AN ABSTRACT OF THE THESIS OF

I-Wayan Mathius for the degree of MASTER OF SCIENCE in ANIMAL SCIENCE presented on October 6, 1987 .

Title : UTILIZATION OF NON-PROTEIN NITROGEN BY RABBITS

Abstract approved : Redacted for Privacy

Peter R. Cheeke

Several studies have been conducted to examine the utilization of non-protein nitrogen by the New Zealand White rabbit.

Soybean meal (SBM) or urea added to a low protein (13% CP) diet and a positive control diet were fed to does and their offspring during a nine month experiment. Urea and SBM provided an equal amount of supplementary nitrogen. Performances of does fed the positive control diet were superior to those fed the other diets. Rabbits fed the low protein diet showed the poorest overall performance. Additional urea to the low-protein diet improved litter birth and preweaning traits but postweaning traits were decreased. Therefore no advantage was observed in using urea as a supplementary nitrogen source with a low-protein diet.

Feeding the same diet to growing rabbits showed that rabbits fed the urea-containing diet had the highest mor-

tality. There was no difference between adult and fryer rabbits in dry matter (DM) and nitrogen digestibility. Fryers utilized the urea-containing diet more efficiently than did adult in terms of nitrogen retention.

The effect of different levels of dietary fiber (10 vs 17% ADF) on urea utilization was studied . Rabbits fed the high fiber diet had increased daily gains and feed intake. Additional urea did not produce any improvement in daily gain. Significant differences in DM, nitrogen and acid detergent fiber (ADF) digestibility were observed. The high fiber diet resulted in decreased apparent digestion coefficients.

The effect of low and high starch levels on the efficiency on urea and biuret utilization was also examined. SBM, urea and biuret provided an equal amount of supplementary nitrogen, added to a low-protein diet (12% CP). Rabbits fed the high-starch diets showed significantly higher daily gains. Urea was used more efficiently by rabbits fed the high-starch diets compared to those fed low-starch diets. Biuret was utilized more efficiently than urea in the low-starch diets. DM and ADF digestibility were lower with the low-starch diets. Addition of urea to the low-protein diet increased nitrogen digestibility and retention, suggesting that to some extent growing rabbits could use urea as a supplementary nitrogen source.

The effects of two levels (0 vs 5%) of dietary zeolite on urea utilization were also tested. Inclusion of SBM or replacement of a part of SBM with urea was added to a low-protein diet. Results showed that additional zeolite did not affect animal performance. Rabbits fed SBM-containing diet showed significant improvement of daily gain. Replacement of some SBM with urea statistically increased rabbit performances.

In conclusion, these studies indicate that urea can not be used effectively for lactating does, but to some extent it can be utilized for growing rabbits, especially if it is used to replace some of the main natural crude protein.

UTILIZATION OF NON PROTEIN NITROGEN BY RABBITS

by

I-Wayan Mathius

A THESIS

submited to

Oregon State University

in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Completed October 6, 1987

Commencement June 1988

APPROVED :

Redacted for Privacy

Professor of Animal Science in charge of major

Redacted for Privacy

Head of Departement of Animal Science

Redacted for Privacy

Dean of Graduate School

Date thesis is presented October 6, 1987.

CONTRIBUTION OF AUTHORS

Dr. N.M. Patton is Director of the OSU-Rabbit Research Center. He was involved in the planning of the experiments and donated the experimental rabbits.

Karen Robbinson was involved directly with the preparation and chemical analysis of the materials used in the experiments.

Mark A. Grobner was involved in the planning of the experiment in chapter 2 and its data analysis.

ACKNOWLEDGEMENTS

It would not be fair to present this thesis without acknowledging the many people who contributed and to a large extent made this project possible.

I wish to express my appreciation to Dr. P.R. Cheeke, my major advisor, for his guidance and patience during my study and preparation of this thesis.

I also wish to thank Drs. Neil Forsberg and R.G. Pettersen for serving as members of the graduate committee. In addition, I also wish to thank Dr. Thomas Savege for serving as the graduate representative.

To my wife, Nurita, deep gratitude and appreciation are expressed for her patience and encouragement during the course of my studies. She is, truely, my best friend.

I also wish to express my gratitude to Litbang Pertanian (Agency for Agriculture Depelopment), Dept. Pertanian, Republic of Indonesia, for giving me the opportunity to pursua my graduate studies, also to people of Republic of Indonesia for financial support.

A special thanks is extended to Mark A. Grobner and Jack Kelly for their technical assistance, valuable advice and friendship. Many thanks and much appreciation to Karen L. Robinson, who in one way or another contributed to this project. The donation of biuret by the Moorman Mtg., Co. of california is appreciated.

TABLE OF CONTENTS

LIST OF TABLES

UTILIZATION OF NON-PROTEIN NITROGEN BY RABBITS

CHAPTER 1

INTRODUCTION

Rabbits, being small non-ruminant herbivores, have potential in contributing to the world's need for high quality protein, particularly in underdeveloped tropical countries (Cheeke, 1986). Due to their small size, rabbits are easy to keep and can be raised on small farms and/or urban areas where other livestock are not practical. Most domestic rabbits are usually raised for meat production. Cheeke (1980,1986) listed several potential advantages of the rabbit as a future source of proteinaceous food for human consumption. Rabbits can subsist on high-forage diets that consist largely on ingredients which are not useful in human food production (Rivera and Madlangsacay, 1978). Their ability to consume forage materials gives them considerable potential in tropical countries (Owen, 1976), where abundant local vegetation can not be used for human consumption and often goes to waste. In Indonesia and some other developing countries, rabbits are becoming one of the most important small animals and they are raised not only on a small scale by the peasants but also in a large scale for commercial purposes. One of the main constraints to increased rabbit production is the need for proper nutrition of the animals.

In order to achieve the maximum production, rabbits need to be fed an adequate amount of feed and proper balance of nutrients. The easiest method of meeting their nutritional needs would be the purchase of balanced, complete manufactured feed in pellet-form. However, in developing countries, many rabbit raisers do not have the financial resources for purchase of commercially prepared feed. Therefore, replacement with urea of some of the protein sources of feedstuffs, commonly used in conventional rabbit feed, may reduce feed costs.

Proteins are essential organic constituents of living organisms, and are the class of nutrients in the highest concentration in muscle tissues of animals (Church, 1978). Protein also function as molecular instruments through which genetic information is expressed (Lehninger, 1982). The percentage of protein required in the diet is usually the highest for young growing rabbits and declines gradually with increasing maturity (NRC, 1977; Sanchez et al., 1985). Protein is an important aspect in rabbit nutrition, and it is also believed that not only protein quantity but also protein quality plays an important role. Therefore, for rapid growth the rabbit is dependent upon adequate qualities of dietary essential amino acids (NRC, 1977). Several studies on protein requirements for the rabbit have been conducted. Spreadbury (1978) recommended that the optimal performance of fryers will be achieved if the crude protein content in the diet is 15 %. Omole (1982) found that the level of crude protein needed was between 18 - 22 % for fryers raised under tropical conditions. Romney and Johnston (1978) and Sanchez et al. (1984) noted that 16.5% crude protein in the diet is adequate for normal growth, while Hassan (1984) found that 13.8 % crude protein in the diet is adequate for growth. The recommended crude protein level for lactating does varies from as low as 13.5% (Adams, 1983) to 21.5% (Harris et al.,1981), whilst Sanchez et al. (1985) stated that 19% crude protein in the diet is enough for does with a 14-day post partum breeding schedule. Reddy et al. (1978) used diets ranging from 16 - 20% crude protein with different sources of protein for lactating does. They found that there was no significant differences between the levels of protein, but sources of protein gave significantly different responses.

The nitrogen requirements of monogastric animals are met by absorption of the peptides and amino acids which result from the degradation of ingested protein in the stomach and small intestine (Scott et al., 1982). The biological value of specific dietary protein to monogastrics is largely determined by the nature and availability of the amino acids. Non-ruminant herbivores, such as rabbits, on the other hand can utilize both protein and non-protein nitrogenous substances for body maintainance and production, because they have a large cecum (Houpt, 1963) in which bacterial action take place (King, 1977) and where the enzyme urease is present (Knutson et al.,1977). Moreover, the practice of coprophagy (cecotropy) offers a potential utilization of urea as a source of nitrogen in rabbit diets and hence suggests a less expensive alternative to conventionally used sources.

One of the factors affecting the utilization of urea is the energy available in the diet (Belasco, 1956). A number of workers showed that in ruminants a readily available carbohydrate as the energy source could improve the efficiency with which urea was utilized (Schartz, 1967; Broome, 1968; Jackson, 1974). Thus, diets providing energy slowly to bacteria in the cecum can be expected to support a low level of protein synthesis whilst those providing energy rapidly will support a much greater utilization of urea/non protein nitrogen. Although rabbits digest the fiber portion of forages poorly (Slade and Hintz, 1969), they utilize the soluble carbohydrate and protein of forages with a high degree of efficiency (Rivera and Madlangsacay,1978). Rabbits have a very large cecum which is involved in the microbial fermentation of the fibrous material, and yet the intestine which absorbs the nutrients is located distal to the cecum (Portsmouth, 1976). To overcome this apparent disadvantage, the rabbit practices coprophagy, which is also called cecotrophy (Hornicke and Batsh, 1977). Kulwich et al., (1953), Myers (1955) and Barness (1962) stated that cecotrophy is a normal process and plays an important role in the nutrition of the rabbit. Rabbits use feed less efficiently when they are prevented from consuming the soft feces than when cecotrophy is permitted (Tadayyon and Lutwok, 1969; Kennedy and Hershberger,1974: Stephens, 1976; Robinson et al.,1985). Because it is cecal contents rather than feces which the animal consumes, the term cecotrophy is more technically correct for the practice in rabbits (Hornicke and Batsh, 1977), and is the term now favored (Fekete and Bakori,1985).

Another factor affecting the utilization of urea is the rate of hydrolysis to ammonia. Ammonia is produced at a rate which is faster than the rate at which it can be utilized by bacteria (Bloomfield et al., 1960; Bartley and Deyoe, 1977). The excess ammonia may be absorbed and excreted in the urine. To reduce the amount of nitrogen wasted by this process, the addition to the diet of ion exchange compounds such as zeolite which release ammonia gradually may have potential. Several studies on the addition of zeolite to the diet have been conducted (Mumpton and Fishman, 1977; Hayhurst and Willard, 1980; Nakaue and Koelliker, 1981; Nakaue et al., 1981). White and

Ohlragge (1974) reported that zeolite apparently affects the pattern of nitrogen metabolism in ruminants by trapping high ammonia concentrations in the alimentary tract, and slowly releasing ammonia that bacteria can use continuously to produce protein (Mumpton, 1978).

Previous studies on urea inclusion in rabbit diets have given conflicting results (King, 1971 ; Cheeke, 1978; Semertzakis, 1978). Therefore, a series of experiments was undertaken to determine if urea supplementation of rabbit diets can be used for both growing fryers and breeding does, and if the nature of dietary carbohydrate and the addition of zeolite influence urea utilization.

CHAPTER 2

EFFECT OF SOYBEAN MEAL AND UREA SUPPLEMENTATION OF A LOW-PROTEIN DIET ON THE GROWTH AND REPRODUCTIVE PERFORMANCE OF NEW ZEALAND WHITE RABBITS

Mathius, I-W., P.R. Cheeke, M.A. Grobner and N.M. Patton

Rabbit Research Center.
Dept. of Anim. Sci., OSU. Corvallis, OR.97331.

CHAPTER 2

EFFECT OF SOYBEAN MEAL AND UREA SUPPLEMENTATION OF A LOW-PROTEIN DIET ON THE GROWTH AND REPRODUCTIVE PERFORMANCE OF NEW ZEALAND WHITE RABBITS

Mathius, I-W., P.R. Cheeke, M.A. Grobner and N.M. Patton

SUMMARY

A nine month experiment was undertaken to examine the effect of additional soybean (SBM) or urea as a supplementary nitrogen source to a low-protein (13% crude protein) diet on growth and reproductive performance of New Zealand White rabbits. The dietary treatments were a positive control diet (19% CP), a low-protein (LP) diet(13% CP), LP + SBM and LP + urea. Soybean meal and urea provided an equal amount of supplementary nitrogen. The positive control diet was significantly ($P < .05$) superior to the LP and LP + urea diets and slightly better than LP + SBM diet in terms of conception rate, litter size, average daily gain and efficiency of food utilization. No significant difference in average litter weight at birth was observed, but litters of does receiving the positive control diet grew faster ($P < .05$), resulting in heavier weight at 28 d and 56 d. Preweaning and postweaning litter mortality was highest ($P < .05$) with the LP + urea diet. The results also indicate that there is no advantage in using urea as a supplementary nitrogen source with a low-protein diet

(13% CP), as far as total number of market animals and feed efficiency are concerned.

INTRODUCTION

One of the most limiting factors in rabbit nutrition is the protein content of the diet. Therefore, in order to achieve the optimal production, diets for both growing and breeding rabbits should be adequate in terms of protein quantity and quality. According to NRC (1977) a level of 12% protein is needed for maintainance. Spreadbury (1978) recommended a 15.6% crude protein (CP) for optimal performance of growing rabbits, while Omole (1982) suggested that a range of 18 - 22% protein would be optimal for efficient rabbit production under tropical conditions. Romney and Johnston (1978) using a range of diets containing 16 - 22 % CP, found that fryers fed a diet with 16 % CP gave the lowest growth response compared to the others. Sanchez et al. (1984) indicated that high alfalfa diets (16 % CP) containing no soybean meal and no other protein supplementation were adequate for normal growth of weanling rabbits. Less information is available regarding lactating rabbits (Adams, 1983; Omole, 1982). The recommended CP level for lactating does varies from as low as 12 % (Chiang et al., 1982) to 22 % (Omole, 1982). Adams (1983) found that 13.5 % may be satisfactory for only a limited period, while Harris et al. (1985) noted that 21.5 % CP is probably higher than necessary. Sanchez et al. (1985) recommended that the CP level for both lactating and growing rabbits should be 19 %.

Regardless of the different findings of CP requirements in rabbit nutrition, most of the conventional feedstuffs used for protein sources are usually expensive and often competitive with human needs. Being non-ruminant herbivores, rabbits do not need to compete with humans or other monogastrics for protein because they have the ability to convert non-protein nitrogen (NPN) compounds in their feed to good quality bacterial protein. The presence of active urease in the cecum (Knutson et al., 1977; Corciani et al.,1984), together with cecotrophy and reingestion of the soft fecal pellets excreted chiefly during at night, means that rabbits can absorb nutrients which have been synthesized by bacteria in their alimentary canal (King, 1971; Lang, 1981). One of the most popular NPN products that has been widely used in animal nutrition is urea. Several studies pertaining to the use of urea for rabbits have been conducted but there is no consistent result on their finding. A few studies have indicated that rabbit performance improves with time on urea-containing diets (Semertzakis, 1978). In most studies the addition of urea as a protein supplement for growing rabbits did not give a beneficial response (Houpt, 1967; King, 1971;

Lebas and Colin, 1973; Hoover and Heitmann, 1975; Fonolla et al.,1977; Cheeke, 1978; Niedzwiadec et al.,1978).

The objective of this study was to determine if urea when added to a low protein (13 % crude protein) basal diet could effectively serve as an NPN source for does in reproduction.

MATERIALS AND METHODS

Forty New Zealand White rabbit does were used in this experiment conducted over a 9-month period (July 1985 to May 1986) at the Rabbit Research Center, Oregon State University.

Animal Feeds. Four diets were used. Diet 1 (Table 1) contained three major feedstuffs, alfalfa meal,wheat mill run and soybean meal, supplemented with molasses. The diet also contained dicalcium phosphate, fat and trace mineral salt. Molasses was used as a binder and for its favorable influence on palatability. This diet was calculated to provide 20 % CP and adequate amounts of the other nutrients. Diet 4 (basal diet) was the lowest protein diet (13.6 %) and consisted of alfalfa meal, rice hulls, ground barley and wheat mill run as the major components, supplemented with the same ingredients as basal diet 1. Diets 2 and 3 were the low protein basal diet supplemented with either soybean meal or urea . The urea or soybean meal was added to provide the same amount of supplementary nitrogen. All diets were pelleted (4.5 mm in diameter and about 1 cm length). Ingredients and nutrient composition are shown in table 1. Samples were ground through a Wiley mill, analyzed for dry matter (DM), crude protein (CP) and acid detergent fiber (AOF). A forced air oven technique (AOAC 1980), micro-kjehdal (AOAC, 1980) and micro-digestion (Waldern, 1971) methods were used to analyze OM, CP and ADF respectively.

