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Study on the effects of different harvest intervals on cassava foliage (cassava hay) and root yield and effects of sunflower oil supplementation in cassava hay based-diets for lactating dairy cows

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Paper I

Paper II

List of abbreviations

ADF	acid-detergent fibre
ADL	acid-detergent lignin
AIA	acid-insoluble ash
AOAC	Association of Official Analytical Chemists
BUN	blood-urea nitrogen
BW	body weight
CF	cassava foliage
CH	cassava hay
CLA	conjugated linoleic acid
CON	control treatment
CP	crude protein
CT	condensed tannin
DIM	day-in-milk
DM	dry matter
DMI	dry matter intake
DPO	Dairy Farming Promotion Organization of Thailand
FCM	fat corrected milk
ha	hectare
K	potassium
MUN	milk-urea nitrogen
N	nitrogen
NH_3-N	ammonia nitrogen
OM	organic matter
P	phosphorous
RCBD	Randomized complete block design
SFA	saturated fatty acid
SNF	solid-not fat
THI	temperature humidity index
UFA	unsaturated fatty acid
UTRS	urea-treated rice straw
VFA	volatile fatty acid

Appendix

This thesis is based on the following papers:

I. Chantaprasarn, B. and Wanapat, M., 2005. Study on effects of different harvest intervals on cassava foliage (cassava hay) and root yield.

II. Chantaprasarn, B. and Wanapat, M., 2005. Effects of sunflower oil supplementation in cassava hay based-diets for lactating dairy cows.

1. Introduction

Dairy farming in Thailand began around 90 years ago, and the introduction of extensive dairy development took place in the early 1960s. It started with the establishment of the Thai Danish Farm and Training Centre at Muaklek, as a joint venture between the Thai and Danish Governments. The approach was clearing land, purchase of cattle, construction of farm buildings, training of farmers, development of a dairy colony, provision of extension services and development of a small dairy plant, as well as a marketing system for pasteurized milk production. In 1971, the Thai Government took over responsibility and the project was organized under the management of the newly established government enterprise, under the name “Dairy Farming Promotion Organization of Thailand (DPO).”

The Thai Government's plan for the development of dairying is aimed at a reduction of foreign exchange for the purchase of imported milk powder and dairy products but also to provide the farmers with the opportunity to earn increased and more regular incomes and generate employment opportunities in farming, milk processing and manufacturing industries. In the past decade, there has been considerably increased activities in dairy extension and production. Examples include government policy supporting dairy extension and dairy production; the Dairy Extension Project improving the structure of agricultural products; the Milk Consumption Campaign; the School Milk Program; the establishment of a dairy plant; bank loans to establish dairy farms, etc. According to statistics the number of dairy farmers has increased from around 6,600 in 1987 to 17,893 in 2003. Similarly, during this same period the number of dairy cattle increased from around 75,500 to about 392,625 head (Office of Agricultural Economics, 2004).

Although dairy farming started in 1960, Thai farmers still can not produce enough raw milk to meet the demand of the whole country. As reported in 2004, Thailand produced 731,923 tons of raw milk and imported milk and milk products equivalent to 183,726 tons (Office of Agricultural Economics, 2004). The major constraints on the raw milk production have been many, for example the high cost of feed, unfavorable climatic conditions (Vercoe, 1999), weak disease control and herd management (Aiumlamai, 1999) and poor nutrition. In tropical developing countries, due to the high population pressure, ruminants are fed mainly with crop residues. Normally, these types of feed are very poor and unbalanced in nutritive value and with low digestibility. Feeding dairy cattle in the tropics is often difficult because of deficiencies in feed supply, in both quality and quantity (Wanapat and Devendra, 1992). However, using available crop residues in ruminant production to reduce the food – feed competition and build up a sustainable production system is a good strategy for development (Wanapat and Devendra, 1999; Preston and Leng, 1987).

The use of local feed resources to improve the nutritional conditions for ruminants on crop residues-based diets is very important for tropical developing countries. Cassava is a vitally important feed resource, which is abundantly available in the tropical countries. In Thailand, traditional cassava cultivation is for root production, as a human food and energy source for animals. Recently, managing cassava for foliage production had been found to have more potential as it is a good high by-pass protein source for animals, especially for ruminants and can improve production and reduce feed costs. Therefore, planting cassava for both root and foliage production could be more advantageous. Nevertheless, factors that affect the yield and quality of cassava root and foliage have to be researched to find out the most suitable practices for higher quality and quantity of cassava root and foliage.

Cows in early lactation and high-producing cows are typically in negative energy balance. In order to balance the ration, the use of fat or fat-rich feedstuffs was a logical step for increasing the energy content of rations. Fat has more potential in high energy concentrations to meet the requirement for early lactation and for high producing cows. It can increase the energy density of the diet, and consequently increase milk yield and milk quality. Other possible advantages would be to improve palatability and to reduce dustiness. Feeding fats to lactating dairy cows by using sunflower oil in the concentrate with cassava hay could be a way to meet the energy and nutrient requirements and to improve rumen ecology as well as milk yield and quality.

2. Objectives

2.1 To determine the effect of different harvest intervals of cassava foliage on cassava hay and cassava root production and chemical composition
2.2 To study effects of sunflower oil in cassava hay and cassava chip diets on early-mid lactating dairy cows.
2.3 To study the economics of using cassava hay as a source of protein, and cassava chip and sunflower oil as a source of fermentable energy and fat to supplement rations for lactating dairy cows.

