

METABOLIC EFFICIENCY OF BOBWHITE (COLINUS VIRGINIANUS)

FOR SEVERAL IMPORTANT DIETARY SEEDS,  
WITH OBSERVATIONS ON THE EFFECTS OF GRIT  
AND RATE OF FOOD PASSAGE

by

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## TABLE OF CONTENTS

INTRODUCTION . . . . .	1
LITERATURE REVIEW . . . . .	3
Energy Studies . . . . .	3
Bobwhite Studies . . . . .	5
Effects of Grit . . . . .	6
Rate of Food Passage . . . . .	7
MATERIALS AND METHODS . . . . .	9
Seed Preparation . . . . .	9
Bird Care . . . . .	10
Data Collection . . . . .	10
Data Analysis . . . . .	11
METABOLIC EFFICIENCY . . . . .	13
Phase I: Main Study . . . . .	13
Methods . . . . .	13
Results . . . . .	14
General . . . . .	14
Weight Change . . . . .	15
Energy Input Variables . . . . .	15
Excretory Energy . . . . .	16
Metabolized Energy . . . . .	21
Metabolic Efficiency . . . . .	21
Discussion . . . . .	22
Environmental Effects on the Metabolism of Corn . . . . .	24
Sorghum, and P-18	
Sources of Error . . . . .	30
Phase II: Auxilliary Study . . . . .	32
Methods . . . . .	32
Results . . . . .	33
General . . . . .	33
Period Effects . . . . .	34
Weight Change . . . . .	43
Energy Input Variables . . . . .	43
Excretory Energy . . . . .	43
Metabolized Energy . . . . .	44
Metabolic Efficiency . . . . .	44
Discussion . . . . .	44
Period and Environmental Effects of the Metabolism . . . . .	46
of Ragweed, Sunflower, and Partridgepea	
Phase III: Starvation Trial . . . . .	54
Methods . . . . .	54
Results . . . . .	55
Discussion . . . . .	56
EFFECTS OF GRIT . . . . .	62
Methods . . . . .	62
Results . . . . .	64
Discussion . . . . .	66
RATE OF FOOD PASSAGE . . . . .	77
Methods . . . . .	77
Results . . . . .	78
Discussion . . . . .	81
MANAGEMENT IMPLICATIONS. . . . .	83
CONCLUSIONS . . . . .	91
ACKNOWLEDGEMENTS . . . . .	93

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LITERATURE CITED . . . . .	94
APPENDIX . . . . .	99

## INTRODUCTION

Winter is often a period of food crisis for quail, and effective management may involve maintaining or improving the supply of winter staple foods (Errington 1936). The availability of energy from food is of ultimate importance in survival for any species. A food source with high metabolizable energy and palatability would be an invaluable tool in quail habitat management.

A long term investigation of the effectiveness of a quail habitat management program in Kansas has been undertaken at Kansas State University. Initial studies were concerned with food habits and weight dynamics (Robel 1969), the retention of seed energy throughout the year (Robel and Harper 1965), and the availability of important seeds in fall and winter (Robel and Slade 1965). Recent emphasis has been placed on the bioenergetic aspects of quail management. Case (1971) determined the existence energy requirements of bobwhites under various controlled environmental conditions. Clements (1970) studied the metabolizable energy of several important foods and the metabolic efficiency of quail at 30°C, 15 hours photoperiod and 20°C, 10 hours photoperiod.

This study involved several experiments to elucidate or clarify some of the aspects concerning the digestive ability of bobwhites under winter conditions (1°C, 10 hours photoperiod). Efficiency with which quail are able to metabolize the energy in acorn (Quercus rubra), VA-70 shrub lespedeza (Lespedeza japonica), sorghum grain (Sorghum vulgare), hemp (Cannabis sativa), corn (Zea mays), and Blackwell switchgrass (Panicum virgatum) was studied in depth. Metabolic efficiency of bobwhites for prostrate lespedeza (L. daurica), sunflower (Helianthus annuus), giant ragweed (Ambrosia trifida) and showy



partridgepea (Cassia faciculata) was given cursory treatment.

The effect of fine commercial quartz grit on metabolizable energy of shrub lespedeza, partridgepea and a pelletized ration (P-18) was studied to determine whether or not birds with grit could utilize more of the seed energy.

To determine if the higher plane of nutrition necessary to meet increased energy requirements of low temperatures (King & Farner 1961:242) is accompanied by a faster rate of food passage, a study timing the passage of a powdered dye through the alimentary canal was conducted.

## LITERATURE REVIEW

Energy Studies

It is commonly known that energy requirements of homeothermic animals are inversely related to temperature. A thermoneutral zone or point exists wherein it is possible to maintain body temperature by changes in insulation; but, below this zone energy balance is maintained by increasing metabolism (King & Farner 1961:233). Maximum potential metabolism is attained at the lower limit of temperature tolerance (Kendeigh 1969a). When heat loss at low temperatures can no longer be balanced by heat produced from metabolism the animal dies (King & Farner 1961:234).

Increased metabolic energy can be obtained by increased energy intake or increased efficiency of energy utilization (metabolic efficiency) or both. Energy intake has been shown to be a linear function of temperature (Kendeigh 1969a, King & Farner 1961:242); however, a predictable change in metabolic efficiency with temperature cannot be generalized. Kendeigh (1949) and West (1960) found that metabolic efficiency of English sparrows (Passer domesticus) and tree sparrows (Spizella arborea) decreased at low temperatures. David (1955) found a peak in the metabolic efficiency of English sparrows at 18°C. Seibert (1949), studying several migrant and nonmigrant species, found that feces had the lowest caloric value at 22°C. This was attributed to either increased efficiency of energy utilization or a change in the ratio of waste from the kidney and the intestine. Zimmerman (1965) found that the dickcissel (Spiza americana) had two peaks in metabolic efficiency, one peak occurring at a temperature just below the point of thermoneutrality and the other between 10°C and 13°C. Case (1971) found no consistent correlation of metabolic efficiency of bobwhites with temperature.

The effect of photoperiod on metabolic efficiency is equally variable. Tree sparrows have increased efficiency (West 1960); but, bobwhite quail have reduced efficiency (Case 1971) at longer photoperiod.

No sex-related differences in energy requirement or metabolic efficiency were found for English sparrows (Kendeigh 1949, Davis 1955), tree sparrows (West 1960), dickcissels at 10 hours photoperiod (Zimmerman 1965), and bobwhite quail at 10 hours photoperiod (Case 1971).

West (1968) found that the metabolized energy (M.E.) of willow ptarmigan (Lagopus lagopus) under natural conditions was quite uniform throughout the year, except for periods of molt and egg laying. Temperature effects on M.E. were masked by molt, egg laying, activity and weight change. This observation was consistent with Kendeigh's (1969a) concept that maximum potential M.E. is necessary for existence at the lower limit of temperature tolerance, and that as temperature increases and existence energy is reduced, some of this potential M.E. becomes potential productive energy for molt, reproduction, activity or fat deposition.

From the equations presented by Case (1971), the existence energy of adult bobwhites at 1°C and 10 hours photoperiod was 48.14 kcal/day, with 63.22 kcal/day intake energy and 15.08 kcal/day excretory energy.

The ability of birds to endure periods of starvation has been studied in passerine species by Kendeigh (1945) and in galliformes by Errington (1939) and Tester and Olson (1959). Kendeigh stated that hunger is more critical at low temperatures due to greater existence energy requirements. Heavier birds, generally males, survive longer, a result of larger fat deposits. A greater percentage of body weight was lost at warm than at cold temperatures, and survival time was related with the ability to lose large

amounts of weight slowly. The greater initial weight of pen-reared pheasants (Phasianus colchicus) allowed them to survive starvation longer than wild trapped birds (Tester and Olson 1959). The wild birds, however, lost a greater percentage of body weight and were considered to be more hardy.

Errington (1939) found no sex-related differences in the ability of bobwhites to withstand starvation in winter. Some quail die at nearly 75 percent of normal body weight, while others lived to nearly 50 percent. Recovery from loss of more than 30 percent body weight was very slow.

#### Bobwhite Studies

Nestler (1949a) found that a diet of 19 to 25 percent protein was necessary to maintain body weight during breeding, but survival, weight and food consumption during winter was as good on diets with 9 to 11 percent protein as those with greater amounts. Vitamin A or carotene is essential for survival of caged birds, but little evidence of vitamin A deficiency was found in wild birds.

Notable food habits studies on quail in the midwestern states have been done by Korschgen (1948), Baumgartner et al. (1952), and Robel (1969). Western ragweed (Ambrosia psilostachya), common ragweed (A. artemisiifolia), corn, sorghum, sunflower, acorn (Quercus sp.), partridgepea, and panic grasses (Panicum sp.) were important food items in each of the studies.

Partridgepea and various species of lespedeza have been used extensively for quail management in the southeastern states (Handley 1936, Rosene 1956, 1969).

Errington (1936) found that corn, sorghum and most cultivated grains were of outstanding value as winter food but were not wholly sufficient by themselves. Common ragweed and acorn mast were important natural food

but could not be considered as staple foods.

Clements (1970) conducted metabolic efficiency trials with six important food items of quail. Seeds from giant ragweed, pin oak (*Q. palustris*), partridgepea, sunflower, and smooth sumac (*Rhus glabra*) were rejected from consideration as staple foods because of excess weight loss, low metabolic efficiency, or low M.E. by quail fed those seeds. Only sorghum grain was considered a good seed by Clements.

#### Effects of Grit

The literature reveals a controversy concerning the value of grit to birds. It is generally agreed (McCann 1939, Nestler 1946, Korschgen 1964, Vance 1971) that grit is an important source of minerals for metabolism, especially calcium necessary for egg shell formation. It is the value of grit as a scarifying agent which is not fully understood.

Grit can be retained in the gizzard for long periods after access to it has been stopped (Handley 1936, McCann 1939, Nestler 1946). The retention time is increased for large grit particles and with a diet of soft food (Hollingsworth et al. 1965).

There is considerable individual variation in grit consumption and retention. Quail gizzard contents analysis revealed grit quantities between a trace and 15 percent by weight (Handley 1936). Consumption of grit by poultry varied "between nil and gluttony" (Hollingsworth et al. 1965:1380). When birds were force fed grit some excreted it all immediately, some retained it, and others excreted pulverized particles (Hollingsworth et al. 1965).

Given a choice, gravel is the preferred type of grit, limestone is second and quartz is third. Quartz is ideal for testing the grinding

functions of grit because it is generally insoluble and provides no nutrition (McCann 1939).

Beer and Tidyman (1942) found an inverse relationship between the volume of grit and the volume of hard seeds (Rosa sp., Cornus sp., Prunus sp.) in the gizzard and concluded that the seeds acted as a substitute when grit was unavailable.

Fritz (1935) found that coefficients of utilization of minerals and fat from argentine flint corn fed to chickens without grit was increased by cracking or grinding the kernels. Because gizzardectomized chickens had normal efficiency on powdered food, but reduced efficiency on whole seeds, it was concluded that the gizzard functioned primarily as a grinding organ (Fritz et al. 1936). The coefficients of utilization of protein, fiber, fat, and ash increase only slightly due to the presence of grit in the gizzard of chickens (Fritz 1937). Titus (1955) stated that grit may increase the efficiency of utilization of whole seeds by 10 percent and of mash by 3 percent.

