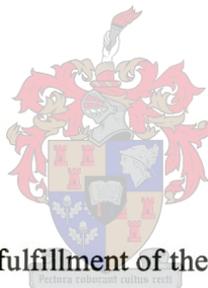


Studies on the Nutritive Value of Lucerne for Dairy Cows

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Thesis presented in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE IN AGRICULTURE
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Supervisor: Prof. C.W. Cruywagen

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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.

Abstract

Title : Studies on the nutritive value of lucerne for dairy cows.
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Degree : M.Sc. Agric.

An experiment was conducted to determine whether the quality of lucerne hay could be improved by artificial drying in a forced air bulk dryer (FABD) in comparison to lucerne hay produced by natural drying in the field. Lucerne fields were divided into four blocks of equal size and blocks were randomly assigned to each of the two treatments (natural or artificial drying). Lucerne was harvested at an early to mid flowering stage on six occasions. In two blocks, cut lucerne was left in the field to dry. Material in the remaining two blocks were left in the field for an initial drying period of no longer than 24 hours, after which it was transferred to a FABD. Samples of lucerne were taken at the time of harvest and then at regular intervals (on average 0, 4, 8, 22, 26, 29, 47, 50, 53, 56, 58, 69, 72, 76 and 80 hours after cutting) in the field and in the FABD until the material was dry enough for baling (*ca.* 15-18% moisture). Collected lucerne samples were dried in a forced draught oven until constant mass to determine moisture content. The rate of moisture loss was compared. Samples of the lucerne hay in the field and in the FABD were taken after baling to determine forage quality by means of chemical analysis. Samples were analysed for crude protein (CP), total digestible nutrients (TDN), digestible organic matter (DOM), acid detergent fibre (ADF) and neutral detergent fibre (NDF) content. Good weather conditions for natural drying during the trial period resulted in lucerne hay of similar chemical composition. Naturally dried lucerne hay had CP, ADF and NDF contents of 17.3, 41.2 and 48.0%, respectively, while values for artificially dried lucerne were 17.6, 40.6 and 47.3%. It was concluded that artificial drying of lucerne does probably not produce lucerne of a better quality than field drying under good weather conditions.

In the following trials eight ruminally cannulated cows (four Jerseys and four Holsteins) were used to compare protein and fibre degradability of lucerne harvested at different

stages of maturity (ie. 4, 5 and 6 weeks' regrowth), and of different lucerne products (ie. lucerne hay, lucerne leaves and 8% leaves added to hay), dried in a forced air bulk dryer. All cows received a total mixed lactation diet for the duration of the trial period. The first *in situ* rumen degradability trial was conducted with lucerne harvested at three stages of maturity namely after 4, 5 and 6 weeks' regrowth. Bags were incubated in the rumen for time intervals of 0, 2, 4, 8, 16, 24, 48 and 72 hours. Samples were analysed for dry matter (DM), crude protein (CP) and neutral-detergent fibre (NDF) content.

The effective DM, protein and NDF degradabilities of lucerne hay did not differ ($P>0.05$) between Holstein and Jersey cows. In Holsteins, DM degradability values calculated at an outflow rate of 0.05/h for lucerne harvested after 4, 5 and 6 weeks' regrowth were 63.1, 57.1 and 55.0%, respectively. Values of 64.6, 58.6 and 55.7% were obtained in Jerseys. CP degradability values for lucerne harvested after 4, 5 and 6 weeks' regrowth were 81.7, 77.2 and 77.6% in Holsteins and 81.3, 78.2 and 79.4% in Jerseys. NDF degradability values for lucerne harvested after 4, 5 and 6 weeks' regrowth were 35.8, 45.5 and 23.2% respectively in Holsteins and 35.1, 45.9 and 24.8% in Jerseys.

Analysis of the effective DM, protein and NDF degradabilities across breeds indicated differences between lucerne harvested after 4, 5 and 6 weeks' regrowth. Rumen degradability of DM and protein was the highest for lucerne harvested after 4 weeks' regrowth. DM degradability values of lucerne harvested after 4, 5 and 6 weeks' regrowth calculated at a flow rate of 0.05/h were 63.9, 57.9, 55.4%, respectively, while protein degradability values were 81.5, 77.7 and 78.5%. The lowest ruminal NDF degradability values were found for lucerne harvested after 6 weeks' regrowth. Values for NDF degradability calculated at a flow rate of 0.05/h for lucerne harvested after 4, 5 and 6 weeks' regrowth were 35.5, 45.7 and 23.7%, respectively. These results indicated that lucerne quality decreased in terms of DM, protein and NDF degradability as the plants mature.

The second *in situ* rumen degradability trial was conducted with three different lucerne components dried in a forced air bulk dryer, namely lucerne hay, lucerne leaves and lucerne hay + 8% leaves. The procedure followed was the same as in the first *in situ* trial.

Dacron bags, containing samples of the lucerne components were incubated in the rumen for time intervals of 0, 2, 4, 8, 16, 24, 48 and 72 hours. Samples were also analysed for DM, CP and NDF content and compared both between breeds and across breeds.

DM and protein degradability values (rate and effective degradability) of the artificially dried lucerne hay were higher in Jerseys than in Holsteins. DM degradability values calculated for Holsteins at a flow rate of 0.05/h for lucerne hay, lucerne leaves and lucerne hay + 8% leaves were 57.6, 66.5 and 61.4%, respectively, while protein degradability values of 76.9, 75.5 and 77.9% were obtained. DM degradability values calculated for Jerseys were 62.9, 69.1 and 61.7%, respectively, while protein degradability values of 82.4, 77.6 and 78.5% were obtained.

Analysis of the mean disappearance values across breeds indicated that protein degradability of lucerne hay in the rumen was higher than that of lucerne leaves. Protein degradability values calculated at a flow rate of 0.05/h for lucerne hay and lucerne leaves were 80.1 and 76.5% respectively. The NDF degradability of lucerne hay was, however, lower than what it was for lucerne leaves (24.6 vs. 29.7%).

Samevatting

Titel : Studies omtrent die voedingswaarde van lusern vir melkkoeie.
Kandidaat : Francois du Toit
Studieleier : Prof. C.W. Cruywagen
Graad : M.Sc. Agric.

'n Eksperiment is uitgevoer om te bepaal of die kwaliteit van lusernhooi verbeter kan word deur gebruik te maak van kunsmatige droging in plaas van die tradisionele landdroging. Lusernlande is in vier blokke verdeel en blokke is ewekansig aan elk van die twee behandelings (kunsmatige en landdroging) toegeken. Gesnyde materiaal in twee van die blokke is op die land gelaat vir die duur van die drogingsproses. Die materiaal in die oorblywende twee blokke is op die land gelaat vir 'n aanvanklike drogingsperiode van maksimum 24 uur, waarna dit in 'n massa-droogoond geplaas is. Lusernmonsters is net na sny op die land geneem en daarna met gereelde (gemiddeld 4, 8, 22, 26, 29, 47, 50, 53, 56, 58, 69, 72, 76 en 80 uur na sny) intervalle op die land en in die droër totdat die materiaal droog genoeg was om te baal. Lusernmonsters is in 'n droogoond gedroog totdat 'n konstante massa bereik is vir die bepaling van die voginhoud van die materiaal. Die tempo van vogverlies van die materiaal in die massadroër en op die land is bepaal. Monsters van die lusernhooi wat op die land en in die oond gedroog is, is na baal geneem en die chemiese samestelling van die lusernhooi is bepaal. Monsters is ontleed vir ruprotein- (RP), totale verteerbare voedingstof- (TVV), verteerbare organiese materiaal- (VOM), suur bestande vesel (SBV) en neutraal bestande vesel (NBV)-inhoud. Weersomstandighede was ideaal vir natuurlike droging van lusern en dit het aanleiding gegee daartoe dat die chemiese samestelling van die kunsmatig- en natuurlik gedroogde lusernhooi nie veel verskil het nie. Die RP, ADF en NDF inhoud van natuurlik gedroogde lusernhooi was 17.3, 41.2 en 48.0% terwyl waardes van 17.6, 40.6 en 47.3% vir kunsmatig gedroogde lusernhooi verkry is. Daar is bevind dat die kunsmatige droging van lusern nie 'n hoër kwaliteit hooi lewer as wat verkry kan word tydens landdroging wanneer weersomstandighede gunstig is nie.

Hierna is twee degradeerbaarheidstudies gedoen. Agt koeie (vier Holsteins en vier Jerseys) met rumenkannulas, is gebruik om die proteïen- en veseldegradeerbaarheid van verskillende lusernkomponente te vergelyk. Lusern op verskillende groeistadia gesny, asook verskillende lusernprodukte wat kunsmatig gedroog is, is vergelyk. Al die koeie het gedurende die proef tydperk 'n hoë-konsentraat laktasierantsoen ontvang.

Die eerste *in situ* degradeerbaarheidstudie is gedoen met lusern wat na 4-, 5- en 6 weke hergroei gesny is. Sakkies met lusernmonsters is in die rumen geplaas vir 0, 2, 4, 8, 16, 24, 48 en 72 uur onderskeidelik. Monsters is na inkubasie in die rumen vir die DM-, RP- en NBV-inhoud daarvan ontleed.

Daar is bevind dat die DM-, proteïen en NBV degradeerbaarhede van lusernhooi nie verskil het ($P.0>05$) tussen Holstein- en Jerseykoeie nie. DM degradeerbaarhede wat by 'n deurvloei tempo van 0.05/h in Holsteinkoeie bereken is vir lusern wat na 4-, 5- en 6 weke hergroei gesny is, was onderskeidelik 63.1, 57.1 en 55.0%. Die waardes wat vir Jerseys bereken is, was onderskeidelik 64.6, 58.6 en 55.7%. Vir lusern wat na 4-, 5- en 6 weke hergroei gesny is, was RP degradeerbaarhede 81.7, 77.2 en 77.6%, onderskeidelik, vir Holsteinkoeie en 81.3, 78.2 en 79.4%, onderskeidelik, vir Jerseys. NDF-degradeerbaarhede vir lusern wat na 4-, 5- en 6 weke hergroei gesny is, was 35.8, 45.5 en 23.2%, onderskeidelik, vir Holsteins en 35.1, 45.9 en 24.8%, onderskeidelik, vir Jerseys. 'n Vergelyking van die DM-, proteïen- en NBV-degradeerbaarhede wat gedoen is met die saamgevoegde data van al die diere, het daarop gedui dat verskille bestaan tussen die lusern wat na 4-, 5- en 6 weke hergroei gesny is. Die lusern wat na 4 weke hergroei gesny is, het die hoogste DM- en proteïendegradearbaarheid in die rumen getoon. DM-degradeerbaarhede wat bereken is teen 'n deurvloei tempo van 0.05/h vir lusern wat na 4, 5- en 6 weke hergroei gesny is, was onderskeidelik 63.9, 57.9 en 55.4% en proteïen-degradeerbaarhede was 81.5, 77.5 en 78.5%. Lusern wat na 6 weke hergroei gesny is het die laagste NDF-degradeerbaarheid gehad. Waardes wat bereken is teen 'n deurvloei tempo van 0.05/h vir lusern wat na 4-, 5- en 6 weke hergroei gesny is, was onderskeidelik 35.5, 45.7 en 23.7%. Hierdie resultate dui daarop dat die kwaliteit van

lusern afneem in terme van DM-, proteïen- en NBV-degradeerbaarhede namate die plante meer volwasse raak.

Die tweede rumendegradearbaarheidstudie is gedoen met 3 lusernprodukte wat in 'n massadroër gedroog is nl. lusernhooi, lusernblare en lusernhooi waarby 8% lusernblare gevoeg is. Dieselfde proefprosedure as tydens die eerste degradeerbaarheidstudie is gevolg. Sakkies met lusernmonsters, is in die rumen geplaas vir 0, 2, 4, 8, 16, 24, 48 en 72 uur. Monsters is ontleed vir DM-, proteïen- en NBV inhoud.

Daar is gevind dat die proteïen degradeerbaarheid (tempo en effektiewe degradeerbaarheid) van kunsmatig gedroogde lusernhooi, hoër was by Jerseys as by Holsteins. DM degradeerbaarhede wat in Holsteinkoeie teen 'n deurvloeitempo van 0.05/h bereken is vir lusernhooi, lusernblare en lusernhooi + 8% blare, was 57.6, 66.5 en 61.4%, onderskeidelik, terwyl proteïen degradeerbaarhede 76.9, 75.5 en 77.9%, onderskeidelik, was. Vir Jerseys is DM-degradeerbaarhede van 62.9, 69.1 en 61.7%, onderskeidelik, bereken terwyl proteïendegradearbaarhede 82.4, 77.6 en 78.5% was. Gemiddelde verdwyningswaardes, wat bereken is deur data van al die diere saam te gebruik, dui daarop dat die proteïen degradeerbaarheid van lusernhooi in die rumen hoër was as in die geval van lusernblare. Die proteïen degradeerbaarhede wat bereken is teen 'n deurvloeitempo van 0.05/h, was 80.1 en 76.5%, onderskeidelik, vir lusernhooi en lusernblare. Die NBV-degradeerbaarheid van lusernhooi was egter laer as vir lusernblare (24.6 vs. 29.7%).

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Chapter 1

General introduction

Lucerne hay production in South Africa is a large industry with a national production of 1.6 million tonnes annually. According to Anonymous (2001a) lucerne hay production figures from 1995 to 1999 were as follows: '95/'96: 1.625 million-; '96/'97: 1.659 million-; '97/'98: 1.646 million- and '98-'99:1.457 million tonnes. The value of the annual lucerne production in South Africa is in excess of R1000 million. Van der Merwe & Smith (1977) described lucerne as the most important hay crop in South Africa. This is because of the high yields per hectare together with high protein, calcium and vitamin contents. Lucerne also has a good palatability resulting in high intakes. In many situations when farmers experience a shortage in feedstuffs, cattle can often be fed a diet consisting of lucerne hay only, often without any appreciable negative effects.

1.1 Methods of lucerne preservation

Dairy cattle are ruminants and therefore have the ability to convert the fibre in forages, which cannot be utilized by humans, into useful products such as milk. The forage content of the total diet for cows should not be less than 40% in order to prevent the occurrence of metabolic disorders as well as butterfat depression(Stewart, 1995). Jones (1995) stated that the constant supply of good quality roughage is the solid foundation of profitable dairy farming. It is therefore important to always ensure an ample supply of good quality roughage on the farm to be used in the diets of dairy cows. Weather conditions do not always allow the production of roughages such as lucerne hay all year round and it is important to preserve lucerne hay for use in times when production is not possible. There are several methods to preserve lucerne. Each method has its advantages and disadvantages. It will be up to the farmer to decide which preservation method will be the best on his farm.

1.1.1 Silage

In this method of lucerne preservation, cut material is preserved while still containing 65-70% moisture. The silage making process is based on the concept that soluble carbohydrates present in the plant material are converted to lactic acid through fermentation. This causes an increase in the acidity of the ensiled material with a resulting drop in pH to a level ranging between 3.8 and 4.2. The level of acidity provides stability to the silage and it can thus be preserved for later use, provided that the conditions are kept anaerobic (Van der Merwe & Smith, 1977).

1.1.2 High moisture baling / Haylage

The high moisture baling method of lucerne preservation is aimed at a reduction in the time that cut lucerne has to wilt in the field. It also decreases leaf loss during baling. A shorter field curing period should reduce the risk of rain damage that may occur. Chemical preservatives can be used to prevent deterioration in the quality of lucerne hay baled at a higher moisture content. Propionic acid used as a preservative reduced storage losses in wetter hay crop material (>20% moisture) (Knapp *et al.*, 1974 as cited by Buckmaster and Heinrichs, 1993). According to Van der Merwe and Smith (1977) haylage is less acidic than silage and enables a larger amount of dry matter intake thereof on a daily basis.

1.1.3 Hay

Successful haymaking involves the quick and efficient removal of moisture from the harvested plant material. For safe storage hay should contain less than 20% moisture since baling at moisture levels above 20% generally increases storage losses due to excessive heating and molding. Hay can be made by drying the harvested material naturally in the field or artificially in a drying shed. The drying method of lucerne determines the quality and feeding value of lucerne hay.

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Drying methods

Field drying

During field drying many factors contribute to the deterioration of the quality of the lucerne hay. Parker *et al.* (1992) found that dry matter (DM) losses during field drying ranged from 4-15% due to plant respiration, 3-35% due to leaf shattering and 5-14% due to leaching by rain. Losses of DM and protein that occur during field drying of lucerne can be directly linked to length of field drying (Johnson *et al.*, 1983). Drying and handling losses were found by Radajewski *et al.* (1990) to be 4% of the yield for every day that the crop remained in the field. Sun bleaching during the field drying process reduces palatability and carotene content of lucerne hay (Vough, 2001).

Collins (1988) found that fibre levels of lucerne increased during hay curing. This increased further when cut material was exposed to rain. When rain occurs during drying, losses can exceed 40% of total DM yield (Collins, 1985). Collins (1991) simulated the effect of rain during the curing process of lucerne by soaking cut material in water. He found that one third of the leaf nitrogen content and 10% of the stem nitrogen content were lost in soaked hay. Collins (1988) found that rain caused a reduction in lucerne digestibility (64% vs. 57% for rain damaged hay). Fibre content was increased (NDF was 46% for normal hay and 54% for rain damaged hay). He also calculated relative feed values (RFV) for fresh herbage, hay not damaged by rain and rain damaged hay and found values of 146, 129 and 99 respectively. By comparing these RFV's to the forage quality standards as reported by Linn & Martin (1989) undamaged hay can be classified as first class, while the rain damaged hay can be considered as third class. The undamaged hay is suitable for use in rations of high producing dairy cows but the rain damaged hay is only suitable for use in dry cow rations during the first phase of the dry period (Coetzee, 2000).

These findings highlight the fact that drying time of cut lucerne in the field should be as short as possible. There are various methods that can be used to decrease the time that

freshly cut lucerne needs to reach a moisture content that would be suitable for baling and storage.

A common practice is to turn cut lucerne over by raking to improve air circulation and to move the material onto dry soil. DM losses through raking were found by Buckmaster & Heisey (1990, as cited by Parker *et al.*, 1992) to average 8%. Losses increased when the moisture content of the raked material decreased. Leaf loss during raking and baling is a serious problem because leaves contain a higher percentage of nutrients than stems (Parker *et al.*, 1992). Collins (1991) determined the relative contribution of separate leaf and stem components to losses in yield and quality during the hay curing process. It was found that leaves accounted for 78% of the respiration and shatter losses of DM, nitrogen (N), ash and *in vitro* digestible DM.

Mechanical conditioning during hay making

Mechanical and chemical conditioning of lucerne during cutting is widely used to decrease the field drying time of cut lucerne. According to Hintz *et al.* (1998) mechanical conditioning applied to material at cutting accelerates the drying process by disrupting the waxy cuticle layer of the plant and by breaking open the stem. This allows water to evaporate from the plant without it having to diffuse through the epidermis. In an experiment by Akkarath *et al.* (1996) mechanical conditioning with a mower-conditioner resulted in faster field drying rates than lucerne hay that was cut with a normal rotary disc mower. Mechanical treatment, however, often leads to an increase in the total DM lost through fragmentation (Klinner, 1975, as cited by Jones, 1991).

Drying rate can be further enhanced through the process of maceration. This process conditions material more intensively than a standard mower-conditioner and involves crushing and shredding of the stems and homogenizing the leaves and stems (Koegel *et al.*, 1988, as cited by Hintz *et al.*, 1998). According to Koegel *et al.* (1992) the process of maceration involves pressing the leaves and stems into a mat. This has the effect that the

loss of leaves due to overdrying and shattering is virtually eliminated which reduces quality loss during the drying process.

Chemical conditioning during hay making

Chemical treatment facilitates water loss from the material through the existing pathways without a serious increase in fragmentation, which will cause extra DM loss during the drying process (Harris & Tullberg, 1980). Products used for chemical conditioning during lucerne drying that contain potassium carbonate (K_2CO_3) as the active ingredient, function by modifying the waxy cutin layer of the leaf and stem surface. This modification makes it more permeable to water (Radler *et al.*, 1965, as cited by Iwan *et al.*, 1993). In an experiment by Akkarath *et al.* (1996), chemical conditioning was done by spraying a 2% aqueous solution of K_2CO_3 at 300 l ha^{-1} at cutting. They found that chemically conditioned lucerne had faster field drying rates than lucerne hay that was only cut with a rotary disc mower. Johnson *et al.* (1983) found that spraying cut lucerne with solutions containing emulsified methyl esters of long chain fatty acids and potassium carbonate increased DM content of baled lucerne hay and shortened the field drying time. Jones (1991) compared the drying rate of cut lucerne treated with a 2% solution of K_2CO_3 with that of untreated lucerne under laboratory conditions. The average reduction in lucerne drying time was 63% following the K_2CO_3 treatment and there was also a decrease in the differential drying of lucerne leaf and stem fractions.

Artificial drying

Although there are ways to reduce the drying time of cut material in the field, they can only prevent quality losses under conditions where no rainfall occurs during the field drying process. In regions where rainfall occurs regularly during the lucerne hay production season, it is commonly found that there are not 4 to 5 consecutive rain free days during which lucerne can be dried in the field. Long-term weather data collected on Elsenburg over a 25 year period up to 1992 is shown in Table 1. This data show that for 7 months of the year it rained on more than 20% of all days. It is especially during the

months of April, September and October that the making of lucerne hay is risky because of the high possibility of rain occurring during the field-curing period.

Table 1. Average number of days on which rain occurred at Elsenburg over a 25 year period up to 1992. (Anonymous, 2001b).

