Effect of complex catalytic supplementation with non-protein nitrogen on the ruminal ecosystem of growing goats pasturing on shrub land in Mexico

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Abstract

Thirty-eight young Alpine goats, 16.1 (±0.370) kg body weight (BW), were reared at Querétaro, Mexico, grazing on a semi-arid woody brush (Cuducifolio espinoso) range land. The experimental goats (n = 20) were pastured daily and supplemented with 200 g/day of a complex catalytic feed (CCF). It consisted of molasses (14–18%), urea (8–10%), salt (3–4%), limestone (3–4%), cottonseed meal (13–18%), rice polishing (10–13%), corn (11–12%), poultry litter (9–10%), commercial mineral salt (1.3%), ammonium sulfate (0.3–0.5%), cement kiln dust (1.5%), and animal lard (10–15%). The control goats (n = 18) were supplemented daily with 300 g of a balanced concentrate (BC), containing 1.5% commercial mineral salt, 60% corn, 32.5% wheat bran, and 4% soybean oil meal. Stocking rates varied from 1.45 to 1.85 AU/ha and daily stocking rate from 36.4 to 58.6 AU/ha. At all times, fibrous forages were available exceeding the voluntary dry matter intake. One fistulated goat was kept in each group. Growth of the experimental goats averaged 95 g/day (±3) compared to 76 g/day (±5) of the controls (P < 0.005) in 150 days from June to November. Supplementation per kg BW was from 17.5 to 10.4 g BC/day for the control goats; the experimental goats received 12.2–6.5 g CCF/day. Weight gain in response to fermentable carbohydrates (FC) averaged 8.95 g BW gain/g FC/day for the control BC goats, compared to 28.2 g BW gain/g FC/day for the experimental CCF goats. Daily supplies of FC to goats on CCF supplementation were always below the limits for cellulolysis at 6 g/day, while FC supplies of BC rations to the control goats always exceeded them. After 2 h of shrub land pasture, the ruminal pH rose when CCF was offered and stayed above 6.6 during 12 h, while the ruminal acidity in BC goats went down to pH 5.57 at 6 h and rose to 6.5 by 12 h. Ammonia (NH₃ mg/l) in ruminal liquid of CCF goats was higher (P < 0.01) in average and all but one sample. Total cost per animal per day including shrub land pasture, management, medicine and salaries was US $0.06 for experimental goats and US $0.09 for controls (market price for goat meat was US $1.15/kg; US $1.00 = 10 Mexican Pesos, November 1998). Daily gain varied during the study period from 77 to 85 g/day in BC control goats compared to 92–97 g/day in experimental CCF goats. CCF supplementation to shrub land pasturing resulted in significantly greater weight gains apparently due to elevated ruminal pH, higher availability of fermentable carbohydrates and ruminal ammonia, augmenting ruminal ecosystem, digestibility and voluntary feed intake. The use of local shrub land
resources and complex catalytic supplementation with non-protein nitrogen provided greater profitability from this feeding system for growing goats than the traditional balanced concentrate feed supplementation. © 2000 Published by Elsevier Science B.V. All rights reserved.

**Keywords:** Nutrition; Goats; Growth; Ruminal ecosystem; Supplementation; Shrub land; Urea

1. **Introduction**

Goats raised on shrub range land, which is rich on fibrous forages, have low performance in body weight (BW) gain of no more than 50 g/day (Galina et al., 1993). Forages and crop residues, rich in fiber and low in protein are the most abundant feeds for ruminants in third world nations (Preston, 1995). Recent studies in Mexico with large ruminants aimed at achieving better performance from local forages by using complex catalytic feed (CCF) supplementation (Galina et al., 1997). Strategies to improve utilization with CCF feeds in dairy goats have been reported (Morales et al., 2000).

Utilization of high fiber diets with CCF needs to develop new feeding standards, because ruminal protein and energy will add to the nutritional offer in the feed to the animal (Jackson, 1980; Galina, 1994; Graham, 1983; Preston, 1995). Goat requirements have been reviewed (AFRC, 1998), after the work of Morand-Fehr and Sauvant (1988) and NRC (1981). Energy requirements for goats are 104.7 kcal/kg BW0.75 for maintenance plus 25–50% increase to cover cost of walking, grazing and other activities, and 13.8 Mcal/kg BW gain (AFRC, 1998). Present information on energy and protein contents of a feed has little bearing on how animals utilize their feed, when digestibility is improved due to bacterial augmentation from favorable energy contents in ration, resulting in more intestinal true protein. It have even been suggested that traditional nutritional approaches should be abandoned for forage-based diets under fibrous forage management (Leng, 1990).

