UTILIZATION OF TROPICAL PASTURE BY BEEF CATTLE: THE CORNELL NET CARBOHYDRATE AND PROTEIN SYSTEM (CNCPS) AND *IN SITU* MINERAL RELEASE IN THE RUMEN.

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI'I IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
IN
ANIMAL SCIENCES
AUGUST 2007

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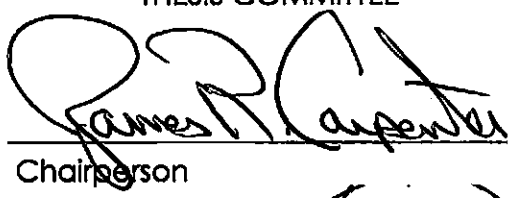

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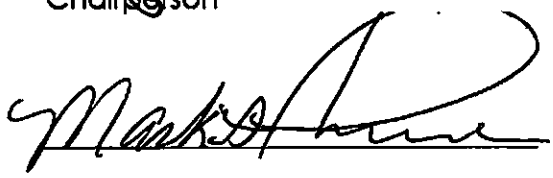

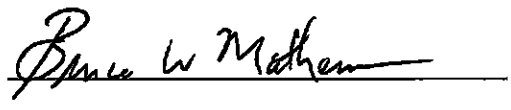

Acknowledgments

I would like to thank my thesis advisor, Dr. James Carpenter, and the other members of my thesis committee, Dr. Mark Thorne, and Dr. Bruce Mathews. Without their guidance I would not have been able to complete this project.

I would also like to thank the County of Hawaii Office of Research and Development for funding the project entitled "Release of mineral elements from Hawaiian pasture grasses and grass-derived processed feeds in both the rumen and a simulated abomasal environment," which partially supported my thesis research.

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Chapter 1. Introduction

Feed costs comprise the majority of the total production costs born by livestock producers, particularly cattle. Because the relative costs of feed are so great, a dramatic economic impact can be realized by utilizing the cheapest feeds available in the most efficient manner possible. In order to make efficient use of a feed, however, it is necessary for the producer to be able to predict how an animal or group of animals will respond to a given feed or mixed ration. A common method for predicting this response is the use of computer models.

Computer models meant to predict animal performance have been around for some time, particularly for cattle. Currently, these models are an integral component of most operations, in both temperate and tropical regions. However, these models have not been validated for beef production in many tropical regions. Poor production by cattle in tropical regions, even in developed countries, has been well-documented (Minson and McLeod, 1970; Stobbs, 1971). Tropical regions differ from temperate regions in that the forages present are often lower in protein and higher in fiber, due to the higher solar intensity and faster growth rate. Also, nutrients in tropical grasses may not be as available to the animal as the same nutrients in temperate grasses, as the higher fiber concentration may bind more of the nutrients.

The Cornell Net Carbohydrate and Protein System (CNCPS) is a mechanistic, deterministic, and static model based on the principles of rumen function, microbial growth, feed digestion and passage and animal physiology that was developed to predict requirements, feed utilization and nutrient excretion for dairy and beef cattle. The system

was first presented in a series of four papers (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992; O'Connor et al., 1993) and has since been continually refined (Ainslie et al., 1993; Tylutki et al., 1994; Fox et al., 1995, 1999; Pitt et al., 1996; Tedeschi et al., 2000a, 2000b, 2001, 2002a, 2002b, 2002c, 2003).

There have been several evaluations of the CNCPS model with animal performance data. Kolver et al. (1998) used a total mixed ration (TMR) and grazing dairy cows to evaluate the performance of the CNCPS and found the CNCPS underpredicted energy allowable milk production by 2.5% in the animals fed TMR and by 6.8% in the animals fed pasture. Dairy replacement heifers have also been used to evaluate the predictions of the CNCPS. Van Amburgh and coworkers (1998) used both the CNCPS and the 1989 Dairy NRC with 273 Holstein replacement heifers. The CNCPS ME allowable ADG accounted for 86% of the actual ADG.

The CNCPS has also been evaluated for tropical cattle production. Lanna et al. (1996) measured energy and protein content of empty body weight gain of growing animals and milk production of dual purpose lactating cows. Using actual DMI of feeds that were characterized for carbohydrate content and protein fractions, as well as digestion rates, the CNCPS accounted for 72% of the variation in live weight gain and 71% of the variation in milk production. Juarez Lagunes et al. (1999) found that, when feeds are properly characterized, an increase in NDF or a decrease in the rate of digestion of NDF, will affect the prediction of milk production of dual-purpose cows by the CNCPS accordingly.

In most tropical areas of the world, particularly in undeveloped countries, the primary source of nutrition for cattle and other ruminants is forage, which is harvested by the animal as live material, as opposed to feed which is harvested by the farmer and provided to the animal. In these areas it is simply not economically practical to provide any large degree of supplementation to the animals. A similar situation can be found in Hawaii. Although the cattle industry in Hawaii is considered by most to be well-developed, because of its geographical isolation the importation and delivery of supplements to the animals is often considered impractical and/or too costly.

This is in contrast to more well-developed, temperate regions of the world where supplements can be produced locally or imported at lower cost. This inability to supplement is compounded by the fact that tropical grasses are primarily C_4 (take in CO_2 at night), rather than C_3 (take in CO_2 during the day) plants and, consequently, are often lower in soluble carbohydrates and higher in cell wall and lignin components (Van Soest, 1994). Because of this increase in lignin and cell wall, tropical grasses are generally about 15% less digestible than temperate forages (Van Soest, 1994). This decrease in digestibility, along with a decrease in intake (INRA [Institut National de la Recherche Agronomique], 1989), can lead to a decrease in nutrients available for the animal. It has been well-documented that animals on tropical grasses typically underperform animals on temperate grasses (Minson and McLeod, 1970; Stobbs, 1971; Kaiser and O'Neill, 1975).

In other warm-climate areas, mineral deficiencies have been blamed for poor production of beef cattle (McDowell and Conrad, 1985). There are extensive records in the literature documenting deficiencies, as well as toxicities, of minerals in both soils and

plants (McDowell and Conrad, 1985; McDowell, 1997). Therefore, it is important to be aware of the mineral status of the animals. Often, only soil and/or plant levels of minerals are assessed in making a decision to supplement, and the level of a mineral in the soil or plant does not necessarily reflect what is available to the animal. Additionally, mineral supplements are often expensive and could lead to excess excretion or poor utilization by the animal. Therefore, unnecessary supplementation can have a dramatic impact on both economic returns and environmental sustainability, in addition to leading to toxicities. To both ensure adequate nutrition and eliminate unnecessary supplementation, it is necessary to know the levels of minerals present in the forages being grazed and their bioavailability to the animal.

Previous *in situ* trials show that there are differences in rate and extent of mineral release in the rumen between forages (Emanuele and Staples, 1990; Emanuele et al., 1991). Therefore, it is dangerous to draw general conclusions from limited studies and it becomes necessary to determine the rate and extent to which minerals are released from each of the forages in question.

It is also of interest how the rate of overall dry matter disappearance tracks with the rate of macromineral release in the rumen. It may be the case that dry matter disappearance is much more rapid and complete than mineral release. This may provide clues as to where certain minerals are sequestered in the plant. Also, if there is a close relationship, the procedure for determining dry matter release is easier, takes less time, and is less expensive.

The objectives of the research presented here were to: 1. evaluate the Cornell Net Carbohydrate and Protein System for use in Hawaii beef production, 2. evaluate how changing body size, body condition, level of intake, and forage composition affects the predictions of the Cornell Net Carbohydrate and Protein System, and 3. determine the levels and rates of macrominerals released from tropical forages in the rumen, and their relationship to DM disappearance.

Chapter 2. Review of Literature

Computer models meant to predict animal performance on a given diet have been around for some time, particularly for cattle. Currently, these models are an integral component of most operations, in both temperate and tropical regions. However, little research has been undertaken to validate these models for beef production in tropical regions. Poor production by cattle in tropical regions, even in developed countries has been well-documented (Minson and McLeod, 1970; Stobbs, 1971). Tropical regions differ from temperate regions in that the forages present are often lower in soluble carbohydrates and higher in cell wall and lignin components (Van Soest, 1994). Because of this increase in lignin and cell wall components, tropical grasses on average are about 15% less digestible than temperate forages (Van Soest, 1994). The decrease in digestibility, coupled with a decrease in intake (INRA, 1989), can lead to a decrease in the animal's nutritional status.

In Hawaii, and most other tropical regions, a large proportion of grazing animals' nutrients comes from forages. This includes minerals. In other warm-climate areas, mineral deficiencies have been blamed for poor production of beef cattle (Salih et al., 1983). Therefore, it is important to be aware of the mineral status of the animals. However, often, only soil and (or) plant mineral composition are assessed in making a decision on whether or not supplementation is required. Because mineral supplements are expensive and could lead to excess excretion by the animal, unnecessary supplementation can have a dramatic impact on both economic returns and environmental sustainability due to runoff. Therefore, to eliminate unnecessary supplementation, it is necessary to

know the animal's mineral requirements, the levels of minerals present in the forages being grazed, and their bioavailability to the animal. Computer modeling can help to determine the necessity of supplementation.

Mathematical Models

Mathematical modeling has been a part of the cattle industry for some time. Gill, et al, (1989) defined a cattle nutrition model as an integrated set of equations and transfer coefficients that describe various physiological functions. Often, modeling is used to improve performance, and can also be used to reduce production costs and nutrient excretion from the animal.

Models can be categorized as static or dynamic, empirical or mechanistic, stochastic or deterministic, continuous or discrete, and spatially homogeneous or heterogeneous (France and Thornley, 1984; Haefner, 1996). A dynamic model will explicitly incorporate time as a variable, whereas a static model will not. Empirical models are a "best fit" to actual data obtained while a mechanistic model will include concepts and make predictions based on the biology underpinning the desired predictions. A stochastic model incorporates an element of probability into the predictions, and, as such will give a range or outcomes for a single input. On the other hand a deterministic model will consistently give the same solution to a given set of inputs. Discrete models represent time as an integer, whereas in a continuous model time can take on any value. Finally, a spatially homogeneous model will have an explicit representation of space, while in a spatially heterogeneous model space is not essential. Not all of these categories are applicable to all models.

There are several commonly used models for predicting nutrient requirements and performance of ruminants. Among these are the National Research Council (NRC) beef cattle (NRC, 2000) and dairy cattle (NRC, 2001) modeling software, the Cornell Net Carbohydrate and Protein System (CNCPS), the Commonwealth Scientific and Industrial Research Organization (CSIRO, 1990) model (sheep), and the Agricultural and Food Research Council (AFRC, 1993) model.

The CNCPS is a mechanistic, deterministic, and static model based on the principles of rumen function, microbial growth, feed digestion and passage and animal physiology that was developed to predict requirements, feed utilization and nutrient excretion for dairy and beef cattle. The system was first presented in a series of four papers (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992; O'Connor et al., 1993) and has since been continually refined (Ainslie et al., 1993; Tylutki et al., 1994; Fox et al., 1995, 1999; Pitt et al., 1996; Tedeschi et al., 2000a, 2000b, 2001, 2002a, 2002b, 2002c, 2003). Version 4.0 of the CNCPS was used as the structure for the most recent NRC beef (2000) and dairy (2001) cattle models (Fox et al., 2003). As the CNCPS is Windows-based, rather than DOS-based as the NRC models, the program is more flexible and easier to use.

The ability of the CNCPS to predict requirements depends on the accuracy of the following predictions (Fox et al., 2003):

1. Maintenance requirement for energy and amino acids
2. Energy and amino acid requirements for tissue deposition and milk synthesis

3. Prediction of intake and ruminal degradation of feed carbohydrate and protein fractions, and microbial growth
4. Prediction of intestinal digestion and excretion
5. Prediction of metabolism of absorbed energy and amino acids

There are other limitations on the accuracy of the CNCPS as well. Chief among these is accurate determination of dry matter intake (DMI). Without accurate DMI, the prediction of performance will be impacted, as it will be impossible to accurately predict nutrient absorption/metabolism, and therefore animal performance. Dry matter intake also impacts the composition and growth rate of microbial pools, and the amino acids produced depend on the types and quantities of feeds being consumed, which will in turn affect the demand for nitrogen by each pool (Tedeschi et al., 2005).

Use of the CNCPS

There have been several evaluations of the CNCPS model with animal performance data. Kolver et al. (1998) used a total mixed ration (TMR) and grazing dairy cows to evaluate the performance of the CNCPS. Using actual feed composition values and actual animal and environmental factors, energy allowable milk production was predicted. The CNCPS underpredicted energy allowable milk production by 2.5% in the animals fed TMR and by 6.8% in the animals grazing pasture.

Dairy replacement heifers have also been used to evaluate the predictions of the CNCPS. Van Amburgh and coworkers (1998) used both the CNCPS and the 1989 Dairy

NRC with 273 Holstein replacement heifers. The CNCPS ME allowable ADG accounted for 86% of the actual ADG.

The 2000 NRC also evaluated the CNCPS for both Holstein and beef breed steers. When using the level 2 model (corresponds to the CNCPS), predicted ADG accounted for 92% of the actual ADG. Guiroy et al. (2001) showed that, when nearly all model inputs are measured, including body composition, the CNCPS version 4.0 was able to predict the feed required for the observed ADG, body weight, and composition of gain, accounting for 74% of the variation in feed actually consumed.