Animals and management. Twenty-eight multiparous and twelve nullparous New Zealand White does were randomly allotted to the dietary treatments. They were housed individually and introduced to the dietary treatments at least 14 days prior to the first mating . Animals that died or showed poor performance during the experiment were culled and replaced with nullparous does of about 18-20 weeks of age. Replacement of the non-productive does was done by using the criteria of Sanchez et al.(1985). Does were bred for the first time at about 154 days of age for multiparous and about 18-20 weeks of age for nullparous animals. Body weights of the does were recorded before mating. Seven days after parturition, does were rebred, and they were serviced at least twice by the same buck which was randomly selected. Does that failed to accept were rebred the day thereafter until the service was observed. Ten days after mating, does were palpated to detect pregnancy and does that failed to conceive were re-bred. On the 28th day of gestation does were provided a four sided wooden nest box lined at the bottom with 3.2 mm and 6.4 mm wire mesh, and laboratory-grade wood shavings were added. At parturition, the number of kits born alive and dead and litter weight were recorded. After kindling the does were fed ad libitum, but whenever the does were without a litter, including the period of gestation,the amount of 180 - 240 g was fed. Water was given ad libitum. The nest box was taken out on day 21 of lactation. Litters were weaned at day 28, put in a separate cage and fed the same experimental diets as for the preweaning phase for the next 28 days until they reached 56 days of age, so that post weaning performance traits could be recorded. Body weight and total feed consumption were measured both at 28-day and 56-day of age. Several variable traits used to measure the doe and litter performance were recorded, including doe weight before mating, conception rate, gestation period, total number of kits born, number of kits born alive and dead, litter weight at birth, weight at 28-day and 56-day, average litter weight gain at 28-day and 56-day, litter size at 28-day and 56-day, feed consumption at 28-day and 56-day, feed efficiency ratio at 28-day (doe and litter intake/litter gain) and at 56-day, average daily gain either at 28-day and 56-day and mortality during birth to 28-day and during 28-day to

56-day.

Housing. All animals were housed individually in an open-sided A-frame building as described by Harris et al,(1983). The cages measuring 76 x 76 x 46 and 76 x 61 x 46 cm were hung and suspended with wire about 120 cm above the ground on two sides of a 90 cm-wide concrete walkway. Each cage was equipped with a J-shaped screened metal feeder (either 25.5 x 8 x 16 cm or 19 x 8 x 16 cm) and an automatic waterer located in the front of each cage. A cycle of 16 h light and 8 h dark was used throughout the experiment.

Statistical procedures. All variables were subjected to one-way analyses of variance with dietary treatments as the only source of variation. The analyses were performed using only the data from those does which completed the experiment and due to uneven numbers of doe losses this resulted in unequal replication among the treatment groups. When significant differences were detected, comparison of mean differences were tested using the least significant difference test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Analyzed dietary concentrations of nutrients are shown in table 1. Although this experiment did not evaluate the effect of calcium (Ca) and phosphorus (P), it is important to know the dietary concentration of these minerals. Dietary Ca and P were present at the expected levels and met or exceeded NRC (1977) requirements. The basal diet was deficient in several amino acids, including lysine, methionine and arginine (Table 2).

Data presented in table 3 summarize the performance of does fed diets containing different levels and sources of nitrogen. Does fed the basal diet had a lower conception rate than does fed the other diets. Although the addition of either SBM or urea to the low-protein diet increased conception rate , it was still lower than reported by Sanchez, et al. (1985) and Raharjo, et al. (1986). The conception rates found in the present study agree with other studies using similar rebreeding schedules (Harris et al., 1982; Luckefahr et al., 1983; Partridge et al., 1981). The higher conception rates reported by Sanchez et al.(1985) and Raharjo et al. (1986) were due to the fact that their calculation of conception rate did not include the non-fertile does which were culled after 3 consecutive failures to conceive or after service

TABLE 1. COMPOSITION OF EXPERIMENT DIETS (%)

Items	Diets			
	Control	SBM	Urea	Basal
Alfalfa meal	54.00	20.00	20.00	20.00
Rice hulls	-	15.00	20.00	15.00
Ground barley	-	22.50	22.50	22.50
Wheat mill run	20.00	24.50	28.70	30.50
Molasses	3.00	3.00	3.00	3.00
Fat	1.25	2.50	2.50	2.50
Dicalcium phosphate	0.25	1.00	1.00	1.00
Trace mineral salt*	0.50	0.50	0.50	0.50
Soybean meal	21.00	11.00	-	-
Urea	-	-	1.80	-
Chemical composition(%)**,				
Dry Matter	90.78	89.97	91.31	90.22
Nitrogen	3.19	2.50	2.71	2.18
Crude protein	19.95	15.63	16.94	13.59
Acid detergent fiber	21.64	23.67	26.89	27.86
Calcium***	0.79	0.45	0.63	0.43
Phosphorus***	0.51	0.23	0.29	0.21
DE, kcal/kg***	3037	2859	2601	2657

* Appendix 1.

** Analytical data (except dry matter) are expressed on dry matter basis.

*** Calculated values using NRC (1977) data.

**** Calculated values using US-Canadian, Tables of feed composition (1982).

TABLE 2. AMINO ACID ANALYSIS OF EXPERIMENTAL DIETS AND AMINO ACID REQUIREMENT FOR GROWTH.

Amino acids	Requirement for growth		Dietary treatments***			
	*	**	Control	SBM	Urea	Basal
Lysine	0.65	0.70	0.94	0.72	0.42	0.41
Methionine + Cystine	0.60	0.60	0.73	0.49	0.38	0.35
Arginine	0.60	1.00	1.18	0.89	0.57	0.38
Histidine	0.30	0.45	0.57	0.36	0.24	0.24
Leucine	1.10	0.90	1.39	1.13	0.76	0.78
Isoleucine	0.60	0.70	0.74	0.71	0.47	0.48
Phenylalanine + Tyrosine	1.10	0.60	1.57	1.21	0.81	0.83
Threonine	0.60	0.50	0.78	0.57	0.38	0.39
Tryptophan	0.20	0.15	0.42	0.23	0.17	0.17
Valine	0.70	0.70	0.91	0.80	0.57	0.58

* NRC (1977).

** Adamson and Fisher (1973).

*** Caculated values using US-Canadian, Tables of Feed Composition data (1982).

TABLE 3. MEANS FOR REPRODUCTIVE TRAITS OF DOES FED EXPERIMENTAL DIETS.

Item	Diets			
	Control	SBM	Urea	Basal
No. of matings	59	39	46	43
Conception rate (%)	62.7	64.1	57.1	44.2
Gestation length (d)	32.0	32.2	32.0	32.7
Body weight before mating (kg)	4.225 b	4.250 b	3.896 a	3.767 a

Means in the same rows, bearing common superscripts are not significantly different ($P < .05$)

but before parturition. The lowest conception rate found in this study was 44.2 %, for does fed the low-protein basal diet (diet 4). The reason for the lowest conception rate is probably because this level of dietary protein is insufficient to maintain normal reproductive performance over several parities, and reflects the poor condition of these does. This is indicated by their low body weight. Gestation length was not influenced by the addition of either SBM or urea to the low-protein diet. Hammond and Marshall (cited by Sittmann et al.,1964) noted that the gestation length of domestic rabbits was approximately 32 days, similar to the present result. Gestation length of 33.7 d was reported when dietary crude protein (CP) content in the diet was reduced to 10% and it was progressively decreased to 31.2 d as CP level increased to 18% in the diet (Omole, 1982). Does fed the diet with added urea (diet 3) showed a slightly higher body weight before mating compared with does receiving the low protein basal diet, even though it was still lower than that of does fed either positive control diet or basal diet supplemented with SBM ($P < .05$). This indicates that to some degree, does can utilize urea as a source of nitrogen. Does fed the low-protein basal diet had low body weights before mating. Spreadbury (1978) found that rabbits decreased their food consumption when the CP concentration of the diet was lower than 15%. In other words, feed consumption reflects protein concentration and protein quality in the diet. It probably explains the low body weight of does fed low protein diets (Partridge and Allan, 1982). Reduction of the dietary CP level will likely decrease the dietary essential amino acids and this may lead to amino acid deficiencies (Raharjo et al., 1986). Low protein diet alone and low protein diet plus urea might not meet amino acid requirements (Table 2), which could also explain the lower body weight for does fed either diets. Does fed the positive control diet and the basal plus SBM diet tended to have the highest body weights before mating.

Litter traits before weaning are presented in tables 4 and 5. Number of rabbits born per litter, born alive and total litter weight tended to be the highest ($P < .05$) on does fed the positive control diet. However, heavier litter weight was a result of larger litter size on that treatment. Harris et al.(1982) reported similar results when does were fed a commercial diet with a CP content of 18.8%. Sanchez et al. (1985), Raharjo, et al.(1986), Omole (1982) and Reddy and Moss (1982) found similar results for total kits born when does were fed diet of 18 to 19% CP. However the total born alive per litter was slightly higher than for the present study. Litter size was the smallest ($P < .05$) for does fed the low protein basal diet. Compared to the findings of Omole (1982),

TABLE 4. MEANS FOR LITTER BIRTH TRAITS OF DOES FED EXPERIMENTAL DIETS

Item	Diets			
	Control	SBM	Urea	Basal
No. litters born	8.42 c	7.72 b	6.31 a	5.59 a
No. born alive	6.32 d	5.56 c	4.19 b	2.83 a
No. born dead	2.08	2.16	2.10	2.76
Total alive weight (g)	392.34 d	327.48 c	245.27 b	165.24 a
Average alive weight (g)	62.10	58.90	58.50	58.48
Mortality (%)	24.5 a	27.9 a	33.1 b	50.4 c

Means in the same rows, bearing common superscripts are not significantly different ($P < .05$)

TABLE 5. MEANS FOR PREWEANING LITTER TRAITS OF DOES FED EXPERIMENTAL DIETS (28 day of age).

Item	Diets							
	Control		SBM		Urea		Basal	
No. Weaned	6.19	d	5.28	c	3.33	a	2.60	a
Total weaned weight (kg)	3.752	d	2.859	c	1.785	b	1.416	a
Average weaned weight(kg)	0.606	c	0.542	b	0.535	a	0.539	a
Average daily gain (g)	19.8	b	17.3	a	17.1	a	16.4	a
Total weaned intake (kg)*	12.493	c	11.556	b	11.222	b	4.500	a
Feed efficiency (FCR)	3.53	a	4.12	b	6.41	c	3.31	a
Mortality (%)	2.05		5.56	b	20.52	c	8.12	b

* 28 days intake, including does' intake.

Means in the same rows, bearing common superscripts are not significantly different ($P < .05$).

litter size in the present study was higher. Moreover, Omole (1982) also noted that litter size decreased to 4.3 when does were fed a diet of 10% CP. Inclusion of urea to the low protein diet non-significantly increased litter size, while the addition of SBM increased litter size(P < .05) to a level still lower than that of does receiving the positive control diet. Urea added to the low protein diet did not influence individual weight of the kits at birth. Similar results were also reported by Niedzwiadek et al. (1978) when 9% fish meal used as a nitrogen source in a diet was replaced by 1 to 2% urea. Mortality rate was the highest in litters from does fed the low protein basal diet (13% CP) and decreased significantly (P < .05) when does received the diet with added urea. Percentage born alive for does fed the positive control diet was 75.3%. Using 54% alfalfa meal and with 19% CP in a diet, Sanchez et al. (1985) reported a similar result. Other preweaning litter traits shown in table 5 include only litters which survived to weaning at 28-day of age. Lower mortality and a higher growth rate of litters were recorded on does fed the control diet. Omole (1982) found that the mortality rate of kits was significantly increased by feeding a low protein diet. The highest preweaning mortality was observed in litters from does fed diet with added urea (P < .05). Niedzwiadek et al. (1978) used 1 and 2% of urea as a replacement of fish meal in the diet and found that mortality increased up to 39.2% when urea used in a diet reached up 2%. The reasons for higher mortality with supplemental urea are three-fold. First, for reasons unknown, does fed the urea diet failed to build good quality nests, resulting in a greater loss of litters from exposure in cold weather. Second, the higher mortality in the present study might be due to the less well-developed gastrointestinal organs of young rabbits compared to the older animals, having little or no urease activity. As a result, young rabbits have less ability to utilize urea as a nitrogen source (Houpt, 1963; King, 1971). Alternatively, it is possible that young rabbits have urease activity but lack a sufficient microbial population for much conversion of urea to microbial protein. Thus, when the kits begin eating they may be subject to ammonia toxicity. The other explanation for high mortality of litters from does fed urea might be due to the inability of the does to utilize poor quality protein for milk production. Like other animals, growing rabbits need amino acids essential for growth (Lang, 1981a), but the urea diet might fail to support almost all amino acid requirements; besides urea can only be used for synthesis of non-essential amino acids (Rose and Dekker, 1956; Broome, 1968; Knutson et al., 1977). However, this would not explain why mortality with the urea diet was higher than with the basal diet. Litters on the positive control diet showed the highest weaned weight (P < .05). Additional SBM increased litter size (P < .05) but did not affect individual weight at 28 days of age. Likewise added urea increased litter size but not as much as with SBM (P < .05). The number of kits per litter at weaning followed the litter size pattern at birth. In other words, different litter size at weaning is partly due to different litter sizes at birth. Feed efficiency, including that of the mother, was the poorest (P < .05) with does fed the diet with added urea, and it was almost twice the value for does fed the low protein diet. Therefore, from the economic stand point, an increase in litter size from 2.6 (diet 4) to 3.33 (diet 3) at 28 d old was of no advantage because of a doubled food consumption. The high apparent feed intake of the basal + urea group may reflect higher feed wastage; urea is a bitter substance which may reduce diet palatability. The highest individual weaned weight was recorded for litters from does fed the positive control diet (P < .05), which was higher than in previous reported studies (Sanchez et al.,1985; Raharjo et al., 1986; Omole, 1982). Addition of either SBM or urea to the low-protein diet did not influence the individual weights of rabbits at weaning. Spreadbury (1978) noted that a higher feed consumption and weight gain occurred when CP level in a diet increased. Omole (1982) found that litter weights from does fed the lowest CP diet were slightly lighter at weaning than those from does fed higher CP diets. The positive control diet (19% CP) met the amino acid requirements (table 2),which could also explain the greater weaned weight compared to litters from does receiving the other diets. Overall results of preweaning performance showed that the positive control diet was superior to the other treatments. Inclusion of SBM or urea alone increased preweaning performance, but economic considerations suggest urea may not be a satisfactory supplement to a low protein diet for does because of the increased feed wastage.

Post weaning traits are represented by the performance during the 28 - 56 d period (table 6), during which rabbits are completely dependent upon their ability to utilize solid feed. Litter size and total litter weight were greater ($P < .01$) for the positive control than for the other treatments. Litter size for rabbits fed the basal plus SBM diet was greater ($P < .05$) than for rabbit fed either the basal or basal + urea diets. Rabbits fed the urea diet gave the lowest litter size. Therefore an increased number of total alive at birth and of total weaned with urea supplementation was no advantage because of a decrease in the number at 56 d of age. Average weight was superior ($P < .05$) for rabbits fed the positive control diet, followed by those fed the basal + SBM diet. Rabbits fed the control diet had a slightly faster growth

TABLE 6. MEANS FOR PERFORMANCE TRAITS OF POSTWEANING LITTERS FED EXPERIMENTAL DIETS

Item	Diets							
	Control		SBM		Urea		Basal	
Litter size	5.68	c	5.06	b	2.15	a	2.20	a
Total litter weight(kg)	8.865	c	7.033	b	2.780	a	2.854	a
Average 56 d weight(kg)	1.560	c	1.387	b	1.296	a	1.316	a
Daily gain, 28 - 56 d (g)	33.1	b	31.9	b	27.0	a	29.4	b
Total 56 d intake (kg)*	19.691	d	16.235	c	9.176	a	12.298	b
Average 56 d intake (kg)	3.466	a	3.202	a	4.267	b	5.590	c
Feed efficiency**	3.6	a	3.7	a	5.6	b	7.2	c
Mortality (%)	8.2	b	4.9	b	35.3	c	16.6	a

* intake from day 28th to day 56th.

** Feed efficiency was the ratio of average 56-day intake to average gain from day 28th to day 56th.

Means in the same rows, bearing common superscripts are not significantly different ($P < .05$).

and better feed efficiency than those on the basal + SBM diet. However there was no significant differences among these variables. Added urea to the low protein diet slightly decreased average weight at 56 d old, but statistically there was no difference. Feed efficiency values did not show any difference between the control and basal + SBM diets, but efficiency was significantly different ($P < .05$) between the two other diets. High mortality of rabbits fed the urea diet occurred ($P < .05$). Mortality during the postweaning period was marked by profuse diarrhea. Grobner (1982) noted that diet plays the major role in influencing diarrhea. Urea is broken down into ammonia by bacterial urease (King, 1971; Knutson et al., 1977; Crociani et al., 1984) and converted to non essential amino acids in the liver (Rose and Dekker, 1956) and to microbial protein (Houpt, 1963),which is reingested during cecotrophy (McBee, 1971). But when urea is broken down into ammonia faster than the ability of bacteria to convert it in to protein, it can be toxic resulting in adverse affects which will initiate conditions causing diarrhea (Grobner, 1982). Regardless of CP level, mortality for other diets agrees with previous studies (Sanchez et al., 1985; Raharjo et al., 1986) but much lower than has been reported by Harris et al.(1982) and Lukefahr (1983). In general, the results of the present study indicate that does receiving either a low-protein basal diet or the basal diet plus urea tended to have lighter body weight than those fed control or the basal + SBM diet. These underweight does in poor condition tended to have weak litters and were not able to provide milk or the litters were born dead (Patton and Cheeke 1986), resulting in high mortality and low litter size. Raharjo et al. (1986) investigated the feeding of urea to rabbits and found that to some extent, rabbits can utilize urea successfully. The lowest level of protein in diet used by Raharjo et al. (1986) was 16% and to this was added urea to give CP percentage of 21.2%. From this stand point, it seems that the good performance shown by rabbits fed this diet was not only due to the presence of urea but also to the basal diet itself.