Month	Number of days per month	% of days	Total rain per month (mm)
January	3.8	12.3	16.4
February	3.4	12.1	17.2
March	4.1	13.2	21.8
April	7.2	24.0	57.0
May	10.5	33.9	83.7
June	11.7	39.0	106.0
July	11.7	37.7	99.7
August	11.7	37.7	84.7
September	10.3	34.3	55.0
October	8.0	25.8	38.8
November	4.6	15.3	19.5
December	5.8	19.3	22.9

One way to eliminate the possibility of losing a batch of lucerne due to rain, is by drying the lucerne artificially after harvesting. Studies on the drying of rectangular hay bales using forced air were done as early as 1946 (Miller, 1946, as cited by Parker *et al.*, 1992). Barn drying or artificial drying has been used in countries like France from the 1960's onwards (Foucras, 1998). Small rectangular bales of alfalfa baled at a moisture content as high as 30% were dried in an experiment by Parker *et al.* (1992) using forced air drying systems with heat from gas, solar energy or ambient air. Radajewski *et al.* (1990) dried lucerne directly after cutting in a step flow dryer using a solar heating system combined with an auxiliary heating system to keep temperatures constant during all conditions. Even in South Africa Du Plessis (1959) reported on the use of an artificial dryer using hot oven gasses to dry forage material that was constantly being moved by a mixing apparatus. Anonymous (1998) reports on the use of a blow-from-below barn curing system that uses gas fired heaters to dry up to 1600 bales of alfalfa hay within 15-48 hours, depending on the initial moisture content. Nagel (1992) used a solar heated forced air dryer to dry lucerne cut at a moisture content of 35%.

1.2 Factors affecting the quality of lucerne hay

1.2.1 Growth stage

As forages (such as lucerne) grow, the physical and chemical composition of the plant is constantly changing. The stage at which the alfalfa is harvested has a great effect on the quality of the hay that is produced. As the plant matures, fibre content increases, the crude protein (CP) content decreases and the digestibility and energy content declines (West, 1998). The increase in fibre content is due to an increase in the acid detergent fibre (ADF) and neutral detergent fibre (NDF) contents of the plant. This results in a decreased feed intake while the degree of lignification that increases with maturity of the lucerne, decreases the digestibility of the plant material (Van Soest, 1982, as cited by West, 1998).

According to Linn & Martin (1989), each percentage point increase in the lignin content of lucerne decreases the digestible dry matter (DDM) by three to four percentage points. When the quality of the forage decreases in terms of energy value due to an increase in maturity, the cost of the ration is also increased. This is because the lower energy content of mature forages must be substituted with high energy feeds such as grain. West (1998) conducted an experiment with lucerne harvested at pre-, early-, mid-, and full bloom. Lucerne was fed at 80, 63, 46, and 29% of the diet dry matter (DM) with the remainder from concentrates. The results of this experiment are shown in Table 2. It was found that increasing concentrate levels increased milk yield in all growth stages. Within a forage to concentrate combination increasing plant maturity decreased milk yield of dairy cows. Cows fed a diet containing 80% of pre-bloom lucerne produced more milk than cows fed a diet containing 29% of full bloom lucerne even though much more concentrates were fed. This trial emphasises the importance of good quality forage. The use of high energy concentrates could not overcome the negative effects caused by the low energy contents of mature lucerne.

Table 2. Effect of plant maturity (as indicated by different bloom stages) of lucerne and concentrate percentage on the milk yield of dairy cows (Adapted from West, 1998).

Concentrate : forage ratio in total diet	Milk yield (kg/day)				Difference (pre to full bloom)
	Growth stage				
	Pre bloom	Early bloom	Mid bloom	Full bloom	
20:80	38.1	34.1	28.0	25.1	13.0
37:63	38.7	36.6	31.9	26.9	11.8
54:46	43.0	40.7	34.5	32.9	10.1
71:29	44.6	42.0	34.8	34.8	9.7
Difference (20 to 71% concentrate)	6.5	7.9	6.8	9.7	

1.2.2. Environmental factors

Environmental factors that affect forage quality include the following: environmental temperature, sunlight and moisture stress (Linn & Martin, 1989). Environmental temperature during the growing phase of lucerne has a large effect on the quality of lucerne hay. Buxton *et al.* (1995 as cited by West, 1998), reported that the optimal growth temperature for cool season species, such as lucerne, is around 20°C. Higher temperatures decrease the leaf to stem ratio and promote the production of lignin in the plant cell walls. These changes decrease the digestibility of the lucerne DM. According to Linn & Martin (1989) high temperatures result in forage containing higher levels of fibre at the same stage of maturity compared to forage growing at lower temperatures. Each 1°C increase in ambient temperature decreases digestibility of forages by 0.3 to 0.7 percentage points (Buxton *et al.*, 1995, as cited by West, 1998). This may explain why forages, such as lucerne hay, produced in the warmer climate of South Africa would be of lower quality and have higher ADF and NDF levels resulting in a lower feeding value than lucerne produced in a more temperate climate.

Where forages like lucerne grow in cloudy conditions plants tend to have a higher CP content than would be the case when sunny conditions are experienced throughout the growing period (Linn & Martin, 1989).

When plants grow under moisture stress conditions, which is often the case in some regions in South Africa where the water supply is limited, plant growth rate is decreased but the leaf to stem ratio is increased. This lower plant growth rate under drier conditions results in a higher digestibility of the plant material. This is because of the lower fibre content of the plant material (Linn & Martin, 1989).

1.3 Fibre content of forages.

Fibre is a measure of the plant's cell wall, which is the structural portion of the plant, lending it support. Some of the characteristics of fibre are that it limits digestion, requires repeated chewing to reduce particle size and is bulky, which means it occupies a lot of space in the rumen. Fibre contains the less rapidly degraded components of feed, such as cellulose and hemicellulose. The indigestible chemical lignin is also contained in fibre (Grant, 1991). Fibre is important in the diet of dairy cattle because of the important role it plays in rumination. Adequate levels of fibre will prevent acidosis and low milk fat (Grant, 1991).

Different methods can be employed to determine the fibre content of forages. According to Linn & Martin (1989) a detergent fibre analysis system can be used to separate forages into different parts. The two different parts are: cell contents or neutral detergent solubles, which includes sugar, starches, proteins, non-protein nitrogen, fats and other highly digestible compounds; and the less digestible compounds found in the fibre fraction.

The different fibre fractions with their chemical components and digestibilities are presented in Table 3.

Table 3. Different fibre fractions in forages with their chemical components and digestibilities (Linn & Martin, 1989).

Fraction	Components	Digestibility (%)
Cell walls (NDF)	Hemicellulose	20-80
	Cellulose	50-90
	Lignin	0-20
	Heat damaged protein	Variable
	Keratin	Variable
ADF	Cellulose	50-90%
	Lignin	0-20%
	Heat damaged protein	Variable
ADL	Lignin	0-20%
Cell solubles (100-NDF%)	Starches	95-100%

ADF = Acid detergent Fibre

ADL = Acid Detergent Lignin

NDF = Neutral Detergent Fibre

The fibre fraction of forages can be divided into neutral detergent fibre (NDF) and acid detergent fibre (ADF). The NDF fraction consists of the cell wall fraction and include cellulose, hemicellulose, lignin, and heat damaged protein. These chemical components are associated with the bulkiness of a feed and are closely related to feed intake and rumen fill in cows. ADF contains cellulose, lignin and heat-damaged protein. This fraction can be related to indigestibility of feeds and it is also used in calculating energy values. The lignin component found in cell walls can be measured by acid detergent lignin (ADL).

According to West (1998) forage quality is a complex interrelationship of many factors that affect among other things, intake potential, nutrient content, digestion and gut fill.

He found that there is a negative correlation between DM digestibility, dry matter intake (DMI) and digestible DMI with ADF and NDF. This means that these variables will decline when the ADF and NDF content of a forage increases. The correlation that exists between cattle response and fibre concentration is shown in Table 4.

Table 4. Correlation between fibre concentration and cattle response (West, 1998).

Item	ADF(%)	NDF(%)
DM digestibility	-0.39	-0.32
DM intake	-0.52	-0.41
Digestible DM intake	-0.55	-0.43
NDF intake	0.30	0.50

ADF = Acid detergent Fibre

DM = Dry Matter

NDF = Neutral Detergent Fibre

Determining NDF has a shortcoming in the sense that it only measures the chemical characteristics of fibre. It does not measure the physical properties, such as particle size, that affect the effectiveness of fibre in meeting the cow's minimum requirements (Mertens, 1999, as cited by Cruywagen, 1999). Mertens (1997) proposed two additional definitions, that could be used in the formulation of diets. He proposed the use of effective NDF (eNDF) and physically effective NDF (peNDF). The eNDF is related to the ability of the feed to maintain milk fat production. Physically effective NDF is related to the physical properties of the fibre and its ability to stimulate chewing activity as well as the establishment of the biphasic stratification of ruminal contents. The biphasic stratification of the ruminal contents is the floating mat of large particles on a pool of liquid and small particles (Mertens, 1997, as cited by Cruywagen, 1999).

1.3.1 Dietary fibre levels and cow production

Ruminants have a symbiotic relationship with ruminal cellulolytic micro-organisms that enable them to utilize cellulose and hemicellulose (Russell & Wilson, 1996). This symbiotic relationship requires the animal to provide a suitable environment in which the

microbial organisms can grow. Microbes degrade cellulose, providing the animal with volatile fatty acids, which are the end products of fermentation (Russel & Wilson 1996). The microbes utilise nutrients such as nitrogen, to grow. When the microbes pass through the rumen, they are absorbed in the small intestines providing the animal with a source of microbial protein (McDonald *et al.*, 1988)

The rumen microbial mass consists of fungi, bacteria and ciliate protozoa (Matsui *et al.*, 1998). The total number of bacteria and also the population of individual species can vary with the diet of the animal. The quality of roughages included in the diets of cows can also have an effect on the microbial population in the rumen. For a forage to be a good basis for a total diet, it must be high in energy and it should also stimulate chewing activity. When a roughage with a low energy content is used in a ration larger amounts of high energy feeds, such as cereal grains, must be included in the diet to maintain a high energy concentration. Concentrate feeds, such as cereal grains, have faster fermentation rates that causes the ruminal pH to decrease because of a build-up of volatile fatty acids in the rumen (Russel & Wilson, 1996).

According to Grant (1991) the first symptom of a diet containing too little fibre, or fibre that is too fine, will be a reduction in chewing activity of the animal. As chewing activity decreases, saliva production is also reduced. Saliva contains bicarbonate and acts as a buffer against acids in the rumen produced by microbial fermentation of feeds. Decreased chewing activity thus results in less saliva secretion and a decreased ruminal pH. The pH level of the rumen content should not fall below 6.0-6.2, or degradation of fibre by microbes will be reduced (Grant, 1991).

The volatile fatty acids, acetate and propionate, are major end products of microbial fermentation of feeds in the rumen (Grant, 1991). When the NDF content of a feed decreases, the level of acetate in the rumen decreases and propionate increases. Acetate is a precursor for milk fat synthesis, while propionate predisposes the cow towards body fat production. This means that a low fibre diet makes a cow more efficient in body fat synthesis and less efficient at milk fat synthesis, leading to milk fat depression (Grant,

1991). In Table 5 the effect that fibre content of the ration has upon the metabolic state of the dairy cow is shown.

Table 5. The effect of forage fibre content of the diet on the metabolic state of the dairy cow (Adapted from Grant, 1991).

Parameters	Long roughage in the diet			
	(%)			
	100	60	40	0
NDF (%)	70	48	36	14
Chewing time (minutes/day)	960	900	820	340
Saliva production (litres/day)	188	176	169	124
Rumen acetate (%)	70	61	55	40
Rumen propionate (%)	15	22	27	40
Milk fat (%)	3.7	3.5	3.4	1.0

NDF = Neutral Detergent Fibre

The optimum fibre level required in the diet of dairy cows is determined by the cow's production level. Cows with a high milk production require a diet with a relatively low fibre level to ensure maximum feed intake. It should be kept in mind that a minimum recommendation of NDF should accompany a maximum NFC and minimum forage NDF recommendation. When the minimum forage NDF decreases, the minimum dietary NDF increases and the maximum NFC decreases. When the dietary NDF levels are too low it can lead to conditions such as acidosis and milk fat depression.

The estimated NDF content of diets required by different production levels of cows is shown in Table 6.

Table 6. Estimated NDF content of optimal diets for dairy cows (Adapted from Grant, 1991).

Lactating cows (milk production)	NDF (% of Dry matter)
Very high production, 45+ kg/day	26
High production, 32-45 kg/day	28
Medium production, 20-45 kg/day	39
Low production, < 20 kg/day	39
Fresh cow (3-4 wk of lactation)	36
Dry cows	50
Heifers	
Less than 180 kg	34
From 180 to 364 kg	42
From 364 to 545 kg	50

NDF = Neutral Detergent Fibre

1.3.2 The role of fibre in the calculation of energy values

Traditionally, the calculation of the energy content of a feed required sophisticated equipment and animal metabolism trials (Linn & Martin, 1989). Because the energy content of a feed is inversely related to the fibre content, it is possible to predict the energy content of a feed from its fibre content. Total digestible nutrients (TDN) is a measure of energy and can be defined as follows:

$$\text{TDN\%} = \text{Digestible CP} + \text{Digestible crude fibre} + \text{Digestible nitrogen free extract} + (\text{Digestible fat} \times 2.25)$$

Estimates of TDN for legumes can be made from ADF by using the following equation:

$$\text{TDN\%} = 88.9 - (0.779 \times \text{ADF\%})$$

There are several factors influencing the feeding value of forages which can be related to fibre such as plant species and date of cutting (Linn & Martin, 1989). Legumes harvested

in early bloom or the late vegetative stage are low in fibre and contains less lignin than legumes cut at a later stage. It is difficult to compare different forages in terms of quality if there is not a standard method of measurement. Relative feed value is an index that combines factors such as potential intake and digestibility into a number and can be used to compare different forages with each other. Relative feed value is calculated by using the estimated digestibility and potential intake of a forage calculated from ADF and NDF fractions.

Digestible dry matter can be calculated from ADF using the same equation as for TDN% as cited by Linn & Martin (1989):

$$\text{DDM (\%)} = 88.9 - (\text{ADF\%} \times 0.779)$$

Dry matter intake (DMI) is expressed as a percentage of body weight and is calculated from NDF using the equation cited by Linn & Martin (1989):

$$\text{DMI (\% of body weight)} = 120/\text{NDF\%}$$

RFV can be calculated by using the following equation cited by Linn & Martin (1989):

$$\text{RFV (\%)} = [\text{DDM (\%)} \times \text{DMI (\% of body weight)}]/1.29$$

The quality standards proposed by the Hay Marketing Task Force of the American Forage and Grassland Council which are based on RFV's, for legumes are presented in Table 7 (Linn & Martin, 1989).

Table 7. Forage quality standards for legumes, grasses and legume-grass mixtures (Linn & Martin, 1989).

Quality standard ^a	RFV ^b	ADF ^c	NDF ^c	DDM ^d	DMI ^e % of BW
		% of DM			
Prime	>151	<31	<40	>65	>3.0
1	151-125	31-35	40-46	62-65	3.0-2.6
2	124-103	36-40	47-53	58-61	2.5-2.3
3	102-87	41-42	54-60	56-57	2.2-2.0
4	86-75	43-45	61-65	53-55	1.9-1.8
5	<75	>45	>65	<53	<1.8

^a: Standard assigned by Hay Market Task Force of the American Forage and Grassland Council.

^b: Relative Feed Value (RFV) calculated from (DDM X DMI) / 1.29.

Reference RFV of 100 = 41% ADF and 53% NDF.

^c: ADF = Acid Detergent Fibre, and NDF = Neutral Detergent Fibre.

^d: Dry matter digestibility (DDM, %) = 88.9 - (.779 X ADF%)

^e: Dry Matter Intake (DMI, % of body weight) = 120 / forage NDF (% of DM).

Coetzee (2000) determined the relationship between different chemical components of lucerne hay. A change in crude fibre content predicts a change in ADF ($R^2=0.821$) and NDF ($R^2=0.736$) while it can also predict a change in RFV ($R^2=0.792$).

Coetzee (2000) used American data to compile Table 8 by which separate chemical components can be predicted through the relationship that exists between them.

Table 8. Specifications for lucerne hay (Coetzee, 2000).

Crude protein (minimum) %	Crude fibre (maximum) %	ADF (maximum) %	NDF (maximum) %	Relative feed value (minimum) %
12	43.8	51.2	57.0	80.0
13	41.0	47.5	53.4	90.0
14	38.4	44.1	50.2	101.0
15	35.9	41.1	47.2	112.0
16	33.6	38.4	44.6	123.0
17	31.4	36.1	42.3	134.0
18	29.5	34.1	40.4	144.0
19	27.7	32.4	38.8	153.0
20	26.0	30.9	37.5	161.0
21	24.5	29.9	36.6	167.0
22	23.2	29.3	35.9	171.0
23	22.1	28.9	35.6	173.0
24	21.1	28.8	35.7	173.0

ADF = Acid Detergent Fibre
NDF = Neutral Detergent Fibre

By using Table 8, CP content for lucerne hay can be determined, as a minimum level and crude fibre, ADF and NDF can be determined as a maximum at different levels. The ADF and NDF values from Table 8 can also be used to determine the minimum relative feed value of lucerne hay.

Coetzee (2000) found, however, that average values obtained from chemical analysis done by the NCD-laboratory for samples of lucerne did not correspond exactly with the values presented in Table 8. For an average protein level of 17% the corresponding values were: ADF=39%, NDF=48% and RFV= 117. By comparison the values for lucerne hay produced in South Africa yield an estimated ADF that is 7.5% higher than the value in Table 8. NDF was 11.8% higher and RFV was 12.7% lower (Coetzee 2000). The difference in these values can be attributed mainly to the difference in environmental conditions where lucerne is being produced. High temperatures in the South African lucerne production regions result in a lower leaf-to-stem ratio (West, 1998). Stems have a larger concentration of NDF, which leads to a lower digestibility of the lucerne hay.

High temperatures also result in a higher rate of lignification in the plant during the growing phase which increases NDF content of the lucerne and decreases the dry matter intake of the hay when fed to animals.

1.4 *In situ* degradability of forages

During the last decade several new systems for the evaluation of feed protein and the calculation of feed protein requirements have been developed. Emphasis is put on the separation of feed protein into ruminally degraded (RDP) and undegraded (RUP) protein fractions. In order to meet the protein requirements of ruminants, it is necessary to assess the protein degradation of feed proteins accurately (Broderick *et al.*, 1988).

There are a variety of methods by which protein degradation in feedstuffs can be measured, such as solubility tests, *in vivo* measurements and the *in situ* bag procedure. The laboratory solubility tests are limited in the sense that it cannot be used to estimate protein degradation over a variety of feedstuffs (Stern & Satter, 1984). Feed protein can be evaluated by the *in vivo* method but it is a complex, expensive and difficult procedure (Owens, 1987, as cited by Erasmus *et al.*, 1990). Although the *in situ* technique has been criticised (Nocek, 1988) it is preferred to *in vivo* experiments (Jarrige, 1987 and Lindberg, 1987, as cited by Erasmus *et al.*, 1990). The *in situ* technique is used as the standard method for determination of protein degradation in the protein evaluation systems in the USA, UK and Nordic countries (Van der Honing & Alderman, 1988).

The South African databases on *in situ* degradability values for different kinds of forages are limited in terms of lucerne. Erasmus *et al.* (1990) established *in situ* degradability values, but values are only reported for unspecified lucerne hay and dehydrated lucerne meal. The chemical composition and feeding value of different lucerne products can vary significantly. It is therefore important to have NDF and protein degradability values available on different types and components of lucerne hay.

1.5 Current study

It is clear from the above discussions that lucerne is considered to be one of the most important hay crops in South Africa. It is being used on a large scale as a forage source in dairy cow diets. Lucerne quality deteriorates during the drying process. It is thus important to try and eliminate some of the factors that reduce the quality of lucerne hay. This can be done by drying lucerne in the shortest possible time and preventing lucerne from being damaged by rain. In ideal weather conditions it is possible to produce good quality lucerne hay by means of field drying. It is, however, difficult to produce good quality lucerne hay in poor weather conditions.

Two studies were conducted to obtain more information pertaining to the nutritive value of lucerne produced in the Western Cape Province of South Africa. The aim of the first study was to determine whether the quality of lucerne hay produced could be improved by drying cut lucerne in a forced air bulk dryer. This was done by drying lucerne in the field and in a forced air bulk dryer and comparing the quality of the hay produced by means of chemical analysis.

The aim of the second study was to expand the South African databases on *in situ* protein and fibre degradability. This was done in two trials. In the first trial the extent of ruminal protein and NDF degradation of lucerne harvested after 4, 5 and 6 weeks' regrowth was determined by using the *in situ* nylon bag technique. In the second trial the extent of ruminal protein and NDF degradation of different lucerne components dried in a forced air bulk dryer were determined. The components included lucerne hay, lucerne leaves and lucerne hay to which 8% leaves were added.

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Chapter 2

A Comparison of the Chemical Composition and Drying rate of Naturally and Artificially Dried Lucerne Hay Produced at Elsenburg.

The objective of this study was to determine whether the quality of lucerne hay could be improved by drying lucerne artificially in a forced air bulk dryer rather than in the field. Lucerne was dried on six harvesting occasions. Lucerne fields were divided into four blocks, of equal size and blocks were randomly assigned to two treatments (natural or artificial drying). Lucerne was harvested at a mid-bloom stage. In two blocks, lucerne was left in the field for the duration of the drying process. In the remaining two blocks material was left in the field for an initial drying period of no longer than 24 hours, after which it was transferred to a forced air bulk dryer (FABD). Samples of lucerne were taken at the time of harvest and then at regular intervals in the field and in the FABD until the material was dry enough for baling. The rate of moisture loss from lucerne in the field and in the FABD was determined. Samples of the material in the field, as well as in the FABD, were collected after baling to determine forage quality by means of chemical analyses. Samples were analysed for crude protein (CP), total digestible nutrients (TDN), digestible organic matter (DOM), acid detergent fibre (ADF) and neutral-detergent fibre (NDF) content. The chemical composition did not differ ($P>0.05$) between the lucerne hay produced by natural or artificial drying. Naturally dried lucerne hay had CP, ADF and NDF contents of 17.3, 41.2 and 48.0%, respectively, while values for artificially dried lucerne hay were 17.6, 40.6 and 47.3% respectively. It can be concluded that artificial drying of lucerne under good weather conditions, does not produce lucerne of a better quality than field drying when lucerne is left in the field for up to 24 hours before it is transferred to the forced air bulk dryer.