The CNCPS has also been evaluated for tropical cattle production. Lanna et al. (1996) measured energy and protein content of empty body weight gain of growing animals and milk production of dual purpose lactating cows. Using actual DMI of feeds that were characterized for carbohydrate content and protein fractions, as well as digestion rates, the CNCPS accounted for 72% of the variation in live weight gain and 71% of the variation in milk production. Molina et al. (2004) found similar results in predicting DMI of dual-purpose cattle in Mexico. Juarez Lagunes et al. (1999) found that, when feeds are properly characterized, an increase in NDF or a decrease in the rate of digestion of NDF, will affect the prediction of milk production of dual-purpose cows by CNCPS accordingly. These studies all used animals with individual feeding and recorded intakes, whereas traditional beef production systems do not deal with individual animals in this manner. Since groups of animals of varying age and size are evaluated, average performance needs to be assessed. If these results can be verified under traditional beef

production conditions and in other tropical regions, models such as these may prove to be especially useful in tropical and subtropical areas of the world.

Tropical Cattle Production

In most tropical areas of the world, and especially in undeveloped countries, the primary source of nutrition for cattle and other ruminants is forages. In these areas it is simply not economically practical to provide any large degree of supplementation to the animals. A similar situation can be found in Hawaii, where although it is well-developed, because of its geographical isolation the importation of supplements is often impractical. Likewise, the delivery of supplements to cattle grazing large areas is difficult.

This is in contrast to more well-developed, temperate regions of the world where supplements can either be produced locally or imported at lower cost. This inability to supplement is compounded by the fact that tropical grasses are often higher in fiber and lower in protein and other nutrients than temperate grasses, and what nutrients are present are often less available to the animal than in temperate grasses. For example, kikuyu grass is low in soluble carbohydrates, but high in soluble protein (Fulkerson et al., 2007). This lack of readily available carbohydrates means that even when ample protein is available, it may be used for energy by rumen microbes, rather than for productive purposes by the animal. For the above reasons, among others, there is a well-documented pattern of animals on tropical grasses generally underperforming those animals on temperate grasses (Minson and McLeod, 1970; Stobbs, 1971; Kaiser and O'Neill, 1975).

Mineral Status

In other warm-climate areas, mineral deficiencies have been blamed for poor production of beef cattle (Salih et al., 1983).

Table 2-1. Mineral deficiencies found in tropical areas.

Source	*Deficiencies*	*Location*
(Salih et al., 1983)	P, Cu, Fe, Se, Zn	Florida
(Vijchulata et al., 1983)	Na, P, Cu, Ca, Zn	Thailand
(de Vaccaro et al., 1984)	Ca, Mg	Venezuela
(Valdes et al., 1988)	Mg, Na	Guatemala
(Youssef et al., 1999)	Cu, Se,	Trinidad

Likewise, there are extensive records in the literature documenting deficiencies, as well as toxicities, of minerals in both soils and plants (Gartner et al., 1980; Salih et al., 1983; McDowell and Conrad, 1985). Table 2-1 shows some of the documented cases of mineral deficiencies found in tropical/subtropical areas. Because of this, it is important to be aware of the mineral status of the animals. However, often, only soil and (or) plant levels of minerals are assessed in making a decision on whether or not supplementation is required, and the level of a mineral in the soil or plant does not necessarily mean that those minerals are available to the animal at the same level. Assessing soil and (or) plant levels of minerals also does not consider the impact of interactions on the digestion and absorption of minerals.

Additionally, mineral supplements are often expensive and could lead to excess excretion by the animal. Therefore, unnecessary supplementation can have a dramatic impact on both economic returns and environmental sustainability, in addition to leading to toxicities. In order to eliminate unnecessary supplementation, it is necessary to know

both the levels of minerals present in the forages being grazed as well as the bioavailability to the animal.

Previous *in situ* trials demonstrate that there are differences in rate and extent of mineral release in the rumen between forages. Therefore, it is dangerous to draw general conclusions from limited studies and it becomes necessary to determine the rate and extent to which minerals are released from individual forages.

Playne et al. (1978), in an experiment using four tropical chopped hays: alfalfa (*Medicago sativa*), Townsville stylo (*Stylosanthes humilis*), purple top chloris (*Chloris barbata*), and spear grass (*Heteropogon contortus*), found that there were differences between forages in the amount of minerals solubilized in the rumen for nitrogen, sulfur, phosphorus, calcium, magnesium, potassium, and sodium, although the differences between forages with respect to potassium and magnesium were small and of no biological importance. Also, they found that no minerals were completely solubilized, and after 24 h the rate of disappearance was minimal and paralleled the rate of disappearance of the dry matter. Similar results were obtained by van Eys and Reid (1987) using tall fescue (*Festuca arundinacea)*, Kenhy fescue (a variety of tall fescue), and tall fescue-red clover pastures. They found a significant effect of forage type on the proportion of phosphorus (81.7-94.5%), potassium (94.0-98.8%), calcium (62.1-89.5%), magnesium (89.2-96.8%), and sulfur (76.1-92.8%) solubility after 48 h in the rumen. Greater solubility of minerals was found in ryegrass silages (Rooke et al., 1983) than in either these feeds or the tropical hays used by Playne et al. (1978), probably due to the difference in pH and partial solubilization of minerals during fermentation of silages.

Other forages that have been evaluated for ruminal mineral release include rice straw, guinea grass, glyricidia, jack leaves, rice bran (Ibrahim et al., 1990; Ibrahim et al., 1998), corn silage (Ibrahim et al., 1990; Ledoux and Martz, 1991), wheat straw (Ibrahim et al., 1990), rhizoma peanut (Emanuele and Staples, 1990), dwarf napiergrass (Emanuele and Staples, 1994; Ibrahim et al., 1998), bermudagrass, bahiagrass, limpograss (Emanuele and Staples, 1994), bromegrass hay (Ledoux and Martz, 1991), erythrina (Ibrahim et al., 1998), orchard grass, and red clover silage (Ceresnakova et al., 2005).

The above studies looked at macromineral release. However, Kabaija and Smith (1988) looked at the release of selected microminerals from four tropical forages, and found that the release of manganese, iron, zinc, and copper likewise differed among forages, as well as with age of regrowth of said forages.

Macrominerals also show varying patterns of release. Van Eys and Reid (1987) found that there were differences among elements in the rate of disappearance of macrominerals within the rumen. They found that phosphorous was released most rapidly, while sulfur was released most slowly. Not only did they find that the rate of release was different among minerals, but, they also found that for nitrogen, calcium and sulfur, the rate of release also differed between forages. However, Rooke et al. (1983) found no differences in the rate of release of potassium, calcium, sodium, phosphorous, magnesium, zinc, and copper from grass silages. This difference may be the result of fermentation solubilizing minerals that would have been bound in the cell wall in fresh grass or hay.

Chapter 3. Use of the Cornell Net Carbohydrate and Protein System (CNCPS) for predicting beef cattle cow-calf production in Hawaii.

Abstract

Models to predict performance of cattle on a given diet are an integral component of many operations. However, little research has been conducted to validate these models for beef production in tropical conditions. The Cornell Net Carbohydrate and Protein System (CNCPS) is a mechanistic, deterministic, and static model based on the principles of rumen function, microbial growth, feed digestion and passage, and animal physiology. Data from previous studies testing the effect of stocking rate or fertilizer application was used to assess the ability of the CNCPS to predict daily change in weight. Groups of animals rather than individuals were used. Mean bias was calculated and a regression was conducted to evaluate the performance of the model. Theoretical trials were also conducted using set animal weights and varying ages of forage with and without legume added in order to evaluate how changing body size, body condition score, level of intake, and forage composition affects the predictions of the CNCPS. No statistically significant mean bias was found, however, the slope of the best fit line did not differ from zero, and the r^2 value was less than one. Possible reasons for the inability of the model to effectively predict daily change in weight are inaccurate dry matter intake predictions, difficulty in accurately describing animal and production characteristics, and a lack of rates of carbohydrate and protein fraction digestion rates. The theoretical trials found a minor effect of increasing crude protein in the diet, as well as a significant effect of body weight, and body condition on both daily body weight change and predicted dry matter

intake. Legume in the diet also had an effect on daily body weight change and predicted dry matter intake when the crude protein in the forage was below 15%. More specific animal vs. average group or herd inputs may be necessary to evaluate the efficacy of the CNCPS for Hawai'i beef production.

Introduction

Computer models intended to predict animal performance on a given diet have been around for some time, particularly for cattle. Currently, these models are an integral component of many operations, in both temperate and tropical regions. However, little research has been undertaken to validate these models for beef production in tropical regions. Poorer production by cattle in tropical regions, even in developed countries has been well-documented (Minson and McLeod, 1970; Stobbs, 1971). Tropical regions differ from temperate regions in that the forages present are often lower in soluble carbohydrates and higher in cell wall and lignin components (Van Soest, 1994). Because of this increase in lignin and cell wall, tropical grasses are on average about 15% less digestible than temperate forages (Van Soest, 1994). The decrease in digestibility, coupled with a decrease in intake (INRA, 1989), can lead to a decrease in nutrients available for the animal.

The CNCPS is a mechanistic, deterministic, and static model based on the principles of rumen function, microbial growth, feed digestion and passage, and animal physiology that was developed to predict nutrient requirements, efficiency of feed utilization, and nutrient excretion for dairy and beef cattle. The system was first presented in a series of four papers (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992;

O'Connor et al., 1993) and has since been continually refined (Ainslie et al., 1993; Tylutki et al., 1994; Fox et al., 1995, 1999; Pitt et al., 1996; Tedeschi et al., 2000a, 2000b, 2001, 2002a, 2002b, 2002c, 2003). Version 4.0 of the CNCPS was used as the structure for the most recent NRC beef (2000) and dairy (2001) cattle models (Fox et al., 2003). As the CNCPS is Windows-based, rather than DOS-based as the NRC models, the program is more flexible and easier to use.

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decrease in the rate of digestion of NDF, affected the prediction of milk production of dual-purpose cows by CNCPS accordingly.

The objectives of the research presented here were to: 1. evaluate the Cornell Net Carbohydrate and Protein System for use in Hawaii beef production; and 2. evaluate how changing body size, body condition, level of intake, forage composition, and legume incorporation in the diet affects the predictions of the Cornell Net Carbohydrate and Protein System.

Materials and Methods

The CNCPS version 5.0 was used in this research. Data from previously conducted trials at the Mealani Research Station were used to evaluate the CNCPS. These trials were not designed for evaluation of the CNCPS, but rather for testing the effect of stocking rate or fertilizer application. Three 3-acre paddocks had previously been established per treatment at Mealani Experiment Station. Each paddock had 6-wk rest and 3-wk grazing cycles. Nine grazing cycles were compared:

1. Spring (late April/early May - late Sept/early Oct) 1993
2. Fall 1993
3. Spring 1994
4. Fall 1994
5. Spring 1995
6. Spring 1996
7. Fall 1996
8. Spring 1997
9. Spring 1998

Table 3-1. Treatments applied to paddocks during Spring 1993 – Spring 1995 grazing cycles and used for evaluation of the CNCPS.

Pretrial treatment	Fertilization Schedule		Total N Applied
	lbs N/acre	Application Interval	lbs N/acre/yr
Control Kikuyu	None	--	None
Kikuyu + N_1 (*Pennisetum clandestinum)*	60.0	18 wk	173.2
Stargrass (*Cynodon nlemfusensis*)	60.0	18 wk	173.2
Kikuyu + Legume	60.0	18 wk	173.2
Kikuyu + N_2	60.0	9 wk	346.4

The grazing cycles from Spring 1993 to Spring 1995 tested the effect of fertilizer application. Table 3-1 contains the fertilizer application schedules applied during these time periods. The legumes consisted of a mixture of greenleaf desmodium (*Desmodium intortum* Urb.), big trefoil (*Lotus ulginosis* Schk.), and New Zealand white clover (*Trifolium repens* L.). During previous studies, legumes represented 20 to 30% of Kikuyu + legume paddocks, but at the start of this experiment legumes represented only 15 to 17% of the forage in the same paddocks. The grazing cycles from Spring 1996 to Spring 1998 tested the effect of stocking rate. Within each grazing cycle five groups of cow-calf pairs of varying stocking rates (from 4 pairs to 12 pairs per paddock) were monitored for performance. Cows ranged in weight from 937.1 lbs to 1310.5 lbs. Calves ranged in weight from 204.3 to 303.7 lbs at the start and 505.0 to 623.2 lbs by the end of the period.

"Theoretical" trials were also run, using standardized weights and rations, in order to evaluate what effect increasing animal weight, higher body condition score, increasing age of grass, and increasing legume content of the diet has on the model predictions. No real world data were available with which to compare these predictions, and they were undertaken in a purely academic interest.

Parameters

Inputs were in English units, on a dry matter basis, using calories, and at Level 1 aggregation, as amino acid profiles of the feeds were not available.

Inputs

Inputs for animal description, production, and management/environment can be found in Table 3-2. A full accounting of the choices available for each of the options can be found in Appendix Table 1.

Rations. Actual dry matter intake could not be measured, as the animals were grazed on kikuyu grass pastures under differing management systems. However, DMI was estimated based on the amount of grass available when the animals entered the paddock versus the amount of grass remaining when the animals were removed from the paddock. In order to determine this, representative plots (3.25' x 5' area) were harvested just prior to cattle being placed on pasture and just after cattle were removed. The forage was weighed, sub-sampled, dried and ground through a 1-mm mesh stainless steel screen by a Wiley mill for nutrient analysis. This was used to determine the DM yield per day per unit land area, and it was assumed that the difference between the yield when the cattle entered the paddock and when the cattle were removed from the paddock was representative of forage consumed by the cattle while in the paddock. Because this number was just an estimate, and in some cases these estimated DMIs were very low or very high, the CNCPS-predicted DMI was also used for evaluations.

