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Simulation of milk production by dairy cows fed sugarcane top-based diets with locally available supplements under Indian conditions

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SUMMARY

A model of sugarcane digestion was applied to indicate the suitability of various locally available supplements for enhancing milk production of Indian crossbred dairy cattle. Milk production was calculated according to simulated energy, lipogenic, glucogenic and aminogenic substrate availability. The model identified the most limiting substrate for milk production from different sugarcane-based diets. For sugarcane tops/urea fed alone, milk production was most limited by amino acid followed by long chain fatty acid availability. Among the protein-rich oil cake supplements at 100, 200 and 300 g supplement/kg total DM, cottonseed oil cake proved superior with a milk yield of 5·5, 7·3 and 8·3 kg/day, respectively. This was followed by mustard oil cake with 5·1, 6·5 and 7·6 kg/day, respectively. In the case of a protein-rich supplement (fish meal), milk yield was limited to 6·6 kg/day due to a shortage of long chain fatty acids. However, at 300 g of supplementation, energy became limiting, with a milk yield of 6·7 kg/day. Supplementation with rice bran and rice polishings at 100, 200 and 300 g restricted milk yield to 4·3, 4·9 and 5·5 and 4·5, 5·3 and 6·1 kg/day, respectively, and amino acids became the factor limiting milk production. The diet comprising basal sugarcane tops supplemented by leguminous fodder, dry fodder (e.g. rice or wheat straw) and concentrates at levels of 100, 200 and 300 g supplements/kg total diet DM proved to be the most balanced with a milk yield of 5·1, 6·7 and 9·0 kg/day, respectively.

INTRODUCTION

Sugarcane is cultivated widely throughout India as a cash crop. The crop serves as a major raw material for more than 500 Indian sugar factories. Its cultivation has become the economic main activity of the majority of farmers in northern India, e.g. the states Uttar Pradesh, Uttaranchal and Haryana, the sugar-growing belt of the country (Rangnekar 1988*a*). Sugarcane produces large quantities of green biomass compared with other crops grown in the tropics and subtropics. The matured part of the plant stem is used for sugar extraction, while the top one-third is usually wasted. Sugarcane and its byproducts (principally molasses and bagasse) can be fed to animals (McDonald *et al.* 1988), with inclusion of supplements to increase milk production.

India has the largest cattle population in the world but there is a scarcity of fodder to feed it (Rangnekar 1988*a*). Improper and inadequate feeding are causes of low milk yield from Indian dairy cows. Feed is the major cost that makes milk production uneconomical (Pandey *et al.* 2002). In the sugarcane belt, for example, negative returns have been reported due to

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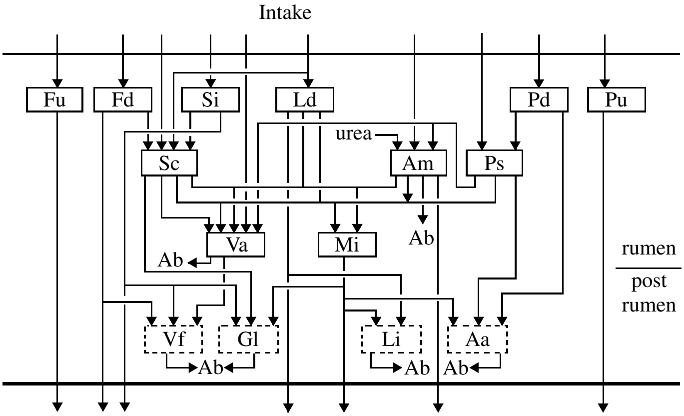

Fig. 1. Diagrammatic representation of the digestion model. Boxes enclosed by solid line indicate rumen state variables; boxes enclosed by dashed lines indicate post-rumen zero pools; arrows indicate flows. The symbol used in the model are: rumen undegradable fibre (Fu); degradable fibre (Fd); soluble starch and sugar (Sc); insoluble starch (Si); long chain fatty acids (Ld); insoluble, degradable protein (Pd); soluble protein (Ps); undegradable protein (Pu); ammonia (Am); volatile fatty acids (Va); microbial dry matter (Mi); post-rumen volatile fatty acids (Vf), glucose (Gl); long chain fatty acids (Li); amino acids (Aa); absorption (Ab).

increasing feed costs and low milk yields. Sugarcane tops (SCT), as well as being abundant, are available at low cost when other green fodder is not available (Rangnekar 1988*b*). Thus, the recycling of such a co-product towards milk production is of potential importance in improving India's dairy industry (Thole *et al.* 1988).

Both sugar and fibre contents of sugarcane are high, but protein and lipid are very low (Valadares Filho *et al.* 1990; Aroeira *et al.* 1993). Milk production with unsupplemented sugarcane is low but animal performance has been shown to improve in feeding trials where supplements such as rice polishings or fishmeal are added (Preston & Leng 1980). Supplementation of sugarcane diets improves the amount and balance of absorbed nutrients through increased microbial growth and fibre degradation in the rumen or increased supply of bypass nutrients. However, high cost of dietary supplements is a major economic constraint and reassessment of potential supplements, such as those produced on farm or as byproducts of agro-industry, is required (Preston & Leng 1980).

To eliminate unnecessary feeding trials, a mechanistic model of sugarcane digestion by cattle was developed to identify suitable supplements for improving milk production in the tropics (Dijkstra *et al.* 1996*a*, *b*). The model predicts nutrient supply to the host animal from dietary intake, and indicates supplements most likely to improve sugarcane utilization. Simulations by previous workers (Kebreab *et al.* 2001) indicated that availability of absorbed amino acids was more limiting to milk production than availability of absorbed glucogenic substrates. The addition of *Leucaena* to a basal diet of sugarcane and urea improved availability of amino acids, with long chain fatty acids and energy-yielding comopounds becoming limiting. Supplementation with both *Leucaena* and rice bran improved milk yield further, with dietary energy then limiting milk production.

Dijkstra *et al.* (1996*b*) showed that addition of urea above 10 g/kg fresh weight of sugarcane fed did not affect nutrient absorption. Leng & Preston (1976) reported the voluntary intake of sugarcane offered to dairy cattle of 470 kg LW to be 16 g DM/kg LW. However, a number of Indian studies reveal lactating dairy cows are fed a diet at about 10 kg DM/day (Patel *et al.* 1983; Ludri & Singh 1987; KVK 2002; NABARD 2002). The diet comprises green fodder (400–500 g/kg DM), concentrate (100–300 g/kg DM) and the remainder a dry fodder, mainly the byproduct (straw) of a crop enterprise. This dietary intake resulted in milk yields of 7·5–11 kg/day depending on concentrate level (Patel *et al.* 1983; Ludri & Singh 1987; KVK 2002; NABARD 2002). Generally, 100–300 g DM/kg DM of the basal diet (sugarcane/urea) is replaced with supplements, depending on availability and the purchasing ability of farmers (Ludri & Singh 1987; KVK 2002; NABARD 2002). Often, 1·0 kg concentrate (100 g/kg DM) is fed by farmers to cut down the cost of milk production (Patel *et al.* 1983; Pandey *et al.* 2002).