In conclusion, this study showed that urea gave poor results when used as a nitrogen supplement to a low-protein basal diet for does and their offspring.

CHAPTER 3

EFFECT OF CECOTROPHY AND AGE ON UREA UTILIZATION BY RABBITS

Mathius,I-W., P.R.Cheeke, K.L.Robinson and N.M.Patton

Rabbit Research Center
Dept. of Anim. Sci. OSU., Corvallis, 97331.

CHAPTER 3

EFFECT OF CECOTROPHY AND AGE ON UREA UTILIZATION BY RABBITS

Mathius, I-W., P.R. Cheeke, K.L. Robinson and N.M. Patton.

SUMMARY

A growth trial and a metabolism trial were conducted to evaluate the effect of addition of urea to a low-protein diet for rabbits. For the growth trial, forty-five New Zealand White rabbits (average 600 g live weight) were individually caged and fed either low-protein (13% CP) basal diet, low-protein + soybean meal (SBM) diet or low-protein + urea diet. The SBM and urea provided an equal amount of nitrogen. Differences among diets were not significant for average daily gain (ADG). Inclusion of SBM resulted in a reduction in daily feed intake and improvement of feed efficiency ($P < .05$). Urea supplementation of the low-protein diet did not result in any significant improvement in performance. The highest mortality was observed with rabbits fed the basal + urea diet. In the second experiment, eighteen adult and eighteen weanling (fryer) New Zealand White rabbits were used in a metabolism trial designed as a 2 x 2 x 3 factorial with three replicates, where each rabbit received one of three dietary treatments. Dietary treatments used were those of the growth trial. Each animal was tested with and without ce-

cotrophy allowed. Digestion coefficients for dry matter (DM) were highest for rabbits fed the basal + SBM diet ($P < .01$). Cecotrophy significantly increased ($P < .01$) DM digestibility, but there were no differences between adult and fryer rabbits. The same pattern also occurred for nitrogen digestibility. Differences for nitrogen retention among diets, age and cecotrophy were significant. Fryers utilized the basal + urea diet more efficiently than adults did in terms of nitrogen retention.

INTRODUCTION

The efficiency of the rabbit in producing meat compares favorably with most other domesticated species (Dickerson, 1978). The potential of the rabbit for meat production, however, rests heavily on its ability to attain a high growth rate and it is in this respect that the shortfall between biological and realized potential is greater for the rabbit than for most conventional farm species.

As expected, it is possible to increase the rate of gain by using good quality diets. It is well recognized that protein in rabbit nutrition is an important component. Several studies have been shown that for optimal growth rabbits require an adequate supply of protein (Templeton,1952; Cheeke and Amberg,1972; Portsmouth,1976; Spreadbury, 1978; Reddy et al.,1979; Omole, 1982). Quantitative estimates have been made for the growing rabbit's requirements for specific amino acids (Cheeke, 1971; Adamson and Fisher, 1973; Spreadbury, 1978). The National Research Council (1977) recommended that a CP level of 12% of the diet is needed for maintainance. Being non-ruminant herbivores, rabbits can utilize diets high in forages (Lang, 1981a). Microorganisms of the lower tract (cecum and colon) can improve the biological value of low quality protein (Yoshida et al., 1971), but the microbial protein thus formed may be poorly digested and absorbed from the hind gut (Kennedy and Hershberger, 1974). However, rabbits can make benefit from this microbial protein synthesis by the process of cecotrophy (Cheeke, 1987). Houpt (1963) found a significant nitrogen metabolism from the utilization of orally ingested urea in an adult rabbit, while Lang (1981a) cited evidence of a considerable protein synthesis from the in vitro incubation of urea in rabbit cecal contents. This finding suggested that the cecum of adult rabbits is more developed than that of young animals.

Therefore, the objectives of this study were to further evaluate the addition of urea to a low-protein diet for fryer rabbits. The second objective was to determine if cecotrophy improves the utilization of urea. A final objective was to evaluate if there were age differences in the digestibility and nitrogen retention in fryer and adult rabbits.

MATERIALS AND METHODS

In both experiments, New Zealand White rabbits were used. One week prior to data collection, all animals were provided an adaptation period to become accustomed to the management. All animals were weighed at the begining and the end of both experiments. Feed offered and mortality were recorded. Any feed spillage was weighed and recorded. Average daily gain, feed consumption and feed conversion were calculated using data only from animals that survived the full length of the experiment. The diets and feces were analyzed for dry matter (DM) using a forced-air oven dry at 100 C for 24 h (AOAC, 1980). Prior to laboratory analysis, all dried samples were ground through a 1 mm screen of a Wiley mill. A subsample of each composite was retained for analysis. Fiber analysis was done using a micro-method for acid detergent fiber (ADF) as described by Waldern (1971), while crude protein (CP) was analyzed using a micro-kjeldahl procedure as recommended by AOAC (1980). Urine was analyzed for nitrogen only.

Feeding trial. Forty-five, 4 week-old weanling New Zealand White rabbits were randomly allotted to three dietary treatments with different sources of nitrogen. Dietary ingredients mainly consisted of alfalfa meal, rice hulls, ground barley and wheat mill run. The basal diet was calculated to provide a CP level of 13 % . Diets 2 and 3 were the basal diet supplemented with either soybean meal (SBM) or urea as a source of nitrogen respectively, to provide the same amount of supplementary nitrogen. All animals were caged individually in an open-sided A-frame building as described by Harris et al.(1983). Cages measuring 76 x 31 x 47 cm were suspended with wire 120 cm above the ground on two sides of a 90 cm-wide concrete walkway. Each cage was equipped with a J-shaped screened metal feeder (14 x 8 x 16 cm) and an automatic waterer which were located at the front of each cage. The statistical analysis for all results was by one way analysis of variance. Due to mortalities, unequal replications within treatment groups occurred.

Digestion Trial. Eighteen adult and eighteen weanling rabbits were used and randomly assigned to a 2 x 2 x 3 factorial arrangement of treatments consisting of two ages of rabbits, two factors of cecotrophy (with and without) and three different diets with three replicates. Dietary treatments were the same as used in the feeding trial. Within each dietary treatment, half of the animals were used with cecotrophy prevented, while the other half were with cecotrophy permitted. A rigid plastic collar measuring 14 cm in diameter was used to prevent cecotrophy as outlined by Robinson et al.(1985). One week prior to the metabolism period in which data were collected, all rabbits were confined in stainless steel cages measuring 61 x 46 x 37 cm. Then, rabbits were transferred for seven days to stainless steel metabolism cages measuring 63 x 46 x 35 cm. Both types of cages (adaptation and metabolism cages) were equipped with automatic waterers and either a ceramic crock or screened metal feeder. Feces and urine were collected every morning during the collection period and frozen until analyses were performed. Five ml sulfuric acid (20%) was added daily into the jar after urine was pooled. Body weights were measured at the begining and the end of collection period. The apparent digestibilities of DM ,CP and ADF were calculated by procedures and formulas for apparent digestibility, as outlined by Church (1978). Nitrogen balance was calculated by subtracting total nitrogen in urine and feces from the nitrogen intake. Data were subjected to an analysis of variance. Any significant differences between means were compared by using least significant difference (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Feed and nutrient composition are presented in table 7. The addition of SBM or urea to the low-protein basal diet containing 2.2% nitrogen, increased the nitrogen level up to 2.5 and 2.7% respectively. Addition of urea to the basal diet did not affect ADF content, while additional SBM increased ADF content by 4 percentage units.

Feeding trial. Performance of fryers fed diets containing different levels and sources of nitrogen is shown in table 8. The highest mortality (20%) occurred with rabbits fed the urea diet. Three out of fifteen rabbits on this diet died from enteritis by the beginning of the second week of study. Lack of the ability of young rabbits to utilize urea as a source of nitrogen (Houpt, 1967) might explain this problem. King (1971) indicated that young rabbits have a very limited capability to utilize the nitrogen of urea in the synthesis of protein. Young rabbits grow faster and need more essential amino acids than older animals (King, 1971; Adamson and Fisher, 1971; Hoover and Heitmann, 1975; Spreadbury, 1978). One possible explanation for the poor results with the urea-containing diet is that the urea may be efficiently hydrolyzed to ammonia in the cecum, but because of a less than fully developed hindgut microbial population, cecal ammonia may be inefficiently used for microbial synthesis.

TABLE 7. COMPOSITION OF EXPERIMENTAL DIETS (%).

Item	Diets		
	Basal	SBM	Urea
Alfalfa meal	20.00	20.00	20.00
Rice hulls	20.00	15.00	20.00
Ground barley	22.50	22.50	22.50
Wheat mill run	30.50	24.50	28.70
Molasses	3.00	3.00	3.00
Fat	2.50	2.50	2.50
Dicalcium phosphate	1.00	1.00	1.00
Trace mineral salt *	0.50	0.50	0.50
Soybean meal	-	11.00	-
Urea	-	-	1.80
Chemical composition (%)**,			
Dry matter	91.26	90.89	91.43
Nitrogen	2.17	2.50	2.71
Crude protein	13.56	15.63	16.94
Acid detergent fiber	27.86	23.67	26.89
DE,kcal/kg ***	2657	2859	2601

* Appendix 1.

** Analytical data (except dry matter) are expressed on a dry matter basis.

*** Calculated values using US - Canadian, Tables of Feed Composition (1982).

TABLE 8. EFFECT OF DIETARY TREATMENTS ON DAILY INTAKE AND RABBIT PERFORMANCE.

Item	Diets.		
	Basal	SBM	Urea
No. of animals started	15	15	15
No. of animals ended	14	14	12
Mortality (%)	6.7	6.7	20.0
Initial weight (g)	602.8	603.1	609.1
Final weight (g)	1331.7	1405.6	1311.4
Daily gain (g)*	26.03	28.60	25.03
Intake (g):			
Dry matter	149.78 b	116.84 a	150.85 b
Nitrogen	3.25 b	2.92 a	4.09 c
Acid detergent fiber	41.73 b	27.66 a	40.56 a
Feed efficiency **	6.29 b	4.36 a	6.53 b

* daily gain was the ratio of average individual gain to the number of days on trial.

** feed efficiency was the ratio of average daily consumption to average daily gain.

Means in the same rows, bearing common superscripts are not significantly different ($P < .05$).

This could result in adverse metabolic effects from elevated blood ammonia levels. There was no difference among dietary treatments in average daily gain (ADG). Although additional SBM to the low-protein diet tended to increase ADG, it was not adequate to support optimum performance of the growing rabbit. Using two groups of rabbits fed diets (13% CP) containing all natural protein or part non-protein nitrogen from urea, Hoover and Heitmann (1975) found no significant differences in weight gain. Daily weight gains in the current study are somewhat lower than those reported by Raharjo et al.(1986). The difference between the two studies might be explained on the basis that the CP level used in this study was lower than that used by Raharjo et al. (1986). Average daily intake of dry matter (DM) was lower ($P < .05$) with the addition of SBM to the low-protein diet. Addition of urea to the low-protein diet did not change average daily intake. This was in agreement with the finding of Lebas and Colin (1974), in which 1.5% of urea was added to a diet low in protein. Conversion of DM intake to body weight gain was improved ($P < .05$) for rabbits fed the basal + SBM diet over the other two diets. The lower feed intake and better feed conversion for this group may at least in part reflect less feed spillage.

<u>Digestion trial</u>. Apparent digestibility coefficients for the experimental diets and nitrogen retention (N-ret)

values are given in tables 9, 10 and 11. There was no significant difference in DM digestibility between adult and fryer rabbits. However, digestibility of DM was highly affected ($P < .01$) by the dietary treatments and cecotrophy. Soybean meal addition to the low-protein diet did not affect the DM digestibility coefficient for adult rabbits, but it did for fryer rabbits. Prevention of cecotrophy lowered DM digestibility for both adults and fryers. These results indicate that prevention of cecotrophy produces significant changes in the ability of rabbits to utilize the diet (Yoshida et al., 1968). Digestibility of nitrogen was not significantly different between adults and fryers. Cecotrophy tended to increase nitrogen digestibility ($P < .01$) for both ages of rabbits. This would agree with the report of Teleki et al.(1986), that digestibility of CP increased as many as 7% units if cecotrophy was allowed. Normally, rabbits practice cecotrophy,resulting in ingestion of cecal bacterial protein and various compounds of microbial metabolism (Barnes, 1962; Weingartner et al. 1981; Cree et al., 1986). In other words, rabbits practicing cecotrophy utilize more nitrogen than when cecotrophy is prevented. Values for N-ret (g/d) were affected ($P < .01$) by both cecotrophy and dietary treatments. Among the dietary treatments, high N-ret was the highest with the basal + SBM diet. There was no difference between basal and basal + urea diets in N-ret, but

TABLE 9. APPARENT DIGESTIBILITY (%) OF DRY MATTER FOR RABBITS OF DIFFERENT AGES AND FED DIFFERENT DIETS

I t e m		Diets: Basal		SBM		Urea		Means**
Adult	(+)*	56.37	abz	58.19	by	55.47	ay	56.66
	(-)	50.91	ax	52.34	bx	49.01	ax	50.75
	Means (NS)	53.64	a	55.26	b	52.24	a	
Fryer	(+)	53.65	ay	57.60	by	55.10	aby	55.45
	(-)	49.19	ax	53.33	bx	47.50	ax	50.01
	Means	51.42	a	55.47	b	51.30	a	

* (+), cecotrophy allowed: (-), cecotrophy prevented.

** significant difference between with and without cecotrophy (P < .01).

ab means in the same rows having different superscripts are significantly different (P < .01).

xyz means in the same colomn having different superscripts are significantly different (P < .01).

NS, not significant differences between adult and fryer.

TABLE 10. APPARENT DIGESTIBILITY (%) OF NITROGEN FOR RABBITS OF DIFFERENT AGES FED DIFFERENT DIETS

Item			Diets			Means**
			Basal	SBM	Urea	
Adult	(+)*		72.13 ay	70.92 ay	77.58 bz	73.51
	(-)		52.97 ax	56.71 bx	64.07 cy	57.90
		Means	62.55 a	63.81 a	70.81 b	
Fryer	(+)		69.55 ay	70.68 ay	78.53 bz	72.91
	(-)		50.51 ax	58.17 bx	59.69 bx	56.12
		Means	60.03 a	64.41 b	69.10 c	

* (+), cecotrophy allowed; (-), cecotrophy prevented.

** Significant difference between with and without cecotrophy ($P < .01$).

abc Means in the same rows having different superscripts are significantly different ($P < .01$).

xyz Means in the same colomn having different superscripts are significantly different ($P < .01$)

TABLE 11. NITROGEN RETENTION (g/d) FOR RABBITS OF DIFFERENT AGES FED DIFFERENT DIETS

Item		Diets: Basal	SBM	Urea	Means**
Adult	(+)*	.98 bq	1.12 cq	.75 aq	.95
	(-)	.38 cp	.16 bp	.04 ap	.19
	Means	.68 cx	.64 bx	.40 ax	
Fryer	(+)	1.37 abr	1.39 br	1.29 ar	1.35
	(-)	.95 aq	1.25 bqr	.83 aq	1.01
	Means	1.16 ay	1.32 by	1.06 ay	

* (+), cecotrophy allowed; (-), cecotrophy prevented.

** Significant difference between with and without cecotrophy ($P < .01$).

abc Means in the same rows having different superscripts are significantly different ($P < .01$).

xyz Means in the same colomn having different superscripts are significantly different ($P < .01$).

pqr Means in the same colomns having different superscripts are significantly different ($P < .01$).

there was between adult and fryer rabbits (P < .01). Fryers utilized the urea-containing diet more efficiently than did adults, as assessed by N-retention. This might be because the amino acids needed for adult rabbits are less than for young rabbits (Lang, 1981a; NRC, 1977; Portsmouth, 1976); therefore excess nitrogen from urea, which can only be used for non-essential amino acid synthesis (Rose and Dekker,1956), is excreted via urine. Urea is hydrolyzed very rapidly to ammonia (Broome, 1968; Jackson, 1974) in the gut , and absorbed (Knutson et al., 1977) prior to excretion via urine. In the liver, part of the ammonia can be used for non-essential amino acid synthesis (Rose and Dekker, 1956; Houpt, 1963), and the rest will be reconverted to urea. Via blood (Knutson et al. 1977) and by simple diffusion (Houpt and Houpt, 1981), urea will move across the epithelium of the cecum (Forsythe and Parker, 1985), and can be utilized for bacterial metabolism and protein synthesis in the cecum. This whole process may account for high nitrogen digestibility and N-ret on young rabbits fed the basal + urea diet, especially when cecotrophy is allowed. Data from the metabolism study indicate that both cecal fermentation and associated cecotrophy are essential in both adult and fryer rabbits for maximum nitrogen utilization. This agrees with previous work done by Griffiths and Davies (1963), Yoshida et al.(1968) Kennedy and Hershberger (1974) and Robinson et al.(1985).

These experiments indicate that some utilization of urea occurs in rabbits, via microbial fermentation in the cecum.

CHAPTER 4

EFFECT OF DIETARY FIBER ON UREA UTILIZATION BY WEANLING RABBITS

Mathius, I-W., P.R. Cheeke and N.M. Patton

Rabbit Research Center
Dept. of Anim. Sci.,OSU. Corvallis, 97331.