3. General discussion

3.1 Cassava production in Thailand

Cassava or tapioca (*Manihot esculenta*, Crantz) is grown widely in tropical and sub-tropical countries. In Thailand cassava is the second most important crop after rice in terms of planting area, generating farmers' income, rural employment and export earnings. The production of cassava roots in 2004 was 21.4 million tons and the planted area cover 1.08 million hectares. The average fresh root yield was 20.3 tons/ha (Office of Agricultural Economics, 2004) as shown in Table 1. Many varieties are being cultivated in different locations, and the most common cassava varieties are Rayong 1, Rayong 5, Rayong 60, Rayong 90, Kasetsart 50 etc. The starch content in the roots is 17.7 to 35%, depending on variety, age of planting, planting area, planting and harvesting season (Sinthuprama *et al.*, 1983; Settasuk, 1994; Sriroth, 2000). In Paper I, the cassava variety Rayong 60 was cultivated with a starch content in the root of 19.3 to 25.3%. The fresh root production was 25.1 tons/ha in the control treatment, which is slightly higher than the average cassava root yield in the whole country.

Table 1. Planted, harvested area and cassava root production in Thailand, 1995-2004

Year	Planted area (ha)	Harvested area (ha)	Production (million tons)	Production (tons/ha)
1995	1,294,880	1,245,120	11.22	9.0
1996	1,261,600	1,228,160	17.39	14.2
1997	1,264,960	1,230,400	18.08	14.7
1998	1,071,040	1,044,320	15.59	14.9
1999	1,152,000	1,065,440	16.51	15.5
2000	1,184,960	1,134,080	19.06	16.8
2001	1,106,880	1,049,280	18.40	17.5
2002	995,840	988,160	16.87	17.1
2003	1,029,600	1,021,760	19.72	19.3
2004	1,081,120	1,057,280	21.44	20.3

Source: Office of Agricultural Economics, 2004 (www.oae.go.th)

3.2 Climate and soil

Most agriculture, particularly in the Northeast of Thailand, is rain-fed. The rainy season extends from May to October. The pattern of the rainy season is bimodal with the first peak occurring in May to June and the second peak in September to October. The quantity and continuity of rainfall at the beginning of the rainy season is varying from year to year (Polthanee *et al.*, 2001). Cassava can grow in the temperature range from 10 to 35°C, with average monthly temperature not lower than 20°C. Cassava can grow well at a mean temperature of 25°C and annual rainfall of 1,000-1,500 mm with a good distribution (Cock and Rosas, 1975). If the dry period occurs in early stage of cassava planting at 1-3 and 3-5 months of growth, this results in cassava root yield reduction (Cock and Reyes, 1985).

The terms of the planted area of cassava, about 60% is produced in the Northeast, 29% in the Central Plain and 11% in the North of the country. Most cassava soils in Thailand are loamy Paleustults and Quartzipsamments. The Paleustults occupy about 75% of the total cassava area and are widespread both in the Northeast and the East, whereas the Quartzipsamments are relatively more dominant in the Eastern region. Most cassava soils are poor in terms of their indigenous soil fertility. They have rather unfavorable physical and chemical properties, such as very light texture in the surface soil, low level of organic matter, low nutrient and water retention capacity and also very low contents of available P and K. The classification of soil chemical characteristics according to the nutritional requirements of cassava is shown in Table 2. In paper I, the experiment was conducted in the soil type of the Paleustults group. The soil texture was sandy clay loam with 0.25% organic matter content and pH 4.5 on average. Total precipitation during the experiment period was 1,113 mm. The average monthly temperature was 27.5°C.

Table 2. Approximate classification of soil chemical characteristics according to the nutritional requirements of cassava

Soil parameter	Very low	Low	Medium	High	Very high
pH	<3.5	3.5-4.5	4.5-7.0	7.0-8.0	>8.0
Organic matter, %	<1	1-2	2-4	4-8	>8
P, µg/g	<2	2-5	5-20	20-50	>50
K, me/100g	<0.1	0.10-0.15	0.15-0.25	>0.25	
Ca, me/100g	<0.25	0.25-1.0	1.0-5.0	>5.0	
Mg, me/100g	<0.2	0.2-0.4	0.4-1.0	>1.0	

Source: modified from Howeler (1996)

3.3 Traditional cassava cultivation

Cassava in Thailand can be planted year round since there is usually sufficient soil moisture. Previous research revealed that planting cassava in the rainy season between May to October gave a root yield that was higher than in the dry season (November to April; Kathong, 1994). However, there are commonly two planting periods. In the first period cassava is planted in the beginning of the rainy season (April to middle of June) and the second planting period is late in rainy season or early in the dry season (October to December).

Land preparation is by ploughing by farm tractor with 8 to 12 inches depth. It was suggested that ploughing 2 times before planting resulted in higher root yield and economical returns (Kathong, 1994). The land is ridged after ploughing. Mature cassava stems of 8-12 months of age with 15-20 cm length is used as a planting material. The spacing of planting material is 70-100 cm between the rows and 50-100 cm between stems. Cassava cultivation for several years in the same piece of land and without application of fertilizer resulted in a decline in soil fertility and root yield. In contrast, the application of chemical fertilizer results in slightly increased root yield in the long term (Wongwiwatchai *et al*., 2001; Nakviroj *et al*., 2001 cited by Wongwiwatchai *et al*., 2002). The average amounts of fertilizers are comparable to the general recommendation of 100 kg N, 50 P_2O_5 and 100 K_2O/ha (Sittibusaya *et al*., 1993).