Errington (1936) found that quail could be kept on a diet of whole corn without grit for several weeks without serious weight loss, but could not continue indefinitely. The weight gain, food consumption and survival of quail raised without grit was equal to those with grit (Nestler 1946).

#### Rate of Food Passage

Kendeigh (1969b) suggested that the reduction in efficiency at low temperatures and short photoperiods could be due to the increased gut mobility and rate of passage of food through the alimentary tract.

McFarland and Freeland (1965) studied the rate of food passage in Coturnix quail (Coturnix coturnix) at an unspecified temperature.

When chromic oxide ( $\text{Cr}_2\text{O}_3$ ) in #2 gelatin capsules was inserted into the esophagus, color appeared in excreta in 1 to 1.5 hours and was gone in most birds by 3 to 3.5 hours. Color appeared again at 5 to 5.5, 6 to 6.5, or 7.5 to 8 hours in various birds, and was attributed to cecal evacuation. The normal time of food passage was 1 to 1.5 hours.

Boyd (1970) conducted a similar study on bobwhite and found that intestinal feces was voided after 1.5 to 2.5 hours and cecal feces after 6.5 to 7.5 hours.

Sturkie (1965:277) summarized the work on rate of food passage. Time of ingesta to pass through the alimentary tract is dependent upon moisture content of food, food type, and age and physiological state of the bird. No specific effect of temperature was mentioned. Generally, passage is fastest through young and laying birds, moderate in nonlaying birds and slowest in brooding birds. In chickens, about half of the ingested food was passed in 4 or 5 hours and the rest completely voided by 16 to 25 hours.

## MATERIALS AND METHODS

### Seed Preparation

Approximately 1 kg of wild sunflower, partridgepea and ragweed seeds were picked after maturity within a 30 km radius of Manhattan, Kansas during the autumn of 1970. Sorghum grain was collected in the same area in January 1971.

Seeds were cleaned by passing them through an appropriate size screen to remove large debris. Small debris and many damaged seeds were removed by winnowing with a small electric fan. Damaged and undamaged sunflower seeds were separated by immersing them in water. Undamaged seeds sank while damaged ones floated and were decanted off (Johnson 1968).

Acorns from red oak were obtained from Lawrence, Kansas through the Forestry Extension Service of Kansas State University. The shell was removed by placing the acorns in a canvas sac and vigorously beating them against a flat solid object until the hulls shattered. The meat was removed and chopped up so that it would pass through a 4.70 mm but not a 2.39 mm screen.

Hemp was obtained from the Kansas Marijuana Eradication and Control Committee, two species of lespedeza and switchgrass from the Kansas Agriculture Experiment Station, and cracked corn from the Kansas State University Department of Milling and Grain Science. A pelletized balanced diet, P-18, formulated by the Department of Milling and Grain Science was fed to all birds between feeding trials and used as a control feed during trials.

Seeds were stored at  $-16^{\circ}\text{C}$  to inhibit further respiration and deterioration (Kendeigh and West 1965).



### Bird Care

Thirty adult male bobwhites were obtained from the Kansas Forestry, Fish and Game Commission hatchery in Pittsburg, Kansas on February 27, 1971. Fourteen of these quail died within a week from undetermined causes, and replacements were received March 13, 1971.

Birds were banded, placed in individual cages and housed within a walk-in environmental chamber controlled for temperature and photoperiod. Initially, the regime was set for 20°C and 10 hours photoperiod. Temperature was reduced 4-5°C per week until 1°C was reached. Relative humidity varied from 25 to 100 percent, and averaged near 50 percent. These conditions approximate midwinter averages for northeastern Kansas (Bark unpublished).

Cages measured 48 x 25 x 13 cm and were fitted with sliding tops of 6.35 mm hardware cloth. A removable floor of 12.7 mm hardware cloth raised about 1 cm above the cage bottom minimized contamination of excreta by spilled seeds as well as minimizing coprophagy. To further reduce mixing of seed and excreta a piece of clear plexiglass was fastened across the cage about 7 cm from one end. A feeder was placed behind a 4 x 5 cm opening, allowing the birds to feed freely.

Birds were weighed every third day to 0.1 g. Weighing was done at the beginning of photoperiod to minimize diurnal weight change (West 1960). Before a feeding trial was begun weight was allowed to stabilize,  $\pm$  2 percent.

### Data Collection

Feeding trials consisted of two consecutive 3-day periods. Trial seeds and water were presented ad libitum but grit was not provided.

Seed consumption was determined by subtracting the weight of uneaten

seed at the end of the trial from the weight of seed presented. Spilled seed was separated from excreta by hand. Excreta collected at the end of each trial period was dried at 60°C for 72 hours and weighed.

Percentage dry weights of seeds were determined by drying, at 60°C for 72 hours, sub-samples of seed taken at the beginning, middle and end of the experiment.

Prior to caloric analysis both dry seeds and dry excreta were ground through a 20 mesh screen in a Wiley micro-mill and dried again at 60°C for several hours. Duplicate energy values of feed and excreta were determined from 1-g samples (approximately) in a Parr 1200 adiabatic calorimeter with a Parr 1101 oxygen bomb under 30 atmospheres of pressure (Parr Instrument Co. 1960).

#### Data Analysis

Dry weight (g) of seed consumed x energy (kcal/g) contained in the seed equals gross energy consumed (kcal). Excretory energy (kcal/g) x dry weight of excreta (g) produced equals total excretory energy (kcal) voided.

A weight loss factor (kcal/g weight loss, determined from energy excreted by starving quail) x weight lost (g) during a trial period was subtracted from total excretory energy to correct for bias incurred by metabolic wastes after the utilization of body storage compounds. No correction value was applied to weight gains.

Metabolized energy (kcal) was computed as gross energy consumed minus total corrected excretory energy. Efficiency (percent) of energy conversion was determined by dividing M.E. by gross energy consumed. No correction in M.E. was made for fermentation of undigested food or utilization of energy

by enteric bacteria (Kendeigh 1949, Uromoto 1961).

The data were analyzed by analysis of variance and means were separated using Duncan's New Multiple Range Test (NMRT) ( $\alpha = 0.05$ ). The majority of the data analysis followed outlines set by Fryer (1966), with calculations done by an IBM 360/50 computer. Means separation of treatments with unequal sample size was accomplished by a Duncan's NMRT ( $\alpha = 0.05$ ) as described by Kemp (1972).

## METABOLIC EFFICIENCY: PHASE I

METHODS

Care and maintenance of the birds, and collection of data from two consecutive 3-day feeding trials followed methods described above.

Bioenergetic data for corn, sorghum, shrub lespedeza, blackwell switchgrass, hemp and acorn were obtained from 12 birds, placed into two 6-bird by 6-seed feeding trial schedules. In this replicated latin square design, all birds received each seed only once during the experiment. Both the seed fed to a specific bird in the first trial and the order in which the other seeds were fed to that bird in subsequent trials, were randomized. With the latin square design it was possible to measure feeding trial differences and bird differences in addition to seed differences. A control group of 3 birds was fed P-18 for the duration of the feeding trials.

Variables measured were: weight loss (g), food consumed (g), gross energy consumed (kcal/3 days), excretory energy (kcal/g), total excretory energy (kcal/3 days), metabolizable energy (kcal/3 days), and efficiency (percent). Clements (1970) found significant differences in all variables between the first and second 3-day period of a feeding trial. Based on his observation, only data collected during each second 3-day period were analyzed in my study.

With the necessity to keep all birds alive throughout the entire experiment for balanced statistical analysis, it was decided to terminate the trial for individual birds at a weight near 75 percent of their original weight. Data from the birds which were removed before the termination of a feeding trial were linearly interpolated to a second 3-day period basis.

Data were analyzed separately for each square, and then combined. The

analysis of variance and a Duncan's New Multiple Range test were computed on an IBM 360/50 computer. The effect of environment was analyzed for comparable seeds (sorghum, acorn, and P-18) with the data collected by Clements (1970) at 20°C, 10 hours and 30°C, 15 hours photoperiod through a two-way unequal subclass analysis of variance program. Means separation was accomplished by a Duncan's NMRT for unequal sample size, as described by Kemp (1972)

## RESULTS

### General

Six feeding trials were conducted between June 10 and November 20, 1971. About 25 days were required for weight recovery and stabilization between trials.

Seed energy (Table 17) ranged from 6.041 kcal/g for sunflower to 4.304 kcal/g for sorghum, and did not differ greatly from published values.

Data from the second 3-day period of the replicated latin square design were analyzed as two separate squares with one degree of freedom for between squares. Since there was no significant difference ( $P > 0.10$ ) between squares or seed x period interaction, the respective degrees of freedom and sums of squares were added to those of the error term to give more power to the test.

There were significant differences ( $P \leq 0.01$ ) in the performance of birds within each square during the feeding trials for feed and energy consumed, total excretory energy, and metabolized energy (Table 1). Variables measured from the two birds in a given block of the latin square were averaged to provide a pooled mean for bird performance. Mean gross

energy consumed by paired birds ranged between 157.04 and 210.96 kcal/3 days when averaged for all seeds. Similarly, total excretory energy ranged between 57.20 and 79.34 kcal/3 days, and metabolized energy, between 99.00 and 132.70 kcal/3 days.

No significant differences ( $P > 0.05$ ) between feeding trials were detected for any variable except M.E., but highly significant differences in all variables ( $P \leq 0.01$ ) were attributed to the effects of feeding different seeds to the quail (Table 1).

#### Weight Change

Mean weight of birds at the start of feeding trials was  $192.3 \pm 12.0$  g (mean  $\pm$  S.D.). Mean initial weight for the second 3-day period was  $178.3 \pm 19.4$  g. Birds on all diets except P-18 lost weight during the first 3-day period of a feeding trial (Fig. 1). In the second period no significant difference ( $P > 0.05$ ) in weight change was detected among birds fed corn, sorghum, hemp and shrub lespedeza, although changes of 1.9 to -5.2 g (Table 2) were observed. Birds fed acorn and switchgrass had weight changes of -20.1 and -23.3 g, respectively, significantly greater ( $P \leq 0.05$ ) than for other seeds and at a rate near that of starvation. Control birds gained an average 0.4 g during the second 3-days of a feeding trial.

Weight loss was significantly ( $P \leq 0.01$ ) and inversely correlated ( $r = -0.6462$ ) with M.E.

#### Energy Input Variables

Differences ( $P \leq 0.01$ ) in weight of feed and gross energy consumed were found for individual birds and for different seeds. Sorghum, corn, hemp and shrub lespedeza were consumed to the same extent ( $P > 0.05$ ), ranging from 47.0 to 43.8 g (Table 2). Acorn and switchgrass were consumed in similar

amounts ( $P > 0.05$ ), 25.7 and 24.7 g, respectively, significantly less ( $P \leq 0.05$ ) than other seeds.

A diet of hemp provided the quail with the greatest energy intake, 245.95 kcal/3 days. Gross energy consumed of sorghum (202.11 kcal/3 days) was not different ( $P > 0.05$ ) from that of shrub lespedeza (220.10 kcal/3 days) or corn (197.10 kcal/3 days); however, the energy consumed from corn and shrub lespedeza was significantly different ( $P \leq 0.05$ ). The gross energy consumed on diets of acorn and switchgrass was 133.46 and 111.58 kcal/3 days respectively (Table 2), different ( $P \leq 0.05$ ) from each other, and significantly lower ( $P \leq 0.05$ ) than other seeds.