Nutritional utilization of fibrous forages requires that the imbalance of nutrients for both rumen microorganisms and the host animal must be corrected for better nutrition of rumen bacteria by providing energy and nitrogen, which then results in improved bypass nutrients to reach the intestines for higher production by the host animal with lowered cost (Ørskov, 1994; Wells and Russell, 1996; Russell and Wilson, 1996; Weimer, 1996).

Better understanding of rumen function and the role of CCF supplementation has been tested in Mexico (Galina et al., 1997). Recent studies lead to the concept of “balancing nutrients” by providing high protein to energy ratios in absorbed nutrients, and improving productive efficiency (Leng, 1990). Goats can be considered as animals with a two-compartment system (Morales et al., 2000). Efficient microbial fermentation relies on the products of the rumen and those digestible feed components that escape fermentation (Preston, 1995). Under laboratory conditions, many factors can be isolated and studied in detail, but few studies have attempted to elucidate simultaneously the interaction of many factors that result in the efficiency of end-product utilization by the animal in production trials (Leng, 1990). The importance of the type of supplement used when evaluating forages has been emphasized by many studies (Sanson, 1993). The addition of soluble carbohydrates to diets can have a negative effect on forage intake and fiber digestibility (Purroy et al., 1993). The hypotheses for this decrease in intake include decreased ruminal pH, a substitution effect, competition for essential nutrients among cellulolytic and non-cellulolytic bacteria, and the possible use of alternative energy sources by cellulolytic bacteria (Mould, 1989). Many workers found that supplementing basic forage diets of low digestibility with small quantities of feed that are rich in digestible cellulose or hemicellulose will increase forage digestibility (Juul-Nielsen, 1981).

The effect of supplementation with feeds balanced in easily digestible carbohydrates in complex catalytic feeds while pasturing on shrub land is unknown. The objective of the present study was to examine the effect of a complex catalytic supplementation with non-protein nitrogen as urea on the utilization of shrub land by growing goats. The study was to be performed
in Querétaro, Mexico, with 38 goats pasturing brush land and supplemented with complex catalytic feeds. The study should allow balancing the nutrients needed by the rumen bacteria and measure the effects of modifying the ecosystem with sufficient bypass nutrients on goat growth and economic feasibility. Traditionally balanced supplementation (Morand-Fehr and Sauvant, 1988) was to be employed for control goats.

2. Material and methods

The study was conducted on the “Puma” farm in the Cerro Prieto region, Querétaro, Mexico, at 20°35’ latitude North and 100°18’ longitude West. The altitude was 1950 m above sea level. Climate is classified as Bs 1 kw (e), described as dry semiarid with isolated rains in the winter and a total of 460 mm of average precipitation per year (García, 1973). The research was performed on 40 ha of shrub range land with grasses: Bouteloua curtipendula, Chloris virginia, Bothriochloa saccharoides, Leptochloa dubia, Rhynchoscythusum roseum, Panicum obtusum, Bouteloua repens, Aristida adscensionis, Setaria parviflora, Urochloa fasciulata; leguminous trees: Prosopis laevigata, Acacia farnesiana, Acacia schaffneri, Mimosa biuncifera; and shrubs: Celtis pallida, Jatropha dioica, Zalazania augusta, Verbascia serrata, Opuntia spp.

A production of 800 kg DM/ha/year was calculated (Galina et al., 1998). Grazing management and techniques for shrub land evaluation was published by Puga (1998). Stocking rates varied from 1.45 to 1.85 AU/ha and daily stocking rate from 36.4 to 58.6 AU/ha. At all times, fibrous forages were available exceeding the voluntary dry matter intake.

Thirty-eight young Alpine goats, 16.1 (±0.37) kg BW, were allocated into two treatment groups in a production function design. Animals were weighed every 15 days. On experimental group of 20 goats were pastured daily and supplemented with 200 g/day of a complex catalytic feed mixture (CCF) consisting of molasses (14–18%), urea (8–10%), salt (3–4%), limestone (3–4%), cottonseed meal (13–18%), rice polishing (10–13%), corn (11–12%), poultry litter (9–10%), commercial mineral salt (1.3%), ammonium sulfate (0.3–0.5%), cement kiln dust (1.5%), and animal lard (10–15%). The control group of 17 goats was kept on similar management but fed 300 g/day of a traditional balanced concentrate (BC) composed of 1.5% commercial mineral salts, 60% corn, 32.5% cottonseed meal, and 4% soybean oil meal. Chemical feed analyses were performed according to AOAC (1995); determination of fiber contents according to Van Soest and Wine (1967) and Goering and Van Soest (1975) methods; total energy with a calorimetric bomb after Hill et al. (1958) and Robinson (1984); shrub land forages were combined for chemical analyses with the method of Puga (1998).

