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# Production and economic potentials of cattle in pasture-based systems of the western Amazon region of Brazil[1]

**B. L. Rueda*, R. W. Blake†[2], C. F. Nicholson‡, D. G. Fox†, L. O. Tedeschi†, A. N. Pell†, E. C. M. Fernandes§, J. F. Valentim#, and J. C. Carneiro#**

*Instituto Nacional de Investigaciones Forestales y Agropecuarias, Melchor Ocampo 234, Veracruz, VE 91700, México; Departments of †Animal Science, ‡Applied Economics and Management, and §Crop and Soil Sciences, Cornell University, Ithaca, NY 14853; and #Centro de Pesquisa Agroflorestal EMBRAPA-Acre, Caixa Postal 321, Rio Branco, AC 69908-970, Brazil

**ABSTRACT:** Our objectives were to evaluate strategies to improve productivity and economic returns from beef and dual-purpose cattle systems based on data collected on one dual-purpose (*Bos taurus* × *Bos indicus*) and two beef (Nellore) cattle farms in the western Amazon region of Brazil. Forage chemical composition and digestion rates of carbohydrate fractions of grazed *Brachiaria decumbens* and *Brachiaria brizantha* cv. Marandu grasses and *Pueraria phaseoloides* (tropical kudzu) legume were measured monthly during a 9-mo period from the end of one dry season to the end of the subsequent rainy season. Measurements of milk and growth responses to grazing these forages were used to predict animal productivity responses to dietary nutrient availability throughout an annual cycle. The ME available for gain in our simulations was always more limiting than metabolizable protein. The predicted ME available for gain was 0.50 kg/d for steers grazing *B. brizantha* and 0.40 kg/d for finishing steers grazing *B. decumbens*. Grasses contained more NDF and neutral detergent insoluble protein and less ME ($P < 0.05$) in the rainiest months than in the less rainy season, which resulted in 20% less predicted weight gain by growing steers ($P < 0.05$). Supplementation with sorghum grain was required to increase milk production and growth by 25 or 50% per animal, respectively, but this strategy was less profitable than current forage-only diets. Greater productivity of land and labor from higher stocking indicated greater net margins for beef production, but not for milk. This study suggested that more intensive beef production by judicious fertilization of grass-legume pastures and greater stocking density is the preferable strategy for owners of these cattle systems to improve economic returns under current conditions. It also might help decrease the motivation for additional forest clearing.

Key Words: Amazonia, *Brachiaria*, Nellore, Simulation Models, Sustainability

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## Introduction

The Brazilian cattle herd comprises 167 million animals (de Gouvea and Kassicieh, 2001). One-fourth of them reside in the Amazon region (INPE, 2000), where extensive systems prevail due to limitations of soil fertility, seasonal variation in rainfall and other climatic and economic factors (Faminow, 1998). Nearly all milk is from dual-purpose cows and most beef is from Nellore steers grazing without dietary supplementation.

Pasture grasses in the Amazon region typically are *Brachiaria spp*. selected for acid soils (Vera et al., 1992; Fisher and Kerridge, 1996). Although the effects of temperature are known (Nelson and Moser, 1994; Van Soest, 1994), there is little published information about the influence of monthly fluctuations in forage composition and digestion rates on animal performance (Tedeschi et al., 1999).

The evaluation of cattle systems is aided by modeling to estimate nutrient requirements of animals (Fox et al., 2003) and nutrients from feeds and diets (Sniffen

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[2]Correspondence—phone: 607-255-2858; E-mail: rwb5@cornell.edu.

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et al., 1992) to predict probable productivity. For example, Juarez et al. (1999) found large variations in milk production potentials of 15 grasses during a 6-wk period in Gulf Coast Mexico using animal and forage inputs into the Cornell Net Carbohydrate and Protein System model (**CNCPS**; Fox et al., 2003). More information of this kind across seasons is required to better manage cattle systems in the tropics.

The purpose of this study was to evaluate management strategies for cattle systems in the western Brazilian Amazon based on data collected for this purpose and knowledge of performance under tropical conditions. Specific objectives were to evaluate seasonal effects on the nutritional values of *B. decumbens* and *B. brizantha* grasses and *Pueraria phaseoloides* legume to support milk production by dual-purpose (*Bos taurus* × *Bos indicus*) cows and growth of Nellore steers and to use these data to evaluate the profitability of options to improve cattle productivity and land use.

## Materials and Methods

### *Site Description*

Study sites were private farms located within 80 km of Rio Branco, Acre (Brazil). This moist humid tropical region is located at lat 07°07′ S and long 66°30′ W. Annual mean rainfall is approximately 1,800 mm, which is especially concentrated from November to March (e.g., 200 to 300 mm/mo). The annual means for temperature and relative humidity are about 25°C and 85%, respectively. The predominant soils are Ultisols and Oxisols with pH 5.5, low P content (<5 ppm), and low cation exchange capacity (Rueda, 2002).

Forages were sampled and animal performance was recorded monthly during a 9-mo period at three collaborating farms (a dual-purpose herd with 90 ha of land and two beef herds with 1,600 ha and 3,000 ha). The period of study was from the end of the 1999 dry season until the end of the subsequent rainy season in June 2000. Initial measurements (October) were taken prior to first precipitation in the 1999 to 2000 rainy season, which corresponded to the annual nadir in soil moisture content and total pasture biomass. Consequently, we were able to infer probable forage nutrient supply and animal performance, thus completing an annual cycle, without actually monitoring them during the rest of the dry season (i.e., July, August, and September).

### *Animal and Environmental Measurements*

Lactating dual-purpose cows, growing steers (210 kg at 16 mo of age), and finishing steers (385 kg at 24 mo of age) were monitored monthly under field conditions. These measurements were used to establish baseline (typical observed) milk and growth responses to rotationally grazed forages from which multiple samples were also taken for chemical and kinetic analysis. Yield of saleable milk from 15 *Bos taurus* (mostly Holstein and Brown Swiss) × *Bos indicus* (mostly Nellore) crossbred cows was estimated from individual daily yields weighed at monthly intervals with calibrated scales. Multiparous lactating cows weighing about 400 kg (Table 1) and approximately 60 d in milk at the beginning of the study grazed a mixed stand of *B. decumbens* and *P. phaseoloides* (hereafter referred to as "kudzu"). Kudzu provided about 10% of available forage DMI. Individual body weights of 50 Nellore steers (10 growing steers grazing *B. brizantha* cv. Marandu and 40 finishing steers grazing *B. brizantha* or *B. decumbens*) were taken during morning routines using calibrated farmer-owned scales. Growing steers and dual-purpose cows received different mineral supplements (Ca, 13.5 and 25%; P, 0.8 and 13.5%; Mg, 0.71 and 1.1%; K, 0.19 and 0.65%; Na, 0.98 and 16.8%; Fe, 2,780 and 3,310 ppm; Zn, 1,120 and 1,290 ppm; Co, 201 and 350 ppm; and Mn, 305 and 500 ppm, respectively on a DM basis) and were visually scored for body condition on a nine-point scale (NRC, 2000). Temperature, relative humidity, rainfall, wind speed, and other environmental information were obtained throughout the period of study from collaborating farms and the EMBRAPA-Acre research station. Animal performance and environmental data were summarized for use as inputs for CNCPS prediction of animal requirements as shown in Table 1.

### *Forage Sampling*

Total accumulated plant biomass was estimated monthly for each of four paddocks by the cutting-quadrants method, with 20 microplot (0.25 $m^2$) cuttings per paddock (Mannetje, 2000) and DM determination of a representative sample. Grasses were cut 20 cm above the soil surface from swards with a measured height of 80 cm. Paddocks were grazed with two animal units per hectare, which is the average stocking rate in this region [one animal unit = 450 kg of live weight] (Faminow, 1998). Two paddocks were sown with *B. decumbens* (14 and 20 yr after establishment) and two were sown with *B. brizantha* cv. Marandu (4 and 8 yr after establishment). Grasses were sampled biweekly, from which 36 grass samples (nine from each paddock) were selected for laboratory analysis. These samples were selected because they were collected closest to the monthly dates when milk production and BW were measured. In addition, one paddock containing kudzu and *B. decumbens* (6 yr after establishment) provided nine monthly samples of kudzu to assess the dietary contribution of this legume. Following recommendations by Van Soest (1994), grass samples were obtained by observing grazing behavior and simultaneously hand plucking plant parts comparable to the ones selected. The top 20 cm of plants in the sward, which was the portion grazed (Rueda, 2002), was also clipped, and green leaves were separated from stems for separate weighing.