Table 3-2. Animal and environment descriptions in the CNCPS.

Description	Units
Animal Type	Lactating Beef Cow
Age*	62 – 105 months
Sex	Cow
Body Weight*	970 – 1310.5 lbs
Breed Type	Beef
Mature Weight	1284 lbs
Condition Score	5 (1-9 scale)
Breeding System	3-way cross
Sire's Breed	Angus
Grandsire's Breed	Hereford
Granddam's Breed	S. Gertrudis
Days Pregnant	0 days
Days since Calving*	50 days
Lactation #*	4 – 8
Relative Milk Production	5
Calving Interval	12 months
Expected Calf Birth Weight	80 lbs
Age at First Calving	24 months
Management Description	
Additive	None
Added Fat in Diet	No
Activity	Intensive Grazing
Time Spent Standing	16 h
# of Body Position Changes	6 per day
Flat Distance Walked	3281 ft
Sloped Distance Walked	0 ft
Environmental Description	
Wind Speed	15 mph
Previous Temperature*	62.37 – 67.27°F
Current Temperature*	61.13 – 67.32°F
Previous Relative Humidity	80%
Current Relative Humidity	80%
H in Sunlight	14
Storm Exposure	Yes
Hair Depth	0.20 inches
Mud Depth	0.00 inches
Hide	Average
Hair Coat	No mud
Cattle Panting	None
Minimum Night Temperature	55°F

*Vary depending on the animals being evaluated. Range of value given.

Feeds

Because the animals were on pasture, the actual nutrient composition of what was consumed could not be determined. However, representative sub-samples of the harvested pasture grasses were taken, dried at 50°C in a forced draft oven, ground through a 1-mm stainless steel screen in a Wiley mill, and analyzed for dry matter (DM), crude protein (CP), digestible protein, acid detergent fiber (ADF), and neutral detergent fiber (NDF) using near infrared (NIR) spectroscopy (Precision Scientific Model 4250) and minerals using inductively coupled plasma-emission (ICPE) spectroscopy. Predicted total digestible nutrients (TDN) was calculated by the equation 4.898 + (89.796 x 1.085 - (.0124 x ADF)). Using a separate database of 46 kikuyugrass/mixed kikuyu pastures, with complete nutrient profiles, including protein and carbohydrate fractions, equations were calculated which allowed the estimation of lignin, starch, crude fat, and ash levels based on the levels of CP and NDF in the grazed pasture. Actual CP, NDF, and DM of the grazed paddocks were used, while values mentioned above as predicted were used in the CNCPS model. The equations used can be found in Table 3-3.

Statistics

Mean bias and mean square prediction error (MSPE) were calculated as described by Tedeschi et al. (2000b). Analysis of regression was performed to determine the accuracy of the model in predicting observed results. The model prediction was the x-variate, while observed values were the y-variate. The regression statistic, r^2, the slope, and intercept confidence intervals were used to evaluate the model. Statistical analyses were conducted using SAS 9.1 (SAS Institute, Inc., 2004).

Table 3-3. Equations and associated correlation coefficients for prediction of nutrients for use in the CNCPS.

Nutrient	Equation	r
Lignin	(-0.20433) x CP + 7.749	0.64
Starch	(-1.14037 x NDF) + (-2.79035 x CP) + 128.05708	0.67
Crude Fat	(-0.05758 x NDF) + 6.72684	0.61
Ash	(0.15899 x CP) 5.10447	0.69

"Theoretical" trials

A series of simulations were conducted using "theoretical" animals. The descriptive, management, and environmental characteristics were the same as for the evaluation of the model above, with the exception that body weight was set to either 900, 1100, or 1300 lbs, and body condition scores of 3, 5 or 7 (9 point system). The model was run using a ration consisting of four different nutrient profiles of kikuyu grass hay, kikuyu + 10% legume hay, or kikuyu + 20% legume hay, and the CNCPS predicted DMI was used to set the level of intake. The nutrient profiles of kikuyu grass used were representative of changes normally seen with age of regrowth. Nutrient profiles for the kikuyu grass and legume were determined by sorting based on CP and NDF, then averaging the nutrient profiles of 46 samples of kikuyu grass and 16 samples of legumes grown in Hawai'i, respectively. As mentioned above, the kikuyu was divided in to four age levels, based on CP content (<12%, 12-15%, 15-18%, and >18%) of the grass. Nutrient profiles of these forages can be found in Table 3-4. A more detailed description of the nutrient composition of these grasses and legumes can be found in the Appendix Table 2.

Table 3-4. Nutritional composition of forages used to determine the response of the CNCPS to changes in age of forage.

Forage (n)	DM (%)	NDF (%DMB)	CP (%DMB)	Lignin (%NDF)	Starch (%NFC)	Fat (%DMB)	Ash (%DMB)
<12% CP Kikuyu (12)	36.33	66.28	9.48	8.79	25.84	2.84	6.53
12-15% CP Kikuyu (15)	24.92	62.63	13.65	8.13	17.12	3.19	7.37
15-18% CP Kikuyu (10)	22.99	58.15	16.28	6.62	16.75	3.41	7.78
>18% CP Kikuyu (9)	20.59	54.31	20.57	7.39	9.91	3.51	8.25
Mixed Legume (16)	24.26	48.23	17.89	9.06	10.34	3.27	7.61

Results

Evaluation of the CNCPS

A statistically significant mean bias was not observed when using the CNCPS to predict daily change in weight of beef cattle on pasture. Mean bias and root mean square prediction error (RMSPE) for both methods of determining DMI can be seen in Table 3-5. Both methods had considerable variation in the bias of the predictions.

Although there was no mean bias of the model in predicting daily change in weight, Figures 3-1 and 3-2 and Table 3-6, make it clear that there is no relationship between the predicted daily change in weight and the observed daily change in weight, regardless of how the DMI was determined. While the intercept is statistically indistinguishable from zero, the slope is not 1. It is, in fact, also statistically indistinguishable from zero, for both methods of determining DMI. The regression coefficient, r^2, is also very close to zero, indicating a lack of predictive ability. These results are in stark contrast to other studies using the CNCPS in tropical conditions (Lanna et. al, 1996; Molina et al., 2004).

Table 3-5. Comparison of CNCPS predicted daily change in body weight and observed daily change in body weight using both model-predicted and pasture-predicted DMI.

	Observed	CNCPS-predicted DMI	Pasture predicted DMI
Mean (lbs/day)	0.136	0.275	0.008
Mean bias	--	0.139	-0.129
RMSPE or SD*	0.577	0.697	1.806

*Standard deviation (SD) for observed data, root mean square prediction error (RMSPE) for predicted data.

Theoretical predictions

Predictions of daily change in weight and DMI of 900, 1100, and 1300 lb animals representative of the beef herd at the Mealani Research Station on the Big Island of Hawaii can be found in Table 3-7. As can be seen, both animal size and protein level of the kikuyu grass have an impact on daily change in weight and DMI. As far as intake is concerned, animal size has a far more dramatic impact than does the nutrient profile of the forage. There is a mild increase in intake as the forage increases from low protein to high protein, with the greatest increase being 1.42 lbs. The effect of weight on DMI, however, is much more pronounced; 6.08 lbs of increased DMI as animal weight increased, in the most dramatic example. The amount of legume in the diet also has an impact on intake, although this impact depends on the amount of protein in the kikuyu. Animals fed kikuyu with a low level of protein see a more dramatic increase in intake (about 1.33 lbs/10% legume) than animals that are fed a high protein kikuyu (about 0.008 lbs/10% legume).

On the other hand, the level of protein in the kikuyu has a much greater impact on daily change in weight than it does on DMI. An increase in percent CP of 11.09% (9.48 to 20.57% CP) corresponds to an increase in daily change in weight of 0.9-1.1 lbs,

Table 3-6. Regression statistics between observed and predicted daily change in body weight.

DMI method	Intercept ± SE	Slope ± SE	r^2	MSE
Pasture prediction	0.17 ± 0.091	0.10 ± 0.066	0.053	0.567
CNCPS prediciton	0.11 ± 0.113	0.10 ± 0.239	0.005	0.583

Figure 3-1. Comparison of observed v. predicted daily change in weight using CNCPS predicted DMI.

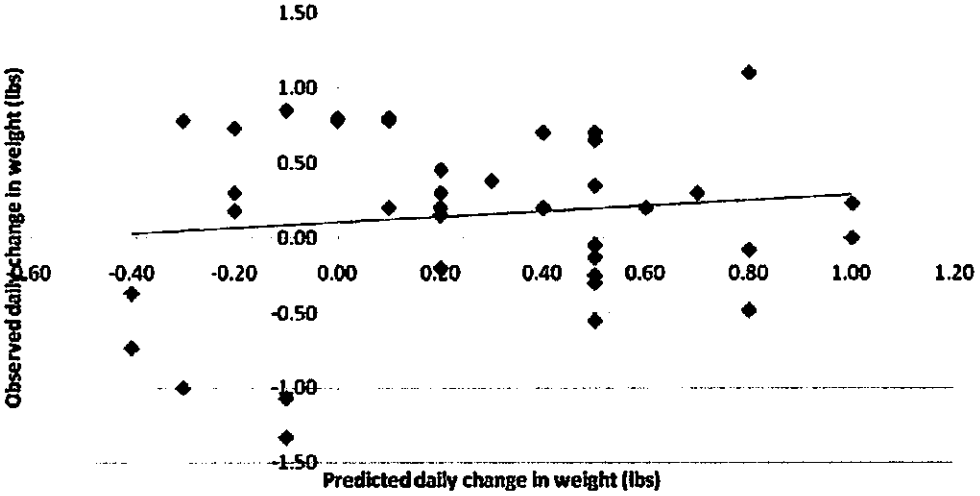
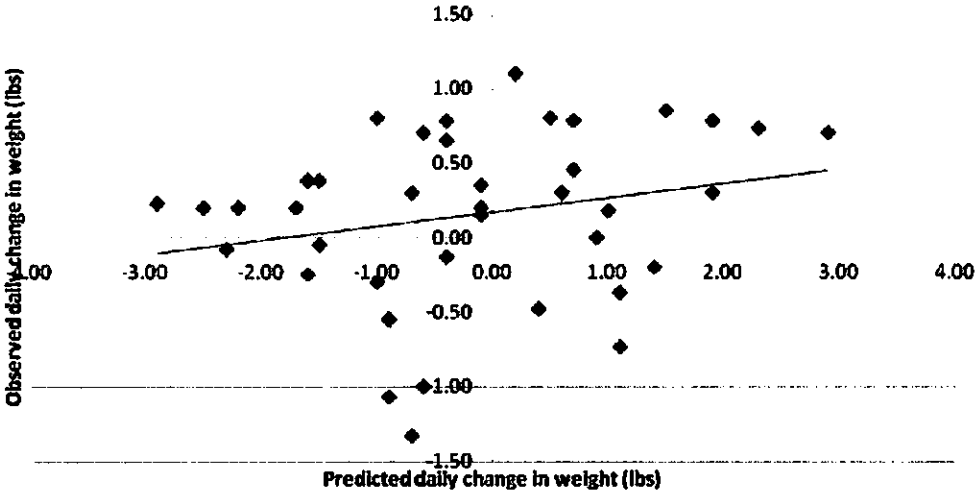


Figure 3-2. Comparison of observed v. predicted daily change in weight using pasture predicted DMI.



depending on the size of the animal, with larger animals showing a greater increase in daily change in weight as protein increases. Here, again, there is an impact of size on daily change in weight. An increase of 200 lbs in animal body weight corresponds to an increase in daily change in weight of 0.1-0.2 lbs, depending on the level of protein in the diet. There is also an impact of adding legume to the diet, but only in animals fed a diet containing kikuyu with CP less than 15%.

Table 3-8 looks at the effect of body condition score (BCS) on daily change in weight and DMI. BCS did not have any effect on DMI, although there was a trend for increased intake with increasing protein levels, but it did have an effect on daily change in weight. Increased BCS decreased daily change in weight for animals fed a high-protein kikuyu, whereas it increased daily change in weight for animals fed a low-protein kikuyu. Heavier animals required less CP in the diet in order to show a decreased daily change in body weight with increasing BCS.

Discussion

Both Lanna et al. (1996) and Molina et al. (2004) found the CNCPS to be far more reliable in predicting productive capabilities and DMI of cattle raised in tropical conditions. Using Nellore cattle, Lanna et al. (1996) found that the CNCPS accounted for 72% of the variation in live weight gain with a 2% bias and 71% of the variation in milk production with a 10% bias. In the evaluation presented in this paper, there was no significant bias, due to the large variation found the data. The model also accounted for none of the variation in observed daily change in weight.

There are a number of reasons why these results may have been obtained. First and foremost is the difficulty in determining an accurate DMI. An attempt was made at predicting DMI on the basis of biomass removed from the pasture by the animals. Other researchers have attempted to measure intake on pasture using n-alkanes as a marker (Molina et al., 2004). However, the CNCPS predicted DMI appeared to have less variation and slightly greater predictive power, although they were not statistically different from each other. However, it is unlikely that inaccuracies in DMI determination alone account for the observed ineffectiveness. Molina et al. (2004) found the CNCPS to account for between 18.0% and 50.3% of the variation in DMI with a bias between -43.86% and 5.78% when DMI was estimated using alkanes as a marker. These results are significantly better than those obtained here.