Introduction

Lucerne (*Medicago sativa*) hay production in South Africa is a large industry with an annual production of approximately 1.6 million tonnes (Anonymous, 2001a). This can be valued at around R1000 million annually. Milk producers in South Africa and especially the Western and Southern parts of the Western Cape Province experience problems each year with the production of good quality lucerne hay through the process of natural- or

field drying. A relatively high moisture content of the air during the day, heavy dew or mist at night and occasional rainfall are factors that can cause cut lucerne to dry slowly in the field. During the field drying process losses in dry matter (DM) and quality occur as a result of respiration, rain damage, and shatter of dried leaves (Akkarath *et al.*, 1996). Sun bleaching also reduces the carotene content of the lucerne (Vough, 2001). Drying and handling losses were found by Radajewski *et al.* (1990) to be 4% of the yield for every day the crop remained in the field. In cases where rain occurred during the drying process, losses could exceed 40% of total dry matter yield (Wilkinson, 1981 as cited by Akkarath *et al.*, 1996).

Traditionally the time that cut lucerne stays in the field is reduced by turning the lucerne over through raking to improve air circulation (Mills, 1993, as cited by Akkarath *et al.*, 1996) and to move the cut material onto dry soil. This handling of lucerne causes leave losses that increase as the moisture content of the lucerne decreases. Loss of leaves is a major concern when it comes to the production of good quality hay as the leaves contain 70% of the total protein content of the plant and 90% of the carotene content (Du Plessis, 1959). With field drying the shattered leaves cannot be collected and is excluded from diets for dairy cows.

Artificial drying of lucerne in a forced air bulk dryer (FABD) has been used to reduce the time cut lucerne stays in the field. This hastens the lucerne regrowth and reduces the number of days of operation in the field. Quality losses that normally occur during the process of field drying are therefore reduced (Radajewski *et al.*, 1990). Selecting the right harvesting schedule for lucerne is important because there is a yield and quality tradeoff (Orloff, 1999). This means that allowing lucerne to grow for a longer period of time gives a higher yield but the quality gets poorer. At a certain stage it can even become unacceptable. The implication of this is that the farmer has to plan his harvesting schedule carefully and there is not always time to wait for the ideal weather conditions before lucerne must be harvested. Having to wait for the right weather conditions often not only leads to poorer quality lucerne, but also fewer cuts per season and therefore a lower production.

At Elsenburg favourable months for natural drying of lucerne hay are December, January, February and March. The average total rainfall during this four month period amounts to 19.6mm while rainfall occurs only on 14 % of all days (Anonymous 2001b). This relatively low rainfall together with high maximum temperatures and wind occurring regularly, create conditions under which field drying can be attempted with some certainty. Although the weather conditions during these months (December to March) is ideal for field drying of lucerne, the low rainfall and high daytime temperatures poses a problem for dry land production of lucerne. Lucerne harvested in April, as well as early in September and October, is risky because more rain occurs during these months. An average total rainfall of 50.3mm occur over these three months while rain occurs on 30% of all days (Anonymous 2001b). This creates a greater risk of lucerne damage occurring during the field drying process.

With the option of artificial drying available, the farmer does not need up to four consecutive days of dry weather to cut and dry lucerne safely in the field, because it can be put into a forced air bulk dryer (FABD) within 24 hours after harvesting. Radajewski *et al.* (1990) found that the artificial drying of lucerne immediately after cutting eliminated quality losses and reduced the number of field operations needed during the drying process. This resulted in a potential financial advantage in lucerne production. Geldenhuys (1995) also found that drying lucerne in a FABD produced hay of higher quality, which contained up to 21% protein. The higher quality of the hay produced is a great advantage along with the fact that leaves can be collected from the floor of the dryer and used as an ingredient in animal rations.

There is little information available in South Africa on the nutritive value of lucerne hay produced by field drying vs. artificial drying. The aim of this investigation was to compare the chemical composition, of naturally and artificially dried lucerne produced in the winter rainfall region of the Western Cape.

Materials and Methods

Location

The study was conducted at the Elsenburg Experimental Station (altitude 177m, longitude 18°50' and latitude 33°51') near Stellenbosch in South Africa. A lucerne field, of 2ha was used in the study. During summer the lucerne was irrigated once a week with a permanent irrigation system (sprinklers 15x15m apart) at a level equivalent to 25mm of rain per irrigation. The lucerne field was divided into 4 blocks. Lucerne was harvested in a mid flowering stage with a mower-conditioner (New Holland model 488).

Blocks were chosen randomly on which the cut lucerne was either left to dry in the field or transferred to the FABD. Lucerne was regarded as ready for baling at a 15-18% moisture content (Iwan *et al.*, 1993). Approximately 24 hours after the lucerne was harvested, the material in the field was turned over with a four-wheel finger rake. Samples of lucerne were collected just after cutting and then at regular intervals thereafter (on average 0, 4, 8, 22, 26, 29, 47, 50, 53, 56, 58, 69, 72, 76 and 80 hours after cutting) up to the point where it could be baled. Part of the samples were dried at 50°C to be used for chemical analysis and part was dried at 100°C to determine and monitor the moisture content of the lucerne being dried in the field. The material on the remaining two blocks of each field was left for an initial drying period of no longer than 24 hours after which it was transferred to the FABD where it was artificially dried to the required moisture content. After the initial 24-hour period of field drying, the average moisture content of the lucerne hay that was transferred to the dryer varied from 40 to 60%.

Forced Air Bulk Dryer

The FABD consisted of a brick shed (8.3 X 4.2m) with a maximum loading height of 2m. This provided for a 70m³ drying compartment. Airflow was created by a 600mm diameter centrifugal fan driven by a 5.5 kW motor supplying an airflow of 4m³/s. A 48 kW element heater was used to increase the air temperature by 10°C. This warm air was

then blown through a chute with a closed end and containing rectangular openings along the top and sides to let the air through.

In the FABD, lucerne was dried in loose bulk form. Lucerne was transported by trailers from the field and then manually transferred from the trailers onto wooden slats (ranging from 300mm from the floor at the front end of the FABD up to 900mm from the floor at the back end) inside the dryer. Each load was then stacked up to the desired height (maximum 2m high). Successive loads were stacked in front of each other to prevent too much trampling on the material to prevent compaction and reduced airflow. An even height was maintained and care was taken to avoid material forming a wedge shape that could cause material at the one end of the dryer to dry excessively while material in the corners at the back would not be dried sufficiently and rot. After the total load of lucerne was transferred into the dryer, corrugated metal sheets were placed at the open end to allow a build-up of air pressure causing the air to flow upwards into the lucerne lying on the wooden slats.

Samples of lucerne in the FABD were taken at the start of the artificial drying process and then at regular intervals *i.e.* initially every 4-6 hours when the material was still wet and then every 2 hours as the material neared the appropriate moisture content for baling. Samples taken from the dryer were divided in two. One part of the sample was dried in a microwave oven (set on high) until a constant weight was reached. This was done to determine when the dryer could be switched off. This was done when the moisture content of the material was approximately 15-18%. The other part of the sample was dried in an oven at 50°C until constant mass for the purpose of chemical analysis.

Chemical analysis

Lucerne samples were analysed for crude protein (CP) content according to the methods of the AOAC (1984). The *in vitro* organic matter digestibility was determined according to the method of Engels & Van der Merwe (1967). Acid detergent fibre (ADF) and

neutral detergent fibre (NDF) contents were determined by the method of Goering & Van Soest (1970) and Robertson & Van Soest (1981).

Statistical Analysis

The DM content of the harvested material was determined from the time it was cut up to the point of baling. The collected data was analyzed with a D-base statistical program to obtain a trend curve to give a visual representation of the rate of the drying process in the field and also in the FABD. The LSMLMW program of Harvey (1990) was used for this purpose. The following model was fitted to the data:

$$Y_{ijk} = \mu + \text{rep}_i + \text{desig}_j + r_i d_j + b_L(t-T) + b_Q(t-T)^2 + e_{ijk}$$

where

Y_{ijk} = the k'th moisture content of a sample at a specific time

μ = overall mean moisture content

rep_i = the effect of the I'th date

desig_j = the effect of the j'th treatment (j = natural or artificial drying)

$r_i d_j$ = interaction of rep_i and desig_j

t = the time lapse from cutting lucerne

T = the average time lapse from cutting

b_L = a linear regression coefficient depicting the linear change associated with time since cutting

b_Q = a quadratic regression coefficient depicting the quadratic change associated with time since cutting

Data obtained from the chemical analyses of freshly cut, artificially dried and naturally dried lucerne hay were analysed to test for significant differences between different samples. A one-way analysis of variance was performed on the data using Statgraphics (1985). Significance was declared at $P \leq 0.05$ unless otherwise indicated. Multiple range tests were used to separate least square means at $P \leq 0.05$.

Results and discussion

Climatic conditions

Lucerne hay was produced over two seasons. Weather conditions were ideal for field drying on all the drying occasions (Table 1). Rainfall occurred only once when a total rainfall of 0.20mm was measured. Warm weather was experienced throughout with an average maximum temperature of 27.7°C and an average minimum temperature of 12.2°C. High windspeeds also occurred on most days.

Table 1. Climatic conditions on six drying occasions at Elsenburg (Anonymous, 2001b).

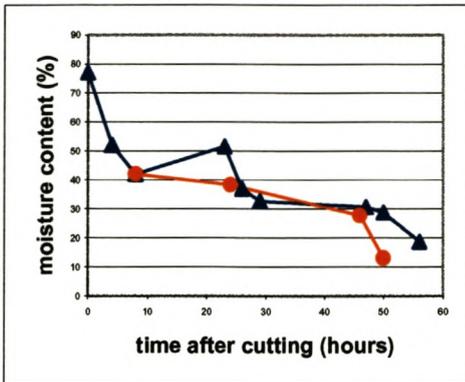
	Lucerne drying occasions						Average
	1	2	3	4	5	6	
Ambient temperature:							
Maximum (°C)	28.7	26.7	19.4	29.1	31.1	29.1	31.96
Minimum (°C)	13.5	11	4.3	14.9	13.1	14.9	13.98
Radiation (MJ/m ²)	29.1	19.3	15	10.5	27.2	28.4	25.2
Sunshine (hours)	10.4	8.4	7.3	5.8	9.8	10	8.61
Windspeed (M/s)	3	2.4	2.1	2.4	3.4	2.9	3.15
Total rainfall (mm)	0.2	0	0	0	0	0	0
Evaporation (mm)	8.5	5.8	3.7	4.4	8.3	8.4	6.51
Humidity (%)	66.2	53.3	68.3	47.9	64.3	68.6	61.4

On average, the relative humidity levels calculated on a monthly basis for the period when the drying took place was higher than the average relative humidity levels for the specific days on which the drying of lucerne hay was done (76.6% compared to 61.0%). This means that the air was relatively dry during these drying occasions. These favorable weather conditions resulted in shorter field drying periods (3 to 4 days) than would normally be expected. No loss of lucerne occurred as a result of rain. Short curing periods in the field produced lucerne hay of high quality and kept the dry matter losses to a minimum.

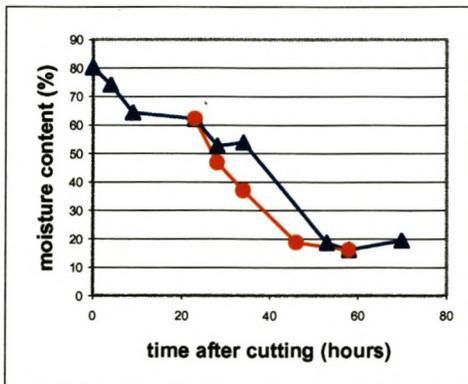
Drying curves

When lucerne is cut, the plant material starts losing moisture immediately. This process is accelerated by factors such as high daytime temperatures, low relative humidity and high winds. With field drying the plant material collects some moisture at night, as air temperatures are lower, together with higher relative humidity levels. This is shown by an increase in the moisture content of the plant material on the first sampling in the next morning. This is increased by dew forming on the plant material. The rate of moisture loss of the cut material on three occasions when the material dried slower in the field than in the FABD is presented in Figure 1.

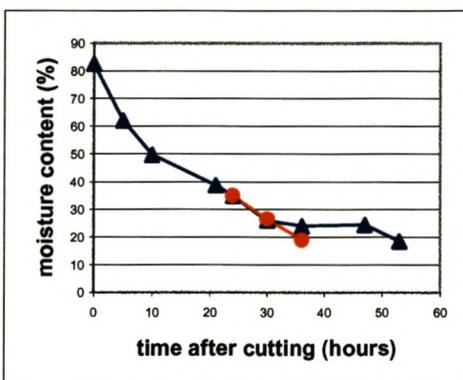
Figures 1 a, b and c indicate that the cut material in the FABD lost moisture at a faster rate than in the field. At the drying occasion presented in Figure 1a, a final moisture content of 19% was reached 56 hours after cutting in the field while the final moisture content of the material in the FABD was 13% at 53 hours after cutting. The increase in moisture content (from 42 to 52%) of the cut material in the field that occurred between 8 and 23 hours after cutting was due to a small amount of rain (0.2mm) that fell during that time.



(a)



(b)

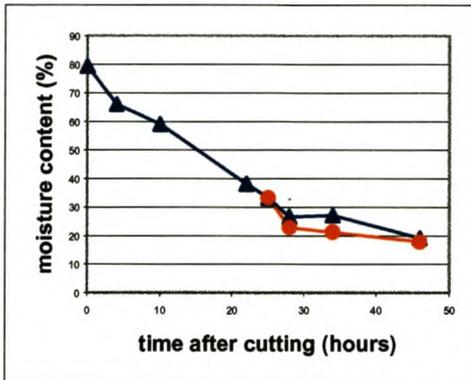


(c)

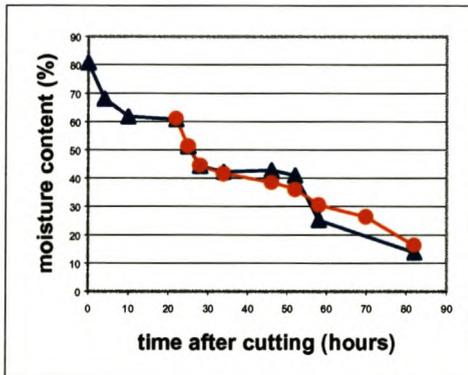
Figure 1. The rate of drying of cut material in the field (▲) and in the forced air bulk dryer (●) on three occasions.

During the drying occasion presented in Figure 1b, the material in the FABD reached a moisture content of 19% at 46 hours after cutting while the material in the field reached a final moisture content of 19%, 70 hours after cutting. The final moisture content of the material in the FABD was 16% at 58 hours after cutting. It can be seen that the moisture content of the cut material in the field stayed virtually constant (changed from 64% to 62%) for a 14 hour period between 9 and 23 hours after cutting. This was because of higher than normal relative humidity levels (78% vs. 68% for the total drying period). The total evaporation was also low (3%) opposed to an average of 6.7% for the remaining 3 days it took for the cut material to dry in the field.

From Figure 1c it can be seen that lucerne dried at a relatively high rate in the field for the first 30 hours after cutting. This, however, did not continue as the moisture content of the material thereafter remained constant for a period of 17 hours. This 17 hour period occurred from 16:00 until 09:00. It was thus mostly during the night when the air temperature dropped and dew occurred. The windspeed during the time (2m/s) was also lower than on the first day of drying (3.07m/s). The moisture content of the material in the field only started to decrease again from 47 hours after cutting.



(a)



(b)

Figure 2. The rate of drying of cut material in the field (▲) and in the forced air bulk dryer (●) on two different drying occasions.

For the drying occasions presented in Figure 2a, the cut material in the field and in the FABD dried at similar rates. The moisture content of the material dried in the field and in the FABD was 19% and 17%, respectively, at 46 hours after cutting. Material in the field lost moisture at a high rate, which can be attributed to low relative humidity levels at the time. The average relative humidity level recorded during this drying occasion was lower than the average relative humidity level recorded during any of the other drying occasions. This caused the lucerne in the field to dry at a similar rate to the material in the FABD.

During the drying occasion presented in Figure 2b, the material in the field reached a moisture content of 14% as opposed to the 16% in the FABD at 82 hours after cutting. The fast rate of moisture loss of the material in the field can be attributed to the high average maximum temperature (31°C) that was recorded during this drying occasion. The evaporation rate during this drying period was also high. Conditions were therefore ideal for drying lucerne in the field.

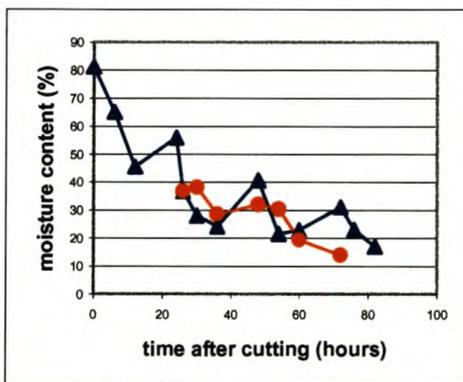


Figure 3. The rate of drying of the cut material in the field (▲) and in the forced air bulk dryer (●).

During the drying occasion presented in Figure 3, the rate of drying of the material in the field and in the FABD was similar up to 60 hours after cutting. Material in the field reached a moisture content of 23% and material in the FABD a moisture content of 19.5%. The moisture content of the lucerne in the FABD continued to decrease and a moisture content of 14% was reached at 72 hours after cutting, and the lucerne was baled. From 60 hours after cutting the moisture content of the material in the field increased to reach a moisture content of 31% at 72 hours after cutting. The increase in moisture content of the material in the field was because of higher than normal relative humidity levels (80% vs. 61%). The lucerne in the field only reached a moisture content of 17%, 82 hours after cutting. This means that the material in the field took 10 hours longer to reach a moisture content at which it could be baled. Under climatic conditions experienced during this drying occasion, the FABD offers a clear advantage in terms of the drying time.

On the whole climatic conditions during the trial period were extremely favorable for making hay. The 2000/2001 summer was the driest (in terms of rainfall) and hottest summer in 40 years in the Western Cape. During this time more than usual bergwinds occurred as well, resulting in an improved drying rate of cut lucerne. A reduction moisture content is not expected at night when air temperatures are low and dew occurs in the morning. Normally the moisture content of the material in the field increases at night because of these factors. These favorable climatic conditions resulted in a quick drying process that was similar to that experienced in the FABD

Regression equations of drying for the natural and artificial drying processes are shown in Table 2. No regression equation is given for the artificial drying process for drying occasion number 3 due to the fact that only three values of the moisture content of the material could be collected (Figure 1c). This was because the material was already relatively dry (35% moisture) when it was transferred into the FABD.

Table 2. Regression equations representing the rate of drying of lucerne for artificial and natural drying processes.

Drying occasion	Regression equations (natural drying)
1	$Y = 35.60 - 0.676 (t_j - 29.93) + 0.009(t_j - 29.93)^2$
2	$Y = 53.07 - 1.085 (t_j - 29.93) - 0.010(t_j - 29.93)^2$
3	$Y = 27.27 - 0.855 (t_j - 29.93) + 0.027(t_j - 29.93)^2$
4	$Y = 28.04 - 0.917 (t_j - 29.93) + 0.025(t_j - 29.93)^2$
5	$Y = 50.89 - 0.744 (t_j - 29.93) + 0.001(t_j - 29.93)^2$
6	$Y = 35.37 - 0.838 (t_j - 29.93) + 0.019(t_j - 29.93)^2$
Regression equations (artificial drying)	
1	$Y = 18.78 - 0.788 (t_j - 50.41)$
2	$Y = 11.85 - 1.550 (t_j - 50.41)$
4	$Y = 16.68 - 0.278 (t_j - 50.41)$
5	$Y = 34.63 - 0.583 (t_j - 50.41)$
6	$Y = 26.69 - 0.472 (t_j - 50.41)$

Equations are given in the format: $Y = \mu + b_L(t_j - T) + b_Q (t_j - T)^2$

Y = moisture content of lucerne t hours after cutting

μ = overall mean moisture content during the drying process

b_L = linear regression coefficient depicting the linear change in moisture content associated with time since cutting.

b_Q = quadratic regression coefficient depicting the quadratic change in moisture content associated with time since cutting

t_j = hours after cutting

T = the average time lapse from cutting from the k'th moisture content

The data on the moisture content of the material collected over time during the 6 drying occasions were analysed and used to calculate average regression equations. The trend lines indicating the change in moisture content in Figure 4 for the lucerne dried naturally and in the FABD, were obtained from regression equations as presented in Figure 4.

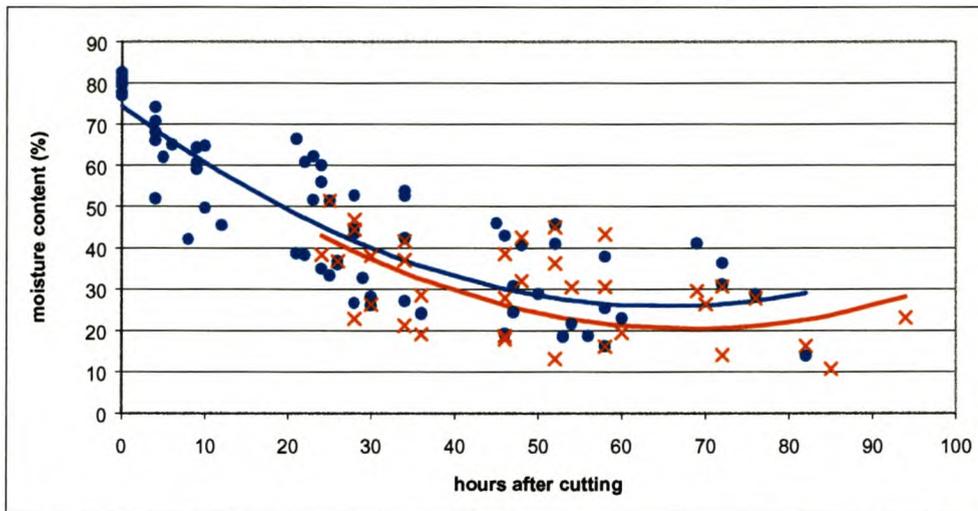


Figure 4. The change in moisture content (x hours after cutting) of lucerne dried naturally (●) ($Y = 39.51 - 0.789(x - 30.65) + 0.0114(x - 30.65)^2$) and in the FABD (×) ($Y = 36.76 - 0.870(x - 30.65) + 0.0116(x - 30.65)^2$)

The models fitted to the data collected during the drying process of lucerne hay for the different cuttings generally described the data well, accounting for more than 90% of the variation in % DM. In the case of the samples from the naturally dried hay the observed R^2 was 0.913. There was a trend ($P=0.08$) for the linear regression coefficients (depicting the linear rate of drying) to differ between cuttings, but the quadratic regression coefficients differed significantly ($P=0.02$). This indicates that the weather conditions on the separate drying occasions had an influence on the rate at which the plant material lost moisture in the field during the natural drying process.