**Table 1.** Animal and environmental descriptions assumed for lactating dual-purpose cows and Nellore steers for simulation with the Cornell Net Carbohydrate Protein System model for Acre, Brazil

| Item | Dual-purpose cows | Growing steers | Finishing steers |
|---|---|---|---|
| Animal description | | | |
| Age, mo | 65 | 16 | 24 |
| Body weight, kg | 420 | 210 | 385 |
| Mature weight, kg | 500 | 500 | 500 |
| Condition score, 1 = thin, 9 = fleshy | 5 | 5 | 6 |
| Harvest, % body fat | — | 22 | 22 |
| Days pregnant | 50 | — | — |
| Days postpartum | 180 | — | — |
| Lactation number | 3 | — | — |
| Calving interval, mo | 16 | — | — |
| Expected calf birth weight, kg | 34 | — | — |
| Age at first calving, mo | 30 | — | — |
| Herd average milk, kg/lactation | 2,000 | — | — |
| Milk production, kg/d | 6.7 | — | — |
| Milk fat, % | 4.0 | — | — |
| Milk protein, % | 3.2 | — | — |
| Management description | | | |
| Type of pasture | *Brachiaria decumbens* + *Pueraria phaseoloides* | *Brachiaria brizantha* | *Brachiaria decumbens* |
| Supplementation | Minerals | None | Minerals |
| Environment description | | | |
| Wind speed, kph | 3 | 3 | 3 |
| Previous temperature, °C | 24 | 24 | 24 |
| Previous relative humidity, % | 80 | 80 | 80 |
| Current temperature, °C | 24 | 24 | 24 |
| Current relative humidity, % | 80 | 80 | 80 |
| Sunlight exposure, h | 10 | 10 | 10 |
| Storm exposure | No | No | No |
| Minimum night temperature | 18 | 18 | 18 |
| Hair depth, cm | 2 | 2 | 2 |
| Hide | Thin | Thin | Thin |
| Mud depth, cm | 0 | 0 | 0 |
| Hair coat | No mud | No mud | No mud |
| Cattle panting | None | None | None |
| Grazing activity | Intensive | Continuous | Intensive |
| Time spent standing, h/d | 16 | 18 | 16 |
| Body position changes, No. | 6 | 6 | 6 |
| Flat distance, m | 1,000 | 2,000 | 1,000 |
| Sloped distance, m | 0 | 0 | 0 |

### *Chemical Composition and Digestion Kinetics of Feeds*

Immediately after collection, 500 g of each forage sample was dried at 55°C in a forced-air oven for 72 h and ground in a Wiley-type mill to pass through a 1-mm screen. Four samples of commercial protein/energy supplements also were obtained from Rio Branco vendors to assess their nutritional composition. Contents of CP, neutral detergent insoluble protein (**NDIP**), and acid detergent insoluble protein (**ADIP**) were determined by a modified Kjeldahl procedure using a boric acid solution (AOAC, 1990). Soluble CP was determined using the sodium borate–sodium phosphate method (Roe and Sniffen, 1990). Acid detergent fiber, acid detergent lignin, ash (AOAC, 1990), and NDF were also determined (Van Soest et al., 1991). The neutral detergent soluble fiber ($\beta$-glucans and fructans) was estimated by the ethanol insoluble residue procedure (Hall et al., 1997). The amount of ether extract was determined and minerals were extracted with acid solution (1.5$N$ $HNO_3$ + 0.5$N$ HCl) and determined by radial spectrometry (Sirois et al., 1994).

*Carbohydrate Fractions and Digestion Rates of Feeds.* The CNCPS model estimates the ME content of feeds based on expected dietary intake, chemical composition, and digestion and passage rates of the carbohydrate fractions. The carbohydrate fractions, in order of decreasing rate of digestion, are: A fraction, which is fully water-soluble (e.g., simple sugars, organic acids, and fructans); $B_1$ fraction, which is polymerized but partially water-soluble (e.g., pectin and starch); $B_2$ fraction, which is insoluble fiber (e.g., cellulose and hemicellulose); and C fraction, which is insoluble and indigestible (e.g., lignin; Sniffen et al., 1992). Digestion kinetics of carbohydrate fractions in the grasses was estimated from water-soluble carbohydrates, in vitro digestion, and the rates of digestion. Digestion rates for kudzu were those reported by Tedeschi et al.

(2002a), which are in the CNCPS feed library, because equipment was not available to lyophilize samples.

*Water-Soluble Carbohydrate Fractions ($A+B_1$).* Approximately 0.75 g of ground forage was stirred for 15 h at 39°C with 75 mL water containing 10% (vol/vol) *t*-butanol. The solids were collected by filtration through a 47-μm nylon mesh screen, washed with cold water, briefly rinsed with 95% ethanol, and dried at 45°C in a vacuum oven. The DM and NDF compositions of this washed preparation were then determined (Pell and Schofield, 1993).

*In Vitro Digestion.* Digestion was estimated using the method of Pell and Schofield (1993), which measures gas produced during fermentation as a pressure increase in a closed bottle (50 mL). Each digestion utilized 100 mg of ground forage plus 8 mL of buffer and 2 mL of fresh ruminal fluid. Ruminal fluid was obtained approximately 2 h after morning feeding from an 8-yr-old, nonlactating Holstein cow weighing 650 kg, which had been fed medium-quality grass hay twice daily, with continuous access to water. Six or seven duplicate samples, a blank, and an alfalfa standard were digested in each incubator. The samples were arranged in the incubators so that both the whole and the water-extracted samples were fermented using the same ruminal inoculum. Gas accumulation was recorded at 30-min intervals during a 48-h period. When digestion was completed, buffer pH was recorded and the medium was analyzed for VFA content. Fiber disappearance was measured using the micro-NDF method described by Pell and Schofield (1993).

*Digestion Rates.* The gas data from 45 samples (36 grass and nine kudzu) were fitted to an exponential growth equation (Schofield and Pell, 1995) using the TableCurve software (SPSS Science, Chicago, IL). Digestion rates for the B3 protein fraction were from published values for *B. decumbens* and *B. brizantha* from Gulf Coast Mexico (Juarez et al., 1999), which are in the CNCPS tropical feeds library (Tedeschi et al., 2002a).

### *Statistical Analysis*

The primary objective was to evaluate the effects of season (rainiest vs. less rainy months) and grass species on the quality of grazed forage because grass is the predominant feed. Preliminary analysis, which included measurements from the end of the 1999 dry season (October), indicated that these grass species were similar in chemical composition. Except for biomass availability ($P < 0.06$), the interaction of species with season was not significant ($P > 0.50$) and was pooled in the residual. Therefore, least squares methods using the GLM procedure of SAS (version 8.1, SAS Inst., Inc., Cary, NC) were used to evaluate these effects with the following fixed effects model:

$$Y_{ijk} = \mu + S_i + F_j + e_{ijk}$$

where $Y_{ijk}$ = the observed total available biomass and chemical composition (DM, NDF, lignin, CP, soluble CP, NDIP, ADIP, fat, ash), the estimated carbohydrate digestion rates ($A+B_1$ and $B_2$ fractions), estimated ME content, and predicted ME and metabolizable protein (**MP**) available for milk production and steer growth of the *j*th grass collected in the *i*th season of year; μ = the overall mean; S = the fixed effect of the *i*th season (rainiest months of December, January, February, and March vs. less rainy months of April, May, June, October, and November surrounding the dry season); F = the fixed effect of the *j*th grass (*B. brizantha* vs. *B. decumbens*); and $e_{ijk}$ = random residual.

Comparisons of average chemical composition between grasses and kudzu were approximated by *t*-test of the unadjusted means.

### *Baseline Prediction of Animal Requirements and Nutritive Values of Forages*

The CNCPS model (version 4.0; Fox et al., 2003) was used to predict nutritive values of forages (ME content), available ME and MP, and animal requirements for baseline calibration. The MP required for maintenance was assumed to be equal to the beef cattle requirements of 3.8 g/kg of $BW^{0.75}$ (NRC, 2000). Response variables for lactating cows grazing *B. decumbens* with 10% kudzu were used to predict milk production from dietary supplies of ME (i.e., ME available for milk) and MP (i.e., MP available for milk). Response variables for steers were the predicted gains in BW from ME and MP (i.e., ME and MP available for gain) of *B. brizantha* for growing steers and *B. decumbens* for finishing steers. The feed DMI required to achieve the observed, or baseline, animal performance was obtained by equating average daily forage intake to the amount matching the predicted ME requirement (Juarez et al., 1999) because actual DMI could not be measured.

### *Potential for Increased Productivity*

Potentials for overcoming dietary limitations of the baseline scenario were evaluated by simulation. Baseline and alternative scenarios to obtain daily milk production and BW 25 or 50% greater than currently observed means were examined in nine CNCPS simulations (three each for cows and growing and finishing steers) using monthly chemical composition and digestion kinetics of the grasses and animal descriptions in Table 1. Nutritional requirements and needed supplementation were estimated monthly for each group of animals. Supplementation options included sorghum grain (85% TDN or 3 Mcal of ME/kg), which is readily available in Acre, and kudzu, a protein-rich (18% CP) forage already in use. Commercial concentrate was not considered because the energy content from our analysis of locally obtained samples (<67% TDN) was only modestly (<20%) better than the grazed portion