Cellulolysis and rumen eco-environment was determined by using one fistulated goat in each treatment group to measure pH and ruminal ammonia (N–NH3) levels. Each goat was sampled every 2 h after supplementation every 15 days, as described by Beatman (1970), with a portable recorder (Orion 250-A) equipped with an ion selective electrode for ammonia (Orion 95-12). From the chemical analyses of the two supplements the contents and supplies of fermentable carbohydrates were calculated in g/day. Supplementation in g/day was also recorded monthly in g/kg BW. Daily voluntary intake was determined for both supplements and for the forages in pasture according to INRA (1988).

Statistical analyses for pH and ammonia were performed comparing means with SAS (1996) procedures (P < 0.05). The statistical model was: \( Y_{ij} = \mu + t_i + E_{ij} \), where \( Y_{ij} \) is pH or NH3 jth observation of the ith treatment; \( \mu \) the overall mean; \( t \) the treatment effect; \( i \) the ith treatment (i = 1, 2, …, 4 supplement type); \( j \) is the jth observation (j = 1, 2, …, 4 (pH); 1, 2, …, 4 (NH3) observation); and \( E_{ij} \) is the error.

Statistical analyses of the 4 × 4 Latin square design were performed with ANOVA (SAS, 1996), and differences between means were analyzed according to Tukey (P < 0.05). The model was: \( Y_{ijkl} = \mu + A_i + B_j + T_t + E_{ijkl} \), where \( Y_{ijkl} \) are variables such as goat growth, supplementation g/kg BW, fermentable carbohydrates in g/kg BW, and supplementation g/day/g BW gain; \( \mu \) is the overall mean; \( A_i \) the effect from the ith line (goat); \( B_j \) the effect from the jth column (time); \( T_t \) the effect of treatment shown in the jth line/column; and \( E_{ijkl} \) is the error associated with the experimental unit line/column (ij).

Statistical analyses were also performed by multiple regression comparing variables (SAS, 1996).
Monthly consumption and nutrient requirements as suggested by Morand-Fehr and Sauvant (1988) were dependent variables. By regression equation, the nutrient density of the feeding treatments and the total requirements of the grazing goats were the determinants of probable consumption.

3. Results

Table 1 shows monthly BW of the control and experimental groups. The amounts of voluntary intake of BC supplementation went from 17.5 g/day/kg BW at the beginning of the trial in control goats to 10.4 g/day/kg BW at the end, when the 300 g/day were offered. The intake of CCF supplementation went from 12.2 to 6.5 g/day/kg BW, when 200 g/day were offered. At the end of the trial, BC supplementation was 59% lower from initial consumption, CCF supplementation 53% lower. While the amounts offered remained constant throughout the trial, the BW increased almost two-fold. Total dry matter intake (DMI) by the CCF group increased from 3.1% to 3.8% of BW, while the DMI of the BC group decreased from 3.3% to 2.9% of BW. Forage intake increased from 265 to 536 g/day in BC, while in CCF goats it changed from 311 to 973 g/day. Goats in the CCF group consumed significantly more forage than the BC controls.

Experimental CCF goats showed an average growth of 95 g/day (+3) compared to 76 g/day (+5) (Table 1) for BC controls during 150 days from June to November (P < 0.005). The rotationally grazed shrub land pasture consistently had more total forage available during midsummer and late summer. However, once the period of plant regrowth finished in early autumn, the rotational pasture had similar or less total forage standing, while grass was available at all times exceeding the voluntary dry matter intake. Experimental CCF feeds were consumed for 6–8 h after offering, in comparison with BC rations, which were eaten in 15–30 min after supply.