Weed control is traditionally done by hand with a hoe. The number of weedings necessary for cassava varies considerably depending on soil fertility, climate factors and varieties. Weeding cost varies according to the planting season, the cost being much higher when cassava is planted in the early rainy season than when planted in the early dry season. Tongglum *et al*. (1992) suggested that two times of hand weeding at 1 and 2 months after planting gave the best results for variety Rayong 60. The root harvesting is 8-12 months after planting. Harvesting in the dry season (November-April) resulted in higher starch percentage in the root (21.4-23.5%) while in the rainy season (May-October) the starch percentage is lower (20%; Settasuk, 1994). In paper I, cassava was planted in the late rainy season (November) with the spacing of cassava planting material of 50×80 cm. (between stems 50 cm, and between the rows 80 cm). The chemical fertilizer contained 15-15-15 (N-P-K) was applied to all plots of 150 kg/ha at 3 months of growth. Weeding was done every 3 months.

3.4 Nutritive values of cassava hay and root

Usually, cassava is grown for its root. However, attention is now being focused on the potential of the whole cassava crop in livestock production. Recently, Wanapat *et al*. (1997) paid attention to cassava hay, which includes combined leaves, stems and petiole of cassava planted for feeding to ruminants. Cassava was planted in rows using stems with spacing 60 × 40 cm (60 cm between rows. and 40 cm between stems.) and harvested 3 months after planting and every 2-3 months thereafter by cutting the whole crop at 15 cm. above the ground, or between the green and brown parts and sun drying for 1-3 days, resulting in cassava hay for direct feeding or for storage. The chemical composition of cassava hay is shown in Table 3. The variation of chemical composition depended on variety, study site and stage of harvesting. Crude protein in cassava hay has many profile of essential amino acids similar to most vegetable proteins with very minimal hydrocyanic acid (HCN; Wanapat *et al*., 1997). In addition, the condensed tannins (CT) content in cassava hay of 3.05-4.20% (Table 3) would be a beneficial level for ruminants. Wanapat (2001) reported that a CT level of 2-4% DM in the feed helps to protect protein from rumen digestion, thereby increasing by-pass protein. Cassava root in the form of cassava chip contains 88-90% DM, and 2.3-2.5% CP. It is an excellent fermentable energy source because of its high soluble carbohydrate content (76-81%; Gomez and Waldivieso, 1983 cited by Wachirapakorn *et al*., 2001) mainly in the form of starch, which is highly degraded in the rumen (94% DM; Vearasilp and Mikled, 2001). However, it is low in protein and all other nutrients. Cassava chip can be used at 55% in a concentrate as a source of energy without any effect on feed intake, milk yield and composition (Wachirapakorn *et al*., 2001). Wanapat and Petlum (2001) demonstrated that a concentrate based on a high level of cassava chips (85%) and high urea (3%) could support a high milk yield. Milk composition was better in terms of fat content, lactose and solids-not-fat as compared with other lactating dairy cows in that area. The feed cost was 60% lower than that of typical commercial products. In paper I, the mean values of the chemical composition of cassava hay were 94.6% DM, 23.2% CP, 6.6% ash, 41.0% NDF, 25.5% ADF, 7.8% ADL and 3.47% CT. The results obtained were similar to those reported in the literature. The CT content was within the range that would be beneficial for ruminants.

Table 3. Chemical composition of cassava hay (%DM)

DM	CP	ash	NDF	ADF	ADL	CT	Authors
93.4	24.9	6.6	34.4	27.0	3.8	-	Wanapat *et al.* (1997)
92.0	23.5	4.2	55.2	31.4	-	3.26	Netpana *et al.* (2001)
92.0	22.0	7.1	58.8	32.0	-	4.20	Poungchompu *et al.* (2001)
92.3	23.4	13.5	50.4	45.0	-	3.05	Wanapat *et al.* (2001)
86.9	24.2	6.6	48.2	31.1	11.8	-	Hong *et al.* (2003)
92.3	20.6	7.5	55.0	38.9	16.8	3.30	Kiyothong and Wanapat(2003)
93.7	27.3	8.0	67.7	41.7	13.2	3.60	Vongsamphanh and Wanapat(2003)
94.6	23.2	6.6	41.0	25.5	7.8	3.47	Boonchan and Wanapat (2005), Paper I

3.5 Cassava hay as a supplement

Feeding trials using cassava hay as a source of protein for lactating dairy cows have been successfully carried out either on research station or on farm. Cassava hay can be used as a supplement to reduce concentrate use or mixed as an ingredient in a concentrate. In addition, cassava hay can be fed as a sole source of feed to cattle. The results revealed high DM intake (11.2kg/hd/d, 3.2% BW) and DM digestibility (71%; Wanapat *et al.*, 1997). Ruminal protein degradation of cassava hay was relatively low (48.8%) which would result in higher by-pass protein, and therefore condensed tannins in cassava hay help to protect protein from rumen digestion (Wanapat *et al.*, 1997). Cassava hay supplementation reduced the ratio of concentrate supplementation to milk yield from 1:2 to 1:4, which could reduce concentrate use by 42% without affecting milk yield (Wanapat *et al.*, 2000a). The reduction in concentrate requirements by dairy cows use was further demonstrated by Wanapat (2001); Hong *et al.* (2003); Kiyothong and Wanapat (2003). The consequence of concentrate reduction could be higher income over feed and thus more advantageous economical returns for small-holder dairy farmers. Moreover, cassava hay supplementation could increase milk yield (Wanapat *et al.*, 2001) milk fat and milk protein percentage (Wanapat *et al.*, 2000a; Hong *et al.*, 2003). Furthermore, cassava hay supplementation is not only a protein source but it also apparently contains a gastrointestinal anthelmintic agent which can reduce total nematode egg counts in grazing cattle and buffaloes by the action of condensed tannins in cassava hay (Netpana *et al.*, 2001). Therefore, cassava hay could be a good supplement to combine with low protein roughages such as grass and rice straw to improve feed intake, digestibility and production of dairy cattle, especially in the dry season. In paper II, 20% of cassava hay was used as an ingredient in a concentrate offered to dairy cows with the ratio of concentrate to milk of 1:2. There was no improvement in milk composition. The difference compared to the studies above could possibly be due to differences in the ingredients and composition of concentrate and cassava hay supplementation. However, in terms of economical returns the study was similar to those discussed above. Cassava hay supplementation reduced concentrate use and resulted in higher income over feed.