Control birds consumed 58.7 g or 235.98 kcal/3 days of P-18. There were no significant differences ( $P > 0.05$ ) between birds or feeding trials in the weight of food and gross energy consumed.

#### Excretory Energy

Energy per gram of excreta produced on a diet of hemp (4.22 kcal/g) was significantly higher ( $P \leq 0.05$ ) than excretory energy from other diets. Energy excreted on diets of sorghum, shrub lespedeza, acorn and corn were not different ( $P > 0.05$ ) ranging between 3.94 and 3.76 kcal/gram. Excretory energy of quail fed acorn and corn was not different ( $P > 0.05$ ) from that of switchgrass, 3.62 kcal/g (Table 2).

Due to the relatively small differences in excretory energy, the weight of excreta and total excretory energy are highly correlated ( $r = 0.9911$ ).

The greatest total amount of excretory energy was produced on a diet of hemp (133.15 kcal/3 days). Quail produced 100.04 kcal of excretory energy from shrub lespedeza, 66.09 kcal from switchgrass, and 49.22 kcal from acorn mast in three days. Corn and sorghum were not significantly different ( $P > 0.05$ ) with 29.49 and 28.39 kcal/3 days excreted, respectively.

Table 1. F-ratios and error variance of variables from analysis of variance of data from the second 3-day period of phase I.

Source	Df	Weight Change	Feed Cons.	Gross Energy Cons.	Exc. Energy	Total		Met. Eff.
						Exc. Energy	M.E.	
Latin Square	Bird	10	1.6	5.2**	1.3	4.0**	3.3**	1.8
	Feeding Trial	10	1.6	2.2	1.0	1.1	2.7*	1.2
	Seed	5	13.3**	48.2**	11.2**	124.3**	75.9**	95.0**
	Error Variance	44	107	27	0.05	167	400	0.005
	Bird	2	2.7	3.3	3.3	4.1*	2.6	1.8
	Feeding Trial	5	1.6	0.7	0.7	0.7	0.9	2.2
	Error Variance	10	2	31	508	43	296	0.0002

\*Significantly different at  $\alpha = 0.05$

\*\*Significantly different at  $\alpha = 0.01$



Table 2. Ranked seed means and standard deviation from analysis of variance for data from the second 3-day period of phase I. Underlined values are not significantly different ( $P > 0.05$ ) using Duncan's New Multiple Range Test. Means ( $\pm$  standard deviation) from controls are presented for comparison.

Variable	Seed Means						Standard Deviation	Control (P-18)
	Corn	Sorghum	Hemp	Shrub Lespedeza	Acorn	Switch-grass		
Weight Change (g/3 days)	1.88	1.1	-3.09	-5.16	-20.06	-23.3	$\pm 2.98$	$0.4 \pm 0.4$
Feed Consumed (g/3 days)	Sorghum 49.96	Corn 45.1	Hemp 44.5	Shrub Lespedeza 43.8	Acorn 25.67	Switch-grass 24.67	$\pm 1.49$	$58.7 \pm 1.3$
Gross Energy Consumed (kcal/3 days)	Hemp 245.95	Shrub Lespedeza 220.10	Sorghum 202.11	Corn 197.11	Acorn 133.46	Switch-grass 111.58	$\pm 7.28$	$235.98 \pm 5.31$
Excretory Energy (kcal/g)	Hemp 4.22	Sorghum 3.94	Shrub Lespedeza 3.81	Acorn 3.77	Corn 3.76	Switch-grass 3.62	$\pm 0.06$	$3.23 \pm 0.15$
Total Excretory Energy (kcal/3 days)	Hemp 133.15	Shrub Lespedeza 100.04	Switch-grass 66.09	Acorn 49.92	Corn 29.49	Sorghum 28.39	$\pm 3.37$	$63.55 \pm 1.54$
Metabolized Energy (kcal/3 days)	Sorghum 174.11	Corn 168.34	Shrub Lespedeza 118.34	Hemp 111.76	Acorn 77.43	Switch-grass 45.17	$\pm 5.77$	$172.77 \pm 4.05$
Metabolic Efficiency (percent)	Sorghum 86.1	Corn 85.6	Acorn 57.3	Shrub Lespedeza 53.6	Hemp 45.1	Switch-grass 41.1	$\pm 2.03$	$73.2 \pm 0.4$



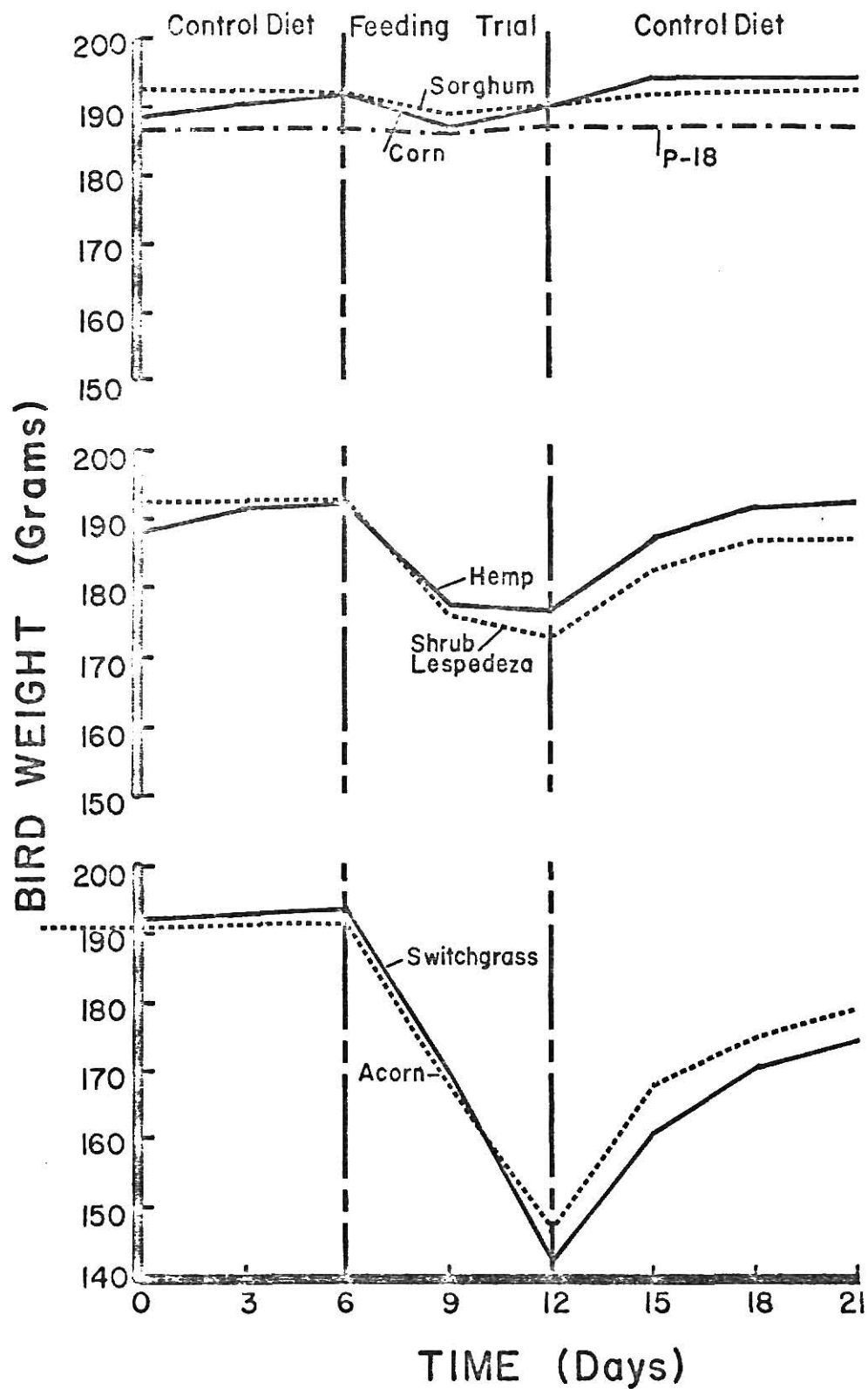
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Fig. 1. Mean weight for 12 quail on each diet preceeding, during, and after two 3-day periods of feeding trial at 1°C and 10 hours photo-period.

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Excretory energy from control birds fed P-18 was 3.23 kcal/g, with a total excretory energy of 63.55 kcal/3 days. Differences in the total amount of energy voided by individual birds were significant ( $P \leq 0.05$ ).

#### Metabolized Energy

Significant differences in the amount of energy metabolized by individual birds ( $P \leq 0.01$ ) and mean M.E. in different feeding trials ( $P \leq 0.05$ ) were detected. No trend in the change of M.E. between consecutive trials was evident to suggest that birds adapted to suddenly changing diets.

No significant differences ( $P > 0.05$ ) existed between energy metabolized from sorghum and corn (174.11 and 168.34 kcal/3 days) or from shrub lespedeza and hemp (118.34 and 111.76 kcal/3 days). Metabolized energy from acorn and switchgrass was significantly ( $P \leq 0.05$ ) lower than from other seeds (77.43 and 45.17 kcal/3 days respectively). Only corn and sorghum provided sufficient energy for continued existence.

Control birds metabolized 172.77 kcal/3 days from P-18.

#### Metabolic Efficiency

The energy in sorghum and corn was readily metabolized by quail, 86.1 and 85.6 percent, respectively. Metabolic efficiency of quail was intermediate for acorn and shrub lespedeza, 57.3 and 53.6 percent, and low for hemp and switchgrass, 45.1 and 41.1 percent, respectively. No significant differences ( $P > 0.05$ ) in efficiency between seed species in these groups were detected.

The efficiency of utilization of energy from P-18 was 73.2 percent, with no differences ( $P > 0.05$ ) between birds or feeding trials appearing.

## DISCUSSION

The practice of drying avian excreta at 60°C has been argued against by Marouko et al. (1964) and Shannon and Brown (1969), who found significant differences in nitrogen content and energy value after drying excreta at 65°C for 12 and 24 hours. Blem (1968) found no difference in these parameters after drying excreta at 65°C for 48 hours. To be consistent with the work of Clement (1970) and Case (1971) the 60°C drying temperature was used.

Case (1971) found no significant sex-related differences in existence energy, total excretory energy, energy consumed or metabolic efficiency of bobwhites maintained at 10 hours photoperiod. Consequently, even though only male bobwhites were used in my study, the results should be valid for both sexes.

From Kendeigh's (1969b) equation for the basal metabolism of all species at 0°C as a function of body weight, the existence energy of 185.6 g quail would be 207.35 kcal/3 days. Case (1971) expressed existence energy of bobwhites as a function of temperature. The calculated value was 144.41 kcal/3 days at 1°C and 10 hours of light.