Rice straw and wheat straw are the common dry fodders, although sorghum and bajara straw are often used (Singh & Rangnekar 1986). Furthermore, increasing attention is given to the use of leguminous fodder/supplements for improving utilization of sugarcane byproducts (Rangnekar 1988*a*). The common leguminous green fodders used are berseem (*Trifolium alexandrinum*) and lucerne (*Medicago*

Table 1. *Principal symbols used in the model*

Symbol	Description
Aa	Post-rumen amino acids
Ab	Absorption
Am	Ammonia in rumen
Ex	Exit from rumen
Fd	Degradable fibre in rumen
Fl	Rumen fluid phase
Fu	Undegradable fibre in rumen
Gl	Post-rumen glucose
In	Intake
Ld	Long chain fatty acids in rumen
Li	Post-rumen long chain fatty acids
Mi	Microbial DM in rumen
Ni	Nitrogen
Pd	Degradable, insoluble protein in rumen
Pu	Undegradable protein in rumen
Ps	Soluble protein in rumen
Sc	Soluble carbohydrates (starch and sugars) in rumen
Si	Insoluble starch in rumen
So	Rumen solid phase
Ur	Urea
V	Rumen liquid volume
Va	Volatile fatty acids in rumen
Vf	Post-rumen volatile fatty acids

sativa), which are fed individually or mixed with SCT (Lal & Tripathy 1987).

The present study was conducted in crossbred lactating dairy cows fed a basal diet of SCT to identify suitable supplements for improving milk production in the Indian context, using the sugarcane digestion model of Dijkstra *et al.* (1996*a*) to predict nutrient supply.

MATERIALS AND METHODS

The model

The model of Dijkstra *et al.* (1996*a*), used to predict nutrient supply, is based on a series of dynamic, deterministic and non-linear differential equations of the form: rate is a function of state. Eleven state variables describe the rumen, namely degradable fibre (Fd), undegradable fibre (Fu), insoluble starch (Si), soluble starch and sugar (Sc), long chain fatty acids (Ld), soluble protein (Ps), insoluble degradable protein (Pd), undegradable protein (Pu), microbial matter (Mi), ammonia (Am) and volatile fatty acids (Va). Four zero pools are used to calculate absorbed amino acids, glucose, long chain fatty acids and volatile fatty acids. A diagrammatic representation of the model is given in Fig. 1, and the principal symbols are defined in Table 1.

The flow equations are represented by Michaelis–Menten and mass action forms. Data from trials with cattle fed sugarcane were used to derive the parameters of the model wherever possible. Degradation of substrates in the rumen depends on characteristics of the feed, microbial biomass present and fractional outflow rates. Microbial growth and protein synthesis were calculated according to the availability of carbohydrate and nitrogen sources. Although the model has some parameter values that are specific for whole sugarcane with its high sugar and fibre contents (in particular, the fraction of protozoa), the SCT are still high in sugar (around 300 g/kg DM) and, at that level, protozoa have a major role in the rumen.

The amount of nutrient absorbed in the intestines is determined from ruminal outflow of the substrate and its respective absorption coefficient in the intestines [the absorption coefficients for amino acids, glucose, and lipids are given in Eqns (12) to (15) of Dijkstra *et al.* (1996*a*)]. Milk production is calculated from the amount of available glucose and propionic acid, amino acids, lipids and energy, and the most limiting of these four groups is identified. The model is written in the advanced continuous simulation language ACSL (Mitchell & Gauthier 1981), and a fourth-order Runge–Kutta method is used for numerical integration. A full description of model structure and calculation of milk production is given by Dijkstra *et al.* (1996*a*, *b*).

Inputs and outputs of the model

Several locally available supplements were evaluated using SCT with and without urea (when supplemented with protein-rich sources) as basal diets, taking Indian practices of feeding dairy animals into consideration (Table 2). The data presented in Table 2 were calculated using the chemical composition of diets reported in the literature and based on a maximum dry matter (DM) intake of 10 kg/day per cow. Whenever possible, Indian sources were used for soluble and insoluble, and degradable and undegradable fractions of sugarcane and supplements. The typical cow was assumed to be a Holstein (or Jersey) × Zebu of liveweight (LW) 450 kg. Lactose, crude protein and fat contents of milk were taken as 46, 28 and 38 g/kg, respectively.

Three levels of supplement inclusion were considered for each basal diet, namely 100, 200 or 300 g/kg total DM. When more than one was included, each supplement was fed in an equal amount of DM. The fractional fluid and solid passage rates and rumen volume were assumed not to be affected by type or level of supplement and were 0·09 and 0·035/h and 75 litre, respectively (Owens & Goetsch 1986).

To assess the value of SCT as an animal feed, simulated and observed milk yields were compared. Limiting factors for different feed options and various levels of supplementation were identified. Better

Table 2. *Feed composition and hydrolysis rate of several locally available supplements in India*[1]

	Feed composition (g/kg DM)									Hydrolysis rate (/h)			
Feed	Fd	Fu	Sc	Si	Ps	Pd	Pu	Ld	Am	Fd	Si	Pd	References[2]
Sugarcane	293	196	445	0	15	0	4	8	0	0·020	–	–	2, 4, 17, 19, 21
Sugarcane tops	380	230	285	0	31	0	3	10	0	0·024	–	–	6, 8, 13, 17, 19, 21, 23
Groundnut oil cake	87	38	102	37	141	412	0	42	0	0·117	0·125	0·148	6, 8, 16, 27, 29
Coconut oil cake	461	102	102	8	36	172	7	42	0	0·072	0·125	0·029	5, 8, 16, 27, 29
Mustard oil cake	160	45	80	95	100	280	50	45	0	0·070	0·125	0·040	7, 15
Cottonseed oil cake	139	92	243	9	65	332	9	85	0	0·065	0·125	0·076	8, 29
Wheat bran	380	163	166	25	45	122	11	37	0	0·077	0·208	0·150	4
Rice bran	53	144	332	159	37	95	15	128	0	0·048	0·118	0·083	4, 7, 8, 23, 27, 29
Rice polishings[3]	15	16	478	165	42	103	13	130	0	0·045	0·076	0·050	8, 23, 29
Fishmeal	0	0	0	0	136	476	68	53	0	–	–	0·010	9, 15
Molasses	0	0	700	0	32	0	0	0	0	–	–	–	3, 18
Concentrate[4]	171	76	221	136	99	182	13	47	0	0·050	0·040	0·050	1, 4, 8, 29
Rice straw[5]	637	123	128	10	18	18	8	13	0	0·040	0·091	0·071	12, 11, 22, 23, 30, 24, 25
Wheat straw	608	148	108	10	5	40	5	23	0	0·031	0·042	0·090	7, 25
Berseem	412	80	30	5	45	220	20	45	0	0·025	0·035	0·081	1, 15
Lucerne	420	141	20	5	21	200	20	15	0	0·035	0·051	0·072	10, 15
Leucaena	210	161	100	0	66	155	40	10	0	0·020	–	0·035	11, 26
Wheat grain	90	40	366	288	34	120	10	30	0	0·150	0·182	0·200	15, 29
Soybean meal	111	43	107	11	32	482	1	7	0	0·054	0·125	0·083	4, 29, 31
Urea	0	0	0	0	0	0	0	0	549	–	–	–	4

[1] Symbols are defined in Table 1.