3.6 Roughage intake

Roughage is a bulky feed that is high in fibre, containing more than 18% crude fibre on a DM basis and/or of low digestibility. Most roughages have a high content of cell wall, which contains amounts of lignin, cellulose, hemicellulose, pectin, and silica, and other components in lesser amounts (Church, 1977). The rumen of the dairy cow was designed to handle roughages. The cow must have a certain amount of roughage in order to keep the rumen healthy. Roughage not only controls pH in the rumen by stimulating salivation but functions from a physical standpoint to keep the lining of the rumen healthy and to keep the rumen muscles in tone. The fibre level of roughage and particle size contribute to the effectiveness of a fibre source for stimulating rumination (cud chewing) and salivation and maintaining normal milk protein and fat composition and rumen health (Schroeder, 1996). Generally, 40-50 percent roughage dry matter in a ration is the minimum amount necessary to avoid low milk fat. Roughage intake depends on its quality, cow factors, and concentrate levels. Milking cows can consume 1.8 to 2.2% of body weight daily as DM from average quality dry roughage. It is suggested that roughage DMI is related to NDF content. Roughage NDF intake in mid lactation is about 0.9% of body weight.

In the tropical countries the available feed resources for ruminants are fibrous, such as crop residues (e.g. rice straw, soybean straw, corn stover etc.). They are relatively high in ligno-cellulose (Leng, 1991), and the ligno-cellulose-hemicellulose complex, which are highly efficient in blocking the enzymatic hydrolysis of cellulose and hemicellulose (Church, 1977). The fibrous feed in the tropics is almost always of low digestibility (40-45%) and has less than 8% CP (often around 3-5%; Leng, 1991). The most common and important crop residue is rice straw with a very low CP content of 3-4%. There are many methods to improve the digestibility and nutritive value of rice straw. Treatment with urea can be a simple, practical method and is more readily accepted by dairy farmers. Wanapat *et al.* (1983) cited by Wanapat (1990a) demonstrated that ensiling rice straw with 5% urea using the ratio of rice straw to water of 1:1 and storing it for 2 weeks increased in vitro DM digestibility by 12% and CP by 9% units. ADL was also decreased and intake of UTRS as compared with untreated rice straw was higher (95 vs. 65 g DM/kg $W^{0.75}$) and digestibility was also higher (52 vs. 42%). Wanapat (1990b) summarized that UTRS could increase CP (from 3-4 to 7-9%), digestibility (from 46% to 50-55%) and intake by 30-40%. In addition, feeding 5% UTRS with a higher pH of 8.0 would help to maintain ruminal pH to be higher or nearly neutral (Wanapat, 1984 cited by Wanapat, 1990a). In paper II, UTRS was prepared using 1:1 rice straw: water with 5% urea and stored for 10 days. UTRS was given ad-libitum as a basal roughage. Chemical composition of UTRS was 49.4% DM, 7.8% CP, 15.2% Ash, 1.2% fat, 74.8% NDF, 45.8% ADF and 5.2% ADL with pH 8.5. It was similar to values discussed above. DMI of UTRS was slightly lower than discussed.

3.7 Factors affecting milk yield and composition

Milk yield and composition strongly influence profitability of dairy farming since farmers are paid for market milk by volume with standards of composition which are in agreement with the buyer or milk plant. In general the mean milk composition values have been reported to be 87% water, 4% fat, 5% lactose, 3.3% protein and 0.7% minerals. The main factors affecting milk yield and composition are:

3.7.1. Genetic factors

Philpot and Nickerson (1990) cited by Teerapataragul, (1990) stated the differences in milk yield and composition are 60% a result of genetic factors. Therefore, genetic differences within breed or among breeds would result in differences in milk yield and composition. Hurley (2003) reported that milk fat was the most variable constituent, while minerals and lactose were the least variable. However, milk fat production cannot be reduced genetically while increasing milk and protein production, due to the fact that genetic correlations among production traits are high and positive (Everett, 1990 cited by Palmquist *et al*., 1993).

3.7.2 Stage of lactation

Stage of lactation has a marked influence on milk yield and yields of all constituents in dairy cows (Sharma *et al*., 1990). Milk yield of a dairy cow at calving characteristically is initiated at a relatively high level and peaks approximately 3 to 6 weeks after parturition. This peak is maintained for a few weeks, and then yield declines. The average decline in milk yield was 6% in first lactation heifers while in mature cows it declined by 9% per month after the peak (Hurley, 2003) or 2.5% per week (McDonald *et al*., 2002). In general, higher milk yields at early stages of lactation and are accompanied by low constituent percentages (Schmidt and Van Vleck, 1974; McDonald *et al*., 2002). Kaewgamchan *et al*. (2001) also reported higher milk yield in early lactation and lower milk fat and protein percentage. In paper II, milking cows in early-mid lactation were used, with average DIM 53 days.