**Table 2.** Summary of technical coefficients, input costs and farm product prices utilized in the partial budgeting analysis of management alternatives in Acre, Brazil

| Item | Baseline | Alternative |
|---|---|---|
| Technical coefficient | | |
| Saleable milk, kg·d$^{-1}$·cow$^{-1}$ [a] | 4.2 | 5.3 to 6.3 |
| Saleable milk, kg·yr$^{-1}$·ha$^{-1}$ [a] | 605 | 908 to 1,210 |
| Labor for milking, workers/d | 0.84 | 0.91 |
| Age steers marketed, months | 34 | 28 to 30 |
| Weight at market, kg | 500 | 500 |
| Average daily gain, kg | 0.55 | 0.65 to 0.76 |
| Reduction in pasture usage, days | | 120 to 180 |
| Additional beef produced, kg | | 66 to 99 |
| Labor for beef cattle, managerial, workers·animal$^{-1}$·yr$^{-1}$ | 1.5 | 2.2 |
| Electric fence, km/ha (lactating cows) | | 0.26 |
| Electric fence, km/ha (steers) | — | 0.12 |
| Labor for fence maintenance, workers·ha$^{-1}$·yr$^{-1}$ | — | 5.0 |
| Labor for fertilization, workers·ha$^{-1}$·yr$^{-1}$ | — | 1.0 |
| Fertilizer, kg·ha$^{-1}$·yr$^{-1}$ | — | |
| 3 animal unit/ha (24 kg urea + 12 kg SP)[b] | — | 36.0 |
| 4 animal unit/ha (30 kg urea + 18 kg SP) | — | 48.0 |
| Input price | | |
| Sorghum grain, $/kg | | 0.1 |
| Labor, $·worker$^{-1}$·d$^{-1}$ | 4.0 | 4.0 |
| Monthly cost of feeders, $/animal | | 0.66 |
| Electric fence, $·km$^{-1}$·yr$^{-1}$ | | 56.0 |
| Fertilizer, kg | | 0.32 |
| Product price | | |
| Milk, $/kg | 0.08 | 0.08 |
| Beef, $/kg | 0.38 | 0.38 |

[a]Consumption of 2.5 kg of milk/d by the calf was assumed (Nicholson et al., 1994).
[b]SP = triple superphosphate.

of pasture grasses, similar to a finding in Venezuela (Townsend et al., 1990).

### *Net Economic Returns from Intensification Strategies*

Net economic returns from alternative nutritional and pasture management were approximated by partial budget analysis of marginal costs and returns. Strategies were to increase individual animal production or land productivity by raising stocking density. Individual animal options were to increase milking or growth performance per animal by 25 or 50% by dietary supplementation. Land intensification options were from increasing stocking from 2 to 4 animal units/ha, which represents the range in observed stocking densities in the Amazon region. For the increased animal performance strategy, it was assumed that additional beef could be produced in the same paddocks with animals marketed 4 to 6 mo earlier than in the baseline case (additional beef sales were included in gross revenues; Table 2). Additional inputs were supplemental feed and labor to increase animal performance or additional fertilizer, electric fencing, and labor to increase stocking density (herd size). Our analysis did not account for requirements to achieve improved reproduction to enlarge the herd and its associated effects on forage availability and variable costs.

Three fertilization strategies were considered for alternative grazing intensities with 3 and 4 animal units/ha. The annual maintenance strategy was based on the EMBRAPA-Acre recommendation of 100 kg/ha of urea and 12 kg/ha of triple superphosphate for average stocking with 2 animal units/ha (Wadt et al., 2002). A grass-only fertilization strategy to assure annual replenishment of nutrients extracted in animal products at stocking densities of 3 animal units/ha (24 kg/ha of urea and 14 kg/ha of superphosphate) and 4 animal units/ha (30 kg/ha of urea and 18 kg/ha of superphosphate) was based on findings in a companion study (Rueda, 2002). A grass-legume strategy combined current EMBRAPA-Acre recommendations with companion findings (Rueda, 2002), fertilizing with 14 or 18 kg/ha of superphosphate for 3 or 4 animal units/ha.

The data for partial budget analyses were quantities of required inputs, expected productivity responses, and prices of inputs and outputs. Technical coefficients for these assessments are summarized in Table 2. This information was obtained through direct interviews with farmers, local agrochemical store managers, milk collectors, intermediary buyers and sellers, and abattoir managers. Benefits and costs (undiscounted) were calculated using average farm-gate prices during the period of study in Rio Branco, Acre. Herbage allowances for alternative stocking densities were estimated assuming more forage of the same quality from more intensively grazed, younger plant regrowth under fertilization (Rueda, 2002).

Partial budgeting with sensitivity analysis helps identify situations where technology change has potential value (Boehlje and Eidman, 1984; Mutsaers et al., 1986). This method considers a restricted range of possibilities and ignores the costs required for transition from the current scenario to a more intensive alternative. Thus, our estimates are initial evaluations designed to identify options with economic potential and to eliminate those that are clearly unprofitable under current conditions. Farmers typically do not consider adoption unless the gain in net margin, where net margin is equal to total revenue minus total variable cost, exceeds some threshold in marginal variable cost (e.g., cash costs of feed, land, and labor) of the alternative technology. The ratio of additional net margin to additional cash costs (the marginal rate of return) often needs to be greater than 0.5 to interest farmers to adopt technologies with which they are familiar (CIMMYT, 1988); an increase equal to the amount of additional investment (marginal rate of return of 1.0) may be required to attract farmers to a new practice or technology. Average returns to labor (net margin plus hired labor costs/units of labor) were compared to the baseline scenario because technologies with higher returns would presumably be most desirable where labor is scarce. Marginal returns to hired labor ([change in net margin plus hired labor costs]/[change in required labor]), an additional indicator of desirability of adoption, was calculated for alternative management.

## Results and Discussion

### *Observed Animal Responses*

Mean milk production from *B. decumbens* and kudzu, with 2.5 kg/d assumed for calf consumption (Nicholson et al., 1994), ranged from 5.4 ± 0.26 kg/d (May) to 8.1 ± 0.26 kg/d (December) during the period of this study. Lowest yields were at the end of lactation in May and June, which was similar to other reports for Brazil based on *Brizantha spp*. without supplementation (Abdalla et al., 1999; Euclides et al., 1993; 2000). Mean milk yield in October was 7.0 ± 0.26 kg/d, indicating similar forage and body tissue support of milk production at the end of the dry season compared to months with rainfall. Mean weight gains were 0.5 ± 0.02 kg/d throughout the study period for growing and finishing steers grazing *B. brizantha*, including October. Finishing steers grazing *B. decumbens* gained an average of 0.4 ± 0.03 kg/d. The BCS of animals were essentially invariant throughout the study period, averaging 4.6 for cows, 5 for growing steers, and 6 for finishing steers. This is further evidence that forage supply during the dry season was sufficient for stocking with 2 animal units/ha.

### *Pasture Biomass Accumulation and Grazing Behavior*

Total plant biomass accumulation during the period of study averaged 2,550 kg of DM·ha$^{-1}$·mo$^{-1}$ (SD =133) for *B. decumbens* and 3,700 kg of DM·ha$^{-1}$·mo$^{-1}$ (SD = 215) for *B. brizantha*. These DM accumulations were within the observed range for *Brachiaria spp*. (2,500 to 4,400 kg of DM/ha) under continuous grazing and similar low stocking in eastern and southern Brazil (Debeux, 1995; Jannoti, 1997; Euclides, 2000). An interaction of grass species × season ($P < 0.06$) indicated unequal biomass response throughout the year and probable unequal amounts of under-grazing.

More DM was accumulated from *B. decumbens* in the rainiest season (especially December to February), whereas the drier months (especially June and October) favored pasture DM from *B. brizantha* ($P < 0.02$). The observed biomass production of *B. decumbens* on a Colombian Ultisol was greatest in the rainy season, regardless of stocking density (Velasquez and Cuesta, 1990). Less accumulated DM from *B. brizantha* in the rainiest season may be due to its intolerance of excess water and poorly drained soils (Dias-Filho and Reis de Carvalho, 2000).

Although total herbage allowances ranged from 7 to 12 kg of DM per 100 kg of BW for *B. decumbens* and 11 to 15 kg of DM per 100 kg of BW for *B. brizantha*, the forage was actually consumed was from the top 20 cm of plants. This portion of the sward, comprising 85% leaves and 15% stems, provided only about 3 kg of DM per 100 kg of BW. Correspondingly, the animals in this study selected these more digestible plant parts from the available pool of forage DM, which was approximately equal to the maximal daily intake that would be expected from unrestricted grazing. This indicates that current stocking in this region with 2 animal units/ha is essentially at the lower limit for pasture management because excessive accumulation of mature plant biomass is permitted.

Grazing management to ensure that the available amount of (more nutritive) herbage more closely matches the animal's daily DM requirement would be expected to increase forage intake by reducing the time devoted to selective feeding (Stockdale and Trigg, 1985). Greatest weight gains from more time spent grazing have been found with 6 to 9 kg of DM per 100 kg of BW/d in (sub)tropical locations with *Pennisetum spp*. and *Cynodon spp*. (Adjei et al., 1980; Stockdale and King 1983; da Silva, 1994). In other studies, about 90% of the DM consumed by animals was leaves (Otoya, 1986; Euclides et al., 1992). Regardless of species in the forage portfolio, management is needed to maintain swards with high leaf (low stem) and low fiber content (Van Soest, 1994). Higher stocking in such a grazing system could help improve feeding conditions, especially with paddock rotation, which assures larger amounts of younger forage with high feeding value. Rotational grazing would require more paddocks and fencing, where the lowest installation cost is from electric fencing (Carvalho and Pinho, 2000).