[2] Data from 1, Agarwal & Mudgal (1982); 2, Aroeira *et al.* (1993); 3, Campos (1975); 4, Dijkstra *et al.* (1996*b*); 5, Francis (1995); 6, Gohl (1975); 7, Gowda *et al.* (1996); 8, Harris *et al.* (1982); 9, Hennessy *et al.* (1983); 10, Jin (1987); 11, Kamatali *et al.* (1992); 12, Verma & Kumar (1988); 13, Kutty & Prasad (1980); 14, Leng & Preston (1976); 15, MAFF (1984); 16, McDonald *et al.* (1988); 17, Pate (1981); 18, Preston & Leng (1980); 19, Preston & Leng (1987); 20, Rangnekar *et al.* (1982); 21, Rangnekar (1988*a*, *b*); 22, Schiere & Ibrahim (1989); 23, Schneider (1947); 24, Shivkumar & Verma (1998); 25, Singh & Kaushal (1997); 26, Singh *et al.* (1995); 27, Van Soest (1994); 28, Sundstol & Owen (1984); 29, Tamminga *et al.* (1990); 30, Tripathy *et al.* (1995); 31, Varga & Hoover (1983).

[3] Proportion of protein degradability assumed as for rice, according to Tamminga *et al.* (1990).

[4] Local concentrate comprising of (g/kg of DM): grains (wheat) 330, oil cake 370 (groundnut 150, cottonseed 100, mustard 120), rice bran 120, wheat bran 150, mineral mixture 20, common salt 10. Composition calculated using references for individual feed ingredients.

[5] Rumen insoluble starch proportion is assumed to be as for rice bran.

nutrient balance for enhancing milk yield in Indian situations was determined.

RESULTS

Nutrient absorption

In Tables 3–5, the simulated effects on absorption of nutrients from a SCT based diet fed with various supplements (100, 200 or 300 g/kg DM) are presented. Supplements low in protein such as molasses showed low amino acid absorption. Among the other supplements, the highest amino acid absorption (642 g/day) was with fishmeal, followed by groundnut oil cake (611 g/day), cottonseed oil cake (570 g/day) and mustard oil cake (530 g/day). Adding urea to the diet above 10 g/kg sugarcane fresh weight did not influence favourably the absorption of amino acids. When part of the SCT and dry fodder was supplemented with leguminous fodder, there was a substantial increase in amino acid absorption. Among the cereal straws, wheat straw influenced amino acid absorption more than rice straw. Among the leguminous fodders, berseem proved superior to lucerne by affecting absorption more favourably (Tables 3–5). In a low protein diet that includes molasses, there was 25·4% improvement in amino acid absorption with berseem inclusion. Supplementation of SCT with *Leucaena* and rice polishings also resulted in 11·3% more absorption of amino acids. When the protein in the supplements was more ruminally degradable, supplementation improved efficiency of microbial growth and hence increased non-ammonia nitrogen (NAN) outflow. Supplementation with concentrates and leguminous fodder such as lucerne or berseem resulted in high amounts of rumen bypass protein, which were largely responsible for increase in NAN outflow and amino acid absorption.

Table 3. *Effect of different diets on absorption of amino acids (A_{Aa}), glucose (A_{Gl}), lipids (A_{Li}), volatile fatty acids (A_{Va}) and energy (A_E), and rumen fermentation indicators*[1] *fed at 10 kg DM with 100 g supplement/kg total diet DM*

Diet[2]	A_{Aa} (g/day)	A_{Gl} (g/day)	A_{Ll} (g/day)	A_{Va} (mol/day)	A_E (MJ/day)	M_{nf} (g N/day)	OM_f (g/day)	T_{OM} (g N/kg OM)	T_{CHO} (g N/kg CHO)
SC+U	413	303	64·5	54·6	83·1	92·8	4305	16·1	16·7
SCT+U	358	228	77·1	44·7	69·0	80·2	5039	17·0	18·5
SCT+U+RS	363	229	79·2	44·7	69·2	79·8	5109	17·0	18·5
SCT+U+C	436	248	103·9	46·9	74·5	81·9	4935	16·8	19·0
SCT+U+RS+C	402	237	91·6	45·8	71·9	81·5	5017	17·0	18·8
SCT+RS+C	418	246	94·9	47·9	75·1	85·3	5167	17·0	18·8
SCT+RS+GO	456	230	93·3	48·0	75·6	83·7	5145	16·8	19·0
SCT+RS+CO	444	232	108·5	48·0	76·0	84·9	5184	17·0	18·7
SCT+RS+CO	410	233	93·3	47·0	73·6	83·9	5234	17·0	18·7
SCT+RS+MO	430	237	94·0	47·4	74·5	83·7	5179	17·0	18·9
SCT+RS+FM	462	222	96·7	47·4	74·9	81·9	5152	16·7	19·0
SCT+RS+RB	400	253	124·3	47·5	75·5	84·9	5198	17·0	18·6
SCT+RS+U+RB	384	244	121·1	45·3	72·3	81·3	5045	17·0	18·7
SCT+RS+RP	407	257	125·2	48·3	76·7	86·3	5122	17·0	18·6
SCT+RS+U+MS	383	248	78·3	48·0	74·0	85·2	5014	16·8	18·2
SCT+RS+C	418	246	94·9	47·9	75·1	85·3	5167	17·0	18·8
SCT+B+RS+C	428	238	98·3	47·5	74·8	84·2	5178	17·0	18·9
SCT+B+WS+C	430	238	100·5	47·4	74·8	84·0	5185	17·0	18·9
SCT+L+RS+C	425	238	91·1	47·3	74·2	83·9	5190	17·0	18·8
SCT+L+WS+C	427	238	93·3	47·2	74·2	83·7	5199	17·0	18·8
SCT+B+RS+GO	454	227	96·8	47·6	75·2	83·1	5162	16·8	19·0
SCT+B+RS+CO	446	229	107·7	47·6	75·4	83·9	5189	16·9	18·9
SCT+B+RS+CO	424	229	96·8	47·0	73·8	83·4	5221	17·0	18·8
SCT+B+RS+MS	437	232	97·5	47·2	74·4	83·1	5187	16·0	18·9
SCT+B+RS+RB	417	242	117·8	47·2	75·1	84·2	5195	17·0	18·8
SCT+LC+RS+C	419	238	89·7	47·3	74·0	83·9	5158	16·1	18·9
SCT+LC+RS+RP	413	244	109·9	47·5	75·1	84·9	5125	17·0	18·8
SCT+B+RS+U+MS	393	237	100·3	45·9	72·2	82·1	5042	17·0	18·7

[1] M_{nf} is microbial non-ammonia N flow to duodenum (g N/day), OM_f is duodenal flow of organic matter (g/day), T_{OM} is true efficiency of microbial growth (g N/kg organic matter) and T_{CHO} is true efficiency of microbial growth (g N/kg carbohydrate).

