Cassava foliage as a protein source for cattle in Vietnam

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Abstract

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The aim of the thesis was to evaluate biomass yield and chemical composition of cassava foliage as influenced by harvesting height and cutting interval (Paper I), the effect of different supplemental levels of dried, ensiled or fresh cassava foliage on rumen fluid parameters, thyroid gland hormones and liver enzymes of cattle fed urea treated fresh rice straw (Paper II to IV), and to determine the changes in live weight gain, thyroid hormones and liver enzymes of heifers supplemented by different levels of dried, ensiled or fresh cassava foliage (Paper V). The experiments were carried out at the experimental farm of Nong Lam University, Ho Chi Minh City, Vietnam, on fistulated cattle of local yellow breed (Paper II to IV), growing heifers of Sindhi breed (Paper V), and at the field crop station (Paper I).

In Paper I, harvesting height and cutting interval influenced the yield of cassava foliage and root tubers and to a lesser extent the nutritional quality of foliage. The highest dry matter foliage yield was 8 times higher at a harvesting height of 30 cm above the ground and 45 day cutting intervals, as compared to only one cut of the green foliage tops at the end of the season. The reverse was seen for tuber production on the same treatments, with only 28% of tuber yield at the highest foliage production.

In Paper II to IV, almost all of the cassava foliage was consumed. Mean values of ruminal pH ranged from 6.14 to 7.03. Average NH_3-N concentration ranged from 10.41 to 16.25 mg 100 g^{-1} of ruminal fluid, volatile fatty acids concentration ranged from 80.9 to 93.4 mmol L^{-1} of ruminal fluid, and both increased with higher amounts of cassava foliage in the rations. Serum triiodothyronine, thyroxin, free thyroxin, thyrotropin-stimulating hormone, alanine aminotransferase and aspartate aminotransferase concentrations were not significantly affected by ensiled cassava foliage and dried cassava foliage. When feeding fresh cassava foliage the triiodothyronine and thyroxin concentrations were lower, and alanine aminotransferase, aspartate aminotransferase and thyrotropin stimulating hormone concentrations were higher. Significant effects of fresh cassava foliage levels were found on triiodothyronine and thyroxin.

In Paper V, increasing supplemental levels of ensiled cassava foliage and pelleted cassava foliage increased live weight gain, while the gain was not significant for fresh cassava foliage. Ensiled cassava foliage and pelleted cassava foliage supplements increased the daily weight gain by approximately 50% at the lowest supplementary level of 50 g CP 100 kg^{-1} LWt day^{-1} and by 100% at the highest supplementary level of 100 g CP 100 kg^{-1} LWt day^{-1}. Thyroid hormones and liver enzymes did not differ among treatments with ensiled cassava foliage and pelleted cassava foliage. A significant effect of fresh cassava foliage levels was only found for triiodothyronine, while the levels of thyroxin, free thyroxin, thyrotropin-stimulating hormone, alanine aminotransferase, and aspartate aminotransferase were not significantly affected by fresh cassava foliage level. Results indicated that pelleted cassava foliage and ensiled cassava foliage could be safe protein supplemental sources for growing heifers without adverse effects on their performance.

Key words: Growing heifers, Cassava foliage, Harvesting height, Cutting interval, Rumen, Feed intake, Thyroid gland hormones, Liver enzymes.

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"M" is for the million things she gave me,
"O" means only that she's growing old,
"T" is for the tears she shed to save me,
"H" is for her heart of purest gold;
"E" is for her eyes, with love-light shining,
"R" means right, and right she'll always be,

Put them all together, they spell
"MOTHER,"
A word that means the world to me.

-- Howard Johnson (c. 1915)--

To Nguyen Thi Hau, my mother!

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Appendix

The thesis is based on the following studies, which will be referred to in the text by their Roman numerals:

I. Khang, D.N., Wiktorsson, H. & Preston, T.R. Yield and chemical composition of cassava foliage and tuber yield as affected by harvesting height and cutting interval (Submitted).

II. Khang, D.N. & Wiktorsson, H. 2000. Effects of cassava leaf meal on the rumen environment of local yellow cattle fed urea-treated paddy straw. *Asian-Australasian Journal of Animal Sciences.* 13 (8), 1102-1108.

III. Khang, D.N. & Wiktorsson, H. 2004. Effects of ensiled cassava tops on rumen environment parameters, thyroid gland hormones and liver enzymes of cows fed urea-treated fresh rice straw. *Asian-Australasian Journal of Animal Sciences.* 17 (7), 936-941.

IV. Khang, D.N. & Wiktorsson, H. 2004. Effects of fresh cassava tops on rumen environment parameters, thyroid gland hormones and liver enzymes of local yellow cattle fed urea-treated fresh rice straw. *Tropical Animal Health and Production* (in press).

V. Khang, D.N. & Wiktorsson, H. Performance of growing cattle fed urea treated fresh rice straw supplemented with fresh, ensiled or pelleted cassava foliage (Submitted).

List of abbreviations

ADF	Acid detergent fiber
ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
CLM	Cassava leaf meal
CP	Crude protein
CRM	Cassava root meal
DM	Dry matter
DMI	Dry matter intake
ECF	Ensiled cassava foliage
EE	Ether extract
FCF	Fresh cassava foliage
FCM	Fat corrected milk
FT_4	Free thyroxin
HCN	Hydrogen cyanide
LWt	Live weight
NDF	Neutral detergent fiber
NH_3-N	Ammonia nitrogen
PCF	Pelleted cassava foliage
T_3	Triiodothyronine
T_4	Thyroxin
TSH	Thyrotropin
UFRS	Urea-treated fresh rice straw
VFA	Volatile fatty acid

Introduction

Meat and milk production by cattle in Vietnam have increased over the last ten years (FAOSTAT data, 2004). Total beef production in 1993 was 75,000 tonnes from 516,000 head slaughtered. The number of cattle slaughtered in 2003 only increased to 590,000 head, with a total beef production of 107,902 tonnes. A substantial increase in milk production by dairy cattle was reported only a few years ago. Milk production was 64,703 tonnes in 2001 compared with 126,697 tonnes in 2003. Important factors for the improvement of productivity are supplementation of essential nutrients, an efficient breeding program for growth and milk yield, prevention of diseases and parasitism, husbandry and housing improvements, and more efficient extension system and computer networks (Haenlein & Abdellatif, 2004). Therefore, concentrates such as low-grade cereal grains and by-products of seeds and grains are often recommended as supplements, in order to utilize the potential for higher milk yield of the improved dairy cows in Vietnam (Vu et al., 1999; Sanh et al., 2002).

Preston & Leng (1987) showed that large improvements in ruminant productivity and efficiency of feed utilization from low quality forages can be achieved by small amounts of supplements that provide essential nutrients to the basal feed. In view of the predicted world shortage of cereal grains, because of increased needs for the expanding human population and the diminishing food producing capacity of the earth's surface (Brown & Kane, 1994), it is argued that a major priority is to develop livestock feeding systems, which do not depend on cereal grains (Preston & Leng, 1987). Progress has been made in the use of leaves from trees and shrubs such as leucaena (Masama et al., 1997), gliricidia (Merkel et al., 1999a, b; Hao & Ledin, 2001) and sesbania (Kaitho et al., 1998; Woldemeskel et al., 2001) particularly as feeds for sheep and goats. Considering this aspect, cassava foliage has high protein content and is recognized by many researchers in Asia as a potential feed supplement for cattle (Wanapat et al., 2000a; Man & Wiktorsson, 2001; Hong et al., 2003).

Cassava production in Vietnam has steadily increased during recent years, mainly because of increases in both area planted and yield per hectare. According to FAOSTAT data (2004), total tuber yield in 2000 was nearly 2 million tonnes grown on 237,600 ha. The area cultivated in 2003 was increased to 371,700 ha, with a total tuber yield of 5.2 million tonnes. The tuber yields in tonnes per hectare were 8.4 and 14.1 for 2000 and 2003, respectively. The most important use of cassava is as a starch source for humans with a production of 2 million tonnes compared with 0.3 million tonnes for animal feed (FAOSTAT data, 2004). Beside the root, there is a considerable amount of cassava foliage available, the amount of which varies due to several factors, such as variety, climatic conditions and time since planting (Gomez & Valdivieso, 1984; Simwambana et al. 1994). If the cassava foliage yield is 0.9 tonnes DM ha^{-1} (Gomez & Valdivieso, 1984) at root harvesting, cassava foliage production can amount to about 330,000 tonnes cassava hay per year in Vietnam.