### *Chemical Composition, Carbohydrate Digestion Rates, and Nutritional Values of Forages*

These *Brachiaria* grasses did not differ ($P > 0.05$) in chemical composition (Table 3), indicating similar

**Table 3.** Average chemical composition and carbohydrate digestion rates of *Brachiaria brizantha*, *B. decumbens*, and *Pueraria phaseoloides* in Acre, Brazil

| Item | *B. brizantha* | *B. decumbens* | *P. phaseoloides* | SE |
|---|---|---|---|---|
| Organic matter | | | | |
| DM, % as-fed | 26.1[a] | 25.0[a] | 20.5[b] | 0.52 |
| NDF, % DM | 70.0[a] | 70.0[a] | 53.7[b] | 1.09 |
| Digestible NDF, $B_2$ fraction as % DM | 57.8[a] | 57.9[a] | 13.7[b] | 2.83 |
| Lignin, % NDF | 5.9[a] | 5.8[a] | 24.6[b] | 1.24 |
| Indigestible carbohydrate, C fraction, % DM | 9.9[a] | 9.6[a] | 31.5[b] | 1.45 |
| CP, % DM | 8.0[a] | 7.9[a] | 17.6[b] | 0.63 |
| Solubility, % CP | 33.1[a] | 37.1[a] | 22.7[b] | 1.47 |
| NDIP, % CP[d] | 27.8[a] | 28.2[a] | 48.4[b] | 1.76 |
| ADIP, % CP[e] | 11.0[a] | 12.3[ab] | 15.5[b] | 0.63 |
| Minerals | | | | |
| Ca, % | 0.2[a] | 0.2[a] | 1.1[b] | 0.05 |
| K, % | 2.3[a] | 2.2[a] | 1.7[b] | 0.05 |
| Mg, % | 0.3[a] | 0.2[b] | 0.3[c] | 0.008 |
| Na, % | 0.004 | 0.004 | Traces | 0.001 |
| P, % | 0.3[a] | 0.2[a] | 0.8[b] | 0.01 |
| S, % | 0.1 | 0.1 | 0.1 | 0.008 |
| Cu, mg/kg | 6.3[a] | 6.9[ab] | 9.2[b] | 0.37 |
| Fe, mg/kg | 137.7 | 181.1 | 164.7 | 14.67 |
| Mn, mg/kg | 224.8[a] | 220.4[a] | 414.6[b] | 29.00 |
| Zn, mg/kg | 42.2[a] | 38.8[a] | 24.7[b] | 1.81 |
| Carbohydrate digestion rates, %/h | | | | |
| A + $B_1$ fraction[f] | 22.7 | 21.3 | 30.0 | 1.83 |
| $B_2$ fraction[g] | 6.8[a] | 6.4[a] | 4.5[b] | 0.18 |

[a,b,c]Means within a row without a common superscript differ ($P < 0.05$) using the Student's *t*-test.
[d]NDIP = neutral detergent insoluble protein.
[e]ADIP = acid detergent insoluble protein.
[f]A+$B_1$ fraction contains sugars, organic acids, starch, and soluble fiber.
[g]$B_2$ contains ruminally degradable insoluble fiber.

nutritive values, which agreed with the results of Juarez et al. (1999) for milk production in Gulf Coast Mexico. The contents of CP and NDF were similar to those reported from other parts of tropical America (Euclides et al., 1999; Juarez et al., 1999; Tedeschi et al., 2002a).

As expected, kudzu differed ($P < 0.05$) from grasses (Table 3) with more lignin, CP, NDIP, and ADIP and less DM, NDF, and soluble CP. More lignin (as a percentage of NDF) suggests lower digestibility and faster fermentation of the unlignified fraction (Van Soest, 1994). The solubility of CP was less for kudzu than for the grasses ($P < 0.05$), which suggests greater availability of protein for microbial growth and, consequently, better degradation of fiber. Therefore, kudzu potentially complements *Brachiaria spp*. providing more dietary CP that is less soluble. The nutritional value of kudzu was similar to that of other tropical legumes (e.g., *Leucaena leucocephala*, *Gliricidia sepium*, *Neonotonia wightii*, and *Macroptilium atropupureum*) that typically range from 12 to 24% CP, 47 to 60% NDF, and 20 to 24% lignin (as a percentage of NDF; Tedeschi et al., 2002a).

Dietary intake and composition affect the ruminal microbial population that degrades the feeds consumed and thus, the rates of digestion and passage (Van Soest, 1994). The rates of digestion for carbohydrate fractions are in Table 3. Rates for the nonstructural carbohydrates (A+$B_1$ fraction) of grasses and kudzu were similar ($P > 0.05$), ranging from 21 to 30%/h. However, the insoluble fiber ($B_2$) fraction in grasses was digested more rapidly ($P < 0.05$) than in kudzu (6.5 vs. 4.5%/h). The more rapid $B_2$ digestion of grasses would potentially yield more MP and AA for milk synthesis from a larger pool of ruminally available fiber (Cerosaletti, 1998; Juarez et al., 1999). Therefore, excessive substitution of kudzu for grasses would be expected to decrease the ME available for milk and growth. Digestion rates for the selected portions of grasses in this study were similar to those in young regrowth of *B. brizantha* in the Gulf Coast of Mexico (Juarez et al., 1999). Hence, the digestion rates and chemical composition of the forage selected by animals from relatively mature Acre pastures were similar in quality to intensively grazed, vegetatively younger plant material.

Digestible NDF ($B_2$ fraction as a percentage of NDF) ranged from 53 to 63% in *B. brizantha* and from 0 to 22% in kudzu. Kudzu had three times more indigestible carbohydrate (C fraction) than grasses (33 vs. 10%). The CP content (DM basis) averaged 8% for the grasses and 17.5% for kudzu (Rueda, 2002).

### *Seasonal Differences*

Season affected chemical composition of grasses (Table 4) with more NDF and NDIP (slowly degraded

**Table 4.** Chemical composition and digestion rates of carbohydrate fractions of *Brachiaria spp*. in two seasons[a]

| Item[b] | Rainiest | Less rainy |
|---|---|---|
| Composition | | |
| DM, % | 24.2[d] | 26.5[e] |
| NDF, % of DM | 71.7[d] | 68.6[e] |
| Lignin, % NDF | 5.6 | 6.1 |
| CP, % DM | 7.8 | 8.1 |
| Solubility, % CP | 34.9 | 35.3 |
| NDIP | 30.7[d] | 25.7[e] |
| ADIP | 12.1 | 11.3 |
| Fat, % | 2.3[d] | 2.6[e] |
| Ash, % | 11.2 | 10.7 |
| ME, Mcal/kg of DM[c] | 1.9[d] | 2.1[e] |
| Carbohydrate digestion rates, %/h | | |
| A + $B_1$ fraction | 19.8 | 23.8 |
| $B_2$ fraction | 6.6 | 6.6 |

[a]The rainiest season included December, January, February, and March; the less rainy season comprised the months surrounding the dry season (April, May, June, October, and November).
[b]Values expressed on a DM basis. NDIP = neutral detergent insoluble protein, percentage CP; ADIP = acid detergent insoluble protein, percentage CP.
[c]ME = metabolizable energy content, predicted by the Cornell Net Carbohydrate and Protein System model (Fox et al., 2003).
[d,e]Means within a row differ ($P \leq 0.05$). Ranges of SE were: 0.6% for DM and NDF, 1.6% to 1.8% for NDFIP, 0.1% for fat and 0.02 Mcal for ME.

protein) and less energy content in the rainiest months ($P < 0.01$). Higher NDF content in grasses decreases the energy available for milk or gain. Hence, animal performance would be expected to diminish in the rainiest season because, even if intake were not depressed, diets with more structural carbohydrates would support less ruminal microbial growth. Nicholson et al. (1994) found that more energy and protein supplementation was required in the rainy months in dual-purpose systems in Venezuela. Figure 1 summarizes monthly variations in CNCPS prediction of forage digestibility (TDN) and dietary intake protein (**IP**) for finishing steers and lactating cows consuming these *Brachiaria* grasses and kudzu. Grasses averaged 55% TDN and 72% IP, which exceeded the biological values for kudzu (46% TDN and 50% IP). Digestibility (TDN) predicted from digestible DM (Van Soest, 1994) averaged 50% for *Brachiaria spp*. across tropical America (Lascano and Euclides, 1996), where most tropical grasses contained 48 to 55% TDN (Tedeschi et al., 2002a). Although grasses and kudzu differed in most elements, there was no significant ($P > 0.90$) seasonal effect on their mineral composition, except for Cu ($P < 0.001$). Predictions indicated that dietary supplies of Ca, P, Na, S, and Cu were substantially below the recommended daily allowances for all animal groups consuming only forage (NRC, 2000).

Seasonal effects on ME and MP available for milk in cows and weight gain in finishing steers were not significant ($P > 0.50$). However, seasonal effects on forage composition resulted in 25% less predicted BW gain in growing steers during the period of highest rainfall from less ME available for gain (0.57 vs. 0.75 kg/d, $P < 0.05$). Our animal measurements generally agreed with these predictions, where the smallest BW gains occurred in February ($P = 0.18$).

### *Animal and Pasture Land Productivity (Baseline Scenario)*

Table 5 shows that predictions of average expected voluntary DMI by the CNCPS model were only 4% less than the amounts that were predicted to be required to match the observed milk production. These results indicate good agreement between DMI based on the intake equation of Traxler (1997) and the amount expected for the observed animal production and forage composition. The required daily DMI was equal to approximately 2.2% of cow BW and contained approximately 2.0 Mcal of ME/kg of DM. For finishing steers, DMI predicted with an empirical equation was 10% less than the CNCPS-predicted DM requirement (2.5% of BW), but these predictions were similar (2.1% of BW) for growing steers (Rueda, 2002).