Analysis of the data obtained during the artificial drying process show that the values for the respective drying occasions representing the average moisture content of the material at 50.4 hours after harvest differed significantly ($P<0.001$). The values representing the linear regression coefficients for the artificial drying curves also differed significantly ($P=0.02$). This indicates that the rate at which the cut material dried in the FABD differed between the individual drying occasions.

The equations derived from the average values of the naturally- and artificially dried lucerne hay indicates the following: The average moisture content of the naturally and artificially dried material at the average drying time ($\mu=30.65$ hours after cutting) were 39.5 and 36.8% respectively. These values tend to differ significantly ($P=0.08$). The values for the linear regression coefficients were 0.79 and 0.87 for natural and artificial drying and also tended to differ significantly ($P=0.13$). This indicates that on average the material in the FABD lost moisture at a faster rate than the material in the field.

Chemical composition

The chemical composition of fresh, naturally and artificially dried lucerne is presented in Table 3. The freshly cut material and the material dried either way differed ($P<0.05$) in terms of CP, TDN, ADF and NDF content. The lower values for the dried lucerne compared to fresh cut lucerne indicate a decline in quality that can be attributed mostly to DM losses during the drying process.

Collins (1991) showed that the CP, ADF, and NDF content of freshly cut forage was 17.9, 34.1 and 46.5% (on DM basis) respectively. Lucerne used in this experiment had a higher CP content (20%), similar ADF (34.1%) content and a lower NDF (41.6%) content just after harvest. The CP content determined for the naturally and artificially dried lucerne hay was 17.3 and 17.6%, respectively. According to the standards of the hay marketing task force of the American Forage and Grassland Council (1986 as cited by Gray, 2001), legumes with a CP rating of 17-19% can be considered as first class. The CP content of 17% for lucerne harvested in mid bloom, reported by Macgregor (1989), compares well with the values of 17.3 and 17.6% found in the current experiment for both naturally and artificially dried lucerne hay. CP per se is, however, not a good measure of the quality of a roughage because no differentiation is made between protein that is available and protein that is not, which makes it necessary to use other measures.

A relative feed value (RFV) can be calculated by using the ADF and NDF analysis of the feeds (see chapter 1 for calculation equation). RFV combines digestibility and intake into a single number, which provides an effective way to evaluate the quality of roughages.

The naturally and artificially dried lucerne used in the current experiment had RFV's of 110 and 113, respectively. These RFV's rate the lucerne as second class according to the standards reported by Gray (2001). ADF and NDF values obtained by Macgregor (1989) for lucerne hay harvested in mid-bloom (35.0 and 46.0%) were lower than the values obtained for naturally dried lucerne hay (41.2 and 48.0%) in the current study. The high ADF and NDF values of lucerne cut in mid-bloom show that it would be better to harvest the lucerne in early bloom.

TDN values found by Macgregor (1989), were higher at 58.0% compared to the values of 55.0 and 55.5% for naturally- and artificially dried lucerne hay in the current study. There was no significant difference ($P>0.05$) in chemical composition between the lucerne hay dried naturally or artificially in the current study.

Table 3. The chemical composition of freshly cut, naturally dried, and artificially dried lucerne hay on a DM basis.

Parameters	Freshly cut lucerne	Naturally dried lucerne hay	Artificially dried lucerne hay	SEM	P
CP	20.0 ^a	17.3 ^b	17.6 ^b	0.4	0.02
TDN	64.0 ^a	55.0 ^b	55.5 ^b	0.6	0.01
DOM	65.2 ^a	60.0 ^b	61.3 ^b	0.8	0.04
ADF	35.4 ^a	41.2 ^b	40.6 ^b	0.7	0.01
NDF	41.6 ^a	48.0 ^b	47.3 ^b	0.8	0.01
Ash	9.6 ^a	9.4 ^a	9.2 ^a	0.5	0.51

CP = Crude Protein

TDN = Total Digestible Nutrients

DOM = Digestible Organic Matter

ADF = Acid Detergent Fibre

NDF = Neutral Detergent Fibre

SEM: Standard Error of the Mean

P: Significance level

^{ab}: Values with different superscripts differ significantly ($P<0.05$)

Conclusion

The artificial drying of lucerne hay involves additional drying and labour costs which has to be compensated for by means of a higher hay quality. It is only when higher quality hay can be produced through artificial drying that the process will be economically viable. Better quality hay can be sold at a higher price or it can result in higher milk productions when fed to dairy cows.

Chemical analyses done on the naturally- and artificially dried lucerne hay produced in this study showed that lucerne quality was not improved by artificial drying under the weather conditions prevailing during the experimental period. Both the naturally and artificially dried lucerne hay had high ADF and NDF values, resulting in lucerne with lower relative feeding values. Using a different approach during the drying process could probably have increased the relative feeding value of the artificially dried lucerne hay. This could be done by transferring the cut material to the dryer directly after harvesting. Not handling the material when a loss in moisture content has already occurred should decrease the DM and leave losses and improve the quality of the final product. These results show that artificial drying of cut lucerne using a forced air bulk dryer will not be economically viable under good weather conditions when cut lucerne can be successfully dried in the field. The FABD could, however, serve a great purpose in drying harvested lucerne in unfavorable weather conditions where a batch of cut lucerne would otherwise have been lost due to rain.

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Chapter 3

Comparison of Protein and Fibre Degradability of Lucerne Harvested at Different Stages of Maturity in the Rumen of Jersey and Holstein Cows

The South African databases on in situ protein and fibre degradability values for lucerne are limited. The chemical composition of lucerne is constantly changing as plants mature. For optimal feed formulation it is useful to have protein and NDF degradability values available for lucerne harvested at different growth stages. Effective DM, protein and NDF degradability values of lucerne harvested after 4, 5 and 6 weeks' regrowth were determined for Holstein and Jersey cows by using the in situ nylon bag technique. It was found that the effective DM, protein and NDF degradability values did not differ ($P>0.05$) between Holstein and Jersey cows at fractional passage rates of 0.05 and 0.08/h. Analysis of mean effective DM, protein and NDF degradability values across breeds indicated differences between lucerne harvested after 4, 5 and 6 weeks' regrowth. The highest effective DM and protein degradability values were found for lucerne harvested after 4 weeks' regrowth. DM degradability values of lucerne harvested after 4, 5 and 6 weeks' regrowth calculated at a flow rate of 0.05/h were 63.9, 57.9 and 55.4% respectively. Protein degradability values were 81.5, 77.7 and 78.5% respectively. The lowest effective NDF degradability values were observed for lucerne harvested after 6 weeks' regrowth. Values calculated at a flow rate of 0.05/h for lucerne harvested after 4, 5 and 6 weeks' regrowth were 35.5, 45.7 and 23.7% respectively. Results from this study suggest that lucerne harvested at an earlier growth stage will be of better quality in terms of DM, protein and NDF degradability and that degradability tends to decrease as the plants mature.

Introduction

Forage quality is a complex interrelationship of many factors affecting, among other things, intake potential, nutrient content, digestion, gut fill and passage rate in ruminants (West, 1998). One of the main factors affecting the feeding value of forages is stage of harvesting (Linn & Martin, 1989). Farmers producing lucerne hay are faced annually with the tradeoff between dry matter (DM) yield and DM quality, because these two

factors are inversely related. Harvesting lucerne at an immature stage results in a higher quality but a lower DM yield. Delaying harvesting results in a higher yield but poorer quality and can often be unacceptable to animals (Orloff, 1999).

As lucerne plants grow, the stems become larger and the lower leaves fall from the plant, which lead to a decrease in the proportion of leaves. Leafiness makes an important contribution to the quality of lucerne because leaves contain 60% of the total digestible nutrients (TDN), 70% of the protein and 90% of the vitamins (Vough, 2001). Maturing of lucerne is also associated with an increase in fibre and lignin contents. The higher acid detergent fibre (ADF) and neutral detergent fibre (NDF) levels and increased level of lignification reduce the digestibility and intake potential of lucerne (Linn & Martin, 1989). According to Linn & Martin (1989) each one percentage point increase in lignin content decreases digestible dry matter (DDM) by three to four percentage points. These negative effects associated with lucerne harvested at a more mature stage have cost implications to the dairy farmer. When lucerne of a poorer quality is included in a dairy diet, less energy is provided to the cow. In order to formulate a ration with sufficient energy, lucerne of poor quality will have to be partially substituted with concentrates, which will increase the cost of the total diet.

Optimal feed formulation can only be done when accurate information is available on the nutrients which are to be included in the diet. Feed formulation programs such as CPM-Dairy and the Cornell Net Carbohydrate and Protein System (CNCPS) have feed libraries available that provides specifications for different types of forages. This data is however, not specific for the quality of forages produced under South African climatic conditions. For accurate feed formulation and diet evaluation it is necessary to analyse locally produced forages, such as lucerne hay, and use these data in the different programs.

The South African databases on *in situ* protein and fibre degradability values for forages such as lucerne are limited. Erasmus *et al.* (1990) established a ruminal protein degradation data base for dairy cattle using the *in situ* polyester bag technique, but values are only reported for unspecified lucerne hay and dehydrated lucerne meal. No values

are reported for lucerne harvested at different growth stages. The fact that the chemical composition of lucerne is constantly changing as the plants grow makes it necessary to have NDF and protein degradability values available for lucerne hay harvested at different growth stages.

The objective of this study was to expand the existing South African database on ruminal protein and NDF degradation. This was done by determining the extent of ruminal protein and NDF degradation of lucerne harvested at different stages of maturity by using the *in situ* nylon bag technique.

Materials and Methods

Lucerne production

The study was conducted at the Elsenburg Experimental Station (altitude 177m, longitude 18°50' and latitude 33°51') near Stellenbosch, South Africa. The study consisted of a protein and fibre degradability trial to evaluate lucerne harvested after 4, 5 or 6 weeks' regrowth. Lucerne was produced on a 1.5 hectare field. During the growing phase, lucerne was irrigated once a week with a permanent irrigation system (sprinklers 15x15m apart) at a level equivalent to approximately 25mm of rain per irrigation.

Harvesting of lucerne and preparation of samples

The lucerne field (1.5 ha) was divided into 25 blocks of equal size (15x15m). Blocks were randomly assigned to the different treatments, namely lucerne harvested at 4, 5 and 6 weeks' regrowth, respectively. On the respective cutting dates, lucerne samples were harvested by means of a hand held sickle. In order to harvest material at random, a wire square (0.25m²) was cast into the plots that were assigned to the different treatments and material was cut at the position where the square landed. Material harvested from the plots on one specific day were pooled. Approximately 20kg of lucerne was harvested for each treatment. This procedure was repeated at 4, 5 and 6 weeks' regrowth on the same lucerne field. The cut lucerne was dried in a forced draught oven at 50°C for 72 hours.

After drying, lucerne was chopped into shorter lengths using a hammer mill. To prepare the samples for use in the digestibility trial, the material from the hammer mill was milled using a Wiley mill with a 2mm screen.

***In situ* trial**

Four Holstein and four Jersey cows were used in the trial. All the cows were non-lactating and fitted with rumen cannulae (Beruc, Johannesburg). Cows were kept in a closed barn in separate stalls with free access to drinking water. A total mixed lactation ration (TMR) was fed *ad libitum* to all the cows. The physical and chemical composition of the TMR is presented in Table 1.

Table 1. Physical and chemical composition of the TMR used during the trial period.

Ingredient ¹	Composition (%)
Oat hay	20.0
Lucerne hay	15.0
Wheat	32.8
Maize	5.0
Oats	10.0
Cottonseed oil cake	15.0
Urea	0.6
Salt	0.5
Limestone	1.1
<hr/>	
Chemical analysis ²	(%)
Crude Protein	16.0
TDN	66.2
Calcium	0.66
Phosphorus	0.41
Crude Fibre	17.3

TDN = Total Digestible Nutrients

¹ On an as fed basis

² On a dry matter basis

The nylon bags (53 µm pore size, Bar Diamond, Inc., P.O. Box 60, Parma, Idaho, 83660-006, U.S.A.) were dried in an oven at 100°C and then put in a dessicator to cool off. Five grams of air-dried test feed were then weighed into the tared bags. Bags were closed with a nylon string and weighed again. To ensure that the bags were completely submerged in the ruminal contents during the digestibility trial, they were tied to a

stainless steel disc (5 cm in diameter, 7 mm thick, 102g) with 10 evenly spaced small holes drilled near the periphery of the disc. The disc was tied to 500mm of nylon string and secured to the lid of the cannula to allow the bags to move freely with the ruminal contents.

Bags were incubated in the rumen for 0, 2, 4, 8, 16, 24, 48 and 72 hours (NRC, 2001) and were inserted in reverse order. Bags that were to be incubated for 72 hours were inserted in the rumen at 14h00 on the first day. The rest of the bags were inserted on appropriate time intervals over the following days to allow the relevant incubation times. All the bags were removed at 14h00 on the fourth day. Incubation times longer than 24 hours would not leave enough residue for all the chemical analysis and therefore duplicate bags were prepared for the 48 and 72 hour incubation times.

After the bags were removed from the rumen they were put into buckets of ice water and then rinsed under running tap water to stop microbial activity. The bags were then washed in cold water in a twin-tub washing machine for ten minutes using the gentle cycle (Erasmus & Prinsloo 1988). Water was drained after five minutes of washing and the bags were then washed in fresh water for another five minutes. Bags containing feed samples but which were not submitted to ruminal incubation (0h) were washed like the other bags to determine the soluble fraction. Bags were dried in a forced draught oven at 60°C for 24 hours. At the end of the drying period bags were cooled in a dessicator and weighed to calculate the residual DM. The forage residues were emptied from the bags and ground, using a Cyclotec mill with a 1mm sieve (Nocek & Grant, 1987). The contents of duplicate bags (48 and 72 h) were composited before milling.

Rumen fluid was taken from on three occasions representing time intervals of 1 hour before feeding to 5 hours after feeding. The pH was measured immediately after the samples of rumen fluid was taken with the aid of a portable pH meter.

Chemical analysis and degradability calculations

Samples of the initial feeds and residues from the bags were analysed for crude protein (CP) according to the methods of the AOAC (1984) and NDF content was analysed with an ANKOM²⁰⁰ fibre analyser (ANKOM Technology corporation, 140 Turk Hill Park Fairport, NY 14450).

The percentage DM, nitrogen (N) and NDF disappearance was calculated from the residue remaining after incubation using the following equation:

$$\text{Percentage disappearance} = \left(\frac{g \text{ before incubation} - g \text{ after incubation}}{g \text{ before incubation}} \right) * 100$$

DM, N and NDF disappearance values were fitted to the following non-linear model as suggested by Ørskov & McDonald (1979):

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

p = the proportion degraded at time t

a , b , and c = non-linear parameters estimated by an iterative least square procedure. Parameter a represents the readily soluble fraction, b the potentially degradable fraction and c the rate at which b is degraded.

By introducing the fractional outflow rate, k , the effective degradabilities (P) were calculated from the following equation (Ørskov & McDonald, 1979):

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

Flow rates of 0.05 and 0.08 per hour were used as suggested by Erasmus *et al.* (1990).

Statistical analysis

The non-linear parameters a, b and c were estimated by least-square iterations using the N-LIN procedure of SAS (1996). A one-way analysis of variance (Snedecor & Cochran, 1991) was performed on the data using Statgraphics (1985). Significance was declared at $P \leq 0.05$ unless otherwise indicated. Multiple range tests were used to separate least-square means at $P \leq 0.05$.

Results and Discussion

The chemical composition of the lucerne harvested at different regrowth periods is presented in Table 2.

Table 2. NDF and protein content (%) on a DM basis of lucerne harvested after 4, 5 and 6 weeks' regrowth.

Item	Regrowth period (weeks)		
	4	5	6
Crude Protein	22.1	19.3	18.0
NDF	39.7	46.0	44.0
Dry Matter	92.0	90.0	91.0

NDF = Neutral Detergent Fibre

The CP content of the lucerne in Table 2 was higher than the tabular values from the NRC (1989) for late vegetative, early bloom and mid-bloom lucerne hay (20, 18 and 17% respectively). This can probably be explained by the difference in drying method, since the forage in the current study were dried in an oven using forced air at 50°C. This prevented leaf loss that normally occurs in field drying. CP values of 19.2 and 19.5% are given by the NRC (2001) for lucerne meal and mid-maturity lucerne hay cubes which corresponds to the value for lucerne harvested after 5 weeks' regrowth (19.3%) in the current study. Although the protein and NDF content of lucerne harvested after 5 and 6 weeks' regrowth did not differ much, it appears that the quality of the lucerne

deteriorated after 4 weeks' regrowth. The protein content of the lucerne harvested after 4, 5 and 6 weeks' regrowth correspond closely to the values reported by Gray (2001) for lucerne described as late bud (21.7%), early bloom (19.2%) and bloom (17.6%). A decrease in lucerne CP content and an increase in NDF content associated with maturing lucerne was also reported by Balde *et al.* (1993). They reported CP values for early bloom, mid bloom and full bloom lucerne of 23.2, 18.7 and 18.3% respectively. These authors also reported NDF values of early bud, early bloom and mid bloom lucerne to be 39.7, 42.4 and 47.7% respectively emphasizing the effect of maturing on the decrease in quality. According to West (1998) such a deterioration in lucerne quality can be expected, because an increase in plant maturity brings about an increase in fibre content and a decrease in CP content.

According to the standards provided by Gray (2001) on CP ratings for legumes and forage quality standards for legumes, lucerne used in this experiment can be rated as follows: lucerne harvested after 4 weeks' regrowth would be prime standard (CP > 19% and NDF < 40%) and the lucerne harvested after 5 and 6 weeks' regrowth would be first class (protein 17-19% and NDF 40-46%).

The effect of breed on the non-linear parameters a, b and c for ruminal DM, protein and NDF disappearance of lucerne harvested at different stages of maturity is presented in Table 3.

The a-value represents the readily soluble fraction of the feed and should be similar to the value (t_0) obtained from bags that were washed but not incubated in the rumen. The a-values are assumed to be similar for Holsteins and Jerseys as it is a function of the feed not influenced by other factors. The b- and c-values are derived functions of feed and microbial interactions.

The potential degradability values (b-values) in Table 3 for DM, protein and NDF did not differ between the two breeds for any of the treatments. This is also illustrated in Figures

1 to 9. It appears that both breeds were similar in their ability to ferment lucerne harvested at different growth stages.

Table 3. The effect of breed on the non-linear parameters a, b and c for DM-, protein- and NDF-disappearance (%) of lucerne harvested after 4, 5 and 6 weeks' regrowth from the rumen.

Component	Regrowth period (weeks)								
	4			5			6		
	Holstein	Jersey	P	Holstein	Jersey	P	Holstein	Jersey	P
Dry Matter									
a	28.87	28.87	-	26.06	26.06	-	30.86	30.86	-
b	46.19	46.38	0.17	44.61	44.54	0.97	37.31	38.16	0.55
c	0.17	0.17	0.96	0.12	0.14	0.4	0.10	0.10	1.00
Protein									
a	37.20	37.20	-	37.32	37.32	-	35.44	35.44	-
b	55.15	54.97	0.75	54.05	54.38	0.57	53.71	53.67	0.97
c	0.23	0.21	0.71	0.14	0.15	0.68	0.19	0.23	0.40
NDF									
a	7.30	7.30	-	15.00	15.00	-	13.96	13.96	-
b	45.47	44.61	0.8	42.39	43.75	0.65	40.31	38.39	0.89
c	0.17	0.09	0.49	0.15	0.12	0.44	0.03	0.03	1.00

a = soluble fraction

b = potentially degradable fraction

c = rate of degradation

NDF = Neutral Detergent Fibre

The c-values represent the rate of degradation of the slowly degraded fraction represented by b. The data in Table 3 indicate that the rate of degradation of DM, protein and NDF did not differ ($P > 0.05$) between Holstein and Jersey cows for lucerne harvested after 4, 5 and 6 weeks' regrowth (Figures 1-9).

Total disappearance values (across breeds) are presented in Table 4 and Figures 10 to 12.

The soluble DM fraction (a-values, Table 4) increased with advancing maturity of the lucerne, while the soluble protein fraction decreased (Figures 10 and 12). While the decrease in soluble protein fraction is probably related to the increase in NDF-content, the increase in soluble fibre fraction after 4 weeks' regrowth cannot be explained. It may be due to experimental error or more likely because of the inability of the particular model to describe all the parameters accurately. Savoie *et al.* (1999) determined zero-time disappearance values by washing bags in cold water until the rinse water was clear. These authors found a soluble DM fraction (30.7%) for chopped lucerne that is similar to the value found here for lucerne after a 6 weeks' regrowth period. Their soluble CP fraction (36.4%) is comparable with the a-values in the current experiment for all the lucerne treatments. The soluble NDF fraction (4.8%) of Savoie *et al.* (1999) for lucerne wilted for a 4 hour period is higher than the a-values found in the current experiment for NDF (Table 4 and Figure 12).

The b values in Table 4 show that the potential NDF degradability of lucerne harvested at different stages of maturity did not differ ($P > 0.05$). Savoie *et al.* (1999) found higher potential NDF degradabilities for lucerne wilted for a 4 hour period, and that had a pre-incubation NDF content of 42.6%, ie. 51.8 vs. 45.0% found in the current experiment. The fact that fibre degradability decreases when ruminal pH is low (pH should be between 6.0 and 6.2) can partly explain the lower NDF degradability values obtained in the current experiment. Rumen pH was generally low and varied between 5.6-5.8 for Holsteins and 5.6-5.7 for Jerseys from 1 hour before feeding to 5 hours after feeding. It should be kept in mind that although the cows were non-lactating, they received a lactating cow diet in an attempt to simulate rumen conditions of lactating cows.