Unlike the tubers that have a low protein content, cassava leaves are rich in protein, minerals and vitamins (Oomen & Grubben, 1978) and are regarded as a good protein source (Lancaster & Brooks, 1983). The dry matter of the green cassava foliage cut at root tuber harvesting contains up to 23% crude protein (Man & Wiktorsson, 2001, 2002). However, up to the present time, the potential of cassava foliage as a protein substitute in livestock feed is yet to be fully exploited, and in most instances, this valuable resource is returned directly to the soil as green manure. The reason for it not being used as a feed resource is its potential toxicity, which may affect animal health. Cassava foliage contains the cyanogenic glucosides, linamarin and lotaustralin. After tissue damage, these are hydrolyzed by the endogenous enzyme linamarase to cyanohydrins. Further hydrolysis to hydrogen cyanide is responsible for chronic toxicity. In cattle and sheep, hydrogen cyanide can be lethal at 2 to 4 mg HCN kg^{-1} body weight (Kumar, 1992). However, the hydrogen cyanide can be rapidly absorbed, eructated or further metabolized in the rumen (Majak & Cheng, 1984, 1987).

Sun drying or ensiling reduce cyanide content in cassava foliage to levels which are safer for animals (Ravindran et al., 1987; Man & Wiktorsson, 2001, 2002). However, in the rainy season it is difficult to sun-dry. Ensiling is an appropriate method during this period, but is less advantageous because it increases labour costs and the risks of unfavourable microbial processes during the time of ensiling and storing, which affect the palatability and nutrient content and may lead to the development of toxic substances (Man & Wiktorsson, 2002). Thus, feeding the fresh cassava foliage as a supplement to ruminants may be an attractive alternative.

The objectives of the studies were:

- to determine and evaluate the biomass yield of cassava foliage and tuber, and the chemical composition of cassava foliage as affected by harvesting heights and cutting intervals.
- to study the effect of different supplemental levels of dried, ensiled or fresh cassava foliage on rumen environment parameters, thyroid gland hormones and liver enzymes of cattle fed urea-treated fresh rice straw as basal diet.

- to determine the changes in live weight gain, thyroid gland hormones and liver enzymes of heifers when supplemented with different levels of dried, ensiled or fresh cassava foliage.

Summary of materials and methods

Location

All experiments were carried out at the experimental farm of Nong Lam University (NLU), Ho Chi Minh City, Vietnam. NLU is located at approximately 10.49'N latitude and 105.13'E longitude in an area with a tropical monsoon climate with two main seasons, rainy and dry. The area receives an annual precipitation of about 1938 mm, falling mainly from May to December, with peaks in June and November. The dry season starts in February and lasts through April. The monthly mean temperature ranges from 27 ^{0}C to 30 ^{0}C, with minima in December and February and maxima during the dry season. The mean relative humidity is 75%. Laboratory chemical analyses were mainly carried out at the NLU Animal Nutrition Department, and partly at the NLU Animal Physiology and Biochemistry Department and the Blood Analysis Department of Cho Ray Hospital, Ho Chi Minh City.

Experimental design

A 3 x 4 completely randomised split-plot design with four blocks was used for the field crop study on cassava foliage and tuber yields as affected by harvesting heights and cutting intervals (Paper I). The blocks were divided into three main plots representing harvesting heights of 10, 30, and 50 cm above the ground. The cutting intervals of 45, 60, 90, and 285 days were randomly split over the main plot (Mead et al., 1993). A 4 x 4 Latin square design was used for the three experiments presented in Paper II to IV on rumen environment parameters, thyroid gland hormones and liver enzymes of cattle fed urea-treated fresh rice straw and different levels of dried, ensiled or fresh cassava foliage. For the feeding experiment (Paper V), the layout was a randomised complete block design. Animals were stratified according to body weight and assigned to the treatments and feeding stalls by using random numbers.

Field crop study: land preparation, planting, data collection, and management

The field study was conducted from June 2002 to March 2003 on a soil with about 54% sand, 39% silt, 7% clay, 0.62% organic carbon, and a pH_{KCl} of 5.79 at 15 cm depth. The study was set up in a field of 3000 m^2, of which 2400 m^2 was used for planting and 600 m^2 was border areas to reduce interactions between treatments. The plots received basal fertilization with 80 kg ha^{-1} nitrogen (N), 40 kg ha^{-1} phosphorus (P_2O_5) and 120 kg ha^{-1} potassium (K_2O), of which half was applied at planting. The rest was split into two to four dressings applied after each successive foliage harvest.

Cassava, variety KM 94, was planted in early June 2002 and the final harvest was 285 days after planting. Planting stakes, 20 - 25 cm long, were planted on 50 cm x 30 cm plots, giving a population of 66,000 plants ha^{-1}. Cassava plants were established 105 days before the first cutting at 10, 30, and 50 cm above the ground. From then onwards the plots were harvested according to the plan at 45, 60 and 90 days until the final harvest 285 days after planting. Plants with 285 day cutting interval were not cut from planting until final harvest.

Cassava foliage was hand-harvested at cutting according to respective treatments. Cassava tubers from all treatments were harvested at the final harvest. All cassava foliage and tubers from each plot were weighed to determine the fresh yield. The fresh foliage was sampled for determination of the ratio of leaf, petiole and stem to total foliage, dry matter determination and chemical composition.

Animal nutrition study: animals, feeds, feeding, data collection, and management

Four female cattle of the local yellow breed (between 2 - 3 years of age and 230 - 330 kg live weight), each fitted with a permanent rumen cannula, were allocated randomly to four treatments in 4 x 4 Latin square design in Paper II to IV. Sixty-eight Sindhi growing heifers were used for the three experiments in Paper V. The heifers used were 1.5 - 2 years of age and weighed on average 120 - 210 kg (Experiment 1), 124 - 228 kg (Experiment 2), and 121 - 230 kg (Experiment 3). All the cows and heifers were penned and stall-fed individually in a barn with open walls. Clean and fresh water was available *ad libitum* during the whole experiment.

The fresh rice straw was collected in the field, directly after threshing and treated with 40 g urea per 1000 g DM of straw. The treated straw was then placed in 1 m diameter plastic bags in 2 layers up to 1 m in height. All the cassava root meal was bought on the market at one occasion. Napier grass was harvested at 42 days of growth. The fresh cassava foliage (KM 94) was harvested from the university farm at 50 days of re-growth cut at 30 cm above the ground. The cassava foliage (KM 94) for ensiling was collected at the same time from one field when harvesting the roots, slightly wilted and ensiled in plastic bags, according to the method described by Man & Wiktorsson (2001). The dried cassava foliage (KM 94) was ground and pelleted in a commercial feed mill. The pellets were 8 mm in diameter.

All cows and heifers were fed individually according to live weight and given a basal diet and different amounts and kinds of cassava foliages according to the experimental plans. The basal diets consisted of urea treated rice straw *ad libitum*, cassava root meal, and in the experiments in Paper V a constant amount of 0.72 kg DM 100 kg^{-1} LWt day^{-1} of Napier grass. In the experiments in Paper II and V, the heifers were supplied with 0.26 - 0.27 kg DM 100 kg^{-1} LWt day^{-1} of cassava root meal, while in Paper III and IV the cows received 0.33 kg DM 100 kg^{-1} LWt day^{-1} of cassava root meal. All animals were supplied with 20 g of a mixture of salt and minerals. The supplemental levels were 0, 50, 100 and 150 g CP 100 kg^{-1} LWt day^{-1} of cassava foliage in the experiments in Paper II to IV, while in the three experiments in Paper V the heifers received 0, 50, 75 and 100 g CP 100 kg^{-1} LWt day^{-1} of cassava foliage. In the experiments in Paper II to IV, the basal diets and supplements were supplied once daily at about 07:30 h. In the experiments in Paper V, the roughages were portioned and fed at 8:00, 10.00, 12:00, 14.00 and 16:00 h, while the cassava root meal and the foliage supplements were given at 7:00 h. The animals had access to feed and water throughout the day.

In Paper II to IV, each treatment period lasted 30 days. The first two weeks of each period were for adaptation of the animals to the new diets. Data on daily feed intake, feed samples for chemical analysis and ruminal fluids for rumen parameters were taken during the last two weeks of each period. In Paper V, each experiment period lasted 135 days. The heifers were weighed on two consecutive days at 15 day intervals. Data on daily feed intake were taken every day throughout the experimental periods. Feed samples for chemical composition analyses in the experiments of Paper V were taken before feeding on the last 3 days of each 15 day period. *In sacco* dry matter degradation of the different feeds in the experiments of Paper II and V was determined on 3 days of the last week of each experimental period. Blood samples were taken on the last day of each experimental period (Paper III and IV) and on the last day of the experiment (Paper V).

Chemical analysis

Dry matter (DM), ash, crude protein (CP), ether extract (EE) and HCN contents in feed samples were determined according to the procedures of the AOAC (1990). The contents of NDF and ADF were determined according to the procedure of Van Soest et al. (1991). Total condensed tannin was determined by the butanol-HCl method (Terrill et al., 1992).