3.7.3 Milking practices

Some milking procedures can influence milk yield and constituents such as milking frequency, milking time, milking equipment etc. Erdman and Varner (1995) studied fixed yield responses to increased milking frequency and reported that increasing milking frequency from 2 times as normal practice to 3-4 times a day resulted in increased milk yields of 3.5 and 4.9 kg/day, respectively and also yields of milk fat and protein were increased. However milk fat and protein percentages tended to decrease as milking frequency increased. Wagner-Storch and Palmer (2003) showed that cows using automatic milking systems gave higher milk yield (26.4 vs. 25.8 kg) than parlor cows. In addition, the first and last milk in the milking process also influence milk composition, as milk first removed from the udder contains much less fat, as low as 1 to 2%, than the milk removed at the end of the milking process, which can be as high as 7 to 9% (Hurley, 2003).

3.7.4 Age of cows

Milk yield increases (at a decreasing rate) until about the 8th year of age and then decreases at an increasing rate. Hurley (2003) reported that mature cows produce about 25% more milk than 2-year-old heifers. The delay of the first lactation of a heifer increases milk yields (Lee, 1976). However, total lifetime production will be reduced. Age of cow effect has been reported to be greater for younger than older cows (Keown and Everett, 1985; Khan and Shook, 1996). Pirlo *et al.* (2000) stated that reduction of age at first calving below 26 months of age consistently produced a positive effect on the difference between milk yield returns and rearing costs per heifer. Reduction of age at first calving to 24 and 23 months of age seemed to be more profitable than reducing the age to 22 months. Effect of age on milk composition has been reported, and older cows (4-6 lactation) had lower milk composition, especially percentage of milk protein, lactose and SNF than younger cows (1-3 lactation; Kaewgamchan *et al.*, 2001).

3.7.5 Environmental temperature

Environmental temperature, radiant energy, relative humidity, and wind speed contribute to the degree of heat stress or cooling that occurs for the cow. Bianca (1965) reported at a temperature of 29°C and 40% relative humidity the milk yield of Holstein, Jersey and Brown Swiss cows were 97, 93, and 98% of normal, but when relative humidity was increased to 90% yields were 69, 75, and 83% of normal. Incorporation of the effect of ambient temperature and relative humidity gives the temperature-humidity index (THI; NOAA, 1976 cited by West, 2003). Leng (2003) calculated THI using the formula: THI= temperature [dry bulb] + (0.36 × temperature [wet bulb]) + 41.2. THI that affect dairy cattle can be classified into values of up to 74 as normal, values 75-78 as alert, values 79-83 as danger and values of 84 as emergency (Hahn *et al.*, 1998 cited by West, 2003). Other research determined that the critical values for minimum, mean and maximum THI were 64, 72, and 76, respectively (Igono *et al.*, 1992) and Ravagnolo *et al.*, 2000 reported that THI was the most critical variable to quantify heat stress, therefore consequently affecting DMI and milk yield. Similarly, Leng (2003) stated that as THI increase above 72 animal body temperature was increased, and consequently feed intake and milk yield decreased. Ravagnolo *et al.*, 2000 reported that milk yield declined by 0.2 kg per unit increase in THI when THI exceeded 72. Other research determined that estimated milk yield reduction was 0.32 kg per unit increase in THI (Ingraham, 1979). Associate with the ambient temperature, Berman *et al.* (1985) suggested that the upper limit of ambient temperatures for dairy cows that may maintain a stable body temperature is 25 to 26°C. In paper II, mean ambient temperature during the experimental period was 27°C. It was higher than the comfort zone for cattle. Mean THI value was 79, a danger level according to the above discussion which would result in a decrease in feed intake and milk yield.

3.7.6. Nutritional factors

Nutritional factors refers to feed and feeding that directly influence the milk and its composition. Inadequate feed intake or underfeeding may be caused by nutritive contents in feed, form of feed, animal factors etc. Underfeeding causes low milk production especially in early lactation, excessive body weight loss, lower conception rate, more herd health problems and less income over feed costs. While feeding above normal nutritional standards results in an increase in SNF and milk protein percentage, and usually results in an increased milk yield. However the cow cannot produce above her genetic potential (Schmidt and Van Vleck, 1974). Feeding high amounts of concentrate, with low roughage causes reduced acetic acid production and increased propionic acid in the rumen and will cause milk fat depression (Schmidt and Van Vleck, 1974). In contrast, feeding high levels of roughage which are high in NDF can result in lower milk yield. West *et al*. (1999) showed that increasing dietary NDF reduced milk yield and was offset by greater milk fat percentage. Ruiz *et al*. (1995) reported similar results when feeding a diet containing 31, 35, or 39% NDF. Milk yield was least for the 39% NDF diet, although FCM yield did not differ for the 31 and 35% NDF diets. In addition, Hurley (2003) reported that excess of starch and sugars, expressed as non-fibre carbohydrates (NFC), could increases milk protein percentage and possibly milk yield, but lowers fat percentage. Insufficient NFC, usually associated with high fibre, results in increased milk fat percentage but reduces yield and protein percentage. The level of 40 to 45% NFC is typical in diets with forage to concentrate ratios of 40 to 60 or less forage, which would maintain milk yield and composition. Generally dietary crude protein level affects milk yield but not milk protein percentage, unless the diet is deficient in crude protein (Hurley, 2003) or inadequate in intake, especially in early lactation or for cows with a high milk yield (Kaewgamchan *et al*., 2001). Feeding dietary fats also influences milk yield and its composition. Dietary fat can increase the energy density and energy intake of diets for early lactating dairy cows. However, feeding large amounts of ruminal unprotected fat may have detrimental effects on fibre digestibility and cause acetic acid reduction. The effect of feeding fat on milk yield and composition are discussed below.