The potential DM and protein degradabilities calculated across breeds, (Table 4) differed significantly. The potential DM degradability for lucerne harvested after 6 weeks' regrowth was significantly lower than that of lucerne harvested after 4 and 5 weeks' regrowth. A potential DM degradability value (47.7%) reported by Savoie *et al.* (1999) for chopped lucerne corresponds to the value found here for lucerne harvested after 4 weeks' regrowth.

Table 4. The effect of the growth stage of lucerne on the non-linear parameters a, b and c for DM, protein and NDF disappearance (%) from the rumen.

Component	Regrowth period (weeks)			SEM	P
	4	5	6		
Dry Matter					
a	28.87 ^a	26.06 ^b	30.86 ^c	-	0.00
b	46.28 ^a	44.58 ^a	37.74 ^b	0.41	0.00
c	0.17 ^a	0.13	0.10 ^b	0.01	0.01
Protein					
a	37.20 ^a	37.32 ^b	35.44 ^c	-	0.00
b	55.06 ^a	54.22 ^{ab}	53.69 ^b	0.17	0.02
c	0.22 ^a	0.15 ^b	0.21 ^a	0.01	0.01
NDF					
a	7.30 ^a	15.00 ^b	13.96 ^c	-	0.00
b	45.04	43.07	39.36	2.24	0.58
c	0.13 ^a	0.14 ^a	0.03 ^b	0.02	0.07

a = soluble fraction

b = potentially degradable fraction

c = rate of degradation

^{ab}: values with different superscripts differ significantly (P≤0.05)

The potential protein degradability of lucerne harvested after 6 weeks' regrowth was also significantly lower than for lucerne harvested after 4 weeks' regrowth. A potential protein degradability value of 57.8% was reported by Savoie *et al.* (1999) for lucerne with a pre-incubational CP content of 17.8%. Their value was higher than the values found in the current experiment. It should be noted that lucerne in their experiment was harvested with a pull-type forage harvester with steel rollers behind the chopping cylinder that breaks coarse particles like lucerne stems during harvest, possibly making material more digestible in the rumen. The results obtained in the current experiment suggest a decrease in the total rumen digestibility value of lucerne as plants mature from 4 to 6 weeks' regrowth.

The rate of DM ($P=0.01$), protein ($P=0.01$) and NDF ($P=0.07$) degradation differed between the lucerne harvested after 4, 5 and 6 weeks' regrowth (Table 4). The rate of DM degradation was the highest for lucerne harvested after 4 weeks' regrowth and the lowest for lucerne harvested after 6 weeks' regrowth as can be seen from Figure 10. The rate of DM degradation ($c = 0.14$) reported by Savoie *et al.* (1999) was similar to values found in the current study.

Lucerne harvested after 5 weeks' regrowth showed the lowest rate of protein degradation, while lucerne harvested after 6 weeks' regrowth had the lowest rate of NDF degradation. The low rate of NDF degradation of lucerne harvested after 6 weeks' regrowth is evident from Figure 12. It is not clear why the rate of protein degradation was the lowest at 5 weeks' regrowth, but in general it appears that the rate of nutrient degradability in the rumen decreased as the plants matured. A faster rate of protein degradation ($c = 0.32$) was reported by Savoie *et al.* (1999) which could probably be explained by the fact that lucerne was crushed during harvest in their experiment.

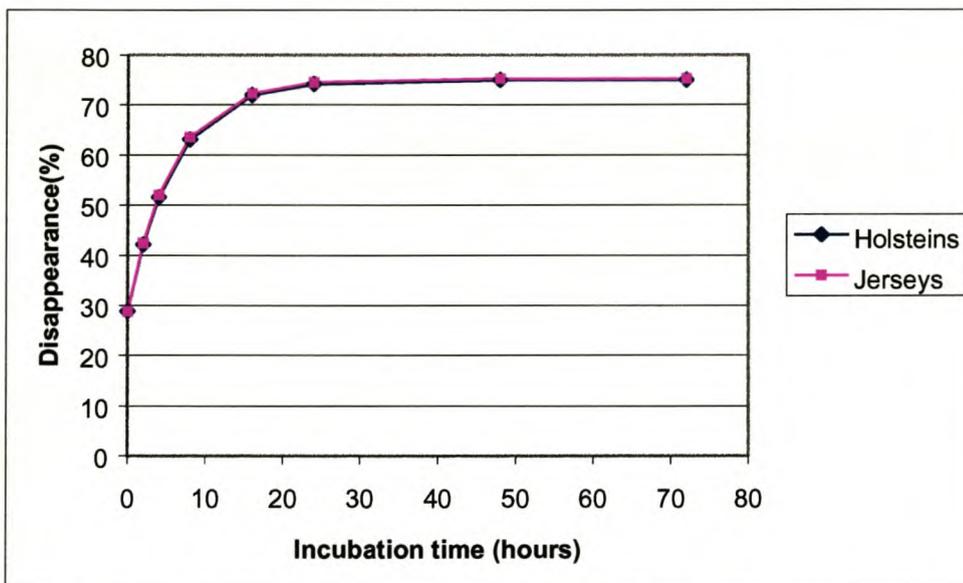


Figure 1. Ruminal DM disappearance of lucerne harvested after 4 weeks' regrowth in Holstein and Jersey cows.

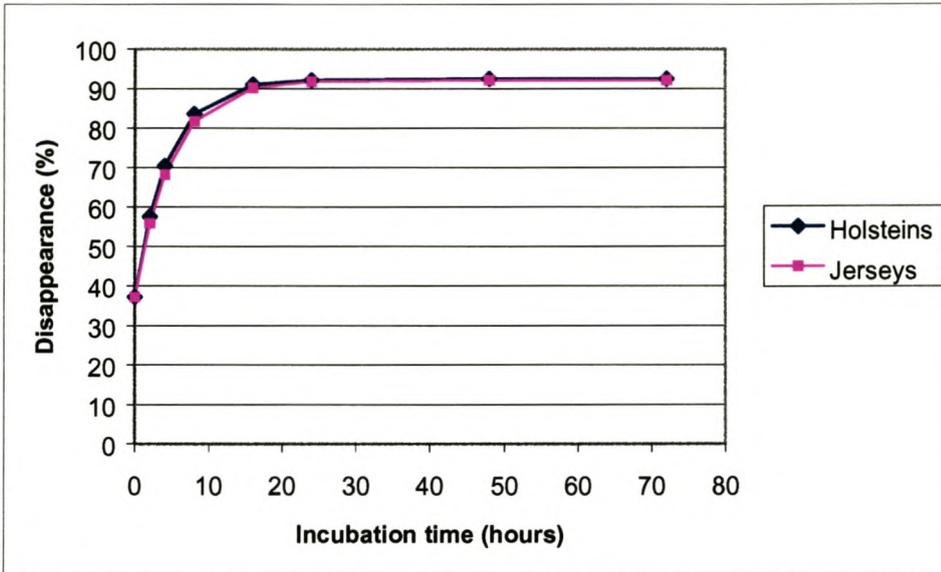


Figure 2. Ruminal protein disappearance of lucerne harvested after 4 weeks' regrowth in the rumen of Holstein and Jersey cows.

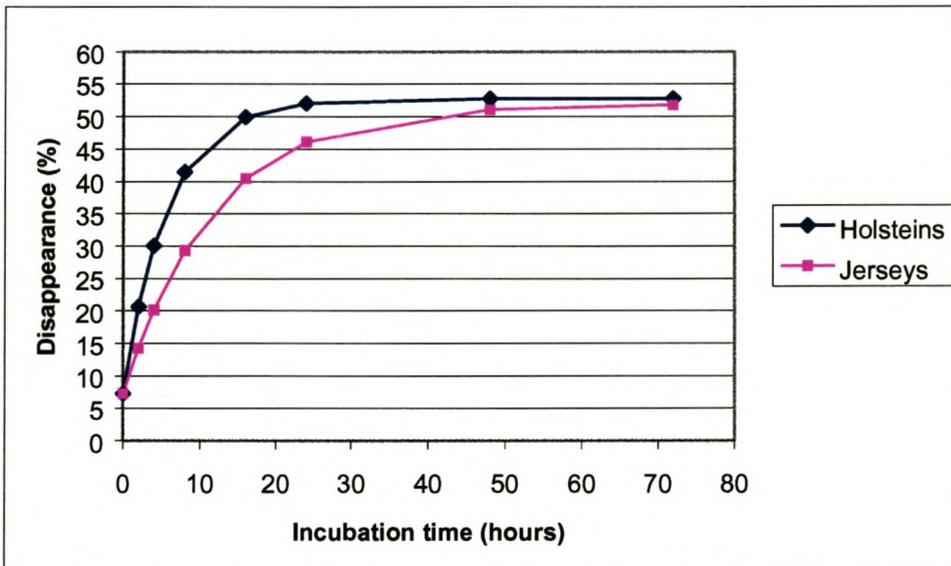


Figure 3. Ruminal NDF disappearance of lucerne harvested after 4 weeks' regrowth in Holstein and Jersey cows.

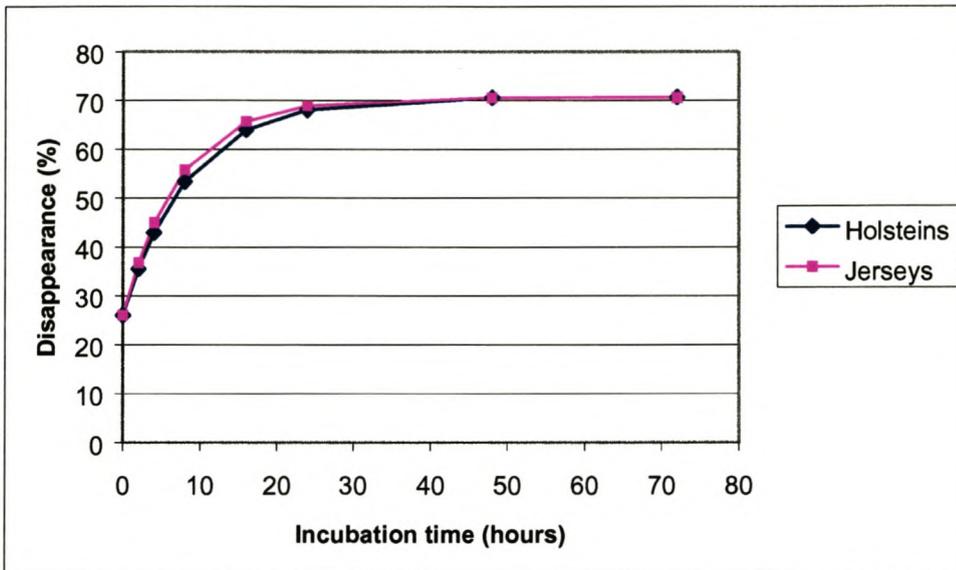


Figure 4. Ruminal DM disappearance of lucerne harvested after 5 weeks' regrowth in Holstein and Jersey cows

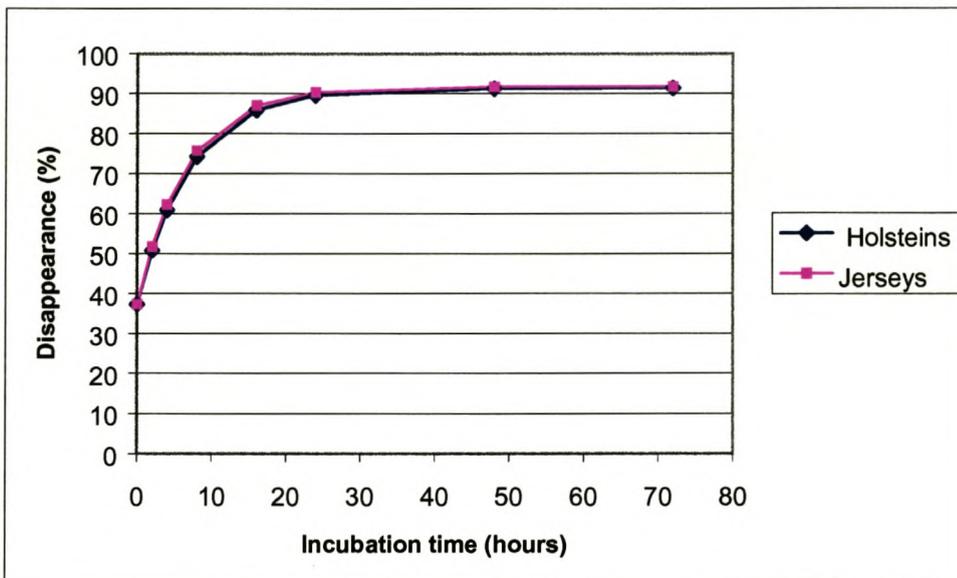


Figure 5. Ruminal protein disappearance of lucerne harvested after 5 weeks' regrowth in Holstein and Jersey cows.

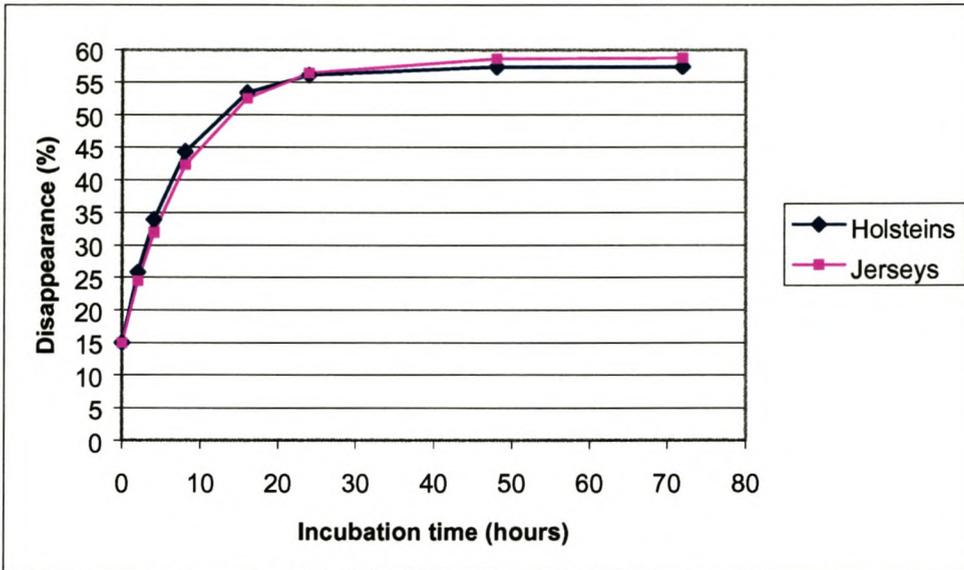


Figure 6. Ruminal NDF disappearance of lucerne harvested after 5 weeks' regrowth in Holstein and Jersey cows

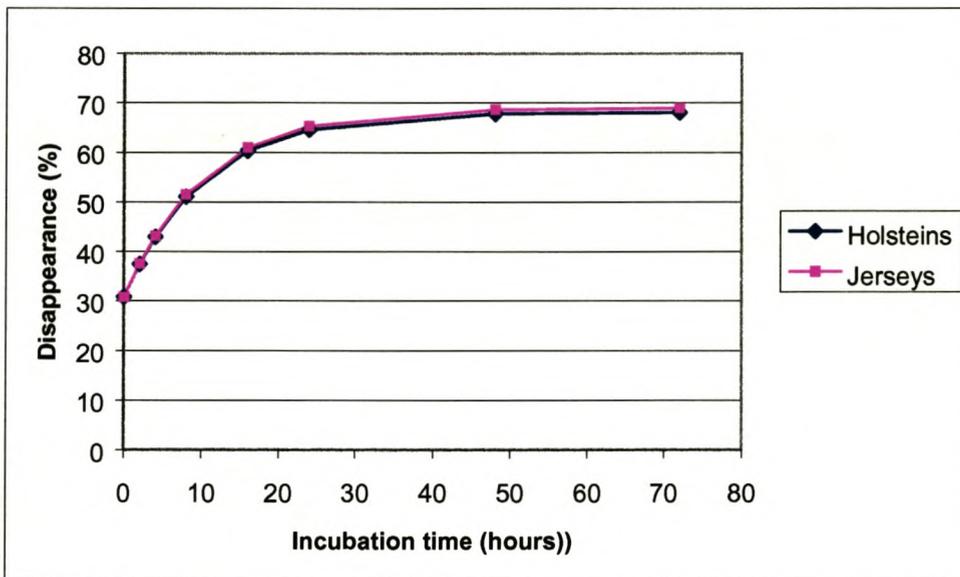


Figure 7. Ruminal DM disappearance of lucerne harvested after 6 weeks' regrowth in Holstein and Jersey cows.

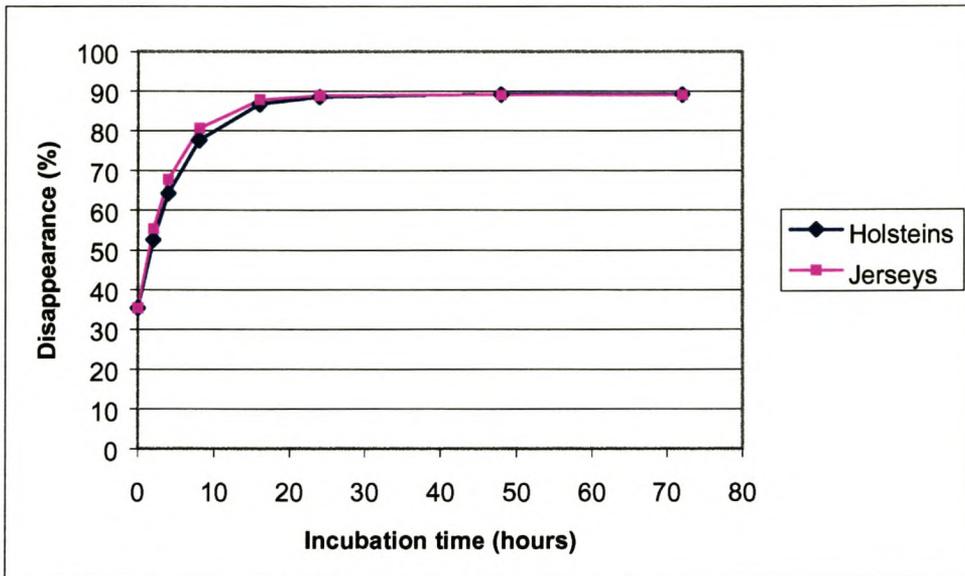


Figure 8. Ruminal protein disappearance of lucerne harvested after 6 weeks' regrowth in Holstein and Jersey cows.

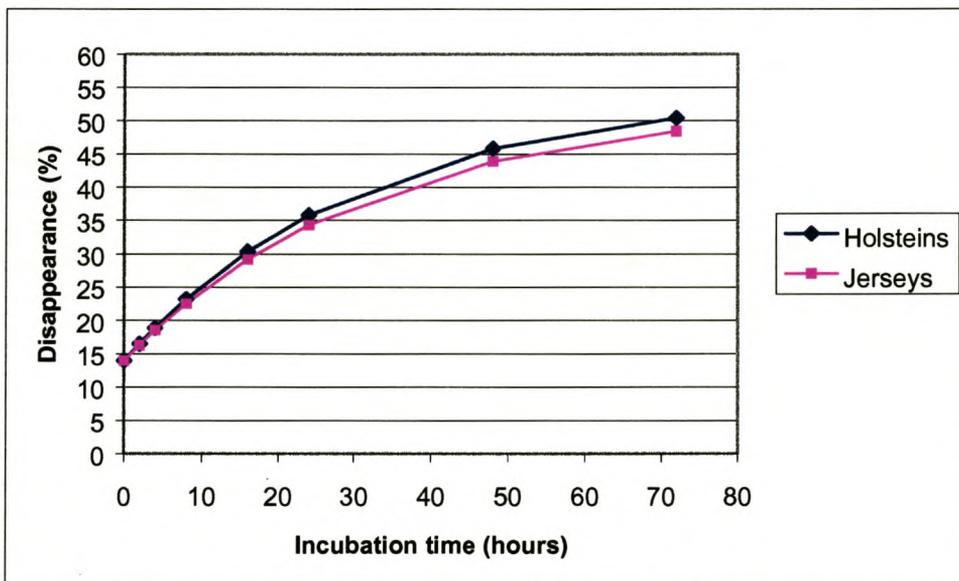


Figure 9. Ruminal NDF disappearance of lucerne harvested after 6 weeks' regrowth in Holstein and Jersey cows.

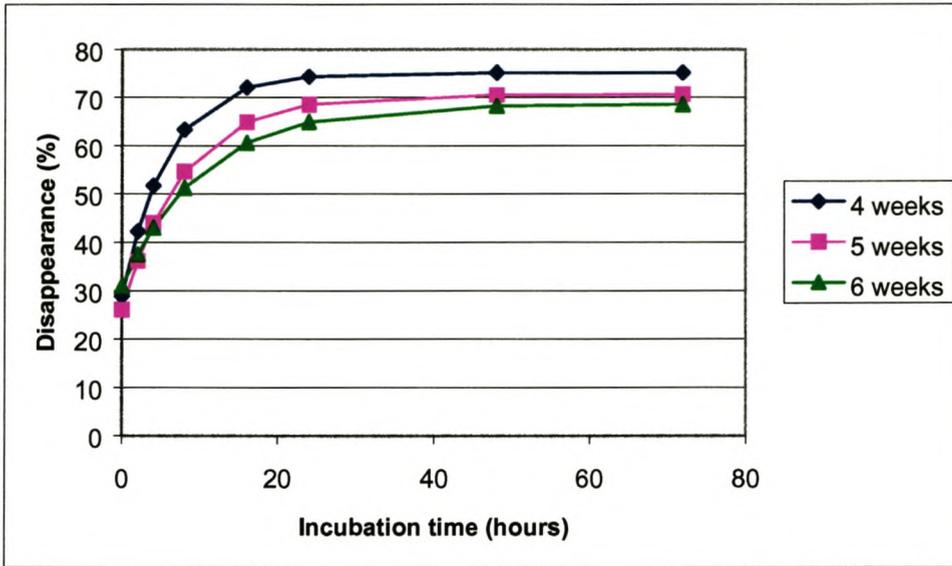


Figure 10. Average ruminal DM disappearance of lucerne harvested after 4, 5 and 6 weeks' regrowth in Holstein and Jersey cows.