In Paper II to IV, the ruminal pH was determined by pH meter immediately after collection of the ruminal fluid. Protozoan and bacterial populations were estimated by counting under light-microscopy, as described by Dehority (1993), Navas et al. (1993a, b), and Joux & LeBaron (1997). Concentration of ammonia nitrogen (NH_3-N) was determined by the standard Kjeldahl procedure (AOAC, 1990). Total VFA concentration was determined by gas liquid chromatography. Dry matter degradation of different feeds in Paper II and V was estimated by the *in sacco* method as described by Ørskov et al. (1980), Preston (1986) and Fonseca et al. (1998).

Blood serum samples for triiodothyronine (T_3), thyroxin (T_4), free thyroxin (FT_4) and thyrotropin-stimulating hormone (TSH) were determined by ELISA procedures using Diagnostic Automation kits Cat. No. 3144, 3149, 3146 and 3122, respectively (Diagnostic Automation Inc., Calabasas, California, USA); for alanine aminotransferase (ALT) and aspartate aminotransferase (AST) by Sigma diagnostic kits, Cat. No. ALSL-0500 and ASSL-0500 (SIGMA, St. Louis, Missouri, USA).

Statistical analysis

Data were statistically analyzed by using the General Linear Model Procedure of Minitab Statistical Software version 12.21 or 13.31. When the *F*-test was significant ($P<0.05$), Tukey's Tests for paired comparisons were used to compare means. In Paper I, the relationship between foliage yields or tuber yield, respectively, and cutting intervals were determined using the linear responses in the Fitted Line Plot procedure of Minitab 13.31.

Summary of results

The results of the experiments are presented under the following parts, namely: effects of harvesting height and cutting interval on cassava foliage and tuber yield; chemical composition of the feeds; dry matter intake of the feeds; effects of different cassava foliages on rumen fluid parameters; degradation of feeds; growth of heifers; influence of different cassava foliages on thyroid gland hormones and liver enzymes.

Effects of harvesting height and cutting interval on cassava foliage and tuber yield

In Paper I, the yield and quality of foliage (variety KM 94) increased with shorter cutting intervals. Harvesting at 10 cm above the ground and every 45 days provided the highest DM yield, and 30 cm harvesting height and 45 day cutting intervals resulted in the highest protein yield (Figure 1 and 2). Cassava foliage harvested 50 cm above the ground and every 90 days produced almost the same amount of tubers but 3 times the amount of foliage compared with only one harvest 285 days after planting.

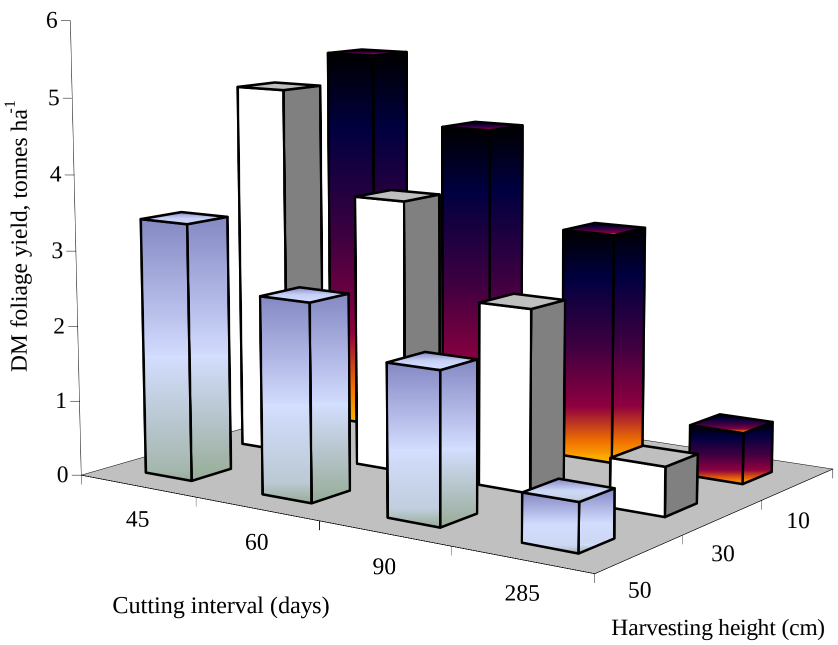

Figure 1. Harvesting height and cutting interval influence on the DM cassava foliage yield (Paper I)

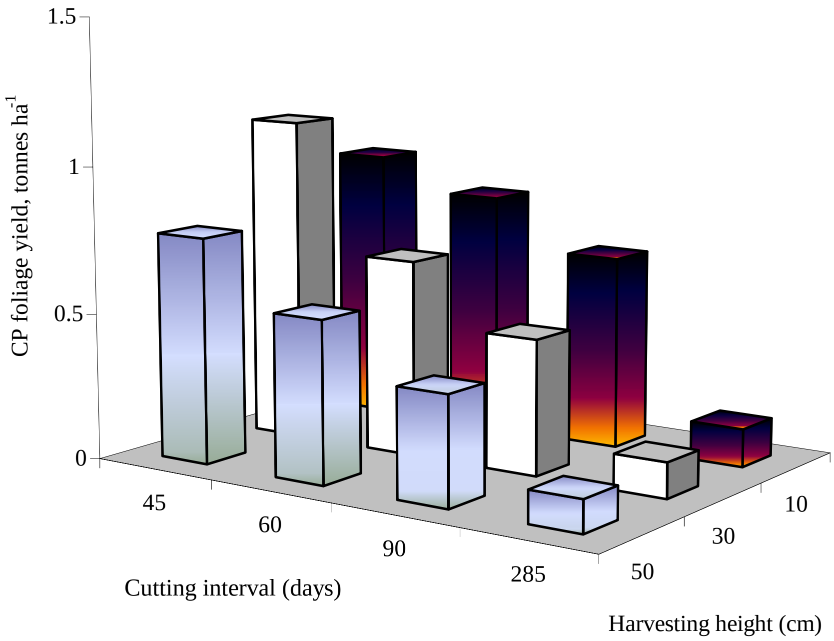

Figure 2. CP foliage yield increased with decreasing cutting interval from 285 to 45 days and harvesting height from 50 to 10 cm above the ground (Paper I)

Chemical composition of the feeds

The CP, NDF, ADF, tannin and HCN contents of cassava foliage varied with harvesting height and cutting interval (Paper I). Foliages harvested at the shortest cutting interval (45 days) had higher content of CP and HCN, but lower NDF and ADF content than longer cutting intervals. Similarly, the lowest harvesting height (10 cm from the ground) resulted in lower CP and HCN content, but higher NDF and ADF content, as compared to higher harvesting heights.

The chemical composition of cassava foliage used in Paper II to V in terms of crude protein, NDF and ADF contents varied from 20 to 23%, 26 to 51% and 19 to 37% of dry matter, respectively. The cassava leaves used in the study in Paper II, had higher CP content, but lower NDF and ADF content compared with the foliage which included petioles and stems (Paper III to V). The high dry matter content of ensiled cassava foliage (39%) was a result of wilting the fresh cassava foliage before ensiling (Paper III and V).

Sun drying and ensiling reduced cyanide and tannin contents in cassava foliage (Paper III and V). Cyanide content was reduced by 92% in pelleted cassava foliage (Paper V) and 78% in cassava foliage silage (Paper III and V) after drying and ensiling, respectively. Tannin content was reduced from 3.51% in fresh cassava foliage to 2.42% and 2.74% after drying and ensiling, respectively (Paper V).

The crude protein content in urea treated fresh rice straw used in Paper II to V ranged from 9.03 to 9.67% of dry matter. The dry matter of urea treated fresh rice straw ranged from 60.0 to 69.2%. The Napier grass had about the same CP content, almost 90 g kg^{-1} DM (Paper V).

Dry matter intake of the feeds

Intake of the offered amount of cassava foliage supplements varied. The cassava leaf meal was eaten to the extent of 88, 94 and 72%, respectively, of the supplement corresponding to 50, 100 and 150 g CP 100 kg^{-1} LWt day^{-1} (Paper II). The ensiled and fresh cassava foliage was consumed completely (Paper III and IV). In Paper V, the heifers normally consumed the pelleted cassava foliage in less than 10 minutes, even on the highest level of 100 g CP of the pelleted foliage 100 kg^{-1} LWt day^{-1}, while on the highest level of fresh and ensiled cassava foliage 80 and 94% of the offered amount were consumed, respectively. There were also slight refusals of 8 and 3% by heifers on the level of 75 g CP 100 kg^{-1} LWt day^{-1} of fresh and ensiled cassava foliage offered, respectively. Increasing the level of cassava foliage supplementation slightly decreased UFRS intake, but to a lesser extent than the added amount of cassava foliage. The highest total DMI were on the highest level of cassava foliage supplement.

