg of fat can be supplemented. If feed intake is 23 kg then fat will make up 6% of diet dry matter.

The amount of oilseed fed should be dictated by the cow's protein requirement (Shaver, 1990). If the basal diet is sufficient in protein (total, undegradable and degradable) oilseeds should not be fed strictly as a fat source because under these conditions it will not be the cheapest source of fat. Cottonseed contains 23.8% fat and if the cow does not require the protein in the cottonseed, one is paying an expensive price for the fat content, as well as running the risk of over feeding protein. Oilseeds that have not been heat processed can be fed if there is a need for degradable protein relative to undegradable protein. If a need for undegradable protein exists then heat treated oilseeds or oilseeds plus a source of undegradable protein, such as animal by-products or grain by-products, should be fed.

The crude protein content of the dairy diet should be increased by 1% for each 3% increase in fat (% of DM). The extra protein must be rumen undegradable to provide maximum benefit to the cow

(Palmquist, 1987a). Hoover & Miller (1990) recommended that non-structural carbohydrates should be between 30 to 40% for optimal rumen microbial synthesis and lactation performance. Hutjens (1990) has described in detail optimal carbohydrate intakes to maximise microbial protein synthesis. If non-structural carbohydrates are replaced by fat in the diet, 72 g of rumen undegradable protein should be included in the diet for each mega calorie of NE*l* from added fat (Chalupa & Fergusson, 1990) which approximates the ruminal microbial yield from fermentation of 1 Mcal of starch.

Another important factor to consider is nutrients in oilseeds other than fat and protein. If a need exists for additional fibre in the diet, cottonseeds may be preferred (Shaver, 1990).

Adequate forage should be fed in all fat supplemented diets. Type of forage may be important, as most studies show greater response in performance when lucerne hay is a part of the diet. Concentrates must always be replaced with supplemented fat and not forage (Harris, 1987). When forage intake is limited it is important to use higher quality fats, including rumen inert fat (Palmquist & Eastridge, 1991).

The calcium content of dairy diets should be at least 0.81% of diet DM (Palmquist *et al.*, 1986). Palmquist *et al.* (1986) recommends supplementing calcium chloride but at levels not exceeding 0.5% of diet DM because of the bitterness of the salt and subsequent palatability problems. The magnesium content of the diet should be at least 0.3% of diet DM (Chandler, 1988). The dietary concentrations of magnesium and calcium must be increased to replace the amount lost in faeces due to insoluble soap formation in the hindgut. Mid lactation hypocalcemia and hypomagnesemia have been observed when dietary calcium and magnesium were not increased in fat supplemented diets (Palmquist & Conrad, 1980; Steele, 1984).

The pKa of calcium salts of long chain fatty acids is 4 to 5, therefore dietary buffers may be needed with certain feeding strategies to maintain the rumen pH above 6, thereby preventing the dissociation of calcium salts (Chalupa & Ferguson, 1987).

Niacin (Vitamin B_3) supplemented at 6 g/cow/day is recommended in diets in which fat has been supplemented (Chandler, 1988; Erasmus, 1988) as it seems to alleviate the depressing effect of fats on milk protein content (Horner *et al.*, 1987).

The suggested limit for feeding whole cottonseed is 2.5 to 3 kg/cow/day or 15% of diet DM (Howard, 1988) although up to 30% of dietary dry matter has been fed to dairy cows without any detrimental effect (Coppock *et al.*, 1985). The suggested limit for soybeans, raw or heated, is 15% of diet DM (Howard, 1988) although intakes of up to 25% of diet DM have been reported without negative effects.

2.4 Fat supplementation and stage of lactation

Dry matter intake is at its lowest point in the first few weeks of lactation. Two weeks after calving dry matter intake was only 2.5% of body weight (Staples *et al.*, 1991). During this time cows consume diets that can only support 25 kg of 3.5% FCM (NRC, 1989) but are producing 33 to 35 kg milk/day by using body reserves to supplement energy output.

It appears that supplementing dietary fat can supply needed energy during the first 6 to 8 weeks of lactation while dry matter intake increases. It could also supply energy beyond 6 to 8 weeks if milk production exceeds 40 kg of milk/day and dietary energy is limiting production. Fat supplementation may be more effective in early lactation due to the greater transfer of fatty acids from the blood to the mammary gland in early versus late lactation (30 vs. 5%) (Storry, 1981). The cow in early lactation will benefit most from fat supplementation in the diet. This is because she will be in a negative energy balance for 15 to 20 weeks after calving (Davis, 1990). Davis (1990) suggested that fat supplementation in the diet should begin 10 to 15 days after calving. Palmquist (1990) suggested that fat supplementation in the diet should begin 5 to 6 weeks after calving and continue for up to 20 weeks after calving based on the reported lack of response in early lactation. It has not been determined whether fat should be fed during the first weeks of lactation to obtain the benefit later on or if fat supplementation should begin 6 to 7 weeks postpartum to get the response immediately. The suggestions of Palmquist (1990) seem to be followed in practice.

Reports from recent experiments with cows fed fat supplements from the start of lactation indicate a lag phase of 5 to 12 weeks post partum until positive energy balance is achieved before a maximum milk response to fat supplementation occurs (Palmquist, 1988a; Skaar *et al.*, 1989). Feeding of additional fat immediately after parturition may reduce adipose tissue mobilisation as the cow attempts to maintain blood lipid concentration. Once she gets close to neutral energy balance this "antagonism" is reduced and milk yield responds (Staples *et al.*, 1991). Delayed (4 to 5 weeks) early lactation response to fat supplementation has also been reported by Mattias (1982: tallow) and Hoffman *et al.* (1990: booster fat). This delayed response is a consequence of early lactation since numerous 14 to 21 day switchback trials with mid to late lactation cows reported significant increases in fat corrected milk yield in response to fat supplementation. The lag phase was associated with lower dry matter intakes even though energy intakes were equal and energy balance favoured fat supplemented cows.

To explain the delayed early lactation response to fat supplementation Palmquist (1990) suggested that if excess dietary fat is provided during periods of rapid adipose tissue mobilisation the cow must decrease feed intake to regulate plasma fatty acid concentration, thereby limiting protein concentration. Increased concentration of non-esterified fatty acids in blood, because of body fat mobilisation during early lactation, could saturate the cow's ability to utilise fat. According to Emery & Herdt (1991) this explanation does not make sense considering that dietary fat is directed to the mammary gland and other hepatic tissues, while non-esterified fatty acids are directed to the liver and other tissues according to blood flow. Starting cows on supplementary fat shortly before calving could alleviate the depression of feed intake caused by the supplementation of fat in the diet during early lactation. Experimental data is lacking to support this practice.

According to Palmquist & Eastridge (1991) the idea that cows need fat only in early lactation no longer holds true. A review of literature indicates that mid lactation cows producing milk as low as 23 to 24 kg/day have increased their production when fed supplementary fat, therefore fat may be playing a role other than supplying additional energy. Fat should be supplemented as long as cows are not getting too fat. Adjusting the ratio of fat : non-structural carbohydrate in the diet can control this (Palmquist & Eastridge, 1991).

2.5 Influence of forage type on fat supplementation response

The correct utilisation of fat supplements in the diets of lactating dairy cows are still uncertain due to the variation in responses obtained with the inclusion of especially oilseeds and commodity fats in some feeding programs (Shaver, 1990). There seems to be an interaction between the type of forage and fat included in the diet, influencing the performance of the lactating dairy cow. The response appears to be greatest on lucerne diets and poorest on all maize silage based diets (Smith & Harris, 1992). Smith & Harris (1992) and Staples et al. (1991) have reviewed the effect of various fat sources in combination with various forage sources on milk production.

2.5.1 Effect of supplementing whole cottonseed with different forage sources

Whole cottonseed especially appears to be influenced by the type of forage included in the diet. When maize silage makes up the primary diet forage, the inclusion of whole cottonseed causes an increase in milk yield with a decrease in milk fat content. In five experiments, as summarised by Staples *et al.* (1991), average milk yield was improved from 24.5 to 26.1 kg/day when whole cottonseed was fed at an average of 11.3% of diet DM. However, milk fat content decreased from 3.73 to 3.31%, resulting in small decreases in milk fat yield. Milk protein content responded variably in that two studies showed decreases while two others showed no effect.

An average decrease in milk production (Chalupa *et al.*, 1985; Coppock *et al.*, 1985; Chik, 1987) and milk fat content (Van Horn *et al.*, 1984; Chik, 1987; Baker *et al.*, 1989) was observed when whole cottonseed was fed to cows on maize silage based diets. Milk fat content increased when whole cottonseed was fed with lucerne hay based diets (Smith *et al.*, 1981; DePeters *et al.*, 1985; Smith, 1988; Hein *et al.*, 1990). These results, as summarised by Smith & Harris (1992), clearly show that there are no production advantages when whole cottonseed is supplemented to dairy diets based on maize silage as the only dietary forage source.

When whole cottonseed was included in diets in which the primary dietary forage was lucerne hay, an increase in milk fat content and fat corrected milk production was usually observed (DePeters *et al.*, 1985; Smith, 1988; Hein *et al.*, 1990; Smith, 1991). When whole cottonseed was included at an average of 18% of diet DM with lucerne hay as primary diet forage source, daily milk yield (summary of six experiments) was unchanged. Milk fat and fat corrected milk production were increased (11.4%) from 3.42 to 3.81% and from 23.3 to 24.9 kg/d (7.0%) (Smith & Harris, 1992). Average milk protein was decreased (2.8%) from 3.17 to 3.08% while dry matter intake was unchanged. These results support the inclusion of whole cottonseed in dairy cow diets with lucerne hay as the primary diet forage especially to increase milk fat content.

Smith *et al.* (1993) fed dairy cows increasing concentrations of lucerne hay in diets based on maize silage and containing whole cottonseed. Production of milk (21 vs. 22.8 kg/d), fat (666 vs. 809 g/d), fat corrected milk (19.9 vs. 22.9 kg/d) and solids corrected milk (19.9 vs. 22.7 kg/d) were lower for cows fed cottonseed-maize diets than those fed cottonseed-lucerne-diets. Milk fat and fat corrected milk yields were lower for all maize silage diets versus lucerne hay diets. Tendencies towards lower dry matter, organic matter, neutral detergent fibre and acid detergent fibre digestibilities suggested that fats probably had a more negative effect on ruminal fermentation when diets were based on maize silage as the only forage (Smith *et al.*, 1993).

When 10 to 17% lucerne or bermuda grass hay was included in maize silage based diets with whole cottonseed, average milk fat content increased to the same extent as in lucerne hay based diets (Ikwuegbo & Sutton, 1982; Palmquist, 1987b; Wilks *et al.*, 1991). The inclusion of 12% lucerne hay was adequate to reverse negative effects of whole cottonseed on maize silage diets. The results of the study by Smith *et al.* (1993) suggests that the depression in milk yield and/or milk fat content due to whole cottonseed inclusion in maize silage based diets could be overcome by replacing 25 to 50% of the maize silage with lucerne hay. The concept is supported by the work of Horner *et al.* (1986) who reported higher milk fat contents ($P < 0.05$) in maize silage-bermuda grass hay diets supplemented with whole cottonseed than in control diets. Inclusion of whole cottonseed in maize silage based diets caused no significant decrease in dry matter intake while dry matter intake tended to increase with increased concentrations of lucerne hay. Cows fed maize silage based diets with whole cottonseed tended to gain less body weight than cows fed maize silage based diets without whole cottonseed. The results were the opposite when 12.5% lucerne hay was added to the diet (Smith *et al.*, 1993).

2.5.2 Effect of supplementing other oilseeds with different forage sources

Feeding raw soybeans decreased milk fat content (6.5%) and had no affect on fat corrected milk production when maize silage was the sole forage source (Van Horn *et al.*, 1984). Voss *et al.* (1988) and Faldet (1989) suggested a possible advantage when using heat treated soybeans in lucerne haylage diets due to the greater solubility of its protein. Bernard (1990) offered a similar suggestion due to the lack of response to the inclusion of roasted soybeans in dairy diets where maize silage was the sole forage source. Voss *et al.* (1988) reported that the inclusion of 16.5% extruded soybeans in maize silage diets had little or no effect on milk production. When extruded soybeans were added to diets based on maize silage and lucerne hay, fat corrected milk production was increased by 2.4%. Roasted soybeans increased fat corrected milk production by 5.6% in diets based on maize silage and lucerne silage. Voss *et al.* (1988) concluded that roasted soybeans would probably provide a more constant increase in milk production when lucerne silage provided 50% or more of the dietary forage. Fat corrected milk production was increased by 10% when roasted soybeans were added to dairy diets based on lucerne silage or haylage (Voss *et al.*, 1988).

Inclusion of full fat rapeseed at three different levels (8, 14 and 20%) of the concentrate with grass silage as the primary forage did not alter milk yield, milk constituents or milk composition from that of the control (Murphy *et al.*, 1995).

2.5.3 Effect of supplementing unprotected feed fats with different forage sources

When grease or tallow is fed to dairy cows with lucerne hay as the only dietary fibre source an increase in milk yield is usually observed. The maximum response occurred with diets containing 3.0 to 3.5% tallow in diet DM. Lubis *et al.* (1990) also reported that the inclusion of fat in the form of hydrolysed mixtures of vegetable and animal fats, animal fats or whole cottonseed usually reduced milk fat content in experiments conducted at the Florida research station when maize silage was the sole forage source. When ruminally active fats such as tallow or grease were added to maize silage based diets or maize silage with other forages, average milk fat content decreased but average milk production was unchanged or increased only marginally (Palmquist & Conrad, 1980; Heinrichs *et al.*, 1981; Jenkins & Jenny, 1989). Pantoja *et al.* (1996) reported increases in milk production without any effects on milk fat content but increases milk protein content on diets containing 25% maize silage supplemented with tallow (5%). They concluded that a milk price structure with emphasis on non-fat milk solids indicated potential economic advantages in feeding tallow in maize silage based diets. In general, the supplementation of maize silage based diets with ruminally active fats is questionable. Diets containing 20 to 30% maize silage should probably not be supplemented with more than 2.3% rumen active fat (Smith & Harris, 1992). Results support the inclusion of tallow at 500 g/cow/day in diets for dairy cows based on ryegrass silage, and 5% supplemental fat, containing 40% tallow and 60% prilled long chain fatty acids, in lucerne haylage based diets (Clapperton & Steele, 1983).

2.5.4 Effect of supplementing rumen inert fat with different forage sources

Downer *et al.* (1987) found that supplementing lucerne hay diets containing whole cottonseed with 2.5% calcium salts of fatty acids increased 3.5% FCM from 32.8 to 34.2 kg/cow/day ($P < 0.01$). The increased fat corrected milk production response experiment appeared favourable for the addition of calcium salts to dairy diets based on lucerne hay and whole cottonseed. When prilled fat was used to supplement lucerne silage based diets, the supplemented prilled fat increased milk fat content in early lactation but had no effect on milk yield or energy intake (Jerred *et al.*, 1990).

Smith & Harris (1992) summarised seven experiments in which calcium salts of fatty acids were the only supplementary fat added to dairy diets in which maize silage was the primary forage source (Robb & Chalupa, 1987; Schneider *et al.*, 1988; Baker *et al.*, 1989; Schneider *et al.*, 1990; West & Hill, 1990; Andrew *et al.*, 1991). Average daily milk yield per cow was improved from 31.0 to 32.7 kg/cow/day (5.5%) when calcium salts were supplemented at an average of 2.9% of diet DM. Milk fat content remained unchanged. The inclusion of calcium salts increased fat corrected milk production by 5.4%. Dry matter intake was decreased from 21.7 to 20.7 kg/cow/day by the inclusion of calcium salts of fatty acids. The average milk protein content decreased from 3.33 to 3.14% (Robb & Chalupa, 1987; Schneider *et al.*, 1988; Schneider *et al.*, 1990; West & Hill, 1990).

Based on the production responses obtained with supplementing calcium soaps in maize silage based diets it can be concluded that calcium soaps could be supplemented to maize silage based diets at 3% of diet DM to provide additional energy (Smith & Harris, 1992).

Smith & Harris (1992) summarised six experiments in which calcium salts of fatty acids were included in dairy diets with lucerne haylage or silage and maize silage as forage sources (Burgess *et al.*, 1987; Grummer, 1988; Schauff & Clark, 1989; Canale *et al.*, 1990; Klusmeyer *et al.*, 1989a; Klusmeyer *et al.*, 1989b). Average daily milk production was improved by 2.8% when calcium salts were supplemented at an average of 3.9% of diet DM. Milk fat content was increased from 3.10 to 3.22% while milk protein content decreased from 3.18 to 3.08%. Daily fat corrected milk yield increased 4.6% which compares with the 5.4% increase that was calculated when calcium salts of fatty acids were supplemented in maize silage based diets (as summarised by Smith & Harris, 1992).

In lucerne based diets the average response of supplementing calcium salts at an average of 2.5% of diet DM to lactating cows was a 3.5% increase in milk yield (Burgess *et al.*, 1987; Canale *et al.*, 1990). Canale *et al.* (1990) reported that 2.6% of supplementary calcium salts in diet DM resulted in an increase in milk fat content from 3.65 to 3.73% while milk protein content was decreased from 3.1 to 3.02%. Fat corrected milk yield was increased with 4.7%.

Calcium salts of long chain fatty acid supplementation seemed to increase milk production reasonably constantly in diets based on different forage sources (Smith & Harris, 1992).