When an individual does not lose weight and the only energy demands are for standard metabolism, chemical heat regulation, specific dynamic action, and securing food and water, then M.E. is a valid estimate of existence energy (West 1960). Case (1971) considered stable weight to be one with changes of less than  $\pm 1$  percent of normal body weight over a 3-day period. In my experiment, control birds were within this limit, and while the birds fed corn and sorghum exceeded it (-1.1 and -1.5 percent) during the feeding trial, they were within the limits (+0.9 and +0.6 percent)



for the second 3-day period. Metabolized energy from these feeds were: 172.77 kcal/3 days of P-18, 174.11 kcal/3 days of sorghum, and 168.34 kcal/3 days of corn. The pooled value for existence energy, 171.74 kcal/3 days, was midway between Kendeigh's (1969b) prediction and Case's (1971) observation. Kendeigh's equation was generalized for all avian species and a deviation from the predicted value could be expected for the existence metabolism of any species. The difference ( $P \leq 0.05$ ) from Case's value for bobwhites may be the result of bird differences, sample size, and differences in experimental techniques.

When M.E. is less than existence energy, an individual will draw upon its body reserves losing weight (Kendeigh 1969a). Weight loss was inversely proportional ( $r = -0.65$ ) to M.E. for birds in this study. Metabolized energy from corn, sorghum, and P-18 was near existence energy and little or no weight change occurred. Energy from hemp and shrub lespedeza (111.34 and 118.76 kcal/3 days) metabolized was below existence requirements and a slight weight loss resulted. Large weight losses occurred on diets of acorn and switchgrass due to the low M.E. (77.43 and 45.17 kcal/3 days) for these species.

The low plane of nutrition on acorn and switchgrass indicates an unpalatability of these species to quail. Because all seed species were equally available to the quail and fed ad libitum, the amounts consumed could be used as an index to acceptability or palatability, even though they were not fed simultaneously. Sorghum, corn, hemp and shrub lespedeza were equally ( $P > 0.05$ ) palatable, with consumption ranging between 50.0 and 43.8 g. Acorn and switchgrass were much less acceptable, 25.7 and 24.7 g consumed, respectively, and not significantly different ( $P > 0.05$ ) from each other.

Generally under winter conditions, quail do not have a large selection of available seeds and it is to the advantage of the game manager to improve areas with feed that is nutritious, readily available, and, if possible, preferred. An index of seed value can be calculated from a palatability index (weight of food consumed under free access conditions) x energy contained within the seed x metabolic efficiency of quail for the seed. This index is the metabolized energy and can be used to rank the value of any seed for metabolic purposes.

Sorghum and corn had the greatest metabolic value (M.E. of 174.11 and 168.34 kcal/3 days), while shrub lespedeza and hemp were of intermediate value (M.E. of 118.34 and 111.76 kcal/3 days). Seeds within these groups were not significantly different ( $P \leq 0.05$ ). Acorn was of lower value (77.43 kcal/3 days) and switchgrass had the lowest value (45.17 kcal/3 days) of the seeds studied for quail management in winter.

#### Environmental Effects on the Metabolism of Acorn, Sorghum and P-18

The data collected for diets of corn, sorghum and P-18 were compared by a two-way analysis of variance (Table 3) with Clements' (1970) data, collected at 20°C, 10 hours and 30°C, 15 hours photoperiod, to determine environmental effects on metabolism. On account of the confounding effect of a longer photoperiod at 30°C, specific effects of temperature were measured using only data obtained at 1°C (from my experiment) and 20°C (from Clements experiments) with 10 hours photoperiod.

Existence energy was 87.99 kcal/3 days at 30°C, 15 hours, 96.36 and 144.41 kcal/3 days at 20°C and 1°C, 10 hours, respectively (Case 1971). Although several of the observed values (Table 4) were below those calculated by Case, birds fed sorghum and P-18 apparently met these energy requirements

and showed no significant ( $P > 0.05$ ) weight change between environments or between seeds (Table 3). Quail were unable to derive sufficient energy from acorn, and a substantial weight loss resulted. Due to the greater energy demands at lower temperatures, the weight loss was greater ( $P \leq 0.05$ ) at  $1^{\circ}\text{C}$ , 10 hours light than under the other environmental conditions.

The energy metabolized by quail at  $1^{\circ}\text{C}$ , 10 hours was significantly greater ( $P \leq 0.05$ ) for all seeds than at  $20^{\circ}\text{C}$ , 10 hours and  $30^{\circ}\text{C}$ , 15 hours. Metabolized energy from sorghum was greater ( $P \leq 0.05$ ) at  $20^{\circ}\text{C}$ , 10 hours than at  $30^{\circ}\text{C}$ , 15 hours.

To supply the increased energy requirements due to low temperature, the weight of feed and gross energy consumed increased significantly ( $P \leq 0.05$ ) between  $20^{\circ}\text{C}$  and  $1^{\circ}\text{C}$  (Table 4). Weight and gross energy of sorghum consumed was also greater ( $P \leq 0.05$ ) at  $20^{\circ}\text{C}$ , 10 hours than at  $30^{\circ}\text{C}$ , 15 hours. Concurrent with increased energy intake, total excretory energy increased significantly ( $P \leq 0.05$ ) at  $1^{\circ}\text{C}$ , 10 hours when compared to energy excreted at  $20^{\circ}\text{C}$ , 10 hours and  $30^{\circ}\text{C}$ , 15 hours.

There was no change ( $P > 0.05$ ) in the metabolic efficiency of quail on P-18 in different environmental conditions (Fig. 2). This was consistent with the observation by Case (1971) that efficiency of energy utilization in quail maintained at 10 hours photoperiod was not related to temperature or plane of nutrition, but inconsistent with his observation that male bobwhites have higher ( $P \leq 0.05$ ) efficiency at  $35^{\circ}\text{C}$ , 15 hours photoperiod. I can offer no explanation for this discrepancy.

Acorn mast was utilized more efficiently ( $P \leq 0.05$ ) at  $1^{\circ}\text{C}$ , 10 hours than at  $20^{\circ}\text{C}$ , 10 hours or  $30^{\circ}\text{C}$ , 15 hours (Fig. 2), but this may be due to use of acorns from red oak, rather than pin oak, at the lower temperature.

Table 3. F-ratios and error variance from a two-way unequal subclass analysis of variance for variables affecting the metabolism of sorghum, acorn, and P-18 by bobwhites maintained at: 1°C, 10 hours; 20°C, 10 hours; and 30°C, 15 hours photoperiod.

Source	DF	Weight Change	Feed Consumed	Gross Energy Consumed	Total Excretory Energy	Metabolized Energy	Metabolic Efficiency
Environment	2	4.9	311.3**	349.3**	240.9**	334.0**	16.1**
Seed	2	62.7**	184.8**	128.9**	100.9**	154.6**	168.3**
Env x Seed	4	7.7**	3.9**	1.5	12.7**	3.6*	10.1**
Error Variance	84	27	22	429	35	269	0.003

\*Significantly different at  $\alpha = 0.05$

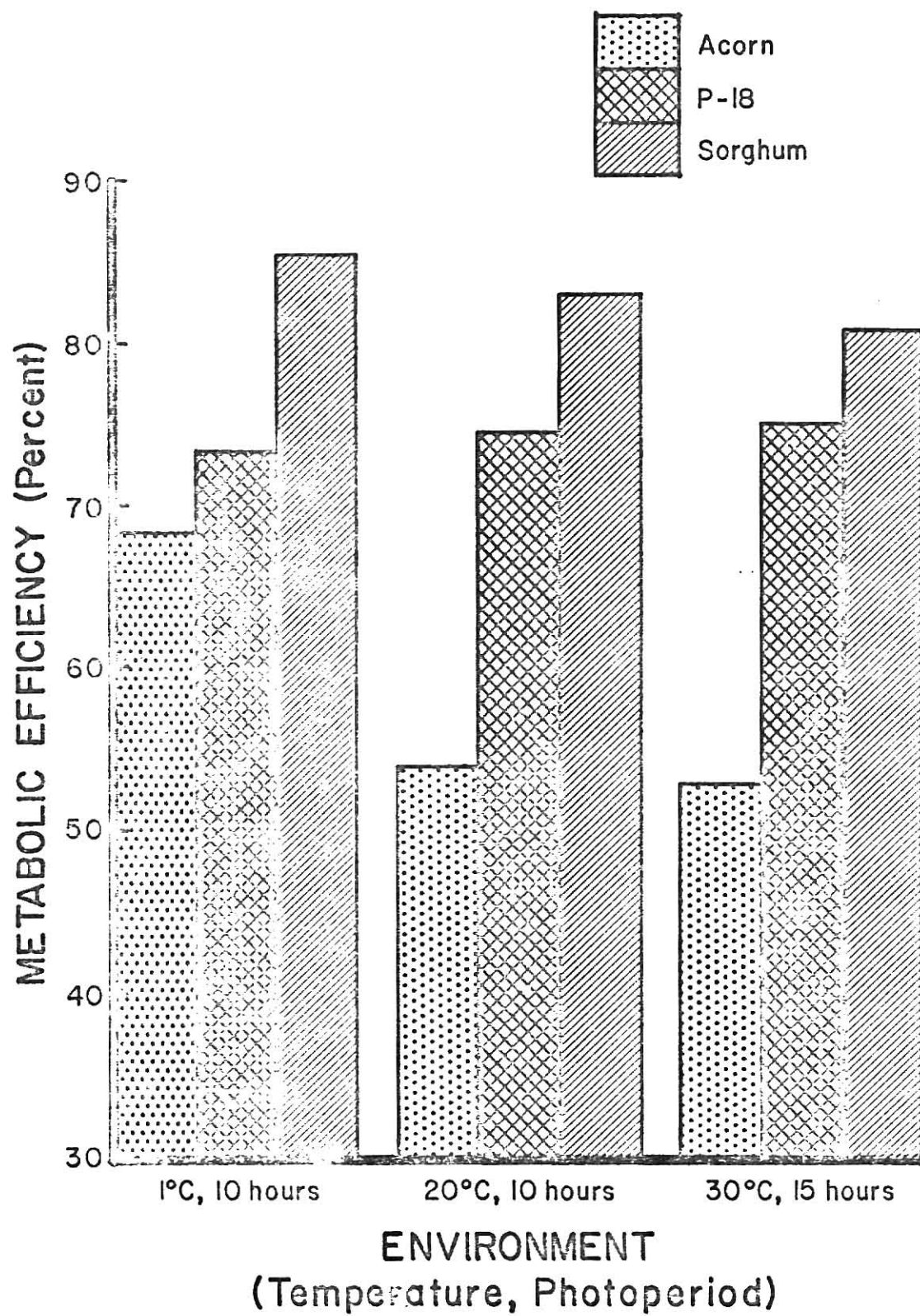
\*\*Significantly different at  $\alpha = 0.01$

Table 4. Means of variables from two-way analysis of variance for acorn, sorghum and P-18 fed to quail maintained at three environmental conditions. Numbers with the same superscript under each variable are not significantly different ( $P > 0.05$ ).