About 6% more MP than ME allowable milk production indicates energy was first limiting. Both grasses with 10% kudzu were predicted to supply protein in excess of dietary requirements for the observed milk production. Consequently, cows consuming a grass+kudzu diet were predicted to excrete 25 g of N/d, which was predicted to incur a 0.1 Mcal of ME/d energy cost to convert ammonia to urea for excretion in urine. This represents an opportunity loss of about 25 kg of milk/cow per 280-d lactation. Excess dietary N is also known to adversely affect cow fertility (Butler, 1998). Larger sacrifices would be expected if cows consumed more legume (from swards containing more of it). About 30% legume is currently recommended to reduce the N-fertilization cost of pastures in Acre (Wadt, 2002). Therefore, kudzu and other suitable legumes have a multipurpose role involving tradeoffs in making pasture-based systems more productive.

Steers consuming *B. brizantha* were predicted to have sufficient ME to gain 0.50 kg/d. Finishing steers consuming *B. decumbens* had enough ME to gain 0.40 kg/d. Energy concentration in these grasses averaged 2.0 Mcal of ME/kg of DM. Surplus protein consumption was predicted in every month of the study period, probably because the supply of energy was not enough to support the amount of gain from the protein that was available.

Intake of energy was the most important dietary limitation for the animal groups monitored. This finding agrees with other studies in the American tropics that found energy more limiting than protein (Townsend et al., 1990; Nicholson et al., 1994), but differs from findings by Juarez et al. (1999), where MP was first limiting. In our case, the DMI predictions for dual-purpose cows were in good agreement with those measured in other tropical studies (Traxler, 1997; Euclides et al., 2000; Molina, 2002). In addition to evaluation

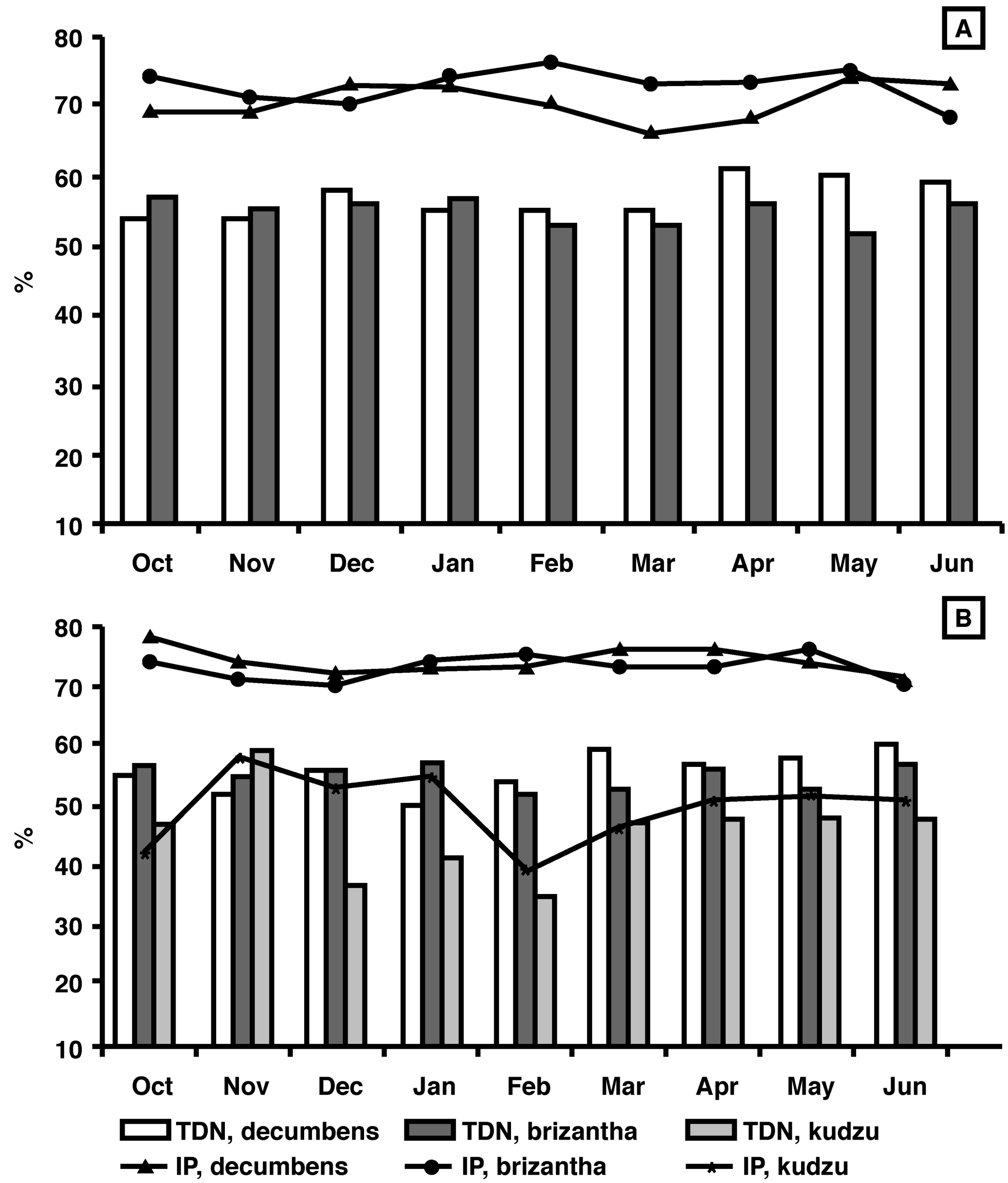


**Figure 1.** Energy and protein composition of *Brachiaria brizantha*, *B. decumbens*, and *Pueraria phaseoloides* (tropical kudzu) consumed by finishing steers (A) and lactating cows (B). TDN given as a percentage of digestible nutrients; IP is dietary intake protein as a percentage of CP.

of alternative feeding strategies (forages and supplements), calibrated nutritional models support farmer decision-making about land use and management of cattle systems in the western Amazon (e.g., supplementation to optimize ruminal fermentative digestion; van Houtert and Sykes, 1999).

At current stocking densities in Acre, excessive accumulation of mature plant biomass of low digestibility is a key constraint to animal and land productivity. This pasture management strategy probably minimizes labor and management inputs to maintain current herd productivity. However, it results in stable but low outputs of milk and beef because it sequesters most nutrients produced by these grasses in indigestible DM. This nutrient stock influences system productivity by slowly releasing nutrients from leaf litter and through periodic burns to maintain grass cover.

### *Net Economic Returns from Intensification Options*

Biological potential exists to increase productivity of Acre cattle systems. Alternative supplies of energy and a higher grazing efficiency would be expected to increase animal and land productivity. However, distinct economic opportunities (a growing market for animal products) and constraints (limited labor and alternative feed source supplies) of Acre cattle systems need to be considered in interpreting these potentials.

*Potential to Increase Animal Performance.* The dietary requirements for increasing milk production by

**Table 5.** Expected milk production and dry matter intake responses to dietary supplementation to increase by 25 or 50% the milk produced by dual-purpose cows grazing *Brachiaria* grasses

| | *B. decumbens* | | | *B. brizantha* | | |
|---|---|---|---|---|---|---|
| Item | Baseline | 25% | 50% | Baseline | 25% | 50% |
| Milk production, kg/d | 6.7 | 8.4 | 10.0 | 6.7 | 8.4 | 10.0 |
| DMI predicted, kg/d[a] | 9.7 | 10.2 | 10.7 | 9.7 | 10.2 | 10.6 |
| DMI required, kg/d[b] | 10.1 | 10.6 | 10.9 | 10.2 | 9.9 | 10.3 |
| MP allowable milk production[c] | 7.1 | 9.3 | 10.7 | 7.8 | 9.6 | 10.7 |
| Dietary nutrient concentration | | | | | | |
| TDN, %[d] | 63.7 | 65.4 | 67.8 | 64.2 | 68.4 | 70.7 |
| ME, Mcal/kg[e] | 1.9 | 2.0 | 2.2 | 2.0 | 2.2 | 2.3 |
| MP from bacteria, g/d[f] | 520 | 565 | 606 | 557 | 644 | 677 |
| Dietary ingredients, kg of DM/d | | | | | | |
| Grass | 9.2 | 7.5 | 6.7 | 6.8 | 7.6 | 7.1 |
| *Pueraria phaseoloides* | 1.0 | 2.1 | 2.2 | 1.0 | 1.0 | 1.2 |
| Sorghum grain | 0.0 | 1.0 | 2.0 | 0.0 | 1.0 | 2.0 |
| Total | 10.2 | 10.6 | 10.9 | 7.8 | 8.6 | 8.3 |

[a]DMI predicted by the Cornell Net Carbohydrate and Protein System (CNCPS) model (Fox et al., 2003).
[b]DMI required to support the observed milk yield predicted by the CNCPS.
[c]MP allowable milk = metabolizable protein available for milk production predicted by the CNCPS.
[d]TDN = total digestible nutrients predicted by the CNCPS.
[e]ME = metabolizable energy content of the diet predicted by the CNCPS.
[f]MP from bacteria = metabolizable protein from microbial yield predicted by the CNCPS.