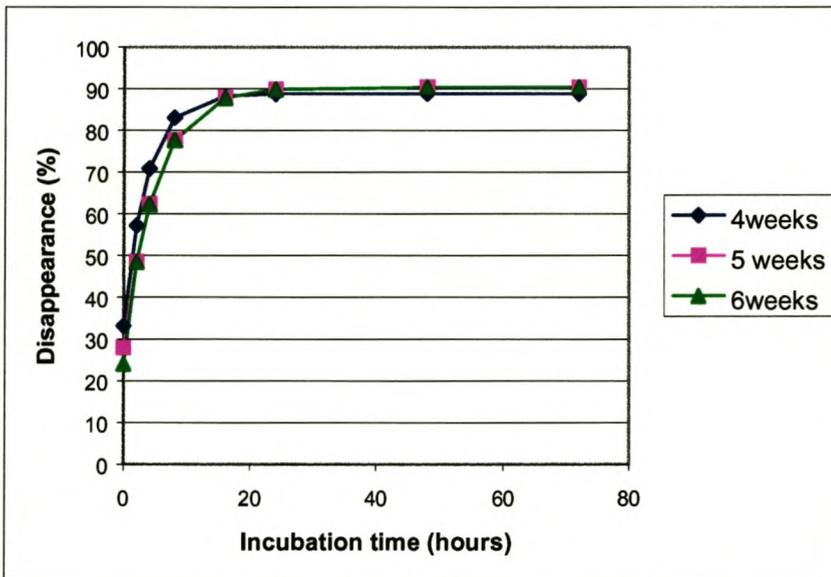


Figure 11. Average ruminal protein disappearance of lucerne harvested after 4, 5 and 6 weeks' regrowth in Holstein and Jersey cows.

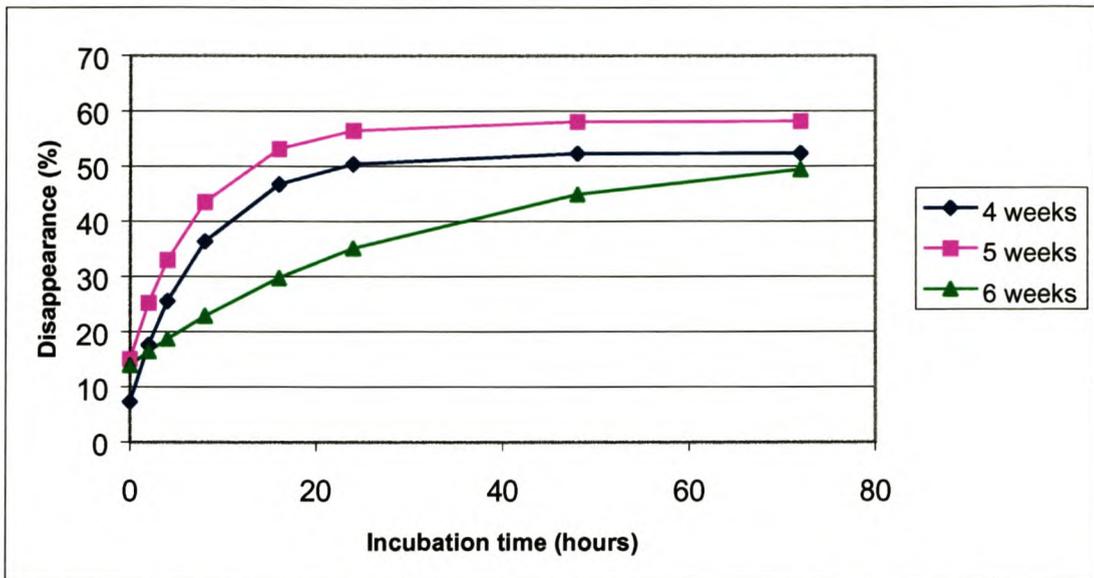


Figure 12. Average ruminal NDF disappearance of lucerne harvested after 4, 5, and 6 weeks' regrowth in Holstein and Jersey cows.

The effective degradabilities of DM, protein and NDF, determined at outflow rates of 0.05/h and 0.08/h, are presented in Table 5.

Table 5. Effective degradability (%) of DM, protein and NDF at fractional outflow rates of 0.05 and 0.08/h for Holstein and Jersey cows.

Component	Regrowth period (weeks)								
	4			5			6		
	Holstein	Jersey	P	Holstein	Jersey	P	Holstein	Jersey	P
Dry Matter									
0.05/h	63.12	64.59	0.46	57.12	58.61	0.18	55.01	55.71	0.59
0.08/h	58.74	60.29	0.54	52.38	54.09	0.16	50.88	51.47	0.7
Protein									
0.05/h	81.72	81.28	0.85	77.18	78.23	0.45	77.63	79.43	0.26
0.08/h	77.22	76.62	0.84	71.79	72.95	0.47	72.89	75.15	0.31
NDF									
0.05/h	35.82	35.12	0.84	45.49	45.89	0.86	23.18	24.75	0.25
0.08/h	32.03	30.04	0.62	41.26	41.29	0.99	20.61	21.77	0.39

NDF = Neutral Detergent Fibre

According to Table 5 the effective DM, protein, and NDF degradability values did not differ ($P>0.05$) between Holstein and Jersey cows for lucerne harvested after a 4, 5 and 6 weeks' regrowth period. This indicates that breed did not affect the effective degradability of DM, protein or NDF of lucerne harvested at different regrowth periods.

Protein degradability values of 78.8 and 75.0% were found by Erasmus *et al.* (1990) at outflow rates of 0.05/h and 0.08/h. Chiou (1995) reported protein degradability values of 78.0 and 72.0% at outflow rates of 0.05 and 0.08/h for lucerne hay. These values compare well with values in the current study.

Data from Holstein and Jersey cows were pooled to obtain effective degradability values that are presented in Table 6.

Table 6. Effective degradability (%) of DM, protein and NDF at fractional outflow rates of 0.05 and 0.08/h for lucerne harvested after 4, 5 and 6 weeks' regrowth.

Component	Regrowth period (weeks)			SEM	P
	4	5	6		
DM					
0.05/h	63.9 ^a	57.9 ^b	55.4 ^c	0.4	0
0.08/h	59.0 ^a	53.2 ^b	51.2 ^b	0.5	0
Protein					
0.05/h	81.5 ^a	77.7 ^b	78.5 ^{ab}	0.5	0.01
0.08/h	76.9 ^a	73.00 ^b	74.0 ^{ab}	0.7	0.06
NDF					
0.05/h	35.5 ^a	45.7 ^b	23.7 ^c	0.6	0
0.08/h	30.7 ^a	41.3 ^b	21.2 ^c	0.7	0

^{ab}: values with different superscripts differ significantly ($P\leq 0.05$)

NDF =Neutral Detergent Fibre

Values in Table 6 indicate that the effective DM, protein, and NDF degradabilities differed between the lucerne harvested at different stages of maturity at both outflow

rates of 0.05 and 0.08/h. The highest effective DM degradability was found for lucerne harvested after 4 weeks' regrowth (63.9%) and degradability decreased as the lucerne matured (57.9 and 55.4% respectively for lucerne harvested after 5 and 6 weeks' regrowth). Balde *et al.* (1993) found similar DM degradability values if their data are recalculated for a passage rate of 0.05/h. Their DM degradability values were calculated to be 66.3, 60.9 and 58.4 % respectively for lucerne cut in early, mid and full bloom.

There was a decrease in protein degradability as the lucerne matured. Lucerne harvested after 4 weeks' regrowth had a protein degradability of 81.5% and lucerne cut after 5 weeks' regrowth had a protein degradability of 77.7%. The decrease in protein degradability associated with maturing of lucerne is confirmed by Hoffman *et al.* (1993). They found lucerne cut in a late vegetative and late bud stage to have rumen degradable CP values of 83.9 and 77.4% respectively. A similar decrease in protein degradability values were found by Balde *et al.* (1993). Their CP degradability values were calculated at a flow rate of 0.03/h giving values of 84.8, 83.8 and 80.4% for lucerne cut in early bud, early bloom and full bloom. If their values were recalculated assuming a flow rate of 0.05/h values of 80.7, 76.6 and 77.2% are obtained. Their protein degradability value for lucerne cut in early bud corresponds well to the value found in the current experiment for lucerne harvested after 4 weeks' regrowth. Their protein degradability values for lucerne cut in early and full bloom are similar to the values found in the current experiment for lucerne cut after 5 and 6 weeks' regrowth.

Lucerne harvested after a 5 week regrowth period had the highest NDF degradability. It is not clear why the NDF degradability value was the highest but it could be due to experimental error. The lowest effective NDF degradability was obtained for lucerne harvested after 6 weeks' regrowth. Hoffman *et al.* (1993) also found a similar decrease in rumen degradable NDF content of lucerne where lucerne cut at a late vegetative, late bud and midbloom stage had rumen degradable NDF values of 47.9, 32.0 and 28.6% respectively. It has been stated by Smith *et al.* (1972) that many of the maturity stage effects on forage digestibility are associated with the increase in forage NDF content and an increase in the lignification of the NDF. It would therefore not be improbable to

believe that total nutrient utilisation would be negatively affected by a decrease in rumen NDF digestibility. These results suggest that lucerne harvested at an earlier growth stage would be of better quality in terms of effective DM, protein and NDF degradability and that the degradability tend to decrease as the lucerne plants mature.

According to Hoffman *et al.* (1993), the rumen degradable CP content of lucerne is negatively correlated ($r = 0.81$) with NDF content. They stated that as maturing advances, NDF increases and CP fractions shift from largely soluble fractions at early maturity to slowly degraded or undegradable fractions at later maturity. Satter (1986) noted that it is important to have information on ruminal protein degradation, but that knowledge pertaining to protein quality of lucerne, including the availability of undegradable protein, is also important.

The protein content of the lucerne harvested at different stages of maturity was separated into rumen degradable protein (RDP) and undegradable protein (UDP) by using the protein degradability values in Table 6. The UDP fraction was then refined to a digestible undegradable protein (DUP) fraction by taking the ADF-bound nitrogen into account. This conversion was done to prevent an over-estimation of duodenal UDP available for absorption.

Acid detergent insoluble N (ADIN) content of the lucerne was used to estimate the DUP fraction thereof. The ADF-N content used in this estimation (7% of total N) was taken as the mean value of the ADF-N content of lucerne hay and dehydrated lucerne meal reported by Erasmus *et al.* (1990). The calculated UDP and DUP values are presented in Table 7.

Table 7. Partitioning of total N between rumen degradable N (RDN) and undegradable N (UDN) fractions as well as undegradable protein (UDP) and digestible undegradable protein (DUP) contents (g/kg DM) of lucerne harvested at different periods of regrowth ($K_p=0.08$).

Component	Regrowth period (weeks)		
	4	5	6
Total N	35.3	31	28.8
RDN	27.15	22.63	21.32
UDN	8.15	8.37	7.48
UDP	50.92	52.33	46.76
ADF-N	2.47	2.17	2.02
DUP	35.48	38.77	34.16

RDN = Rumen Degradable Nitrogen

UDN = Undegradable Nitrogen

UDP = Undegradable Protein

ADF-N = Acid Detergent Fibre Nitrogen

DUP = Digestible Undegradable Protein

From Table 7 it is clear that lucerne harvested after 5 weeks' regrowth had the highest UDP and DUP values. This could be because of the fact that this treatment had the highest NDF content (Table 2). However, it should also be noted that the ADIN value was probably under-estimated for lucerne with the higher NDF values. DUP values were similar for lucerne harvested after 4 and 6 weeks' regrowth. UDP and DUP values found by Erasmus *et al.* (1990) were lower than the values found in the current experiment. The lucerne used in their experiment was lower in CP and similar in NDF content (16.1 and 42.8% respectively) than lucerne used in the current experiment.

Conclusion

The chemical quality of lucerne hay decreased as plants matured from 4 to 6 weeks' regrowth. The decrease in quality of the maturing lucerne was confirmed by results from the *in situ* rumen digestibility trial. It was found that the effective DM, protein and NDF degradability values of lucerne decreased as plants matured. A reduction in rumen degradability associated with the maturing of lucerne can have a negative effect on the production of dairy cows as it can cause microbial CP production to decrease due to a reduction in the fermentability of the forage.

The results from this study also indicate that it would be advisable to harvest lucerne after 4 weeks' regrowth rather than after 6 weeks' regrowth in terms of DM, protein and NDF degradability values. Although the lucerne harvested after 4 weeks' regrowth is of better quality, the DM yield would be less than it would be if the lucerne were harvested at a more mature stage such as 6 weeks' regrowth. It is thus important to consider whether the improvement in the quality of the lucerne harvested at an earlier stage will bring about an improvement in cow production that can offset the loss in lucerne DM yield when material is cut at an earlier stage. Results from this study can make a valuable contribution towards South African databases on lucerne nutrient degradability values and can be used in dynamic feed formulation models.

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Chapter 4

Comparison of Protein and Fibre Degradability of Lucerne Hay Dried in a Forced Air Bulk Dryer in the Rumen of Jersey and Holstein Cows

There is a big demand for good quality lucerne hay in South Africa, but weather conditions often make it difficult to produce lucerne hay by means of field drying. When weather conditions are not suitable for field drying, lucerne can be dried artificially in a forced air bulk dryer. There is, however, a lack of information on ruminal protein and fibre degradability of artificially dried lucerne hay. In this study, the effective DM, protein and NDF degradability of lucerne products (lucerne hay, lucerne leaves and lucerne hay + 8% leaves) dried in a forced air bulk dryer was calculated for Holstein and Jersey cows. Degradability values were calculated by using the in situ nylon bag technique. Effective DM and protein degradability values of artificially dried lucerne hay were higher in Jerseys than in Holsteins. DM degradability values calculated for Holsteins at a flow rate of 0.05/h for lucerne hay, lucerne leaves and lucerne hay + 8% leaves were 57.6, 66.5 and 61.4% respectively while protein degradability values of 76.9, 75.5 and 77.9% were obtained. DM degradability values calculated for Jerseys were 62.9, 69.1 and 61.7% while protein degradability values of 82.4, 77.6 and 78.5% respectively were obtained. Analysis of the pooled effective DM, protein and NDF degradability values of Holstein and Jersey cows indicated that rumen degradability of protein was higher for lucerne hay than for lucerne leaves. At a flow rate of 0.05/h protein degradability values for lucerne hay and lucerne leaves were 80.1 and 76.5% respectively. NDF degradability was higher for lucerne leaves than for lucerne hay (29.7 vs. 24.6%).

Introduction

Dairy cattle are ruminants and are well adapted to utilising large amounts of forage. Forage is regarded as a primary constituent of dairy rations for physiological and economic reasons. In the formulation of diets for dairy cattle the quality of the forage needed to supply nutrients required by the dairy cow is considered as first priority. Essential nutrients, which are not supplied by the forage, must then be supplemented by

means of concentrates (Linn & Kuehn, 1997). Supplementation with concentrates increases the total feed bill and it is more economically viable to use a high quality forage with a high nutritive content (including crude protein and digestible energy) and a good palatability (Vough, 2001). In general, the forage content of the total mixed ration (TMR) fed to dairy cattle ranges between 40 and 60% (McCullough, 1986) and it can supply about 50% of the total dietary protein fed (Waldo & Jorgensen, 1981).

According to Erasmus *et al.* (1990), several new systems for the evaluation of feed protein have been proposed during the last decade and these systems are all based on common concepts. Emphasis is put on the separation of dietary protein into ruminally degraded (RDP) and undegraded (UDP) protein fractions. According to Erasmus *et al.* (1990) there was very little data available at that time on the extent of protein degradation of feedstuffs which limited the application of feed formulation based on RDP and UDP. Currently there is more information available on the extent of protein degradation of forages but data on South African forage sources is still limited.

Different procedures such as laboratory solubility tests, *in vivo* measurements and the *in situ* bag procedure have been used to measure protein degradation in feedstuffs. Most of these methods, however, have limitations. Protein solubility cannot be used to estimate protein degradation over a variety of feedstuffs (Stern & Satter, 1984). *In vivo* estimates remain the reference technique but is a labor intensive, expensive and difficult procedure (Owens, 1987 as cited by Erasmus *et al.*, 1990). The *in situ* technique has also been criticised (Nocek, 1988) but it is used as the standard method for the determination of protein degradation in the protein evaluation systems of the United States of America, United Kingdom and Nordic countries (Van der Honing & Alderman, 1988).

The total neutral-insoluble fibre content of a forage is contained in the neutral detergent fibre (NDF) or cell wall fraction (Linn & Martin, 1989). Chemically this fraction includes cellulose, hemicellulose, lignin and heat damaged protein. These components are associated with the bulkiness of feeds and therefore NDF is closely related to feed intake and rumen fill in cows (Linn & Martin, 1989). Because of the influence that the fibre content of the diet has on the level of intake and the passing rate thereof, it will

affect the amount and composition of the milk produced by the dairy cow. The important role that forages play in the diet of the dairy cow makes it essential to have data available on the protein and fibre degradation dynamics of different forages.

Milk producers in South Africa have a great demand for good quality forage, such as lucerne hay, but the supply is often a problem. The production of good quality lucerne hay in certain parts of the country, such as the southern parts of the Western Cape Province, is often very difficult because of climatic conditions. These parts have a relatively high air moisture content during the day, heavy dew or mist at night and occasional rainfall during times when cut lucerne is still in the field. These environmental factors make it difficult to produce good quality lucerne hay through the process of natural (field) drying. One way to eliminate the deterioration of lucerne quality, which occurs during field drying, is to dry lucerne artificially. This is done by transferring lucerne to a forced air bulk dryer (FABD) soon after cutting. The FABD is a barn type dryer in which lucerne is dried by means of warm air being blown through the cut material. Radajewski *et al.* (1990) found that the artificial drying of lucerne immediately after cutting eliminated quality losses and reduced the number of field operations needed during the drying process.

South African databases on *in situ* protein and fibre degradability values for forages are limited in terms of lucerne. Erasmus *et al.* (1990) established a ruminal protein degradation data base for dairy cattle using the *in situ* polyester bag technique, but values are only reported for unspecified lucerne hay and dehydrated lucerne meal. The chemical composition of lucerne hay produced by different drying methods can vary significantly. It is therefore important to have NDF and protein degradability values available on lucerne hay produced through different drying methods.

The objective of this study was to expand the existing South African database on ruminal protein and NDF degradation to include data on artificially dried lucerne. This was done by determining the extent of ruminal protein and NDF degradation of artificially dried lucerne hay components using the *in situ* nylon bag technique.

Materials and methods

The study was conducted at the Elsenburg Experimental Station (altitude 177m, longitude 18°50' and latitude 33°51') near Stellenbosch, South Africa. The study consisted of two phases: The first phase involved lucerne hay production and the second a degradability study with Jersey and Holstein cows. Lucerne was produced on a 1 hectare field. During the growing phase, lucerne was irrigated once a week with a permanent irrigation system (sprinklers 15x15m apart) at approximately 25mm of rain per irrigation. Lucerne was harvested after 5 weeks' regrowth using a mower conditioner (New Holland model 488). The cut material was left in the field for an initial drying period of approximately 24 hours after which it was transferred to a FABD at a moisture content between 40 and 60%.

Forced Air Bulk Dryer

The FABD used in this experiment, as well as the procedure used to transfer material from the field to the dryer, was the same as was described in chapter 2.

Lucerne samples were collected at the start of the artificial drying process and then at regular intervals during the drying process to determine when the FABD had to be switched off. Drying was terminated when the hay reached a moisture content of approximately 15-18%. The material was baled from the FABD using a baling machine, which was positioned on a cement slab, covered with a durable plastic cover. The plastic cover allowed retrieval of leaves that shattered from the stems during the baling process.

Sample preparation

Retrieval of leaves indicated an 8% DM loss during baling of the artificially dried lucerne. It was therefore decided to determine the fermentation dynamics of three different lucerne components. Treatments were: 1.) Lucerne baled at 15-18% moisture after drying in a FABD. A pooled sample of 20kg was collected by taking samples from the center of randomly selected bales. Lucerne samples were very leafy due to the fact

that samples were taken from the centre of the bales 2.) Recovered lucerne leaves, which were collected from the plastic cover after the baling process. There was an amount of stem material that was collected with the leaves which could not be removed. 3.) Lucerne collected from the center of randomly selected bales to which 8% of lucerne leaves were added.

Material from all the treatments was hammer milled to chop it into shorter lengths. Samples of all the treatments were then milled through a Wiley mill with a 2mm screen.

***In situ* trial**

Four Holstein and four Jersey cows were used in the trial. All the cows were non-lactating and fitted with rumen cannulae. Cows were kept in a closed barn in separate stalls with free access to drinking water. A total mixed lactation ration (TMR) was fed *ad libitum* twice daily. Cows were adapted to the diet over a two-week period prior to the trial.

The ingredient and chemical composition of the TMR is presented in Table 1.

The nylon bags (53 μm pore size, Bar Diamond, Inc., P.O. Box 60, Parma, Idaho, 83660-006, U.S.A.) were dried in an oven at 100°C and then put in a dessicator to cool off and weighed. Five grams of air-dried test feed were then weighed into the tared bags. Bags were closed with a nylon string and weighed again. To ensure that the bags were completely submerged in the ruminal contents during the digestibility trial, they were tied to a stainless steel disc (5 cm in diameter, 7 mm thick, 102g) with 10 evenly spaced small holes drilled near the periphery of the disc. The disc was tied to 500mm of nylon string and secured to the lid of the cannula to allow the bags to move freely with the ruminal contents.

Table 1. Ingredient and chemical composition of the TMR used during the trial period.