	Environment	Weight Change (g/3 days)	Feed Consumed (g/3 days)	Gross Energy Consumed (kcal/3 days)	Excretory Energy (kcal/3 days)	Metabolized Energy (kcal/3 days)	Metabolic Efficiency (percent)
P-18	1°C, 10 hours	0.4 <sup>a</sup>	55.2	236.11	63.55	172.76 <sup>a</sup>	73.2 <sup>d</sup>
	20°C, 10 hours	0.8 <sup>ab</sup>	30.4 <sup>a</sup>	128.35 <sup>ab</sup>	32.46 <sup>a</sup>	96.04 <sup>b</sup>	74.6 <sup>cd</sup>
	30°C, 15 hours	0.1 <sup>ab</sup>	25.1 <sup>a</sup>	106.01 <sup>b</sup>	27.76 <sup>ab</sup>	78.33 <sup>b</sup>	74.9 <sup>cd</sup>
	Average	0.4	36.9	157.8	41.3	115.7	73.9
Sorghum	1°C, 10 hours	1.1 <sup>ab</sup>	46.9	202.04	29.32 <sup>ab</sup>	172.79 <sup>a</sup>	85.4 <sup>a</sup>
	20°C, 10 hours	0.8 <sup>ab</sup>	26.7 <sup>a</sup>	106.90 <sup>b</sup>	18.89 <sup>cd</sup>	88.22 <sup>b</sup>	82.6 <sup>ab</sup>
	30°C, 15 hours	-1.6 <sup>ab</sup>	15.5	61.90 <sup>c</sup>	10.90 <sup>d</sup>	51.55	80.2 <sup>bc</sup>
	Average	0.1	29.7	123.6	19.7	104.2	82.7
Acorn	1°C, 10 hours	-20.9	27.3	142.08 <sup>a</sup>	52.50	95.58 <sup>b</sup>	68.3 <sup>d</sup>
	20°C, 10 hours	-11.5	8.5 <sup>b</sup>	43.35 <sup>cd</sup>	23.69 <sup>bc</sup>	23.50 <sup>c</sup>	54.0 <sup>e</sup>
	30°C, 15 hours	-6.8 <sup>bc</sup>	5.4 <sup>b</sup>	27.33 <sup>d</sup>	15.12 <sup>d</sup>	14.50 <sup>c</sup>	52.6 <sup>e</sup>
	Average	-13.1	13.8	70.9	30.4	44.9	58.3



Fig. 2. Metabolic efficiency of bobwhites for sorghum, acorn, and P-18 during the second period of a feeding trial consisting of two 3-day periods. Quail were maintained at three different controlled environments.





Smith and Follmer (1972) found that squirrels (Sciurus carolinensis and S. niger) assimilated with different efficiencies the energy from various species of Oak.

Quail utilized sorghum with greater ( $P \leq 0.05$ ) efficiency at 1°C, 10 hours than at 30°C, 15 hours (Fig. 2). The metabolic efficiency of quail kept at 20°C, 10 hours was not different ( $P > 0.05$ ) from that in the other two environments (Table 4).

An increase in metabolic efficiency at lower temperatures was opposite to the observations of Kendeigh (1949) and West (1960). Wilson and Osbourn (1960) stated that rate of food passage rather than plane of nutrition affected efficiency. Rate of food passage is influenced by moisture content of food, its consistency, and hardness (Sturkie 1965:278). The differences in these factors between experimental foods may have affected the rate of food passage and thus the efficiency of energy utilization by quail.

#### Sources of Error

Any contamination of feces with spilled feed would increase the estimate of food consumed, food energy consumed, and of total energy excreted. This error would not affect the calculated metabolized energy, but would tend to lower the efficiency.

The research done at 20°C, 10 hours and 30°C, 15 hours used randomly selected birds in each feeding trial. An individual bird could be fed the same seed more than once, several different seeds, or only one seed during the experiment. It was not possible to measure bird differences statistically, and this could have biased the observations attributed to seed differences.

Slight differences between personnel in laboratory technique could add

additional error into the comparison of the effects of environment on the energy utilization of various seeds.

The effect of a monospecific diet was not determined. Michael and Beckwith (1952) showed that quail fed only one seed species for 20 days lost weight; but, when a second species was added between 20 and 40 days the birds gained weight.

Morphological changes in the alimentary canal which may effect metabolic efficiency occur in relation to diet (Leopold 1953), environment (Davis 1961), and captivity (Moss 1972). No attempt was made to verify possible morphological changes in bobwhites during this study.

## METABOLIC EFFICIENCY: PHASE II

The metabolic efficiency of quail for sunflower, partridgepea, ragweed and prostrate lespedeza were given cursory attention in order to afford further comparison with previous work and to test assumption used in the previous phase of this study.

## METHODS

Three spare quail were fed each seed for several consecutive 3-day periods. Occasionally a feeding trial was terminated early, if the bird appeared to be dying, rather than after a 25 percent weight loss as was done in phase I of the study. Care and treatment of birds and collection of data were described previously. Weight of food and gross energy consumed, total excretory energy, M.E., and metabolic efficiency were calculated for all periods and analyzed to determine differences among periods, in addition to differences among seed.

Percent moisture was estimated in subsamples of seed taken at the beginning and end of each feeding trial. Energy determinations were made on those same samples.

A three-way unequal subclass analysis of variance was performed on the data from the first two 3-day periods for all seeds. A second three-way analysis of variance was conducted on the data collected from quail fed sunflower and prostrate lespedeza for three 3-day periods. Means separation for the main effects was calculated by a Duncan's NMRT for unequal sample size (Kemp 1972). Fourth period data for prostrate lespedeza was eliminated from the analysis of variance due to small sample size and lack of comparable data for sunflower, but was compared to third period data for

prostrate lespedeza by a paired T-test (Fryer 1966).

## RESULTS

### General

The seed energy of sunflower was 6.041 kcal/g. Giant ragweed seeds contained 5.680 kcal/g, prostrate lespedeza, 4.949 kcal/g, and partridgepea, 4.638 kcal/g. These were similar to other reported values (Table 17).

Sunflower was fed to quail for three 3-day periods (27 bird-days). Prostrate lespedeza was fed for four 3-day periods. Bird 326, nearing death was removed at the end of the second period. Thirty bird-days of data were obtained. The feeding trial for ragweed seeds lasted two 3-day periods, but only 9 bird-days of acceptable data were recovered. Two separate feeding trials of partridgepea were conducted with 27 bird-days of data gathered.

It was apparent that birds could subsist without serious weight loss (Fig. 3a) on a diet of sunflower seeds. Two of three quail fed prostrate lespedeza survived for 12 days, but lost weight throughout (Fig. 4a). One bird lost sufficient weight to warrant its removal from the trial after two days. Only one of three birds fed ragweed completed six days of feeding trial, another was removed at three days. Bird #315 lasted four days on a diet of ragweed. While it had consumed feed, its metabolic efficiency of zero and data for this bird were deleted from analysis. Its weight was recorded with those of the other two birds in figure 4b.

Three birds fed partridgepea died, apparently of starvation, in the second 3-day period. Necropsy revealed that both crop and gizzards of these birds retained seeds. All surviving birds had lost considerable weight by the end of the second period and the trial was terminated (Fig. 3b).

### Period Effects

In the comparison of all four seeds, significant ( $P \leq 0.05$ ) differences existed in the amount of food and energy consumed and the total excretory energy during the first and second period (Table 5). No differences ( $P > 0.05$ ) in weight change, M.E. or metabolic efficiency were detected.

On account of the small sample size of quail fed ragweed, and the death of several birds fed prostrate lespedeza, I felt that period effects could be more reliably analyzed using only the data collected on diets of sunflower and prostrate lespedeza. Significant differences ( $P \leq 0.01$ ) for all variables measured were found between periods (Table 6). Weight lost on a diet of sunflower was significantly greater ( $P \leq 0.05$ ) in the first period than in the second or third periods (Table 7). No significant change ( $P > 0.05$ ) was detected between periods for weight loss on a diet of prostrate lespedeza. Consumption of sunflower in the second and third period was not significantly different ( $P > 0.05$ ). The weight of seed consumed in both the second and third periods was greater ( $P \leq 0.05$ ) than in the first period. The weight of prostrate lespedeza consumed increased significantly ( $P \leq 0.05$ ) in each successive period.

Gross energy consumed from sunflower and total excretory energy on both diets were significantly different ( $P \leq 0.05$ ) in each period. The weight of prostrate lespedeza consumed in the third period was less ( $P \leq 0.05$ ) than in the first period.

Energy metabolized was greater ( $P \leq 0.05$ ) in the second and third periods, while metabolic efficiency was higher ( $P \leq 0.05$ ) in the first period. No difference ( $P > 0.05$ ) in any of the variables was found between the third and fourth period for birds fed prostrate lespedeza.



Fig. 3a. Weights of three quail preceeding, during, and after three 3-day periods on a diet of sunflower. Birds were maintained at 1°C and 10 hours photoperiod.

Fig. 3b. Weights of five quail preceeding, during, and after feeding trials (each with two 3-day periods) on a diet of partridge-pea seeds. Birds #316, #317, and #326a were used in the first trial; only #326a survived. Birds #325, #326b, and #327 were used in the second trial. Bird #325 died during the sixth day of the trial. Birds #326b and #327 were provided with grit in addition to partridgepea (....) seed at day 12 and sacrificed at day 15. Data from bird #316 (.-.-) were not used in the analysis of seed value.