The HCN intakes were 1.94, 1.72 and 1.15 g 100 kg^{-1} LWt day^{-1} for the treatments supplying 100, 75 and 50 g CP 100 kg^{-1} LWt day^{-1}, respectively, of fresh cassava foliage to the heifers (Paper V). Similarly, the HCN intakes were 3.85, 2.56 and 1.28 g 100 kg^{-1} LWt day^{-1} for treatments supplying 150, 100 and 50 g CP 100 kg^{-1} LWt day^{-1}, respectively, of fresh cassava foliage (Paper IV). The higher HCN intakes in the experiments in Paper IV were due to the higher intakes of fresh cassava foliage supplemented in the diets. The tannin intakes were 13.9, 12.3 and 8.3 g 100 kg^{-1} LWt day^{-1} on treatments supplying 100, 75 and 50 g CP 100 kg^{-1} LWt day^{-1}, respectively, of fresh cassava foliage (Paper V), while the tannin intakes were 23.4, 15.6 and 7.8 g 100 kg^{-1} LWt day^{-1} on the treatments supplying 150, 100 and 50 g CP 100 kg^{-1} LWt day^{-1}, respectively, of fresh cassava foliage (Paper IV).

Effects of different cassava foliages on ruminal fluid parameters and degradation of feeds

Mean values of ruminal pH in Paper II to IV ranged from 6.14 to 7.03. No significant effect on pH was observed with inclusion of different levels of cassava leaves (Paper II), while pH in the ruminal fluid was lowered on diets containing fresh or ensiled cassava foliage (Paper III and IV). Average NH_3-N concentration in the rumen in Paper II to IV ranged from 10.41 to 16.25 mg 100 g^{-1} of ruminal fluid. The NH_3-N concentration increased with higher amounts of cassava foliage in the rations. VFA concentration was increased with increasing levels of fresh or ensiled cassava foliage and ranged from 80.9 to 93.4 mmol L^{-1} of ruminal fluid (Paper III and IV). VFA concentration in the rumen fluid was not measured on diets including cassava leaf meal.

The protozoa population was not significantly changed when feeding cassava leaf meal (Paper I), while inclusion of fresh or ensiled cassava foliage reduced the number of protozoa (Paper II to IV). The number ranged from 0.49 to 1.14 x 10^6 ml^{-1}. Numbers of bacteria increased with increasing amounts of cassava foliage in the rations and ranged from 1.07 to 1.57 x 10^9 ml^{-1} (Paper II to IV).

In sacco degradation of the feeds was studied and reported in Paper II and V. The different types of cassava foliage showed great similarities in *in sacco* degradation. Mean values of dry matter degradation of cassava root meal, cassava leaf meal and urea treated rice straw were 85, 75 and 40%, respectively, after 24 hrs of incubation (Paper II), while dry matter degradation of cassava root meal, cassava foliage (fresh, ensiled or pelleted), Napier grass and urea treated fresh rice straw were 84, 66, 52 and 44%, respectively (Paper V).

Growth of heifers

The weight gain increased with increasing ensiled or pelleted cassava foliage level, while the differences in live weight gain on fresh foliage were small and not significant (Paper V). Ensiled and pelleted cassava foliage increased the daily weight gain by approximately 50% on the lowest supplementary level (50 g CP 100 kg^{-1} LWt day^{-1}) and by 100% on the highest supplementary level (100 g CP 100 kg^{-1} LWt day^{-1}) as compared with no cassava foliage supplement at all.

Influence of different cassava foliages on thyroid gland hormones and liver enzymes

Serum T_3, T_4, FT_4, TSH, ALT and AST concentrations were not significantly affected by ensiled and pelleted cassava foliage (Paper III and V). Significant effects of fresh cassava foliage levels were found on T_3 and T_4 (Paper IV) and T_3 (Paper V), while the levels of free T_4, TSH, ALT, and AST were constant (Paper IV). When feeding fresh cassava foliage the T_3 and T_4 concentrations were lower and ALT, AST and TSH concentrations were higher (Paper IV and V). Mean values of blood serum concentrations ranged from 0.56 to 1.36 ng ml^{-1} for T3, 42.43 to 60.93 ng ml^{-1} for T_4, 9.78 to 12.58 ng ml^{-1} for FT_4, 0.16 to 0.37 µUI ml^{-1} for TSH, 19.43 to 31.53 units L^{-1} for ALT and 35.08 to 50.63 units L^{-1} for AST (Paper III to V).

General discussion

Planting and cutting of cassava foliage as feed for cattle

The most common cassava production systems in Vietnam today aim at optimising the root tuber yield harvested after a growing period of almost one year, with the foliage being left in the field. The plant population density is generally about 10,000 ha^{-1}. With increasing demand for high quality feeds for cattle there is a growing interest to also utilize the cassava foliage as a protein supplement, which may revise the present cassava production system into a dual-purpose crop.

The effect of plant population density on cassava forage production was investigated by Meyrelles et al. (1977a) in the Dominican Republic. In their study, the foliage was harvested once 3 to 5 months after planting, and the tops were harvested at an average height of 40 cm above the ground. The results showed that the dry matter foliage yield was higher with increasing plant population density. The cassava foliage yield was 3.8, 5.7 and 10.9 tonnes DM ha^{-1} for plant population densities of 10,000, 15,000 and 53,000 ha^{-1}, respectively. The dry matter foliage yield at the highest plant population density was considerably higher than the yield from any of the treatments with different harvesting heights and cutting frequencies presented in Paper I. The highest yield in that study was 5.3 tonnes DM ha^{-1} at a plant population density of 66,000 ha^{-1} and 10 cm harvesting height over the five harvests during a total growing period of 285 days with the first harvest 105 days after planting and subsequent harvests at 45 day cutting interval. When cassava foliage was harvested only as a by-product at tuber harvesting 285 days after planting, the yield amounted to 0.64 tonnes DM ha^{-1} (Paper I). This amount is similar to that reported by Gomez & Valdivieso (1984) after a 9 months growing period (Figure 3). However, they found a considerable increase in foliage yield after only two months additional growing period. They ascribed the high growth rate to increasing rainfall during that period, but the response was different between the two varieties included in the study (Figure 3). Thus these results show that the potential yields of cassava foliage at root tuber harvesting can be affected by the variety and plant age, as well as climatic and environmental factors such as dry periods or rains. Furthermore, differences in DM foliage yield could be due to the differences in soils and fertilization (Molina & El-Sharkawy, 1995), age at first cutting and interval between cuttings (Lockard et al., 1985; Simwambana et al., 1992; Tung et al., 2001; Hong et al., 2003).

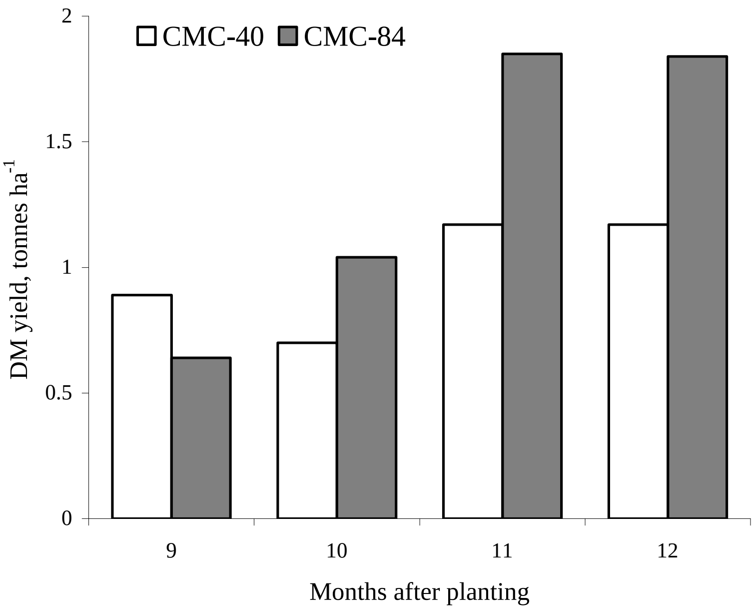

Figure 3. Cassava foliage yield affected by variety and plant age at root harvesting (Source: Gomez & Valdivieso, 1984)

Recent research in Malaysia (Tung et al., 2001) showed that dry foliage yields of MM 92, Black Twig and Local cut at 45 day cutting intervals and with about 15 cm harvesting height over the 5 harvests were 5.9, 5.7 and 4.3 tonnes ha^{-1}, respectively. Hong et al. (2003), investigating the foliage yield of the cassava variety KM 60, cut at 1 and 2 month intervals and 10 cm harvesting height, reported dry matter yields of 6.5 and 7.9 tonnes ha^{-1}, respectively.