Fig. 1 shows the amounts of fermentable carbohydrates consumed daily/kg BW calculated from the chemical analyses of the feeds. Response to fermentable carbohydrates in terms of grams BW gain/day/g FC averaged 8.95 for BC, compared to 28.27 for CCF goats (P < 0.05) (Table 1). Daily supplies of FC to goats on CCF supplementation were always below the limits of 6 g/day for cellulolysis (Mould, 1989), while FC supplies of BC rations to the control goats always exceeded them.

Table 1

<table>
<thead>
<tr>
<th>Days (d)</th>
<th>0</th>
<th>30</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>150</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW (kg), BC goats</td>
<td>17.14</td>
<td>19.45</td>
<td>21.55</td>
<td>21.40</td>
<td>26.60</td>
<td>28.84</td>
<td>22.44 ± 4.4</td>
</tr>
<tr>
<td>BW (kg), CCF goats</td>
<td>16.41</td>
<td>19.29</td>
<td>22.19</td>
<td>25.06</td>
<td>27.93</td>
<td>30.68</td>
<td>25.59 ± 5.35</td>
</tr>
<tr>
<td>BC total (g/day)</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>CCF total (g/day)</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>FI–BC group (g)</td>
<td>265</td>
<td>387&lt;sup&gt;a&lt;/sup&gt;</td>
<td>400&lt;sup&gt;a&lt;/sup&gt;</td>
<td>346&lt;sup&gt;a&lt;/sup&gt;</td>
<td>478&lt;sup&gt;a&lt;/sup&gt;</td>
<td>536&lt;sup&gt;a&lt;/sup&gt;</td>
<td>402 ± 95.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>FI–CCF group (g)</td>
<td>311</td>
<td>536&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>617&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>752&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>832&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>973&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>670 ± 234&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total DMI BC (g)</td>
<td>565</td>
<td>687</td>
<td>700&lt;sup&gt;a&lt;/sup&gt;</td>
<td>646&lt;sup&gt;a&lt;/sup&gt;</td>
<td>778&lt;sup&gt;a&lt;/sup&gt;</td>
<td>836&lt;sup&gt;a&lt;/sup&gt;</td>
<td>702 ± 95.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total DMI CCF (g)</td>
<td>511</td>
<td>736</td>
<td>817&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>952&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1032&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1173&lt;sup&gt;b&lt;/sup&gt;</td>
<td>870 ± 234&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>DMI (%) BW–BC</td>
<td>3.3</td>
<td>3.5</td>
<td>3.2</td>
<td>3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.1 ± 0.24&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>DMI (%) BW–CCF</td>
<td>3.1</td>
<td>3.8</td>
<td>3.7</td>
<td>3.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.7 ± 0.28&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>BC (g/kg) BW</td>
<td>17.50</td>
<td>15.42</td>
<td>13.92</td>
<td>12.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.27&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>10.40&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>13.39 ± 2.66</td>
</tr>
<tr>
<td>CCF (g/kg) BW</td>
<td>12.18</td>
<td>10.36</td>
<td>9.01</td>
<td>7.98&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.97 ± 2.31</td>
</tr>
<tr>
<td>FC (g/day) BC</td>
<td>11.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.71&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.76&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.55&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.49 ± 1.67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>FC (g/day) CCF</td>
<td>4.62&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.93&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.36 ± 0.80&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>FC (g/g) BW BC gain</td>
<td>7.92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.69&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.45&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.95&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>FC (g/g) BW CCF gain</td>
<td>24.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.36&lt;sup&gt;b&lt;/sup&gt;</td>
<td>31.68&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.24&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.27&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>BC gain (g/day)</td>
<td>77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>CCF gain (g/day)</td>
<td>96&lt;sup&gt;b&lt;/sup&gt;</td>
<td>97&lt;sup&gt;b&lt;/sup&gt;</td>
<td>96&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96&lt;sup&gt;a&lt;/sup&gt;</td>
<td>92&lt;sup&gt;b&lt;/sup&gt;</td>
<td>95&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>
Table 2 shows the chemical composition of forages, CCF and BC supplements. Crude protein contents for both forages were 7.68% and 8.10%, respectively; metabolizable energy was 2.12 and 2.49 Mcal for BC and CCF forages, respectively. Supplements contained 19.8% crude protein for BC and 26.13% for CCF, due in part to the amount of urea. The table also shows crude fiber, NDF, ADF, cellulose, hemicellulose and lignin contents, the later above 8% in both forages.