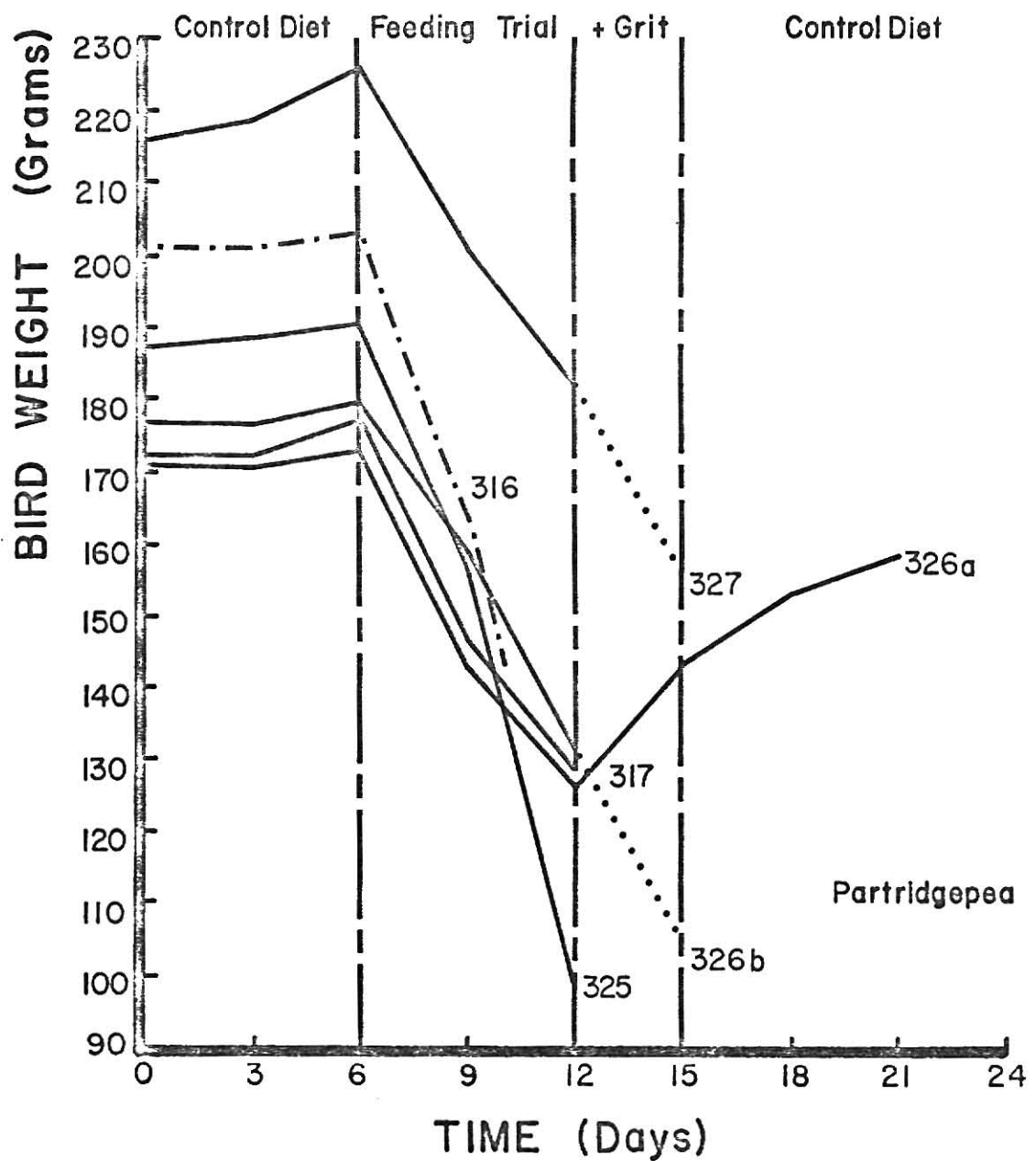
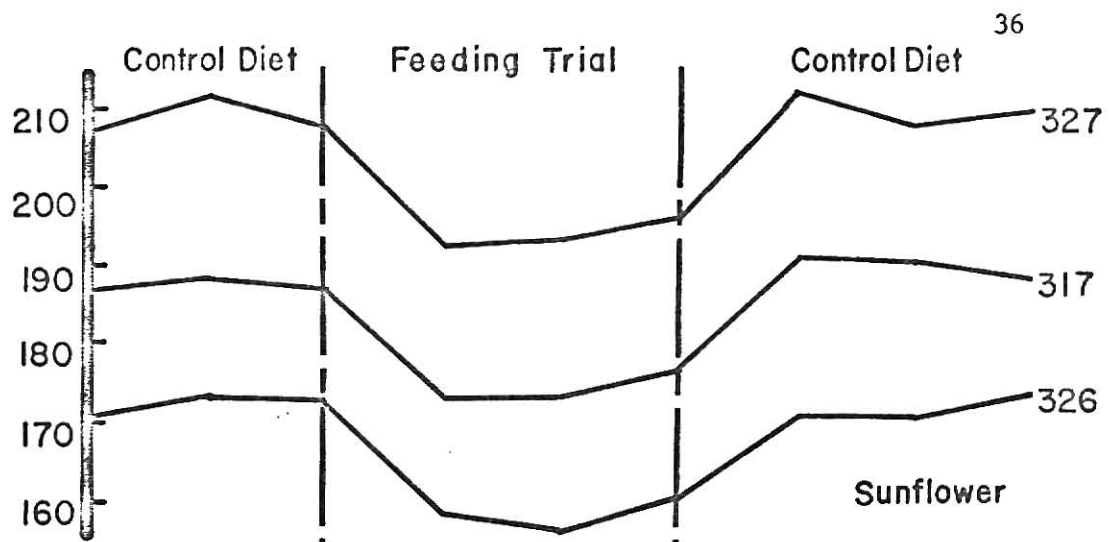






Fig. 4a. Weights of three quail maintained at 1°C, 10 hours photoperiod preceeding, during, and after four 3-day periods on a diet of prostrate lespedeza. Dashed line marks recovery weights of bird #326 after it was removed from the trial at day 12 and provided with P-18 ad libitum.

Fig. 4b. Weights of three quail maintained at 1°C, 10 hours photoperiod, preceeding, during, and after two 3-day periods on a diet of ragweed seed. Dashed line marks recovery weight of bird #326 after it was removed from the trial at day 9 and provided with P-18 ad libitum. Bird #315 (-.-.-) consumed some seed before it was removed from the trial at day 10, but had a metabolic efficiency of zero so data recovered were not used in analysis.

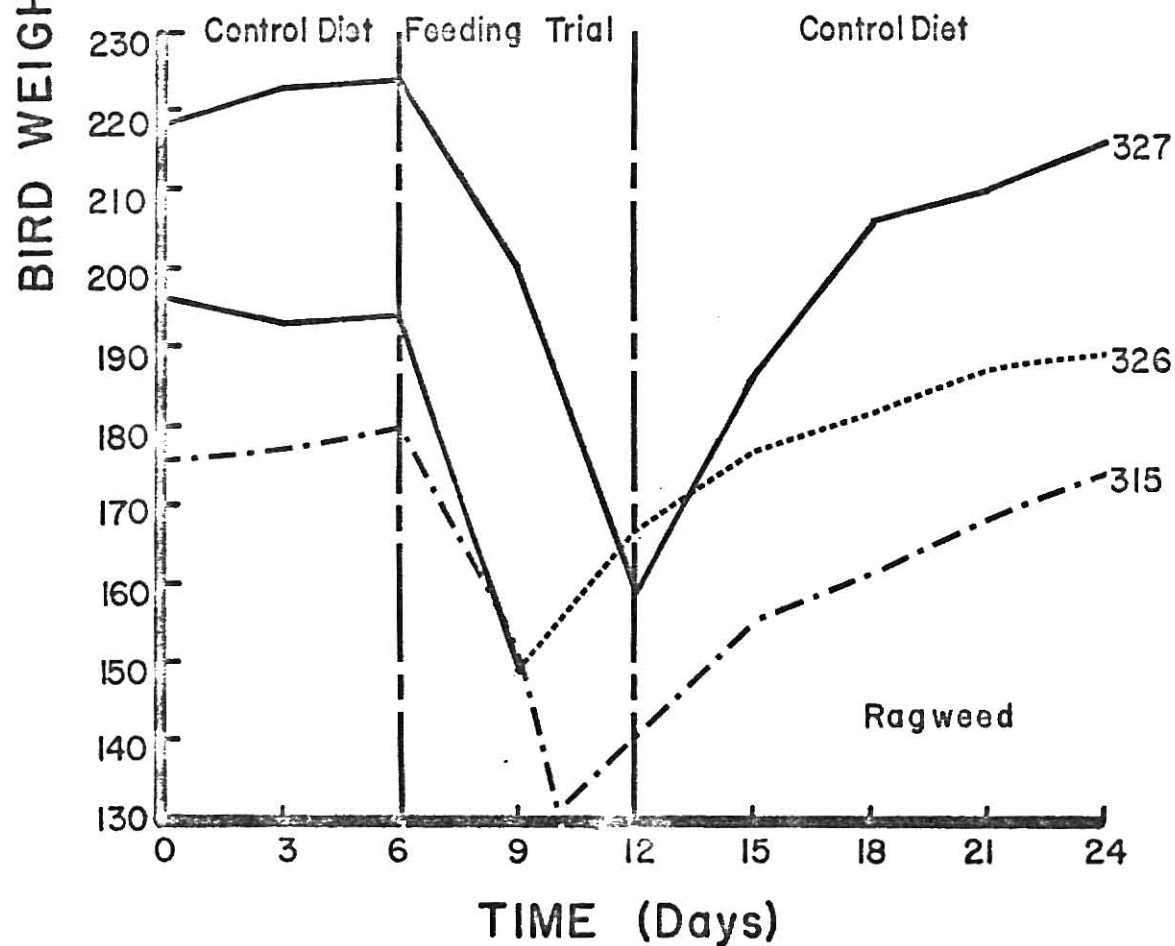
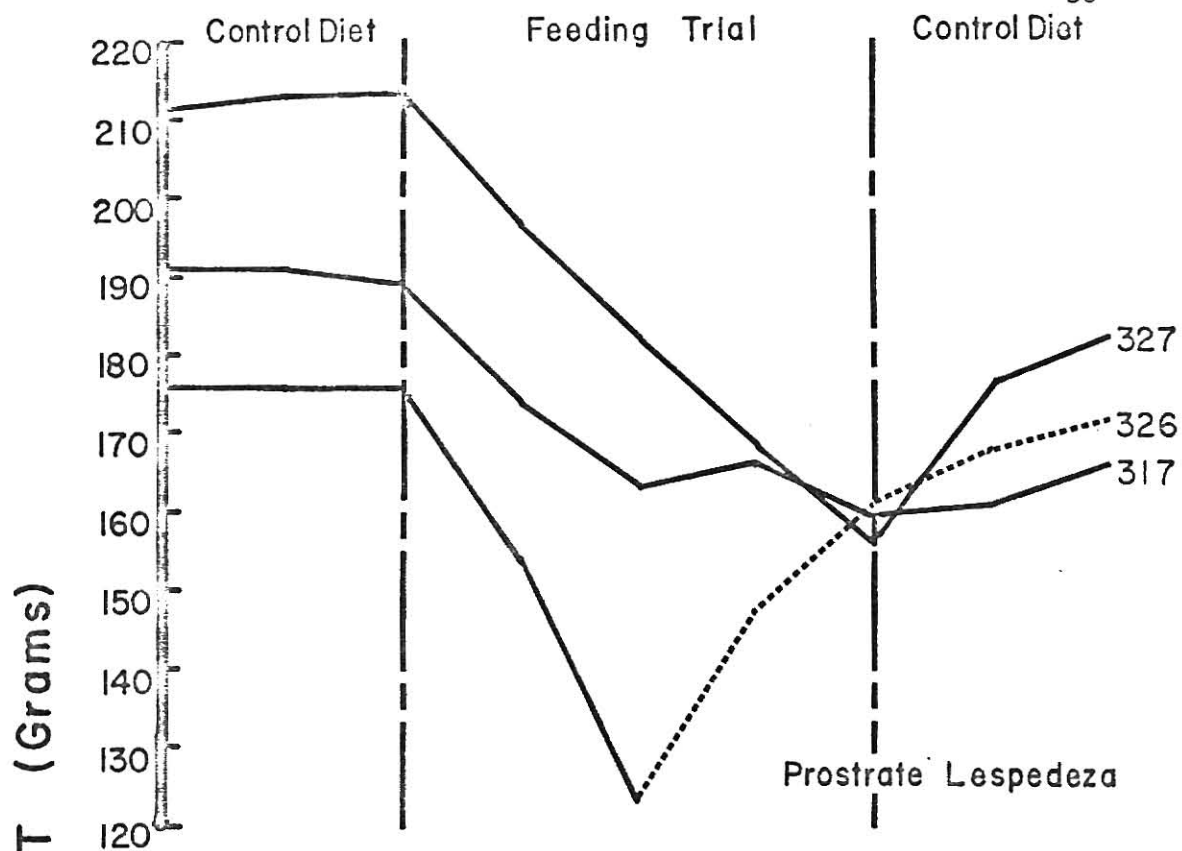


Table 5. F-ratios and error variance of variables for the first and second 3-day periods of phase II, from a three-way unequal subclass analysis of variance.