Ingredient ¹	Composition (%)
Oat hay	20.0
Lucerne hay	15.0
Wheat	32.8
Maize	5.0
Oats	10.0
Cottonseed oil cake	15.0
Urea	0.6
Salt	0.5
Limestone	1.1
<hr/>	
Chemical analysis ²	(%)
Crude Protein	16.0
TDN	66.2
Calcium	0.7
Phosphorus	0.4
Crude Fibre	17.3

TDN = Total Digestible Nutrients

1 On an as fed basis

2 On a Dry Matter Basis

Bags were incubated in the rumen for 0, 2, 4, 8, 16, 24, 48 and 72 hours (NRC, 2001) and were inserted in reverse order. Bags that were to be incubated for 72 hours were inserted in the rumen at 14h00 on the first day. The rest of the bags were inserted on appropriate time intervals over the following days to allow the relevant incubation times. All the bags were removed at 14h00 on the fourth day. Incubation times longer than 24 hours would not leave enough residue for all the chemical analysis and therefore duplicate bags were prepared for the 48 and 72 hour incubation times.

After removal from the rumen, bags were put into buckets of ice water and then rinsed under running tap water to stop microbial activity. The bags were then washed in cold water in a twin-tub washing machine for ten minutes using the gentle cycle (Erasmus & Prinsloo, 1988). The water was drained after five minutes of washing and the bags were

washed in fresh water for another five minutes. Bags containing feed samples, but which were not submitted to ruminal incubation (0h), were washed along with the other bags to determine the soluble fraction. Bags were dried in a forced draught oven at 60°C for 24 hours. At the end of the drying period, bags were cooled in a dessicator and weighed to calculate the residual DM. The forage residues were emptied from the bags and ground, using a Cyclotec mill with a 1mm sieve (Nocek & Grant, 1987). The contents of duplicate bags (48 and 72 h) were composited before milling.

Rumen fluid was taken from on three occasions representing time intervals of 1 hour before feeding to 5 hours after feeding. The pH was measured immediately after the samples of rumen fluid was taken with the aid of a portable pH meter.

Chemical analysis

Samples of the initial feeds and residues from the bags were analyzed for crude protein (CP) according to the methods of the AOAC (1984). NDF was analyzed with an ANKOM²⁰⁰ fibre analyzer (ANKOM Technology corporation, 140 Turk Hill Park Fairport, NY 14450).

The percentage DM, nitrogen (N) and NDF disappearance was calculated from the residue remaining after incubation using the following equation:

$$\text{Percentage disappearance} = \left(\frac{\text{g before incubation} - \text{g after incubation}}{\text{g before incubation}} \right) * 100$$

DM, N and NDF disappearance values were fitted to the following non-linear model as suggested by Ørskov & McDonald (1979):

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

p = the proportion degraded at time t

a , b , and c = non-linear parameters estimated by an iterative least square procedure.

Parameter a represents the readily soluble fraction, b the potentially degradable fraction and c the rate at which b is degraded.

By introducing the fractional outflow rate, k , the effective degradabilities (P) were calculated from the following equation (Ørskov & McDonald, 1979):

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

Flow rates of 0.05 and 0.08 per hour were used as suggested by Erasmus *et al.* (1990).

Statistical analysis

The non-linear parameters a , b and c were estimated by least-square iterations using the N-LIN procedure of SAS (1996). A one-way analysis of variance (Snedecor & Cochran, 1991) was performed on the data using Statgraphics (1985). Significance was declared at $P \leq 0.05$ unless otherwise indicated. Multiple range tests were used to separate least-square means at $P \leq 0.05$.

Results and Discussion

The chemical composition of the different lucerne hay components is presented in Table 2.

Table 2. Chemical composition (%) on a DM basis of different lucerne hay components used in the *in situ* trial.

Item	Lucerne hay	Lucerne leaves	Lucerne hay + 8% leaves
NDF	38.0	24.0	40.0
Crude Protein	20.6	21.4	20.9
Ash	0.40	5.34	0.63
Dry Matter	88.8	87.8	89.0

NDF = Neutral Detergent Fibre

The values in Table 2 indicate that lucerne hay was higher in NDF content than lucerne leaves. It would be expected that the NDF value for lucerne hay + 8% leaves would be somewhere in-between the value found for lucerne hay and lucerne leaves. The NDF content of the lucerne + leaves was, however, quite similar to that of the lucerne hay alone and only slightly higher. This was probably due to the fact that an 8% inclusion of leaves was too little to result in a noticeable difference in the chemical composition between lucerne hay and lucerne + leaves. Sampling error could have resulted in the slightly higher NDF content of the lucerne + leaves and it should be kept in mind that the leave component also contained a significant amount of fine stem material.

The protein content of the lucerne leaves corresponded to the value of 21.1% found for lucerne leaf meal by Morrison (1961), but is lower than the protein content of 27.8% (4.45% N) reported for lucerne leaves by Coblenz *et al.* (1998). The protein content of the artificially dried lucerne hay is, however, higher than the value of 17.7% found by Morrison (1961) for barn dried lucerne hay. The CP content of the lucerne found in the current study are similar to the value of 20% reported by Beauchemin & Rode (1994) for lucerne cut at 10% bloom and wilted and the value of 21% reported by Coblenz *et al.* (1998) for lucerne dried with forced air at 50°C. The high protein content of the artificially dried lucerne hay in the current study could partly be explained by the fact that samples were taken from the centre of the lucerne bales where post-baling leaf loss is at a minimum. It could also be because lucerne was cut at an early age (5 weeks' regrowth).

The effect of breed on the non-linear parameters a, b and c for ruminal DM, protein and NDF disappearance of different lucerne components are shown in Table 3 and in Figures 1 to 9.

The a-value represents the readily soluble fraction of the feed and is assumed to be similar to the value (t_0) obtained from bags that were washed but not incubated in the rumen. The a-values are assumed to be similar for Holsteins and Jerseys as it is a function of the feed and is not influenced by other factors. The b and c-values are derived functions of feed and microbial interactions.

The potential degradability values (b values) in Table 3 for DM, protein and NDF did not differ ($P>0.05$) between the two breeds for any of the treatments. It therefore appears that breed did not have an effect on potential degradabilities for the three treatments used in this experiment. The potential protein degradability values (b values) in both Holstein (53.6%) and Jersey cows (58.0%) obtained for lucerne hay in the current experiment was higher than the value of 44.7% found by Erasmus *et al.* (1990).

Table 3. Effect of animal breed on the non-linear parameters a, b and c for DM, protein and NDF disappearance (%) of different lucerne components from the rumen.

	Lucerne hay			Lucerne leaves			Lucerne hay + 8% leaves		
	Holstein	Jersey	P	Holstein	Jersey	P	Holstein	Jersey	P
Dry matter									
a	27.70	27.70	-	35.80	35.80	-	28.98	28.98	-
b	42.77	44.50	0.42	41.64	42.30	0.43	43.10	44.14	0.49
c	0.12 ^a	0.20 ^b	0.04	0.15	0.21	0.30	0.16	0.15	0.89
Protein									
a	33.1	33.10	-	27.94	27.94	-	24.01	24.01	-
b	53.55	58.01	0.28	62.8	62.12	0.68	65.30	65.75	0.75
c	0.26	0.31	0.54	0.16	0.24	0.31	0.26	0.24	0.70
NDF									
a	1.06	1.06	-	9.05	9.05	-	5.90	5.90	-
b	51.61	41.62	0.14	24.7	29.8	0.17	39.44	36.91	0.59
c	0.03 ^a	0.11 ^b	0.01	0.14	0.30	0.41	0.52	0.40	0.09

a = soluble fraction

b = potentially degradable fraction

c = rate of degradation

^{ab} values with different superscripts differ significantly ($P\leq 0.05$)

The c values represent the rate of degradation of the slowly degraded fraction b. From Table 3 it can be seen that the DM and NDF fermentation rates were higher ($P < 0.05$) for Jerseys than for Holsteins but only for the lucerne hay treatment. This difference can also be seen in Figures 1 and 3. The faster rate of fermentation observed in Jerseys especially for NDF can be attributed partly to the fact that pH in the rumen was generally higher in Jerseys than in Holsteins. Values varied between 5.5-5.8 for Holsteins and 5.7-6.0 for Jerseys from 1 hour before feeding to 5 hours after feeding. There was no significant difference in the rate of protein degradation between the two breeds for any of the three lucerne components used.

Total disappearance values for DM, protein and NDF across breeds are presented in Table 4 and in Figures 10 to 12.

Table 4. Non-linear parameters a, b and c for DM, protein and NDF disappearance (%) of different lucerne components from the rumen (mean values of Holstein and Jersey data).

Item	Lucerne hay	Lucerne leaves	Lucerne hay + 8% leaves	SEM	P
Dry Matter					
a	27.70 ^a	35.80 ^b	28.98 ^c	0	0
b	43.63	41.96	43.62	0.46	0.26
c	0.16	0.18	0.16	0.13	0.73
Protein					
a	33.10 ^a	27.90 ^b	24.00 ^c	0	0
b	57.50 ^a	62.46 ^b	65.52 ^c	0.37	0
c	0.27	0.20	0.26	0.02	0.29
NDF					
a	1.06 ^a	9.05 ^b	5.90 ^c	0	0
b	46.61 ^a	27.24 ^b	38.17 ^c	1.49	0
c	0.07 ^{ab}	0.22 ^a	0.51 ^b	0.35	0

a = soluble fraction

b = potentially degradable fraction

c = rate of degradation

^{ab} values with different superscripts differ significantly ($P \leq 0.05$)

NDF = Neutral Detergent Fibre

When data of both breeds were pooled, it appeared that the leaf component had the highest soluble DM and NDF fractions (a values). This is illustrated in Figure 10 and Figure 12. Lucerne hay had the highest soluble protein fraction (Figure 11). Due to the leaf composition (Table 2) it was to be expected that the leaves would contain more readily soluble material than the other treatments.

No differences in potential DM degradability values were observed between treatments (Table 4). The potential degradability values of protein ($P < 0.001$) and NDF ($P < 0.001$) did, however, differ significantly between the three treatments. The highest potential

degradability of protein was found for lucerne hay + 8% leaves and the lowest for lucerne hay. The potential degradability of NDF was, however, highest for lucerne hay and the lowest for leaves. Although the lucerne leaves had a much lower NDF content than the other components it appears that apart from a readily soluble fraction leaf NDF has a relatively low digestibility in the rumen.

Coblentz *et al.* (1998) reported values on the extent (comparable to the sum of a and b values in Table 4 of the current study) of ruminal degradation of different lucerne components namely leaf, stem and whole plant components. The extent of DM degradation found by them for lucerne hay and lucerne leaves (76.6 and 89.6%) was higher than the values found in the current study for lucerne hay and lucerne leaves (71.3 and 77.8%). The extent of protein degradation reported by these authors for lucerne hay (91.3%) compares well to the value found in the current study (90.6%), but their value for lucerne leaves (95.4%) was higher than the value (90.4%) found in the current study. They did, however, find much higher NDF degradability values for lucerne hay, as well as lucerne leaves (53.2 and 75.4%) than was found in the current study (47.7 and 36.3%). It should be noted that the lucerne hay used by Coblentz *et al.* (1998) was similar in CP and NDF content to the lucerne used in the current study (CP = 21.06% and NDF = 40.9%). The lucerne leaves used in their experiment were, however, higher in CP and lower in NDF content (CP = 27.8% and NDF = 25.4%). This could explain the large difference in the extent of CP degradation of the lucerne leaves components. The large differences observed in the extent of NDF degradation could be due to the inability of the particular model used in the current experiment to describe all the parameters accurately. It should also be noted that rumen pH of the cows in the current trial was generally low as was mentioned earlier.

The c values presented in Table 4 indicate that the rate of DM and protein degradation did not differ significantly between the three treatments. The similar rates of DM and protein degradation of the different treatments is apparent from Figures 10 and 11. The rate of NDF degradation did, however, differ significantly ($P < 0.001$) between the treatments and was highest for lucerne hay + 8% leaves. The differences that exist in the

rate of NDF degradation between the different lucerne products are illustrated in Figure 12 where it can be seen that lucerne hay had the slowest rate of NDF degradation and that lucerne hay + 8% leaves had the fastest NDF degradation rate. The rate of protein degradation of lucerne hay observed in this experiment ($c=0.27$) corresponds with the value ($c=0.21$) reported by Erasmus *et al.* (1990).

The disappearance curves of DM, protein and NDF are presented in Figures 1 to 12.

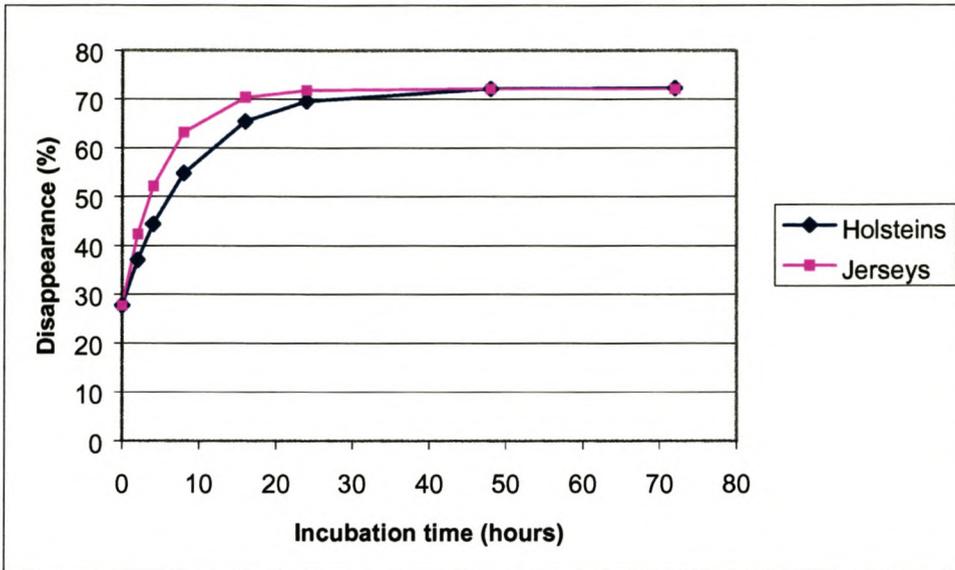


Figure 1. Ruminal DM disappearance of lucerne hay in Holstein and Jersey cows.

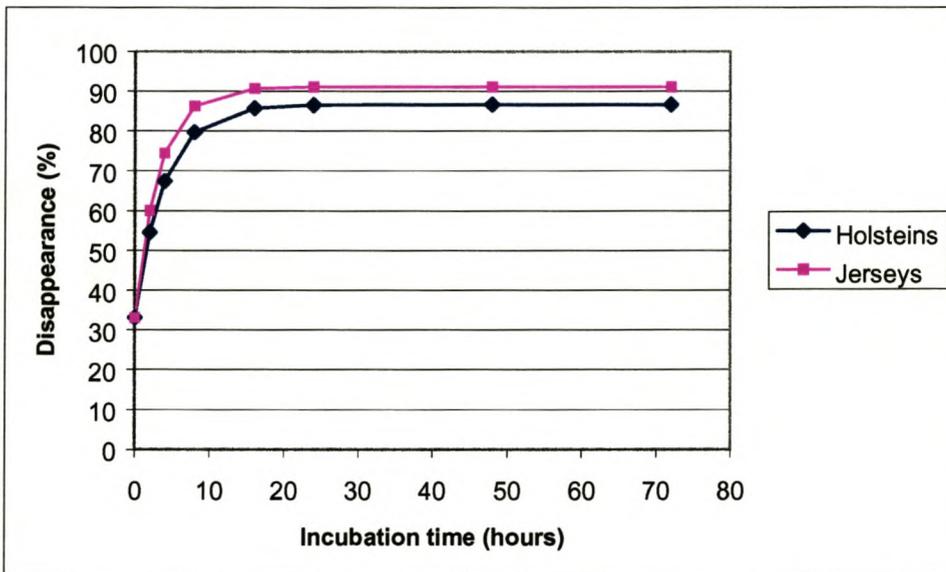


Figure 2. Ruminal protein disappearance of lucerne hay in Holstein and Jersey cows.

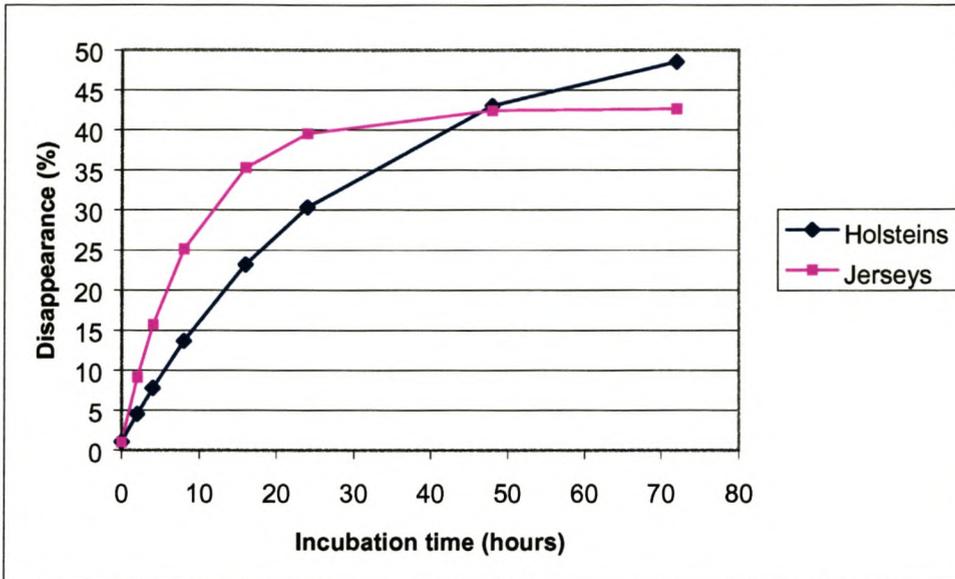


Figure 3. Ruminal NDF disappearance of lucerne hay in Holstein and Jersey cows.

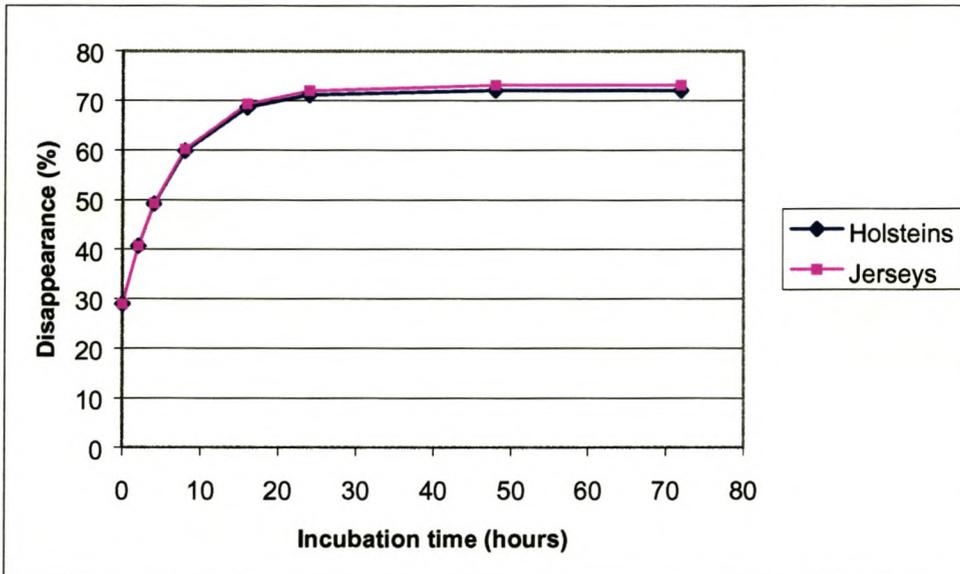


Figure 4. Ruminal DM disappearance of lucerne hay + 8% leaves in Holstein and Jersey cows.

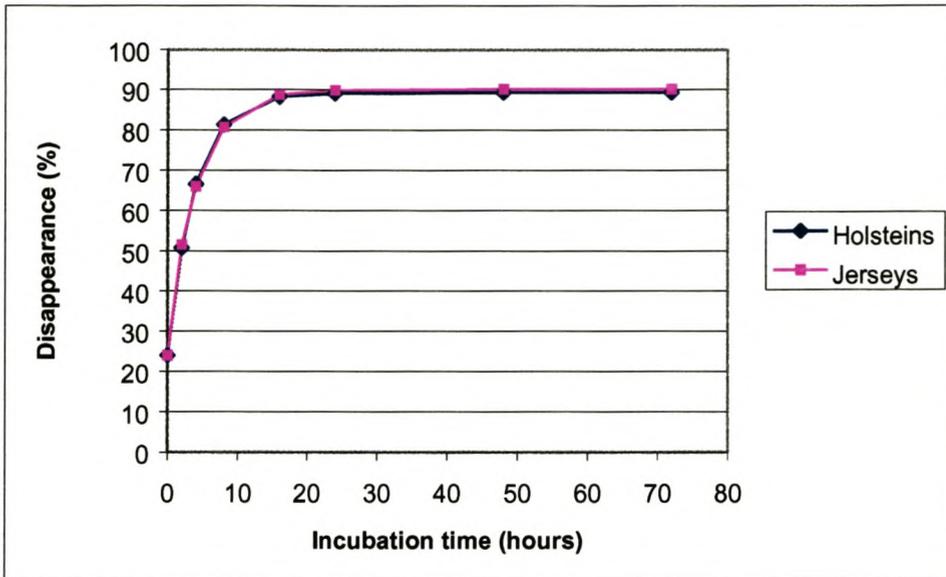


Figure 5. Ruminal protein disappearance of lucerne hay + 8% leaves in Holstein and Jersey cows.