2.5.5 Possible reasons for the response of fat supplements to different forage sources

The reason why maize silage based diets seem to be more subject to fat induced milk fat depression is not clear. Maize silage could possibly be more subject to the modes of action as summarised by Devendra & Lewis (1974) (see 2.7) because of the relative short particle size and the soft physical structure of the fibre. The reduction in milk production and milk fat content with maize silage based diets may also be due to the effects of unsaturated cotton oil on ruminal fermentation (Devendra & Lewis, 1974). It is not clear why ruminal fermentation is affected on corn based diets but not on lucerne hay based diets. Calcium released by fermentation of the lucerne hay could form insoluble soaps with long chain fatty acids which are presumed not to be detrimental to rumen fermentation (Ikwuebo & Sutton, 1982; Chalupa *et al.*, 1984).

Spearow & Clarke (1984) and Palmquist *et al.* (1986) demonstrated no appreciable saponification within the rumen when calcium was provided in the form of calcium-di-hidroxide or limestone. Maize silage may also be more accessible than lucerne hay to the coating effect of lipids, which prevents microbial enzyme activity (Devendra & Lewis, 1974). Lipid supplementation also modifies the ruminal population concerned with cellulose digestion. Fatty acids inhibit the growth of certain micro-organisms due to an effect on cell permeability brought about by adsorption of fatty acids to the cell wall (Chalupa *et al.*, 1984).

2.6 Lipid digestion by the ruminant

Several authors extensively reviewed lipid digestion in the ruminant (Dawson & Kemp, 1970; Harfoot, 1978; Palmquist & Jenkins, 1980; Palmquist, 1984). On a diet of hay the concentration of total lipid in the rumen remains relatively constant during the day. According to Keeney (1970) approximately 80% of the lipids are associated with food particles, 16% with protozoa and 4% with bacteria. The first group consists largely of unesterified saturated fatty acids (Harfoot, 1981).

The digestibility of supplemental fat in lactating dairy cows have been reported by numerous researchers (Palmquist & Conrad, 1978, 1980; Sharma *et al.*, 1978; Smith *et al.*, 1981; Van der Honing *et al.*, 1981; Jenkins & Palmquist, 1984; Murphy *et al.*, 1987; Grummer, 1988; Jenkins & Jenny, 1989). Total fatty acid digestibility have been reported to be lower for cows fed diets supplemented with fats (Pantoja *et al.*, 1996; Pantoja *et al.*, 1994). True digestibility of fat often is decreased at higher intakes, apparently due to the limited absorptive capacity of ruminants (Bines *et al.*, 1978; Palmquist & Conrad, 1978). In comparing the digestibility of several commercially available fats (USA), Palmquist (1991) found a curvilinear relationship with digestibility decreasing at higher intakes. Apparent digestibility of fat was relatively constant with fatty acid intakes in the range of 2 to 5% of diet DM. True digestibility decreased 2.2 percentage units per 100 g fat consumed. At the maximum recommended fat intake of approximately 8% of diet DM, apparent digestibility of the fat was 72% (Palmquist, 1991). Chilliard *et al.*, (1991) found true digestibility of fat to be 71%.

2.6.1 Lipid digestion in the rumen

Conventional diets contain mostly esterified fatty acids, which are usually rapidly hydrolysed by lipolytic bacteria in the rumen (Hawke & Silcock, 1969). Protozoa may not be capable of lypolitic activity (Girard & Hawke, 1978). Hydrogenation of unsaturated fatty acids from glycerol takes place.

The glycerol and sugars are rapidly fermented to volatile fatty acids. When natural feedstuffs are fed the two major lipid classes to leave the rumen are free fatty acids (85 to 90% of total lipid content) and phospholipids (10 to 15%). The phospholipids are transported as part of the microbial cells while the free fatty acids attach to feed particles as well as other particulate matter and move with these materials to the lower gut (Davis, 1990).

The fatty acids leaving the rumen are highly saturated and consist of 80 to 90% palmitic (16:0) and stearic (18:0) fatty acids. This changes very little when relatively saturated fats such as tallow are supplemented at levels of up to 3% of diet DM. Similarly, when unsaturated oils are fed in whole seeds, release of oil, hydrolysis and biohydrogenation remains in reasonable balance. The scenario changes when free unsaturated fatty acids are fed. Lypolysis releases unsaturated fatty acids at a rapid rate with two main results. The capacity to biohydrogenate the unsaturated fatty acids is exceeded and the unsaturated intermediate *trans* (11)-C18:1 accumulates (Grummer, 1991). The increased concentration of free unsaturated fatty acids is toxic to gram positive bacteria, which include most of the cellulolytic and methane bacteria. Similarly protozoa in the rumen are killed. Toxicity results in reduced ruminal fibre digestion and acetate : propionate ratio (A:P) and therefore lowered milk fat content (Palmquist, 1991).

The importance of bacteria in the hydrogenation of unsaturated fatty acids has been established with certainty. The extracellular and intracellular enzymes that catalyse these metabolic sequences appear to be produced by a wide range of rumen bacteria. The function of protozoa in the process seems to be of secondary importance (Harfoot, 1981).

All forms of fatty acids are potentially inhibitory to ruminal protozoa and gram positive bacteria with consequent negative effects on fibre digestion and end product formation. Negative effects in the rumen are modulated by:

- the rate of appearance of the fatty acids (lipolysis or feeding free fatty acids),
- the fatty acid chain length,
- the rate of biohydrogenation,
- the quantity, quality and forage type,
- the amount of lipid supplemented,
- less certainly the calcium content of the diet (Palmquist, 1991) and
- forage particle size and characteristics of the fibre (Tackett *et al.*, 1996).

Pantoja *et al.* (1994) stated that supplemental fat with iodine values between 18 (saturated) and 62 (unsaturated) appear to be optimal for fatty acid digestibility and dry matter intake. Iodine values exceeding this guideline seem to interfere with fibre digestion even at high fibre levels in the diet Tackett *et al.* (1996).

2.6.2 Lipid absorption

In contrast to the extensive absorption of short chain fatty acids that occur in the rumen, virtually no long chain fatty acids are absorbed from the digesta before it reaches the small intestine of the ruminant. Fat absorption occurs in the jejenum region of the small intestine. Prior to reaching the jejenum, bile and pancreatic juice are added to the small intestine. Both are essential for fat absorption, but whether they are limiting under normal conditions is uncertain (Davis, 1990).

Digestibilities of fatty acids differing in carbon length and unsaturation are less variable in ruminants than non-ruminants. Ruminants show lower digestibilities for unsaturated fatty acids than non-ruminants, whereas the opposite is the case for saturated fatty acids (Steele & Moore, 1968). Digestibility of moderate amounts of added true fat (3 to 5%) is about 80%, but fatty acids in excess of 5 to 6% of diet DM (up to 10% supplemental fatty acids) are absorbed less efficiently (56%) (Palmquist & Conrad, 1980).

An inverse relationship was reported between fatty acid melting point and fatty acid digestibility (Steele & Moore, 1968; Chalupa *et al.*, 1986). Relationships between the melting points of long chain fatty acids and the production of volatile fatty acids *in vitro,* suggest that hard fats (high melting point) would be more insoluble in the rumen and thus likely to associate with either bacterial cells or feed particles (Chalupa *et al.*, 1980). When long chain fatty acids are fed at 6 to 8% of the diet DM in the form of those fatty acids with high melting points, they would have a minimum effect on ruminal fermentation (Chalupa *et al.*, 1986). This same characteristic could, however, lower absorption from the small intestine (Palmquist, 1988b).

2.7 Dietary fat and fibre digestibility

Researchers showed in several studies that supplementing dietary lipids to the ruminant diet decreased fibre digestibility in the rumen (Devendra & Lewis, 1974; Kowalczyk *et al.*, 1977; Jenkins, 1988; Palmquist & Jenkins, 1980) and narrowed acetate : propionate ratio of the rumen contents (Steele & Moore, 1968; Ikwuegbo & Sutton, 1982; Palmquist, 1984; Tackett *et al.*, 1996). Research trials have shown that dietary lipids decrease the digestibility of the crude fibre feed fraction (Kowalczyk *et al.*, 1977; Palmquist & Jenkins, 1980; McAllen *et al.*, 1983; Palmquist, 1984). Some experiments have shown no effect of fat supplementation on fibre digestibility (White *et al.*, 1958; Van der Honing *et al.*, 1981; Weakly *et al.*, 1990) or even an increase in fibre digestion (Esplin *et al.*, 1963; Palmquist & Conrad, 1980; Olubobokun *et al.*, 1985). There are contrasting results in the literature with regard to the effect of supplemental fat on fibre digestibility. The more accepted conclusion is that supplemental fat within the recommended limits in ruminant diets does suppress the digestibility of the crude fibre feed fraction.

The degree of suppression depends to a large extent on the amount and type of fat added to the diet (Shaver, 1990; Palmquist & Eastridge, 1991; Ohajuruka *et al.*, 1991). Fibre characteristics of the diet may influence the extent to which fats interfere with ruminal fermentation (Tackett *et al.*, 1996).

Short chain fatty acids have a more negative effect on fibre digestibility than longer chain fatty acids. According to Chalupa *et al.* (1986) saturated fatty acids (myristic C14:0, palmitic C16:0 and stearic C18:0) are less likely to interfere with ruminal fermentation than unsaturated fatty acids (palmitoleic C16:1, oleic C18:1, linoleic C18:1 and linolenic C18:3). One characteristic of fat that limits its use in dairy rations is the degree of saturation. The negative effects of unsaturated fats on ruminal fibre digestion have been documented (Jenkins & Jenny, 1989; Pantoja *et al.*, 1994). Free fatty acids exert a stronger negative effect on fibre digestibility than their corresponding triglycerides (MacLeod & Buchanan-Smith, 1972; Chalupa *et al.*, 1984). It is still not clear as to why fat supplementation exerts a negative effect on fibre digestion in ruminants. Several hypotheses have been presented as an explanation (Devendra & Lewis, 1974).

The first explanation is based on the theory of Brooks *et al.* (1954), Ward *et al.* (1957) and Pfander & Verma (1957). Their theory suggest that the effect is due to a coating of the fibrous portion of the diet with lipids, thereby preventing microbial attack by micro-organisms in the rumen. The possible mechanism by which the physical wetting effect of dietary lipids on the fibre component might lead to a decreased digestibility of the latter is explained by Devendra & Lewis (1974). Initially the fibre surface is hydrophilic with the micro-organisms in the aqueous medium actively breaking down the fibre so that digestibility is high. The addition of lipids causes a complete physical wetting of fibre and the surface is made hydrophobic. This in turn reduces the angle of contact of the micro-organisms on the fibre surface leading to the depression in crude fibre digestibility which is commonly noted. The extent of which physical wetting of fibre occurs probably determines the magnitude of fibre digestibility and is dependent on the level of fibre in the diet. When the level of dietary fibre is high, the lipid is spread over a wider surface area so that the physical wetting effect is much less in comparison with diets with low fibre content. This explanation is consistent with the observation that more lipid is utilised at higher levels of fibre inclusion with the same level of added lipid (Andrews, 1966).

The approach for a mechanism to restore normal fibre digestibility is one of isolating a procedure which could react at the fibre surface in such a way that the fibre surface is made hydrophilic so as to allow the micro-organisms to increase the breakdown of fibre. The extent to which the fibre surface is hydrophilic would in turn determine the improvement in crude fibre digestibility. The depressing effect of lipids on fibre utilisation must therefore be eliminated. The exploitation of the influence of lipids at the fibre bacterial interface may provide the key to the full exploitation of lipids as attractive sources of energy in ruminant diets (Jespersen, 1993).

A second theory stems from studies of the effect of prolonged supplementation of 5% maize oil in the diet on crude fibre digestibility. Cellulose digestibility was progressively depressed over a period of 40 days and recovery was not complete until 17 days after the oil was withdrawn from the diet. It was therefore suggested that lipid supplementation modified the rumen population concerned with cellulose digestion. It was concluded that the inclusion of plant oils in ruminant diets negatively influences the microbial population in the rumen responsible for fibre digestion (White *et al.*, 1958). McAllen *et al.* (1983) supported this by demonstrating depressions in both cellulose and hemicellulose digestibility in the same manner by lipid supplementation. They concluded that if the physical coating (theory one) of the fibre was a factor in decreased fibre digestibility, it was either selective or did not take place fully. Because this is unlikely, their results would suggest that certain species of bacteria were negatively influenced by the addition of lipids.

Palmquist & Jenkins (1980) indicated that the suppressing effect of fatty acids on the microbial activity of certain microbe species can lead to changes in the rumen microbial population. The activity of cellulolytic bacteria was depressed by especially oleic acid (Maczulak *et al.*, 1981). Probably the most important influence of oil in the diet on the rumen microbial population is the reduction which occurs in the protozoa population when fat is supplemented (Ikwuegbo & Sutton, 1982; Sutton *et al.*, 1983). Demeyer (1981) found that protozoa in the rumen account for approximately 30% of the total microbial fibre digestion.

Dietary supplementation of saturated fats and calcium salts of long chain fatty acids may minimise the adverse effects associated with fat feeding (Chalupa *et al.*, 1984; Chalupa *et al.*, 1986). Unsaturated fatty acids are more likely to alter microbial fermentation because they are less likely to adhere to feed particles and therefore more available to exert toxic effects on rumen micro-organisms. Saturated fatty acids may be less toxic to rumen fermentation because they react more readily with metal ions, forming insoluble salts within the rumen (Jenkins & Palmquist, 1982). Saturated and unsaturated long chain fatty acids have less effect on ruminal fermentation when they are supplemented as calcium salts of long chain fatty acids than as free fatty acids (Chalupa *et al.*, 1984; Chalupa *et al.*, 1986).

The action of lipids on fibre digestion may depend on methanogenic and cellulolytic bacteria and protozoa which are most reduced by lipid supply (Maczulak *et al.*, 1981). Optimum levels of fibre concentration and fibre length are needed for optimum rumen function (Hoover, 1987). The same is true for non-structural carbohydrates (starch, sugar and pectin) in order to stimulate microbial growth and optimum rumen turnover.

The third theory as discussed by Devendra & Lewis (1974) suggests inhibition of microbial activity from the surface active effects of fatty acids on cell membranes. Neiman (1954) suggested in a review of the effect of fatty acids on the growth of micro-organisms that fatty acids may inhibit or promote growth due to an effect on cell wall permeability brought about by the adsorption of fatty acids on the cell wall. Most available data supports this third theory of inhibition of microbial activity, perhaps sufficient to change the competitiveness and therefore rumen populations (Palmquist & Jenkins, 1980). Fatty acids have been found to inhibit rumen bacteria in pure culture (Henderson, 1973; Maczulak, 1979), and to bind to microbial cells (Neiman, 1954; Henderson, 1973). This bond can be reduced by adding fibre (Harfoot *et al.*, 1974) thus reducing inhibition in pure cultures (Maczulak, 1979). Bacterial numbers may increase when fat is fed with corresponding decreases in protozoa numbers (Czerkawski, 1973; Maczulak, 1979). Thus protozoa may be more sensitive to fatty acids allowing bacteria to move into the voided ecological niche.

Fatty acids can be absorbed by cell membranes (Maxcy & Dill, 1967; Henderson, 1973). The theory of inhibition of microbial activity by lipids cannot stand alone from the theory that lipids cause a change in the rumen microbial population because any selective inhibition of activity will lead to a population disturbance (theory two).

The fourth theory of Devendra & Lewis (1974) is based on the observation that the inclusion of lipids in ruminant diets is characterised by the increased excretion of calcium and magnesium soaps of lipids in the faeces. It is conceivable that the reduced availability of calcium and magnesium may interfere with microbial activity since these elements have been shown to be essential for the growth of micro-organisms (Bryant *et al.*, 1959). A reduced availability of minerals for microbial activity may also be related to the formation of mineral complexes. White *et al.* (1958) found that supplementing calcium could alleviate the depression in crude fibre digestibility. Johnson & McClure (1973) demonstrated the ability of 1% added limestone to prevent the reduction of fibre digestibility in sheep and steers fed ensiled maize. It is postulated that calcium improves the fibre digestibility of high fat diets by forming insoluble soaps that remove the fatty acids from solution so they are no longer available to bind to the rumen microbes. Palmquist *et al.* (1986) reported that in an *in vitro* study preformed calcium soaps of fatty acids were less liable to influence rumen fermentation than when calcium was added separately with lipid supplements.

Although rumen pH may alter fibre digestibility, evidence for added dietary fatty acids changing pH or cation availability is lacking (Beitz & Davis, 1964). Nevertheless the bacterial uptake of fatty acids in buffered test systems is decreased by increasing pH (Gallbraith *et al.*, 1971; Gallbraith & Miller, 1973). Increasing pH increases ionisation, hydrophilicity and solubility. The bacterial uptake of fatty acids is increased by increasing hydrophobosity (Bean, 1967).

2.8 Supplementary dietary fat, rumen fermentation and whole tract nutrient digestibilities

Apparent total tract digestibilities of dry matter, neutral detergent fibre and nitrogen are not affected by fat supplementation, fat source or degree of fat saturation (Grummer, 1988; Drackley & Elliot, 1993; Pantoja *et al.*, 1996). Pantoja *et al.* (1994) reported a linear decrease in neutral detergent fibre digestibility in the rumen but not in the total tract with decreased fat saturation. Shifts in the site of neutral detergent fibre digestion probably occurred but were not detected in other studies in which unsaturated fats were fed and only total tract digestion was measured.

Ruminal pH can vary from above 7 to less than 5 depending on the type of diet fed (Johnson & Sutton, 1968; Tremere *et al.*, 1968), as well as on the rate and frequency of feeding (Kaufmann, 1976). Cellulolytic activity decreases drastically when pH levels are decreased from 6 to 5.5 (Erfle *et al.*, 1982). Sensitivity of cellulolytic rumen microbes to pH has been shown *in vivo* (Slyter *et al.*, 1970) and *in vitro* (Terry *et al.*, 1969; Stewart, 1977).