In Malaysia, Ahmad (1973) demonstrated that not only the foliage yield was different between varieties but also the tuber yield was affected. In this study the foliage was first cut three months after planting, with subsequent foliage cutting at six week intervals. The fresh foliage harvests yielded an average of 21.8 and 34.2 tonnes ha^{-1} per year for the varieties Medan and Black Twig, respectively. The mean fresh tuber yields, with leaf harvests, were 20.1 tonnes ha^{-1} for Medan and 28.1 tonnes ha^{-1} for Black Twig, while fresh tuber yields with no cutting were 38.5 tonnes ha^{-1} for Medan and 51.2 tonnes ha^{-1} for Black Twig. The mean fresh tuber yield decreased by 48 and 45%, respectively, for Medan and Black Twig when the foliage was harvested at 42 day cutting interval. In Paper I, the mean fresh tuber yield decreased by 56, 45 and 27% when the foliage was harvested at 45, 60 and 90 day cutting intervals, respectively, as compared with the tuber yield at harvest 285 days after planting (variety KM 94). These results lead to the conclusion that harvesting at between 10 and 30 cm above the ground and every 45 days provided a good cutting option for harvesting cassava foliage as ruminant feed, while harvesting at 50 cm above the ground and 90 day cutting intervals produced almost the same amount of tubers but 3 times the amount of foliage compared with conventional harvesting. The optimum combination of different cutting options will depend on the relative value of foliage and tubers.

The crude protein content of cassava foliage ranged from 17.7 to 22.6% on DM basis when harvested at an early stage of growth (45 to 105 days) with different harvesting heights and cutting intervals. Cassava foliage harvested at 45 day cutting intervals and 50 cm harvesting height from the ground contained up to 22.6% crude protein (Paper I). Hong et al (2003) reported similar figures, with crude protein content varying between 20.8 and 28.7% in cassava foliage harvested at one and two month cutting intervals. Other authors have reported crude protein contents of cassava foliage collected at root harvesting of 22.5% (Paper II), 18.8% (Man & Wiktorsson, 2001), 21.1% (Man & Wiktorsson, 2002), and 20.0% (Paper III).

Estimated protein yield ranged from 0.37 to 1.11 tonnes ha^{-1}, and increased with increasing cutting frequency from three to five cuts at 90 day and 45 day intervals, respectively, during the growing period of 285 days (Figure 2, Paper I). This was lower than the values of 1.2 to 1.6 tonnes ha^{-1} with three to six cuts (Hong et al., 2003), and from 1 to 1.5 tonnes ha^{-1} with five cuts at 45 day interval for three cassava varieties reported by Tung et al. (2001). These studies showed that the protein yield was high and could be available all the year around if cassava is planted and harvested frequently as forage for cattle.

When cassava foliage was cut at root harvesting, protein yield amounted to 122 kg ha^{-1} (Paper I). Assuming that the foliage at root harvesting from the total cultivated area for cassava root production in Vietnam (371,700 ha in 2003; FAOSTAT data, 2004) was used as feed for cattle, the protein quantity would amount to 45,000 tonnes.

Influence of cassava foliage on ruminal fluid parameters, thyroid gland hormones and liver enzymes

The results presented in Paper II, III and IV show that level and type of cassava foliage influenced microbial populations in the rumen. The bacterial population increased with increasing supplemental levels of fresh, ensiled and dried cassava foliages in the diet, while the protozoal population in the rumen decreased with increasing supplemental level of ensiled and fresh cassava foliages but increased on the dried cassava foliage diets. Meyrelles et al. (1977b) found that inclusion of fresh cassava foliage in the diet had different effects on the protozoa, depending on the NH_3-N level in the rumen and whether urea was added to the diet or not. In cattle on a sugar cane basal diet and with a low rumen ammonia level (6 - 7 mg 100 ml^{-1} rumen fluid) protozoal biomass increased with increasing fresh cassava foliage levels in the diet. The means of the rumen protozoa biomass were 0.10, 0.38, 0.57, and 0.64% of the packed cell volume in the rumen, respectively, for the substitution of chopped whole sugar cane with 0, 15, 30, and 45% fresh cassava foliage in the diets. In another experiment, where animals were offered 20 and 40% fresh cassava foliage as a replacement for chopped whole sugar cane, the means of rumen protozoa biomass were 0.20 and 0.15% of the packed cell volume in the rumen, and the mean ruminal NH_3-N concentrations were 19.4 and 15.3 mg 100 ml^{-1} rumen fluid, respectively. When 80 - 100 g urea day^{-1} was added to the diets, the NH_3-N concentration was 20.1 mg 100 ml^{-1} rumen fluid and protozoa biomass 0.23% as compared with 9.6 mg 100 ml^{-1} rumen fluid of NH_3-N and 0.12% protozoa biomass without urea in the diets. The results showed that rumen protozoa biomass decreased in the diets supplemented at the higher level of fresh cassava foliage, but increased in urea supplemented diets. This was similar to the results of Kanjanapruthipong & Leng (1998), who found that when the concentration of ruminal fluid ammonia increased from 6 to 18 mg%, the protozoal population increased. At about 20 mg% of ruminal fluid ammonia the protozoal growth decreased again, while the bacterial growth increased.

In the above reported studies by Meyrelles et al. (1977b), the ruminal pH value was high and not affected by cassava foliage, while the ruminal NH_3-N concentration increased with increasing fresh cassava foliage level in the diet, and was higher three hours after feeding (Figure 4). Ruminal NH_3-N concentration was 25.1 mg 100 ml^{-1} rumen fluid in the urea supplemented diet, which was considerably higher than the 9.6 mg 100 ml^{-1} rumen fluid in the diet without urea supplementation, and tended to increase with time after feeding. The results showed that supplementation of urea and cassava foliage increased the fermentable nitrogen in the rumen.

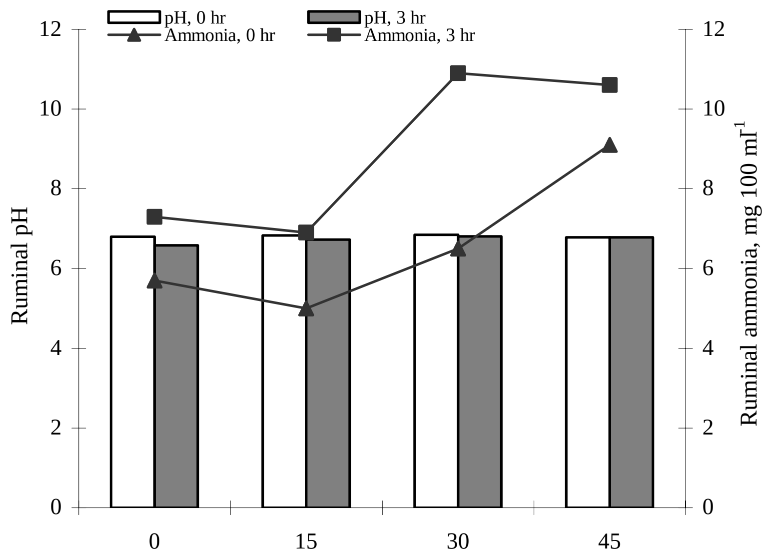

Figure 4. pH and NH_3-N concentration at feeding and three hours after feeding with increasing fresh cassava foliage levels in the diet (Source: Meyrelles et al., 1977b)

The same was observed for the ruminal pH and NH_3-N concentrations (Wanapat et al., 2000a) when concentrate was replaced by cassava hay in urea treated rice straw diets for dairy cows (Figure 5). Ruminal pH and NH_3-N concentrations were lowest in the diet where cassava hay was fed *ad libitum* and supplemented with cassava chips including 3% urea at 2 kg DM per day. It has long been recognized that ruminants fed concentrate diets have a lower ruminal pH than those fed forages (Slyter, 1976; Lana et al., 1998, Hussain & Cheeke, 1995). Low pH can also be caused by an accumulation of VFA in the rumen (Burrin & Britton, 1986; Sahoo et al., 1999; Paper III and IV), high diet intake and highly rumen degradable protein (Doreau et al., 2004). The ruminal NH_3-N concentration (Paper II to IV) had a good profile, with values between a minimum of 2 mg 100 ml^{-1} (Satter & Slyter, 1974) and a maximum of 30 mg 100 ml^{-1} (Srinivas & Gupta, 1997) suggested for maximum microbial growth in rumen. Krebs & Leng (1984) suggested that a ruminal NH_3-N concentration of above 20 mg 100 ml^{-1} is required for sufficient voluntary intake of low quality roughage.