25 and 50% with a more nutrient-rich diet are summarized in Table 5. Milk production goals were predicted to be achievable with 1 to 2 kg/d of sorghum grain and 20% of total daily forage as kudzu (about 2 kg of DM/d) when grazing *B. decumbens*. *Brachiaria brizantha* required less kudzu (10% of total forage) than *B. decumbens* because of its greater CP content with lower solubility, which resulted in more MP available for production. Less sorghum, 0.4 to 1.8 kg/d, was required to similarly increase growth of steers also needing 1.3 kg of DM/d of kudzu for sufficient MP to achieve 50% greater weight gains.

Partial budgeting analysis indicated this approach would be less profitable than current practices to produce milk and beef, a clear disincentive for farmers to alter productivity of animals, land, and labor in this manner. Table 6 illustrates this result for the case of milk production, where the increase in feed costs alone nearly equals the increase in revenues. Sensitivity analysis indicated that an unrealistically higher milk price ($0.16/kg vs. $0.08/kg) or 60% lower grain cost for 50% more milk would be required to achieve a marginal rate of return of 1.0. Therefore, supplementation to increase individual cow productivity is financially unattractive with a low (unitary) milk:sorghum price ratio (Table 6). Net margins were also lower at current prices of beef and grain for more rapid growth of steers with grain supplementation (Table 7). The increase in feed cost for beef production was more than twice the assumed increase in revenues. Only the unrealistic combination of about 100% higher beef price ($0.76/kg vs. $0.38/kg) and 75% lower grain cost would provide adequate incentive (marginal rate of return of 0.5) for farmer investment in more rapid growth. These evaluations differ from those in Venezuela, where low-cost feeding strategies (supplementation with cassava, urea and molasses) for dual-purpose cows proved more profitable than the baseline forage-concentrate diet (Townsend et al., 1990; Nicholson et al., 1994). A key difference is the lower milk:supplement price ratio, which markedly limits the profitability of supplementation for more milk.

Average and marginal returns to labor were substantially lower in the alternative management options, also implying low incentives for adoption by farmers. Although dietary supplementation would permit growth in herd size and animal productivity (without clearing more land for grazing) this option is economically unattractive with current relative prices of milk, beef, and grain.

*Potential to Increase the Productivity of Land.* Variable costs for fertilization strategies with alternative stocking densities exceeded those for the baseline scenario for both cattle systems due to greater requirements for labor, fencing, and especially, fertilizer (Table 8). Net margins at higher stocking densities in the dual-purpose system were always lower than for baseline management. None of these options are likely to be adopted for milk production because the increased labor and fertilizer costs exceeded the increase in revenues, all strategies having negative returns.

For beef production, fertilization and higher stocking increased net margins up to 65% over the baseline, with marginal rates of return up to 1.55. The largest predicted net margin was for fertilization to replace the extracted P in a grass–legume association stocked with 4 animal units/ha. Other strategies with high marginal rates of return were for replacement of the

**Table 6.** Marginal revenues and variable cash costs of dietary supplementation strategies to achieve increases of 25 and 50% in milk production from a herd of 15 lactating cows grazing *Brachiaria decumbens* in Acre, Brazil ($US)

| Item | Baseline[a] | 25% increase | Change from baseline | 50% increase | Change from baseline |
|---|---|---|---|---|---|
| Gross revenues | | | | | |
| Saleable milk, kg/d | 63.00 | 78.75 | 15.75 | 94.50 | 31.50 |
| Milk price, $/kg | 0.08 | 0.08 | 0.00 | 0.08 | 0.00 |
| Total revenues, $/d | 5.04 | 6.30 | 1.26 | 7.56 | 2.52 |
| Variable costs[b] | | | | | |
| Feed costs | | | | | |
| Sorghum, kg/d | 0.00 | 15.00 | 15.00 | 30.00 | 30.00 |
| Sorghum price, $/kg | 0.00 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sorghum cost, $/d | 0.00 | 1.20 | 1.20 | 2.40 | 2.40 |
| Equipment, $/d | 0.00 | 0.004 | 0.004 | 0.004 | 0.004 |
| Total feed costs, $/d | 0.00 | 1.20 | 1.20 | 2.40 | 2.40 |
| Hired labor costs | | | | | |
| Labor milking, workers/d | 0.84 | 0.91 | 0.08 | 0.91 | 0.08 |
| Labor cost, $ worker$^{-1}$·d$^{-1}$ | 4.00 | 4.00 | 0.00 | 4.00 | 0.00 |
| Labor cost, $/d | 3.36 | 3.66 | 0.30 | 3.66 | 0.30 |
| Total variable costs, $/d | 3.36 | 4.86 | 1.50 | 6.06 | 2.70 |
| Economic returns | | | | | |
| Net margin (from milk only), $/d | 1.68 | 1.44 | −0.24 | 1.50 | −0.18 |
| Marginal rate of return[c] | — | −0.16 | — | −0.07 | — |
| Average return to total labor, $/labor[d] | 3.00 | 2.79 | −0.22 | 2.82 | −0.18 |
| Marginal return to total labor, $/labor[d] | — | 0.37 | — | 0.77 | — |

[a]Baseline diet included *Pueraria phaseoloides* (kudzu) as 10% of total intake, alternative diets included kudzu as 20% of total intake. Labor to collect kudzu seed is part of establishment cost, but was not included.
[b]There are other associated variable costs that were not included because they were equal for all scenarios.
[c]Marginal rate of return = change in net margin/change in variable cost.
[d]Average return to labor = (net margin + hired labor costs)/total labor.
[e]Marginal return to total labor = (change in net margin + hired labor costs)/(change in number of units of required labor).

nutrients extracted. Unlike milk, more intensive beef production is profitable because the relationship between the beef price and the labor cost is much more favorable. Consequently, net margins from increased stocking were 13% and 66% higher than those obtained with the baseline density of 2 animal units/ha. Efficiency of total labor used in alternative management was less than the baseline strategy because the average return to labor was about 65% lower. However, the marginal return to labor indicated that one extra labor unit employed under the alternative options would yield 1.5 to 2.7 times the daily wage rate of $4.00. Therefore, these options offer significant economic potential for more intensive beef production based on the assumed input requirements.

In both production systems, the EMBRAPA-recommended maintenance fertilization strategy for the western Amazon had the lowest marginal rate of return, and also may be 20 to 60% deficient in P. According to our estimations (Rueda, 2002), the annual nutrient exports in animal products were 6 and 3 kg/ha of N and P, respectively, at baseline stocking with 2 animal units/ha. As stocking density increases, more nutrients would be exported in greater sales of milk and beef.

Although there is biological potential to increase the productivity of individual animals and land, only the more intensified use of land for beef production seemed profitable. This management strategy has the potential to benefit owners of both dual-purpose and beef herds. However, the transition process and associated capital cost to achieve larger herds and greater land productivity were not accounted, which may imply lower returns (higher costs) than indicated here. More farm-level research is needed to more fully evaluate the transition dynamics of these low equilibrium systems to more intensive ones.

The technological options evaluated are labor-intensive (or potentially land-saving), since under our assumptions, they require more than four times the yearly amount of labor used in baseline management. Given that labor is scarce in this region and farmers, especially those with limited resources, have restricted access to capital, it is unclear whether these more intensified activities would be adopted. However, the cost of forest clearing and seeding with grass is about $100/ha (Banco da Amazônia, 2000), which exceeds the approximate $80 cost of more intensive pasture use for beef production. Thus, more intensive use of land may discourage land clearing to maintain the

**Table 7.** Marginal revenues and cash costs of dietary supplementation strategies to achieve 25% and 50% increase in weight gain per animal from Nellore steers grazing *Brachiaria brizantha* in Acre, Brazil ($US)

| Item | Baseline[a] | 25% increase | Change from baseline | 50% increase | Change from baseline |
|---|---|---|---|---|---|
| Gross revenues | | | | | |
| Sales of beef, kg[b] | 500.00 | 566.00 | 66.00 | 599.00 | 99.00 |
| Beef price, $/kg | 0.38 | 0.38 | 0.00 | 0.38 | 0.00 |
| Total revenues | 190.00 | 215.08 | 25.08 | 227.62 | 37.62 |
| Variable costs[c] | | | | | |
| Feed costs | | | | | |
| Sorghum, kg/period | 0.00 | 528.00 | 528.00 | 915.00 | 915.00 |
| Sorghum price, $/kg | 0.00 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sorghum cost, $/period | 0.00 | 42.24 | 42.24 | 73.20 | 73.20 |
| Feeding equipment, $/period | 0.00 | 20.00 | 20.00 | 18.67 | 18.67 |
| Total feed costs, $/period | 0.00 | 62.24 | 62.24 | 91.87 | 91.87 |
| Hired labor costs | | | | | |
| Labor workers·$d^{-1}$·$animal^{-1}$ | 0.004 | 0.006 | 0.002 | 0.006 | 0.002 |
| Fattening period, days | 1,080.00 | 960.00 | –120.00 | 870.00 | –210.00 |
| Total labor workers·$period^{-1}$·$animal^{-1}$ | 4.32 | 5.76 | 1.44 | 5.22 | 0.90 |
| Labor cost, $·$worker^{-1}$·$d^{-1}$ | 4.00 | 4.00 | — | 4.00 | — |
| Labor cost, $/period | 17.28 | 23.04 | 5.76 | 20.88 | 3.60 |
| Total variable costs, $/period | 17.28 | 85.28 | 68.00 | 112.75 | 95.47 |
| Economic returns | | | | | |
| Net margin, $/period | 172.72 | 129.80 | –42.92 | 114.87 | –57.85 |
| Marginal rate of return[d] | — | –0.63 | — | –0.61 | — |
| Average return to labor, $/labor[e] | 39.98 | 22.53 | –17.45 | 22.01 | –17.98 |
| Marginal return to total labor, $/labor[f] | — | –25.81 | — | –60.27 | — |

[a]Baseline diet included *B. brizantha* as the sole feed; alternative diets included kudzu as 20% of total intake. Labor to collect kudzu seeds is part of establishment cost but was not included.