Source	Df	Weight Change	Feed Consumed	Gross Energy Consumed	Total Excretory Energy	Metabolized Energy	Metabolic Efficiency
Bird	3	5.3*	1.1	1.1	0.9	1.3	0.5
Seed	3	10.1**	10.6**	19.8**	3.2	87.1**	2.8
Period	1	0.6	10.0**	13.6**	4.5	35.6**	0.0
Seed x Period	3	2.7	1.6	2.7	0.6	10.5**	0.8
Error Variance	13	51	56	1015	805	97	0.027

\*Significantly different at  $\alpha = 0.05$

\*\*Significantly different at  $\alpha = 0.01$

Table 6. F-ratios and error variance from an unequal subclass analysis of variance for variables affecting the metabolism by bobwhites of sunflower and prostrate lespedeza during three 3-day periods.

Source	Df	Weight Change	Feed Consumed	Gross Energy Consumed	Total Excretory Energy	Metabolized Energy	Metabolic Efficiency
Bird	2	2.7	0.4	0.4	0.3	0.7	0.6
Seed	1	17.4**	8.4**	49.8**	92.4**	16.7**	66.9**
Period	2	9.4**	75.1**	79.8**	90.5**	51.4**	20.5**
Seed x Period	2	2.3	0.2	2.1	5.1	0.9	2.9
Error Variance	9	26	14	347	59	154	0.0005

\*Significantly different at  $\alpha = 0.05$

\*\*Significantly different at  $\alpha = 0.01$

Table 7. Means from an unequal subclass analysis of variance for variables affecting the metabolism by bobwhites of sunflower and prostrate lespedeza during three 3-day periods. Means from a fourth 3-day period on a diet of prostrate lespedeza are included. Superscripts within columns indicate no significant difference ( $P > 0.05$ ).

	Weight Change (g./3 days)	Feed Consumed (g./3 days)	Gross Energy Consumed (kcal/3 days)	Total Excretory Energy (kcal/3 days)	Metabolized Energy (kcal/3 days)	Metabolic Efficiency (Percent)
Sunflower	Period 1	-13.2 <sup>a</sup>	20.2 <sup>c</sup>	114.10 <sup>cd</sup>	48.93 <sup>b</sup>	69.59 <sup>cd</sup>
	Period 2	-1.6 <sup>b</sup>	39.9 <sup>ab</sup>	224.81 <sup>a</sup>	97.07 <sup>a</sup>	128.30 <sup>ab</sup>
	Period 3	3.4 <sup>b</sup>	48.9 <sup>a</sup>	275.75	125.47	150.28 <sup>a</sup>
Prostrate Lepedeza	Period 1	-17.6 <sup>a</sup>	16.6 <sup>c</sup>	74.87 <sup>d</sup>	26.29	54.46 <sup>d</sup>
	Period 2	-18.4 <sup>a</sup>	33.5 <sup>b</sup>	150.94 <sup>bc</sup>	62.89 <sup>b</sup>	94.21 <sup>bc</sup>
	Period 3*	-6.9 <sup>ab</sup>	42.8 <sup>a</sup>	193.9 <sup>ab</sup>	72.38 <sup>a</sup>	124.25 <sup>ab</sup>
	Period 4*	-9.8	42.3	190.55	72.13	121.70
Standard Error	Prostrate Lepedeza Period 3	±3.7	±2.7	±13.60	±5.63	±9.06
	Period 4	±4.5	±3.2	±14.35	±4.78	±17.61
	All Others	±2.7	±2.2	±10.75	±4.45	±7.16

\*Period 3 and 4 compared by paired T-test with no significant differences ( $P > 0.05$ )

Table 8. Ranked seed means ( $\pm$  standard deviation) averaged for the first and second period 3-day period of phase II from a three-way analysis of variance. Mean energy per gram of excreta is included but was not analyzed. Underlined values are not significantly different ( $P > 0.05$ ).

Weight Change (g)	Sunflower -12.8 $\pm$ 3.3	Prostrate Lespedeza -23.7 $\pm$ 3.3	Partridgepea -29.7 $\pm$ 2.4	Ragweed -31.4 $\pm$ 8.8
Feed Consumed (g)	Sunflower 27.8 $\pm$ 3.4	Prostrate Lespedeza 22.7 $\pm$ 3.4	Partridgepea 12.1 $\pm$ 2.5	Ragweed 3.3 $\pm$ 0.5
Gross Energy Consumed (kcal/3 days)	Sunflower 159.84 $\pm$ 14.50	Prostrate Lespedeza 103.29 $\pm$ 14.50	Partridgepea 50.85 $\pm$ 10.74	Ragweed 17.19 $\pm$ 2.61
Excretory Energy (kcal/g)	Sunflower 4.33 $\pm$ 0.17	Prostrate Lespedeza 3.70 $\pm$ 0.15	Partridgepea 3.51 $\pm$ 0.47	Ragweed 3.32 $\pm$ 0.42
Total Excretory Energy (kcal/3 days)	Sunflower 67.80 $\pm$ 12.91	Partridgepea 41.79 $\pm$ 9.57	Prostrate Lespedeza 39.40 $\pm$	Ragweed 14.65 $\pm$ 0.82
Metabolized Energy (kcal/3 days)	Sunflower 96.32 $\pm$ 4.48	Prostrate Lespedeza 71.72 $\pm$ 4.48	Partridgepea 19.03 $\pm$ 3.32	Ragweed 13.04 $\pm$ 1.14
Metabolic Efficiency (Percent)	Ragweed 76.0 $\pm$ 10.9	Prostrate Lespedeza 69.0 $\pm$ 7.5	Sunflower 60.4 $\pm$ 7.5	Partridgepea 52.1 $\pm$ 5.6

### Weight Change

Significant differences ( $P \leq 0.05$ ) in the mean weight lost by individual birds were detected (Table 5). Bird #325, fed only ragweed and partridgepea, lost 42.5 g, while other birds fed all seeds lost 19.0 to 24.5 g.

Birds fed sunflower lost less ( $P \leq 0.05$ ) weight (12.8 g/3 days) than birds fed other seeds. Weight loss on a diet of ragweed (31.4 g/3 days) was the greatest, significantly different ( $P \leq 0.05$ ) than that for birds on prostrate lespedeza (23.7 g/3 days). A diet of ragweed resulted in a weight loss of 29.7 g/3 days, not different ( $P > 0.05$ ) than the weight lost on diets of ragweed or prostrate lespedeza (Table 8).

### Energy Input Variables

No individual bird differences ( $P > 0.05$ ) in the weight of food or energy consumed were detected. The weight and gross energy consumed of sunflower (27.8 g/3 days, 159.8 kcal/3 days) were significantly ( $P \leq 0.05$ ) greater than other seeds. Prostrate lespedeza (22.7 g/3 days, 103.29 kcal/3 days) was consumed in significantly ( $P \leq 0.05$ ) greater quantity than ragweed (3.3 g/3 days or 17.19 kcal/3 days), but not than partridgepea (12.1 g/3 days or 50.85 kcal/3 days). Consumption of ragweed and partridgepea was not considered to be different ( $P > 0.05$ ).

### Excretory Energy

The total excretory energy produced on a diet of sunflower, 67.80 kcal/3 days, was not significantly different ( $P > 0.05$ ) from that produced on a diet of ragweed, 17.19 kcal/3 days. Energy excreted by quail fed partridgepea and prostrate lespedeza was intermediate, 41.79 and 39.40 kcal/3 days, respectively.



Mean excretory energy calculated from raw data was 4.33 kcal/g on a diet of sunflower, 3.70 kcal/g on prostrate lespedeza, 3.51 kcal/g on partridgepea, and 3.32 kcal/g on ragweed (Table 8).

#### Metabolized Energy

The amount of energy metabolized was significantly different ( $P \leq 0.05$ ) from each of the experimental seeds, except ragweed and partridgepea. The greatest energy was derived from sunflower seeds (94.32 kcal/3 days). Prostrate lespedeza provided 71.72 kcal/3 days. Metabolized energy from ragweed and partridgepea was 13.04 and 19.03 kcal/3 days, respectively.

A significant ( $P \leq 0.01$ ) seed x period interaction (Table 5) indicated that certain seeds were metabolized more during specific periods. It was extremely difficult to determine the exact interactions on account of the confounding effects of comparing means based on different size samples.

#### Metabolic Efficiency

The efficiency of seed energy utilization by bobwhites ranged from 52.1 percent for partridgepea to 76.0 percent for ragweed, but the differences were not considered significant (Table 5).

### DISCUSSION

The small sample of quail used in these feeding trials coupled with the inability to correct the data analysis for differences in birds or unmeasured sources of error associated with the different times of feeding trials, reduces the reliability of conclusions proffered from this experiment. In phase I, differences of 16 kcal/3 days in total excretory energy and 8.5 percent in metabolic efficiency were considered significant. Due to small samples and large error variance in this phase, differences of 53 kcal and 24 percent for the respective variables were not significant.

Due to the death of birds on partridgepea and ragweed, and the small sample of birds fed ragweed, period differences were more accurately analyzed using only the data from diets of sunflower and prostrate lespedeza. All variables, except metabolic efficiency and weight change, were higher ( $P \leq 0.05$ ) in the second, third and fourth periods than in the first period (Table 7). This supported the observations made by Clements (1970) that the first period was one of adaption to a new diet. Weight change of birds on a diet of sunflower was less ( $P \leq 0.05$ ) during the second and third period, but on a diet of prostrate lespedeza was not significantly different ( $P > 0.05$ ) than in the first period. Efficiency was significantly ( $P \leq 0.05$ ) greater in the first period, contrary to the lack of significant difference found by Clements (1970). Peak efficiency was coincident with the lowest intake energy level. It seems reasonable that at lower planes of nutrition and high energy requirements, efficiency would increase due to slower passage of a reduced food volume (Kendeigh 1969a). These same trends were generally observed of birds fed ragweed and partridgepea. Only the metabolic efficiency of the one quail fed ragweed increased in the second period. This increase was coincident with lower consumption.

Quail consumed very little ragweed and partridgepea (3.3 and 12.1 g/3 days, respectively), metabolizing only 13.04 and 19.03 kcal respectively, in three days. The energy used from these seeds was less than one-tenth of existence energy requirements, and weight was lost at a rate near that of starving birds. Evidence from food habits studies (Korschgen 1948, Baumgartner et al. 1952, Robel 1969) indicated that giant ragweed was utilized less than western and common ragweeds, but such a drastic refusal of quail to eat it was not expected. The seeds have sharp spines on one end; and, if

these are felt in the alimentary tract it might account for reduced consumption. Both giant ragweed and partridgepea were considered to be poor seeds for supplying the energy required by quail.

Bobwhite utilized the energy contained in sunflower seeds with comparatively low efficiency, (60.4 percent) but because of its high rate of consumption it provided the greatest amount of M.E. (96.32 kcal/3 days), and was considered the best of the four seeds studied in phase II.

Prostrate lespedeza ranked second highest in metabolic value of the seeds used in this phase, but was of considerably less value than shrub lespedeza, based on the energy metabolized by quail in the second period (91.59 compared to 118.34 kcal/3 days, respectively).

#### Period and Environmental Effects on the Metabolism of Ragweed, Sunflower and Partridgepea

The data gathered from quail fed diets of ragweed, sunflower, and partridgepea and maintained at 30°C, 15 hours; 20°C, 10 hours; and 1°C, 10 hours photoperiod were compared. An unequal subclass analysis of variance was used to determine the effect on quail metabolism of different seeds, environment, periods, and their interactions. On account of unequal sample size, means separation is very complex and of dubious value when considering the small sample of quail fed ragweed at 1°C. There were no significant ( $P > 0.05$ ) seed x environment x period interactions (Table 9), so seed means for the first and second periods were averaged for the three sets of environmental conditions to evaluate period effects (Table 10). The average of variables for both periods were used to determine environment effects on quail metabolism (Table 12).