Ruminal volatile fatty acid production is sensitive to rumen pH. Generally, as pH is lowered from 7 to 5.5 the relative amounts of acetate produced decreased while propionate and butyrate production may be sustained or only slightly decreased. A reduction in molar percentage butyrate has been associated with reduced protozoa numbers during oil feeding (Ikwuegbo & Sutton, 1982; Sutton *et al.*, 1983). Altered ruminal fermentation could be a response to changes in the population of rumen microbes resulting from pH change.

Changes in rumen pH could cause existing species to shift their metabolism towards greater acetate production. Although rumen pH may alter fibre digestibility, evidence for added dietary fatty acid changing pH or cation availability is lacking. Although lipid supply in the diet does not usually modify rumen pH, increases in pH have been observed (Grummer, 1988; Marty & Block, 1990; Mir, 1988) with different sources and amounts of dietary fat.

Free lipids have caused decreases in acetate : propionate ratios in the rumen as a result of increased propionate coupled by a decreased acetate level (Selner & Schultz, 1980). It is generally expected that fat supplementation will increase the relative proportions of propionate in the rumen (Zinn, 1988; Jenkins, 1988; Zinn. 1989).

2.8.1 Effect of oilseeds on rumen fermentation

Fatty acids in whole cottonseed and soybeans are 71 and 85% unsaturated, respectively (Palmquist, 1988a). Whole oilseeds are less likely to interfere with ruminal fermentation because oilseeds are digested slowly, allowing for a slow release of oil into the rumen and more extensive microbial hydrogenation (Steele, 1984). Jespersen (1993) summarised the effects of whole oilseeds on rumen pH and volatile fatty acids (Table 2.7).

Table 2.7 The effect of feeding whole oilseeds to lactating dairy cows on ruminal pH and volatile fatty acids (VFA) (Compiled by Jespersen, 1993)

Reference	Fat source	Fat in diet (% DM)	pH	Acetic molar (% of control)	Propionic molar (% of control)	A:P[1] ratio (% of control)
Knapp & Grummer (1990)	Soybeans	0	6.22	(63)	(20.9)	(3.01)
	Roasted	2.4	6.22	100	101	99
	Roasted	3.6	6.22	100	100	100
	Roasted	4.9	6.27	102	98	104
Scot *et al.* (1990)	Soybeans[2]	3.3	6.3	(66.1)	(19.1)	(3.5)
	Ground	3.3	6.2	99	104	97
	Roasted	3.3	6.3	103	91	111
	Extruded	3.2	6.2	102	95	109
Schingoethe *et al.* (1988)	Soybeans	0	6.3[3]	(55.9)	(30.7)	(1.82)
	Extruded	1.6	6.4	98	95	104
Mohammed *et al.* (1988)	Soybeans	0	6.0	(63.4)	(19.1)	(3.4)
	Soy oil	4.0	6.1	94	131	74
	Raw	4.0	6.0	98	119	82
	Roasted	4.0	5.8	102	101	100
	Cottonseed	0	6.2	(65.7)	(18.2)	(3.7)
	Oil	4.0	6.1	96	124	76
	Raw	3.4	6.0	97	113	84
	Roasted	3.3	6.1	99	107	92
Perry & MacLeod (1968)	Soybeans	0		(51.9)	(28.9)	(1.79)
	Raw	1.6		103	99	103
Hutjens & Schultz (1971)	Soybeans[4]	0	6.63	(49.6)	(26.6)	(1.9)
	Raw	4	6.6	84	150	58
	Soybeans[5]	0		(54.6)	(23.2)	(2.4)
	Raw	2.5		101	94	104

[1]A:P = Acetate : Propionate ratio

[2]Soybeans = Raw rolled

[3]Samples collected via stomach tube

[4]Soybeans = 75% grain, 15% diet acid detergent fibre

[5]Soybeans = 67% grain, 18% diet acid detergent fibre

Feeding fat at up to 4.9% of diet DM from roasted soybeans did not adversely affect rumen pH, volatile fatty acid or *in situ* forage dry matter disappearance (Knapp & Grummer, 1990; Table 2.7). Scott *et al.* (1990) found the A:P ratio was 3.4 or higher for cows fed raw, roasted or extruded soybeans at 3.3% of diet DM and there were no differences in rumen pH or *in situ* forage dry matter and neutral detergent fibre disappearance.

There were no adverse effects on rumen volatile fatty acids when supplementing fat at 1.6% of diet DM from extruded soybeans (Schingoethe *et al.*, 1988) or raw soybeans (Perry & MacLeod, 1968). In both trials soybeans were fed in total mixed diets with 50 to 55% forage. Hutjens & Schultz (1971) reported that the rumen A:P ratio was 58% of the control when cows were fed fat at 4% of diet DM from raw soybeans in 75% grain, 15% acid detergent fibre diets. However, rumen volatile fatty acids were not adversely affected when fat was fed at 2.5% of diet DM from raw soybeans in 67% grain, 18% acid detergent fibre diets (Hutjens & Schultz, 1971).

Supplementing fat at 3.3 to 4% of diet DM from whole cottonseed and roasted soybeans had little influence on rumen volatile fatty acids (Mohammed *et al.*, 1988). Supplementing fat at 3.4 and 4% of diet DM from whole cottonseed, raw soybeans or the free oil of each source increased the molar percentage propionate and reduced the A:P ratio. Adverse effects on rumen fermentation were more pronounced for the free oil supplements (Mohammed *et al.*, 1988). Supplementing cows soy oil at levels up to 7.6% of diet DM in late lactation in diets containing 65% forage had no effect on rumen pH, volatile fatty acids or *in situ* forage dry matter disappearance (Weakley *et al.*, 1990). The dramatic reductions of feeding of large amounts of soy oil (Mohammed *et al.*, 1988; Weakley *et al.*, 1990) cannot be explained on the basis of alterations in rumen volatile fatty acids.

Christensen *et al.* (1978) as quoted by Akerne & Kennelly (1982) examined the use of 6.3 and 12.6% full fat rapeseed on milk production, feed utilisation and rumen chemistry (Table 2.8).

Table 2.8 Influence of feeding whole full fat rapeseed (WRS) to lactating cows on digestibility and rumen chemistry (Christensen *et al.*, as quoted by Akerne & Kennelly, 1982)

Parameter	Concentrate[1]		
	Soybean	WRS (6.3%)	WRS (12.6%)
Digestibility of energy (%)	65.2	63.9	60.8
Digestibility of protein (%)	68.8	68.9	67.6
Total rumen VFA (mg/dl)	105	114	111
A:P ratio	1.78:1	1.54:1	1.72:1

[1]The total diet consisted of 40% chopped lucerne-bromegrass hay and 60% concentrates.

The level of full fat rapeseed supplementation in the diet did not affect milk production and milk composition. Feed intake and digestibility coefficients were similar for all diets. According to acetate : propionate ratios rumen fermentation was not adversely affected by inclusion levels of up to 12.6% full fat rapeseed (Christensen *et al.*, 1978).

Khorasani *et al.* (1989) fed five concentrate mixtures containing 0, 3, 6, 9 and 12% fat (equivalent to 0, 7.5, 15, 22, and 29% whole canola seed), formulated by substituting jet sploded whole canola meal. For early, mid and late lactation, diets consisted of 30, 25 or 15% lucerne silage, 10, 25, or 45% whole crop oat silage and 60, 50 or 40% of one of the concentrate mixtures (DM basis). Increasing dietary fat with jet sploded whole canola seed depressed feed intake in early, mid and late lactation. Adding fat to the diet did not effect rumen pH or ammonia concentration at any stage of lactation. Adding fat to early lactation diets caused linear depressions in the rumen concentrations of acetate, isobutyrate and butyrate while concentrations of other volatile fatty acids were not affected.

2.8.2 Effect of oilseeds on total tract digestibilities

Free vegetable oils should not be used in ruminant diets as free fats inhibit rumen cellulose fermentation (Palmquist & Jenkins, 1980). This inhibition is minimised when full fat oilseeds are fed, probably due to the slow release of fat from the cellular structure of the seed (Steele, 1984) with subsequent biohydrogenation to more saturated, less rumen inhibitory fatty acids. Rates of release and lipolysis of fats in different oilseeds have not been published and so no data base exists on which to rank effectiveness of whole oilseeds in maintaining rumen function (Jesperson, 1993).

Jespersen (1993) tabulated the effects of feeding whole oilseeds to lactating dairy cows on apparent total tract digestibility of dry matter and fibre (Table 2.9).

Feeding fat up to 5.6% of diet DM from whole cottonseed (Smith *et al.*, 1981) or 4.9% of diet DM from roasted soybeans (Knapp & Grummer, 1990) had no influence on total tract dry matter or fibre digestibilities (Table 2.9).

Cows fed free oil or whole oilseeds had similar total tract digestibilities of dry matter even though alterations in rumen fermentation were more pronounced for the cows fed free oil (Mohammed *et al.*, 1988), suggesting hind gut compensation.

Digestion studies by Coppock *et al.* (1985), Chik (1987) and Umphrey (1989) found no evidence to suggest lower fibre digestibility in cows fed diets supplemented with whole cottonseed. Ether extract digestibility was found to be higher for whole cottonseed diets than diets with no whole cottonseed ($P < 0.01$) (Smith *et al.*, 1993). Smith et al. (1981) also found higher digestibilities of ether extract concentrations in the diet. Dry matter, organic matter, acid detergent fibre and neutral detergent fibre digestibilities tend to be lower for maize silage-whole cottonseed diets than lucerne hay-whole cottonseed diets (Smith *et al.*, 1993). Their results confirm that cotton oil had a more negative effect on ruminal fermentation with maize silage based diets than lucerne based diets.

Table 2.9 Effect of whole oilseeds on apparent total tract digestabilities of dry matter (DMD) or organic matter (OMD) and acid detergent fibre (ADFD) or neutral detergent fibre (NDFD) in lactating dairy cows (Compiled by Jespersen, 1993)

Reference	Fat source	Fat (%)	OMD or DMD (% of control)	ADFD or NDFD (% of control)
Smith *et al.* (1981)	Whole cottonseed	0	(65.3)	(37.0)
		1.1	101	108
		3.4	101	101
		5.6	100	101
Knapp & Grummer (1990)	Soybeans[1]	0	(63.1)[2]	(43.6)[3]
		2.4	99	101
		3.6	102	105
		4.9	101	102
Scott *et al.* (1990)	Raw soybeans	3.3	(67.3)	(57.4)[3]
	Ground raw	3.3	89	82
	Roasted	3.3	85	81
	Extruded	3.2	89	73
Mohammed *et al.* (1988)	Soybeans	0	(67.4)	
	Soy oil	4.0	89	
	Raw	4.0	91	
	Roasted	4.0	94	
	Whole cottonseed	0	(60.5)	
	Cottonseed oil	4.0	96	
	Raw	3.4	97	
	Roasted	3.3	98	

[1]Rolled

[2]Organic matter digestibility

[3]Neutral detergent fibre (NDF) digestibility

Palmquist (1987b) included whole cottonseed at 0, 1.7, 3.4 and 5.1 kg/day (0, 300, 600 or 900 g supplemental fat/cow/day). The level of 5.1 kg/day caused a depression in dry matter digestibility ($P < 0.06$). Acid detergent fibre digestibility increased linearly with whole cottonseed inclusion ($P < 0.05$).

The apparent digestibility coefficients of dry matter, organic matter, crude protein, crude fibre, neutral detergent fibre, acid detergent fibre, nitrogen free extract and bruto energy were lowered ($P < 0.05$) with the addition of larger amounts of whole cottonseed to total mixed diets fed to sheep. Whole cottonseed levels were 0, 10, 15 and 20% of diet DM. The apparent digestibility coefficient of ether extract was significantly increased with the addition of larger amounts of whole cottonseed (Smith, 1988).

Whole cottonseed must be ruminated to release the cotton oil (Palmquist, 1984) and the linters help to distribute the seed in the rumen mat. This feedstuff therefore probably has little effect on rumen function and is highly valued by ruminant feed suppliers (Coppock *et al.*, 1987). Studies summarised by Coppock *et al.* (1987) found no significant differences in dry matter intake when whole cottonseed was included at up to 25% of the diet and did not suggest any depression in fibre digestibility when whole cottonseed was fed up to 30% in the diet. This implies that total fat intake from 30% whole cottonseed in the diet was not a restricting factor on rumen metabolism.

Intakes of up to 25% of diet DM for soybeans have been reported without any digestive problems (Steele, *et al.*, 1971). According to these authors, whole soybeans must be roasted and cracked, not extruded or finely ground, as this releases highly unsaturated oil which are then too rapidly available in the rumen and cause adverse effects on rumen fermentation.

Silva & Wanderley (1992) studied *in situ* disappearance of whole soybeans versus cracked soybeans. Five grams of each were placed in heat sealed dacron bags and incubated in the rumen for 0, 2, 4, 6, 12, 24 and 48 hours. Their results are summarised in Table 2.10.

Table 2.10 Dry matter and crude protein ruminal disappearance of whole soybean seeds (WSB) versus cracked soybeans (CSB) as fed to ruminants (Silva & Wanderley, 1992)

	WSB		CSB			
Parameter	**24 h**	**48 h**	**24 h**	**48 h**	**SEM**	**P <**
Dry matter RD[1] (%/h)	1.4^c	2.5^b	3.6^a	3.2^a	0.1	0.01
Crude protein RD (%/h)	1.2^d	5.6^b	2.9^c	8.6^a	0.2	0.05

[1]RD = Ruminal disappearance

[a,b,c,d]Means with different superscripts within categories differ.

Rumen disappearance was greater for the whole soybean than the cracked soybean seed supplement. Degradation of whole soybeans was markedly lower than cracked soybean seeds at 24 hours. Thereafter rumen disappearance was increased, reducing the magnitude of the difference (Silva & Wanderley, 1992).

Whole rolled sunflower seeds were reported to be a satisfactory fat supplement when incorporated at 10% of diet DM in lactating dairy cow diets (McGuffey & Schingoethe, 1982). Palatability of sunflower seeds appears to be the main reason for restricting the inclusion levels in ruminant diets to

10% of diet DM (Akerne & Kennelly, 1982). The inclusion of whole or processed sunflower seeds in diets for dairy cows would seem to be more limiting than that of soybeans or whole cottonseed.

Deacon *et al.* (1986) calculated the effective ruminal dry matter and crude protein disappearance at two rumen outflow rates of 0.05/hour and 0.08/hour when feeding whole canola seeds (WCNS), extruded whole canola seed, jet sploded whole canola seed (JSWCNS) and Protec^{R} (Table 2.11). Protec^{R} (Legal Alfalfa Products, Barrhead, AB, Canada) is a canola meal formaldehyde protected fat (75% whole canola seed and 25% canola meal treated with formaldehyde) commercially available in Canada for use in dairy diets and contains 20% crude protein and 30% ether extract.

Table 2.11 Effective ruminal DM and crude protein disappearance in cows calculated at two rumen outflow rates, 0.05/h and 0.08/h (Deacon *et al.*, 1986)

	DM		CP	
Fat source	**0.05/h**	**0.08/h**	**0.05/h**	**0.08/h**
WCNS	83.7	80.5	86.7	83.5
Extruded WCNS	83.7	80.7	86.2	83.5
JSWCNS	42.6	35.9	60.8	43.2
Protec^{R}	54.4	46.0	42.9	36.0

Jet sploding significantly decreased crude protein and dry matter degradabilities of whole canola seeds. Degradabilities observed for whole canola seeds were similar to values obtained for Protec^{R} but based on ruminal and intestinal data it can be concluded that jet sploding did not adversely affect the digestibility of whole canola seeds (Deacon *et al.*, 1986).

Jet sploded whole canola seed included at levels up to 10% (6% supplemental dietary fat) exerted positive effects on milk production, but high levels of inclusion (above 10% whole canola in diet DM) reduced dry matter intake and milk production by adversely affecting rumen function (Khorasani *et al.*, 1989).

In an experiment to determine the effect of different amounts of crushed full fat rapeseed (low erucic and glucosinolate content) on nutrient digestibilities in the rumen and total tract, extent of biohydrogenation on microbial synthesis and on volatile fatty acid production in the rumen, Murphy *et al.* (1987) fed cows one of 3 treatments in a Latin square 3 by 3 design. The control diet (Treatment 0) contained 7 kg of concentrate and 10 kg hay. In Treatment 1 & 2, 1 and 2 kg concentrate were replaced with crushed full fat rapeseed, which had been passed through a 5 mm hammermill (Table 2.12).

Table 2.12 Least square means of dry matter intake and digestibility of dry matter (DM), neutral detergent fibre (NDF), cellulose and hemicellulose in lactating cow diets supplemented with 0, 1 and 2 kg full fat rapeseed (Murphy *et al.*, 1987)

Parameter	Treatment			
	0	1	2	P (linear)
Dry matter intake kg/day	14.89	15.04	14.67	
Dry matter ruminal digestibility (%)	52.1[a]	46.3[ab]	44.4[b]	0.043
Total dry matter digestibility (%)	72.7[a]	71.4[ab]	68.3[b]	0.042
NDF ruminal digestibility (%)	46.1	41.9	38.6	0.105
Total NDF digestibility (%)	63.2	61.1	57.7	0.219
Cellulose ruminal digestibility (%)	51.8[a]	47.1[ab]	42.6[b]	0.029
Total cellulose digestibility (%)	64.7	62.1	59.8	0.024
Hemicellulose ruminal digestibility (%)	49	45.3	42.4	0.198
Total hemicellulose digestibility (%)	63.1	61.7	58.0	0.223

[a,b,c]Means with different superscripts within categories differ ($P < 0.05$).