Another factor to consider is that animals were not evaluated individually, but as a group. Because of this, average characteristics were used, including age, days since calving, lactation number, weight, and condition score. The aggregate of these estimations will undoubtedly introduce uncertainty into the predictions of the CNCPS. Likewise, there was uncertainty introduced in the characterization of the breed. A three-way cross was used, as laid out in Table 3-2, but many of the animals used in this study have more complicated genetics (composite breed developed from multiple breeds, to include Holstein) than can be described by a three-way cross. This will introduce additional uncertainty into the model. Also, animal interactions, such as dominant behavior in a grazing environment, were not able to be considered in the model, which may have introduced variation.

Another aspect that will introduce uncertainty in to the predictions is the nutritional characterization of the forages consumed by the animals. The forages consumed by the animals in this study were able to be well characterized as far as the nutrients classes characterized by proximate analysis and the Van Soest detergent techniques are concerned. However, for minerals, only typical mineral values were used, rather than the values for the actual grasses grazed. Likewise, amino acid and vitamin levels were not characterized. More importantly, no information on bioavailability and rates of digestion were available for these grasses. The CNCPS default values were used in these cases, and likely were not entirely accurate. While any one of these issues may not have rendered the model unable to accurately predict daily change in weight, taken in aggregate the model was not able to accurately predict daily change in weight under the conditions of the research conducted here. However, based on the research of Lanna et al. (1996), Juarez Lagunes et al. (1999), and Molina et al. (2004), if the common forages used in Hawaii can be more accurately characterized, including bioavailability and rates of digestion of nutrients, the CNCPS will likely be an adequate tool for predicting animal performance. Further investigations into the use of the CNCPS should take care to evaluate the feed used as thoroughly as possible and to accurately determine the DMI, if at all possible, as well as use purebred and crossbred animals, to remove the confounding effect of genetics.

Table 3-7. Daily change in weight and DMI predicted by CNCPS using theoretical animals and typical Hawaii forages; effect of adding legume.

Weight (lb)	Daily change in weight (lbs/day)				DMI (lbs/day)				
	Kikuyu protein level				Kikuyu protein level				
	>18%	15-18%	12-15%	<12%	>18%	15-18%	12-15%	<12%	
900	0.2	0.1	-0.4	-0.7	22.347	22.178	21.613	21.274	
1100	0.4	0.3	-0.3	-0.6	25.455	25.259	24.600	24.204	Kikuyu only
1300	0.6	0.4	-0.1	-0.5	28.425	28.204	27.454	27.003	
900	0.2	0.1	-0.3	-0.6	22.354	22.200	21.686	21.372	
1100	0.4	0.3	-0.2	-0.5	25.462	25.284	24.684	24.318	Kikuyu + 10% legume
1300	0.6	0.5	-0.1	-0.4	28.433	28.232	27.549	27.133	
900	0.2	0.1	-0.3	-0.5	22.360	22.222	21.760	21.474	
1100	0.4	0.3	-0.1	-0.4	25.470	25.310	24.770	24.436	Kikuyu + 20% legume
1300	0.6	0.5	0	-0.3	28.441	28.261	27.647	27.267	

Table 3-8. Daily change in weight and DMI predicted by CNCPS using theoretical animals and typical Hawaii forages; effect of BCS.

Weight (lb)	Daily change in weight (lbs/day)				DMI (lbs/day)				
	Kikuyu protein level				Kikuyu protein level				
	>18%	15-18%	12-15%	<12%	>18%	15-18%	12-15%	<12%	
900	0.2	0.1	-0.4	-0.7	22.347	22.178	21.613	21.274	
1100	0.4	0.3	-0.2	-0.8	25.455	25.259	24.600	24.204	BCS 3
1300	0.7	0.3	-0.2	-0.7	28.425	28.204	27.454	27.003	
900	0.2	0.1	-0.4	-0.7	22.354	22.200	21.686	21.372	
1100	0.4	0.3	-0.3	-0.6	25.462	25.284	24.684	24.318	BCS 5
1300	0.6	0.4	-0.1	-0.5	28.433	28.232	27.549	27.133	
900	0.1	0.0	-0.4	-0.6	22.360	22.222	21.760	21.474	
1100	0.3	0.2	-0.3	-0.5	25.470	25.310	24.770	24.436	BCS 7
1300	0.5	0.3	-0.2	-0.5	28.441	28.261	27.647	27.267	

Chapter 4. In situ rates of macro-mineral release from alfalfa and tropical grasses, and relationships with dry matter disappearance

Abstract

In Hawaii, most of a ruminant's nutrients come from forages, including minerals. Mineral supplements are often expensive and may lead to excess excretion by the animal, impairing economic returns and environmental sustainability. Therefore, one must know the concentration and availability of minerals in forages for accurate ration formulation. The objectives of this research were to determine the concentration and rates of insoluble macrominerals released from tropical forages in the rumen, and their relationship to DM disappearance. Both ground (1 mm) forage and digesta residue samples (0, 12, 24, 48, and 96 h after nylon bag insertion) from previous *in situ* rumen digestion studies, each with 2 or 3 fistulated steers, were analyzed for macromineral (Ca, Mg, P, K, Na, S) concentration using inductively coupled plasma-emission spectroscopy. Seven tropical grasses and alfalfa harvested from single species plots were evaluated. After 96 h, the proportion of minerals remaining averaged across all grasses (as a percent of insoluble mineral initially present ± SE) was 32.8 ± 1.69%, 67.1 ± 9.68%, 22.9 ± 1.6%, 13.68 ± 2.8%, 79.6 ± 11.49%, and 59.3 ± 3.78% and for alfalfa hay was 20.6 ± 3.11%, 60.1 ± 30.08%, 23.2 ± 1.49%, 8.4 ± 3.37%, 27.3 ± 4.45%, 19.5 ± 0.39%, for Ca, Mg, P, K, Na, and S, respectively. Several of the samples had a net recovery of minerals exceeding 100% at 96 h. There was also a significant effect of species ($p \leq 0.05$) on the proportion of macrominerals remaining after 96 h. Drying also appears to increase the release of magnesium, phosphorous, and potassium in pangola grass. This suggests that a given

species of forage should be evaluated for extent of mineral release before concluding that it provides sufficient levels of minerals to an animal. Additional research may need to be done to determine how efficiently minerals released in the rumen are absorbed into the bloodstream and the impact of abomasal digestion on mineral release of tropical forages.

Introduction

In most tropical areas of the world, particularly in undeveloped countries, the primary source of nutrition for cattle and other ruminants is forage, which is harvested by the animal as live material, as opposed to feed which is harvested by the farmer and provided to the animal. In these areas it is simply not economically practical to provide any large degree of supplementation to the animals. A similar situation can be found in Hawaii. Although the cattle industry in Hawaii is considered by most to be well-developed, because of its geographical isolation the importation and delivery of supplements to the animals is often considered impractical and/or too costly.

This is in contrast to more well-developed, temperate regions of the world where supplements can be produced locally or imported at lower cost. This inability to supplement is compounded by the fact that tropical grasses are primarily C_4, rather than C_3, plants and, consequently, are often lower in soluble carbohydrates and higher in cell wall and lignin components (Van Soest, 1994). Because of this increase in lignin and cell wall, tropical grasses are generally about 15% less digestible than temperate forages (Van Soest, 1994). This decrease in digestibility, along with a decrease in intake (INRA, 1989), can lead to a decrease in nutrients available for the animal. It has been well-documented

that animals on tropical grasses typically underperform animals on temperate grasses (Minson and McLeod, 1970; Stobbs, 1971; Kaiser and O'Neill, 1975).

In other warm-climate areas, mineral deficiencies have been blamed for poor production of beef cattle (McDowell and Conrad 1985). There are extensive records in the literature documenting deficiencies, as well as toxicities, of minerals in both soils and plants (McDowell and Conrad 1985; McDowell, 1997). Therefore, it is important to be aware of the mineral status of the animals. Often, only soil and (or) plant levels of minerals are assessed in making a decision to supplement, and the level of a mineral in the soil or plant does not necessarily reflect what is available to the animal. Additionally, mineral supplements are often expensive and could lead to excess excretion or poor utilization by the animal. Unnecessary supplementation can have a dramatic impact on both economic returns and environmental sustainability, in addition to leading to toxicities. To both ensure adequate nutrition and eliminate unnecessary supplementation, it is necessary to know the levels of minerals present in the forages being grazed and the bioavailability to both rumen microorganisms and the animal.

Previous *in situ* trials show that there are differences in rate and extent of mineral release in the rumen between forages (Emanuele and Staples, 1990; Emanuele et al., 1991). Therefore, it is dangerous to draw general conclusions from limited studies and it becomes necessary to determine the rate and extent to which minerals are released from each pasture grass or legume, or harvested forage in question.

It is also of interest how the rate of overall dry matter disappearance tracks with the rate of macromineral release in the rumen. It may be the case that dry matter

disappearance is much more rapid and complete than mineral release. This may provide clues as to where certain minerals are sequestered in the plant. Also, if there is a close relationship, the procedure for determining dry matter release is easier, takes less time, and is less expensive.

The objectives of this research were: (1) to determine the levels and rates of insoluble macrominerals released from tropical forages in the rumen, (2) their relationship to DM disappearance, and (3) the impact of processing on mineral release.

Materials and methods

Forage and digesta residue samples from previously conducted *in situ* rumen digestion studies were used in this study.

Grasses/legume

Seven grasses and alfalfa were included in this study. The species, as well as processing of samples is shown in Table 4-1. Grasses were obtained from plots at the Mealani Experiment Station in Kamuela, and alfalfa was obtained from the experimental plots in Kohala, both on the Island of Hawaii. Forages were harvested with a sickle bar mower. Both fresh and air dried hay samples were chopped so average particle length was <16 mm before being placed in the nylon bags for the *in situ* studies. To evaluate the effect of drying on mineral release, only pangola and kikuyu grass were used, as these were the only grasses with both fresh and dry samples available.

Table 4-1. Species evaluated for mineral release.

Common name	Scientific name	Processing
Kikuyu grass	*Pennisetum clandestinum*	Fresh, hay
California grass	*Brachiara mutica*	Hay
Guinea grass	*Panicum maximum*	Hay
Green Panic grass	*Panicum maximum* var. *trichoglume*	Hay
Napier grass	*Pennisetum purpureum*	Fresh
Pangola grass	*Digitaria eriantha*	Fresh, hay
Pearl millet	*Pennisetum glaucum*	Fresh
Alfalfa	*Medicago sativa*	Hay

Animals

Fistulated steers from the Mealani Research Station on the Big Island of Hawaii were used for these studies. All trials to assess the various grasses used either 2 or 3 steers and most of the studies were conducted at the Waialee Livestock Research Farm on Oahu. All animals were kept on an alfalfa hay/cube diet. Prior to the trials, a trace mineral salt mix was available, but this was removed during the trials.

Incubation procedure

Enough sample of each feed to provide for 10-15 g of dry matter was inserted into each nylon bag. Each feed was run in duplicate per steer. The duplicate bags for each time period were clamped together then inserted into the steer and tied to a 1 kg stainless steel weight. The bags were incubated for 4, 8, 12, 24, 36, 48, 72, and 96 h in the rumen. In addition 0 h samples were rinsed in tap water to simulate immediate solubility when placed in the rumen. Only the 0, 12, 24, 48, and 96 h samples, as well as control samples (unrinsed) samples for guinea, napier, and pangola grass, were assayed for mineral content. Bags were rinsed several times with warm water and frozen upon removal from

the rumen. At time of analysis samples were thawed, each bag was re-rinsed and gently squeezed until water flowing through the bags remained clear, and bags with samples were dried in a forced draft oven (50°C), and ground through a 1-mm stainless steel screen in a Thomas Wiley mill.

Mineral analysis

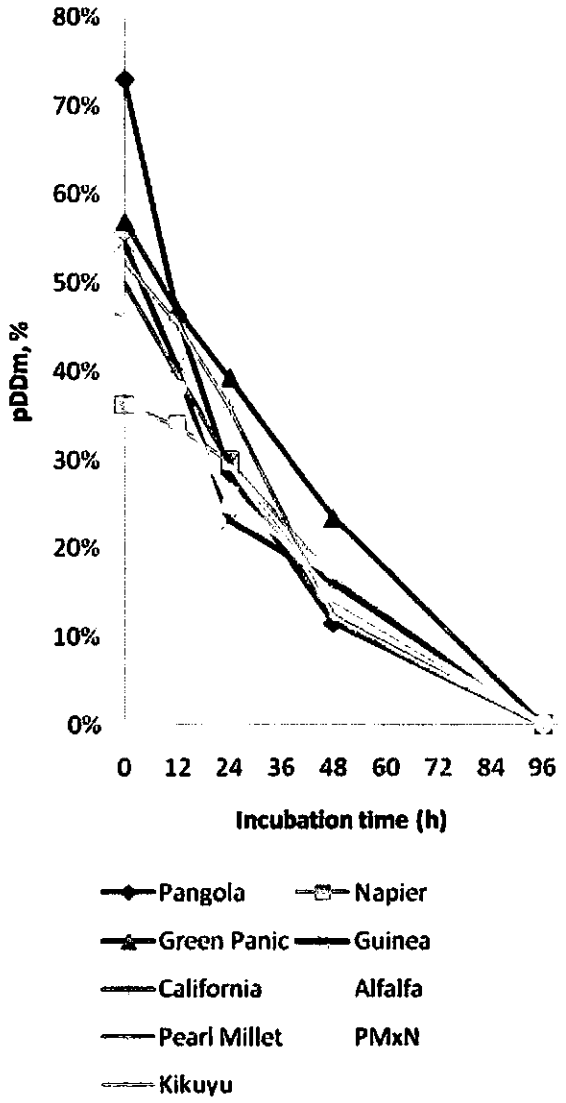
Samples were assayed for macromineral (Ca, P, Mg, K, Na, and S) concentration using inductively coupled plasma-emission spectroscopy following HNO3-H2O2 digestion at the Louisiana State University Soil Test and Plant Analysis Lab. Residues from the duplicate bags for each time period for each animal were combined and subsampled before mineral analysis.