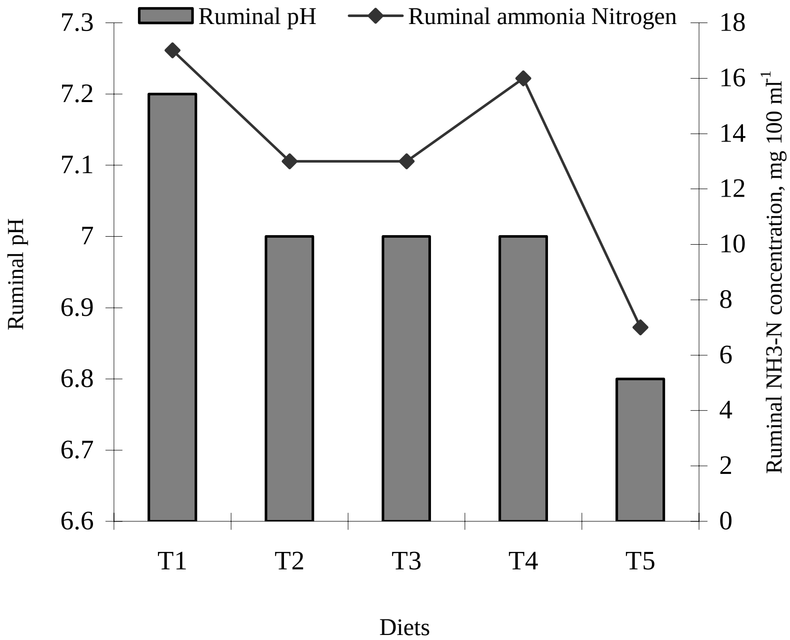

Figure 5. Effects of cassava hay supplement levels on ruminal pH and NH_3-N concentration in lactating cows fed urea treated rice straw (UTRS, 5% urea) (T1= UTRS + Concentrate; T2= UTRS + Concentrate + Cassava hay at 0.56 kg DM cow^{-1} day^{-1}; T3= UTRS + Concentrate + Cassava hay at 1.13 kg DM cow^{-1} day^{-1}; T4= UTRS + Concentrate + Cassava hay at 1.70 kg DM cow^{-1} day^{-1}; T5= Cassava hay *ad lib*. + Cassava (cassava chip + 3% urea) at 2 kg DM day^{-1}. See also Table 2 (Source: Wanapat et al., 2000a)

Increasing levels of cassava foliage supplementation in the diets for cattle increased the ruminal cyanide concentration (Paper III and IV) and had different effects on thyroid hormones and liver enzymes (Paper III, IV and V). The cyanide concentration in the rumen was highest in the diets supplemented with fresh cassava foliage (Paper IV) compared with ensiled cassava foliage (Paper III). The total cyanide concentration determined in the rumen was the sum of free cyanide and cyanide which is released from cyanogenic compounds degraded by rumen microbial enzymes (Majak & Cheng, 1984). The level of free cyanide is affected by diet, feeding time and rumen pH (Majak et al., 1990). The ruminal cyanide concentrations in the present studies increased rapidly after the morning feeding and peaked at two h after feeding. However, at eight h after feeding, the ruminal cyanide concentrations were close to zero (Figure 6), because the cyanide was rapidly absorbed, eructated or further metabolized in the rumen contents (Majak, 1992). Knowles (1976) found that a type of bacteria in the rumen could detoxify cyanide by its rhodanase enzyme. Cyanide concentration is reduced by continued hydrolysis by microbiota of the digestive tract (Majak & Cheng, 1984). Cyanide absorbed from the gut is rapidly trapped in the erythrocytes (Lundquist et al., 1985) and later converted to the less toxic thiocyanate in the liver and excreted in the urine (Barrett et al., 1978; Gutzwiller, 1996; Bibi & Bachmann, 1997). Thiocyanate is less toxic than cyanide, but interferes with the iodine accumulation of the thyroid gland as competitive inhibitors for iodine intake and hormone synthesis (Wemheuer, 1993). The lower concentration of serum T_3 and T_4 hormones of animals on the diets supplemented with fresh cassava foliage (Paper IV and V) was the likely result of thiocyanate that inhibited the incorporation of iodine into precursors of thyroxin and also inhibited iodine uptake by the thyroid gland (Cliff et al., 1985; 1986). Although there was a significant reduction in serum T_3 and T_4 concentrations (Figure 7) at the highest supplementation level of fresh cassava foliage (Paper IV and V), the results showed that thyroid hormones (Paper III, IV and V) were within the normal physiological range (Tveit & Larsen, 1983; Singh & Goel, 1986; Tyagi & Singhal, 1993; O'Kelly & Spiers, 1994; Anderson et al., 2000).

There is no information available on thyroidal response to cassava products but almost all of the triiodothyronine reduction or thyroid hormone changes in blood depend on the production and turnover of thyroid hormone, which occurs in the liver and kidney by conversion of T_4 to T_3. About 80% of T_3 results from conversion from T_4 by monodeiodination either in the 5' or 5 positions to form either T_3 or reverse T_3. The remaining 20% of T_3 production comes from direct secretion by the thyroid gland (Griffin & Ojeda, 2000). Therefore, T_4 reduction with increasing levels of fresh cassava foliage supplementation (Paper IV and V) is the likely reason for the lower levels of T_3.

The concentrations of the enzymes ALT and AST (Paper III, IV and V) were within normal physiological ranges (Bide et al., 1983; Marai et al., 1999; Mohamed et al., 2003). The results indicated that no damage to liver had occurred as increases in activities have been reported to be associated with hepatic necrosis and other disease conditions related to histopathological changes (Benjamin, 1978).

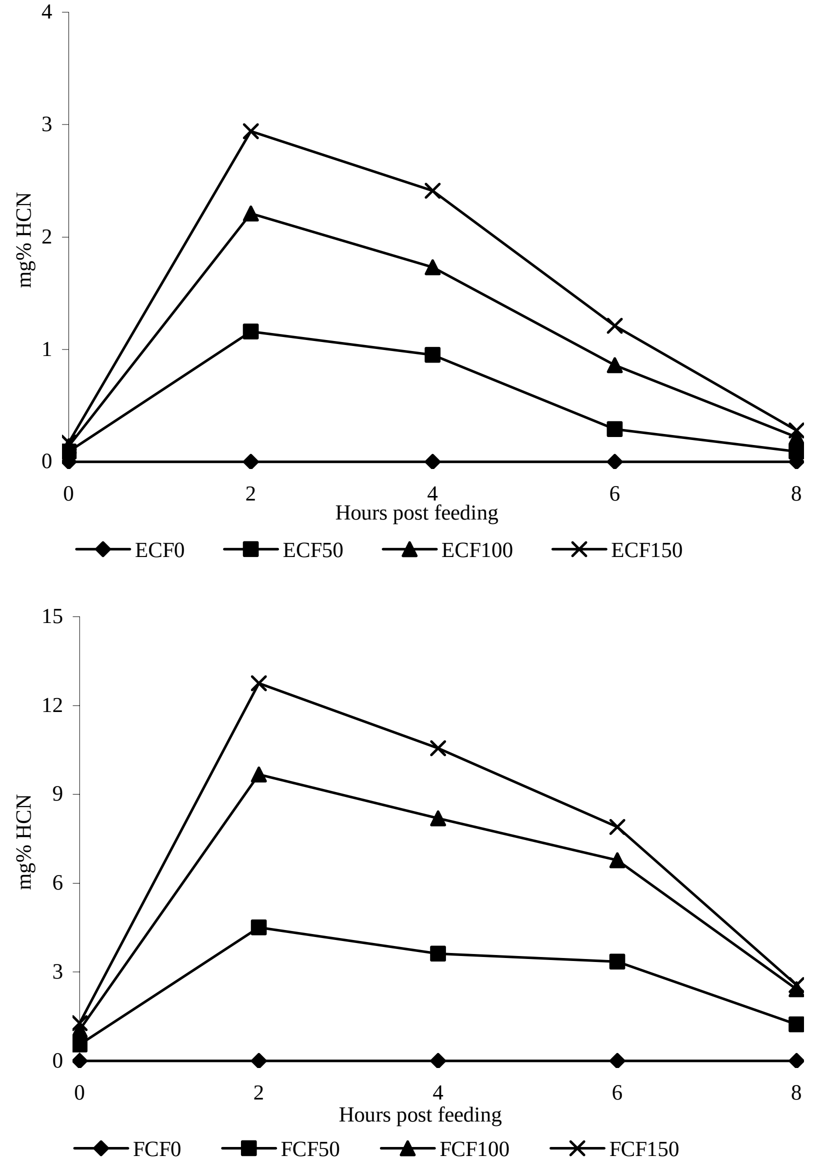

Figure 6. Responses of cyanide concentrations in rumen fluid of animals supplemented different levels (0; 50; 100 and 150 g CP 100 kg^{-1} LWt day^{-1}) of ensiled (ECF) or fresh (FCF) cassava foliage in diets based on urea treated fresh rice straw (Paper III and IV)