Rumen digestibility of neutral detergent fibre decreased from 46.1% in Treatment 0 to 38.6% in Treatment 2. Although not detectable as being significant due to low animal numbers ($P = 0.105$) the effect was probably real (Murphy *et al.*, 1987). With 7.1% fat in the diet (Treatment 2) cellulose and hemicellulose digestion in the diet were reduced by only 16%. The proportion of dry matter and neutral detergent fibre digested in the hindgut increased with rapeseed feeding ($P < 0.05$). Total digestibility of Treatment 0, 1 & 2 was 89.9, 82.5 and 76.6% respectively, (P (linear) = 0.132). Fatty acid digestibility was not different between diets. The inclusion of supplemental rapeseed decreased rumen - and total dry matter digestibilities and proportions of dry matter digested in the rumen (Murphy *et al.*, 1987).

Rumen digestibility of cellulose was decreased by the inclusion of rapeseed in the diet, but this was apparently compensated for by hindgut fermentation. Dry matter, NDF and hemicellulose digestibilities were compensated at 1 kg inclusion of rapeseed, but not at 2 kg/day (Murphy *et al.*, 1987; Table 2.12).

Biohydrogenation of C18:1 fatty acids increased with increasing levels of supplementary dietary fat, whereas that of C18:2 and C18:3 was 85% on all diets. The slow release of fat from crushed rapeseed minimised the negative effects on rumen metabolism. It can be concluded that full fat rapeseed may be fed at 1 to 2 kg/day to lactating dairy cows without detrimental metabolic effects (Murphy *et al.*, 1987). Data on pH and volatile fatty acid production supports this suggestion with only small effects on rumen fermentation occurring at 1 to 2 kg/day full fat rapeseed supplementation (Murphy *et al.*, 1987; Table 2.13).

Table 2.13 Characteristics of rumen fermentation in lactating cows fed 0, 1 and 2 kg/day rapeseed in the diet (Least square means and probability for linear effect) (Murphy *et al.*, 1987)

	Treatment			
Parameter	**0 kg**	**1 kg**	**2 kg**	**P (linear)**
Factor:				
VFA, mM/*l*	113.00	112.00	100.00	0.264
Rumen pH	6.35	6.39	6.43	0.471
(Ac + Bu)/Pr[1]	5.31	4.04	4.46	0.331

[1]Ac = Acetic acid, Bu = Butyric acid, Pr = Propionic acid.

2.9 Effect of oilseeds on production responses of lactating dairy cows

2.9.1 Whole cottonseed

Coppock *et al.* (1987) found no significant differences in dry matter intake when whole cottonseed was included at levels up to 25% of diet DM in 18 trials and concluded that, in most trials, an increase in consumption of NE*l* occurred. The impact of feeding whole cottonseed on animal performance appears to be influenced by the type of forage in the diet (Harris, 1987; Shaver, 1990; Staples *et al.*, 1991; Smith & Harris, 1992).

When maize silage comprises the primary dietary forage, an increase in milk yield, with a decrease in milk fat content, is usually observed. The effect of supplementing whole cottonseed to maize silage diets on production response in lactating dairy cows is summarised in Table 2.14. Staples *et al.* (1991) reviewed 5 experiments where maize silage was the primary dietary forage with whole cottonseed inclusion levels averaging 11.3% of diet DM. Average milk yield was improved from 24.5 to 26.1 kg/day with cows on the whole cottonseed diet consuming 1.9 kg more dry matter than control fed cows. Milk fat content decreased from 3.73 to 3.31% resulting in small decreases in milk fat yield. Variable milk protein response was obtained as two studies showed decreases while two others showed no response.

Lubis *et al.* (1990) reported that the addition of fat in the form of hydrolysed mixtures of vegetable and animal fats, animal fats or whole cottonseed usually reduced milk fat tests in experiments conducted at the Florida station.

Table 2.14 Effect of supplementing maize silage based diets with whole cottonseed on dry matter intake (DMI), milk yield (MY) and composition (Compiled by Jespersen, 1993)

Reference	WCS (% of diet DM)	DMI (kg/day)	MY (kg/day)	Milk fat (%)	Milk protein (%)
Baker *et al.* (1985)	0	-	24.4	4.41	3.39
	12	-	24.5	4.33	3.37
Chalupa *et al.* (1985)	0	-	24.5	2.87	-
	20[1]	-	23.1	2.76	-
	20[2]	-	22.9	3.30	-
	0	-	24.6	3.43	-
	15[1]	-	24.9	3.60	-
	15[2]	-	24.3	3.52	-
Cummins & Sartin (1987)	0	26.2	35.2	3.47	-
	18.5	18.0	31.1	3.20	-
Hawkins *et al.* (1985)	0	18.9	27.5	3.72	3.30
	18.5	17.9	27.5	3.71	3.27
Van Horn *et al.* (1984)	0	18.8	24.0	3.30	2.84
	15	20.7	26.3	3.22	2.89
	0	22.7	25.4	3.95	3.31
	14	22.8	27.2	3.07	3.41
Chik (1987)	0	21.1	21.7	3.55	-
	15	21.5	22.0	3.2	-
Umphrey (1989)	0	16.1	24.7	3.37	3.09
	10.4	17.7	27.2	3.12	3.01
Baker *et al.* (1989)	0	22.3	26.9	4.5	3.92
	11.5	20.2	28.0	3.92	3.49
Horner *et al.* (1986)	0	23.2	31.2	2.97	3.13
	15[3]	23.4	31.6	3.38	3.02
Mohammed *et al.* (1988)	0	23.0	26.9	3.54	3.03
	16.5	21.4	25.8	3.7	3.11
Coppock *et al.* (1985)	0	-	22.8	3.49	3.35
	15	-	21.3	3.35	3.48
	30	-	21.5	3.12	3.37
Wilks *et al.* (1991)	0	21.0	30.1	3.11	3.30
	15[3]	22.5	31.4	2.93	3.13

[1]Linted cottonseed

[2]Delinted cottonseed

[3]30 Maize silage : 10 Bermudagrass : 60 Concentrate

Smith & Harris (1992) summarised 9 experiments in which whole cottonseed was supplemented in diets with maize silage as the only forage source (Baker *et al.*, 1985; Chalupa *et al.*, 1985; Coppock *et al.*, 1985; Cummins & Sartin, 1987; Hawkins *et al.*, 1985; Van Horn *et al.*, 1984; Chik, 1987; Umphrey, 1989; Baker *et al.*, 1989; Table 2.14). Average daily milk yield was unchanged at 25.3 kg/cow for both the control diets and for the whole cottonseed supplemented diets which included whole cottonseed at an average of 16.2% of diet DM. The average milk fat content was decreased from 3.58 to 3.37% while milk protein content was unchanged. Cows on the whole cottonseed diets produced 0.9 kg less FCM/day than cows on control diets (22.7 vs. 23.6 kg/day) and also consumed 0.9 kg less dry matter (20.2 vs. 21.1 kg/day).

According to Smith & Harris (1992) the results of the nine trials do not support the inclusion of whole cottonseed in diets for lactating cows when maize silage is the only dietary forage, except when economics dictate.

Horner *et al.* (1986) and Mohammed *et al.* (1988) fed whole cottonseed at approximately 16% of diet DM in diets based on maize silage and observed no effect of whole cottonseed on milk yield or milk fat yield (Table 2.14). The fact that bermuda grass hay or lucerne silage made up 10 and 15% of diet DM, respectively, for these studies may have prevented the drop in milk fat content seen in other studies as summarised by Staples *et al.* (1991) and Smith & Harris (1992).

Maize silage based diets seem to be more subject to milk fat content depression. The exact mechanisms involved are unclear. Maize silage could be more subject to the modes of action as summarised by Devendra & Lewis (1974) because of the relative short particle size and the soft physical structure associated with maize silage. Digestion studies by Coppock *et al.* (1985), Chik (1987) and Umphrey (1989) found no evidence to suggest lower fibre digestibility for cows on whole cottonseed supplemented diets.

Inconsistent results obtained when calcium salts and whole cottonseed are included in maize silage based diets do not support the inclusion of calcium salts and whole cottonseed in maize silage based diets (Baker *et al.*, 1989; Lubis *et al.*, 1990).

Whole cottonseed supplementation appears to have a different effect when the primary dietary forage is lucerne (Table 2.15). Staples *et al.* (1991) summarised five trials where whole cottonseed was supplemented with lucerne as the primary dietary forage. The studies showed remarkable consistency in their results (Smith *et al.*, 1981; DePeters *et al.*, 1985; Palmquist, 1987b; Chik, 1987; Hein *et al.*, 1990; Table 2.15). Milk yield was changed little but milk fat content increased dramatically with 0.33 percentage units while milk protein content decreased 0.08 percentage units with increasing amounts of whole cottonseed in the diet. The dry matter intake at increasing levels of whole cottonseed inclusion remained constant or decreased slightly.

Table 2.15 Effect of supplementing lucerne based diets with whole cottonseed (WCS) on dry matter intake (DMI), milk yield (MY) and composition (Compiled by Jespersen, 1993)

Reference	WCS (% of diet DM)	DMI (kg/day)	MY (kg/day)	Milk fat (%)	Milk protein (%)
Smith *et al.* (1981)	0	19.7	20.8	3.95[a]	3.31
	5	19.0	19.4	3.90[a]	3.24
	15	19.1	21.6	4.29[b]	3.20
	25	20.4	21.2	4.52[b]	3.22
Smith & Collar (1980)	0	18.8	32.1	3.70[a]	3.14[a]
	15	18.5	30.4	4.00[b]	2.99[b]
	30	19.1	31.7	4.18[b]	3.01[b]
DePeters *et al.* (1985)	0	19.0	24.4[a]	3.14[a]	3.22[a]
	10	19.3	25.0[a]	3.49[b]	3.14[b]
	15	19.1	25.5[b]	3.49[b]	3.14[b]
	20	19.0	25.4[b]	3.61[b]	3.16[b]
Brown *et al.* (1982)	0	-	27.6	2.28[a]	2.82
	15	-	28.1	2.86[b]	2.74
Hein *et al.* (1990)	0	21.7	29.6	3.46	3.19
	13.8	21.1	28.4	3.65	3.12
Chik (1987)	0	25.4	22.0	3.25	-
	15	22.5	22.3	3.55	-
	30	21.4	21.2	3.40	-
Smith (1988)	0	17.5	21.9[a]	3.20[a]	2.95
	25	18.3	23.0[b]	3.86[b]	2.95
Palmquist (1987b)	0	17.4[d]	21.8[d]	3.66[d]	3.47[d]
	9.4[1]	18.0	22.5	3.97	3.40
	20.2[1]	16.8	21.5	4.02	3.42
	32.1[1]	15.9	20.9	4.32	3.34

[a,b,c]Means with different superscripts in the same column differ ($P < 0.05$).

[d]Response trends were highly significant ($P < 0.01$) for fat and protein content and significant ($P < 0.05$) for milk yield and dry matter intake.

[1]Forage : concentrate 50 : 33, Maize silage 16.5, Lucerne hay 16.5

DePeters *et al.* (1985) included whole cottonseed at levels of 0, 10, 15 and 20% of diet DM (Table 2.15). Dry matter intakes were 19.0, 19.3, 19.1 and 19 kg/day, respectively. Smith *et al.* (1981)

included whole cottonseed at levels of 0, 5, 15 and 25% of diet DM and recorded dry matter intakes of 19.7, 19.0, 19.1 and 20.4 kg/day, respectively.

Whole cottonseed has little effect on animal performance when fed with cottonseed hulls, although limited research prevents accurate conclusions (Van Horn *et al.*, 1984; Chik, 1987; Table 2.15). Kutches *et al.* (1987) found that the effect of fuzzy versus delinted whole cottonseed on milk yield, milk fat content and milk fat yield were similar.

The primary benefit of whole cottonseed supplementation, in general, lies in the improved milk fat test resulting in higher fat corrected milk yields. It is difficult to separate the response due to the supplemental fat from the response due to fibre (Shaver, 1990). Supplementing fat at high inclusion levels (5 to 6%) from whole cottonseed did not adversely affect milk fat tests (Smith *et al.*, 1981; Palmquist, 1987b).

In experiments summarised by Smith & Harris (1992) daily milk production was unchanged when whole cottonseed was included at an average of 18% of diet DM with lucerne hay as the primary forage (Brown *et al.*, 1982; DePeters *et al.*, 1985; Hein *et al.*, 1990; Smith, 1988; Smith and Collar, 1980; Smith *et al.*, 1981; Table 2.15). Average milk fat content and fat corrected milk production were, however, increased from 3.26 to 3.85% and from 24.4 to 25.9 kg/day (6.2%), respectively. Milk protein content was decreased from 3.16 to 3.07% while average dry matter intake was unchanged at 19.2 kg/cow/day.

Horner *et al.* (1986), Wilks *et al.* (1991) (Table 2.14) and Palmquist (1987; Table 2.15) included maize silage as the primary forage and lucerne hay or bermuda grass hay as the secondary forage in diets supplemented with whole cottonseed. Average milk fat content was unchanged while milk yield increased (5.2%) from 23.3 to 24.5 kg/cow/day. Data is limited but it appears that the inclusion of 10 to 20% hay in maize silage based diets alleviates the dietary fat induced milk fat depression caused by the inclusion of whole cottonseed. Results from summarised trials (Staples *et al.*, 1991; Smith & Harris, 1992) support the inclusion of whole cottonseed in dairy diets with lucerne hay as the primary dietary forage, especially to increase milk fat tests.

Downer *et al.* (1987) supplemented lucerne hay diets containing whole cottonseed with 2.5% calcium salts of fatty acids and found increased 3.5% FCM production (32.8 to 34.2 kg/cow/day; $P < 0.01$). The increased fat corrected milk production response appears favourable for the addition of calcium salts of long chain fatty acids to dairy diets based on whole cottonseed and lucerne hay.

2.9.2 Soybeans

2.9.2.1 Whole raw soybeans

Whole raw soybeans have been fed to lactating dairy cows in order to increase their energy intake. As shown in Table 2.16, the main consistent effect of feeding raw soybeans was to depress dry matter feed intake from an average of 22.9 to 21.4 kg/cow/day. This resulted in an improved efficiency of 1.24 to 1.32 kg milk/kg feed.

Table 2.16 Effect of including raw whole soybeans (WSB) in the diet of lactating dairy cows on dry matter intake (DMI), milk yield (MY) and composition (Compiled by Jespersen, 1993)

Reference	WSB (% of diet DM)	DMI (kg/day)	MY (kg/day)	Milk fat (%)	Milk protein (%)
Faldet (1989)	0	23.4	34.5	3.40	3.00
	14	22.3	34.2	3.50	2.90
Mohammed *et al.* (1988)	0	23.1	26.2	3.53	3.45
	20	20.9	25.7	3.59	3.28
Baker *et al.* (1989)	0[a]	22.3	26.9	4.50	3.93
	10.5[a]	21.5	29.2	3.89	3.59
Van Horn *et al.* (1984)	0[a]	22.7	25.4	3.93	3.31
	14[a]	20.8	24.2	3.64	3.39
Bernard (1990)	0[a]	20.6	30.7	3.61	3.23
	9.4[a]	20.5	31.9	3.74	3.21

[a]Based on maize silage diets

Supplementation of raw soybeans on maize silage based diets increased milk yield from 27.7 to 28.6 kg/cow/day. Milk fat content was decreased from 4.02 to 3.76% while 4% FCM production was unchanged. It seems that the inclusion of raw soybeans in maize silage based diets had a slightly positive effect on milk production but a negative effect on the milk fat content (Van Horn *et al.*, 1984; Baker *et al.*, 1989; Bernard, 1990; Table 2.16).

2.9.2.2 Extruded soybeans

The processing of whole soybeans changes the nutritional properties of the beans. One such method, which has improved milk yield dramatically, is extrusion (Table 2.17).

Table 2.17 Effect of including extruded soybeans (ESB) in the diet of lactating dairy cows on dry matter intake (DMI), milk yield (MY) and composition (Compiled by Jespersen, 1993)

Reference	ESB (% of diet DM)	DMI (kg/day)	MY (kg/day)	Milk fat (%)	Milk protein (%)
Scott *et al.* (1990)	0*	25.9	33.5	3.31	3.06
	16*	25.4	35.9	3.20	2.97
Schinghoethe *et al.* (1988)	0*	19.3	32.2	2.98	2.99
	19*	20.5	36.2	2.63	2.85
Kim *et al.* (1990)	0*	21.1[a]	31.7	3.24	3.03
	17*	19.7[b]	33.8	3.05	2.94
	0	21.0	31.8	3.29	3.03
	17.5	20.6	35.3	2.91	2.96
Casper *et al.* (1990)	0*	21.0	31.7	3.26	3.03
	17.5*	21.1	34.5	2.98	2.95
Voss *et al.* (1988)	0**	22.5	37.5	3.14	3.14[a]
	16.5**	21.3	38.5	3.19	2.93[b]
Stern *et al.* (1985)	0*	15.5	17.9	3.17	3.32
	19.4*	15.6	18.0	3.26	3.22
Mielke & Schinghoethe (1981)	0*	21.2	28.6	3.57	3.00
	11.3*	21.5	29.1	3.61	2.92

[a,b]Means with different superscripts in the same column differ ($P < 0.05$).

*Included in maize silage and lucerne hay based diets.

**Included in maize silage based diets.

In four experiments (Scinghoethe *et al.*, 1988; Kim *et al.*, 1990; Scott *et al.*, 1990; Table 2.17) milk yield increased with an average of 3.1 kg/cow/day (from 31.6 to 34.7 kg/cow/day) with no real change in dry matter intake. Milk fat content was depressed from 3.19 to 2.86%, most likely due to a more complete release of soy oil in the rumen following extrusion. Milk protein content decreased slightly. This effect on milk yield and fat content is similar to that seen with whole cottonseed in maize silage based diets. Voss *et al.* (1988) reported that the inclusion of 16.5% extracted soybeans in maize silage based diets had little or no effect on milk production (Table 2.17). Voss *et al.* (1988) suggested a possible advantage of using heat treated soybeans in lucerne haylage diets because of the greater solubility of its protein.