Calculations and statistical analysis

The fractional rate of disappearance for DM and minerals was calculated from the slope of the equation ($y=k_Dx+c$) relating the natural logarithm of the proportion of mineral remaining in the bag (y) to time of incubation (x), as demonstrated by Rooke et al. (1983). Treatment effects were evaluated by ANOVA and treatment means were compared with Duncan's multiple range test. Data were statistically analyzed using SAS 9.1 (SAS Institute, Inc., 2004).

Results

Figure 4-1. Potentially digestible dry matter disappearance of forages during *in situ* incubation.



Dry matter disappearance

Figure 4-1 shows the rate of dry matter disappearance of the feeds. All the forages show a similar pattern of dry matter disappearance. Dry matter was released faster than magnesium and sodium, at the same rate as sulfur and calcium, and more slowly than phosphorus and potassium ($p \leq 0.05$). Rates of release for DM can be found in Table 4-3.

Mineral Release

The proportion of insoluble minerals in guinea grass, pangola grass, and napier grass can be found in Table 4-2. The pattern of insoluble mineral release of the different grasses is shown in Figures 4-2 through 4-7.

Calcium (Figure 4-2). Napier grass absorbed calcium immediately upon entering the rumen. Guinea and pangola grass, however, released 15.8 and 17.9% of their calcium

Table 4-2. Insoluble mineral as a fraction of total mineral in the sample.

Forage	Calcium	Phosphorous	Magnesium	Potassium	Sodium
Guinea Grass	0.841^{b}	0.223^{a}	0.269^{a}	0.024^{a}	0.581^{b}
Napier Grass	1.187^{a}	0.131^{a}	0.433^{a}	0.039^{a}	1.493^{a}
Pangola Grass	0.821^{b}	0.234^{a}	0.516^{a}	0.113^{a}	0.156^{c}

*Data in the same column with different superscripts are significantly different ($p \leq 0.05$).

immediately (Table 4-2). There is little difference in the pattern of calcium release of the feeds. With the exception of alfalfa (51% release), there was little calcium release at 12 h, and a small amount of calcium appears to have been absorbed; percent recoveries range from 95% in pangola grass to 149% in pearl millet and napier grass mix. From this point there is a steady decrease in calcium recoveries until 96 h. Percent recoveries range from 14% in alfalfa hay to 49% in napier grass. Overall release of calcium was 41.7, 78.4, and 83.5% for napier, guinea, and pangola grass, respectively.

Phosphorus (Figure 4-3). There was no statistical difference between feeds in the immediate solubility of phosphorous (Table 4-2). However, there is an obvious difference in the patterns of phosphorous release in the test feeds. Napier grass and california grass sorbed phosphorous; 96 h recoveries of 132 and 165%, respectively. Guinea grass, pearl millet, and pearl millet x napier, on the other hand, exhibited very little phosphorous release (97-101% recovery after 96 h). The other feeds exhibited varying levels of phosphorous release. Recovery after 96 h ranged from 17% in kikuyu to 45% for green panic, with the majority of the phosphorous released by these feeds being released within 12 h. Overall release of phosphorous was 78.1, 82.7, and 96.0% for guinea, napier, and pangola grass, respectively.

Magnesium (Figure 4-4). There was no difference among feeds evaluated in the quantity of magnesium immediately soluble in the rumen (Table 4-2). Magnesium, like calcium, showed little difference in the pattern of release between feeds. None of the feeds demonstrated any sorption of magnesium, and, after 96 h, magnesium recovery ranged from 13% in pangola grass to 42% in california grass. Total release of magnesium in pangola, napier, and guinea grass was 94.1, 88.8, and 92.9%, respectively.

Potassium (Figure 4-5). Potassium had a very high immediate solubility in the rumen (Table 4-2). There is more variation over time and within feed in the release of potassium from the test feeds than there is among the other macrominerals. California grass and guinea grass sorbed potassium from 24 to 48 h (43 to 49% and 23 to 27%, respectively). Overall, however, after 96 h all the feeds had released most of the insoluble potassium present at the beginning of the incubation. Recovery after 96 h ranges from 1% in kikuyu grass to 38% in california grass. Of particular note is the rapidity with which kikuyu released its potassium; at 36 h recovery was only 2% of total insoluble potassium. When immediate solubility and release during incubation are considered, pangola, napier, and guinea grass released greater than 99.2, 99.5, and 99.7%, respectively, of the potassium in the samples.

Sodium (Figure 4-6). There were considerable differences in the immediate solubility of sodium. (Table 4-2) Napier grass initially absorbed sodium, while guinea grass released 41.9% and pangola grass released 84.3% immediately. Kikuyu grass, napier grass, and pearl millet x napier sorbed large quantities of sodium during the incubation. Kikuyu grass in particular had 24 h recoveries of 338%, while napier grass

Figure 4-2. Calcium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h.

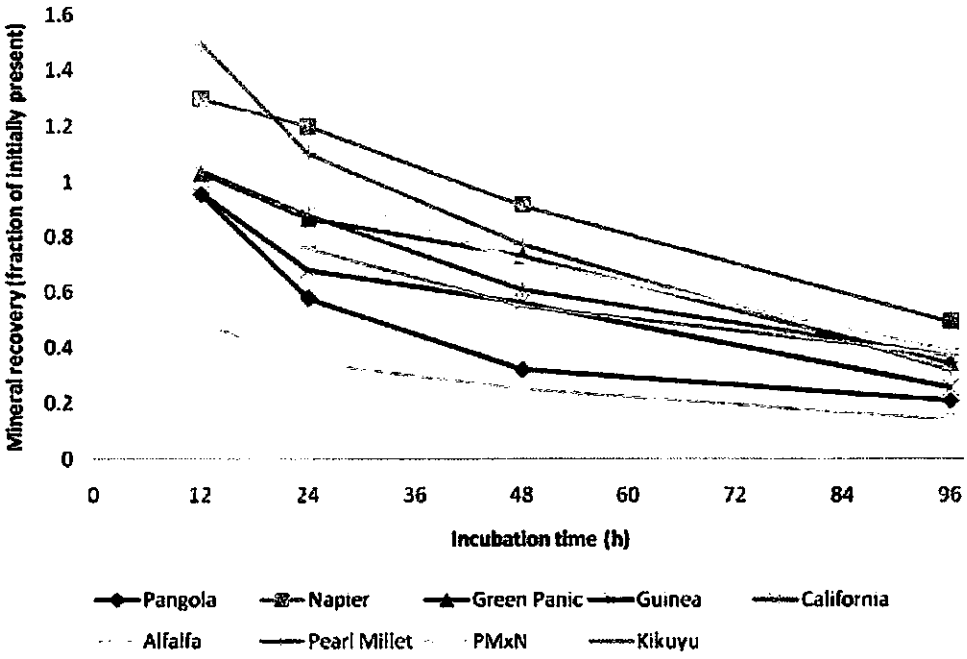


Figure 4-3. Phosphorous recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h.

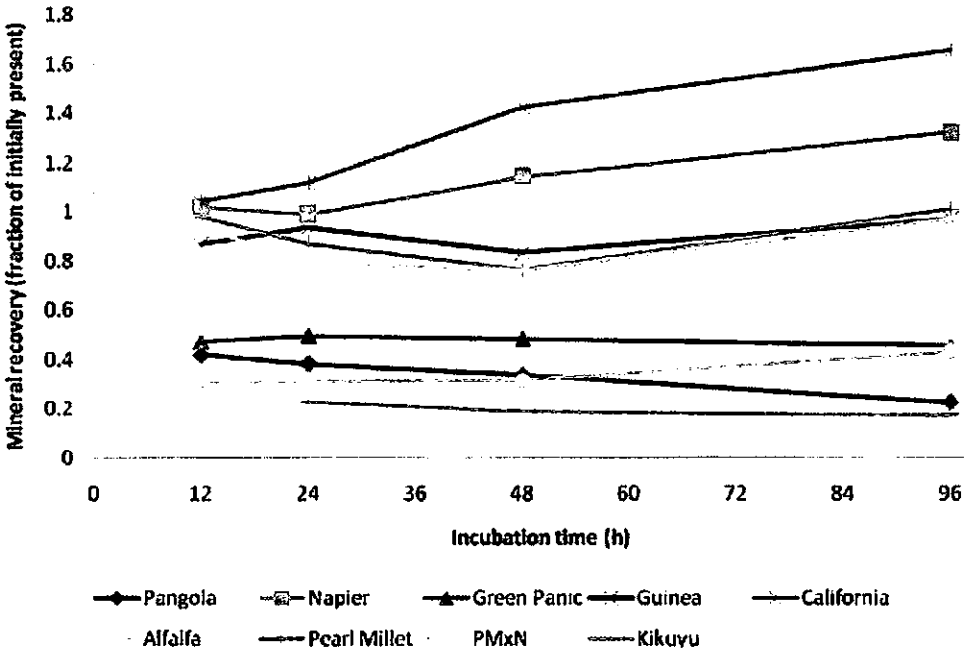


Figure 4-4. Magnesium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h.

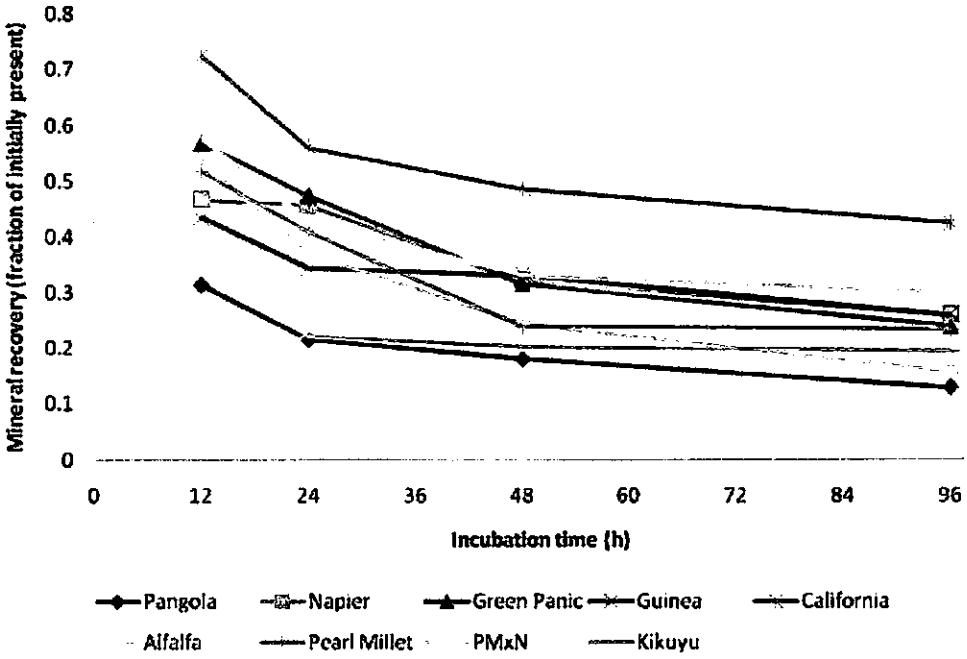


Figure 4-5. Potassium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h.

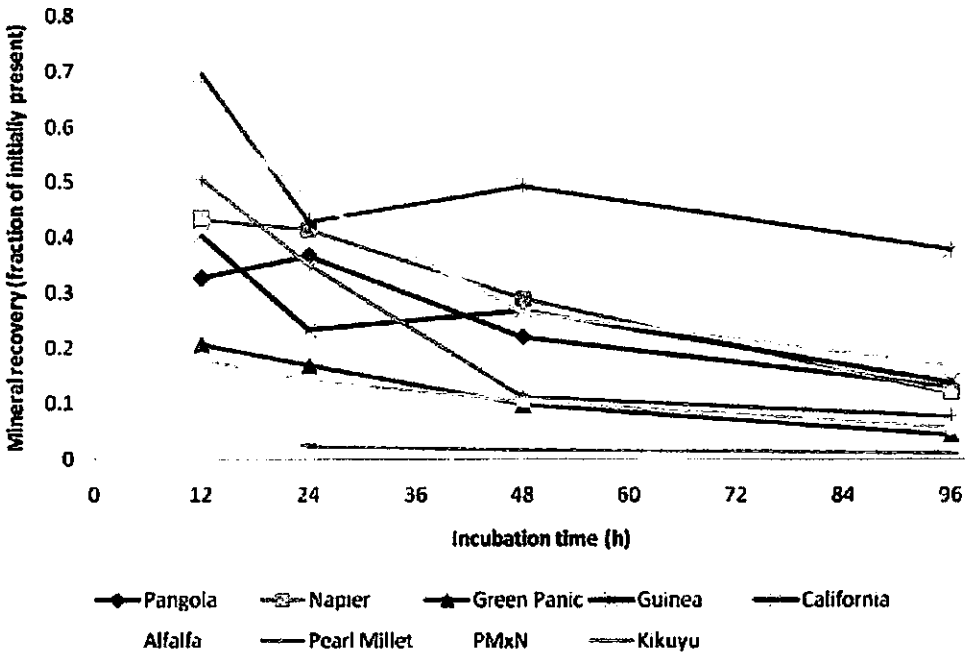


Figure 4-6. Sodium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h.