[b]Includes the additional beef produced in the same paddocks where animals with more intensified management grazed (the age to market is 4 and 6 mo earlier than baseline).

[c]There are other associated variable costs that were not included because they were equal for all scenarios.

[d]Marginal rate of return = change in net margin/change in variable cost.

[e]Average return to labor = (net margin + hired labor costs)/total labor.

[f]Marginal return to total labor = (change in net margin + hired labor costs)/(change in number of units of required labor).

same level of production. Technological change increases profits and the incentive to deforest (Carpentier et al., 2000). Labor intensity is an important factor affecting these outcomes. Profitable, labor-intensive agricultural technologies tend to reduce forest clearing because they exhaust available labor that otherwise could be used to deforest (Angelsen and Kaimowitz, 2001). Although this relationship is not the focus of this research, our analysis points out that some intensification strategies (supplementation, more milk per land area) are unlikely to affect forest clearing because their use is economically unattractive.

In conclusion, chemical composition of grasses differed between rainiest and less rainy seasons. Grasses were of poorer quality (more NDF and NDIP and less ME) during the rainiest months. Simulations indicated that ME is first limiting in the baseline scenario and MP is limiting at higher milk production and weight gain. *Brachiaria brizantha* provided slightly more MP than *B. decumbens* to support lactation. Seasonal variability in forage quality suggests that diet supplementation is needed during the months with highest precipitation, in contrast to the common recommendation to supplement only in the dry season.

Voluntary DMI predicted by empirical equations and the DMI required for the observed animal performance predicted with the CNCPS model were in close agreement. Animals grazed selectively because accumulated biomass exceeded the recommended herbage per animal, even in the months with lowest precipitation. Thus, there is opportunity for greater productivity in this region from managed grazing of less mature forage.

Partial budgeting analyses indicated that increases in individual animal performance by dietary supplementation are less profitable than baseline management. More intensive beef production by judicious fertilization of grass–legume pastures and greater stocking density is the preferable strategy for owners of both cattle systems to improve net economic returns under current conditions. It may also help reduce incentives for additional forest clearing. Further analysis is required to evaluate alternative practices to increase productivity in these cattle systems, including

**Table 8.** Economic returns from alternative fertilization strategies and stocking densities in dual-purpose and beef cattle systems in Acre, Brazil

| Fertilization strategy[a] | 3 animal units/ha | Change from baseline[b] | 4 animal units/ha | Change from baseline[b] |
|---|---|---|---|---|
| Dual-purpose system | | | | |
| Recommended maintenance | | | | |
| Net margin, $\$\cdot ha^{-1}\cdot yr^{-1}$ | –26.78 | –58.53 | –10.90 | –42.65 |
| Marginal rate of return[c] | –0.71 | — | –0.47 | — |
| Average return to labor, $\$\cdot labor^{-1}$ [d] | 0.91 | –4.90 | 1.62 | –4.19 |
| Replace extracted nutrients | | | | |
| Net margin, $\$\cdot ha^{-1}\cdot yr^{-1}$ | –3.10 | –34.85 | 9.58 | –22.17 |
| Marginal rate of return[c] | –0.59 | — | –0.31 | — |
| Average return to labor, $\$\cdot labor^{-1}$ [d] | 5.11 | –0.90 | 5.25 | –0.75 |
| Grass-legume with P replacement: | | | | |
| Net margin, $\$\cdot ha^{-1}\cdot yr^{-1}$ | 4.58 | –27.17 | 19.18 | –12.57 |
| Marginal rate of return[c] | –0.53 | — | –0.21 | — |
| Average return to labor, $\$\cdot labor^{-1}$ [d] | 2.19 | –3.62 | 2.67 | –3.14 |
| Beef cattle system | | | | |
| Recommended maintenance | | | | |
| Net margin, $\$\cdot ha^{-1}\cdot yr^{-1}$ | 136.02 | –4.87 | 203.54 | 62.65 |
| Marginal rate of return[c] | –0.06 | — | 0.70 | — |
| Average return to labor, $\$\cdot labor^{-1}$ [d] | 10.82 | –37.43 | 13.79 | –34.46 |
| Replace extracted nutrients | | | | |
| Net margin, $\$\cdot ha^{-1}\cdot yr^{-1}$ | 159.70 | 18.81 | 224.02 | 83.13 |
| Marginal rate of return[c] | 0.33 | — | 1.20 | — |
| Average return to labor, $\$\cdot labor^{-1}$ [d] | 12.70 | –35.55 | 15.18 | –33.07 |
| Grass-legume with P replacement: | | | | |
| Net margin, $\$\cdot ha^{-1}\cdot yr^{-1}$ | 167.38 | 26.49 | 233.62 | 92.73 |
| Marginal rate of return[c] | 0.53 | — | 1.55 | — |
| Average return to labor, $\$\cdot labor^{-1}$ [d] | 13.32 | –34.93 | 15.83 | –32.42 |

[a]Fertilization strategies evaluated: EMBRAPA recommendations for Western Amazon: 100 kg of urea + 12 kg of triple superphosphate; replacement of nutrient exports calculated in farms in Rio Branco, Acre: 24 kg of urea +14 kg of triple superphosphate and 30 kg of urea + 18 kg of triple superphosphate for 3 animal units/ha and 4 animal units/ha; nutrients exports with EMBRAPA recommendation of use of legumes: 14 kg of triple superphosphate and 18 kg of triple superphosphate for 3 animal units/ha and 4 animal units/ha.

[b]Baseline net margins and returns to labor were as follows: dual-purpose system, $31.70 and $5.80; beef system, $140.90 and $48.20.

[c]Marginal rate of return = change in net margin/change in variable cost.

[d]Average return to labor = (net margin + hired labor cost)/total labor.

soil-plant-animal nutrient dynamics and nutritional support of herd reproduction and its effect on profit (Tedeschi et al., 2002b).

## Implications

Simulations based on data collected on dual-purpose and beef farms indicate alternative strategies to produce more milk and beef with inputs of feeds and fertilizers may lower profitability on farms in the western Amazon region of Brazil. Despite biological potentials for increasing productivity, under current price relationships, the only profitable strategy is more intensive grazing to produce more beef. Further research is needed to: 1) develop more effective grazing and nutrient management of pasture lands; 2) develop grass and legume species with adaptability to acid soils and better nutritional quality; and 3) determine the biological and economic implications of the transition to more intensive beef production. Evaluations of underexploited local sources of additional feed energy inputs (e.g., cassava flour, peach palm concentrate) and better quality commercial concentrates also are needed to improve animal productivity.

## Literature Cited

Abdalla, A. L., H. Louvandini, I. C. S. Bueno, D. M. S. S. Vitti, C. F. Meirelles, and S. M. Gennari. 1999. Constraints to milk production in grazing dairy cows in Brazil and management strategies for improving their productivity. Prev. Vet. Med. 38:217–230.

Adjei, M. B., P. Mislevy, and E. Y. Ward. 1980. Response of tropical grasses to stocking rate. Agric. J. 72:863–868.

Angelsen, A., and D. Kaimowitz. 2001. When does technological change in agriculture promote deforestation? Page 89 in Trade-offs or Synergies? Agricultural Intensification, Economic Development and the Environment. D. R. Lee, and C. B. Barrett, ed. CABI Publishing, Wallingford, Oxon, U.K.

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Banco da Amazônia. 2000. Informação trimestral sobre atividades agropecuarias. Agencia Rio Branco, AC, Brazil.

Boehlje, M. D., and V. R. Eidman. 1984. Farm Management. John Wiley and Sons, New York.

Butler, W.R. 1998. Effect of protein nutrition on ovarian and uterine physiology in dairy cattle. J. Dairy Sci. 81:2533–2539.

Carpentier, C. L., J. Valentim, S. A. Vosti, and J. Witcover. 2000. Intensified small-scale cattle production systems in the western Brazilian Amazon: Will they be adopted and can they save the forest? Agric. Ecosys. Environ. 82:73–88.

Carvalho, dos S. J., and de Sá C. Pinho. 2000. Estimativa de custos de instalação e manutenção de cerca elétrica solar, como divisoria de pastagem no estado de Acre. Comunicado Técnico No. 120. EMBRAPA, Rio Branco, Acre, Brazil.

CIMMYT. 1988. From Agronomic Data to Farmer Recommendations: Economic Training Manual. Centro Internacional de Mejoramiento de Maiz y Trigo (International Center for the Improvement of Maize and Wheat), Texcoco, Mexico.