[2] B = Berseem, C = Concentrates, CO = Coconut oil, FM = Fish meal, GO = Groundnut oil, L = Lucerne, LC = *Leucaena*, MO = Mustard oil, MS = Molasses, RB = Rice bran, RP = Rice polishings, RS = Rice straw, SC = Sugarcane, SCT = Sugarcane tops, U = Urea, WS = Wheat straw.

Coefficient of soluble sugar fermentation simulated on the basal diet (sugarcane with 10 g urea/kg sugarcane fresh weight) is $>0·97$ and glucose (plus propionic acid) available for absorption arises largely from microbial polysaccharides synthesized in the rumen. Higher quantities of bypass starch in rice bran and rice polishings increased the amount of glucose absorbed in the intestine compared with the basal diet (SCT/urea). Absorption of glucose was lowest in fish meal. There was a 6·4–13·4 % decrease in glucose absorption with supplementation by leguminous fodder.

Long chain fatty acid absorption increased with increasing level of supplementation except for molasses. Dry fodder addition to the basal diet increased absorption, while urea addition resulted in a marginal decrease. Lowest long chain fatty acid absorption was observed with molasses supplementation and highest with rice bran and rice polishings. There was an improvement of between 13·1–48·1 % in absorption of long chain fatty acids when berseem was supplemented. Increase in absorption was highest in the case of molasses indicating that molasses feeding should be supplemented with leguminous fodder.

Volatile fatty acid absorption generally increased with increasing level of supplementation, while in the case of fish meal it remained constant. The highest level of absorption was recorded for the rice polishings and molasses diet. Addition of berseem/leucerne/*Leucaena* resulted in a marginal decrease in absorption of volatile fatty acids.

Energy absorption increased with increasing level of supplementation. Highest energy absorption occurred using rice polishings, while it was lowest for the basal diet. Energy absorption increased by 2·3–3·6 %

Table 4. *Effect of different diets on absorption of amino acids (A_{Aa}), glucose (A_{Gl}), lipids (A_{Li}), volatile fatty acids (A_{Va}) and energy (A_E), and rumen fermentation indicators*[1] *fed at 10 kg DM with 200 g supplement/kg total diet DM*

Diet[2]	A_{Aa} (g/day)	A_{Gl} (g/day)	A_{Li} (g/day)	A_{Va} (mol/day)	A_E (MJ/day)	M_{nf} (g N/day)	OM_f (g/day)	T_{OM} (g N/kg OM)	T_{CHO} (g N/kg CHO)
SC+U	413	303	64·5	54·6	83·1	92·8	4305	16·1	16·7
SCT+U	358	228	77·1	44·7	69·0	80·2	5039	17·0	18·5
SCT+U+RS	368	230	84·9	44·6	69·5	79·5	5184	17·0	18·5
SCT+U+C	508	271	131·2	49·1	80·0	81·3	4850	16·3	19·1
SCT+U+RS+C	442	249	106·7	46·9	74·7	81·6	5005	16·8	19·0
SCT+RS+C	455	256	109·2	48·8	77·6	85·1	5134	16·8	19·0
SCT+RS+GO	530	225	105·2	48·9	78·5	80·5	5105	16·2	19·1
SCT+RS+CO	507	228	136·5	48·8	79·3	83·8	5173	16·6	19·1
SCT+RS+CO	442	229	105·4	47·0	74·6	82·9	5263	17·0	18·9
SCT+RS+MS	479	239	107·4	47·7	76·4	81·3	5169	16·6	19·0
SCT+RS+FM	545	209	112·7	47·4	77·0	76·6	5127	16·0	19·1
SCT+RS+RB	423	267	167·6	47·9	78·4	85·5	5184	17·0	18·8
SCT+RS+U+RB	409	259	165·1	46·0	75·5	82·2	5052	17·0	18·8
SCT+RS+RP	438	275	169·3	49·5	80·9	88·6	5032	17·0	18·8
SCT+RS+U+MS	394	255	75·6	49·1	75·6	86·9	4815	16·8	18·1
SCT+RS+C	455	256	109·2	48·8	77·6	85·1	5135	16·8	19·9
SCT+B+RS+C	476	241	116·2	48·0	77·1	82·5	5159	16·7	19·0
SCT+B+WS+C	480	240	121·2	47·7	77·0	81·9	5179	16·7	19·0
SCT+L+RS+C	470	241	101·7	47·5	75·8	82·2	5184	16·8	19·0
SCT+L+WS+C	473	240	106·7	47·3	75·7	81·7	5202	16·7	19·0
SCT+B+RS+GO	527	220	113·7	48·0	77·6	79·3	5145	16·3	19·1
SCT+B+RS+CO	511	222	134·1	48·0	78·1	81·5	5189	16·6	19·1
SCT+B+RS+CO	467	222	113·9	46·8	75·0	81·1	5247	16·8	19·0
SCT+B+RS+MS	493	230	115·2	47·2	76·2	79·8	5186	16·5	19·1
SCT+B+RS+RB	456	248	155·1	47·4	77·6	83·3	5190	16·9	19·0
SCT+LC+RS+C	458	239	99·6	47·5	75·4	81·9	5123	16·7	19·0
SCT+LC+RS+RP	447	251	139·5	48·0	77·6	84·8	5047	16·9	18·9
SCT+B+RS+U+MS	409	236	120·9	44·8	71·9	79·6	4879	17·0	18·9

[1] M_{nf} is microbial non-ammonia N flow to duodenum (g N/day), OM_f is duodenal flow of organic matter (g/day), T_{OM} is true efficiency of microbial growth (g N/kg organic matter) and T_{CHO} is true efficiency of microbial growth (g N/kg carbohydrate).

[2] Diets as described in Table 3.

with berseem supplementation, while it decreased marginally with lucerne and *Leucaena*. Energy absorption with cottonseed oil cake was also among the highest.