Table 3 summarizes the ruminal kinetics of pH over time in goats fed CCF or BC while pasturing shrubland. After 2 h on CCF the pH rose and stayed above 6.6 for 12 h, while the ruminal acidity in

<table>
<thead>
<tr>
<th>BC forage</th>
<th>CCF forage</th>
<th>BC</th>
<th>CCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (%)</td>
<td>93.69</td>
<td>99.65</td>
<td>90.53</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>5.08</td>
<td>9.21</td>
<td>5.60</td>
</tr>
<tr>
<td>Ether extract (%)</td>
<td>2.70</td>
<td>1.08</td>
<td>4.07</td>
</tr>
<tr>
<td>Crude protein (N × 6.25) (%)</td>
<td>7.68</td>
<td>8.10</td>
<td>19.83</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>36.04</td>
<td>35.81</td>
<td>12.56</td>
</tr>
<tr>
<td>Neutral detergent fiber (%)</td>
<td>75.17</td>
<td>68.82</td>
<td>68.40</td>
</tr>
<tr>
<td>Acid detergent fiber (%)</td>
<td>39.73</td>
<td>45.75</td>
<td>13.16</td>
</tr>
<tr>
<td>Cellular content (%)</td>
<td>34.83</td>
<td>31.17</td>
<td>31.59</td>
</tr>
<tr>
<td>Cellulose (%)</td>
<td>32.90</td>
<td>31.67</td>
<td>7.84</td>
</tr>
<tr>
<td>Hemicellulose (%)</td>
<td>67.27</td>
<td>65.37</td>
<td>55.23</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>8.54</td>
<td>9.48</td>
<td>4.86</td>
</tr>
<tr>
<td>Nitrogen free extract (%)</td>
<td>61.50</td>
<td>60.80</td>
<td>57.94</td>
</tr>
<tr>
<td>Total digestible nutrients (%)</td>
<td>95.49</td>
<td>92.91</td>
<td>99.89</td>
</tr>
<tr>
<td>Metabolizable energy (Mcal) a</td>
<td>2.12</td>
<td>2.49</td>
<td>2.83</td>
</tr>
<tr>
<td>Digestible energy (Mcal) a</td>
<td>3.59</td>
<td>3.35</td>
<td>3.61</td>
</tr>
<tr>
<td>Total energy (Mcal) a</td>
<td>4.37</td>
<td>4.08</td>
<td>4.39</td>
</tr>
</tbody>
</table>

a Mcal/kg dry matter.
BC goats went down to pH 5.57 at 6 h and rose to 6.5 by 12 h.

Table 4 shows the ruminal kinetics of ammonia (NH₃ mg/l) over time in goats fed CCF or BC while on shrub land pasture. Ammonia was higher (P < 0.01) in the CCF group on an average and in all but one sample.

Total cost per animal per day including grass, management, medicine and salaries was US $0.06 for the experimental CCF goats but US $0.09 for control BC goats. Market price per kg meat was US $1.15 calculated in Mexican Pesos per dollar exchange rate of November 1998 (1 US $ = 10 Pesos). Daily gain varied during the trial from 70 to 85 g/day in control BC goats to 92 to 97 g/day in experimental CCF goats (Table 1).

Table 3
Ruminal kinetics of pH over time in goats fed CCF or BC on shrub land pasture (CCF: complex catalytic feed; BC: balanced concentrate; A,B: means with different letters indicate statistical significance (P < 0.01); a,b: means with different letters indicate statistical significance (P < 0.01))

<table>
<thead>
<tr>
<th>Hours</th>
<th>CCF</th>
<th>BC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.75ab ± 0.50</td>
<td>6.58a ± 0.30</td>
</tr>
<tr>
<td>2</td>
<td>6.98ab ± 0.09</td>
<td>5.93ab ± 0.36</td>
</tr>
<tr>
<td>4</td>
<td>6.80ab ± 0.16</td>
<td>5.59b ± 0.06</td>
</tr>
<tr>
<td>6</td>
<td>6.60b ± 0.26</td>
<td>5.57b ± 0.24</td>
</tr>
<tr>
<td>8</td>
<td>6.61b ± 0.29</td>
<td>6.00b ± 0.22</td>
</tr>
<tr>
<td>10</td>
<td>6.66ab ± 0.16</td>
<td>6.12ab ± 0.28</td>
</tr>
<tr>
<td>12</td>
<td>6.69ab ± 0.29</td>
<td>6.50b ± 0.23</td>
</tr>
<tr>
<td>Average pH</td>
<td>6.72A ± 0.10</td>
<td>6.04B ± 0.39</td>
</tr>
</tbody>
</table>