CHAPTER 4

EFFECT OF DIETARY FIBER ON UREA UTILIZATION BY WEANLING RABBITS

Mathius, I-W., P.R. Cheeke and N.M. Patton

SUMMARY

Two trials were conducted to evaluate the utilization of urea by weanling rabbits fed diets differing in type of carbohydrate. Urea or an equivalent (on N basis) level of soybean meal (SBM) were used as N supplements to low-protein basal diets based on either grain (high starch diet) or roughage (high fiber diet). Sixty weanling New Zealand White rabbits (average weight 1025 g) were used in a growth trial . Average daily gain (ADG), feed intake and feed efficiency were measured. The high fiber diet tended to increase (P < .01) ADG and feed intake. Urea or SBM supplementation of the basal diets did not affect ADG and dry matter (DM) intake. There were no significant differences in feed efficiency among dietary treatments. The same dietary treatments were used in a metabolism trial, using seventy-two New Zealand White rabbits. Twelve rabbits were fed each diet, with six in each treatment equipped with collars to prevent cecotrophy. Significant differences (P < .01) in DM, N and ADF digestibility were found between groups. The high fiber diet resulted in a statistically significant (P < .01) de-

crease in DM, N and ADF digestibility, but increased N retention. The results of these experiments suggest that the efficiency of utilization of urea by rabbits is not markedly influenced by the type of dietary carbohydrate.

INTRODUCTION

Urea is a form of non-protein nitrogen (NPN) that can be used to furnish a portion of the nitrogen (N) requirement of the rabbit and it provides a low-cost replacement for more expensive preformed protein. King (1971) stated that NPN appears to be converted into ammonia rapidly, through the action of the enzyme urease, elaborated by microorganisms in the gut. Knutson et al. (1977) noted that the presence of urease activities in the digestive tract of the rabbit appears to fit the concept of the cecum playing a central role in the nitrogen metabolism (Crociani et al., 1984). Microbial fermentation in the cecum and the colon of the rabbit can improve the biological value of NPN. The amount of ammonia that can be utilized by microorganisms will depend on their number and growth rate which will depend largely on the amount of substrate available for the microorganisms or the amount of fermentable feed consumed.

The objectives of this study were to determine; (1)

the effect of feeding low or high fiber on the utilization of urea and (2) the effect of cecotrophy on urea utilization by rabbits fed low or high levels of fiber.

MATERIALS AND METHODS

Two experiments were conducted, each involving a feeding trial and a digestion-N balance trial, using New Zealand White rabbits. All animals were provided an adaptation period and fed a regular diet one week prior to the experiment, so that they became accustomed to the management conditions before experimental diets were fed. All rabbits were weighed at the beginning and the end of the trials and fed the experimental diets ad libitum throughout the experiment. Performance traits measured included average daily gain, feed consumption, feed efficiency, mortality percentage, nutrient digestion coefficients and N-balance, using data only from surviving rabbits. Average daily feed consumption was the ratio of total feed intake per cage to the number of animal days for that particular cage. Diet 1, formulated on a dry matter basis to contain approximately 12 % CP, contained 55% ground wheat (Table 13) which resulted in a high level of fine particles of fermentable carbohydrates and a low fiber content (low fiber basal diet). Diets 2 and 3 were the low fiber basal diet supplemented with soybean meal (SBM) and urea respectively. The SBM and urea provided the same amount of supplementary CP of 6.7 %. Diet 4 was a high-fiber basal diet, but contained the same level of CP as the low-fiber basal diet , while diet 5 and 6 were diet 4 supplemented with SBM and urea respectively. All diets were pelleted and fed ad libitum. Any feed spillage was weighed and recorded. Samples of feed and feces were taken during the experiments. Samples were dried in a forced-air oven at 100 C for 24 h. Dried samples were ground and analyzed for CP and acid detergent fiber (ADF) according to the methods of the AOAC (1980) and Waldern (1971) respectively. For the calculation of nitrogen balance, urine was collected for a 7-day period corresponding to the collection period for the digestibility study. Five ml sulfuric acid was added daily to the collection jar after urine was pooled. Urine samples then were stored at - 2 C for subsequent chemical analysis.Urinary nitrogen was determined using a semi micro-kjeldhal technique (AOAC,1980).

Feeding Trial. Sixty 4-5 week-old weanling rabbits were randomly assigned to one of six diets and were housed individually in cages measuring 76 x 31 x 47 cm in an open-sided A-frame building as described by Harris (1983). Cages were suspended with wire 120 cm above the ground on two sides of 90 cm-wide concrete walk-way. Each cage was equipped with a metal feeder and an automatic waterer.
All animals were exposed to 16 h light and 8 h dark. Data

were collected over a 28-day period.

Metabolism Trial . Seventy two rabbits, average weight of 1.8 - 2 kg, were randomly allotted to a completely random design with six replicates of a 2 x 2 x 3 factorial arrangement of treatments consisting of two factors of cecotrophy two levels of fiber and three different sources of nitrogen. One week before the collection / metabolism period, all rabbits were confined in stainless steel adaptation cages, then rabbits were transfered to metabolism cages for a 7-day collection period. Rabbit performance was measured by average daily gain, feed intake, feed/-gain and nutrient digestion coefficients. Data were analyzed by analysis of variance using the general linear model procedure as outlined by SAS (1985). Any significant differences between means were compared by using least significant differences (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Diets and chemical composition of the six rations are shown in table 12. Although the diets, except for the two basal diets, were calculated to be isonitrogenous, analyzed values showed some variation in CP content.

Feeding trial. The results of the feeding trial can be seen in tables 13, 14 and 15. No mortality was observed in this study. Interaction between nitrogen sources and fiber level was not significant for average daily gain (ADG) and feed efficiency. ADG did not differ among nitrogen sources and the over all mean was 26 g. Urea supplementation of the low-protein diet tended to depress ADG of rabbits fed the low fiber diet. This result is in agreement with King (1971) who reported reduced daily gain when part of the crude protein in a high starch diet was replaced by urea. The response to SBM supplementation of the low protein basal diets was less than expected, and the ADG for these groups was lower than values reported by Sanchez et al.(1985) and Raharjo et al.(1986). It is possible that the animals in the present study experienced marginal hypovitaminosis A. At the time this experiment was conducted, a vitamin A deficiency problem occurred throughout the rabbitry as a result of poor quality alfalfa meal used in preparation of the standard diet. The greater ADG of rabbits fed the high fiber diets (table 13)

TABLE 12. DIET AND CHEMICAL COMPOSITION (%)

Item	Low Fiber			High Fiber		
	Basal	SBM	Urea	Basal	SBM	Urea
Alfalfa meal	10.00	10.00	10.00	25.00	25.00	25.00
Grass hay	10.00	10.00	10.00	25.00	25.00	25.00
Ground barley	-	-	-	25.00	25.00	25.00
Ground wheat	55.00	55.00	55.00	-	-	-
Wheat mill run	21.00	6.00	18.60	21.00	6.00	18.60
Molasses	2.50	2.50	2.50	2.50	2.50	2.50
Trace mineral salt*	.50	.50	.50	.50	.50	.50
Dicalcium phosphate**	1.00	1.00	1.00	1.00	1.00	1.00
Soybean meal	-	15.00	-	-	15.00	-
Urea	-	-	2.4	-	-	2.4
Chemical composition(%);						
Dry matter	92.01	92.42	92.13	94.12	92.62	91.85
Nitrogen	1.93	2.81	3.03	2.12	2.80	2.90
Crude protein	12.07	17.64	18.95	13.26	17.53	18.14
Acid detergent fiber	10.95	8.23	10.18	19.66	14.69	17.71
DE,Kcal/kg ***	3254	3350	3179	2813	2882	2739

* Appendix 1.

** Dicalcium phosphate; Simphos 18.5%, contains P not less than 18.5% and calcium between 19 - 26%.

*** Calculated values using US-Canadian, Tables of Feed Composition (1982).

TABLE 13. EFFECT OF FIBER AND NITROGEN SOURCES ON RABBIT PERFORMANCE

I t e m	N-sources	Level of fiber		Means
		Low	High	
Daily gain(g)	Basal	21.6	27.8	24.7
	SBM	24.4	31.6	28.0
	Urea	19.7	30.7	25.2
	Means	21.9 a	30.0 b	
Feed efficiency *	Basal	3.3	3.6	3.5
	SBM	3.1	3.2	3.2
	Urea	3.8	3.3	3.5
	Means	3.4	3.4	

* Feed efficiency was the ratio of average daily consumption to average daily gain.

ab, Means in the same row having different superscripts are significantly different ($P < .01$).

TABLE 14. EFFECT OF FIBER AND NITROGEN SOURCES ON DAILY INTAKE (g).

I t e m	N-sources	Level of fiber		Means
		Low	High	
Dry matter	Basal	71.22 a	97.40 b	84.34
	SBM	72.95 a	95.35 b	84.15 (NS)
	Urea	73.65 a	99.47 b	86.56
	Means	72.63 a	97.41 b	
Nitrogen	Basal	1.38 a	2.07 b	1.73 x
	SBM	1.83 a	2.67 b	2.25 y
	Urea	2.23 a	2.89 b	2.56 z
	Means	1.81 a	2.54 b	
ADF	Basal	7.81 a	19.15 b	13.48 y
	SBM	6.00 a	14.00 b	10.00 x
	Urea	7.50 a	17.63 b	12.57 y
	Means	7.10 a	16.93 b	

ab, Means in the same rows having different superscripts are significantly different ($P < .01$).

xyz, Means in the same colomn having different superscripts are significantly different ($P < .01$).

NS, differences not significant.

may be a result of a higher vitamin A intake because of the higher level of forage (alfalfa meal and grass hay) in these diets (table 12). The lower ADG of the animals on the low fiber diets could also be a reflection of the low fiber content, although de Blas et al.(1986) found no differences in ADG among rabbits fed diets ranging from 9.8 to 32.7% ADF. Various levels of ADF, ranging from 3.9 to 27.8%, were also studied by Spreadbury and Davidson (1978). They reported that there was no significant difference in ADG between rabbits fed diets containing 11.7% and 18.6% ADF. On the other hand, Carregal (1978) found that weight gains of rabbits fed a 7% crude fiber diet were higher ($P < .05$) than for two other diets containing 10 and 13% crude fiber. There appeared to be some increase in ADG in the high fiber diet supplemented with urea (table 13) but it was not significant(table 15). Feed consumption among dietary treatments did not differ (table 14); however, there was significantly increased (P .01) feed consumption for rabbits fed the high fiber-containing diets. This confirms the results of other studies (Hoover and Heitmann, 1972; Spreadbury and Davidson, 1978; Champe and Maurice, 1983; de Blas et al.,1981; de Blas et al.,1986). Moreover, Cheeke (1976), Spreadbury and Davidson (1978) and Evans (1981) stated that increased feed intake in rabbits fed high fiber-containing diets was due to the need of daily energy. A high fiber level on a diet

TABLE 15. SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES OF PERFORMANCE TRAITS OF RABBITS FED UREA-CONTAINING DIETS WITH DIFFERENT LEVELS OF FIBER.

Item	Av. Daily	FCR	Intake		
			DM	N	ADF
Fiber	P < .01	NS	P < .01	P < .01	P < .01
N-sources	NS	NS	NS	P < .01	P < .01
Fiber * N-sources	NS	NS	NS	NS	NS

NS, not significant different.

usually corresponds to a low energetic concentration (de Blas et al., 1986), therefore in order to maintain their energy requirement, rabbits tend to eat more than usual to keep their daily energy intake constant.

Digestion trial. The apparent dry matter (DM) digestibilities of the experimental diets are given in table 16. Interactions between level of fiber x cecotrophy, nitrogen sources x cecotrophy and level of fiber x cecotrophy x nitrogen sources were not significant (table 19). Apparent digestibility of DM was higher ($P < .01$) for the low-fiber diet than for the high-fiber diet. DM digestibilities were also affected ($P < .01$) by nitrogen sources and cecotrophy . de Blas et al.(1986) found that digestibilities of dry matter decreased linearly as the ADF increased. The digestibility of nitrogen (CP) can be seen in table 17. Interactions of fiber levels, nitrogen sources and cecotrophy were non-significant. However, there were significant differences in nitrogen digestibilities either between fiber level or among nitrogen sources or with and without cecotrophy. Apparent nitrogen digestibility coefficients were greater ($P < .01$) for the low-fiber than for the high-fiber diets. Shah et al. (1982) and Mitaru and Blair (1984) found that increasing dietary fiber significantly reduced apparent nitrogen digestibility in rats. Increasing dietary fiber may cause increased endogenous excretion of fecal nitrogen (Kelsay et al.,1978),

TABLE 16. EFFECT OF LEVEL OF FIBER AND NITROGEN SOURCES ON DRY MATTER (DM) DIGESTIBILITY (%)

N-sources		Level of fiber: Low	Level of fiber: High	Means**
Basal	(+)*	75.33 br	53.81 ap	64.57
	(-)	70.85 bq	53.25 ap	62.05
	Means	73.09 by	53.53 ax	
SBM	(+)	76.86 br	63.19 aq	70.03
	(-)	72.33 bq	61.67 aq	67.00
	Means	74.60 by	62.43 az	
Urea	(+)	73.83 bq	61.53 aq	67.68
	(-)	66.15 bp	54.20 ap	60.17
	Means	69.98 bx	57.53 ay	

* (+)/(-), with or without cecotrophy.

** Significant difference between with and without cecotrophy.(P < .01).

ab, Means in the same rows having different superscripts are significantly different (P < .01).

xyz, Means in the same colomns having different superscripts are significantly different (P < .01).

pqr, Means in the samecolomns having different superscripts are significantly different (P < .01).

which probably could explain the lower nitrogen digestibility coefficient for the high fiber diet. Sheard et al.(1980) suggested the possibility that fiber might increase the sloughing of intestinal mucosal cells, resulting in reduction of intestinal ability to absorb amino acids or nitrogen. Howard et al.(1986) also reported that fiber in a diet can bind essential amino acids and may contribute to the decrease in protein utilization. Rabbits, however, may be able to compensate for the effect of fiber in increasing the loss of endogenous fecal nitrogen. Fekete and Bokori (1985) observed that the quantity of cecotropes consumed by rabbits increased when the dietary fiber level increased, thus resulting in a greater reingestion of endogenous nitrogen. They found a positive relationship between the "protein minus fiber" content of the diet and the quantity of unconsumed cecotropes discharged. Nitrogen digestibility was reduced when cecotrophy was prevented. This result agrees in general with the results of Shah et al. (1982) and Cree et al.(1986), who evaluated effect of cecotrophy on nitrogen utilization. Robinson et al. (1985) and van Soest (1985) stated that cecotrophy is essential in the rabbit for efficient utilization of feed. Nitrogen digestibility also differed ($P<.05$) among nitrogen sources. The digestibility of nitrogen in the urea-containing diet was much higher ($P<.01$) than for the other two diets. Urea is almost completely

TABLE 17. EFFECT OF FIBER LEVEL AND NITROGEN SOURCES ON NITROGEN DIGESTIBILITY (%)

Nitrogen sources		Level of fiber		Means**
		Low	High	
Basal	(+)*	76.96 bq	66.04 aq	71.50
	(-)	66.33 bp	55.99 ap	61.16
	Means	71.64 bx	61.01 ax	
SBM	(+)	79.45 bq	73.93 ars	76.69
	(-)	67.93 ap	68.73 aq	68.33
	Means	73.69 bxy	71.32 ay	
Urea	(+)	80.59 bq	77.16 as	78.78
	(-)	70.66 bp	67.75 aqr	69.21
	Means	75.63 by	72.02 ay	

* (+)/(-), with or without cecotrophy.

** Significant difference between with and without cecotrophy (P < .01).

ab, Means in the same rows having different superscripts are significantly different (P < .01).

xyz, Means in the same colomns having different superscripts are significantly different (P < .01).

pqrs, Means in the same colomns having different superscripts are significantly different (P < .01).

hydrolyzed to ammonia in the stomach (Crociani et al., 1984) and small intestine (Houpt, 1963; Knutson et al., 1977). Ammonia can be absorbed and metabolized in the liver with the synthesis of non essential amino acids (Rose and Dekker, 1956). This process causes nitrogen absorption to be increased, resulting in increased nitrogen (CP) digestibility. In the rabbit, part of the absorbed ammonia is recycled to the cecum (Crociani et al.,1984) by simple diffusion means (Houpt and Houpt, 1968) and is used in microbial protein synthesis. The bacterial protein will be ingested by cecotrophy (McBee, 1971) and subsequently digested with absorption of the component amino acids. When cecotrophy is prevented, bacterial protein can not be ingested, with resulting reduction of amino acids utilization. Consequently, nitrogen utilization and digestibility are reduced. The cecum appears to play an important role in the nitrogen metabolism of the rabbit (Knutson et al. 1977). There was no interaction affecting ADF digestibility, except level of fiber x nitrogen soueces interaction ($P < .05$) (table 19). High fiber level tended to reduced ADF digestibility ($P < .01$) for the basal and soybean meal diets, but not for the urea-containing diet. de Blas et al.(1986) found similar responses, with reduced fiber digestibility when ADF content in a diet increased. Digestibility of ADF decreased ($P < .01$) when cecotrophy was prevented. Contrary to the

TABLE 18. EFFECT OF LEVEL OF FIBER AND NITROGEN SOURCES ON ACID DETERGENT FIBER DIGESTIBILITY (%)

N- sources			Level of fiber		Means **
			Low	High	
Basal	(+)*		23.23 bs	9.86 aq	16.55
	(-)		15.06 br	7.28 aq	11.17
		Means	19.14 bz	8.55 az	
SBM	(+)		12.75 bqr	8.13 aq	10.44
	(-)		8.59 bpq	4.55 ap	6.57
		Means	10.67 by	6.34 ax	
Urea	(+)		10.33 bq	9.99 aq	10.16
	(-)		4.76 ap	4.96 ap	4.86
		Means	7.55 ax	7.25 ay	

* (+)/(-), with or without cecotrophy.
** Significant difference between with and without cecotrophy ($P < .01$).
ab, Means in the same rows having different superscripts are significantly different ($P < .01$).

xyz, Means in the same colomns having different superscripts are significantly different ($P < .01$).
pqrs, Means in the same colomns having different superscripts are significantly different ($P < .01$).