Smith & Harris (1992) summarised six experiments using extruded soybeans in diets containing maize silage as the primary forage and lucerne hay as the secondary forage for lactating dairy cows (Mielke & Schinghoethe, 1981; Schinghoethe *et al.*, 1988; Stern *et al.*, 1985; Casper *et al.*, 1990; Kim *et al.*, 1990; Table 2.17). Average milk yield was increased (7.7%) from 28.6 to 30.8 kg/cow/day when extruded soybeans was added at an average of 17% in diet DM. Average milk fat content was decreased from 3.24 to 3.03% while the average fat corrected milk production was increased (2.4%) from 25.4 to 26 kg/cow/day. Milk protein content decreased from 3.06 to 2.97% while cows on extruded soybeans supplemented diets consumed the same amount of feed as cows on the control diet (19.4 vs. 19.3 kg/cow/day).

Schingoethe *et al.* (1988) reported that milk yield and fat corrected milk yield were respectively 3.95 and 1.57 kg/cow/day higher and that the milk fat test was 0.4 percentage units lower for extruded soybeans compared to the soybean meal control diet. Extruded soybean meal increased milk yield by 2.29 kg/cow/day suggesting that much of the milk response to extruded soybeans was due to undegradable intake protein.

The depression observed in the milk fat tests with extruded soybeans supplementation (Schingoethe *et al.*, 1988; Kim *et al.*, 1990; Casper *et al.*, 1990; Scott *et al.*, 1990; Table 2.17) is most likely related to the release of free oil during the extrusion process. Mohammed et al. (1988) reported that supplementing fat at 0.81 kg/cow/day (4% of diet DM) from soy oil reduced milk fat tests by 0.7 percentage units but feeding the same amount of fat from raw or roasted soybeans did not depress milk fat tests.

2.9.2.3 Roasted soybeans

Roasting of soybeans has been used to inactivate the trypsin inhibitor and to decrease the proportion of protein that is ruminally degradable. Cows fed roasted whole soybeans receive supplementary fat and undegradable protein thus making any response in milk yield difficult to interpret. In most of the experiments reported in Table 2.18 soybeans replaced soybean meal.

Including roasted soybeans in the diet at 12 to 24% of diet DM improved milk yield an average of 2.2 kg/cow/day from 34.1 kg/cow/day (Ruegsegger & Schultz, 1985; Mohammed *et al.*, 1988; Voss *et al.*, 1988; Faldet, 1989; Knapp & Grummer, 1990; Bernard, 1990; Driver *et al.*, 1990; Table 2.18). Dry matter intakes were not significantly different. Milk fat content was improved with an average of 0.09 percentage units from 3.43%, while milk protein content, however, was depressed with an average of 0.11 percentage units from 3.04%.

Table 2.18 Effect of including roasted whole soybeans (RWSB) in the diet of lactating dairy cows on dry matter intake (DMI), milk yield (MY) and composition (Compiled by Jespersen, 1993)

Reference	RWSB (% of diet DM)	DMI (kg/day)	MY (kg/day)	Milk fat (%)	Milk protein (%)
Bernard (1990)	0[1]	20.6	30.7	3.61	3.23
	20[1]	21.2	32.3	3.53	3.20
Mohammed *et al.* (1988)	0[2]	23.1[a]	26.2	3.53	3.45[a]
	20[2]	20.9[b]	26.9	3.59	3.21[b]
Voss *et al.* (1988)	0[2]	20.3	37.2	3.52	2.89
	15[2]	20.2	38.7	3.73	2.78
	0[3]	19.6	35.2	3.47	2.82
	13[3]	20.7	37.4	3.82	2.72
Faldet & Satter (1989)	0[3]	21.9	34.5[a]	3.41	2.99
	13[3]	22.8	38.9[b]	3.41	2.85
Knapp & Grummer (1990)	0[3]	24.5	34.9	3.23[a]	3.11
	12[3]	24.9	37.4	3.20[a]	3.03
	18[3]	25.0	38.7	3.32[b]	3.00
	24[3]	24.9	38.7	3.37[b]	3.10
Socha & Satter (1991)	0[3]	24.7	36.0	3.45	3.00
	13[3]	22.5	37.5	3.35	2.95
Ruegsegger & Schultz (1985)	0[4]	22.7	36.2	3.50	2.95
	12.9[4]	22.5	37.0	3.59	2.95
Driver *et al.* (1990)	0[5]	21.4	38.5	3.53	2.84
	13.7[5]	19.3	38.5	3.38	2.66
Faldet (1989)	0[5]	23.4	34.5	3.40	3.00
	13[5]	23.6	38.9	3.40	2.90

[a,b]Means with different superscripts in the same column differ ($P < 0.05$).

[1]Maize silage based diets

[2]Maize silage/lucerne silage diets

[3]Lucerne silage/haylage diets

[4]Handfed 50% grain

[5]Total mixed diets, 50% grain

The primary benefit of roasted soybeans was an increase in milk yield, although it is difficult to determine how much of this response was due to supplemental fat versus undegradable intake protein (Shaver, 1990). Feeding fat at 0.58 kg/cow/day from roasted soybeans increased milk yield 4.35 kg/day, but there was no effect when the same amount of fat from raw soybeans was fed. (Faldet, 1989) suggested that the response of roasted soybeans was primarily due to undegradable intake protein, or possibly a synergism between supplemental fat and undegradable intake protein. Scott *et al.* (1990) found no difference in response between raw and roasted soybeans fed to supply fat at 3.3% of diet DM.

An increase in FCM (1.7 kg/cow/day) was obtained by feeding roasted soybeans to lactating cows in diets based on maize silage as the primary forage and lucerne silage as the secondary forage (Mohammad *et al.*, 1988; Voss *et al.*, 1988; Table 2.18).

Voss *et al.* (1988) concluded that supplementing roasted soybeans had little or no effect on milk production with maize silage or mixed silage diets, respectively. Bernard (1990) found a response in milk yield of 1.6 kg/cow/day, but with a decrease in milk fat content (0.08%). Milk protein content remained stable.

Mohammed *et al.* (1988), Voss *et al.* (1988) and Bernard (1990) suggested that matching protein supplements and forage type according to ruminal protein degradation and amino acid content may provide a more efficient way to utilise proteins. Resistant proteins may provide a more consistent increase in milk production with lucerne silage than in feeding programs with 50% or more of the forage coming from maize silage.

Voss *et al.* (1988), Faldet & Satter (1989), Knapp & Grummer (1990) and Socha & Satter (1991) supplemented roasted soybeans to diets for lactating cows containing lucerne silage or haylage (Table 2.18). Daily milk yield was increased with 3.1 kg/cow/day with roasted soybeans at an average inclusion level of 15.5% of diet DM. Average milk fat content increased from 3.34 to 3.42% for cows on diets supplemented with roasted soybeans, while fat corrected milk production was increased from 33.1 to 36.5 kg/cow/day. Dry matter intake was similar for cows receiving both diets (23.5 vs. 23.3 kg/cow/day).

Due to limited data, it is difficult to draw accurate conclusions, but it would appear that inclusions of 13 to 24% roasted soybeans in lucerne silage or haylage based diets could result in significant fat corrected milk production increases, without decreasing the milk protein content (Jesperson, 1993).

2.9.3 Sunflower seeds

Whole unprocessed sunflower seeds were included at 0, 10, 20 and 30% in diet concentrates and fed to early lactating cows. Cows fed 10% sunflower seeds in diet DM produced more milk ($P < 0.05$) than the control group and were energetically more efficient (Rafalowski & Park, 1982). According to McGuffey & Schingoethe (1982) production indices suggest that whole sunflower seeds may constitute as much as 10% of the total diet DM without adversely affecting production.

Anderson *et al.* (1984) found that including 12% whole sunflower seeds in the diet DM depressed dry matter intake, milk yield, milk fat and protein content. Casper *et al.* (1988) reported that 10% regular (high linoleic fatty acid) sunflower seed depressed milk fat content whereas high oleic fatty acid sunflower seed nearly maintained milk fat content.

Finn *et al.* (1984) found that the addition of 1.54% limestone to a diet containing 9.7% sunflower seeds of diet DM increased fat corrected milk production ($P < 0.01$) from 28.1 to 30.3 kg/cow/day. White *et al.* (1987) found that the addition of 9% whole sunflower seeds in diet DM increased milk fat content and yield ($P < 0.05$), but that the additional inclusion of sodium bicarbonate did not increase milk fat content significantly.

The inclusion of whole or processed sunflower seed in dairy diets would seem to be more limiting than that of soybeans or whole cottonseed. Whole rolled sunflower seeds were reported to be a satisfactory fat supplement when incorporated at 10.5% of diet DM (McGuffey & Schingoethe, 1982; Rafalowski and Park, 1982). Sunflower seeds supplemented at 10% of diet DM appear to be the absolute maximum inclusion level.

2.9.4 Canola (Rapeseed)

A trial was conducted by Wiesen *et al.* (1989) to determine the effects of ground and extruded edible rapeseed on milk yield and feed intakes of lactating cows. Treatments were control, 6.5% ground edible rapeseed and 6.5% extruded edible rapeseed (low erucic acid, low glucosinolate variety, *Tobin*). Dietary fat was increased from 3.37% in the control to 6.4% and 6.7% in the ground extruded edible rapeseed and extruded edible rapeseed treatments. Dry matter intake averaged 22.3 kg/cow/day and milk production 42 kg/cow/day and did not vary ($P < 0.5$) between treatments (Wiesen *et al.*, 1989). Murphy *et al.* (1995) fed three levels of full fat rapeseed (control, 8.0%, 14% and 20% of concentrate DM) and found no significant differences between milk yield, milk constituent yield or milk composition.

Khorasani et al. (1989) fed lactating cows one of five concentrate mixtures containing 0, 3, 6, 9 and 12% fat from jet sploded whole canola seeds. For mid lactation and late lactation respectively, the diets consisted of 25% or 15% lucerne silage, 25 % or 45% whole crop oat silage and 50% or 40% of one of the concentrate mixtures (DM basis) (Table 2.19).

Increasing levels of dietary fat in the diet tended to have a quadratic effect ($P = 0.07$) on dry matter intake in mid lactation while the effect was less pronounced in late lactation ($P = 0.1$) (Table 2.19). Milk production in mid lactation was not affected by supplemental dietary fat but a negative linear trend ($P = 0.16$) was observed in late lactation (Khorasani *et al.*, 1989).

Table 2.19 Effect of including jet sploded whole canola seed (JSWC) in the diet of lactating dairy cows on dry matter intake (DMI), milk yield (MY) and composition (Khorasani *et al.*, 1989)

Parameter	Fat added to concentrates from JSWC					
	0	3	6	9	12	Relationship
DMI (kg/day)	17.12	18.29	17.98	15.89	15.76	L (0.017)
MY (kg/day)	27.61	28.78	30.00	29.72	27.81	Q (0.138)
FCM (kg/day)	25.60	24.60	25.95	25.88	25.30	C (0.368)
Butterfat (%)	3.33	3.32	3.09	3.17	3.35	Q (0.221)
Protein (%)	3.00	3.07	2.94	2.95	2.85	L (0.015)
Lactose (%)	4.86	5.01	4.85	4.95	4.84	Q (0.283)

Fat corrected milk, milk production and composition were not affected by the supplementation of fat to the diet in the form of jet sploded canola seed. During both periods the proportion of long chain fatty acids (C18:0, C18:1, C18:2) increased ($P < 0.05$) while those of short (C6:0, C8:0, C10:0) and medium chain (C14:0, C15:0, C16:0) fatty acids decreased ($P < 0.05$; Khorasani *et al.*, 1989).

Increasing dietary fat with jet sploded whole canola seed depressed feed intake in early lactation. However, this effect was less pronounced as the stage of lactation progressed. Milk production increased in a non-linear fashion with a maximum milk production at 6% addition of dietary fat as jet sploded whole canola seeds. Milk protein content declined linearly ($P < 0.05$) with jet sploded whole canola seed inclusion (Khorasani *et al.*, 1989).

2.10 Effects of oilseeds on milk composition

The feeding energy dense diets containing oilseeds have been reported to increase milk production and decrease milk protein content (Mielke & Schingoethe, 1981; Palmquist & Moser, 1981; Drackley & Schingoethe, 1986; Schingoethe *et al.*, 1988; Casper *et al.*, 1988).

Research trials summarised by Shaver (1990) indicated that the reduction in milk protein content due to fat supplementation is approximately 0.08 to 0.15 percentage units for various fat sources. Protein yield is usually not reduced when feeding fat, because milk yield is typically increased, therefore the true effect of fat supplementation is not a reduction in protein synthesis but rather an increase in lactose synthesis (which determines milk volume) without a commensurate increase in milk protein synthesis (Grummer, 1992). Wu & Palmquist (1991) reported that protein content was negatively correlated (r = -0.24), but protein yield was positively correlated (r = 0.31) with the ether extract concentration of the diet.

Milk fat depression may occur when rumen fermentation is shifted to a lower acetate : propionate ratio by reduced feed fibre digestibility such as with feeding of polyunsaturated oils (Davis & Brown, 1970). Selner & Schultz (1980) found that the accumulation of *trans* acids in the rumen during the hydrogenation of unsaturated long chain fatty acids caused a significant milk fat depression. Actual production of volatile fatty acids by ruminal bacteria can be reduced by unsaturated dietary lipids (Sutton, 1980), thus reducing the amount of precursor for synthesis of short chain fatty acids by the mammary gland. This is thought to be the main mechanism by which, on occasion, dietary fat reduces milk fat concentration (Staples *et al.*, 1991).

2.10.1 Effects of oilseeds on milk fat composition

Milk fat composition is easily modified by supplemental dietary fat. Mammary uptake of long chain fatty acids from blood increases with dietary lipid supplementation (Cant *et al.*, 1991) and the proportion of short and medium chain-length fatty acids in milk declines indicating reduced synthesis from acetate (Clapperton & Steele, 1983; DePeters *et al.*, 1987; Murphy *et al.*, 1995). Depressed yields of C4 to C16 fatty acids in milk have frequently been observed with addition of fats, oils or long chain fatty acids to the diet (Palmquist & Conrad, 1978).

The unsaturated 18-carbon fatty acids in oilseeds are hydrogenated in the rumen to stearic acid (C18:0). This is then absorbed from the intestine and it is converted to oleic acid (C18:1) in the mammary gland by an intramammary stearic acid desaturase. Thus increasing the supply of stearic acid to the gland results in an increasing level of oleic acid in the milk fat with a concomitant reduction in palmitic acid (C16:0) thereby resulting in a softer fat (Murphy *et al.*, 1995).

The fat type (C16/C18 ratio) does not only effect the hardness of the milk fat, but also lipolysis, presumably by affecting the fragility of the milk fat globule membrane (Palmquist & Eastridge, 1991). Factors that may alter proportions of fatty acids in milk when cows are fed supplemental fat include:

- the duration of fat supplementation,
- the amount and type of fat supplemented,
- the stage of lactation,
- energy balance of the cows and
- the genetic potential of the cows (Schauff & Clark, 1992).

Murphy *et al.* (1990) showed that alterations to milk fat composition (as mentioned above) was easily done by including ground full fat soybeans or full fat rapeseed to the concentrate mixture fed to lactating cows. These changes are similar to those observed previously with feeding of full fat soybeans (Perry & McLeod, 1968), sunflower seeds (Rafalowski & Park, 1982) or whole cottonseed (De Peters et al., 1985).

2.11 Conclusion

The type of forage seems to influence the production response of dairy cows receiving supplements of whole cottonseed. The literature indicates that the inclusion of whole cottonseed in diets with maize silage as the only dietary forage resulted in improved milk yields, but depressions in milk fat content. Milk protein content responded variably in that both increases and decreases were reported. There appears to be an interaction between maize silage and whole cottonseed that leads to these responses. There therefore seems to be no production advantage in whole cottonseed supplementation on maize silage based diets.

The reason why maize silage based diets seem to be more subject to fat induced milk fat depression is not clear. Several possible explanations have been given, but the exact mode of action is not yet certain. Most authors agree that it is most probably a characteristic of maize silage that would make it more susceptible to the modes of actions as presented by Devendra and Lewis (1974). The relative short particle size and the soft physical structure of the fibre has been given as possible reasons for maize silage to be more accessible than lucerne hay to the coating effect of lipids which prevents microbial enzyme activity. Lipid supplementation also modifies the ruminal population concerned with cellulose digestion. This modification could affect micro-organisms responsible for maize silage digestion to a greater extent. The formation of calcium soaps of long chain fatty acids (presumed not to be detrimental to rumen fermentation) from the calcium released during the fermentation of lucerne hay has been proposed. The addition of calcium to maize silage based diets did, however, not alleviate the depression of milk fat. A tendency towards lower dry matter, organic matter, NDF and ADF digestibility suggests that fats have a more negative effect on ruminal fermentation when diets were based on maize silage as the only forage.

The inclusion of lucerne hay (and possibly other types of hay) or lucerne haylage at levels of 10 to 15% of diet DM alleviates this milk fat depression when whole cottonseed are fed. Milk production, fat corrected milk and solids corrected milk also improved.

The literature lack information about the substitution of maize silage with other forms of silage in diets containing whole cottonseed, and the resulting effects on production. Maize silage appears to be the only forage that, in combination with whole cottonseed, results in a depression in milk fat percentage. No information could be found which would suggest that cereal grain silages in combination with whole cottonseed would have the same effect on milk fat than maize silage.