Effects on milk yield of dry fodder and concentrates as supplements

Figures 2–4 show milk production by a typical crossbred cow, based on availability of energy, amino acids, glucose and propionic acid, and long chain fatty acids, for SCT based diets fed at 10 kg DM/day, with 100, 200 or 300 g/kg of total DM replaced by various combinations of locally available supplements. The supplements were chosen for their feed composition characteristics, i.e. high availability of soluble sugars and starch (molasses), amino acids (fish meal, groundnut oil cake, cottonseed oil cake), rumen insoluble starch (rice bran) and a balance of these nutrients (cottonseed oil cake and *Leucaena*). The basal diet shows a clear imbalance between the amount of amino acid and energy absorbed and required, with low availability of absorbed amino acids limiting milk production to 3·2 kg/day when fed unsupplemented at 10 kg DM/day. Glucogenic substrate availability for milk production with the basal diet is high due to microbial storage polysaccharides and high proportion of propionic acid in the VFA absorbed.

Replacing part of the SCT by starch or soluble sugar-rich supplements, including molasses, is inappropriate because of further increase in glucose absorption while amino acid absorption remains low (Figs 2–4AB). Replacing 100–200 g/kg DM of sugarcane by a high protein supplement such as fish meal significantly increases milk production due to improved amino acid and glucose and propionic acid availability but long chain fatty acids and energy then

Table 5. *Effect of different diets on absorption of amino acids (A_{Aa}), glucose (A_{Gl}), lipids (A_{Li}), volatile fatty acids (A_{Va}) and energy (A_E), and rumen fermentation indicators[1] fed at 10 kg DM with 300 g supplement/kg total diet DM*

Diet[2]	A_{Aa} (g/day)	A_{Gl} (g/day)	A_{Li} (g/day)	A_{Va} (mol/day)	A_E (MJ/day)	M_{nf} (g N/day)	OM_f (g/day)	T_{OM} (g N/kg OM)	T_{CHO} (g N/kg CHO)
SC+U	413	303	64·5	54·6	83·1	92·8	4305	16·1	16·7
SCT+U	358	228	77·1	44·7	69·0	80·2	5039	17·0	18·5
SCT+U+RS	381	235	85·6	45·6	71·1	80·9	5314	17·0	18·5
SCT+U+C	585	298	159·2	52·2	86·8	82·1	4819	15·8	19·2
SCT+U+RS+C	480	261	121·2	47·9	77·6	81·2	4996	16·6	19·1
SCT+RS+C	491	267	123·6	49·7	80·1	84·3	5107	16·6	19·1
SCT+RS+GO	611	221	117·4	49·7	81·4	76·8	5079	15·6	19·2
SCT+RS+CO	570	225	164·4	49·7	82·5	82·1	5170	16·3	19·2
SCT+RS+CO	473	226	117·9	47·0	75·6	81·4	5303	16·8	19·0
SCT+RS+MS	530	242	120·8	47·9	78·1	78·3	5170	16·2	19·1
SCT+RS+FM	642	197	128·7	47·3	79·0	70·9	5122	15·3	19·2
SCT+RS+RB	445	282	211·2	48·3	81·3	85·9	5174	17·0	18·9
SCT+RS+U+RB	434	275	208·9	46·7	78·8	82·9	5059	17·0	18·9
SCT+RS+RP	468	293	213·8	50·8	85·0	90·5	4946	17·0	18·9
SCT+RS+U+MS	403	263	73·2	50·2	77·1	88·4	4618	16·7	18·0
SCT+RS+C	491	267	123·6	49·7	80·1	84·3	5108	16·6	19·1
SCT+B+RS+C	524	245	134·0	48·5	79·3	80·2	5153	16·3	19·1
SCT+B+WS+C	530	243	141·1	48·0	79·0	79·3	5181	16·3	19·1
SCT+L+RS+C	515	244	112·3	47·7	77·3	79·7	5187	16·4	19·1
SCT+L+WS+C	520	243	119·4	47·4	77·2	79·0	5217	16·4	19·1
SCT+B+RS+GO	609	214	133·4	48·4	80·3	75·0	5143	15·6	19·2
SCT+B+RS+CO	580	216	162·6	48·4	80·9	78·6	5202	16·1	19·2
SCT+B+RS+CO	513	217	133·8	46·6	76·3	78·3	5286	16·5	19·1
SCT+B+RS+MS	553	228	132·1	47·2	77·9	76·0	5200	16·1	19·2
SCT+B+RS+RB	493	254	192·4	47·6	80·1	81·8	5185	16·7	19·1
SCT+LC+RS+C	496	242	113·0	47·7	77·0	79·4	5096	16·4	19·1
SCT+LC+RS+RP	480	260	168·9	48·5	80·1	84·2	4981	16·7	19·1
SCT+B+RS+U+MS	425	236	140·8	43·7	71·6	76·6	4720	16·8	19·0

[1] M_{nf} is microbial non-ammonia N flow to duodenum (g N/day), OM_f is duodenal flow of organic matter (g/day), T_{OM} is true efficiency of microbial growth (g N/kg organic matter) and T_{CHO} is true efficiency of microbial growth (g N/kg carbohydrate).

[2] Diets as described in Table 3.

become limiting. Supplementing with rice bran increased long chain fatty acid absorption, but amino acid availability still limited milk production.

Addition of dry fodder (rice straw) to the basal diet slightly increased milk yield due to improved availability of energy, amino acids, glucose and propionic acid and long chain fatty acids at all levels of supplementation.

Among oil cake supplements, maximum milk production due to energy, glucose and propionic acid, and long chain fatty acids availability was for cottonseed oil cake with 8·3, 7·9 and 9·3 kg milk/day, respectively, while for amino acids, it was for groundnut oil cake (9·8 kg milk/day). Molasses and urea addition to the SCT+rice straw diet improved potential milk production due to better availability of energy, glucose and propionic acid. However, absorption of amino acids and long chain fatty acids were only marginally affected, limiting milk production. Milk yield increased with supplementation by rice bran. There was a pronounced increase in potential milk yield due to availability of long chain fatty acids, but amino acid availability limited obtaining these high levels.