TABLE 19. SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES OF NUTRIENT DIGESTIBILITY OF RABBITS FED UREA-CONTAINING DIETS WITH DIFFERENT LEVELS OF FIBER

Item	OM	N	ADF
Fiber	P < .01	P < .01	P < .01
N-Sources	P < .01	P < .01	P < .01
Cecotrophy	P < .01	P < .01	P < .01
Fiber*N-sources	P < .05	NS	P < .05
Fiber*cecotrophy	NS	NS	NS
N-sources*cecotrophy	NS	NS	NS
Fiber*N-sources*cecotrophy	NS	NS	NS

NS, not significant difference.

current results, Cree et al.(1986) indicated that cecotrophy has little impact on fiber digestibility in the rat. Cheeke et al.(1986) stated that fiber and non-fiber are separated in the hindgut of the rabbits, with the rapid excretion of much of the fiber part in the hard feces, so that cecotrophy would not be expected to have a major effect on ADF digestibility in rabbits. In the high fiber diets, a greater proportion of the ADF was derived from forage (alfalfa meal and grass hay) than from the more digestible wheat mill run than was the case with the low fiber diets. Therefore, it would be anticipated that the % ADF digestibility would be higher in the low fiber diets, and this was observed (table 18). The highest digestibility of ADF was found on the basal diets. Nitrogen retention (N-ret) which is dependent on both nitrogen intake and nitrogen output via fecal and urine, was only affected by fiber level and cecotrophy ($P < .01$). N-ret (table 20 and 21) differed between with and without cecotrophy (0.928 vs. 0.600 g/d). This finding indicated that cecotrophy improves the efficiency of nitrogen utilization, regardless of the nitrogen sources (preformed protein or NPN). This agrees with the report of Robinson et al. (1985), that cecotrophy is essential for full utilization of dietary nutrients. Although there were not significant differences among dietary treatments, N-ret of rabbits on the urea supplemented diet showed higher values than

TABLE 20. NITROGEN BALANCE OF RABBITS FED DIFFERENT LEVELS OF FIBER AND NITROGEN SOURCES

Nitrogen	N-sources		Level of fiber		means	
			Low	High		
Intake(g/d)	Basal	(+)*	1.25 ap	2.50 bp	1.88	NS
		(-)	1.26 ap	2.58 bp	1.92	
		Means	1.25 ax	2.54 bx		
	SBM	(+)	2.07 aq	3.30 bqr	2.68	
		(-)	1.50 apq	3.03 bq	2.27	
		Means	1.79 ay	3.17 bx		
	Urea	(+)	2.34 aq	3.72 br	3.03	
		(-)	1.60 apq	3.51 br	2.56	
		Means	1.99 az	3.60 by		
Feces(g/d)	Basal	(+)	0.29 a	0.84 b	0.57	NS
		(-)	0.48 a	1.14 b	0.81	
		Means	0.36 a	0.99 b		
	SBM	(+)	0.43 a	0.87 b	0.65	
		(-)	0.48 a	0.94 b	0.71	
		Means	0.46 a	0.91 b		
	Urea	(+)	0.45 a	o.85 b	0.65	
		(-)	0.46 a	1.13 b	0.79	
		Means	0.46 a	1.00 b		
Urine (g/d)	Basal	(+)	0.48 a	0.92 b	0.70	NS
		(-)	0.46 a	0.70 b	0.58	
		Means	0.47 ax	0.81 bx		
	SBM	(+)	0.78 a	1.34 b	1.06	
		(-)	0.61 a	1.02 b	0.81	
		Means	0.69 ax	1.18 bx		
	Urea	(+)	1.07 a	1.85 b	1.46	
		(-)	0.99 a	1.50 b	1.23	
		Means	1.03 ay	1.67 by		
Retention(g/d)	Basal	(+)	0.46 ap	0.74 bp	0.60	**
		(-)	0.44 ap	0.83 bp	0.64	
		Means	0.45 a	0.79 b		
	SBM	(+)	0.85 aq	1.12 bq	0.99	
		(-)	0.39 ap	1.03 bpq	0.71	
		Means	0.63 a	1.08 b		
	Urea	(+)	0.86 aq	1.02 bpq	0.94	
		(-)	0.21 ap	0.81 bp	0.51	
		Means	0.57 a	0.93 b		
Retained as % consumed	Basal	(+)	35.10 r	28.72 p	31.91	**
		(-)	30.56 q	26.89 p	28.72	
		Means	32.70	27.81		
	SBM	(+)	40.76 r	33.86 q	37.31	
		(-)	25.65 p	32.74 q	29.20	
		Means	33.20	33.30		
	Urea	(+)	36.72 r	27.42 p	32.07	
		(-)	15.61 p	23.37 p	13.49	
		Means	26.60	25.39		
Retained as % absorbed	Basal	(+)	47.92 qr	44.58 q	46.25	**
		(-)	56.41 r	57.64 r	57.03	
		Means	52,17 z	51.10 y		
	SBM	(+)	51.83 r	46.09 q	48.96	
		(-)	38.24 q	49.28 qr	43.76	
		Means	45.03 y	47.68 xy		
	Urea	(+)	45.50 qr	35.54 p	40.52	
		(-)	18.42 p	34.03 p	26.22	
		Means	31.96 x	34.79 x		

* (+)/(-), with or without cecotrophy.
** Significant difference between with and without cecotrophy.
ab, Means in the same rows having different superscripts are significantly different ($P < .05$)
xyz, Means in the same columns having different superscripts are significantly different ($P < .05$).
pqr Means in the same columns having different superscripts are significantly different ($P < .05$).
NS, not significant between with and without cecotrophy.

TABLE 21. SUMMARY OF STATISTICALLY SIGNIFICANT DIFFERENCES OF NITROGEN METABOLISM OF RABBITS FED UREA-CONTAINING DIETS WITH DIFFERENT LEVELS OF FIBER

Item	N-intake	Fecal N	Urinary N	N-retention	N-retained as % consumed	N-retained as % absorbed
Fiber	$P < .01$	$P < .01$	$P < .01$	$P < .01$	NS	NS
N-Sources	$P < .01$	NS	$P < .01$	NS	NS	$P < .01$
Cecotrophy	NS	NS	NS	$P < .01$	$P < .01$	$P < .01$
Fiber*N-sources	NS	NS	NS	NS	NS	NS
Fiber*cecotrophy	NS	NS	NS	NS	NS	NS
N-sources*cecotrophy	NS	NS	NS	NS	NS	NS
Fiber*N-sources*cecotrophy	NS	NS	NS	NS	NS	NS

NS, not significantly different.

those on the basal diets, indicating that to a limited extent rabbits can utilize urea as a source of nitrogen.

This study indicates that rabbits can utilize dietary urea to some extent in meeting part of their protein requirements. Cecotrophy is necessary for urea utilization. The source of dietary carbohydrate does not appear to have a major influence on urea utilization.

CHAPTER 5

EFFECT OF DIETARY STARCH LEVEL ON THE UTILIZATION OF UREA AND BIURET BY GROWING RABBITS

Mathius, I-W., P.R. Cheeke and N.M. Patton

Rabbit Research Center
Dept. of Animal Science. Corvallis, OR. 97331.

CHAPTER 5

EFFECT OF DIETARY STARCH LEVEL ON THE UTILIZATION OF UREA AND BIURET BY GROWING RABBITS

Mathius, I-W., P.R. Cheeke and N.M. Patton

SUMMARY

A feeding trial with New Zealand White weanling rabbits (975 g initial weight) and a digestion trial were undertaken to evaluate the effect of dietary starch level on the efficiency of utilization of urea and biuret. Two levels of starch (high vs low) with different nitrogen sources, were used. Treatments included the basal diet, basal + soybean meal (SBM), basal + urea and basal + biuret. Soybean meal, urea and biuret provided an equal amount of supplementary nitrogen. The basal diet contained 2% nitrogen, while the supplement to the basal diet gave nitrogen percentages of about 2.8%. In the growth trial, eighty rabbits were randomly located in a 2 x 4 factorial arrangement of dietary treatments. Although the additional nitrogen sources did not affect daily intake of dry matter (DM), the average daily gains were significantly increased($P < .01$). There was a tendency for average daily gain to increase ($P < .05$) when high-starch diets were fed. No interaction between starch level and nitrogen sources was recorded for all independent variables measured. With the low starch diet, ADG with the basal + biuret diet was significantly greater ($P < .05$) than with the basal + urea diet. In the digestion trial, ninety six rabbits were used in a 2 x 2 x 4 factorial arrangement with two factors of cecotrophy, two levels of starch and four different sources of nitrogen. Dry matter and acid detergent fiber (ADF) digestibilities were less ($P < .01$) with the low-starch diets. Although nitrogen sources did not affect apparent digestion coefficients of DM and ADF, it did for both nitrogen digestibility and retention ($P < .01$). Allowing rabbits to practice cecotrophy increased nitrogen utilization. Results of both studies suggest that rabbits can utilize urea and biuret; under some conditions (eg. high fiber diet), biuret may be utilized more efficiently than urea. Dietary carbohydrate source does not appear to have a major effect on efficiency of NPN utilization in rabbits.

INTRODUCTION

Urea is the most commonly used NPN source in animal feeding. Since urease activities are present in the alimentary tract (Knutson et al., 1977; Crociani et al., 1984), rabbits can utilize urea to some extent as a source of supplementary nitrogen (Houpt, 1963) . One of the problems associated with the use of urea in rabbits is the low efficiency of urea-N utilization in the alimentary tract. Urea is broken down very rapidly to ammonia by urease activities (Broome, 1968; King, 1971), exceeding the capacity for bacterial protein synthesis (Jackson, 1974). Bloomfield et al. (1960) and Bartley and Deyoe (1977) noted that the rate of hydrolysis of urea in the rumen was about four times that of bacterial nitrogen fixation. In order to get a maximum ability of microorganisms to utilize ammonia, supplementation with readily fermentable carbohydrates is needed (Coombe et al.,1960; Coombe and Tribe, 1962; Slatter and Roffler, 1977), as suitable sources of carbon skeleton and the production of fatty acids as sources of energy (Broome, 1968). Belasco (1956) and Bartley and Deyoe(1977) found that urea utilization by microorganisms in vitro was dependent on the amount and type of carbohydrates used. They also noted that the extent of urea utilization was greater with starch than with other types of carbohydrates. Therefore, the addition of readily fermentable carbohydrate, such as starch, to increase the utilization of urea is another area of rabbit feeding which should be considered. Houpt (1966) noted that the quantity of bacterial protein synthezised using this source of nitrogen might be significant in the nitrogen metabolism of the rabbit. However, due to the location of the cecum and colon, near the end of the digestive tract, most of the bacterial protein is of little value to the animal, unless cecotrophy is permitted (Thacker and Brandt, 1955 ; Myers, 1955 ; King, 1971). Previous studies showed that feeding urea in general did not have any significant effect on the growth rate of rabbits. This may be due to the rapid rate of hydrolisis of urea to ammonia, exceeding the rate at which ammonia could be used for bacterial protein synthesis in the cecum. Biuret, on the other hand, is hydrolysed much more slowly than urea, and may be used more effectively than urea (Schwartz,1967; Jackson, 1974). The objectives of this study were to determine the effects of addition of urea or biuret to diets either high or low in starch content on growth, feed efficiency and nitrogen balance.

MATERIALS AND METHODS

A feeding trial (trial 1) and a digestion-N balance trial (trial 2) were conducted to evaluate the effect of dietary starch level on utilization of non-protein nitrogen (NPN) by New Zealand White rabbits. Trial 1 was initiated in February 23 and completed in April 23,1987, and trial 2 was began in February 15 and ended in May 21, 1987. Housing, management and chemical analyses were the same as described earlier, unless specified otherwise. Eight dietary treatments were used. Diet 1 (high-starch diet) was based primarily on ground corn, corn cobs, wheat mill run and alfalfa meal, with a nitrogen level of 2%. Corn was used as a source of starch (Table 23). Diets 2, 3 and 4 had similar constituents to diet 1 except the additional soybean meal (SBM), urea, or biuret was added to increase the nitrogen level to about 2.8%. Diet 5 (low-starch diet) was based on alfalfa meal, ground oats, wheat mill run and corn cobs, and contained the same level of nitrogen as diet 1. Diet 6,7 and 8 were the low-starch diet supplemented with either SBM, urea or biuret respectively. All diets were pelleted (4.5 mm x 1 cm).

Performance Trial. A total of eighty weanling rabbits from 4-5 weeks of age and averaging 975 g were randomly allotted to eight dietary treatments. This trial was conducted for 28 days. The animals were weighed at weekly intervals while daily feed consumption was recorded by the weight-back technique. Various parameters were determined as described previously.

Digestion-N balance Trial. This trial consisted of two periods, each involving a 7-day adaptation period followed by a 7-day collection period. Ninety six rabbits between 1.8 - 2 kg of live weight were used and housed individually in cages allowing the separation of feces and urine. Rabbits were randomly assigned to a completely random design with six replicates of a 2 x 2 x 4 factorial arrangement of treatments consisting of two different levels of starch, four different sources of nitrogen and two factors of cecotrophy. All parameters were subjected to analysis of variance using the general linear model procedure (SAS, 1985). Any significant differences between means were compared by using least significant difference (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Chemical composition of the mixed diets is shown in table 22. The basal diets had N contents of 1.94 and 1.96, corresponding to crude protein levels of 12.21 and 12.13%. Additional soybean meal (SBM), urea and biuret added to the basal diet increased the nitrogen contents from 2.7 to 3% or equal to 17.9 to 18.7% crude protein (CP). Acid detergent fiber (ADF) content in the high-starch diet ranged from 11.13 to 12.68% and from 19.79 to 21.53% in the low-starch diet. Cummings (1981) stated that fiber content in a diet is often closely associated (inversely proportional) with starch level in that particular diet. de Blas et al. (1984, 1986) found that there was high correlation (r = .90) between ADF and digestible energy in rabbit diets.

Feeding trial . The growth rates of the rabbits fed the basal diets were remarkably high, considering that the diets contained only about 12% crude protein. As a result, the response to supplementary nitrogen was small. Overall results for the feeding trial and the significant differences among treatments and their interactions are listed in table 23 and 24. Except for the addition of urea to the low starch diet, average daily gain was improved ($P < .01$) by additional nitrogen with both starch levels. The tendency for this effect appeared to be higher (P <

TABLE 22. DIET AND CHEMICAL COMPOSITION

I t e m	High starch				Low Starch			
	Basal	SBM	Urea	Biuret	Basal	SBM	Urea	Biuret
Ground corn	37.25	22.25	35.35	25.90	-	-	-	-
Corn cobs	20.00	20.00	20.00	20.00	10.00	10.00	10.00	10.00
Molasses	4.00	4.00	4.00	4.00	6.00	6.00	6.00	6.00
Mineral salt*	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin mixture ***	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Wheat mill run	17.00	17.00	17.00	17.00	12.25	12.25	12.25	12.25
Alfalfa meal	10.00	10.00	10.00	10.00	45.00	45.00	45.00	45.00
Vegetable oil	2.00	2.00	2.00	2.00	5.00	5.00	5.00	5.00
Soybean meal	8.00	23.00	8.00	8.00	-	15.00	-	-
Ground oats	-	-	-	-	20.00	5.00	18.10	17.80
Urea	-	-	1.90	-	-	-	1.90	-
Biuret	-	-	-	2.20	-	-	-	2.20
Chemical composition (%);								
Dry matter	88.84	89.06	88.43	88.32	88.94	89.61	89.78	90.09
Nitrogen	1.96	2.86	2.96	2.92	1.94	2.66	2.67	2.72
Crude protein	12.21	17.81	18.50	18.25	12.13	16.70	16.69	17.00
Acid detergent fiber	12.68	11.99	11.87	11.13	19.99	19.76	21.53	20.18
DE, kcal/kg ****	2911	2909	2839	2860	2643	2766	2587	2579

* Appendix 1.