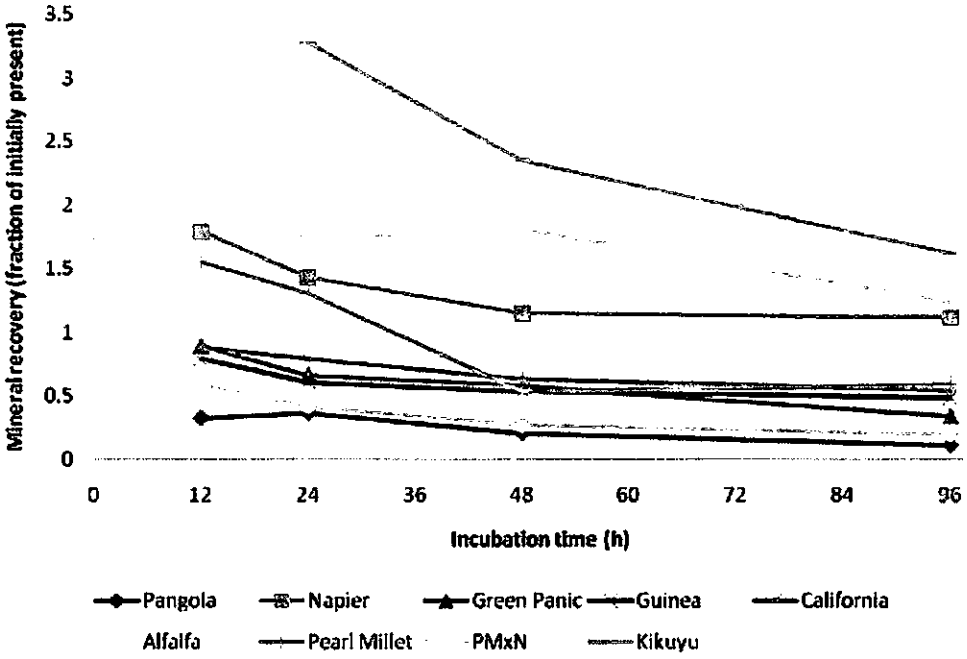
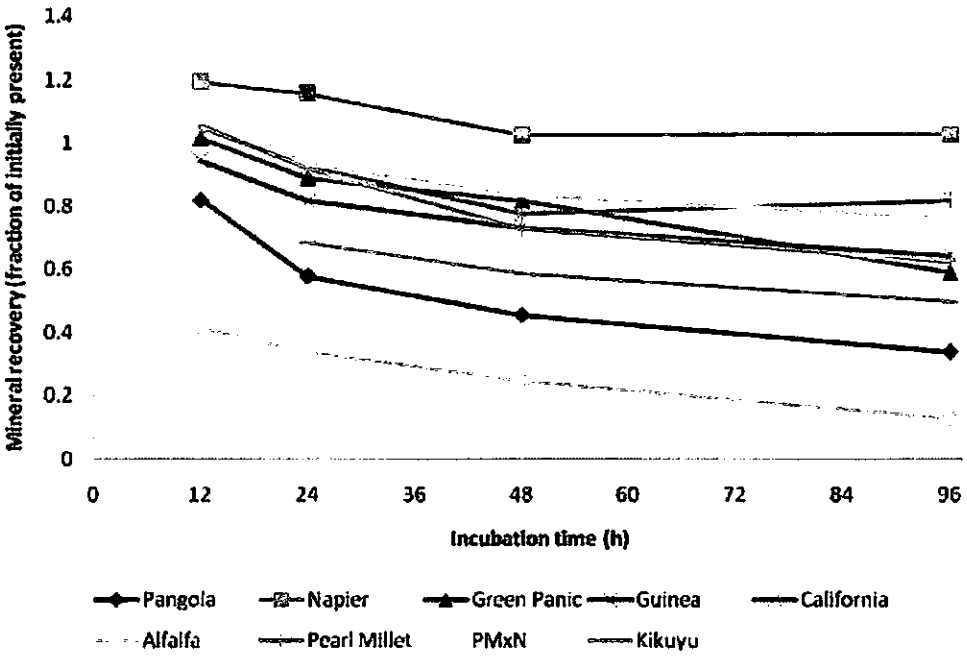


Figure 4-7. Sulfur recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h.



and pearl millet x napier had a 12 h recovery of 179 and 209%, respectively. All four of these grasses released sodium from that point on, resulting in 96 h recoveries of 161, 111, and 123% for kikuyu grass, napier grass, and pearl millet x napier, respectively. The other five feeds released sodium readily and evenly across the incubation, resulting in 96 h recoveries ranging from 11% in pangola hay to 59% in pearl millet. Overall release of sodium varied. After 96 h, napier grass had absorbed 66.1% more sodium than was initially in the sample. Guinea grass and pangola grass, however, released 71.4 and 98.9% of the sodium initially in the sample.

Sulfur (Figure 4-7). Napier grass sorbed sulfur (12 h recovery of 119%) but released to near initial levels at 96 h (recovery of 103%). California grass, green panic grass, and pearl millet x napier also initially sorbed some sulfur (12 h recoveries of 105, 102, and 110%, respectively), but released sulfur from there. Alfalfa released sulfur particularly well, probably owing to high levels of digestible protein. The other feeds released sulfur to varying degrees, with 96 h recoveries ranging from 34% for pangola grass to 82% for california grass.

Fractional rate of disappearance

Table 4-3 shows the fractional rate of disappearance (k_D) of minerals and DM for the 11 forages looked at in this paper. Across all feeds, calcium, phosphorus, and potassium had significantly greater fractional rates of disappearance than did DM. The other minerals did not differ significantly from DM.

Table 4-3. Fractional rate of disappearance of DM and macrominerals during *in situ* incubation.

Forage	Fractional rate of disappearance (k_D), %/h						
	DM	Ca	Mg	P	K	Na	S
Pangola grass	1.32^{d}	1.77^{c}	1.80^{d}	1.26^{d}	1.91^{b}	2.07^{d}	1.12^{f}
Napier grass	0.49^{a}	0.92^{a}	1.16^{b}	-0.34^{ab}	1.78^{ab}	0.18^{ab}	0.07^{a}
California grass	0.73^{b}	1.13^{ab}	0.79^{a}	-0.56^{a}	0.84^{a}	0.63^{bc}	0.27^{ab}
Guinea grass	0.79^{b}	1.45^{b}	1.06^{ab}	-0.01^{b}	1.67^{ab}	0.66^{bc}	0.45^{bcd}
Green panic grass	0.88^{bc}	1.16^{ab}	1.33^{bc}	0.55^{c}	2.66^{b}	1.12^{c}	0.57^{de}
Kikuyu grass	0.79^{b}	1.06^{a}	1.59^{cd}	1.73^{e}	4.48^{d}	-0.32^{a}	0.72^{e}
Pearl millet	0.82^{b}	1.45^{b}	1.37^{bc}	0.01^{b}	2.54^{b}	0.91^{c}	0.56^{cde}
Pearl millet x napier	0.49^{a}	1.14^{ab}	1.08^{ab}	0.03^{b}	1.74^{ab}	0.18^{ab}	0.35^{bc}
Alfalfa	1.01^{c}	1.45^{b}	1.37^{bc}	0.11^{b}	2.01^{b}	1.20^{c}	1.43^{g}

*Data in the same column with different superscripts are significantly different ($p \leq 0.05$).

Hay vs. fresh

Figures 4-8 through 4-13 compare the release of macrominerals from hay and from fresh grass. Again, as shown in Figure 4-2, there is an effect of species on extent of macromineral release for all minerals except phosphorus. Drying had an effect on the extent of mineral release for magnesium ($p \leq 0.0054$), phosphorous ($p \leq 0.0178$), and potassium ($p \leq 0.0023$). However, there was also a significant interaction between species and processing for these minerals; drying appeared to have an effect on pangola grass, and in each case, drying increased the extent of mineral release from the forage.

Table 4-4 shows the fractional rate of disappearance of each mineral from kikuyu and pangola grass and hay. Again, there is a significant effect of processing on the rate of release of magnesium, phosphorous, and potassium, and a significant interaction between species and processing for magnesium and phosphorous, with only pangola affected by

Figure 4-8. Calcium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h for kikuyu and pangola grass and hay.

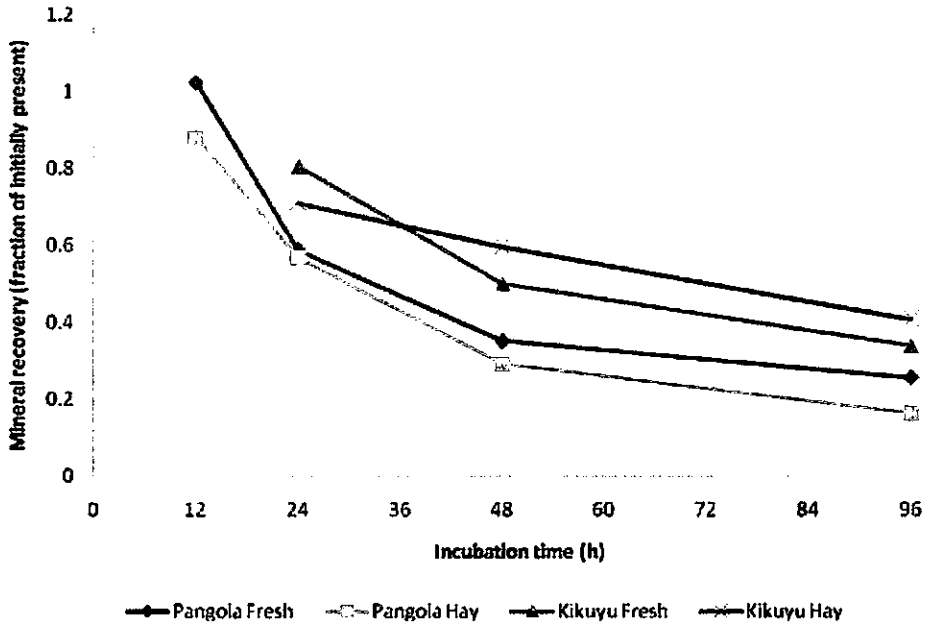


Figure 4-9. Phosphorous recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h for kikuyu and pangola grass and hay.

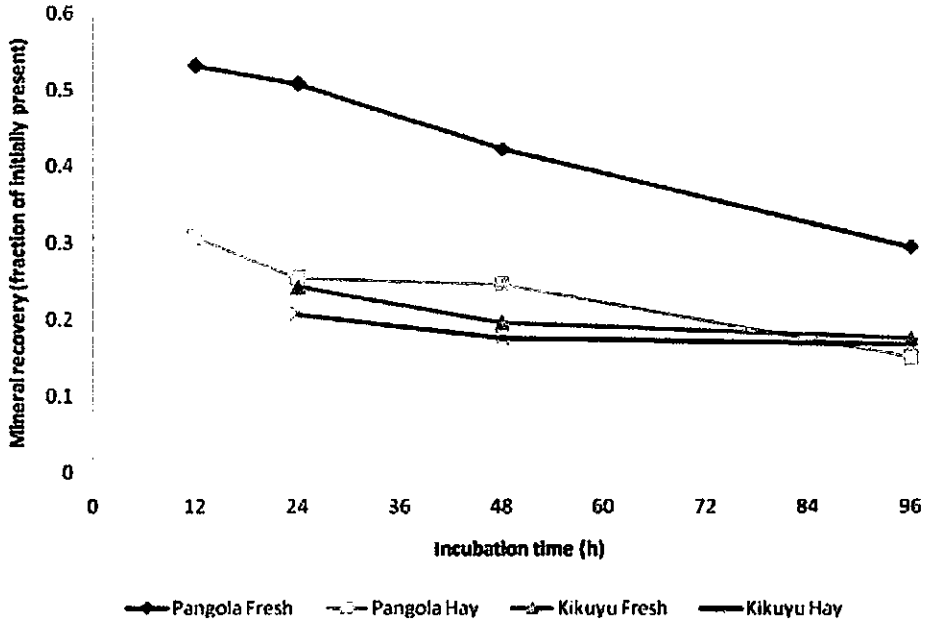


Figure 4-10. Magnesium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h for kikuyu and pangola grass and hay.

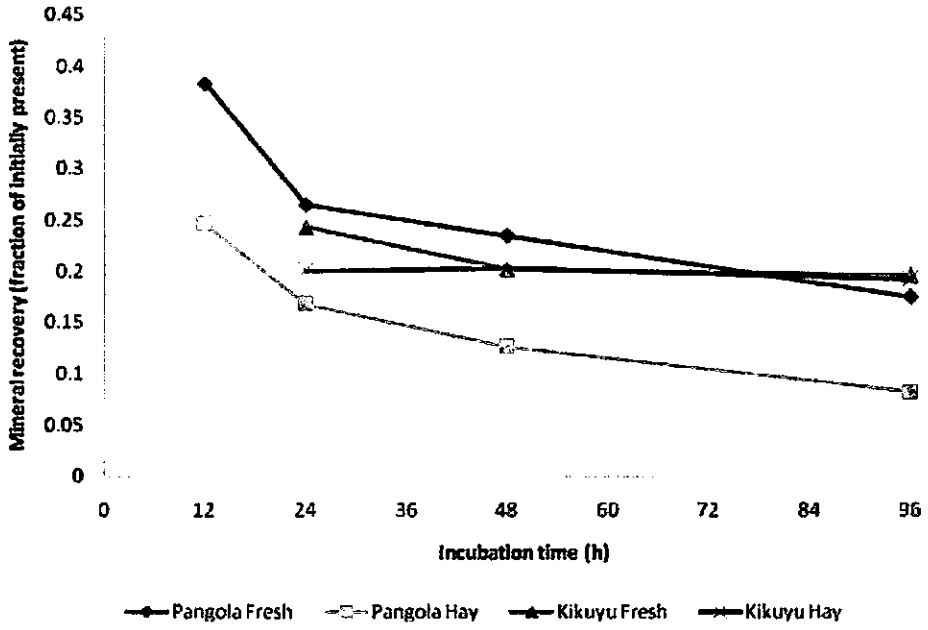


Figure 4-11. Potassium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h for kikuyu and pangola grass and hay.