4. Discussion
Results showed differences in growth rate (P < 0.05) for experimental over control goats, suggesting that daily gains of 100 g (AFRC, 1998) can be obtained with good nutritional management. The protein needs of the experimental goats for growth were met by correcting the nutrient imbalance of the grasses and providing a continuous non-protein nitrogen source of urea (Hennessay and Williamson, 1990) or ammonium sulfate to the rumen bacteria (Leng, 1990; Silva et al., 1989). Ruminal bypass protein, e.g. fishmeal, and bypass carbohydrates in corn and rice polishings have proven important in cattle performance when fed fibrous forages (Elliot et al., 1978; Leng et al., 1977; Naidoo et al., 1977; Galyean, 1996; Popp and McLennan, 1995). Bypass protein in our experiment was supplied by the legume tree leaves (Puga, 1998). Growth in the control goats was supported mainly by the high protein content in the BC ration, which hand a substitution effect for the poor forages (Tables 1 and 2). Low rumen pH and less ammonia contents in the control goats explained the effects of concentrate intake in pastured goats. The high amounts of fermentable carbohydrates also affected cellulolysis (Elías, 1983; Madrid et al., 1998). When microbial protein is the main source of nitrogen for growth, there must be considerable concern covering the requirements by rumen microbes for efficient growth. Mean et al. (1989) suggested that microbial growth efficiency was improved in washed rumen microbes by including amino acids as well as urea in the incubation medium. Amino acids such as leucine, lysine, threonine and tryptophan were supplemented in the CCF experimental diet by the addition of poultry litter as also demonstrated by Zinn et al. (1996).

Previously, Elías (1983) has shown that small amounts of easily available energy from fermentable carbohydrates like in molasses, sugar cane or starch could increase cellulose digestibility because ruminal microorganisms are not capable to obtain energy from cellulose for their cellular functions until the molecule is digested. Therefore, goats, sheep and cattle supplemented with low levels of sugars between 2 and 6 g/kg BW/day could improve cellulose digestibility because rumen microorganisms now have energy for their cellular functions. Similar findings have been reported.
when low amounts of citrus by-products were supplemented at 100 g/day and improved digestibility and intake of DM of urea–NaOH treated straw based diets (Madrid et al., 1998). The explanation was that at low levels the supplementation with degradable carbohydrates such as from citrus by-products supplied energy for ruminal microorganism and improved the ruminal ecosystem for cellulolysis and straw digestion (Madrid et al., 1998). However, at more than 6 g of fermentable carbohydrates (FC) per kg of BW, cellulose digestibility diminished because concentrate supplementation substituted for forage. It has been shown that moderate amounts of cellobiose added to pure cultures of cellulolytic bacteria inhibit cellulose hydrolysis, which suggests an enzyme depressing system based on less specific activity for cellulose from microorganisms growing in a cellobiose-rich environment (Elias, 1983). Similar results have been published by Madrid et al. (1998), when higher levels of digestible carbohydrates in supplements depressed the digestion of straw. This is also explained by the negative effects on cellulolytic activities of the rumen microflora, when high levels of energy supplements decrease ruminal pH (Rihan et al., 1993). In our study, CCF fermentable carbohydrates were always below the above limits (4.62–2.47 g FC/day) (Table 1) favoring the ruminal ecosystem to stimulate feed intake and BW gain, while FC from the BC ration was always above the limits (11.02–6.55 g/day) apparently affecting cellulolysis.

Daily weight gain in the present work apparently did not equal the levels of metabolizable energy in the forages (Table 2). Increased voluntary dry matter intake supplied more energy, because of improved digestibility from the improved action of cellulolytic bacteria (Fibrobacter succinogenes, Ruminococcus albus, R. Flavefaciens) favored by the continuous presence of non-protein nitrogen (Leng, 1990; Fondevila and Dehory, 1995; Preston, 1995; Brown et al., 1988). This is indicated by the higher levels of ruminal ammonia (17.37 mg/l; P < 0.01) (Table 4) in CCF supplemented goats compared to the BC goats (10.30 mg/l), creating a favorable protein/energy ratio for bacterial protein formation (Leng, 1991). The experimental CCF supplement was consumed over a period of 6–8 h, while the commercial BC supplement was ingested in less than 30 min after offering (15–30). This mixture could have insured sufficient ammonia for microbial growth (50–80 mg NH₃-N/l rumen fluid) (Leng, 1991), but the level of ammonia needed is dependent on the pH of the rumen (Smith, 1984).