3.8 Feeding fat to lactating dairy cows

Fat supplements have traditionally been fed to dairy cattle to meet the energy demands of high milk yields without sacrificing fibre intake. Feeding fat for dairy cows can improve reproductive performance, increase milk yield (Amaral *et al*., 1997; Avila *et al*., 2000; Ruppert *et al*., 2004) as well as increase milk fat and long-chain fatty acid content in milk (Aldrich *et al.*, 1997). However, dietary fats are antimicrobial and interfere with normal function of the ruminal microbes and result in fibre digestion depression. Fat is rapidly hydrolyzed in the rumen and the resultant long chain fatty acids are absorbed onto the fibre, which decreased its accessibility to microbial attack (Leng, 1987) or have a direct toxic effect on the ruminal microorganisms (Jenkins, 1993) and hence reduce fibre digestibility. Depression of fibre digestion is most severe for fat sources high in unsaturated fatty acids than saturated fatty acids (Jenkins, 1993). In addition, unsaturated fatty acids cause milk fat depression (MFD) and decreased DMI. Allen (2000) found that as the proportion of unsaturated fatty acids in the fat source increased, DMI generally decreased. Strong evidence in recent years points to their interference with fatty acid biohydrogenation as the likely cause of the MFD. Specifically, they block terminal steps of ruminal biohydrogenation, which leads to the accumulation of *trans* fatty acid intermediates that were shown to cause MFD. The *trans*-10 fatty acid isomers cause more of the decline in milk fat than any other positional isomers (Griinari *et al.*, 1998; Baumgard *et al.*, 2000). Unsaturated fatty acids are abundant in the diet of dairy cows, but largely disappear as the feed material passes through the rumen of the cow and the unsaturated fatty acids are converted to saturated fatty acids by the fermentative microbes. Ruminal microbes can alter the majority of the dietary unsaturated fatty acids by conversion to saturated fatty acids through a process called biohydrogenation. At the same time, biohydrogenation can produce a number of *trans* fatty acids. The limitation of fat supplementation is less than 10% of dairy rations. Normally, fat content of ruminant diets is low (< 50 g/kg) and if it increased above 100 g/kg the activities of rumen microbes are reduced (McDonald *et al.*, 2002). Looper (2001) suggested a limit in total fat of 6-7% of the ration dry matter. Similarly, Palmquist and Conrad (1978); Coppock and Wilks (1991) suggested an unprotected fat limit of no more than 4-5% of DM or no more than 7-8% of total crude fat. Source of fat supplementation can be from animal origin (tallow, grease, etc), plant oils (soybean oil, canola oil, sunflower oil etc), oil seeds (cottonseeds, soybeans, etc), and high fat byproducts such as residues from food processing plants. In paper II, 2.5 or 5% sunflower oil was mixed with concentrate. Total crude fat in the concentrate was not higher than the 7% as suggested above. Digestibility and milk fat contents were found to be similar to those discussed above. Increasing sunflower oil up to 5% tended to reduce digestibility and milk fat but did not differ with the control treatment. Supplemented sunflower oil could increase milk yield, although 5% sunflower oil in the diets tended to reduce milk yield, because it is high in unsaturated fatty acids that cause fibre digestion depression and milk fat depression, as discussed above.

3.9 Supplementation sunflower oil to lactating dairy cows

Sunflower oil is a source of fat that can be used as a supplement, and which contains 12% saturated fatty acids and 88% unsaturated fatty acids (Grant and Kubik, 1990) Palmquist (1988) reported sunflower oil as consisting of 8%

palmitic ($C_{16:0}$), 3% stearic($C_{18:0}$), 13.5% oleic($C_{18:1}$), 75% linoleic($C_{18:2}$) and 0.5% linolenic ($C_{18:3}$) acid . Petit *et al.* (2004) indicated that feeding TMR consisting of whole sunflower seed (6.7% crude fat) did not alter DMI and DM, CP, NDF and ADF digestibilities. Similarly, Kalscheur *et al.* (1997) and Sackmann *et al.* (2003) reported supplementation 2 or 4% and 3.7% sunflower oil, respectively did not alter DMI and apparent ruminal DM, NDF and ADF digestibilities. Supplementation of sunflower oil to dairy cows has been reported to lower the percentage of milk fat and reduce milk fat production (Kalscheur *et al.*, 1997). However, sunflower oil can be used as a dietary fat supplement to increase milk yield and the proportion of unsaturated fatty acids in milk fat (Schingoethe *et al.*, 1996). In addition, feeding sunflower oil resulted in increased concentrations of *trans*10, *cis*12 $C_{18:2}$ and *cis*9, *trans*11 $C_{18:2}$ in rumen (Loor *et al.*, 2004).