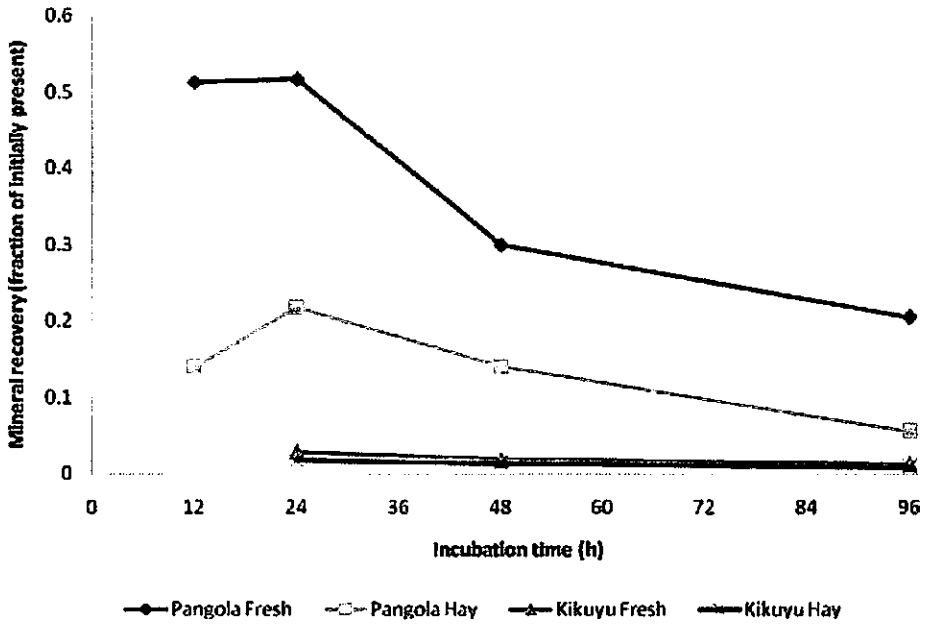


Figure 4-12. Sodium recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h for kikuyu and pangola grass and hay.

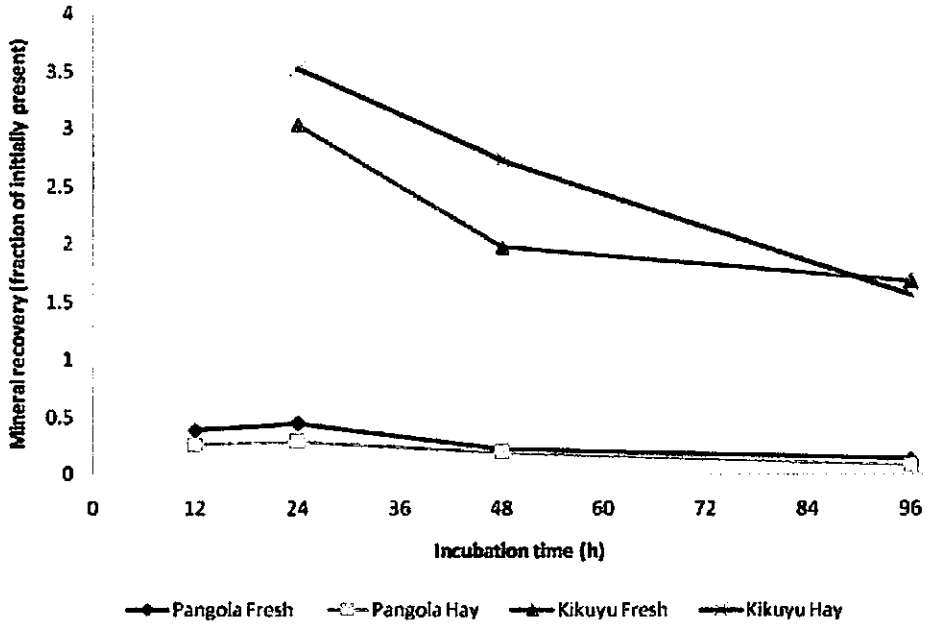


Figure 4-13. Sulfur recovery after ruminal incubation as a fraction of initial insoluble mineral in sample at 0, 12, 24, 48, and 96 h for kikuyu and pangola grass and hay.

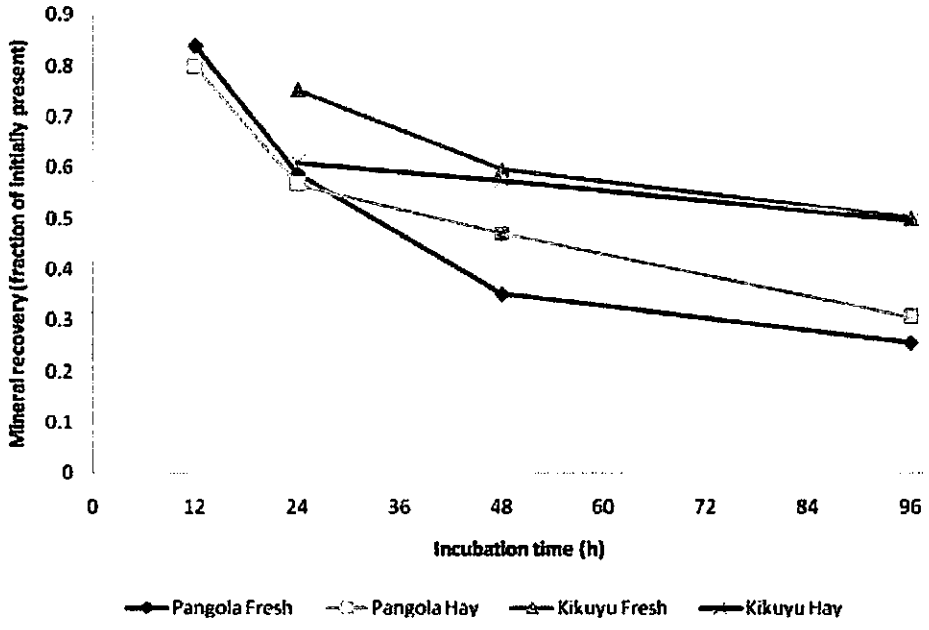


Table 4-4. Fractional rate of disappearance of DM and macrominerals for pangola and kikuyu grass and hay during *in situ* incubation.

Forage	Fractional rate of disappearance (k_D), %/h					
	Ca	Mg‡*	P‡*	K‡	Na	S
Pangola hay	2.00	2.13	1.49	2.35	2.34	1.20
Pangola pasture	1.55	1.46	1.03	1.47	1.81	1.04
Kikuyu hay	0.95	1.58	1.75	4.67	-0.25	0.70
Kikuyu pasture	1.18	1.60	1.72	4.29	-0.38	0.73

‡Significant effect of processing on k_D ($p \leq 0.05$); *Significant interaction between processing and species ($p \leq 0.05$)

drying, and drying increasing the rate of release of the minerals. Rate of release of potassium is affected by drying for both grasses, increasing from 4.29%/h and 1.47%/h for fresh kikuyu and pangola, respectively, to 4.67%/h and 2.35%/h for dried kikuyu and pangola, respectively.

Discussion

The data presented here make it evident that different feeds vary in their ability to sorb/release the various minerals assayed. Furthermore, within an individual feed, different minerals are released differently. Playne et al. (1978) looked at the release of minerals from four tropical hays, and found differences between the hays in minerals released, as was found here. However, the rank order of least released to most released mineral is different. Playne and workers found that P<Ca<Na<S<Mg<K, whereas the data here suggest a ranking of Na<Mg<S<Ca<P<K. With the exception of potassium, these data are almost the inverse of those results obtained by Playne and workers. The findings in this paper, however, match up well with Rooke et al. (1983) who looked at the release of minerals from grass silages.

Calcium was sorbed in the early stages of the incubation by some of the grasses, although in relatively small quantities. Ibrahim et al. (1998) also found that calcium was sorbed by certain feeds that are low in calcium. They found that guinea grass and rice bran had calcium recoveries of 315 and 455%, respectively, after rinsing in water.

Phosphorous was sorbed by napier grass and california grass, as well. Of the grasses that had a net release of phosphorous after 96 h, only four of the grasses released greater than 70% of the initially insoluble phosphorous.

In the same study, Ibrahim et al. (1998) found that, in grasses, 55-78% of the magnesium was released during ruminal incubation. The data obtained in this study ranged from 58-96%, and are roughly in line with the data obtained by the above authors. Potassium was released to a similar extent as magnesium. Half of the feeds released more than 70% of potassium after 48 h. However, within 96 h, only california grass hay released less than 80% of the total insoluble potassium.

Sodium was not as thoroughly released as other minerals and there was a large amount of sorption by napier grass and kikuyu grass. Only pangola grass and alfalfa released more than 80% of the insoluble sodium, and of the remaining grasses, only guinea and green panic grass released more than 50%.

Sulfur was sorbed by napier grass and small quantities early in the incubation by california grass, pearl millet, and green panic grass. The remaining forages released 13-76% of the insoluble sulfur after 96 h of incubation. There does not appear to be a discernible pattern of mineral release among the feeds and minerals tested, and, therefore,

it may be necessary to test a given grass individually in order to accurately determine the extent to which a given mineral will be released.

Fractional rate of disappearance of minerals is much lower than that found by Rooke et al. (1983), which is not surprising given the nature of the feeds involved. They also found no significant difference between minerals in the fractional rate of disappearance of the slowly released (initially insoluble) fraction. Here again, however, this study found significant differences between forages in the rate of release of minerals.

Drying of grasses appears to have an effect on both the extent of release on the rate of release of magnesium, phosphorous, and potassium from forages in the rumen. However, for magnesium and phosphorous, this effect was only found in pangola grass, and was not found in kikuyu grass. There does appear to be an inconsistency in that drying has an effect on the rate of release of potassium from kikuyu grass, but not on the extent of release of potassium. However, given that nearly all the insoluble potassium was released from kikuyu within 24 h, it is apparent that although the rate of release may differ between dried and fresh kikuyu grass, the amount of potassium released within 96 h is not statistically different. Because release of macrominerals was affected by drying for pangola grass, but generally not for kikuyu grass, it is dangerous to draw conclusions on the effect of drying on grasses not tested here. Likewise, it is dangerous to conclude that calcium, sodium, and sulfur are never affected by drying; it may be the case that they are unaffected by drying in these two grasses, but drying will have an effect on their release in other grasses.

Incomplete washing of samples may have lead to bacterial contamination of the samples assayed via retention on particulate matter in the rumen. There is also the matter of elemental flux in steers during rumination. Because these were live animals, the recycling of mineral elements via the saliva could not be controlled.

The data presented here are not the entire picture as far as mineral availability to livestock is concerned. This paper does not consider the impact of abomasal digestion on mineral release and further investigation will be necessary to determine the complete picture of mineral availability of tropical grasses.

Chapter 5. Conclusions, Implications & Recommendations.

Computer models are a useful tool for managing livestock herds, particularly when used to predict performance or nutrient requirements. However, successful use of such models requires accurate inputs, especially characterization of animal type, size and BCS, and dry matter intake. It is also crucial that accurate nutrient profiles of the diet are available. While the failure of the CNCPS to predict animal performance in the research presented here can't be narrowed down to one single cause, it can still serve as an indication of the importance of obtaining accurate information to plug into a computer model. There is no way of confirming whether the DMI intake used in this research is accurate, but assuming it is, as other research has found it to be (Molina et al., 2004), there remains the difficulty of characterizing the nutritional composition of the forages, especially bioavailability and rates of digestion.

The second part of the research contained here attempted to characterize bioavailability for the macrominerals in some common Hawaii forages. There does not appear to be a discernible pattern of mineral release among the feeds and minerals tested, and, therefore, it may be necessary to test a given grass individually in order to accurately determine the extent to which a given mineral will be released. Processing appears to have an indefinite effect on mineral release as well; release of macrominerals was affected by drying for pangola grass, but generally not for kikuyu grass. Because of this it is dangerous to draw conclusions on the effect of drying on grasses not tested here.

These findings demonstrate the difficulty in characterizing the bioavailability of nutrients in tropical forages. It appears that each species is a somewhat unique case, at least as far as ruminal digestion of macrominerals is concerned. Therefore, it becomes necessary to evaluate forages individually. Also, given the possible effects of drying on mineral release, it may even be necessary to evaluate forages of different ages in order to get an accurate idea of mineral availability. Future research should focus on determining what factors other than species and drying have an effect on mineral availability. It would also be useful to look at the bioavailability of other nutrients, such as vitamins, in Hawaii forages. To go along with this, it would help to conduct a study specifically designed to test the applicability of the CNCPS to Hawaii, using animals fed a known diet, preferably kikuyu or another common Hawaiian grass, across a variety of ages of regrowth. There is also the question of the robustness of the model. In other words, how accurately must nutrient bioavailability be determined before it begins to negatively affect the predictions of the model.