Forage offer was kept high all time through the rational technological mobile grazing (RTMG) system developed by Puga (1998), boosting digestibility of the basal diet (Juul-Nielsen, 1981; N’dlovu and Buchannan-Smith, 1985). Grass was allowed to regrow before returning to be pastured (Puga, 1998). Sudana and Leng (1986). Showed that supplements must provide continuous adequate levels of ammonia for persistent growth of both fibrolytic and saccharolytic microorganisms, by providing in the supplement high concentrations of salt–urea and molasses–urea to avoid fast intake. Supplementation with branched-chain VFA has been reported to increase the apparent flow of microbial-N to the duodenum (Silva and Ørskov, 1988). Ruminal pH supported by calcitic limestone and cement kiln dust could have played a key role of maintaining cellulolytic bacteria in our experimental animals (Wheeler, 1979; Wheeler et al., 1981a, b; Noller et al., 1980).

Rumen acidity is produced by high intake of starches. Amylose and amylopectin are broken down early under the influence of amylases. Ruminal pH environment for microbial activity was lower in the BC supplemented goats (Table 3). CCF supplementation kept pH above 6.6 all the time, while BC decreased pH to 5.57 inhibiting celullolysis (Leng, 1991). This may explain the lesser growth of the BC control goats, depending on energy and protein from their supplementation, because of less bacterial protein formation. As rumen pH is depressed below 6.2 (Istasse et al., 1986), cellulolysis progressively decreased and ceased altogether at rumen pH of around 5.9 (Ørskov, 1994; Russell and Wilson, 1996; Russell et al., 1979; Weimer, 1996).

Sulfur and phosphorus have been proven to be essential for bacterial growth (Leng, 1990) as was assured in our experimental diets. In general practice there is either no mineral supplement provided or a “shot gun” mixture is given as salt licks (McDowell et al., 1984). In this study, molasses, which is already rich in minerals was suitably fortified with minerals (Kunju, 1986). Acetic acid does not seem to be a major constrain to oxidation, because the ruminant reacts to excess supplies by excreting acetate in the urine.
Long-chain fatty acids in animal lard, as provided in the CCF supplement, potentially generate reduced nicotinamide adenine dinucleotide (NADPH) and electron acceptors (NAD$^+$) for increased use of acetate. This and the high energy density of the animal lard may explain the better growth performance of the CFF goats on less supplement (200 vs 300 g/day) than the BC controls (Houtert, 1993).

Molasses as a cheap source of FC, and the buffer effects of limestone and cement kiln may explain the complex relationships established by this feed in manipulating fiber digestion in the rumen (Ørskov, 1991). High levels of molasses–urea have been successfully used for fattening of cattle on pasture in Australia (Anon, 1984), Colombia (Huerta and González, 1987) and Cuba (Valdés and Delgado, 1990).

It could be suggested from the present results that goat kids adequately supplemented with small quantities of essential nutrients performed equally well on a lower digestibility feed, as animals on higher digestibility forage. Pasture management was the other key to obtain gains from grass offered throughout the study (Puga, 1998). Heat increment of added acetogenic substrates will depend on the pattern of fermentation in the rumen, VFA and the balance of protein available from the intestine. Goats need to oxidize acetate, the major thermogenic substrate. Ruminants confined to calorimeters are usually maintained at what is supposed to be thermoneutrality, however, in our study, animals were exposed to heat and cold (rain) stress and they responded metabolically according to the insulative properties of their skin. Variances in weekly gains were related to environmental effects. Acetogenic substrate is the major source of ATP for muscle metabolism (Pethick, 1984), therefore acetate formation in this study could explain the growth of the supplemented goats (Leng, 1990).

5. Conclusion

Utilization of fibrous diets by ruminants can be manipulated in various ways. Digestibility and intake was improved as evidenced by superior weight gain of 95 g/day for CCF goat kids compared to 76 g/day by BC goats. This was apparently due to elevated rumen pH and ammonia levels augmenting the bacterial ecosystem by offering essential amino acids, long-chain fatty acids, non-protein nitrogen, calcium, sulfur and phosphorus, which in turn improved cellulose digestion. Direct bypass protein and glycogenic carbohydrates from the rumen are other key ingredients to the present results. Use of the local resources of shrub land pasture provided the economical feasibility and profitability of the diet.

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