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Chapter 3

Degradability of corn silage, oat silage and lucerne hay in rumen environments with or without whole cottonseed as a fat supplement

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Abstract

During two experimental periods, four non-lactating, rumen fistulated Friesian cows were given two total mixed diets containing either more than 7 % fat (26 % whole cottonseed) and less than 3 % fat. The rumen degradability of three types of forage, (lucerne hay, corn silage and oat silage) were studied in these two environments, using the *in situ* polyester-bag method. The estimated effective rumen degradability of dry matter (DM), organic matter (OM) and acid detergent fibre (ADF) of the three forages did not differ ($P > 0.05$) between the two diets after 48 hours of incubation. The degradability of neutral detergent fibre (NDF) of corn silage was higher ($P < 0.05$) in the diet without WCS (23.12 %) than in the diet with WCS (22.73 %) at an outflow rate of $0.08h^{-1}$. There was no difference between NDF disappearance of oat silage or lucerne hay between the diets. The rates of outflow (0.02, 0.05, 0.08 h^{-1}) did not contribute significantly to any difference in degradability. The estimated effective rumen degradability of DM, OM, NDF and ADF differed between the three forages within a diet with lucerne being the most degradable and corn silage the least. Incubation times of up to 48 hours were found to be inadequate to complete NDF and ADF degradabilities.

Keywords: forage, silage, hay, degradability, dairy cows

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3.1 Introduction

The feeding of dietary fats to high producing dairy cows has become routine due to the fact that their potential for milk yield has exceeded their ability to meet their energy needs from conventional diets. Although several reviews (Palmquist & Eastridge, 1991; Smith, 1991) summarised the most important aspects of feeding fats, inconsistent responses to supplemented fat occurred in some feeding programs (Lubis *et al.*, 1990). The variation of the action of fats on ruminal digestion depends, to a large extent, on the nature of the fatty acids (the negative effects are more common with polyunsaturated fatty acids) and on the nature of the basal diet (negative effects seem to be greater on maize silage diets than on hay diets) (Elmeddah *et al.*, 1991).

The inclusion of corn silage as the primary dietary forage in diets containing whole cottonseed (WCS) either had no effect on milk yield (Smith & Harris, 1992), or increased milk yield (Staples *et al.*, 1991), while milk fat percentage was decreased (Smith & Harris, 1992; Staples *et al.*, 1991). Mean fat corrected milk (FCM) production was decreased by 4% in the 11 trials summarised by Smith & Harris (1992).

According to a review by Smith & Harris (1992) the inclusion of WCS in diets containing lucerne hay as primary dietary forage did not decrease milk fat percentage. The same was found for corn silage-based diets supplemented with WCS when 10 to 17 % lucerne or bermudagrass hay was included. Mean milk fat percentage increased to the same extent as in lucerne hay diets. Therefore the supplementation of corn silage-based diets with ruminally active fats is uncertain. Devendra and Lewis (1974) suggested four theories for explaining the depression of fibre degradation induced by fat supplementation, but none could explain the difference between hay and corn silage.

In the winter rainfall areas of the Western Cape (South Africa) large amounts of small grain silage are produced annually and fed to dairy cows. Whole cottonseeds are used extensively as a supplement, especially on oat silage-based diets in the form of total mixed diets. It is therefore important to determine the effect of WCS as a supplement on the fibre degradability and production traits of these diets.

The nature in which different roughages, especially oat silage, respond in rumen environments with or without an active fat needs to be addressed. The objective of this study was to determine the effect of whole cottonseed as a rumen active fat on the degradability of DM, OM, NDF and ADF of corn silage, oat silage and lucerne hay.

3.2 Materials and methods

3.2.1 Experimental animals

Four mature, non-lactating Friesian cows with mean bodyweight of 653 kg and fitted with rumen fistulae were used. The fistulae were fitted 8 cm from the last rib and 15 cm from the spinal column. The fistulae were made of rubber with a diameter of 85 mm to facilitate manual placement of the bags in the ventral portion of the rumen. The opening of the fistula could be sealed with a cork kept in place by a wire clip. The cows were adapted for fourteen days on complete dairy diets with or without whole cottonseed, before the experiment started.

3.2.2 Experimental design

Experimental change-over design no. 5 of Patterson and Lucas (1962) was used in duplicate. The four cows received two diets and could therefore be divided in two groups of two each in every of the eight experimental periods (Table 3.1). One group received the diet without whole cottonseed (Diet A, approximately 3 % fat) and the other group the diet containing 26 % whole cottonseed (Diet B, approximately 7 % fat). A period of adaptation of two weeks was allowed between the treatments to eliminate carry-over effects. The three roughages were incubated in the rumen for six time intervals. The control never entered the rumen. That gave 112 values for every roughage on each diet (16 values for every time interval) (Mehrez & Orskov, 1977).

Table 3.1 Change over design no. 5 of Patterson & Lucas (1962)

Experimental periods	Cows			
	I	II	III	IV
Period 1	A	A	B	B
Period 2	B	A	A	B
Period 3	A	B	B	A
Period 4	B	B	A	A

3.2.3 Experimental diets

A complete dairy diet without whole cottonseed was given to two of the cows. The remaining two cows received the diet with whole cottonseed added at a level of 26 % in order to provide at least seven percent fat in the diet. The experimental diets were formulated to approximately similar regarding nutrient composition. The composition of the two diets is presented in Table 3.2. Both diets were offered twice daily for *ad libitum* intake and water was freely available throughout the duration of the experiment.

Table 3.2 Composition of experimental diets A and B on a DM basis for *in sacco* degradability studies

Ingredient (%)	Diet A	Diet B
Wheat straw	15.0	12.0
Lucerne hay	14.5	14.5
Yellow maize (crushed)	40.0	28.0
Cottonseed oilcake	11.4	0.0
Whole cottonseed	0.0	26.0
Corn gluten feed	10.5	10.5
Urea	1.0	1.4
Molasses	5.0	5.0
Dicalcium phosphate	0.8	0.8
Limestone	1.3	1.3
Salt	0.4	0.4
Mineral premix	0.1	0.1
Calculated nutrient composition (%)		
DM	90.00	90.00
TDN	65.00	67.19
Crude protein	16.99	16.90
Fat	3.00	7.00
Fibre	13.00	15.63
NDF	28.00	31.88
ADF	17.10	21.00
Calcium	0.95	0.95
Phosphorus	0.45	0.45

3.2.4 Management and housing

The animals were kept individually in cement-floored (7.4 m x 3.6 m) and partially covered (3.7 m x 3.6 m) enclosures. Each enclosure had an automatic water trough and a feeding trough. The housing facilities were cleaned twice daily and untreated pine cuttings served as bedding in the covered half. Cows were adapted for 14 days on their diets and feed were given *ad libitum.*

3.2.5 Polyester bags

Polyester material (ASTM 270-53 from Rholagan Engineering , P.O. Box 45097, Mayfair, as manufactured by Swiss Silk) with a pore size of 53 (± 6) μm was used for the manufacturing of the polyester bags (16 x 9 cm). They were sewed with double seams and the seams were sealed with a contact adhesive. Bags were closed with nylon lines and secured with elastic bands to prevent them from opening in the rumen.

3.2.6 Preparation of the samples and procedures of the experiment

The corn silage, oat silage and lucerne hay samples were dried and milled (Nocek, 1988a) with a laboratory mill through a 2 mm mesh (Aerts *et al.*, 1977; Judkins *et al.*, 1991). Eight grams of milled sample were weighed into each bag. The bags, containing glass marbles (1 cm diameter) as weights, were dried in a forced-draught oven for 48h at 60°C before weighing. Each bag was fitted with a plastic tag for identification. Eighty-four bags were prepared for each period. Eighteen bags (six samples of each of the three roughages) per cow were incubated in the rumen for different time intervals (2, 4, 8, 16, 24, 48h) (Semptey, 1990). All the samples were removed simultaneously (Nocek, 1988b) and placed in ice water to stop microbial action. Thereafter, the samples were thoroughly washed and rinsed with tap water until the water was clear (Nocek, 1988b). Bags and residues were then dried for 48h at 60°C in a forced-draught oven. Control samples (0h) received the same treatment as the other samples except that they were not ruminally incubated.

3.2.7 Chemical procedures, measurements and analysis

Dry matter (DM) and organic matter (OM) of samples and residues were determined according to methods described by the AOAC (1995). Residual DM was calculated from the weight of sample incubated and the weight of sample remaining in the bag. The values of the above mentioned analysis were used for the calculation of the effective ruminal degradation of DM and OM. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) fractions were determined according to the method described by Goering and Van Soest (1970).

3.2.8 Statistical analysis

Degradability data was fitted to the exponential equation proposed by Orskov and McDonald (1979):

$$p = a + b(1 - e^{-ct})$$

where

p = actual degradation at time (t),
a = the intercept of the degradation curve at time zero,
b = potential degradability of the insoluble fraction and
c = the rate constant for the degradation of the fraction described by b.

Effective degradation (P) of DM, OM, NDF and ADF (Orskov & McDonald, 1979) was calculated for each treatment by introducing fractional outflow rates (k) of 0.02, 0.05 and 0.08/h (ARC, 1984) as follows:

$$P = a + \frac{bc}{c + k}$$

Analysis of variance was used to test for significance of treatment by using SAS (1989). Means were compared according to orthogonal contrasts (Snedecor & Cochran, 1991).

3.3 Results

Results from the analysis of DM, OM, NDF and ADF for the three different forages are presented in Tables 3.3 to 3.5. Although some authors experienced carry-over effects from feeding supplemental fat to cows (Chalupa & Ferguson, 1990; Schingoethe & Casper, 1991), nothing were observed in the present study.

In sacco ruminal disappearance of oat silage DM, OM, NDF and ADF increased as time of incubation increased. Figure 1 plots the mean *in sacco* disappearance of the NDF in oat silage for cows fed diets A and B.

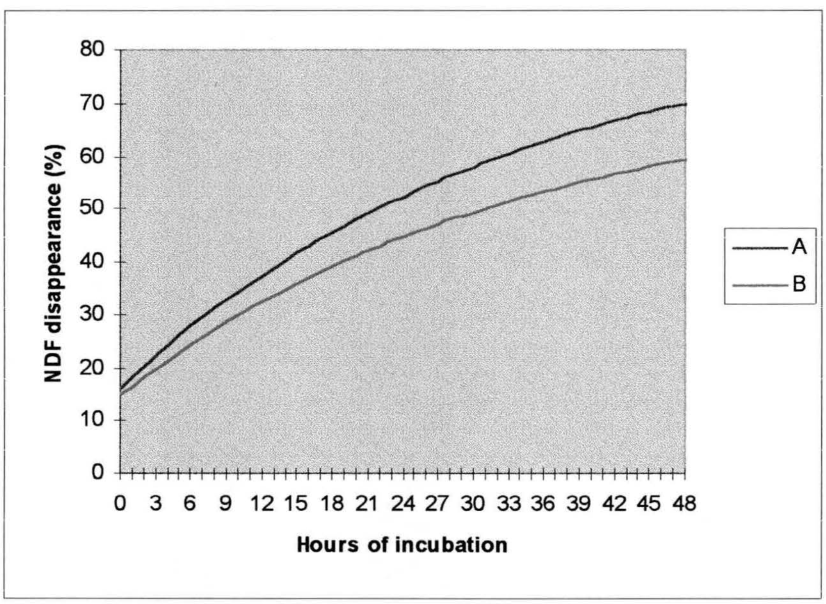

Figure 1 Disappearance of oat silage NDF for cows fed diets without (A) and with WCS (B).

From the data in Table 3.3 it appears that the degradability parameters (OM, NDF & ADF) of oat silage were greater in the diet without WCS. Dry matter degradability, was greater in the diet without whole cottonseed at the higher outflow rates. These differences, however, were not significant. *In sacco* disappearance of the mentioned parameters, however, did not differ significantly between diets containing WCS or diets without WCS at the different outflow rates of 0.02, 0.05 and 0.08 $^{-h}$.

Table 3.3 Effective degradation and standard deviations of oat silage at different outflow rates when incubated in the rumen of dairy cows which received either a low (A) or high fat (B) diet

Outflow rate	Diet	Effective degradability (%)			
(per h)		DM	OM	NDF	ADF
0.02	A	54.77 ± 3.681	49.09 ± 2.812	50.55 ± 4.576	46.90 ± 4.208
	B	52.98 ± 2.887	48.02 ± 2.688	49.45 ± 4.000	46.61 ± 2.679
0.05	A	41.28 ± 1.939	35.95 ± 1.831	37.25 ± 2.583	34.11 ± 2.338
	B	41.61 ± 1.243	34.74 ± 1.680	36.63 ± 1.301	33.08 ± 4.365
0.08	A	36.12 ± 1.521	29.97 ± 1.597	31.69 ± 1.972	28.86 ± 2.892
	B	36.26 ± 1.232	28.58 ± 1.784	30.88 ± 1.036	27.15 ± 4.957

Degradability within columns at each outflow rate did not differ ($P < 0.05$)

Table 3.4 Effective degradation and standard deviations of lucerne hay at different outflow rates when incubated in the rumen of dairy cows which received either a low (A) or high fat (B) diet

Outflow rate	Diet	Effective degradability (%)			
(per h)		DM	OM	NDF	ADF
0.02	A	67.01 ± 3.050	64.30 ± 4.021	59.72 ± 5.133	52.16 ± 3.086
	B	66.67 ± 2.550	64.75 ± 3.737	57.73 ± 7.044	50.88 ± 3.966
0.05	A	59.17 ± 2.248	54.56 ± 4.734	50.62 ± 5.239	44.78 ± 3.326
	B	59.17 ± 2.338	56.71 ± 3.875	50.35 ± 6.567	43.89 ± 2.726
0.08	A	54.54 ± 2.460	48.96 ± 5.051	46.86 ± 5.754	40.69 ± 3.466
	B	54.72 ± 2.794	51.75 ± 4.345	47.21 ± 6.842	40.18 ± 2.946

Degradability within columns at each outflow rate did not differ ($P < 0.05$)

The degradability of lucerne hay increased as the time of incubation increased and followed more or less the same curve as in Figure 1. The percentage degradability decreased as the rate of flow increased, as expected (Table 3.4). There were no significant differences between the two diets for DM, OM, NDF and ADF degradability.

Table 3.5 Effective degradation and standard deviations of maize silage at different outflow rates when incubated in the rumen of dairy cows which received either a low (A) or high fat (B) diet

Outflow rate (per h)	Diet	Effective degradability (%)			
		DM	OM	NDF	ADF
0.02	A	50.27 ± 3.030	47.62 ± 5.150	47.08 ± 3.770	44.31 ± 5.026
	B	49.05 ± 3.196	47.40 ± 7.270	45.07 ± 3.979	43.80 ± 5.284
0.05	A	37.41 ± 0.808	29.10 ± 2.745	29.91 ± 3.069	31.29 ± 2.629
	B	37.83 ± 2.201	30.57 ± 3.315	29.07 ± 3.811	32.86 ± 2.968
0.08	A	31.65 ± 0.992	22.18 ± 1.954	23.12^{a} ± 2.811	25.95 ± 2.396
	B	32.68 ± 2.180	24.33 ± 2.925	22.73^{b} ± 3.468	28.07 ± 2.734

Means with different superscripts within columns at each outflow rate differ ($P < 0.05$)

In sacco degradation of corn silage appears to followed the same pattern as oat silage and lucerne hay. The degradabilities increased as time of incubation increased, but decreased as rate of flow increased (Table 3.5). The only significant difference occurred at a flow rate of 0.08 were NDF degradability was higher in the diet without a supplement of WCS. A shorter rumen retention time (increased rate of outflow) appears to have a greater affect on corn silage NDF degradation in a WCS environment.

3.4 Discussion

The physical and chemical characteristics of the three roughages tested differed (Table 3.6). Therefore the mean rumen retention times of the three forages would differ. This could influence their degradability under practical conditions when WCS were to be added to the diet. Differences in the quality of the three forages complicated the interpretation of the results.

Table 3.6 The chemical composition of oat silage, lucerne hay and corn silage on a DM basis

Nutrient	Oat silage	Lucerne hay	Corn silage
Dry matter	25.60	88.58	38.25
Crude protein	8.68	15.22	9.15
Fat	3.37	1.78	3.54
Fibre	34.40	31.55	35.21
NDF	66.34	45.79	68.86
ADF	35.52	33.36	38.12

A further possible effect on the degradability of the silage samples could be the fact that they were dried before grinding, weighed and placed in the rumen in stead of freeze dried, ground and weighed as suggested by Mir *et al.* (1990).

Degradability of lucerne hay corresponds well with that found by Mir *et al.* (1990), Mir *et al.* (1993) and Reeves *et al.* (1991). The inclusion of WCS in the diet did not affect the effective degradability of DM, OM, NDF or ADF of lucerne hay.

Degradability values for corn silage found by most authors (Mir *et al.*, 1990; Elmeddah *et al.*, 1991) were higher than found in this study. According to Wattiaux *et al.* (1991) the digestion rate of corn silage was less than half that of lucerne hay, $0.019h^{-1}$ as to $0.039h^{-1}$. Lower digestibility values could be expected with higher outflow rates. The composition of the basal diet, according to Elmeddah *et al.* (1991), will contribute significantly towards the results that fat will have on fibre digestion. As the basal diet contained almost equal amounts of lucerne hay and wheat straw, the rumen environment might have been more favourable for the degradation of lucerne hay than for the silages. It has been shown by Tamminga *et al.* (1983) that the feeding of fat modifies rumen microbial populations.

Nocek (1988) suggested incubation times of 72 to 96 hours for forages. The data from this study indicates that an incubation time of 48 hours is not enough to determine the true degradability of low quality forages (Figure 1) in diets with slow passage rates.

3.5 Conclusion

No clear interaction of WCS with the fibre digestion (ADF & NDF) of lucerne hay or oat silage could be established. The degradation of corn silage ADF was not changed by the inclusion of WCS. The effective degradation of DM and OM of lucerne hay, corn silage and oat silage was not altered by the inclusion of WCS. The rate of outflow had no effect on the effective degradation of DM, OM, NDF and ADF of lucerne hay and oat silage between the high and low fat diets. It seems that the digestion kinetics of oats silage tend to be more like that of lucerne hay than that of corn silage.