Effects on milk yield of dry fodder, leguminous green fodder and concentrates as supplements

Partial replacement of SCT and dry fodder with berseem increased potential milk yield due to increased availability of energy, amino acids and long chain fatty acids. However, milk yield was marginally lower due to reduced glucose and propionic acid availability. Supplementation by lucerne rather than berseem proved slightly inferior. The cereal straws (rice *v.* wheat) when used with berseem behaved more or less the same. Potential milk yield due to energy, and to glucose and propionic acid availability rose by

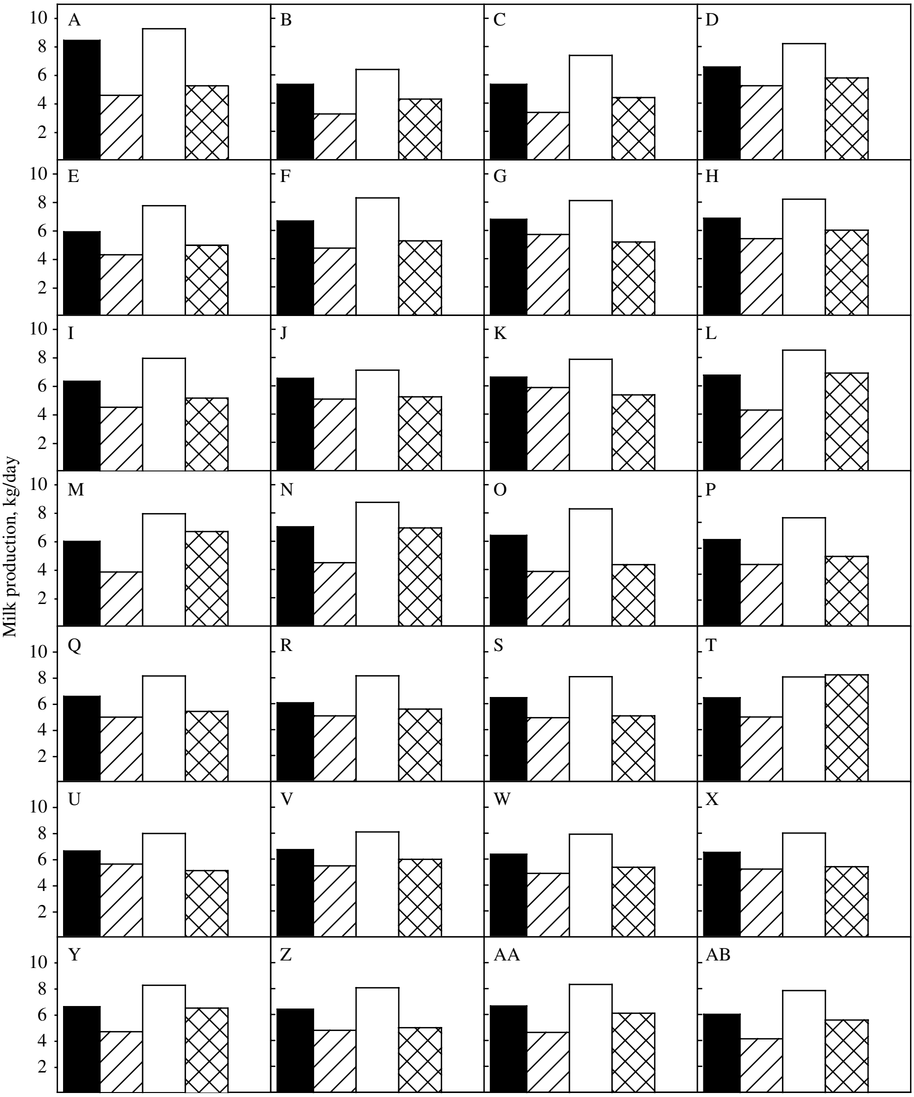

Fig. 2. Milk production (kg/day) based on availability of energy (solid bars), amino acids (striped bars), glucose and propionic acid (open bars) and long chain fatty acids (crossed bars) fed at 10 kg DM with 100 g supplement/kg total diet DM. (A) SC + U; (B) SCT + U; (C) SCT + U + RS; (D) SCT + U + C; (E) SCT + U + RS + C; (F) SCT + RS + C; (G) SCT + RS + GO; (H) SCT + RS + CO; (I) SCT + RS + CO; (J) SCT + RS + MO; (K) SCT + RS + FM; (L) SCT + RS + RB; (M) SCT + RS + U + RB; (N) SCT + RS + RP; (O) SCT + RS + U + MS; (P) SCT + RS + C, (Q) SCT + B + RS + C, (R) SCT + B + WS + C, (S) SCT + L + RS + C; (T) SCT + L + WS + C; (U) SCT + BS + RS + GO; (V) SCT + B + RS + CO; (W) SCT + BS + RS + CO; (X) SCT + BS + RS + MO; (Y) SCT + BS + RS + RB; (Z) SCT + LC + RS + C (AA) SCT + LC + RS + RP; (AB) SCT + BS + RS + U + MS. Diet abbreviations are as described in Table 3.

1·6 *v.* 0·4 % and 3·6 *v.* 2·4 %, respectively, and due to amino acid and long chain fatty acid availability by 5·4 *v.* 5·8 % and 11·6 *v.* 14·8 %, respectively. Berseem inclusion in the diet improved potential milk yield due to energy availability by 5·1–8·9 % and yield due to amino acid availability also improved significantly. Its effect is particularly pronounced when molasses are given as a supplement, with milk yield increasing 31·6–56·8 % depending on the nature of supplementation. Berseem also proved to be beneficial in enhancing milk yield where long chain fatty acid availability is the limitation. Potential milk yield due to long chain fatty acid availability improved by 13·2–48·5 % with berseem supplementation.