Appendix

Appendix Table 1. List of all variables available for entry in the CNCPS.

Description	Options
Animal Type	Lactating Beef Cow, Growing/Finishing, Lactating Dairy Cow, Dry Cow, Replacement Heifer
Age*	##, months
Sex‡	Cow, Bull, Steer, Heifer
Body Weight*	##
Breed Type‡	Beef, Beef x Dairy, Dairy
Mature Weight*	##
Condition Score*	#, 1-9 scale or 1-5 scale
Breeding System	Straightbred, 2-way cross, 3-way cross
Breeds (Sire, Grandsire, and Granddam)	Angus, Brown Swiss, Brahman, Brangus, Charolais, Chianina, Friesian, Galloway, Gelbvieh, Gir, Guzerat, Hereford, Holstein, Jersey, Limousin, Longhorn, Maine Anjou, Nellore, Piedmontese, Pinzgauer, Polled Hereford, Red Poll, S. Gertrudis, Sahiwal, Salers, Shorthorn, Simmental, South Devon, Tarentaise
Days Pregnant*†	##, days
Days since Calving*†	##, days
Lactation number*†	##
Calving Interval*†	##, months
Expected Calf Birth Weight*†	##
Age at First Calving*†	##, months
Relative Milk Production (Lactating Beef Cow only)*	#, 1-9 scale
Grading System (Growing/Finishing only)	Devoid of marbling, 22% body fat; Traces of marbling, 25% body fat; Slight marbling, 27% body fat; Small marbling, 28% body fat
Rolling Herd Average*°	##
Milk Production*°	##
Milk Fat*°	##, %
Milk Protein*°	##, %
Milk Price*°	##
Management Description	
Additive‡	None, Ionophore, Implant, Implant+Ionophore
Added Fat in Diet	No, Yes

*Any number can be entered. If units are not given, they depend on the parameters (i.e. metric or English units).
‡Choices depend on previous entries
†Only available when animal is lactating cow/replacement heifer
°Lactating Dairy Cow only

Appendix Table 1 cont. List of all variables available for entry in the CNCPS.

Activity	Tie-Stall Barns; Small Free-Stalls (<200 cows); Large Free-Stalls, Close Parlor; Large Free-Stalls, Far Parlor; Dry Lots; Intensive Grazing; Continuous Grazing
Time Spent Standing*	##, h
# of Body Position Changes*	##, per day
Flat Distance Walked*	##
Sloped Distance Walked*	##
Environmental Description	
Wind Speed*	##
Previous Temperature*	##
Current Temperature*	##
Previous Relative Humidity*	##, %
Current Relative Humidity*	##, %
H in Sunlight*	##
Storm Exposure	No; Yes
Hair Depth*	##
Mud Depth*	##
Hide	Thin; Average; Thick
Hair Coat	No mud; Some mud on lower body; Mud on lower body and sides; Heavily covered with mud
Cattle Panting	None; Rapid/shallow; Open mouth
Minimum Night Temperature*	##

*Any number can be entered. If units are not given, they depend on the parameters (i.e. metric or English units).
‡Choices depend on previous entries
†Only available when animal is lactating cow/replacement heifer
°Lactating Dairy Cow only

Appendix Table 2. Nutrient Composition of Kikuyu Grass sorted by Adjusted Crude Protein.

Moisture	Dry Matter	NDF (%DM)	Lignin (%NDF)	TDN (%DM)	Adj. CP (%DM)
8.7	91.3	70.1	9.84	52	6.4
8.2	91.8	68.4	9.21	56	7.6
10.8	89.2	67.4	10.83	56	7.9
10.6	89.4	67.5	9.78	55	8.2
8.7	91.3	68.7	6.99	57	9.1
8.2	91.8	69.4	7.78	57	9.3
10.6	89.4	65.4	6.42	61	9.9
7.6	92.5	64.2	9.19	58	10.1
9	91.1	60.4		57	10.8
6.9	93.1	64.7	11.13	56	11.2
9.3	90.7	65.3	8.12	59	11.3
10.3	89.7	63.9	7.36	62	11.9
9.2	90.8	66.3	6.94	59	12.1
7.8	92.2	66.2	8.01	59	12.3
8.5	91.6	64	7.81	60	13.2
10.2	89.8	61	7.70	60	13.4
7	93	61.9	9.69	59	13.4
9.8	90.2	63.4	6.15	61	13.5
7.9	92.1	62.1	9.18	60	13.8
7.7	92.3	66.7	7.20	57	13.8
9.4	90.6	63	7.46	60	13.9
10	90	61.7	6.48	63	14
8.3	91.7	58.8	12.59	57	14
7.2	92.8	63.7	10.99	56	14.1
11.7	88.4	60.7	6.59	62	14.3
10.1	89.9	63.2	6.96	61	14.3
9.6	90.5	56.8		59	14.6
11.6	88.5	58.5	7.18	63	15
9.5	90.5	61.5	6.02	63	15
8	92	58.5	6.67	64	15.2
11.4	88.6	55.1	9.07	62	15.4
8.2	91.8	54.1	6.47	65	15.8
8.4	91.6	59.8	7.02	63	16.2
10.2	89.8	56.9	5.10	65	17.1
8.6	91.4	56.8	6.87	64	17.6
8.5	91.5	58.4	6.34	64	17.6
8.4	91.6	62.2	5.47	60	17.9
11.4	88.6	50.7	12.82	61	18.2
8.1	91.9	55.4	9.39	62	18.2
11.4	88.6	54.8	5.11	65	19
10.6	89.4	60.4	6.95	62	19.1
7.5	92.5	57.1	9.46	61	19.3
7.4	92.6	57.1	8.06	62	19.4
11.6	88.5	51.8	2.51	69	23
9	91	50.4	5.75	67	23
7	93	51.1	6.46	66	25.9

Appendix Table 2 cont. Nutrient Composition of Kikuyu Grass sorted by Adjusted Crude Protein.

Degradable Protein (%CP)	Sol.Protein (%CP)	Starch (%NSC)	Crude Fat (%DM)	Ash (%DM)
61	31.25	48.06	2.1	8.02
60	39.47	38.83	2.2	5.49
48	25.32	13.74	3.3	4.91
50	36.59	23.33	2.7	6.52
56	43.96	30.94	2.3	7.46
64	43.01	24.44	2	6.34
60	30.30	13.45	2.8	5.85
66	29.70	36.67	3.3	7.36
66	27.78		3.2	6.54
52	26.79	24.58	3.3	7.9
62	44.25	19.17	3.2	6.51
60	33.61	11.02	3.7	5.42
64	41.32	14.05	2.9	6.87
62	40.65	23.08	3.2	6.85
71	53.03	10.14	3.1	7.23
71	37.31	15.83	3.4	7.77
61	29.85	21.05	3.2	6.98
72	37.04	10.40	3	7.02
62	28.99	30.56	3.6	7.14
65	36.23	13.48	2.4	8.22
68	35.97	14.17	3.4	7.62
71	42.86	21.13	3.3	6.51
73	42.86	30.00	3.1	7.99
67	28.37	13.39	3.2	7.64
67	41.96	7.09	3.5	7.39
68	34.97	15.27	3.3	7.51
72	34.25		3.3	7.88
67	40.00	12.59	3.8	7.63
70	33.33	13.33	3.4	7.67
67	32.89	22.81	3.2	6.97
65	38.96	16.44	3.4	7.78
68	31.65	32.98	3	7.12
68	24.69	21.99	3.2	7.37
72	35.09	8.00	3.5	7.89
72	28.41	14.57	3.8	8.03
71	39.77	16.43	3.8	7.43
65	27.93	8.33	3	9.87
70	32.97	22.73	3.5	8.02
69	32.97	19.05	3.5	7.65
72	36.84	3.42	3	7.93
74	36.65	5.77	3.1	6.98
68	25.91	17.92	3.8	8.21
71	25.77	14.81	4.2	8.61
72	39.13	2.13	2.7	8.09
73	34.78	1.57	3.6	8.89
70	30.89	1.79	4.2	9.83

Appendix Table 2 cont. Nutrient Composition of Kikuyu Grass sorted by Adjusted Crude Protein.

Ca (%DM)	P (%DM)	Mg (%DM)	K (%DM)	Na (mg/kg)	S (%DM)	Cu (mg/kg)	Fe (mg/kg)
0.414	0.283	0.309	1.170	260.515	0.113	2.914	126.761
0.622	0.236	0.268	0.510	259.037	0.145	2.997	384.774
0.531	0.119	0.256	1.550	317.776	0.088	3.727	432.100
0.461	0.177	0.294	1.910	566.397	0.130	4.093	270.500
0.518	0.192	0.317	1.580	259.172	0.126	4.029	265.596
0.445	0.195	0.270	0.770	308.484	0.167	3.836	662.874
0.388	0.228	0.317	2.500	403.152	0.140	5.760	151.600
0.358	0.310	0.232	1.930	303.307	0.138	5.814	115.355
0.554	0.306	0.320	1.930	370.664	0.105	3.681	86.521
0.402	0.269	0.229	2.760	8,194.854	0.169	8.444	58.956
0.491	0.234	0.243	2.320	270.609	0.102	3.640	102.401
0.578	0.228	0.301	2.040	347.254	0.134	5.570	190.900
0.383	0.365	0.248	2.170	314.206	0.118	4.545	70.750
0.461	0.288	0.329	2.140	387.146	0.146	5.233	72.267
0.453	0.352	0.299	2.450	333.501	0.146	5.169	72.242
0.294	0.374	0.267	2.640	355.071	0.164	6.400	331.034
0.575	0.326	0.270	2.560	1,759.250	0.206	7.893	74.297
0.286	0.297	0.233	2.670	392.646	0.134	5.424	58.529
0.434	0.407	0.288	2.250	2,483.388	0.173	8.471	75.577
0.386	0.198	0.291	2.890	2,141.107	0.285	9.427	323.665
0.363	0.378	0.297	2.550	310.804	0.148	5.960	86.630
0.345	0.351	0.262	2.660	352.195	0.136	4.993	74.093
0.382	0.383	0.220	2.210	288.467	0.180	6.704	188.826
0.488	0.371	0.315	2.120	572.280	0.153	5.276	58.222
0.346	0.253	0.260	2.820	488.529	0.152	6.330	198.200
0.481	0.368	0.254	2.500	261.426	0.139	5.906	121.744
0.307	0.427	0.207	2.700	366.802	0.161	6.751	143.655
0.468	0.379	0.228	3.020	300.812	0.159	5.880	250.100
0.284	0.365	0.262	2.790	291.825	0.171	6.520	159.348
0.339	0.288	0.435	2.090	513.568	0.208	7.437	201.106
0.579	0.379	0.356	2.820	292.190	0.140	6.460	219.700
0.326	0.263	0.321	2.140	935.117	0.207	7.816	173.694
0.377	0.279	0.299	2.390	462.346	0.196	6.981	163.430
0.343	0.353	0.305	2.990	379.185	0.172	7.325	242.514
0.487	0.386	0.262	2.700	558.163	0.225	7.994	166.944
0.466	0.383	0.243	3.210	397.648	0.160	7.467	88.290
0.349	0.422	0.305	3.440	11,469.761	0.243	10.358	141.496
0.802	0.330	0.315	2.790	280.974	0.144	6.850	390.400
0.354	0.329	0.399	2.750	698.885	0.245	9.190	288.079
0.348	0.389	0.313	3.670	307.854	0.205	7.880	74.580
0.330	0.285	0.601	2.710	366.066	0.230	7.376	222.098
0.387	0.413	0.339	2.840	1,872.426	0.214	10.789	368.759
0.437	0.272	0.419	2.910	2,024.765	0.231	9.995	116.890
0.306	0.281	0.255	3.680	490.383	0.251	10.450	96.200
0.286	0.306	0.217	3.360	259.837	0.206	8.978	140.856
0.349	0.493	0.345	3.610	623.232	0.276	12.121	144.747

Appendix Table 2 cont. Nutrient Composition of Kikuyu Grass sorted by Adjusted Crude Protein.

Mn (mg/kg)	Se (mg/kg)	Zn (mg/kg)
27.780	1.463	22.195
39.546	1.492	35.079
231.500	2.384	24.600
16.110		32.580
37.752	1.692	30.906
51.348		43.423
44.080		31.240
66.034	1.880	31.551
22.924		16.759
103.223	2.961	32.556
24.594		17.468
97.400	1.578	19.030
9.779		21.804
21.842		18.006
19.355		20.312
18.205		30.335
98.668	1.306	30.923
11.410		17.712
120.314	2.302	35.547
30.279	6.967	32.043
16.813		28.505
29.059		27.861
26.489	1.544	40.277
37.933		24.600
15.580		35.310
13.374		32.079
23.695	2.529	29.178
21.350		34.070
80.711	1.129	23.917
81.910	2.190	29.377
22.610		30.270
71.901	2.534	27.296
81.614	2.564	30.709
21.129		21.973
51.274	1.492	42.745
25.752		28.065
24.014	1.147	32.061
21.190		30.140
105.081	1.587	37.254
9.235	1.052	31.257
50.516		47.965
150.879	3.223	50.005
140.069	2.797	39.029
27.580		34.800
33.685		25.172
41.909		40.717

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