3.10 Rumen biohydrogenation

The function of biohydrogenation is the disposal of reducing power which is essential for bacteria living in a reduced environment (Lennarz, 1966), to detoxify the unsaturated fatty acids (Kemp and Lander, 1984) and the utilization of dietary fatty acids by fatty acid autotrophic bacteria (Hazlewood and Dawson, 1979). The major unsaturated fatty acids in ruminants rations are linolenic ($C_{18:3}$) linoleic ($C_{18:2}$), and oleic ($C_{18:1}$) acid. Two important transformations occur in the rumen when unsaturated fatty acids are consumed (Dawson *et al.*, 1977). The initial transformation is hydrolysis of the ester linkages catalyzed by microbial lipases. This step is a prerequisite for the second, that is biohydrogenation of the unsaturated fatty acids. Bacteria are largely responsible for biohydrogenation of unsaturated fatty acids while the protozoa are of only very minor importance (Harfoot and Hazlewood, 1988). Diverse rumen bacteria have been isolated that have the capacity for biohydrogenation of the unsaturated fatty acids (Yokoyama and Davis, 1971; Kemp *et al.*, 1975). *Butyrivibrio fibrisolvens* was proved to be the major hydrogenating bacteria (Polan *et al.*, 1964; Kepler and Tove, 1967). Kemp and Lander (1984) divided the hydrogenating bacteria into two groups based on the reaction and end-products of biohydrogenation. Group A bacteria mostly hydrogenate linoleic acid to *trans*-11 octadecenoic acid while group B bacteria are capable of hydrogenating a wide range of octadecenoic acids, including *trans*-11 acids to stearic acid (Figure 1). The pathway involves an initial isomerisation step resulting in the formation of *cis*-9, *trans*-11 conjugated linoleic acid (*cis*-9, *trans*-11 CLA) which then undergoes hydrogenation of its *cis* double bond leaving *trans*-11 octadecenoic acid. Finally this is hydrogenated to stearic acid (Dawson and Kemp, 1970). The conversion of *trans*-11 $C_{18:1}$ to $C_{18:0}$ appears to involve a different group of organisms and occurs at a slower rate (Griinari *et al.*, 1997).

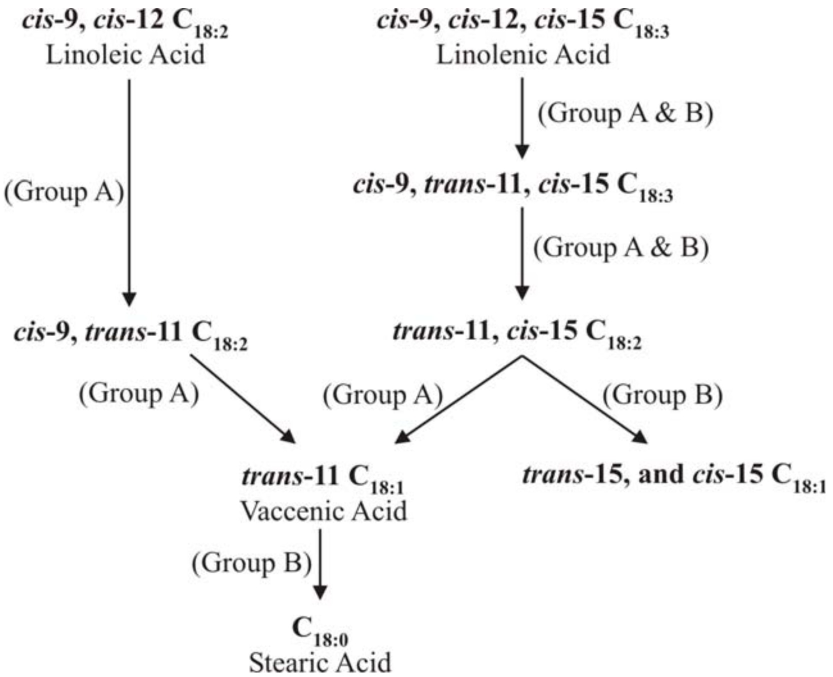

Figure 1. Biochemical pathways for the biohydrogenation of linoleic and linolenic acids in the rumen (Bauman *et al*., 2003).

3.11 Biosynthesis of conjugated linoleic acid (CLA) in the cow

Conjugated linoleic acid (CLA) is formed in the rumen as an intermediate product in the digestion of dietary fat. The *cis*-9, *trans*-11 $C_{18:2}$, is the major isomer of CLA which is formed from the first intermediate formed in the biohydrogenation of linoleic acid by the rumen bacteria and possibly from dietary $C_{18:3}$ (Bessa *et al*., 2000 and Wang *et al*., 2002). After formation in the rumen *cis*-9, *trans*-11 CLA may be directly absorbed or further biohydrogenated rapidly to *trans*-11 $C_{18:1}$ and following absorption (Pariza *et al*., 2001). The CLA in ruminant fat originates from two sources: from CLA that is absorbed and used directly and from *trans*-11 $C_{18:1}$, which is absorbed and used for the endogenous synthesis of CLA at the tissue level (i.e., mammary gland). The *cis*-9, *trans*-11 CLA found in bovine milk is actually synthesized within the mammary gland from *trans*-11$C_{18:1}$. This is possible through the action of stearoyl-CoA desaturase (SCD), an enzyme capable of adding a *cis*-9 double bond to *trans*-11 $C_{18:1}$ to give *cis*-9, *trans*-11 CLA (Figure 2). This appears to be a major pathway in the formation of *cis*-9, *trans*-11 CLA in cow’s milk (Griinari and Bauman, 1999). Although the *cis*-9, *trans*-11 is the predominant CLA isomer in bovine milk, other isomers can be formed with double bonds in positions 8/10, 10/12, or 11/13. Each of these double bonds can be in a *cis* or *trans* configuration, giving a range of possible CLA isomers (Song and Kennelly, 2002). The amount of CLA found in whole milk is generally about 4.5 to 5.5 mg/g fat (approximately 0.45 to 0.55%), although variation of as much as 2.5 to 18 mg/g fat has been reported. The CLA content in ruminant fat depends on the ruminal production of both CLA and *trans*-11 $C_{18:1}$ and the tissue activity of Δ^9-desaturase (Bauman *et al*., 1999). In addition, the breed, age of the dairy cow and stage of lactation may influence the milk CLA content (Song and Kennelly, 2002). However, the amount of CLA and *trans* 11 $C_{18:1}$ in rumen will be affected by dietary factors which provide lipid substrate for the production of CLA and *trans*-11 $C_{18:1}$ and alter the rumen environment. Dietary fat such as plant oil (sunflower, safflower soybean etc.) are high in linoleic acid and linolenic acid, resulting increased CLA and *trans*-11 $C_{18:1}$. Feeding high-concentrate, low-fibre diets is the cause of decreasing ruminal pH and is associated with a change in the *trans*-octadecenoic acid profile of milk fat (Griinari *et al*., 1998). Martin and Jenkins (2002) observed that ruminal pH influences biohydrogenation, as low pH decreases the biohydrogenation of *cis*-$C_{18:2}$ and *cis*-$C_{18:3}$ with a decrease of *trans*-$C_{18:1}$ and CLA. Therefore, in a low pH situation, *trans*-10 octadecenoic acid replaces *trans*-11 $C_{18:1}$ as the predominant *trans*-11 $C_{18:1}$ isomer in milk fat (Griinari *et al*., 1998). Therefore, to maximize CLA synthesis in the rumen the diet has to be formulated to maintain ruminal pH above 6.0 or nearly neutral (Martin and Jenkins, 2002; Troegeler *et al*., 2003). In paper II, the diet was supplemented with sunflower oil, which is high in linoleic acid and a substrate of CLA formation. The results were significantly higher CLA in milk fat, of two to three-fold, in the sunflower oil supplemented groups. Increasing sunflower oil in the diets from 2.5 to 5% significantly increased CLA in milk fat (5.2 vs. 7.3 mg/g fat). In addition, the ruminal pH of cows fed UTRS as a basal roughage ranged from 6.8 to 7.1, which was the optimum level to maximize CLA synthesis in the rumen, as discussed above.