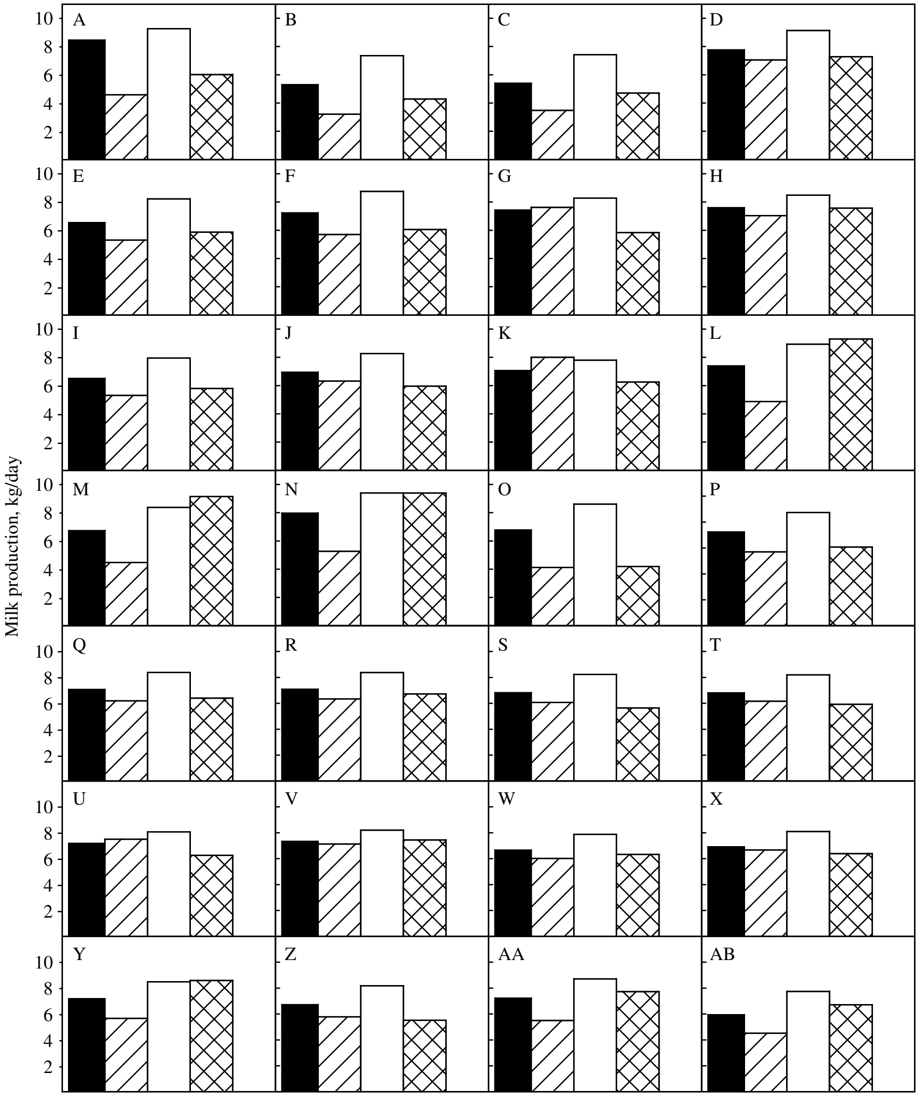

Fig. 3. Milk production (kg/day) based on availability of energy (solid bars), amino acids (striped bars), glucose and propionic acid (open bars) and long chain fatty acids (crossed bars) fed at 10 kg DM with 200 g supplement/kg total diet DM. (A) SC+U; (B) SCT+U; (C) SCT+U+RS; (D) SCT+U+C; (E) SCT+U+RS+C; (F) SCT+RS+C; (G) SCT+RS+GO; (H) SCT+RS+CO; (I) SCT+RS+CO; (J) SCT+RS+MO; (K) SCT+RS+FM; (L) SCT+RS+RB; (M) SCT+RS+U+RB; (N) SCT+RS+RP; (O) SCT+RS+U+MS; (P) SCT+RS+C, (Q) SCT+B+RS+C, (R) SCT+B+WS+C, (S) SCT+L+RS+C; (T) SCT+L+WS+C; (U) SCT+BS+RS+GO; (V) SCT+B+RS+CO; (W) SCT+BS+RS+CO; (X) SCT+BS+RS+MO; (Y) SCT+BS+RS+RB; (Z) SCT+LC+RS+C (AA) SCT+LC+RS+RP; (AB) SCT+BS+RS+U+MS. Diet abbreviations are as described in Table 3.

DISCUSSION

The model of digestion and absorption of sugarcane by Dijkstra *et al.* (1996*a*) was used to evaluate various supplements for lactating Indian dairy cattle. The model predicts nutrient supply to the host animal from dietary intake, indicating locally available supplements most likely to improve milk production. In the present study, SCT based diets are evaluated by taking into consideration feeding practices in different parts of India.

Owing to scarcity of published information on feeding sugarcane to dairy cows, the study is based on limited data. However, some published information