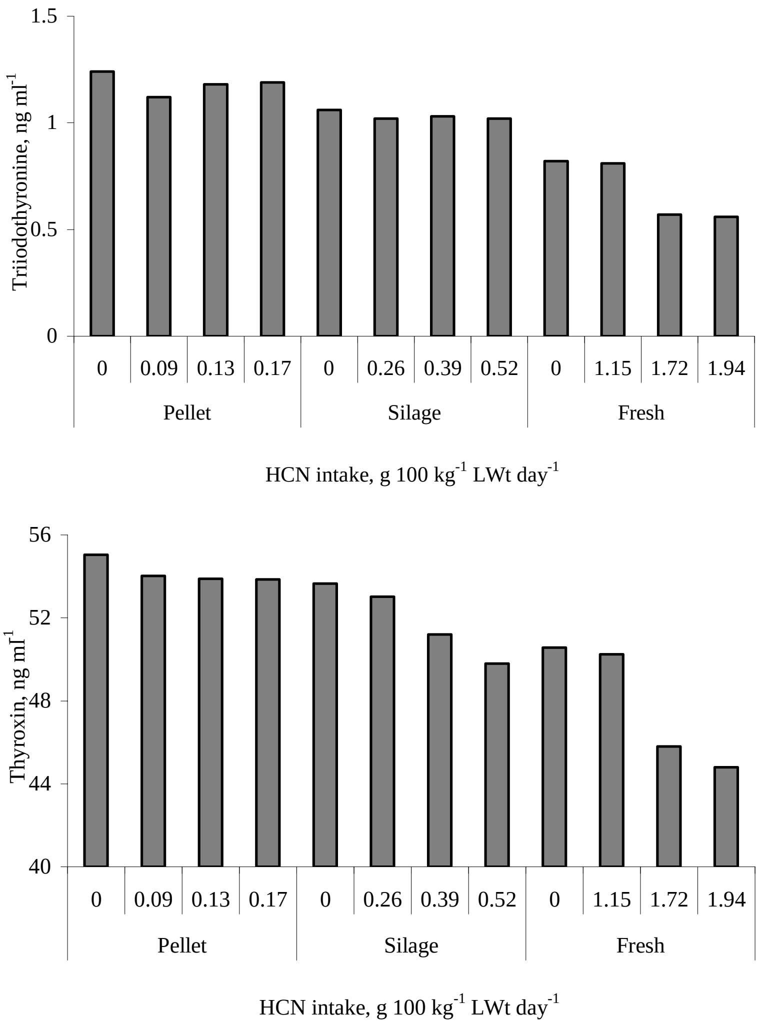

Figure 7. Serum triiodothyronine and thyroxin concentrations in growing heifers on diets containing different levels of HCN from pelleted, ensiled or fresh cassava foliage (Paper V)

Cassava foliage as a combined source of protein and roughage for cattle production

According to Leng (1997), rates of growth and milk production by ruminants grazing tropical pastures alone or fed poor quality tropical foliages, crop residues and agroindustrial by-products are only about 10% of the animal's genetic potential. The reasons for this low productivity are low feed intake due to poor nutrition and without supplements, resulting in low digestibility, prolonged rumen retention time, bulkiness and low palatability (Aitchison et al., 1986). Therefore, cattle require additional protein and energy to maintain an efficient rumen ecosystem that will stimulate nutrient intake and improve animal performance (Preston & Leng, 1987). Several reports have shown that protein supplementation of low quality roughages improved the utilization of feeds (Hussain et al., 1996). Supplementing cassava foliage to a low-quality roughage diet could possibly increase the ratio of protein to energy, and hence increase productivity in ruminants (Devendra, 1977; Wanapat, 2003).

Sitorus et al. (1986) showed that fresh cassava leaves could be used as the sole source of protein for supplementing a diet based on rice straw for Ongole bulls. Growth rates were 250 g day^{-1} and were not improved when 9 kg day^{-1} of additional fresh cassava leaves was given compared with the diets supplemented with 6 kg of fresh cassava leaves or 1.8 kg soy sauce waste. The better performance of the cattle given a supplement containing 2.7 kg soy sauce waste might have been associated with a greater supply of by-pass protein (Figure 8). Ffoulkes & Preston (1978) conducted an experiment to evaluate sweet potato forage as an alternative to fresh cassava foliage in molasses based fattening diets for Zebu bulls. The results showed that growth rates were over 800 g day^{-1} and fresh cassava foliage was better than sweet potato in the diets without supplementary soybean protein, but the opposite effect was observed in the presence of soybean meal. When 400 g day^{-1} of additional soybean meal was given, the sweet potato forage had a better feed conversion compared with the fresh cassava foliage.

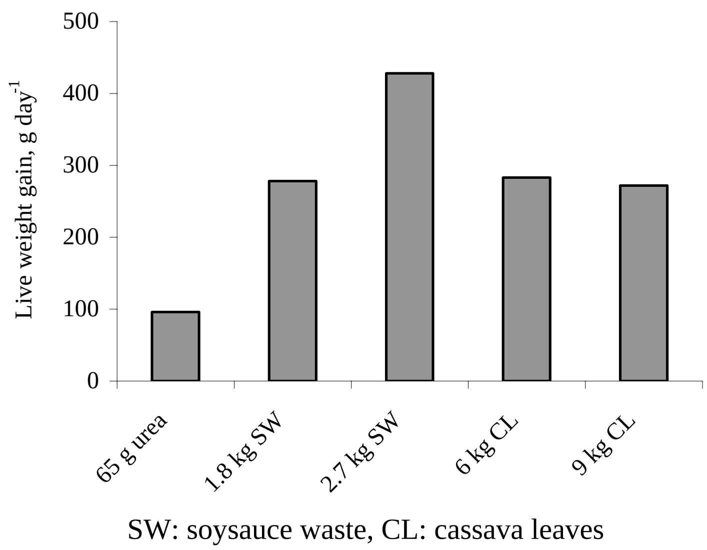

Figure 8: Growth of cattle consuming a basal diet of rice straw with supplements of urea, cassava leaves and soysauce waste as nitrogen (N) sources (Source: Sitorus et al., 1986)

In Paper V, it was demonstrated that the growth rate of Sindhi heifers fed urea treated fresh rice straw as basal diet and limited amounts of Napier grass increased with increasing amounts of supplementary protein from different kinds of cassava foliage (Figure 9). Animal responses to the fresh cassava foliage as a protein roughage supplement were positive but low, partly due to low palatability, which also was stressed by Hahn (1988). Higher and better responses were obtained when ensiled, and particularly pelleted cassava foliage was used as a protein supplement. This was probably due to the high hydrogen cyanide toxicity in fresh cassava foliage supplemented diets that contributed to the poor response in animals fed low quality roughages (Meyrelles et al., 1977b; Paper V). The utilization of fresh cassava foliage as a protein roughage supplement in basal diets affected both the growth and reproductive phases of development (Tewe, 1992). However, no evidence was provided to implicate HCN toxicity in the reproductive phase in ruminants in Paper V. In the study with growing heifers weighing 170 kg (Paper V), the live weight gain was 160 g and 159 g day^{-1}, respectively, for supplement levels of 100 and 75 g CP 100 kg^{-1} LWt day^{-1} of fresh cassava foliage in diets based on urea treated fresh rice straw and small amounts of Napier grass. Contrary to heifers fed ensiled or pelleted cassava foliages, growth rates were not improved with increasing supplement level of fresh cassava foliage (Figure 9) and were lower than in other studies. For example, Sindhi heifers with average weights of 275 kg had an average daily weight gain of 285 g day^{-1} on diets based on pasture (Thuong & Pryor, 1996). Therefore a growth rate of 160 g day^{-1} of Sindhi heifers of about 170 kg live weight supplemented with fresh cassava foliage is not satisfactory. Contributing factors for low live weight gain might be low digestibility and palatability (Aitchison et al., 1986). The daily intake of the fresh cassava foliage was only 80% of the offered amount.

Fresh cassava foliage was converted into silage with the aim of reducing the risks of HCN toxicity when used as a supplementary source of protein for Zebu calves (Moore & Cock, 1985). The daily gain, feed efficiency and protein utilization were not improved for animals fed only ensiled cassava foliage (Table 1). The addition of dried cassava chips as an energy source to an ensiled cassava foliage diet improved growth rate by 59% and feed efficiency by 34% compared with a diet containing only ensiled cassava foliage, while the addition of cottonseed meal to the diet did not further improve animal performance. The authors suggested that energy was more limiting than protein in the diet with only ensiled cassava foliage.