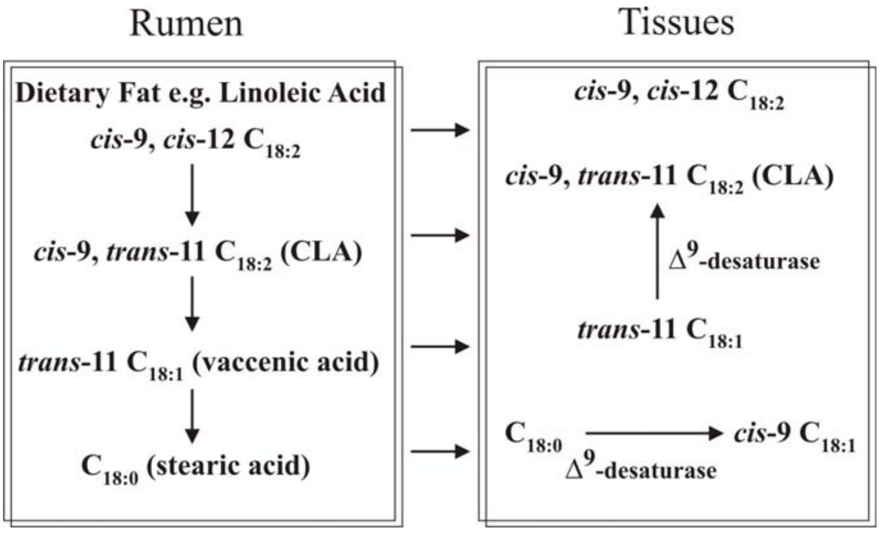

Figure 2. Role of rumen biohydrogenation and tissue Δ^9-desaturase in the production of *cis*-9, *trans*-11 CLA in ruminant fat (Bauman *et al*., 1999)

3.12 Health benefit of CLA

That CLA is produced in the rumen during the biohydrogenation process has been known for a long time. The unexpected effects of these fatty acids on health have only been discovered in more recent years. The *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA isomers are thought to be active as a potential health benefit (Lin *et al*., 1995; Park *et al*., 1999). CLA has been reported to have numerous potential impacts on health such as by reducing atherosclerosis (Lee *et al*., 1994), in diabetes treatment and in the modulation of the immune system (Houseknecht *et al*., 1998), and also has anticarcinogenic, and antiobesity properties (Chouinard *et al*., 2001; Song and Kennelly, 2002). Kang and Pariza (2000) reported that the effective level of CLA to give human health benefits for adults was 3.4 g/day. The difference in requirement depends on age, sex and physiology. CLA can be synthesized in the laboratory from vegetable oils like sunflower oil, but CLA produced in this way tends to contain a mixture of CLA isomers. Consumers could increase their CLA intake by taking synthetic CLA in pill form, which are already available in health food stores. However, CLA enriched in ruminants through the manipulation of ruminant diets has an advantage over synthetic CLA in that it can be promoted as a natural source of CLA, which is readily accepted by consumers.

4. Conclusions

Based on the results of this experiment, it can be concluded that:

- Harvest intervals of cassava foliage had no major effect on quality, but affected the quantity of foliage and root yield.
- Planting cassava for making cassava hay as a protein source for ruminants, especially for dairy cows, could be more profitable and increase income under small-holder farming systems.
- Cassava hay in the diet, especially for dairy cows, should be highly recommended as a protein source, as it could reduce dairy production costs and improve the efficiency of use of local feeds.
- Supplementing sunflower oil at 2.5-5% in dairy rations did not affect DMI, digestibility and milk composition, but these tended to decrease with increasing sunflower oil levels in the diets.
- Daily milk yield tended to be higher with supplementing cassava hay, but increasing sunflower oil from 2.5 to 5% in cassava hay based-diets tended to lower milk yield.
- CLA in milk fat were significantly increased with increasing sunflower oil levels in the diets.
- Sunflower oil can be used at 2.5% in cassava hay based-diets with the greatest improvements in income over feed, milk yield and composition.

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