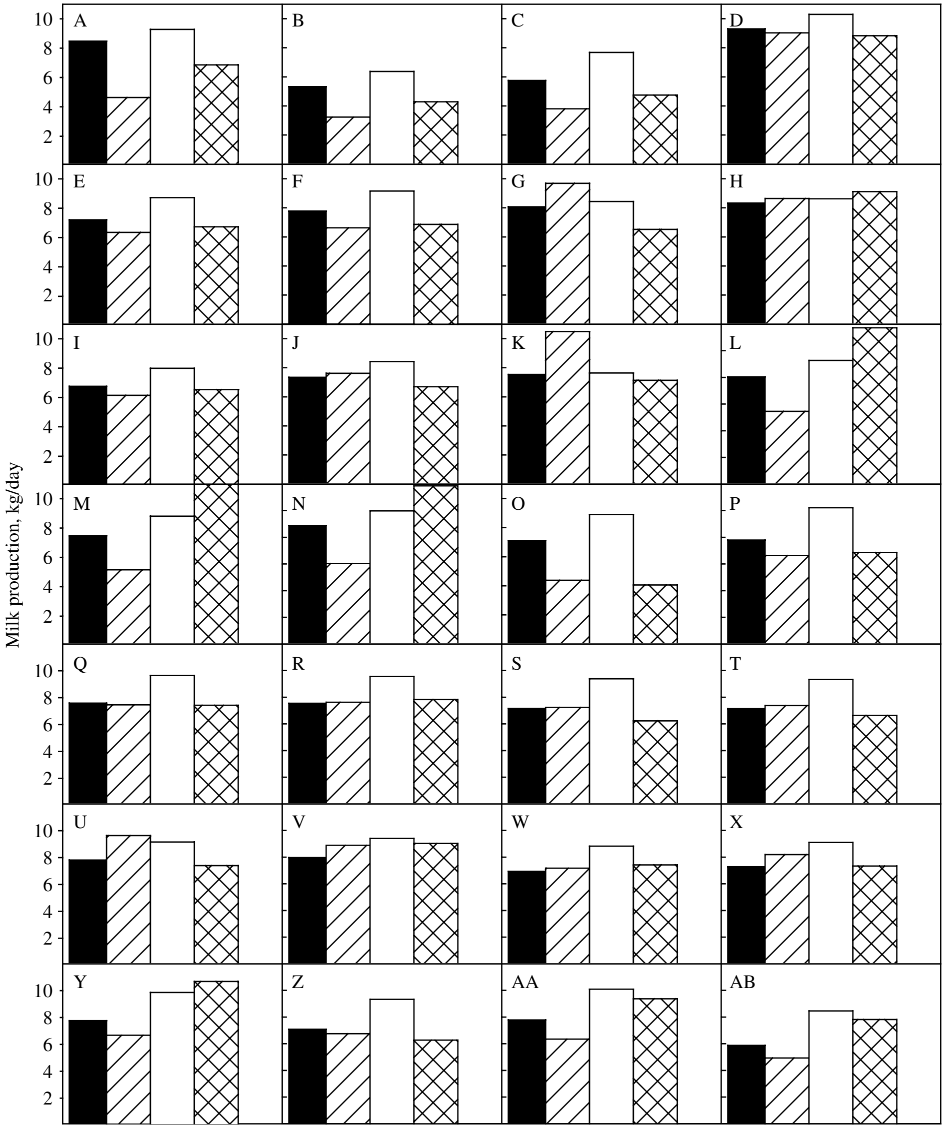

Fig. 4. Milk production (kg/day) based on availability of energy (solid bars), amino acids (striped bars), glucose and propionic acid (open bars) and long chain fatty acids (crossed bars) fed at 10 kg DM with 300 g supplement/kg total diet DM. (A) SC + U; (B) SCT + U; (C) SCT + U + RS; (D) SCT + U + C; (E) SCT + U + RS + C; (F) SCT + RS + C; (G) SCT + RS + GO; (H) SCT + RS + CO; (I) SCT + RS + CO; (J) SCT + RS + MO; (K) SCT + RS + FM; (L) SCT + RS + RB; (M) SCT + RS + U + RB; (N) SCT + RS + RP; (O) SCT + RS + U + MS; (P) SCT + RS + C, (Q) SCT + B + RS + C, (R) SCT + B + WS + C, (S) SCT + L + RS + C; (T) SCT + L + WS + C; (U) SCT + BS + RS + GO; (V) SCT + B + RS + CO; (W) SCT + BS + RS + CO; (X) SCT + BS + RS + MO; (Y) SCT + BS + RS + RB; (Z) SCT + LC + RS + C (AA) SCT + LC + RS + RP; (AB) SCT + BS + RS + U + MS. Diet abbreviations are as described in Table 3.

giving feed composition was available for comparing predicted with observed milk yield. Furthermore, some of the reported experiments do not give feed composition, so typical values from the literature were used, which might have affected the predictions. However, earlier studies revealed that model predictions for milk yield and absorbed nutrients are in close agreements with experimental results (Dijkstra *et al.* 1996*a*, *b*; Kebreab *et al.* 2001). Evaluation of the model against independent data at a range of intake and supplementation levels also showed reasonable agreement for rumen NDF degradation and VFA and ammonia concentration levels in rumen fluid (Dijkstra *et al.* 1996*a*). Hence, the model has been shown capable of giving insight into factors influencing or limiting milk production in cows fed sugarcane as their basal diet.

Milk yield with the SCT/urea diet was lower than that obtained with whole sugarcane/urea. Although SCT was supplemented with urea to meet the N requirement of rumen microbes, amino acid availability was still the factor most limiting milk yield, while long chain fatty acids was most limiting for whole sugarcane diets. Yield predicted from availabilities of glucose and propionic acid and energy is higher with sugarcane than with SCT, due to higher content of soluble sugar in whole cane (Preston & Leng 1987; Rangnekar 1988*a*, *b*). A predicted milk yield of 3·2 kg/day was obtained with SCT without supplementation, within the range 2–4 kg/day reported by Rangnekar (1988*a*) in the study conducted in Mauritius.

Predicted milk yield improved with addition of leguminous fodders such as berseem and lucerne to SCT. This is due to increase in bypass nutrients and improvement in physical attributes of the rumen ecosystem (Meyreles *et al.* 1979; Hulman & Preston 1981). Substituting SCT with *Leucaena* increased potential milk yield by 1·4–1·5 kg/day depending on level of supplementation, mainly owing to a rise in amino acid availability in the small intestine because of increased ruminally undegradable protein. These predictions from the model agreed with the findings of Alvarez & Preston (1976) and Alvarez *et al.* (1978) that addition of *Leucaena* to a sugarcane/urea diet improved milk production by increasing the availability of amino acids and long chain fatty acids.

Rice bran supplementation of the basal diet also improved the availability of energy, glucose and propionic acid and long chain fatty acids, with amino acids then becoming limiting. The milk production predicted from available amino acids is only slightly lower than observed (5·3 kg/day *v.* observed mean of 5·5 kg/day). Supplementation by both *Leucaena* and rice polishings provided a better balance of nutrients available for absorption, further improving milk yield with energy availability now limiting production. Rice polishings have proved to be a good source of bypass nutrients because of their richness in essential amino acids, starch and lipids. When molasses are used with roughages to improve their palatability and utilization, it can act adversely at higher levels of inclusion by depressing fibre digestion (Rangnekar 1988*a*, *b*). It is a poor protein source and hence needs to be supplemented with both readily fermentable and bypass protein to sustain higher levels of production. Hence, inclusion of berseem in a molasses diet improves milk yield by elevating bypass protein levels (Preston & Wills 1974; Meyreles *et al.* 1982).

The feed option combining SCT, berseem as green fodder, rice straw/wheat straw as dry fodder, and concentrates provided the most balanced option for enhancing milk yield. With 100 g supplement/kg DM, a milk yield of 5·9 kg/day was obtained, close to the yield reported by Patel *et al.* (1983) from farm fields (with 1·0 kg concentrate) over a large area consisting of 30 villages. Typical daily yield (taking the average lactation period) for a randomly selected farm in the project area was 7·5 litres from crossbred cows fed similarly. With a basal diet of sugarcane supplemented with rice straw and concentrate at a level of 300 g/kg total DM, the milk yield predicted was 9·8 kg/day. This milk yield is also very close to that obtained in the dairy demonstration unit of the KVK farm at the National Dairy Research Institute, Karnal, 1999–2000, where average milk production of 10·4 to 11·4 kg/day was obtained from crossbred cows fed at levels of 5 kg/animal dry fodder, 15 kg/animal green fodder and 1 kg concentrate/3 litres of milk, which equates to 10–11 kg DM/day. Feeding trials conducted by Rangnekar & Joshi (1978) using a sugarcane-based diet also yielded 10–12 kg of milk/day. Ludri & Singh (1987), using six Karan Swiss and six Karan Friesian lactating crossbred cows fed green fodder, dry fodder and concentrate, reported a milk yield of 11·4 and 10·0 kg/day for a feeding level of 10·8 and 10·9 kg DM intake/day, respectively.

CONCLUSIONS

SCT/urea provides a suitable basal diet for feeding dairy cows in India, provided appropriate supplements are added. Amino acid availability limits milk production most, followed by long chain fatty acids. Addition of cereal straw to SCT has a slight beneficial effect, increasing milk yield due to greater availability of energy, amino acids, glucose and propionic acid, and long chain fatty acids. Among protein-rich supplements to SCT + rice straw, cottonseed oil cake proved most suitable for balancing the diet and improving milk yield. Leguminous fodder added to a SCT based diet proved useful in increasing milk yield. Its effect was most pronounced with diets containing molasses, improving milk yield by up to 49·6%. SCT + leguminous fodder (berseem/lucerne) + dry fodder (rice/wheat straw) + concentrate proved to be the most balanced diet for realizing higher milk yields from Indian crossbred cows. On account of the shortages of amino acids and long chain fatty acids in a SCT diet, supplements containing high bypass protein and starch contents are important in increasing milk yield. Bypass nutrient availability is improved with inclusion of leguminous fodders such as berseem, lucerne and *Leucaena*. Milk production is further enhanced by increased degradable protein and long chain fatty acids, provided rumen fermentation is not affected adversely.

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