Cerosaletti, P. E. 1998. Application of the Cornell Net Carbohydrate System in a pasture-based dairy farm. M.S. Thesis, Cornell Univ., Ithaca, NY.

da Silva, D. S., J. A. Gomide, and A. C. de Queiroz. 1994. Grazing pressure on *Pennisetum purpureum Schum* cv. Mott pasture. 2. Effect on nutritive value, intake and milk yield. Rev. Bras. Zoot. 23:453–454.

Debeux, J. C. B. 1995. Desempenho de pastagens de braquiárias submetidas a um pastejo contínuo controlado. M.S. Thesis, Universidade Federal Rural de Pernambuco, Recife, PE, Brazil.

de Gouvea, R., and S. K. Kassicieh. 2001. Resource-based innovation: The case for the Amazon region. Eng. Manag. J. 13:28–32.

Dias-Filho, M. B., and C. J. Reis de Carvalho. 2000. Physiological and morphological responses of *Brachiaria spp*. to flooding. Pesq. Agrop. Bra. 35:1959–1966.

Euclides, V. P. B., E. G. Cardoso, M. C. M. Macedo, and M. P. de Oliveira. 2000. Consumo voluntário de *B. decumbens* cv. Basilisk e *B. brizantha* cv. Marandu sob pastejo. Rev. Bras. Zootec. 29:2200–2208.

Euclides, V. P. B., L. R. L. S. Thiago, M. C. M. Macedo, and M. P. de Oliveira. 1999. Consumo voluntário de forragem de três cultivares de *Panicum maximum* sob pastejo. Rev. Bras. Zootec. 28:1177–1185.

Euclides, V. P. B, A. H. Zimmer, and A. Vieira. 1993. Evaluation of *Brachiaria decumbens* and *Brachiaria brizantha* under grazing. Page 1997 in Proc. Int. Grassland Cong., New Zealand Grassland Assoc., Rockhampton, Australia.

Euclides, V. P. B., M. C. M. Macedo, and M. P. Oliveira. 1992. Avaliação de diferentes métodos de amostragem (para se estimar o valor nutritivo de forragens) sob pastejo. Rev. Bras. Zoot. 21:691–702.

Faminow, M. D. 1998. Cattle, Deforestation and Development in the Amazon. An Economic, Agronomic and Environmental Perspective. CAB International, New York, NY.

Fisher, M. J., and P. C. Kerridge. 1996. The agronomy and physiology of *Brachiaria* species. Pages 43–52 in *Brachiaria*: Biology, Agronomy and Improvement. J. W. Miles, B. L. Mass, and C. B. Valle, ed. CIAT, Cali, Colombia.

Fox, D. G., T. P. Tylutki, L. O. Tedeschi, M. E. Van Amburgh, L. E. Chase, A. N. Pell, T. R. Overton, and J. B. Russell. 2003. The net carbohydrate and protein system for evaluating herd nutrition and nutrient excretion: Model documentation. Mimeo No. 213. Anim. Sci. Dept., Cornell Univ., Ithaca, NY.

Hall, M. B., B. A. Lewis, P. J. Van Soest, and L. E. Chase. 1997. A simple method for estimation of neutral-detergent soluble fiber. J. Sci. Food Agric. 74:441–449.

INPE. 2000. Instituto Nacional de Pesquisas Espaciais. Monitoring of the Brazilian Amazon forest by satellite 1999–2000. Available: http://www.inpe.br/Informacoes_Eventos/amz1999_2000/Prodes/html/pag_2.htm. Accessed April 30, 2002.

Jannoti, I. W. 1997. Produção de leite em pastagem de capim Braquiária (*Brachiaria decumbens*) sob duas ofertas diarias de forragem. M.S. Thesis, Universidade Federal de Viçosa, MG, Brasil.

Juarez, F. I., D. G. Fox, R. W. Blake, and A. N. Pell. 1999. Evaluation of tropical grasses for milk production by dual-purpose cows in tropical Mexico. J. Dairy Sci. 82:2136–2145.

Lascano, C.E., and V.P.B. Euclides. 1996. Nutritional quality and animal production of *Brachiaria* pastures. Pages 106–110 in *Brachiaria*: Biology, Agronomy and Improvement. J. W. Miles, B. L. Mass, and C. B. Valle, ed. CIAT, Cali, Colombia.

't Mannetje, L. 2000. Measuring biomass of grassland vegetation. Page 151 in Field and Laboratory Methods for Grassland and Animal Production Research. 't Mannetje L., and R. M. Jones, ed. CAB International, Wallingford, U.K.

Molina, D. O. B. 2002. Prediction of intake of lactating cows in the tropics and of the energy value of organic acids. Ph.D. Diss., Cornell Univ., Ithaca, NY.

Mutsaers, H. J. W., N. M. Fisher, W. O. Vogel, and M .C. Palada. 1986. Farming Systems Program: A Field Guide for On-Farm Research with Special Reference to Improvement of Cropping Systems and Technologies in West and Central Africa. Int. Inst. Trop. Agr., Ibadan, Nigeria.

Nelson, C. J., and L. E. Moser.1994. Plant factors affecting forage intake. Page 115 in Forage Quality Evaluation and Utilization. G. C. Fahey Jr., ed. Am. Soc. Agron./Crop Sci. Soc. Am./Soil Sci. Soc. Am.

Nicholson, C. F., R. W. Blake, C. I. Urbina, D. R. Lee, D. G. Fox, and P. J. Van Soest. 1994. Economic comparison of nutritional management strategies for Venezuelan dual-purpose cattle systems. J. Anim. Sci. 72:1680–1696.

NRC. 2000. Nutrient Requirements of Beef Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Otoya, V. E. 1986. Efecto de la época del año y dias de ocupación en la calidad nutritiva de *Brachaiaria decumbens*. Pasturas Tropicales 8:2–5.

Pell, A. N., and P. Schofield. 1993. Computerized monitoring of gas production to measure forage digestion in vitro. J. Dairy Sci. 76:1063–1073.

Roe, M. B., and C. J. Sniffen. 1990. Techniques for measuring protein fractions in feedstuffs. Page 81 in Proc. Cornell Nutr. Conf. Feed Manufacturers, Ithaca, NY.

Rueda, B. L. 2002. Nutrient dynamics and productivity potentials of pasture-based cattle systems in the western Amazon of Brazil. Ph.D. Diss. Cornell University, Ithaca, NY.

Schofield, P., and A. N. Pell. 1995. Measurement and kinetic analysis of the neutral detergent-soluble carbohydrate fraction of legumes and grasses. J. Anim. Sci. 73:3455–3463.

Sirois, P. K., M. J. Reuter, C. M. Laughlin, and P. J. Lockwood. 1994. A method for determining macro and micro elements in forages and feeds by inductively coupled plasma atomic emission spectrometry. Spectroscopist 3:6–9.

Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets. II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562–3577.

Stockdale, C. R., and K. R. King. 1983. Effect of stocking rate on the grazing behavior and fecal output of lactating dairy cows. Grass Forage Sci. 38:215–218.

Stockdale, C. R., and T. E. Trigg. 1985. Effect of pasture allowance and level of concentrate feeding on the productivity of dairy cows in late lactation. Austr. J. Exp. Agric. 25:739–744.

Tedeschi, L. O., C. Boin, R. F. Nardon, and P. R. Leme. 1999. Effects of concentrate supplementation on growth, from weaning to slaughter, on steers of the Guzera breed and their crossbreds grazing Guinea grass (*P. maximum*, Jacq.) Bol. Industr. Anim. 56:195–205.

Tedeschi, L. O., D. G. Fox, A. N. Pell, D. P. D. Lanna, and C. Boin. 2002a. Development and evaluation of a tropical feed library for the Cornell Net Carbohydrate and Protein System model. Sci. Agric. 59:1–18.

Tedeschi, L. O., R. F. Nardon, C. Boin, and P. R. Leme. 2002b. Effects of dry season and year-round feed supplementation on reproductive performance and body weight of Guzera breed cattle and their crossbreds grazing guineagrass (*Panicum maximum* Jacq.). Bol. Ind. Anim. 59:185–195.

Townsend, P. W., R. W. Blake, F. J. Holmann, P. J. Van Soest, S. J. Sniffen, and D. G. Sisler. 1990. Low cost feeding strategies for dual-purpose cattle in Venezuela. J. Dairy Sci. 73:792–803.

Traxler, M. J. 1997. Predicting the effect of lignin on the extent of digestion and the evaluation of alternative intake models for lactating cows consuming high NDF forages. Ph.D. Diss., Cornell Univ., Ithaca, NY.

van Houtert, M. F. J., and A. R. Sykes. 1999. Enhancing the profitability of pasture-based dairy production in the humid tropics through improved nutrition. Prev.Vet. Med. 38:147–157.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. Cornell Univ. Press. Ithaca, NY.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Velasquez, J. E., and P. A. Cuesta. 1990. Productividad animal de *Brachiaria decumbens* (Stapf) bajo pastoreo continuo con tres cargas en el piedemonte amazónico. Livest. Res. Rural Dev. 2:79–87.

Vera, R. R., R. Thomas, L. Sanint, and J. I. Sanz. 1992. Development of sustainable farming systems for the acid-soil savannas of tropical America. Annais Acad. Bras. Cienc. 64:105–125.

Wadt, P. G. S., J. F. Valentim, C. M. S. de Andrade, and E. F. Amaral. 2003. Manual técnico de calagem e adubação de pastagens no Estado do Acre. EMBRAPA, Acre, Rio Branco, Acre.