** Dicalcium phosphate cantains P not less tahn 18.5% and Ca between 19 - 26%.

*** Vitamin mixture #1 - #75; manufactured by INMAN and Co., Inc. (Appendix 2.).

**** Calculated values using US-Canadian, Table of Feed Composition (1982) data.

.01) with rabbits fed the biuret-containing diets compared with those fed the urea-containing diets (36.25 g vs 41.35 g), indicating that biuret is used more efficiently than urea. Biuret is hydrolyzed to ammonia slower than is urea (Bartley and Deyoe, 1977). Slow release action of the biuret is due to its immunity from degradation by all but a few microorganisms (Jackson, 1974). Therefore ammonia from biuret, which can be used for protein synthesis in the gastrointestinal tract, is available to the bacteria for a longer period of time in comparison with urea. Additional urea increased average daily gain (ADG) for rabbits fed the high-starch diet, but not for those fed the low-starch diet. These results support the hypothesis that additional starch as an energy source in urea-containing diets can improve urea utilization (Jackson, 1974). A significant difference was observed ($P < .05$) for ADG of rabbits fed different levels of starch. Rabbits fed the high starch diet showed higher ADG than those fed the low starch diets(40.57 g vs 37.64g). Feed conversion ratio (FCR) differed ($P < .05$) between starch levels. This finding is in agreement with de Blas et al. (1986) who found that FCR increased with increasing fiber content of the diet. Since both ADG increased and FCR decreased for rabbits fed the high-starch diets, rabbits fed the high starch diets utilized the feed more efficiently than those fed the low starch diets. The daily intake of dry

TABLE 23. EFFECT OF STARCH LEVEL AND NITROGEN SOURCE ON RABBIT PERFORMANCE

Item	High Starch				Low Starch			
	Basal	SBM	Urea	Biuret	Basal	SBM	Urea	Biuret
No. of animals	10	10	10	10	10	10	10	10
Initial weight(g)	1072.1	1082.7	1079.9	1086.9	1092.8	1085.0	1073.3	1071.5
Final weight(g)	2129.0	2285.1	2206.3	2242.3	2113.3	2217.8	1978.6	2229.5
Mean daily gain(g)	37.7b	42.9d	40.2c	41.3c	36.4b	40.5c	32.3a	41.4c
Feed efficiency *	3.3a	2.9a	3.0a	3.3a	3.8b	3.3a	4.1c	3.4a
Mean daily intake(g);								
Dry matter	123.0a	122.0a	119.8a	136.2b	141.3c	137.3b	138.8bc	140.0c
Nitrogen	2.7a	3.9bc	3.7b	4.5c	3.0a	4.0c	4.1c	4.2c
Acid detergent fiber	17.3b	16.2ab	15.1a	17.2a	31.2c	30.0c	31.5c	31.0c

* Feed efficiency was the ratio of average daily intake to average daily gain.

abcd, Means in the same rows having different superscripts are significantly different ($P < .05$).

TABLE 24. SUMMARY OF STATISTICALLY DIFFERENCES OF PERFORMANCE TRAITS OF RABBITS FED NON-PROTEIN NITROGEN-CONTAINING DIETS WITH DIFFERENT LEVELS OF STARCH

Item	ADG	FCR	Intake		
			OM	N	ADF
Starch	$P < .05$	$P < .05$	$P < .01$	NS	$P < .01$
Nitrogen sources	$P < .01$	$P < .01$	NS	$P < .01$	NS
Starch * N-sources	NS	NS	NS	NS	NS

NS, not significant.

matter was higher (139.37 vs 125.24 g) for animals fed the low-starch diets. Cheeke and Patton (1980) stated that diets low in starch generally are high in fiber, and have a low energetic concentration (de Blas et al.,1986). As mentioned earlier, the increase of feed intake of rabbits fed high fiber or low starch diets was associated with meeting the daily energy requirement (Spreadbury and Davidson, 1978; Evans, 1981). Nitrogen intake increased statistically ($P < .01$) as additional nitrogen from SBM, urea and biuret was added. Overall, growth response was greater for rabbits fed the SBM-containing diets on both levels of starch. Biuret gave a significantly better ($P < .05$) response than urea with the low starch diet. The ADG was significantly reduced ($P < .05$) when urea was added to the low starch basal diet.

Digestion trial. Apparent digestibilities of the various diets are in tables 25,26,27 and significant differences among them are presented in table 28. Interaction among starch levels, nitrogen sources and cecotrophy was not detected (table 28) for DM digestibilities. Apparent digestibility of DM was higher ($P < .01$) for the high-starch diets as compared with the low-starch diet (57 vs 54). The results in the present study are in agreement with those obtained by other workers (Hoover and Heitmann, 1972; Spreadbury and Davidson, 1978; Evans, 1981; de Blas et al. 1986) who have reported increased DM di-

TABLE 25. EFFECT OF STARCH LEVEL AND NITROGEN SOURCES ON DRY MATTER (DM) OIGESTIBILITY (%)

Nitrogen sources		Starch level		Means **
		High	Low	
Basal	(+)*	58.75 byz	54.97 axy	56.86
	(-)	54.47 bx	51.70 ax	53.09
	Means	56.61 b	53.34 a	
SBM	(+)	60.44 b	56.80 ayz	58.62
	(-)	52.20 x	54.07 x	53.14
	Means	56.32 a	55.44 a	
Urea	(+)	60.30 bz	54.01 ax	57.16
	(-)	56.29 bxyz	51.24 ax	53.77
	Means	58.30 b	52.63 a	
Biuret	(+)	59.77 yz	58.55 z	59.16
	(-)	58.01 byz	51.07 ax	54.54
	Means	58.89 b	54.81 a	

* (+)/(-), with or without cecotrophy.

** significant difference between with and without cecotrophy (P < .01).

ab , means in the same rows having different superscripts are significantly different (P < .01).

xyz, means in the same colomns having different superscripts are significantly different (P < .01).

gestibility with low-fiber as compared to high-fiber diets. Egum et al.(1985) reported that transit time decreased as fiber level increased, resulting in a shortened time for micro-organisms to digest some nutrients. Consequently, low digestibilities of some nutrients will be observed. No differences in DM digestibilities were detected among the diets containing different sources of nitrogen. Digestibility of DM decreased ($P < .01$) when cecotrophy was prevented (table 25), in agreement with a previous study (Robinson et al. 1985). This indicates that feed is more efficiently utilized by rabbits when cecotrophy is permitted than when the animals are prevented from consuming the cecotropes. Nitrogen digestibility was unaffected by starch levels(table 26). There were also no interactions observed among starch levels, nitrogen sources and cecotrophy (table 28) for nitrogen digestibility. Digestibility of nitrogen (crude protein) was affected ($P < .01$) by nitrogen sources. The results in table 26 show that nitrogen digestibilities were higher for the high-starch diets. Shah et al.(1982), Miratu and Blair (1984) and Howard et al.(1986) indicated that fiber level affected protein utilization. They also noted that the negative effect increased as the level of fiber consumed increased. The same finding also was reported by de Blas et al. (1986), that digestibilities of crude protein decreased linearly as the ADF content of the diet in-

TABLE 26. EFFECT OF STARCH LEVEL AND NITROGEN SOURCES ON NITROGEN DIGESTIBILITY (%)

Nitrogen sources		Starch level		Means **
		High	Low	
Basal	(+) *	66.68 ab	65.10 b	65.89
	(-)	57.78 a	52.16 a	54.97
	Means	62.23 x	58.63 x	
SBM	(+)	72.87 bc	69.85 bc	71.36
	(-)	59.11 a	55.08 a	57.09
	Means	65.99 xy	62.47 xy	
Urea	(+)	73.19 bc	72.48 c	72.84
	(-)	59.23 a	63.84 b	61.35
	Means	66.21 xy	67.98 y	
Biuret	(+)	74.40 c	73.94 c	74.17
	(-)	66.54 ab	59.53 ab	63.04
	Means	70.47 yz	66.74 yz	

* (+)/(-), with or without cecotrophy.

** significant difference between with and without cecotrophy ($P < .01$).

abc, means in the same colomns having different superscripts are significantly different ($P < .01$)

xyz, means in the same colomns having different superscripts are significantly different ($P < .01$).

creased (r = -0.86). Low nitrogen digestibility on the high fiber diets indicates that fiber might have detrimental effects on nitrogen utilization. Shah et al.(1982) noted that fiber might increase the sloughing of intestinal mucosal cells and lower the intestinal ability to absorb some amino acids. Increased intestinal transit time associated with fiber-containing diets could also be a factor. High fiber in the diet results in less time for micro-organisms to digest and absorb some nutrients including dietary nitrogen (Burkitt et al.,1972; Howard et al.,1986). Some fiber may also coat the absorptive lining of the gut, thereby interfering the absorption of end products of protein digestion (Formann and Schneeman, 1980; Sigleo et al, 1984). Adding nitrogen or increasing crude protein level of the basal diets of either the high or low-starch diets resulted in increased apparent nitrogen digestion coefficients. The nitrogen digestibilities were highly affected by cecotrophy. Allowing rabbits to reingest the cecotropes increased ($P < .01$) nitrogen digestibility. Again, this indicates that cecum fermentation along with practicing cecotrophy plays an important role in increasing biological values of some nutrients in rabbits (Barnes, 1962; Yoshida et al., 1968; Kennedy and Hershberger, 1974; Emaldi et al.,1979; Robinson et al., 1985). Coefficients of apparent ADF digestibility are presented in table 27. Digestibility of ADF was not af-

TABLE 27. EFFECT OF STARCH LEVEL AND NITROGEN SOURCES ON ACID DETERGENT FIBER DIGESTIBILITY (%)

Nitrogen source		Starch level High	Starch level Low	Means**
Basal	(+)*	12.45 b	5.63 a	9.04
	(-)	8.05 b	5.17 a	6.62
	Means	10.26 b	4.40 a	
SBM	(+)	15.95 b	6.53 a	11.24
	(-)	17.08 b	2.00 a	9.54
	Means	16.52 b	4.26 a	
Urea	(+)	14.40 b	9.87 a	12.27
	(-)	15.12 b	5.93 a	10.53
	Means	14.76 b	7.46 a	
Biuret	(+)	18.37 b	2.83 a	10.60
	(-)	13.52 b	2.51 a	8.02
	Means	15.84 b	2.69 a	

* (+)/(-), with or without cecotrophy.

** Differences not significant.

ab, Means in the same rows having different superscripts are significantly different ($P < .01$).

TABLE 28. SUMMARY OF STATISTICAL DIFFERENCES OF NUTRIENT DIGESTIBILITY OF RABBITS FED NON-PROTEIN NITROGEN-CONTAINING DIETS WITH DIFFERENT LEVELS OF STARCH

Item	OM	N	ADF
Starch	P < .01	NS	P < .01
Nitrogen sources	NS	P < .01	NS
Cecotrophy	P < .01	P < .01	NS
Starch*Nitrogen sources	NS	NS	NS
Starch*cecotrophy	NS	NS	NS
N-sources*cecotrophy	NS	NS	NS
Starch*cecotrophy*N-sources	NS	NS	NS

NS, not significant.

fected by nitrogen source, cecotrophy or any interaction among them. Only starch levels influenced ($P < .01$) ADF digestibility, and it was higher for the high-starch diet (14.3 vs 5.0). Using different levels of ADF, ranging from 9.8 to 32.7% , de Blas, et al. (1986) found that ADF digestibility was decreased as ADF content in the diet increased. Although a similar response was observed in the present study, the coefficients of apparent digestibility reported here are lower than the finding of de Blas et al. (1986). No interactions were observed among starch levels, nitrogen sources and cecotrophy for nitrogen retention (table 29). The low-starch diet decreased ($P < .01$) nitrogen retention (N-ret)of rabbits fed either basal, SBM, urea or biuret-containing diets (table 29). Overall values, N-ret for rabbits fed high-starch diet was higher as much as 0.407 unit (1.324 g/d vs 0.917 g/d). This indicates that rabbits fed the high-starch diet utilize the ration more efficiently in comparison to those fed the low-starch diet, resulting in a better response in terms of ADG (40.57 g vs 37.6 g). The higher ADG of rabbits fed the high-starch diet was not related to daily intake. Rather, it was probably due to the higher ability to utilize nitrogen. Regardless of starch levels, additional SBM, urea or biuret resulted in higher ($P < .01$) N-ret than for the basal diet. Although there were no significant differences among SBM, urea and biuret-contain-

TABLE 29. NITROGEN BALANCE OF RABBITS FED DIFFERENT LEVELS OF STARCH AND NITROGEN SOURCES.

Nitrogen	N-sources		Level of starch: High	Level of starch: Low	Means
Intake (g/d)	Basal	(+)*	2.81 p	3.12 p	3.00 **
		(-)	3.15 p	3.01 p	3.80
		Means	2.98 x	3.06 x	
	SBM	(+)	5.00 q	3.91 pq	4.46
		(-)	4.59 q	4.80 q	4.58
		Means	4.79 y	4.25 y	
	Urea	(+)	4.74 q	3.91 pq	4.32
		(-)	4.90 q	4.60 q	4.75
		Means	4.80 y	4.25 y	
	Biuret	(+)	4.21 q	4.16 q	4.18
		(-)	5.17 q	4.35 q	4.76
		Means	4.70 y	4.25 y	
Feces (g/d)	Basal	(+)	0.99 p	1.33 pq	1.15 **
		(-)	1.33 pq	2.22 q	1.76
		Means	1.16 x	1.78 y	
	SBM	(+)	1.37 pq	1.33 pq	1.35
		(-)	1.83 q	2.22 q	2.02
		Means	1.80 y	1.78 y	
	Urea	(+)	1.29 p	1.07 p	1.15
		(-)	1.73 q	1.69 q	1.70
		Means	1.51 y	1.38 xy	
	Biuret	(+)	1.07 p	0.91 p	0.98
		(-)	1.73 q	1.69 q	1.70
		Means	1.40 xy	1.30 x	
Urine (g/d)	Basal	(+)	0.99	1.28	1.13 NS
		(-)	0.79	1.03	0.92
		Means	0.89 x	1.15 x	
	SBM	(+)	2.03	2.05	2.04
		(-)	1.53	2.28	1.90
		Means	1.78 y	2.16 y	
	Urea	(+)	1.74	1.79	1.76
		(-)	1.91	2.06	1.98
		Means	1.83 y	1.93 y	
	Biuret	(+)	1.88	1.89	1.88
		(-)	1.96	1.80	1.77
		Means	1.83 y	1.84 y	
Retention (g/d)	Basal	(+)	0.83 bp	0.76 apq	0.80 **
		(-)	1.03 bp	0.54 ap	0.79
		Means	0.93 bx	0.65 ax	
	SBM	(+)	1.60 bq	1.06 aq	1.33
		(-)	1.23 bpq	0.45 ap	0.84
		Means	1.41 by	0.75 ax	
	Urea	(+)	1.72 bq	1.05 aq	1.38
		(-)	1.26 bpq	0.85 apq	1.05
		Means	1.48 by	0.94 axy	
	Biuret	(+)	1.45 aq	1.56 aq	1.51
		(-)	1.48 bq	1.06 aq	1.27
		Means	1.46 y	1.31 y	
Retained as % consumed	Basal	(+)	29.65 bpq	22.94 aq	26.30 **
		(-)	32.16 bq	17.17 aq	24.66
		Means	30.90 b	20.06 a	
	SBM	(+)	32.29 bq	24.46 aq	28.37
		(-)	27.13 bp	9.09 ap	18.11
		Means	29.71 b	16.41 a	
	Urea	(+)	34.99 bq	27.65 aqr	31.32
		(-)	29.94 b	15.54 aq	22.22
		Means	29.94 b	23.90 a	
	Biuret	(+)	34.25 aq	34.45 ar	34.35
		(-)	28.58 apq	24.33 aq	26.45
		Means	31.42 a	29.39 a	
Retained as % absorbed	Basal	(+)	45.80 bqr	37.25 ar	41.42 **
		(-)	56.59 br	34.38 aqr	45.48
		Means	51.08 by	35.82 ay	
	SBM	(+)	44.08 bq	34.30 aqr	39.18
		(-)	44.56 bq	16.48 ap	30.52
		Means	44.32 bx	25.37 ax	
	Urea	(+)	49.71 br	36.97 arq	43.34
		(-)	39.75 bp	29.21 aq	34.48
		Means	44.73 bx	33.09 ay	
	Biuret	(+)	46.18 ar	48.00 ar	47.08
		(-)	43.02 bpq	39.85 ar	41.44
		Means	44.60 ax	43.93 az	

* ((+)/(-), with or without cecotrophy.

** Significant difference between with and without cecotrophy ($P < .01$).

ab, Means in the same rows having different superscripts are significantly different ($P < .01$).

xyz, Means in the same columns having different superscripts are significantly different ($P < .01$).

pqr, Means in the same columns having different superscripts are significantly different ($P < .01$).

NS, not significant between with and without cecotrophy.

TABLE 30. SUMMARY OF STATISTICAL DIFFERENCES OT NITROGEN METABOLISM OF RABBITS FEO NON-PROTEIN NITROGEN-CONTAINING DIETS WITH OIFFERENT LEVEL OF STARCH

I T E M	N-intake	Fecal-N	Urinary-N	N-retention	N retained as % consumed	N retained as % absorbed
Starch	P NS	NS	NS	P .01	P .01	P .01
N-sources	P .01	P .01	P .01	P .01	NS	P .05
Cecotrophy	P .01	P .01	NS	P .01	P .01	P .01
Starch*N-sources	NS	NS	NS	NS	NS	NS
Starch*cecotrophy	NS	NS	NS	NS	NS	NS
N sources*cecotrophy	NS	NS	NS	NS	NS	NS
Strach*N sources*cecotrophy	NS	NS	NS	NS	NS	NS

NS, not significant.

ing diet on N-ret, the values tended to be the highest on diets with added biuret, followed by the urea and the SBM-containing diets. N-retention on the high fiber (low starch) diets was greatest with the biuret treatment. This indicates that biuret may be a better NPN source than urea for rabbit diets with low fermentation potential, as is true with ruminants. The slower release of ammonia from biuret provides nitrogen to the microbes for a longer period than is the case with urea. In ruminants, a fairly long adaptation period is required for development of optimal utilization of biuret as a nitrogen source (Oltjen et al. 1969). This aspect should be examined in rabbits. Statistically different results were found for N-ret between cecotrophy permitted and prevented. Again, N-ret of rabbits with cecotrophy prevented was lower ($P \leq .01$) compared with cecotrophy permitted (0.987 vs 1.253).