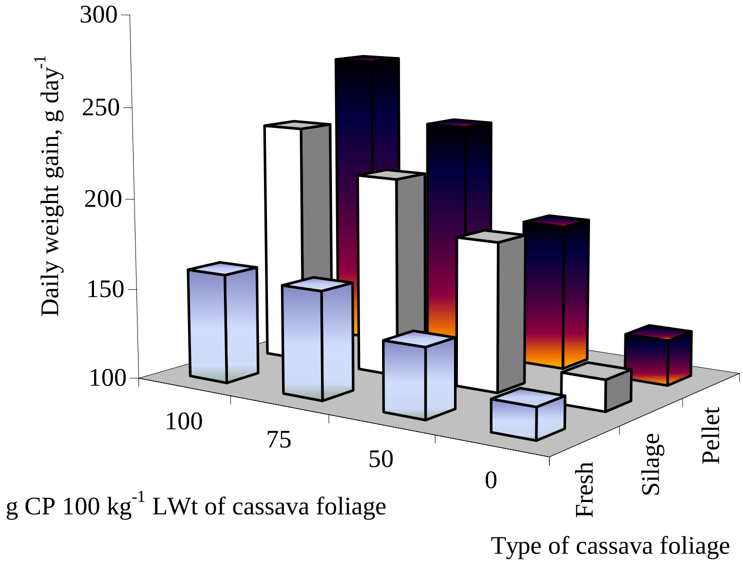

Figure 9. Response of daily weight gain of growing Sindhi heifers to different levels of fresh, ensiled or pelleted cassava foliage as a protein supplement to urea treated fresh rice straw diets (Paper V)

Table 1. Performance of zebu calves given ensiled cassava foliage *ad libitum* as basal diet (ECF), with addition of dried cassava chips (DCC) and further addition of cottonseed meal (CSM)

Parameter	Diet		
	ECF	ECF + 0.5 kg of DCC	ECF + 0.5 kg of DCC + 0.25 kg of CSM
Daily gain (g)	254.0	405.0	472.0
Feed efficiency (kg feed/kg gain)	7.89	5.87	5.27
Protein utilization (kg crude protein/kg gain)	1.79	1.18	1.17

Source: Moore & Cock (1985)

Recent studies have focussed on cassava foliage as a feed for dairy cows. In Cuba, it was suggested that the whole cassava plant could be used for dairy cows as a supplement to pasture (Garcia et al., 1994; Garcia & Herrera, 1998), and in Thailand, cassava hay was used as a partial replacement for concentrates to dairy cows (Wanapat et al., 2000a, b, c; Hong et al., 2003; Kiyothong & Wanapat, 2004). These studies were designed to evaluate animal responses with regards to milk yield and milk composition to cassava foliage feed as a supplementary source of protein and roughage, and are summarized in Table 2.

Studies on preservation and processing technologies for improved utilization of cassava foliage as a protein supplement together with other feedstuffs for dairy cattle feeding have been conducted. The cassava tops were directly sun-dried or chopped before sun-drying to obtain a dry matter content of 80 - 90%. Chopping into 3 - 4 cm lengths shortened the drying process. Sun-drying enhanced the palatability and increased the storage time. Drying the cassava tops also reduced the HCN content by more than 90% (Ravindran et al., 1987; Paper V). Commercially, dried cassava foliage is ground and pelleted together with other feed ingredients to form concentrates in feed mill. Ensiling of cassava tops as feed for cattle was recently introduced as an alternative preservation method. Ensiling preserves the nutritional value, reduces HCN content by 80 to 90% and improves long-term storage (Man & Wiktorsson, 2001; Paper III and V). Feed intake and digestibility studies in cattle demonstrated that cassava silage was palatable (Man & Wiktorsson, 2001).

Table 2. Summary of studies on cassava foliage as a supplementary source of protein and roughage for dairy cows

Basal diets and number of cows	Cassava foliage supplementation cow^{-1} day^{-1}	Responses	References
Grass (Cynodon dactylon, 7.5% CP). Twenty four Cuban Holstein. Two groups	• T_1 = No cassava supplementation • T_2 = Whole cassava plant (14.4% CP) supplementation at 15 kg	• Milk yield of 6.4 and 9.7 kg day^{-1} • Milk fat of 3.6 and 3.5%	Garcia & Herrera, 1998
Urea treated rice straw (7.6% CP) + Concentrate (17.7% CP). Concentrate: Milk according to dietary treatments and milk yield at: T_1 and T_2 = 1:2; T_3 = 1:3; T_4 = 1:4 and T_5 = No concentrate, cassava hay *ad libitum* + 2 kg Cassava chip (including 3% urea). Thirty HF crossbred cows, randomised block	• T_1 = No cassava • T_2 = Cassava hay (23.6% CP) at 0.56 kg DM • T_3 = Cassava hay at 1.13 kg DM • T_4 = Cassava hay at 1.70 kg DM • T_5 = Cassava hay at 5.20 kg DM	• 3.5% FCM of 6.8, 6.2, 6.0, 7.1 and 6.4 kg day^{-1} • Milk fat of 4.0, 3.6, 4.2, 4.5 and 4.6% • Milk total solids of 12.6, 12.3, 12.0, 12.2 and 12.6%	Wanapat et al., 2000a
Urea treated rice straw (8.2% CP) + dry Ruzi grass (7.2% CP) + Concentrate (17% CP). Concentrate: Milk according to dietary treatments and milk yield at: T_1 = 1:2; T_2 = 1:3 and T_3 = 1:4. Six HF crossbred cows, change over design	• T_1 = No cassava • T_2 = Cassava hay (24.5% CP) at 1 kg DM • T_3 = Cassava hay at 1.7 kg DM	• 3.5% FCM of 12.7, 12.5 and 12.6 kg day^{-1} • Milk fat of 4.61, 4.98 and 4.80% • Milk total solids of 13.4, 13.5 and 13.5%	Wanapat et al., 2000b

Urea treated rice straw (8.6% CP) + 30 kg of Napier grass (11.7% CP) + Concentrate (16.0% CP). Concentrate: Milk according to dietary treatments and milk yield at: T_1 = 1:2; T_2 = 1:2; T_3 = 1:3; T_4 = 1:2 and T_5 = 1:3. Five HF cows. Latin square	• T_1 = No cassava • T_2 = Cassava hay (24.2% CP) at 1 kg DM • T_3 = Cassava hay at 1 kg DM • T_4 = Cassava hay at 2 kg DM • T_5 = Cassava hay at 2 kg DM	• 3.5% FCM of 7.8, 9.5, 8.8, 9.1 and 8.9 kg day^{-1} • Milk fat of 4.3, 4.9, 4.9, 5.0 and 4.9% • Milk total solids of 12.7, 13.5, 13.8, 13.6 and 13.9%	Hong et al., 2003
Ruzi grass (8.2% CP) + Concentrate (16.1% CP). Concentrate: Milk according to dietary treatments and milk yield at: T_1 = 1:2; T_2 = 1:2; T_3 = 1:2 and T_4 = 1:3. Sixteen HF crossbred. Complete block	• T_1 = No cassava and stylo 184 hay • T_2 = Cassava hay (20.6% CP) at 1 kg DM • T_3 = Cassava hay at 0.5 kg DM + Stylo 184 hay (17.1% CP) at 0.5 kg DM • T_4 = Cassava hay at 1 kg DM + Stylo 184 hay at 1 kg DM	• 3.5% FCM of 13.9, 14.3, 14.3 and 14.6 kg day^{-1} • Milk fat of 3.81, 3.93, 3.83 and 3.89% • Milk total solids of 12.4, 12.3, 12.9 and 12.8%	Kiyothong & Wanapat, 2004

Conclusions

- Harvesting height and cutting interval influenced the yield of cassava foliage and root tuber, while only small changes in chemical composition of foliage were observed during a growing season of 285 days. The cassava harvested at 30 cm above the ground and with 45 day cutting intervals resulted in eight times higher DM foliage yield and 28% lower root tuber yield, as compared to only one cut of the green foliage tops at the end of the growing season. Therefore, different foliage harvesting strategies can be developed depending on the need for fodder, the economic value of the tubers and harvesting costs.

- There were positive effects on rumen function and without negative effects on thyroid gland and liver functions in cattle fed large amounts of dried or ensiled cassava foliage, while serum triiodothyronine and thyroxine concentrations were reduced in heifers fed 16.5% of total DMI of fresh cassava foliage in rations.

- Ensiled and pelleted cassava foliage increased the daily weight gain by approximately 50% at the lowest supplementary level and by 100% at the highest supplementary level as compared with no protein supplements. Therefore slightly wilted and ensiled, or dried and pelleted cassava foliage can be used as a safe protein source in cattle diets to improve the productivity, without negative effects on thyroid gland and liver functions.

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