The degradation of NDF in corn silage was depressed ($P < 0.05$) at an outflow rate of 0.08 h^{-1} with WCS inclusion. No differences in degradability were found at the slower outflow rates. This effect appears to be greater with shorter rumen retention times and would therefore affect high producing dairy cows with high rumen outflow rates. The average NDF degradability of corn silage, however, appeared to be lower than that of the other forages tested. The explanation might be the poor quality of the silage due to the late stage at which the silage was made.

The different ways in which corn silage NDF reacted between treatments may need further investigation. This could be of importance to high producing dairy cows with high rates of outflow.

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Chapter 4

Effect of substituting oat silage with lucerne hay in diets supplemented with whole cottonseed on the performance of dairy cows

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Abstract

Twelve lactating Holstein cows (primiparous and multiparous) were allocated into two groups of six each in a crossover design. They received diets supplemented (18%) or not supplemented with whole cottonseed (WCS). The roughage content of the diets was 40%, with oat silage as the primary forage and the lucerne hay concentration varying from 0 to 20% with 10% increments. WCS supplementation to oat silage based diets did not affect milk or fat yield. Milk fat percentage (as measured with a Infrared Analyser, wavelength; 3.5 micron) increased from 3.09 to 3.33% ($P < 0.01$), but milk protein percentage decreased from 2.84 to 2.75% ($P < 0.01$). Dry matter intake was also reduced with 400g/cow/day from 18.2 to 17.8 kg ($P = 0.05$). The substitution of oat silage with lucerne hay improved all the production variables significantly ($P < 0.05$), except milk fat percentage. Dry matter intake and feed conversion efficiency improved from 16 to 20.2 kg and 1.42 to 1.27 ($P < 0.01$), respectively, with the inclusion of lucerne hay. Milk fatty acid composition changed to longer chain fatty acids with the inclusion of WCS, but due to the amount of interaction between the levels of the two roughages and the supplementation of WCS, it could not be quantified. Margins over feed cost did not differ significantly, although differences in diet costs and milk prices were observed.

Keywords: oat silage, lucerne hay, whole cottonseed, dairy cows

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4.1. Introduction

The type of forage and fat included in the diets of dairy cows appear to interact, influencing performance (Staples *et al.*, 1991). This was supported by a recent review of data by Smith & Harris (1992) in which the response to fat supplementation appears to be greatest on lucerne based diets and poorest on maize silage based diets.

A summary of three experiments (Smith & Harris, 1992) indicated that the supplementation of maize silage based diets with raw soybeans increased daily milk yield from an average of 27.7 to 28.6 kg/cow/day. Average milk fat percentage decreased from 4.02 to 3.76% while 4% fat corrected milk (FCM) production was unchanged. These findings suggest that the inclusion of raw soybeans in maize silage based diets had a negative effect on milk fat percent.

Data from six experiments using extruded soybeans in diets for lactating cows, containing corn silage as the primary forage and lucerne hay as the secondary forage, showed the same tendencies. Average daily milk yield increased with 2.4% from 28.6 to 30.8 kg/cow/day, while milk fat percentage decreased with 6.5% from 3.24 to 3.03%. Although milk production increased slightly, the decrease in milk fat percent cancelled the expected increase in FCM (Smith & Harris, 1992). When lucerne hay was the only forage source, the supplementation of roasted whole soybeans increased milk yield from an average of 35.1 to 38.2 kg/cow/day, milk fat percentage from 3.34 to 3.42% and average FCM production from 33.1 to 36.5 kg/cow/day.

The results of feeding whole cottonseed (WCS) to lactating dairy cows appears to be affected more by the type of forage in the diet. Lubis *et al.* (1990), Staples *et al.* (1991) and Smith & Harris (1992) reported no change in milk production, but decreased milk fat percentages (average 5.9%) when WCS was included at an average of 16.2% of diet DM in diets with maize silage as the only forage.

The inclusion of 10 to 20% hay as a secondary forage alleviated the depression of milk fat from 3.41 to 3.72%, induced by the feeding of WCS. While milk production was unchanged, average FCM increased from 23.3 to 24.5 kg/cow/day. When WCS was included in dairy cow diets with lucerne hay as the primary forage, similar results were obtained with no change in average milk production, while average milk fat percentage increased 11.4% and average FCM production increased from 23.2 to 24.9 kg/cow/day (Smith & Harris, 1992).

Very little data is available on the response of dairy cows supplemented with dietary fats and other silages as the primary source of roughage. Clapperton & Steele (1983) obtained positive results when ryegrass silage was supplemented with tallow (maximum 3.0 to 3.5% of diet DM). They reported increases in milk yield (20.7 to 22.3 kg/cow/day) and milk fat percentages (3.9 to 4.15%).

The lack of data on the effect of WCS supplementation on small grain silage based diets for dairy cows initiated this study. Oat silage was included as the primary forage source. The objective of this trial was to determine any interaction between oat silage and fat supplementation in the form of whole cottonseed and the effect of increasing amounts of lucerne hay on the production characteristics of dairy cows.

4.2. Materials and methods

4.2.1 Experimental animals

A digestion and production trial was conducted with twelve mid-lactation Friesian cows without considering parity. The cows were calved within one week of each other and were assigned randomly to six experimental diets. Each cow was fitted with a transponder that identified the cow to a specific feed bunk.

4.2.2 Experimental design and chemical procedures

The twelve cows were allocated into two groups of six each according to the crossover design no. 14 of Patterson and Lucas (1962) (Table 4.1). Each experimental period of twelve days was pre-empted by a fourteen day adaptation period to avoid possible treatment carry over effects.

Table 4.1 Experimental design

Period	Cows											
	1	2	3	4	5	6	7	8	9	10	11	12
I	A*	A	B	B	C	C	D	D	E	E	F	F
II	B	B	C	C	D	D	E	E	F	F	A	A
III	F	F	A	A	B	B	C	C	D	D	E	E
IV	C	C	D	D	E	E	F	F	A	A	B	B
V	E	E	F	F	A	A	B	B	C	C	D	D
VI	D	D	E	E	F	F	A	A	B	B	C	C

* A, B, C, D, E and F represent the six experimental diets

Cows were milked twice daily and fed after milking. *Ad libitum* dry matter intake (DMI) was determined daily over the twelve day experimental period. Samples were collected on a daily basis and pooled to give one sample per week. Samples were stored at -20°C for dry matter (DM) determinations and chemical analysis. Dry matter, organic matter (OM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and ether extract (EE) digestibility coefficients were determined.

Total faecal output was measured over 8 days (day 4 to 12 of every experimental period) using Chromic III Oxide as a marker (Williams *et al.*, 1962). Gelatin capsules containing 10 g of Chromic III Oxide were administered twice daily at 07:00 and 17:00 from day 2 to 11 of each period with a balling gun (Smith & Harris, 1992). Faecal grab samples were collected twice daily at 07:00 and 17:00 from day 4 to 12 of each experimental period. Faecal samples were pooled, dried at 55 °C in a forced draught oven, ground with a hammermill (Christy and Norris no. 8; 8-inch mill, 2mm mesh), transferred to sample bottles, and stored for chemical analysis. For the determination of faecal chrome concentration, a standard chromic nitrate solution was used according to Swart (1989). Feed and faecal samples were analysed for DM, OM, Kjeldahl nitrogen (N), EE (AOAC, 1995), NDF and ADF (Goering & Van Soest, 1970). All results were calculated on a dry matter basis.

Total daily nutrient intake and excretion were calculated as the products of daily intake, excretion and nutrient concentration (Smith & Harris, 1992).

Two representative milk samples were taken every fourth day of the experimental period during the afternoon and morning milking and pooled according to the production. One sample was preserved with potassium dichromate for analysis of protein, milk fat, lactose (Milkoscan 104 - A-filter, Milkoscan 133 - B-filter) and somatic cells (Fossomatic 360). The fresh sample was churned into butter, stored at -25 °C and analysed for milk fatty acid composition (gas chromatography, Irene Animal Production Institute, Private bag X2, Irene, 0062).

The 4 % FCM values were calculated according to the formulae of Lubis et al. (1990) and the AFRC (1993). The latter recommendation would appear to be more appropriate for South African conditions. Body weight was measured at 07:00 on two consecutive days at the end of each period. Milk solid prices were obtained from Bonnita Pty. Ltd. (P.O. Box 809, Stellenbosch, 7599), and used to determine a milk price for each cow on each diet during each experimental period. These values, together with dry matter intake values were used in the economic evaluation.

4.2.3 Experimental diets

Six complete dairy cattle diets in which oat silage were replaced by lucerne hay, with or without whole cottonseed supplementation, were fed. The main difference between the diets is shown in Table 4.2. The total amount of roughage was kept constant at 40%.

Table 4.2 Main differences between the six experimental diets

Ingredient	Ration A	Ration B	Ration C	Ration D	Ration E	Ration F
Oat silage	40	40	30	30	20	20
Lucerne hay	0	0	10	10	20	20
Whole cottonseed	0	18	0	18	0	18

Experimental diets were formulated to be approximately similar regarding nutrient composition. The composition of the six diets is shown in Table 4.3. The roughage to concentrate ratio was kept constant at 1:1.5. This, however, made it impossible to keep the NDF concentration similar in all the diets due to the contribution of NDF from the lint of the whole cottonseed. The high protein and energy levels of whole cottonseed also impacted on the levels of the other energy and protein sources, making it impossible to keep their inclusion levels constant.

The oat silage, made during the previous season with a double chop silage chopper, was taken out of the bunker in the morning and afternoon prior to mixing. Mixed forage and concentrate allotments for each cow were weighed separately and were thoroughly mixed at each feeding. The diets were offered twice daily after milking (06:00 and 16:00) for *ad libitum* intake (5% orts) and water was freely available throughout the duration of the experiment.

4.2.4 Management and housing

Cows were group-housed, but gained individual access to feed throughs via transponder controlled gates. A 28 day period of teaching the cows to open the feed gates and adaptation to the facility and diets preceded the trial. The housing facility was cleaned twice daily during milking.

4.2.5 Statistical analysis

The data were analysed statistically using one way analysis of variation (ANOVA)' followed by F tests (Snedecor & Cochran, 1991). The ANOVA was done with the aid of "Statistical Analysis System" (SAS, 1989). Total daily nutrient intake and excretion were calculated as the products of daily intake and excretion and nutrient concentration. Computations were made separately for each cow on each treatment, statistically analysed and an average value presented using least square means (LSMEANS). All repeated measurements (milk production variables) were reduced to experimental period means for each cow before statistical analysis.

Table 4.3 Composition of experimental diets on a DM basis

Ingredient (%)	Ration A	Ration B	Ration C	Ration D	Ration E	Ration F
Yellow maize (Crushed)	24.46	11.17	20.28	12.21	19.00	12.00
Barley	10.00	9.95	17.80	12.15	20.34	11.49
Fish meal	4.00	4.00	4.00	4.00	4.00	4.00
Sunflower oilcake	13.54	9.18	10.10	6.35	9.37	5.56
Urea	1.00	0.50	1.00	0.50	0.80	0.50
Molasses	5.00	5.00	5.00	5.00	5.00	5.00
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Limestone	1.35	1.35	1.17	1.14	0.84	0.74
Premix	0.25	0.25	0.25	0.25	0.25	0.25
Whole cottonseed	-	18.00	-	18.00	-	18.00
Lucerne hay	-	-	10.00	10.00	20.00	20.06
Oat silage	40.00	40.00	30.00	30.00	20.00	20.00
Calculated nutrient composition (%)						
DM	48.00	48.50	54.00	54.40	62.90	63.20
TDN[1]	69.50	70.60	70.00	70.83	70.68	71.09
Crude protein	17.40	17.50	17.40	17.50	17.50	17.50
UIP[2]	5.47	5.30	5.42	5.28	5.49	5.27
NSC[3]	44.80	36.78	46.31	37.69	47.32	38.74
Fat (Ether extract)	3.96	6.78	3.55	6.54	3.18	6.28
Fibre	15.07	18.76	15.20	19.30	15.26	20.00
NDF[4]	29.83	34.94	28.74	34.27	28.00	33.48
ADF[5]	21.61	26.00	20.87	25.94	20.73	25.94
Calcium	0.91	0.95	0.95	0.95	0.95	0.95
Phosphorus	0.49	0.54	0.47	0.52	0.47	0.48

[1]TDN = Total digestible nutrients

[2]UIP = Undegraded intake protein

[3]NSC = Non-structural carbohydrates (100 - crude protein - NDF - fat - ash)

[4]NDF = Neutral detergent fibre

[5]ADF = Acid detergent fibre

4.3. Results and discussion

No interactions between the two main effects (silage level or cottonseed supplementation) were observed. The substitution of oat silage with lucerne hay affected all the production variables ($P < 0.05$) except milk fat percentage. At the highest inclusion level of lucerne hay, milk production, fat corrected milk production (all parameters), milk protein (percentage and kg), kg milk fat, milk lactose (percentage and kg), feed conversion efficiency and dry matter intake were significantly higher than in the diets without lucerne hay (Table 4.4). This accentuates the value of lucerne hay as a quality source of roughage for dairy cows.

As was expected, the inclusion of whole cottonseed alleviated milk fat percentage with 8.74% ($P < 0.01$) from 3.09 to 3.33 as measured with an Infrared Analyser (B filter, wavelength: 3.5 micron). This is due to the changes in milk fat composition (Table 4.6) that has been reported by others (DePeters *et al.*, 1985; Robertson, 1986; Mohammed *et al.*, 1988). Whole cottonseed levels did not affect milk production and therefore the kg of milk fat produced (0.742 vs 0.795) also differed ($P = 0.01$). In spite of these differences, the inclusion of whole cottonseed did not alter 4% FCM.

The inclusion of whole cottonseed at a level of 18% depressed milk protein percentage ($P < 0.01$) from 2.84 to 2.75% without affecting milk yield. Wu & Huber (1994) reported both contrasting and similar results in their review on milk protein concentration on dietary fat supplementation. According to these authors, the casein fraction is most subjected to depression by dietary fat suggesting that the mechanism causing milk protein depression resides in mammary tissue. Dry matter intake was also depressed ($P < 0.05$) from 18.2 to 17.8 kg with inclusion of whole cottonseed. DePeters *et al.* (1985) reported similar results.

Low milk fat and protein values were experienced throughout this trial without production being very high. This made it even more difficult to discern between fat and fibre effects of WCS. As noted by Clark & Armento (1992), NDF and ADF increased, consequently lowering non-structural carbohydrates (NSC), which could have a positive effect on rumen fermentation. This was true for the WCS diets, but the NSC levels in the diets without WCS might have been too high (Table 4.3). Feng *et al.* (1993) reported a marked decreased ruminal turnover rate with NSC levels above 39%.

Table 4.4 Least square means for lactation variables, milk production and milk solids

Parameters	Oat silage and lucerne hay levels			LSD (P = 5%)	Whole cottonseed levels		LSD (P = 5%)
	40:0	30:10	20:20		0	18	
Milk yield (kg/day)	22.8[a]	23.7[a]	25.6[b]	1.22	24.1	24.0	1.00
FCM (A)	20.1[a]	20.6[a]	22.8[b]	1.27	21.1	21.2	1.03
FCM (B)	20.0[a]	20.7[a]	22.8[b]	1.19	20.8	21.5	0.97
AFRC (A)	21.9[a]	22.6[a]	25.0[b]	1.38	23.2	23.1	1.12
AFRC (B)	21.8[a]	22.7[a]	25.0[b]	1.32	23.0	23.4	1.08
Milk fat A (%)	3.19	3.16	3.25	0.160	3.16	3.24	0.130
Milk fat A (g/day)	729[a]	741[a]	833[b]	58	761	774	47
Milk fat B (%)	3.17	3.19	3.27	0.141	3. 09[x]	3.33[y]	0.114
Milk fat B (g/day)	720[a]	748[a]	838[b]	52	742[x]	795[y]	43
Milk protein (%)	2.76[a]	2.78[a]	2.84[b]	0.056	2.84[x]	2.75[y]	0.046
Milk protein (g/day)	629[a]	655[a]	723[b]	42	681	656	34
Milk lactose (%)	4.47[a]	4.52[a]	4.59[b]	0.107	4.54	4.51	0.087
Milk lactose (g/day)	1018[a]	1080[a]	1181[b]	64	1098	1088	52
SST	280	235	160	146	227	222	119
DMI	16.0[a]	17.8[b]	20.2[c]	0.50	18.2[x]	17.8[y]	0.40
FCE	1.42[a]	1.33[b]	1.27[b]	0.070	1.34	1.35	0.060

[a, b, c] Means with different superscripts within rows differ ($P < 0.05$)

[x, y] Means with different superscripts within rows differ ($P < 0.05$)

FMC (A) = Fat corrected milk using milk fat A percentage

FMC (B) = Fat corrected milk using milk fat B percentage

AFRC (A) = Fat corrected milk according to the AFRC using milk fat A percentage

AFRC (B) = Fat corrected milk according to the AFRC using milk fat B percentage

Milk fat A (%) = Milk fat percentage according to Infrared analyser (wavelength, 5.73 micron)

Milk fat B (%) = Milk fat percentage according to Infrared analyser (wavelength, 3.5 micron)

FCE = Feed conversion efficiency

This trial produced no evidence of any depression in milk fat percentages when whole cottonseed was fed with oat silage as the primary source of roughage. In fact, the opposite appeared to be true. Milk fat percentage seemed to increase ($P < 0.10$), with the inclusion of whole cottonseed. Although higher milk fat percentages were observed with increasing levels of lucerne hay, it was not significant ($P = 0.18$). The inclusion of whole cottonseed in such diets boosted milk fat percentage (B filter) significantly (Table 4.5).