Results of these studies suggest that to some degree non-protein nitrogen (urea and biuret) along with additional starch can improve rabbits performance. Additional research needs to be conducted to determine the level of starch that could be included in order to achieve optimal levels of rabbit performance.

CHAPTER 6

EFFECTS OF DIETARY ZEOLITE ON UREA UTILIZATION BY WEANLING RABBITS

Mathius, I-W., P.R.Cheeke, K.L. Robinson and N.M. Patton

Rabbit Research Center
Dept. of Anim. Sci., OSU. Corvallis, OR. 97331.

CHAPTER 6

EFFECT OF DIETARY ZEOLITE ON UREA UTILIZATION BY WEANLING RABBITS

Mathius, I-W., P.R. Cheeke, K.L. Robinson and N.M. Patton

SUMMARY

A 28-day feeding trial was conducted to determine whether zeolite, a natural crystalline, hydrated alumino-silicate of alkali and alkaline earth cations, can improve urea utilization when fed to rabbits. Sixty New Zealand White weanling rabbits (average weight of 979 g) were randomly assigned to a 2 x 3 factorial experiment with two levels of zeolite (0% and 5%) and three sources of nitrogen (basal, soybean meal and urea). The average daily gain (ADG), average daily intake (ADI) and feed conversion ratio (FCR) were not affected by additional zeolite. Nitrogen source influenced ($P < .01$) ADG, ADI and FCR of rabbits. Rabbits fed SBM and urea-containing diets grew faster ($P < .01$) than those fed the basal diet. A highly significant response ($P < .01$) to urea supplementation occurred, with ADG almost doubled compared to those fed the basal diet. Zeolite does not appear to be effective in improving urea utilization in rabbits.

INTRODUCTION

The utilization of urea by rabbits involves cecal fermentation and synthesis of bacterial protein (Robinson et al., 1985). The efficiency of urea utilization is influenced by the extent to which ammonia is absorbed and excreted in the urine. The urease activity in the rabbit stomach and intestine is high (Houpt, 1963; Knutson et al., 1977; Crociani et al., 1984), so that dietary urea is hydrolyzed before reaching the site of fermentation. A portion of the absorbed ammonia can be transferred to the cecal contents by simple diffusion (Houpt and Houpt, 1981) from the blood (Forsythe and Parker, 1985). Zeolites are natural clay minerals with ion-exchange properties, and can bind ammonia (Mumpton and Fishman, 1977; Mumpton, 1978). Therefore, the inclusion of zeolite in the feed when urea is fed may result in the binding of ammonia released from urea hydrolysis, and its subsequent slow release in the cecum. This would improve the efficiency of conversion of urea nitrogen into bacterial protein. The objective of this experiment was to determine if the addition of zeolite to urea-containing diets improves the growth of weanling rabbits.

MATERIALS AND METHODS

Sixty New Zealand White weanling rabbits, 4 - 5 weeks of age and an average weight of 979 g, were randomly assigned to six dietary treatments. Diets and their chemical composition are presented in table 32. Diets used in this experiment were similar to the high-starch diet used in the previous experiment with slight modifications. The crude protein (CP) level of the basal diet (1) was 9.3%, while diet 2 and 3 consisted of the addition of soybean meal (SBM) (diet 2) and a mixture of SBM and urea (diet 3). Diets 4,5 and 6 were the same as diet 1,2 and 3 except for supplementation with 5% of zeolite. All diets were pelleted. Animals were weighed weekly. Feed offered, spillage and feed remaining were recorded during the experiment, which lasted 28 days. Performance traits measured included average daily feed consumption, average daily gain and feed efficiency ratio. Results were subjected to a one-way analysis of variance (SAS, 1985) using the general linear model. Means between treatments were compared by using Least Signifficant Difference (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Chemical analyses of the diets used in this study are shown in table 31. The performance of rabbits fed the different dietary treatments is given in table 32. No interaction among zeolite and nitrogen source was observed for all variables measured. Additional zeolite did not affect mean daily intake of DM, nitrogen and ADF, and overall values were 121.2 g, 3.3 g and 14.6 g respectively. Although DM and ADF intake were not significantly different between diets with and without zeolite, there was a tendency that rabbits fed the diet supplemented with zeolite had increased DM and ADF intake, being 6.4 g for DM and 0.5 g for ADF over those fed the diet without additional zeolite. Feed efficiency, calculated using feed to gain ratio, showed that rabbits fed diets with no zeolite were more efficient than those fed diets with added zeolite (4.0 g feed/g gain vs 4.3 g feed/g gain). However, these were not significantly different. Similarly, there was no significant effect ($P < .05$) of zeolite on average daily gain. These results are in agreement with previous values which have been reported elsewhere (Nakaue and Koelliker, 1981; Pond and Yen, 1982; Grobner et al.,1983 and Dion and Carew Jr, 1984). Dion and Carew Jr. (1983) reported a similar response in ADG and feed conversion ratio (FCR) in chicks with levels of 5 to 10% added clinoptilolite. Using pullets fed different levels of cli

TABLE 31. DIET AND CHEMICAL COMPOSITION (%) OF ZEOLITE-CONTAINING DIETS

I t e m	Without Zeolite			With Zeolite		
	Basal	SBM	Urea	Basal	SBM	Urea
Ground corn	42.25	22.25	35.35	42.25	22.25	35.35
Corn cobs	23.00	20.00	20.00	23.00	20.00	20.00
Molasses	4.00	4.00	4.00	4.00	4.00	4.00
Wheat mill run	17.00	17.00	17.00	17.00	17.00	17.00
Alfalfa meal	10.00	10.00	10.00	10.00	10.00	10.00
Trace mineral salt *	0.50	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate **	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin mixture ***	0.25	0.25	0.25	0.25	0.25	0.25
Vegetable oil	2.00	2.00	2.00	2.00	2.00	2.00
Soybean meal	-	23.00	8.00	-	23.00	8.00
U r e a	-	-	1.90	-	-	1.90
Zeolite (g/100 g diet)	-	-	-	5.00	5.00	5.00
Chemical composition(%);						
Dry matter	88.70	88.90	88.50	89.00	89.20	87.80
Nitrogen	1.49	2.81	2.80	1.42	2.77	2.73
Crude protein	9.30	17.60	17.50	8.90	17.30	17.10
Acid detergent fiber	12.41	12.04	11.91	12.01	11.87	11.83

* Appendix 1.
** Dicalcium phosphate, contains P not less than 18.5%, Ca. between 19 - 26%.
*** Vitamin mix #1 -#75; manufactured by INMAN Co., Inc. (Appendix 2).
**** Calculated values using US-Canadian, Tables of Feed Composition data (1982).

noptilolite, ranging from 0 to 10%, Nakaue and Koelliker (1981) found no significant effect of zeolite on body weight gain. No differences in growth rate, mean daily intake and feed/gain ratio of swine due to use of clinoptilolite were recorded by Pond and Yen (1982) and Shurson et al.(1984). These effects are similar to those reported by Grobner et al.(1983) with rabbits fed 5% bentonite.

Mean daily gain, feed intake and utilization (feed/ gain ratio) were altered ($P < .01$) by nitrogen sources. Rabbits fed either the SBM or urea-containing diets had a significantly greater ($P < .01$) ADG than those fed the basal diets. An excellent ADG in excess of 40 g was obtained with the SBM-containing diet, similar to results reported by Sanchez et al.(1985). The overall ADG among rabbits fed different sources of nitrogen were 18.1, 41.2 and 33.8 g/d for basal, SBM and urea-containing diets respectively. Rabbits fed the urea-containing diet had an ADG of almost twice as much as those fed the basal diet.A part of the urea-containing diet consisted of SBM, of which might be partly responsible for the good response of the rabbits fed the urea-containing diets. The results obtained in the current study are in contrast with those obtained by other workers who reported no effect (Cheeke, 1978) or decreased ADG (King, 1971; Fonolla et al.,1977). This stresses the importance of the addition of urea to a low protein basal diet if maximum utilization of the basal

TABLE 32. EFFECT OF ZEOLITE AND NITROGEN SOURCES ON RABBIT PERFORMANCE

Item	without zeolite			with zeolite		
	Basal	SBM	Urea	Basal	SBM	Urea
No. of animals	10	10	10	10	10	10
Initial weight (g)	983.9	975.2	965.4	979.5	984.9	976.7
Final weight(g)	1502.6	2144.4	1918.7	1476.7	2121.3	1915.3
Daily gain (g)*	18.5 a	41.8 c	34.1 b	17.8 a	40.6 c	33.5 b

* daily gain was the ratio of average individual gain to the number of days on trial.

Means in the same row having different superscripts are significantly different ($P < .01$).

TABLE 33. EFFECT OF ZEOLITE AND NITROGEN SOURCES ON FEED INTAKE

Daily intake	without zeolite			with zeolite		
	Basal	SBM	Urea	Basal	SBM	Urea
Dry matter	94.4 a	140.7 cd	116.2 b	97.9 a	144.9 d	134.8c
Nitrogen	1.7 a	4.4 c	3.8 b	1.9 a	4.1 c	4.0 b
Acid detergent fiber	11.3 a	16.9 c	13.8 ab	12.2 a	17.2 c	15.9 bc
Feed efficiency *	5.6 b	3.4 a	3.4 a	5.2 b	3.6 a	3.7 a

* Feed efficiency was the ratio of average individual gain to the number of days on trial ($P < .01$).

diet is the main aim of the feeding system. Additional SBM and urea showed statistically increased daily intake of DM by 46.7 and 28.5 g over the basal diet (table 33). Feed utilization was more efficient ($P < .01$) on rabbits fed the SBM-containing diet, followed by those fed the urea-containing diet.

In conclusion, the results indicated no response to zeolite in the diet in terms of body weight gain and feed conversion ratio. The improvements in daily weight gain, intake and FCR observed for rabbits fed a urea-containing diet suggested that urea can be used more efficiently by the rabbit if urea is added to a diet with low level of crude protein.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

Most feeding standards have relied upon crude protein or digestible crude protein. The presence of urease activity in the digestive tract of rabbit offers a potential utilization of urea as a nitrogen source in rabbit nutrition. Therefore, it is feasible in rabbit feeding practice to partially replace an expensive natural protein with cheaper non-protein nitrogen supplements, such as urea.

Based on data found in these studies, several conclusions and recommendations for further study can be made;

(i) inclusion of urea as a supplementary nitrogen source with a low-protein diet (13% CP) for does, as far as number of market animals and feed conversion concerned,has no advantage. Does fed a positive control diet resulted in a superior performance either for does or for their offspring

(ii) in both fryer and adult rabbits, cecotrophy is necessary for utilization of urea as a nitrogen source. Weanling rabbits may be more susceptible than older animals to urea toxicity. The toxic levels of dietary urea and the effect of age on urea toxicity in rabbits should be determined.

(iii) it was found that the efficiency of urea utilization by rabbits is not markedly influenced by the level of fiber. Using urea with different sources of fiber should be further examined.

(iv) inclusion of starch sources in urea-containing diets improves urea utilization. Higher growth response of rabbits fed biuret-containing diets compared to those fed the urea-containing diets suggests that biuret is utilized more efficiently than urea, especially on high fiber diets.

(v) dietary zeolite does not appear to be effective in improving urea utilization in rabbit diets. Replacement of a part of soybean meal with urea results good response, suggesting that rabbits can utilize urea effectively as a partial replacement for dietary protein.

Further study is indicated, to determine the optimal conditions for supplementation of rabbits diets with urea and biuret. The apparently good utilization of biuret in a high fiber diet warrants further investigation. The toxicity of urea and biuret to rabbits, and the effect of age on toxicity, should be examined further.

REFERENCES

Adams, C. E. 1983. Reproductive performance of rabbits on a low protein diet. Lab. Anim. 17:340-344.

Adamson,I. and H. Fisher. 1973. Amino acid requirement of he growing rabbit: An estimate of quantitative needs. . Nutr. 103: 1306-1310.

Ayoade, J.A., T.P.E. Makhambera and M. Kayange. 1985. Studies the nutrition of rabbits in Malawi. I. A preliminery study on the chemical composition of some central Malawi plants eaten by rabbits. J. Appl. Rabbit Res. 8:81-82.

A.O.A.C. 1980. Official method of analysis. Thirteen edition Association of Official Analytical Chemists.Washington,DC.

Barnes, R. H. 1962. Nutrition implications of coprophagy. Nutr. Rev., 20; 289-291.

Bartley, E.E. and C.W. Deyoe. 1977. Reducing the rate of ammonia release by the use of alternative non protein nitrogen sources. In. Harsign,W. and D.Lewis (ed.). Recent advances in animal Nutrition. Butterworths. pp. 50-65.

Bloomfield, R.A., G.B. Garner and M.E.Muhrer. 1960. Kinetics of urea metabolism in Sheep. J. Anim. Sci. 19: 1248 (Abstr).

Broome, A.W. 1968. The use of non-protein nitrogen in animal feeds. In. Swan, H. and D.Lewis (Ed.). Proc. Second nutrition conference for feed manufacture. J & A. Hcurchill Ltd. pp.92-113.

Burkitt, D. P., A.R.P. Walker, N.S. Painter. 1972. Effect of dietary fibre on stools and transit times and its role n the causation of disease. Lancet 2: 1408-1412.

Carregal, R.D. 1978. Crude protein in rations for growing rabbits. Nutr. Abstr. Rev. 48. (Abstract 4068)

Champe, K. A. and D. V. Maurice. 1983. Response of early weaned rabbits to source and level of dietary fiber. J.Anim. Sci. 56:1105-1114.

Chiang, S.H., C.T.Huang, M.S. Lee and C.M. Hong. 1983. The study of protein requirements of growing rabbits. In. Nutr. Abstr. Rev. 53: (Abstract 4384).

Cheeke, P.R, 1971. Arginine lysine and methionine needs of the growing rabbit. Nutr. Rep. Int. 3:123-128

Cheeke, P.R. 1978. Use of urea and other NPN source by the rabbit. J. Appl. Rabbit. Res. 2:6-7.

Cheeke, P.R. 1976. Nutrition of the domestic rabbits. Lab. Anim. Sci. 26: 654-658.

Cheeke, P.R. 1980. The potential role of the rabbit in meeting world food needs. J. Appl. Rabbit Res. 3:3-5.

Cheeke, P.R. 1986. Potential of rabbit production in tropical and subtropical agricultural system. J. Anim. Sci. 63: 1581-1586.

Cheeke, P.R. 1987. Rabbit Feeding and Nutrition. Academic Press. Orlando, Fl.

Cheeke, P.R. J.W. Amberg. 1972. Protein nutrition of the rabbit. Nutr. Rep. Int. 5:259-266.

Cheeke, P.R. and N.M. Patton. 1980. Carbohydrate-overload ofthe hindgut-a probable cause of enteritis. J. App. Rabbit Res. 3: 20-23.

Church, D.C. 1978. Livestock feeds and feeding. O & B Books Inc., Corvallis, Oregon

Coombe,J.B. and D.E.Tribe. 1962. The effects of urea supplements on the utilization of straw plus molasses diets by sheep. Aust. J. Agric. Res. 14:70-92.

Coombe, J.B., D.E. Tribe and J.W.C. Morrison. 1960. Some experimental observations on the toxicity of urea to sheep. Aust. J. of Agric. Res. 11:247-266.

Cree, T.C., D.M. Wadley and J.A. Marlett. 1986. Effect of preventing coprophagy in the rat on neutral detergent fiber digestibility and apparent calcium absorption. J. Nutr. 116: 1204-1208.

Crociani, F., B. Biavati, P. Castagloni and D. Matteuzzi. 1984. Anaerobic ureolitic bacteria from cecal content and soft faeces of rabbit. J. Appl. Bacteriol. 57: 83-88.

Cummings, J.H. 1981. Dietary fibre. Brit. Med. Bull. 37: 65-70.

de Blas, J.C., G.Santoma, R.Carabano and M.J. Fraga. 1986. Fibre and starch levels in fattening rabbit diets. J. Anim. Sci. 63: 1897-1904.

de Blas, J.C., E. Perez, J.M. Rodriquez, M.J. Fraga and J.F.Galvez. 1981. Effect of diet on feed intake and growth of rabbits from weaning to slaughter at different ages and weights. J. Anim. Sci. 52:1225-1232.

de Blas,J.C., J.M. Rodrigues, G.Santoma and M.J. Fraga. 1984. The nutritive value of feeds for growing fattening rabbits 1. Energy evaluation. J. Appl. Rabbit Res. 7:72-74

Dickerson, G.E. 1978. Animal size and efficiency: basic concepts. Anim. Prod. 27:367-379.