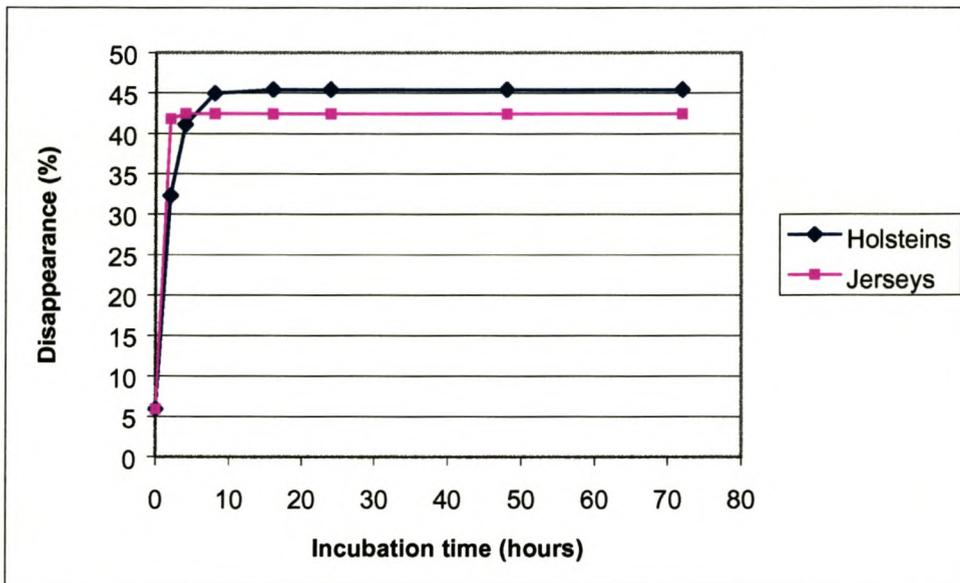


Figure 6. Ruminal NDF disappearance of lucerne hay + 8% leaves in Holstein and Jersey cows.

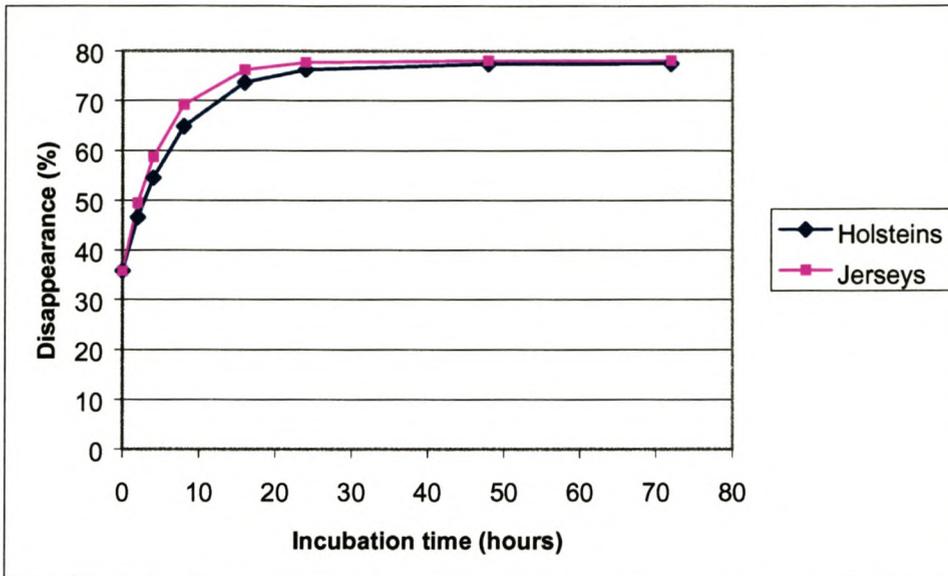


Figure 7. Ruminal DM disappearance of lucerne leaves in Holstein and Jersey cows.

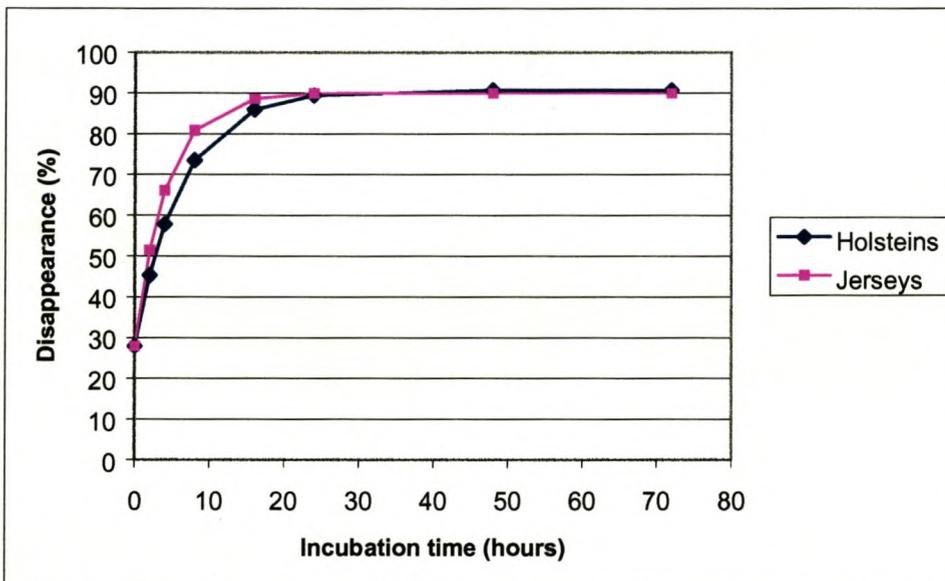


Figure 8. Ruminal protein disappearance of lucerne leaves in Holstein and Jersey cows.

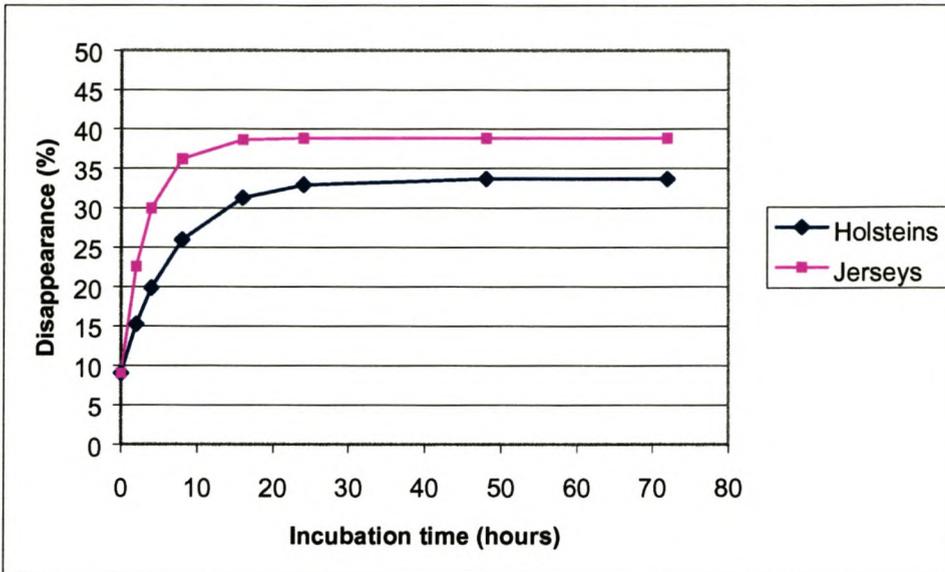


Figure 9. Ruminal NDF disappearance of lucerne leaves in Holstein and Jersey cows.

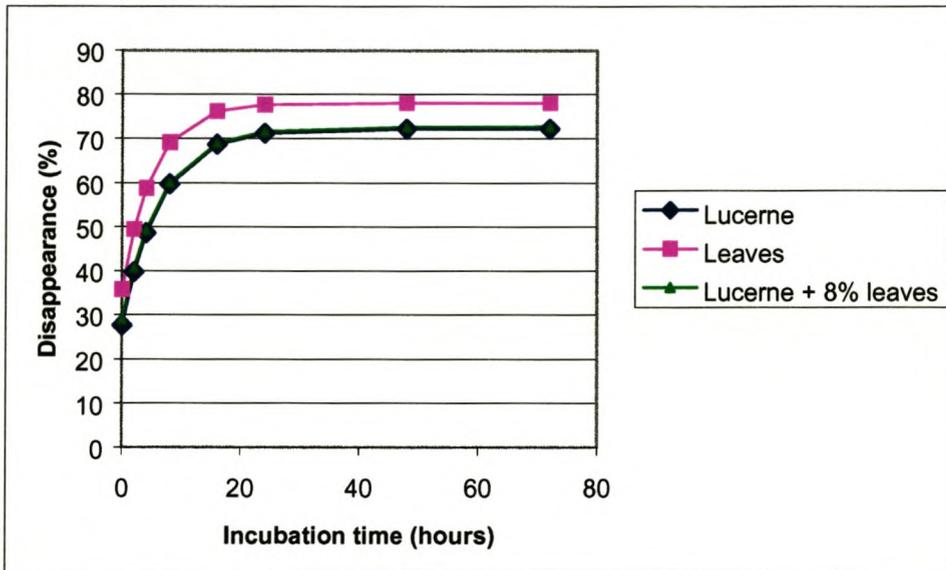


Figure 10. Average DM disappearance of lucerne hay, lucerne leaves and lucerne hay + 8% leaves in the rumen of Holstein- and Jersey cows.

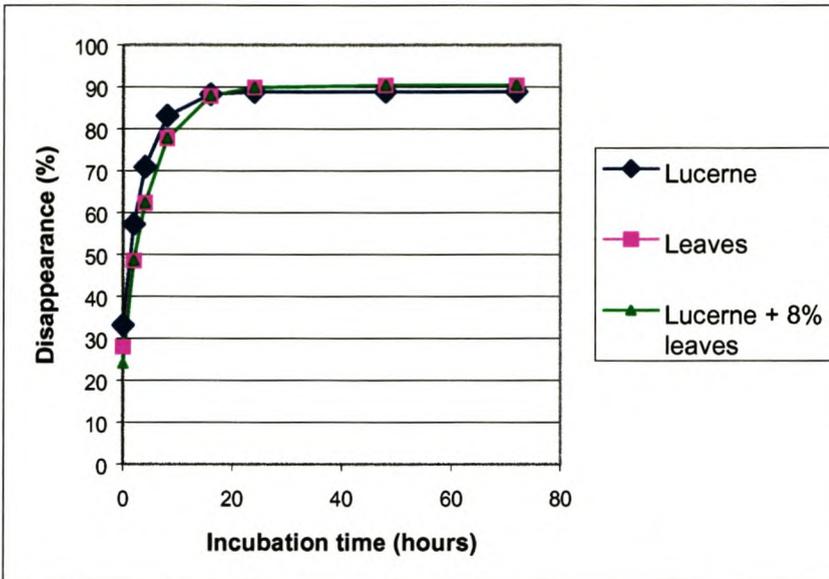


Figure 11. Average ruminal protein disappearance of lucerne hay, lucerne leaves and lucerne hay + 8% leaves in Holstein and Jersey cows.

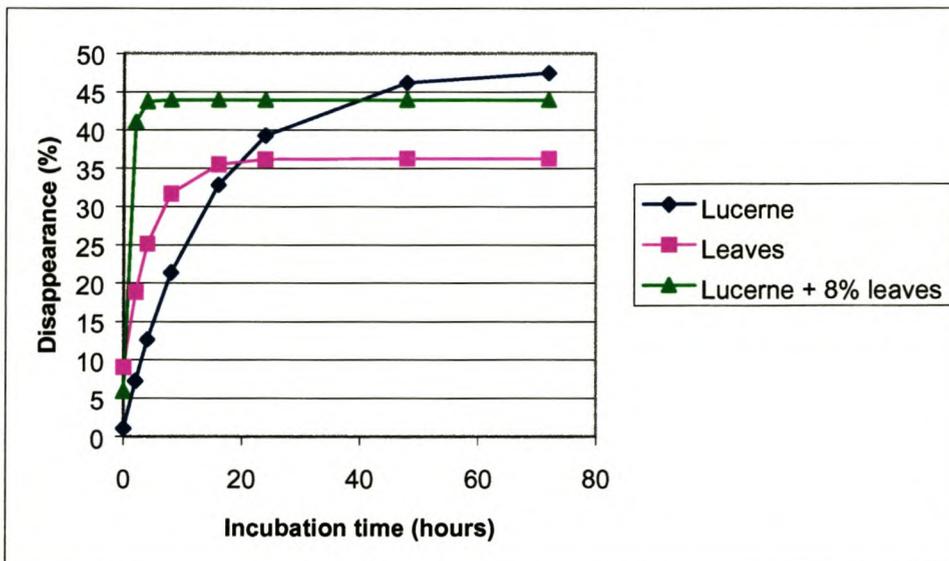


Figure 12. Average ruminal NDF disappearance of lucerne hay, lucerne leaves and lucerne hay + 8% leaves in Holstein- and Jersey cows.

The extent of ruminal DM, protein and NDF degradation (effective degradabilities) of lucerne hay, lucerne leaves and lucerne hay + 8% leaves in Holsteins and Jersey cows, calculated at fractional outflow rates of 0.05/h and 0.08/h, is presented in Table 5.

Table 5. Effective degradability (%) of DM, protein and NDF at fractional outflow rates of 0.05 and 0.08/h for Holstein and Jersey cows.

	Lucerne hay			Lucerne leaves			Lucerne hay + 8% leaves		
	Holstein	Jersey	P	Holstein	Jersey	P	Holstein	Jersey	P
Dry Matter									
0.05/h	57.64 ^a	62.87 ^b	0.05	66.47	69.08	0.26	61.36	61.71	0.84
0.08/h	53.08 ^a	59.02 ^b	0.04	62.38	65.42	0.38	57.2	57.4	0.93
Protein									
0.05/h	76.94	82.37	0.08	75.47	77.61	0.33	77.89	78.45	0.39
0.08/h	72.69	78.37	0.11	69.49	72.45	0.32	72.89	73.37	0.82
NDF									
0.05/h	19.99	29.16	0.04	27.34	31.69	0.26	42.09	39.25	0.45
0.08/h	15.10 ^a	24.63 ^b	0.02	24.90	29.45	0.28	40.34	37.66	0.40

^{ab}: Values with different superscripts differ significantly

NDF = Neutral Detergent Fibre

From Table 5 it can be seen that the effective DM and NDF degradability values for lucerne hay was significantly higher in Jerseys than in Holsteins at fractional outflow rates of 0.05 and 0.08/h. The effective protein degradability of lucerne hay tended to be higher for Jerseys at fractional outflow rates of 0.05/h (P=0.08) and 0.08/h (P=0.11). This indicates that breed had an influence on the effective DM, protein and NDF degradabilities of lucerne hay. The higher effective degradability values found in Jerseys, especially NDF degradability can be related to the higher rumen pH found in Jerseys. This brings about a more favorable rumen environment which enhances degradation of fibre by micro organisms.

In the case of the other two treatments, namely lucerne leaves and lucerne hay + 8% leaves, the effective DM, protein and NDF degradabilities were similar in Holsteins and Jerseys at both fractional outflow rates. Ruminant protein degradation values of 78% in Holsteins were reported by Chiou *et al.* (1995) for lucerne hay at an outflow rate of 0.05/h. This value was slightly higher but comparable to the value of 76.9% found in the current experiment for Holsteins but lower than the value of 82.4% found for Jerseys.

In Table 6 the data for the ruminal DM, protein and NDF degradation in Holstein and Jersey cows were pooled to determine degradation values of lucerne hay, lucerne leaves and lucerne hay + 8% leaves.

Table 6. Effective degradability of DM, protein and NDF (%) at fractional outflow rates of 0.05 and 0.08/h for lucerne hay, lucerne leaves and lucerne hay + 8% leaves.

Component	Lucerne hay	Lucerne leaves	Lucerne hay + 8% leaves	SEM	P
DM					
0.05/h	60.26 ^a	67.77 ^b	61.54 ^c	0.64	0
0.08/h	56.05 ^a	63.89 ^b	57.30 ^a	0.72	0
Protein					
0.05/h	80.13 ^a	76.54 ^b	78.17 ^{ab}	0.53	0.05
0.08/h	75.55 ^a	70.97 ^b	73.14 ^{ab}	0.77	0.08
NDF					
0.05/h	24.57 ^{ab}	29.65 ^{ab}	40.24 ^c	1.22	0
0.08/h	19.86 ^a	27.17 ^b	38.30 ^c	1.21	0

^{ab} values with different superscripts differ significantly

NDF = Neutral Detergent Fibre

Table 6 indicates that the effective DM, protein and NDF degradability values differed significantly between the three lucerne components. Lucerne leaves had the highest effective DM degradability at both flow rates but the lowest effective protein degradability.

Lucerne hay had the highest effective protein degradability value. Erasmus *et al.* (1990) reported a protein degradability value of 78.8% at an outflow rate of 0.05/h, for lucerne hay. This value is slightly lower, but compares well with the value of 80.1% found in the current experiment for protein degradability calculated across breeds. The slightly higher

protein degradability value in the current experiment could be because the lucerne used by Erasmus *et al.* (1990) was lower in CP content and higher in NDF content than the lucerne used in the current experiment (16% and 42.8% compared to 20.6% and 38%). Lucerne hay + 8% leaves was the component with the highest effective NDF degradability at flow rates of 0.05 and 0.08/h. The high NDF degradability for the latter treatment is not readily apparent, but relates to the exceptionally high fermentation rate for this treatment (Table 4) which was also inexplicable.

According to Hvelplund, (1985, as cited by Erasmus *et al.*, 1990) protein degradation is not a positive or negative characteristic of feedstuffs as in some feeding situations a high, and in some a lower protein degradation is necessary for optimum production. It is equally important to know something about protein quality including the availability of undegraded protein (Satter,1986).

The protein degradability values given in Table 6 were used to separate the protein component of the lucerne products into ruminally degradable protein (RDP) and undegradable protein (UDP). The UDP fraction was then separated into available UDP or digestible undegradable protein (DUP) and indigestible undegradable protein fractions. This separation was done so that the UDP fraction which will be available for absorption in the duodenum will not be overestimated.

Acid detergent insoluble N (ADIN) content of the lucerne products was used to estimate the DUP fraction thereof. ADF-N contents were taken to be 7% of the nitrogen content of the feed samples used. The factor of 7% was derived from the average values reported by Erasmus *et al.* (1990) for lucerne hay and dehydrated lucerne meal. The calculated UDP and DUP values are given in Table 7.

Table 7. Partitioning of total N between rumen degradable N (RDN) and undegradable N (UDN) fractions and undegradable protein (UDP) and digestible undegradable protein (DUP) content (g/kg DM) of different lucerne components dried artificially ($K_p=0.08$).

	Lucerne hay	Lucerne leaves	Lucerne hay + 8% leaves
Total N	33.4	33.5	32.6
RDN	25.23	23.77	23.84
UDN	8.17	9.73	8.76
UDP	51.04	60.78	54.73
ADF-N	2.34	2.35	2.28
DUP	36.43	46.13	40.64

^a Undegraded dietary protein = (UDN x 6.25).

^b Digestible undegraded protein = (UDN - ADF-N) x 6.25.

From Table 7, it is evident that UDP values were higher for lucerne leaves than for the other two components. This relates to the low effective protein degradability values found for the lucerne leaves component (Table 6). DUP values were also higher for lucerne leaves than for lucerne hay and lucerne hay + 8% leaves. This indicates that a bigger proportion of the leaf component would probably be utilised in the duodenum than would be the case for the other components. The UDP and DUP values of all the components used in the current experiment were larger than the values reported by Erasmus *et al.* (1990) for lucerne hay (unspecified; UDP = 40.3 and DUP = 28.0g/kg DM).

Conclusion

Although the protein content of lucerne leaves were only slightly higher than that of lucerne hay, the NDF content of the leaf material was much lower than that of the hay, indicating a superior nutritive value. It should be kept in mind, however, that the leaf material contained significant amounts of fine stem material and that pure leaves would have an even higher nutritive value.

Results obtained from the comparison of digestibility values between breeds indicate that the effective DM and NDF degradability values appear to be higher in Jerseys than in Holsteins. Although ruminal protein degradability values did not differ between breeds, Jerseys appear to digest lucerne hay NDF more efficiently than Holsteins.

Analysis of the pooled data indicated that lucerne leaves have a higher soluble fraction and ruminal DM and NDF digestibility than lucerne hay. The protein degradability of lucerne leaves was, however, lower than that of lucerne hay. It should be noted that lucerne leaves was the component with the highest DUP value indicating that leaves can serve as a source of bypass protein which could be utilised in the duodenum. This emphasizes the necessity of good haymaking practices to ensure the production of lucerne hay with a higher percentage of leaf material for inclusion in diets for dairy cows.

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Chapter 5

General conclusions

Lucerne loses quality during the process of haymaking. Factors such as bleaching by the sun, dew or mist at night, rainfall and shatter of leaves bring about this decrease in the quality of lucerne hay. The longer lucerne stays in the field to dry, the greater the quality losses will be. It was expected that lucerne quality would be improved by artificial drying of the cut material. Chemical analysis done on the lucerne hay produced by natural and artificial drying showed that the quality of lucerne hay was not improved by artificial drying under the conditions experienced during the experimental period. Better quality lucerne hay can probably be produced by following a different approach during the drying process. The lucerne could be transferred to the FABD directly after cutting to reduce the shatter of leaves caused by the handling of the lucerne after some moisture had already been lost. It can be concluded that the FABD should only be used to dry lucerne when weather conditions are not ideal for field drying.

It was found from the comparison made between the protein and fibre degradability of lucerne harvested at different stages of maturity that lucerne increases in fibre content and decreases in protein content as the plants mature. During the degradability trial the highest DM and protein degradability values were found for lucerne harvested after 4 weeks' regrowth. The lowest effective NDF degradability was found for lucerne cut after 6 weeks' regrowth. These results indicate that in terms of DM, protein and NDF degradability the quality of lucerne would be better when it is harvested after 4 weeks' regrowth than after 6 weeks' regrowth. It is important to consider quality factors such as these together with the influence that the stage of maturity has on the DM yield when a harvesting schedule for lucerne is planned.

The comparison of the protein and fibre degradability of artificially dried lucerne products in the rumen of Holstein and Jersey cows indicated that Jerseys appear to be more efficient in utilizing artificially dried lucerne hay than Holsteins. Although ruminal

protein degradability values did not differ between breeds, Jerseys appear to digest lucerne hay NDF more efficiently than Holsteins.

Analysis of the pooled data indicated that lucerne leaves have a higher soluble fraction and ruminal DM and NDF digestibility than lucerne hay. The protein degradability of lucerne leaves was, however, lower than that of lucerne hay. Lucerne leaves was the component with the highest DUP value indicating that leaves can serve as a source of bypass protein which could be utilised in the duodenum. This emphasises the necessity of good haymaking practices to ensure the production of lucerne hay with a higher percentage of leaf material for inclusion in diets for dairy cows.