Table 4.5 Least square means for amount of milk fat and milk fat percentage for cows receiving the experimental diets

Oat silage (% of DMI)*	WCS (% of DMI)	Milk fat A (%)	Milk fat A (g/day)	Milk fat B (%)	Milk fat B (g/day)
40	0	3.15	735^{a}	3.08^{ab}	712^{a}
40	18	3.23	723^{a}	3.26^{bc}	729^{ab}
30	0	3.11	728^{a}	3.02^{a}	707^{a}
30	18	3.21	754^{ab}	3.36^{c}	790^{bc}
20	0	3.22	820^{bc}	3.17^{abc}	809^{cd}
20	18	3.28	845^{c}	3.37^{c}	866^{d}

* = The difference between oat silage % and 40 % constituted the inclusion level of lucerne hay.

a,b,c,d = Means with different superscripts in the same column differ ($P < 0.05$)

WCS = Whole cottonseed

Milk fat A = Milk fat according to Infrared analyser (wave length, 5.73 micron)

Milk fat B = Milk fat according to Infrared analyser (wave length, 3.5 micron)

The changes in milk fatty acid composition associated with the feeding of whole cottonseed are well documented (DePeters *et al.*, 1985, Mohammed *et al.*, 1988). Inclusion of whole cottonseed lowered average C8:0 fatty acids from 41 to 28 mg/100g of milk fat ($P < 0.01$), C10:0 from 136 to 88 mg/100g ($P < 0.01$), C12:0 from 147 to 93 mg/100g ($P < 0.01$), C14:0 from 398 to 311 mg/100g ($P < 0.01$) and C14:1 from 31 to 21 mg/100g ($P = 0.01$). The longer chain fatty acids increased ($P < 0.01$), C16:0 (814 to 912 mg/100g), C18:0 (292 to 388 mg/100g) and C18:1 (693 to 902 mg/100g). This, however, cannot be interpreted with certainty in the present study due to the interaction experienced between the levels of the two roughages (oat silage and lucerne hay) and the inclusion of whole cottonseed (Table 4.6). The levels of oat silage and lucerne hay are compliments of each other and it is therefore impossible to attribute the interaction to the decreasing levels of oat silage or the increasing levels of lucerne hay.

Table 4.6 Least square means for fatty acid composition

Fatty acids (mg/100g)	Oat silage: WCS						LSD (P = 0.05)
	40:0	40:18	30:0	30:18	20:0	20:18	
C8:0	38b[c]	26[a]	47[c]	31[a]	37[b]	29a[b]	11
C10:0	120[b]	83[a]	141[c]	86[a]	147[c]	93[a]	14
C12:0	125[b]	91[a]	149[c]	89[a]	168[d]	98[a]	14
C14:0	362[b]	309[a]	393[b]	305[a]	440[c]	318[a]	33
C16:0	772[a]	911[b]	793[a]	925[b]	877[b]	901[b]	71
C17:0	12	11	13	11	11	10	3
C18:0	301[a]	395[b]	294[a]	390[b]	282[a]	380[b]	41
Saturated*	1730[a]	1826[a]	1830[ab]	1838[ab]	1962[b]	1828[a]	132
C14:1	30[b]	22[a]	30[b]	20[a]	34[c]	22[a]	3
C16:1	48	36	25	49	36	41	25
C18:1	757[b]	868[c]	646[a]	916[c]	678[ab]	921[c]	82
Mono-uns.*	835[b]	925[c]	701[a]	985[c]	748[ab]	984[c]	88
C18:2	76	78	63	73	64	63	34
C18:3	12[bcd]	7[a]	8[abc]	14[d]	6[a]	9[abc]	4
Poli-uns.*	88	85	71	87	70	72	35

[a,b,c,d] = Means with different superscripts in the same row differ ($P < 0.05$)

* = Saturated, Mono-unsaturated and Poli-unsaturated fatty acids.

The response obtained in the amount of C10:0, C12:0, C14:0, C16:0, C18:1, C18:3, saturated and mono-unsaturated fatty acids could be ascribed to the interaction of either the rising levels of lucerne hay or the declining levels of oat silage and the inclusion of whole cottonseed. The literature agrees that the inclusion of WCS will alter the fatty acid composition of milk fat irrespectable of the roughage source (DePeters *et al.,* 1985, Mohammed *et al.*, 1988). The effect of oat silage on fatty acid composition could not be established.

The amount of interaction between the oat silage and lucerne hay levels, and whole cottonseed inclusion, on the saturated and mono-unsaturated fatty acids are indicated in Figure 4.1 - 4.3. No difference was observed in poli-unsaturated fatty acids.

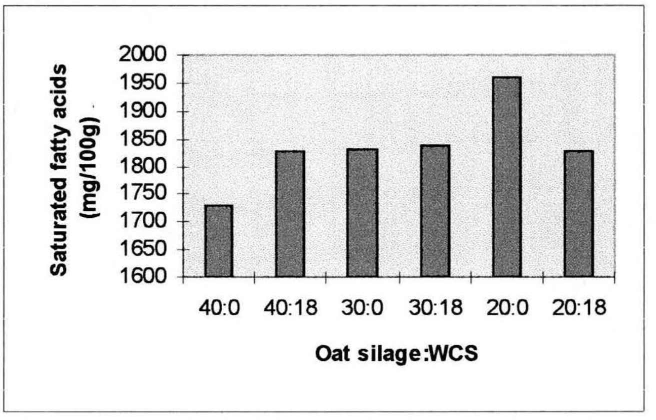

Figure 4.1 The influence of the different levels of oat silage and lucerne hay and the supplementation of whole cottonseed on the amount of saturated fatty acids.

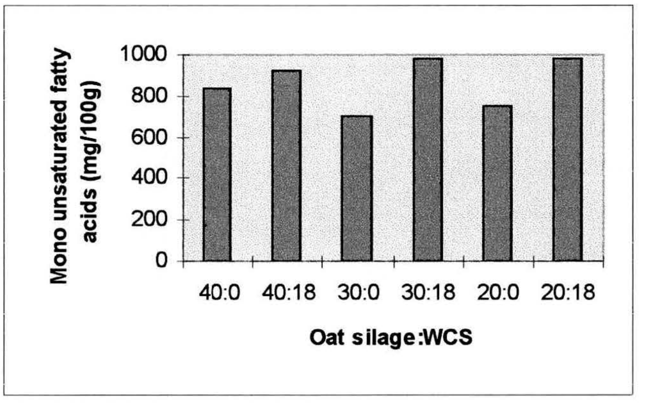

Figure 4.2 The influence of the different levels of oat silage and lucerne hay and the supplementation of whole cottonseed on the amount of mono-unsaturated fatty acids.

Figure 4.1 and 4.2 display different fatty acid concentrations at different levels of WCS, lucerne hay and oat silage. In Figure 4.1 it can be seen that at the highest level of oat silage inclusion (least lucerne hay), the concentration of saturated fatty acids was at its lowest. The inclusion of WCS in that diet led to an increase in the concentration. At the lowest level of oat silage inclusion (most lucerne hay), the saturated fatty acid concentration was at its highest, but the inclusion of WCS decreased this concentration. Figure 4.2 indicates a decrease, followed by an increase, as the concentration of oat silage decreased (lucerne hay increased). The differences that were significant are indicated in Table 4.6.

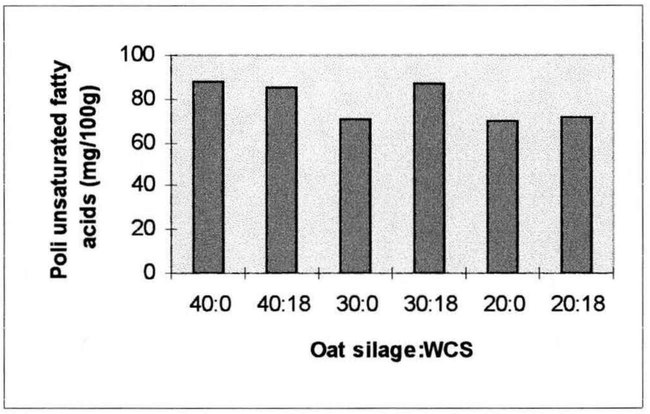

Figure 4.3 The influence of the different levels of oat silage and lucerne hay and the supplementation of whole cottonseed on the amount of poli-unsaturated fatty acids.

Digestibility coefficients that evaluate *in vivo* rumen function are shown in Table 4.7. All of the coefficients measured interacted except for NDF. NDF digestibility was influenced ($P < 0.01$) by the level of oat silage and lucerne hay, while the inclusion of whole cottonseed had no effect. It is true that the experimental diets where whole cottonseed was included had much higher levels of NDF (Table 4.3) due to the contribution of the cottonseed lint. This might have been an aspect that affected the results. The fat and ADF digestibility showed a trend towards interaction with P-values of 0.066 and 0.067, respectively. Like NDF, ADF digestibility increased ($P < 0.01$) as the amount of oat silage decreased and the amount of lucerne hay increased. The digestibility of fat increased ($P < 0.01$) from 78.24 to 82.38 % with the inclusion of whole cottonseed. This means that higher digestibility values for fat were obtained in the diets with the higher levels of fat inclusion. The ability of the animals to digest the additional fat also improved ($P < 0.05$) as the levels of oat silage decreased while lucerne hay increased.

Dry matter, organic matter and protein digestibility depended on the interaction between roughage levels and whole cottonseed inclusion. From Table 4.7 it can be seen that as the levels of the two roughages changed and whole cottonseed was added to the diets, digestibility of DM and OM decreased ($P < 0.05$). At the highest level of lucerne hay supplementation however, the inclusion of whole cottonseed alleviated the digestibility and no differences were observed. It would seem that higher levels of oat silage (or lower level of lucerne hay) with the inclusion of whole cottonseed limited digestibility to a certain extent. At the highest level of lucerne hay and whole cottonseed inclusion, all the digestibility parameters were at their best, although only ADF and fat were significantly ($P < 0.05$) better.

Table 4.7 Least square means of the digestibility coefficients

Oat silage to lucerne hay levels (% of DM)	WCS (% of DM)	Digestibility Coefficients					
		DM	OM	CP	NDF	ADF	Fat
40:0	0	69.76^{bc}	70.47^{bc}	77.79^{bc}	55.57^{ab}	39.73^{a}	77.30^{a}
40:0	18	64.20^{a}	64.89^{a}	74.19^{a}	53.20^{a}	41.97^{ab}	80.56^{b}
30:10	0	71.54^{c}	72.22^{c}	78.52^{bc}	61.62^{cd}	47.36^{ab}	79.45^{ab}
30:10	18	66.76^{ab}	67.97^{ab}	76.18^{ab}	58.33^{bc}	45.98^{ab}	82.09^{bc}
20:20	0	71.98^{c}	72.27^{c}	77.88^{bc}	61.83^{cd}	46.86^{ab}	77.98^{a}
20:20	18	73.43^{c}	74.27^{cd}	80.15^{c}	65.93^{d}	55.99^{c}	84.49^{c}

^{a,b,c,d} Means with different superscripts within columns differ ($P < 0.05$)

WCS = Whole Cottonseed
DM = Dry matter
OM = Organic matter
CP = Crude protein
NDF = Neutral detergent fibre
ADF = Acid detergent fibre

Most dairy companies in South Africa have complicated milk price structures. Although intricate, more or less 65-75 % of the price is based on milk solids ($^2/_3$ protein, $^1/_3$ milkfat) while 25-35% is based on volume. In order to do an economic evaluation of the six different diets, the price structure of Bonnita (second largest dairy company) was used to determine a milk price for each cow on each diet. Feed prices of October 1996 together with dry matter intake was used to determine the margin over feed costs. The diets tend to become more expensive as the amount of oat silage decreased ranging from R739.00 at the highest inclusion level to R830.00 per ton at the lowest inclusion level. Despite these differences in diet prices, no significant differences in the margins over feed costs (Table 4.8) were experienced.

Table 4.8 Least square means of margins over feed costs

	Oat silage:WCS						LSD
Parameter	**40:0**	**40:18**	**30:0**	**30:18**	**20:0**	**20:18**	**(P = 0.05)**
Margin/feed costs*	963.15	909.97	935.28	850.34	851.08	970.09	186.34

* Cent per cow per day

The feeding of whole cottonseed increased milk fat (B) percentage and amount of milk fat (B) (Table 4.4). This, however, could not increase the milk price so that significant margins over feed cost could be achieved. The reason being the high cost of WCS and the drop in milk protein percentage experienced with its inclusion. The lower DM intake associated with the inclusion of WCS could not contribute enough to lower the daily feed costs in order to achieve better margins over feed costs.

The higher productions and consequent better feed conversion ratios obtained on high inclusion levels of lucerne hay could not compensate for the higher feed costs. This may change as the genetic potential of the cows increase (Chandler, 1996).

4.5. Conclusions

The inclusion of whole cottonseed in oat silage based diets did not depress milk fat percentage, which are contradictory to results obtained when maize silage was supplemented with WCS (Smith & Harris, 1992).

Significant increases in milk solids and productions were observed as the inclusion levels of oat silage decreased and lucerne hay increased. This accentuates the value of lucerne hay as quality forage for dairy cows. These increases were alleviated further with the inclusion of WCS, without changing the nutrient composition of the diets. The changes in milk fat composition associated with the inclusion of whole cottonseed (Coppock & Wilks, 1991) were expressed in this trial with a shift from the short chain fatty acids to the longer chain fatty acids.

The inclusion of WCS in the diets did affect the ratio of the raw materials used in order to keep the nutrient composition similar. The contribution of these changes might have influenced the results, but the extent is unknown.

The lack of significant margins over feed costs leads to the conclusion that the possibility of dairy farmers gaining by substituting cheaper oat silage with more expensive lucerne hay in order to achieve higher productions and possibly better milk solids, are slim. The provision being that the milk price structure and difference in roughage costs are maintained. The possible drop in milk protein percentage outweighed the increase in milk fat percentage when whole cottonseed was included in oat silage based diets.

Oat silage can be used as the sole source of roughage in economic viable dairy cow diets. Improved productions, however, is possible when lucerne hay and/or WCS is added. It can, therefore be concluded that whole cottonseed can be included at accepted levels in diets containing oat silage as the main source of roughage.

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Chapter 5

General discussion and conclusion

It is more or less accepted that the feeding of dietary fats decrease ruminal degradation, especially for fibre (Palmquist & Jenkins, 1980). The nature of the fatty acids predominant in the type of fat supplemented frequently is cited as a factor for variation. Poly-unsaturated fatty acids generally have a more negative effect on ruminal digestion than saturated or mono-unsaturated fatty acids (Maczulac *et al.*, 1981). The fibre characteristics of the diet may influence the extent to which fats interfere with ruminal fermentation (Tackett *et al.*, 1996).

Whole oilseeds are less likely to interfere with ruminal fermentation because oilseeds are digested slowly allowing for a slow release of oil into the rumen and more extensive microbial hydrogenation (Steele, 1984). The production responses of feeding whole cottonseed to lactating cows appear to be influenced by the type of forage in the diet (Smith & Harris, 1992).

The interaction between the type of forage and fat included in the diet seems to be greatest on lucerne diets and poorest on maize silage based diets. Whole cottonseed especially appears to be influenced by the type of forage in the diet. With maize silage as the primary diet forage, the inclusion of whole cottonseed causes an increase in milk yield with a decrease in milk fat content. Milk protein responses were variable (Smith & Harris, 1992).

Data on the use of other silages in combination with whole cottonseed and the effect on production responses of lactating dairy cows are unavailable. The available data on the influence of fats and oils in silage based diets other than maize silage in general seems to be influenced by the form in which the fat is supplemented more than by the type of silage (Tesfa *et al.*, 1992).

The *in sacco* degradability of dry matter, organic matter, neutral detergent fibre and acid detergent fibre of oat silage appeared not to be influenced by supplemental whole cottonseed. Neutral detergent fibre degradability was significantly lower in diets supplemented with whole cottonseed at the highest outflow rate (0.08/h). This suggests that the production responses of dairy cows on maize silage based diets could be linked to the effect of whole cottonseed on rumen fermentation. A somewhat contradictory statement if one consider the fact that the oils in whole cottonseed are supposed to be released slowly as the seeds are being ruminated. The fact that effective NDF degradability was only affected at the highest outflow rate, could have implications for the high producing dairy cow.

It would seem that the negative effects associated with the inclusion of whole cottonseed in primary maize silage diets, are a function of the forage (maize silage), and not of silage as such. No proof of any negative effects of whole cottonseed or degradability of oat silage on production responses of lactating dairy cows could be found. It seems that oat silage can be used as the sole source of forage in dairy cow diets where whole cottonseed is supplemented.

The value of quality forage were once again demonstrated as of utmost importance in the performance of dairy cows. Differences in production characteristics experienced in this trial were almost constantly due to the difference in forage quality. Lucerne hay, being of a better quality, provided significant better performances than oat silage. The moisture content of diets with oat silage as the only forage seemed to be an additional constriction on production.

Considering the price difference (October 1996) between oat silage and lucerne hay, the improvements in production achieved with lucerne hay could not outweigh the added feed costs. In conclusion it can be said that the substitution of good quality oat silage with lucerne hay is not economically viable. The same, however, cannot be said of poor quality oat silage.

The price of whole cottonseed varies as the season changes. Unless the current milk price structure changes, the benefit of additional milk fat associated with the feeding of whole cottonseed would not be economic. According to Chandler (1996) the value of whole cottonseed increases as the genetic potential of the cow increases. This would mean that the inclusion of whole cottonseed in diets of genetically superior cows might provide economic responses.

This trial did not produce any evidence that would suggest that primary oat silage diets supplemented with whole cottonseed would react in the same way as primary maize silage diets. This trial would support the inclusion of whole cottonseed in oat silage based diets, but the decrease in milk protein percentage is troubling.

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