Dion, J.A. and L.B.Carew Jr. 1984. Effect of dietary dilution or free-choice intake of clinoptilolite in broiler chicks. In. Pond, W.G. and F.A. Mumpton (ed). Zeo-Agriculture. Use of natural zeolites in agriculture and aquaculture. pp.195-203. Westview-ress/ Boulder, Colorado

Eden, A. 1940. Coprophagy in the rabbit. Origin of night feces., Nature, 145: 628.

Egum, B. O., R. M. Beames and K. E. B. Knudsen. 1985. The effect of the first limiting amino acid, gastrointestinal microbial activity and the level of nitrogen intake on protein utilization and energy digestibility in rats. Brit. J. Nutr. 54: 727-739.

Evans,E. 1981. Effect of dietary energy and fibre levels on performance of fryer rabbits. J. Appl. Rabbit Res. 4: 41-43.

Evans,E., V. Jebelian and W. C. Rycquart. 1983. Effect of partial replacement of fibre from alfalfa with fibre from other ingredients upon performances of fryer rabbits. J. Appl. Rabbit Res. 6: 6-8.

Fekete, S. and J. Bakori. 1985. Effect of the fiber and protein level of the ration upon the cecotrophy of rabbit. J. Appl. Rabbit Res. 8: 68-71.

Fonolla, J., R. Sanz and J. Aguilera. 1977. Urea in the nutrition of monogastric. 1. Part of total replacement of soy by urea in a ration for rabbit. In. Nutr. Abstr. Rev.47:234 (Abstrac 1886) .

Forman, L.P. and B.O. Scheeman. 1980. Effects of dietary pectin and fat on the small intestinal contents and exocrine pancreas of rats. J. Nutr. 110: 1992-1999.

Forsythe, S. J. and D.S. Parker. 1985. Ammonia-nitrogen turn over in the rabbit caecum and exchange with plasma urea-N. Brit. J. Nutr. 54: 285-292.

Fraga, M.J. and C.de Blas. 1978. Effect of coprophagy on digestion of feed by rabbits. Nutr. Abstr. Rev. 48. (Abstract 5184).

Grobner, M.A. 1982. Diarchea in the rabbit. A review. J. Appl. Rabbit Res. 5; 115-127.

Grobner, M.A., P.R.Cheeke and N.M.Patton. 1983. The effect of sodium bentonite on performance of weanling rabbits. Proc. WSASAS. 34: 133-137.

Hayhurst,D.T. and J.M. Willard. 1980. Effects of feeding clinoptilolite to roosters. Proc. 5th int. Conf. Zeolites. Naples. pp.805-812.

Hassan, T. 1984. Daily weight gain, feed conversion efficiency and digestibility coeffisients as affected by protein levels and amino acids supplementation. Proc. Third World Rabbit Congress, Rome. Italy. pp.294-304.

Harris, D.J. 1983. Construction of quonset style cages. J. Appl. Rabbit Res. 6:142-143.

Harris, D. J., P.R.Cheeke and N.M.Patton. 1981. Utilization of high alfalfa diets by rabbits. J. Appl. Rabbit Res. 4(2);30-34.

Hornicke, H. and F. Batsch. 1977. Coecotrophy in rabbits-a circadian function. J. of Mammal. 58:240-241.

Houpt, T. R. 1963. Urea utilization by rabbits fed a low-protein ration. Am. J. of Physiol. 205:1144-1150.

Houpt,T.R. 1961. Urea metabolism in the rabbit. Fed. Proc. 20; 349(Abstr).

Houpt, T.R. and K.A.Houpt. 1968. Transfer of urea nitrogen across the rumen wall. Am. J. Physiol. 214: 1296-1303.

Hoover,W.H. and R.N. Heittmann. 1972. Effect of dietary fibre level on weight gain, cecal volume and volatile fatty acids production in rabbits. J, Nutr. 102: 375- 379.

Howard,P., R.R. Mahoney and T. Wilder. 1986. Binding of amino acids by dietary fibres and wheat bran. Nutr. Rep. Int. 34: 135-140.

Hutcheson, D.P. 1984. Addition of clinoptilolite ores to the diets of feeder cattle. In. Pond, W.G. and F.A. Mumpton (ed). Zeo-Agriculture. Use of natural zeolite in agriculture and aquaculture. Westviewpress/ Boulder, Co. pp.189-193.

Jackson, P. 1974. Non-protein nitrogen as an alternative nitrogen source. In. Swan,H. and D. Lewis (Ed.) Proc. Nutr. Conf. for Feed Manufacture :8 Butterworths. pp. 123-150.

Kelsay,J.L., K.M. Behall and E.S. Prather. 1978. Effect of fibre from fruits and vetetables on metabolic responses of human subjects. I. Bowel transit time, number of defecations, fecal weight, urinary excretions of energy and nitrogen and apparent digestibilities of energy and nitrogen and fat. Am. J. Clin. Nutr. 31: 1149-1153.

Kennedy, L.G. and T.V. Hershberger. 1974. Protein quality for the nonruminat herbivore. J. Anim. Sci., 39; 506 -511.

King, J. O. L. 1971. Urea as aprotein supplement for growing rabbits. Brit. Vet. J. 127 : 523- 527.

Knutson, R. S., R. S. Francis, J. L. Hall, B. H.Moore and J. F. Heisinger. 1977. Ammonia and urea distribution and urease activity in the gastrointestinal tract of rabbits (Oryctolagus and sylvilagus). Comp. Biochem. Physiol. 58A:151-154.

Kulwich, R., L. Strugilia, and P.B. Pearson. 1953. The effect of coprophagy on the excretion of B vitamins by the rabbit., J. Nutr., 49:639-645.

Lang, J. 1981a. The nutrition of the commercial rabbit. Part 1. Physiology, digestibility and nutrient requirements. Nutr. Abstr. Rev. 51:197-225.

Lang, J. 1981b. The nutrition of the commercial rabbit. Part 2. Feeding ang general aspect of nutrition. Nutr. Abstr. Rev. 51:287-302.

Lebas, F. 1983. Small-scale rabbit production-feeding and management systems. W. Anim. Rev. 46: 11-17.

Lebas, F. and M. Colin. 1974. Effect of addition of urea to a diet poor in protein for growing rabbits. Nutr. Abstr. Rev. 44 (Abstract 2455).

Lukefahr, S., W.D. Hohenboken, P.R. Cheeke and N.M.Patton. 1983. Doe reproduction and preweaning litter performance of straightbred and crossbred rabbits. J. Anim.

Sci. 57: 1090-1099

McBee, R.H. 1971. Significance of intestinal microflora in herbivory. Annu. Rev. of ecol. and syst. 2: 165-176.

McKinley,J.E.,D.B. Gilbert, P.Y.Chao and E.B. Reeve. 1970. Urea metabolism and distribution in rabbits treated with neomycin. Am. J. Physiol. 218: 491-497.

McNitt, J.I. 1980. The rabbit as a domestic meat source in malawi. J. Appl. Rabbit Res. 3:5-11.

Mumpton, F.A. 1978. Role of zeolites in animal feeding.In. Proc. Cornell Nutr. Conf. for Feed Manufactures. Cornell Univ.,Ithaca, N.Y. pp. 68-76.

Mumpton,F.A. and P.H. Fishman.1977. The application of natural zeolites in animal science and aquaculture. J.Anim. Sci.,45:1188-1203.

Mitaru, B.N. and R. Blair. 1984. The influence of dietary fibre sources on growth, feed efficiency and digestibilities of dry matter and protein in rats. J. Sci. Fd. Agric. 35: 625-631

Myers,K. 1955. Coprophagy in the european rabbit (Oryctolagus cuniculus) in Australia. Austr. J. of Zool. 3:336-346.

Nakaue,H.S. and J.K. Koelliker. 1981. Studies with clinoptilolite in poultry. 1. Effect of feeding varying levels of clinoplolite (zeolite) to Dwarf Single Comb White lehgron pullets and ammonia production. Poul. Sci. 60: 944-949.

Nakaue, H.S., J.K. Koelliker and M.L. Pierson. 1981. Studies with clinoplolite in poultry. 2. Effect of feeding broilers and the direct application of clinoplolite (zeolite) on clean and reused broiler litter on broiler performance and house enviroment. Poul. Sci. 60: 1221-1228.

Niedzwiadek, S., J. Kawinska and J. Tuczynka. 1978. Urea in feeds for rabbits. In Nutr. Abstr. Rev. 48:297 (Abstract 2455).

N.R.C. 1977. Nutrient requirements of domestic animals, No. 9. Nutrient requirements of rabbits. Second Revised Ed. National Academic of Sciences - National Research Council , Washington, DC.

Oltjen,R.R.,E.E.Williams, L.L.Slyter and G.V.Richardson.

1969. Urea versus biuret in a roughage diet for steers. J. Anim. Sci. 29: 816-822.

Omole, T.A. 1982. The effect of level of dietary protein on growth and reproductive performance in rabbits. J. Appl. Rabbit Res. 5:83-88.

Owen,J.L. 1976. Rabbit production in tropical developing countries. Trop. Sci. 18:203-210.

Owen, J.L. 1981. Rabbit meat for developing countries. World Anim. Rev.,39:2-11.

Partridge, G.G. and S.J. Allan. 1982. The effects of different intakes of crude protein on nitrogen utilization in the pregnant and lactating rabbit. Anim.Prod. 35: 145-155.

Partridge, G.G.,S. Foley and W.Corrigall. 1981. Reproductive performance in purebred and crossbred commercial rabbits. Anim. Prod. 32: 325-331.

Patton, N.M. and P.R. Cheeke. 1986. Winter reproduction failure. J. Appl. Rabbit Res. 9: 113-115.

Pond, W.G. and F.A. Mupton. 1984. Zeo-agriculture : Use of natural zeolites in agriculture and aquacylture. Westview Press, Boulder, Co.

Pond, W.G. and J.T. Yen. 1982. Response of growing swine to dietary clinoptilolite from two geographic sources. Nutr. Rep. Intr., 25: 837-847.

Portsmouth, J. 1976. The Nutrition of rabbits. Proc. Nutrition Conference for Feed Manufacturers. Butterworths. pp. 93 - 111.

Raharjo, Y.C.,P.R. Cheeke and N.M. Patton. 1986. Growth and reproductive performance of rabbits on a moderately low protein diet with or without methionine or urea supplementation. J. Anim. Sci. 63: 795-803.

Reddy,R.S. and C.W. Moss. 1982. The influence of dietary protein and energy level on New Zealand White doe reproduction. J.Anim. Sci. 57 (Suppl 1):265(Abstr).

Reddy, R. S.,M. E. McCoy, C. W. Moss and O. R. Holiday. 1979. Rabbit production as influenced by dietary protein. Arkansas Farm Res. 28:3

Rivera, L. S. and P.L. Madlangsacay. 1978. Carcass yield and product characteristics of rabbit meat. The Philippine J. of Anim. Industry. 33:50-66.

Robinson, K.L.,P.R. Cheeke and N. M. Patton. 1985. Effect of prevention of coprophagy on the digestibility on high-forage and high-concentrate diets by rabbits. J. Appl. Rabbit Res. 8:57-59

Romney, C.P. and N.P. Johnston. 1987. Dietary protein level and early weaning on rabbit performance. Proc. WSASAS. 29: 201-202.

Rose, W.C. and E.E. Dekker. 1956. Urea as a source of nitrogen for the biosynthesis of amino acids. J. Biol. Chem. 233: 107-121.

Sanchez, W. K., P.R. Cheeke and N.M. Patton. 1984. Influence of dietary level of soybean meal, methionine and lysine on the performance of weanling rabbits fed high alfalfa diets. J. Appl. Rabbits Res. 7:109-116.

Sanchez, W.K., P.R. Cheeke and N.M. Patton. 1985. Effect of dietary crude protein level on the reproductive performance and growth of New Zealand White rabbits. J. Anim. Sci. 60:1029-1039.

SAS. 1985. SAS User's Quide: basic statistical analysis system Institute, Inc., Cary, NC.

Satter, L.D. and R. E. Roffler. 1977. Influence of nitrogen and carbohydrate inputs on rumen fermentation. In. Haresign, W and Lewis, D.(Ed). Recent Advances in Animal Nutrition-1977: Butterworths. pp.25-49.

Schneeman, B.O. 1978. Effect of plant fibre on lipase, trypsin and chymotrypsin activity. J. Fd. Sci. 43: 634-635.

Schwartz,H.M. 1967. The rumen metabolism of non-protein nitrogen. In. Briggs,M.H.(Ed). Urea as a Protein Supplement. Pergamon Press. p.95-107.

Semertzakis, N. 1978. Utilization of non-protein nitrogen by adult female rabbits for maintainance and during pregnancy. Nutr. Abstr. Rev. Series B 48;198 (Abstract 1548).

Shah, N.,M.T. Atallah, R.R. Mahoney and P.L. Pellett. 1982. Effect of dietary fibre components on fecal nitrogen excretion and protein utilization in growing rats. J. Nutr. 112: 658-666.

Sheaed, N.F. and B.O. Schneeman. 1980. Wheat bran's effect on digestive enzyme activity and bile acid levels in rats. J. Fd. Sci. 45: 645-648.

Shurson,G.C.,P.K.Ku,E.R.Miller and M.T. Yokoyama. 1984. Effects of zeolite A or clinoptilolite in diets of growing swine. J.Anim. Sci. 59: 1536-1545.

Sigleo,S., M.J. Jacksoa and G.V. Vahouny. 1984. Effects of dietary fibre contituents on intestinal morphology and nutrient transport. Am. J. Physiol. 246: G34-G39.

Sittmann,D.B., W.C. Rollins, K. Sittmann and R.B. Casady. 1964. Seasonal variation in reproductive traits of New Zealand White rabbits. J. Reprod. Fertil. 8: 29-37.

Slade, L.M. and H.F. Hintz. 1969. Comparison of digestion in horses, ponies, rabbits and quinea pigs. J. Anim. Sci.,28: 842-843.

Spreadbury, D. 1978. A study of the protein and amino acid requirements of the growing New Zealand White rabbit with emphasis on lysine and the sulphur-containing amino acids. Brit. J. Nutr. 39: 601-613.

Spreadbury,D. and J. Davidson. 1978. A study of the need for fibre by the growing New Zealand White rabbit. J. Sci. Fd. Agric. 29: 640-648.

Steel,R.G.D. and J.H. Torrie. 1980. Principles and Procedure of Statistics. A Biometrical Approach. Second Edition. McGraw Hill Book Co., New York.

Tadayyon, B. and L. Lutwak. 1969. Role of coprophagy in utilization of triglycerides, calcium, magnesium and phosphorus in rat., J. Nutr., 96:243-245.

Teleki, M., J.Jecsai and B. Juhasz. 1986. Effect of cecotrophy on the nitrogen metabolism of Angora rabbits. Nutr. Abstr. Rev. 56 (5) (Abstract 2481).

Templeton,G.S.1952. Protein requirements for domestic rabbit. Am. Rabbit J. 22:109-110.

van Soest, P.J. 1985. Comparative fibre requirements for ruminant and non ruminants. Proc. of Cornell Nutr. Conf. for Feed Manufactures. Cornell Univ. Ithaca, N.Y. pp. 52-60.

Vietmeyer, N.D. 1985. Potentials of microlivestock in developing countries. J. Appl. Rabbit Res. 8: 10-11.

Waldern, D.C. 1971. A rapid microdigestion procedure for neutral and acid detergent fibre. Can. J. Anim. Sci. 51:67 - 69.

Weingartner, K.E., L. Franzen and J.W. Erdman Jr. 1981. Effect of coprophagy in rats upon bioavailability of calcium added to casein and soy flour based diets. Nutr. Reps. Int. 23: 755-761.

Willis, W.L., C.L. Quarles and D.J. Fagerberg. 1982. Evaluation of zeolites fed to male broiler chickens. Poul. Sci., 61: 438-442.

White, J.L.and A.J. Ohlrogge. 1974. Ion exchange materials to increase consumption of non protein nitrogen in ruminants. Can. Patent 939186.

Yoshida, T., J.R. Pleasants, B.S. Reddy and B.S. Wostmann. 1968. Efficiency of digestion in grem-free and conventional rabbits. Brit. J. Nutr. 27: 723-737.

Yoshida, T., J.R. Pleasants, B.S. Reddy and B.S. Wostmann. 1971. Amino acids composition of cecal content and feces in germ-free and conventional rabbits. J. Nutr. 101:1423-1430.

APPENDICES

APPENDIX 1. TRACE MINERAL SALT

Contained NaCl and the following level of trace minerals when added at 0.5% of the diet.

	(mg/kg of complete diet)
Zn	17.50
Mn	14.00
Fe	8.75
Cu	1.75
I	0.35
Co	0.35

APPENDIX 2. VITAMIN MIX COMPOSITION *

I t e m s	per kg
Vitamin A	1,666,666.7 USP Unit
Vitamin D-3	555,555.6 USP Unit
Vitamin E	555.6 IU
Vitamin K	0.28 gm
Vitamin B-12	2.78 mg
Riboflavin	1.67 gm
Panthotenic acid	2.78 gm
Niacin	11.11 gm
Choline chloride	111.11 gm
Folic acid	111.11 mg
Etoxyquin	31.53 gm

* Manufactured by INMAN and Co., Inc.