There were no significant differences ( $P > 0.05$ ) detected between

periods for any of the variables measured from quail fed ragweed. Significantly more ( $P \leq 0.05$ ) energy was metabolized from sunflower in the second period, resulting in a reduced ( $P \leq 0.05$ ) weight change. The weight and gross energy of both sunflower and partridgepea were greater ( $P \leq 0.05$ ) in the second period (Table 10). No differences ( $P > 0.05$ ) in the metabolic efficiency of quail in the first and second period were observed for any of the seeds.

Environment x seed interactions ( $P \leq 0.05$ ) for several variables (Table 9) indicated that the performance of quail on certain diets was different under some environmental conditions. Weight lost by quail fed sunflower did not differ ( $P > 0.05$ ) with the environment, while on a diet of ragweed, weight loss was greater at 1°C, 10 hours than at 20°C, 10 hours and 30°C, 15 hours. Quail fed partridgepea had significantly different ( $P \leq 0.05$ ) weight change in each environment (Table 11). Where differences occurred, the weight loss was greatest at 1°C, 10 hours, due to increased energy expenditures to maintain body temperature (Kendeigh 1969a).

The energy variables measured from birds fed ragweed did not change ( $P > 0.05$ ) at different environmental conditions, with the exception of increased food consumption at 20°C, 10 hours. Variables measured from quail fed on a diet of partridgepea generally increased ( $P \leq 0.05$ ) at 20°C, 10 hours, except that no difference ( $P > 0.05$ ) in total excretory energy in different environments was detected. Although the weight of sunflower consumed at 1°C, 10 hours, was not significantly different ( $P > 0.05$ ) from consumption at 20°C, 10 hours, the gross energy consumed and M.E. was greater at 1°C. All of the energy variables (except total excretory energy) concerning the metabolism of sunflower by bobwhites were significantly lower

Table 9. F-ratios and error variance from a three-way unequal subclass analysis of variance for variables affecting the metabolism by bobwhites of ragweed, sunflower and partridgepea seeds. Birds were maintained at: 1°C, 10 hours; 20°C, 10 hours; and 30°C, 15 hours photoperiod.

Source	Df	Weight Lost	Feed Consumed	Gross Energy Consumed	Total Excretory Energy	Metabolized Energy	Metabolic Efficiency
Environment	2	38.3**	23.3**	31.7**	9.6**	37.8**	1.3
Seed	2	40.1**	43.4**	66.6**	19.9**	88.0**	1.8
Period	1	4.1*	25.2**	31.5**	13.5**	24.5**	0.0
Env. x Seed	4	7.5*	10.2**	13.2**	2.4	21.6**	2.0
Env. x Period	2	1.5	0.3	0.6	0.4	2.6	2.0
Seed x Period	2	3.1*	3.6*	6.0**	2.0	8.9**	1.4
Env. x Seed x Period	4	1.1	0.7	1.2	0.3	2.0	1.4
Error Variance	99	47	38	857	630	213	0.039

\*Significantly different at  $\alpha = 0.05$

\*\*Significantly different at  $\alpha = 0.05$

Table 10. Period means from an analysis of variance of pooled data collected at 1°C, 10 hours; 20°C, 10 hours; and 30°C, 15 hours for the variables affecting the metabolism by bobwhites of sunflower, partridgepea and ragweed seeds. Superscripts within columns indicate no significant difference ( $P > 0.05$ ).

	Weight Change (g)	Feed Consumed (g/3 days)	Gross Energy Consumed (kcal/3 days)	Total Excretory Energy (kcal/3 days)	Metabolized Energy (kcal/3 days)	Metabolic Efficiency (Percent)	
Sunflower	Period 1	-9.1 <sup>a</sup>	15.1 <sup>ab</sup>	86.81 <sup>a</sup>	39.09 <sup>a</sup>	47.71	54.5 <sup>a</sup>
	Period 2	-0.9	26.6	153.80	71.46 <sup>a</sup>	82.34	51.9 <sup>a</sup>
Partridge-pea	Period 1	-15.5 <sup>b</sup>	12.5 <sup>b</sup>	56.91	31.01 <sup>a</sup>	25.90 <sup>ab</sup>	51.6 <sup>a</sup>
	Period 2	-13.6 <sup>ab</sup>	20.1 <sup>a</sup>	91.78 <sup>a</sup>	57.49 <sup>a</sup>	34.29 <sup>a</sup>	44.7 <sup>a</sup>
Ragweed	Period 1	-22.2 <sup>c</sup>	3.1 <sup>c</sup>	16.64 <sup>b</sup>	7.26 <sup>a</sup>	9.39 <sup>c</sup>	52.6 <sup>a</sup>
	Period 2	-23.0 <sup>c</sup>	4.8 <sup>c</sup>	25.60 <sup>b</sup>	10.58 <sup>a</sup>	15.01 <sup>bc</sup>	64.6 <sup>a</sup>

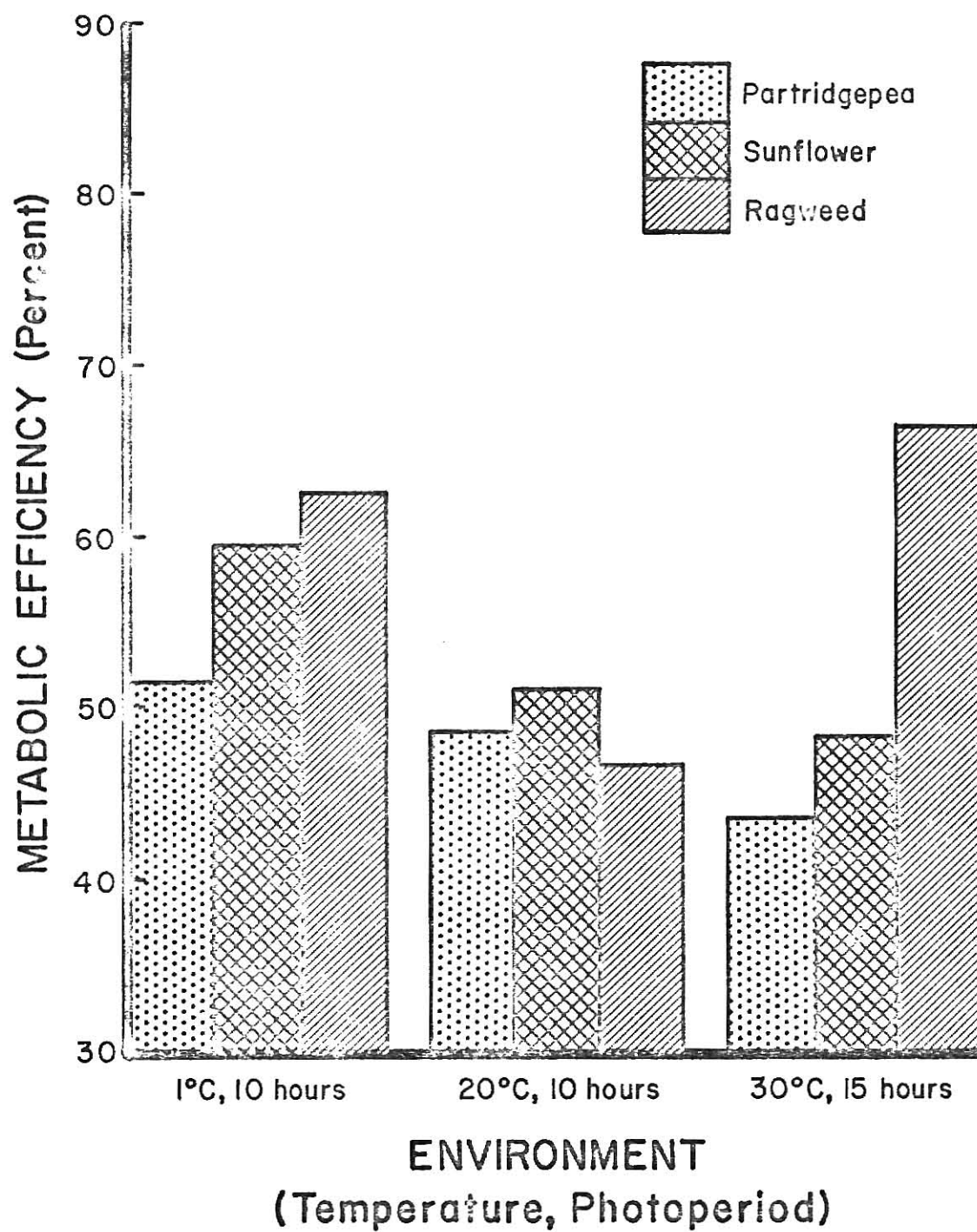
Table 11. Means from an analysis of variance for environmental effects on the variables affecting the metabolism by bobwhite of sunflower, partridgepea and ragweed averaged over two three-day periods. Superscripts within columns indicate no significant difference ( $P > 0.05$ ).

	Weight Change (g/3 days)	Feed Consumed (g/3 days)	Gross Energy Consumed (kcal/3 days)	Total Excretory Energy (kcal/3 days)	Metabolized Energy	Metabolic Efficiency	
Sunflower	1°C, 10 hours	-7.4 <sup>abc</sup>	28.1 <sup>a</sup>	169.55	69.77 <sup>a</sup>	99.78	59.3 <sup>a</sup>
	20°C, 10 hours	-1.5 <sup>a</sup>	22.2 <sup>a</sup>	123.50 <sup>a</sup>	60.20 <sup>a</sup>	63.31 <sup>a</sup>	51.8 <sup>a</sup>
	30°C, 15 hours	-6.2 <sup>ab</sup>	12.2 <sup>b</sup>	67.86 <sup>b</sup>	35.86 <sup>ab</sup>	31.99 <sup>b</sup>	48.5 <sup>a</sup>
Partridgepea	1°C, 10 hours	-29.6 <sup>d</sup>	11.1 <sup>b</sup>	51.57 <sup>bd</sup>	31.86 <sup>abc</sup>	19.71 <sup>b</sup>	59.3 <sup>a</sup>
	20°C, 10 hours	-4.2 <sup>a</sup>	26.2 <sup>a</sup>	118.98 <sup>a</sup>	65.30 <sup>a</sup>	53.68 <sup>a</sup>	48.6 <sup>a</sup>
	30°C, 15 hours	-9.9 <sup>bc</sup>	11.5 <sup>b</sup>	52.49 <sup>bc</sup>	35.60 <sup>abc</sup>	16.88 <sup>c</sup>	43.6 <sup>a</sup>
Ragweed	1°C, 10 hours	-38.1 <sup>d</sup>	2.7 <sup>c</sup>	15.48 <sup>cd</sup>	5.29 <sup>bc</sup>	10.18 <sup>c</sup>	62.7 <sup>a</sup>
	20°C, 10 hours	-15.1 <sup>c</sup>	6.3 <sup>b</sup>	33.15 <sup>cd</sup>	17.06 <sup>bc</sup>	16.08 <sup>c</sup>	46.5 <sup>a</sup>
	30°C, 15 hours	-14.5 <sup>c</sup>	2.8 <sup>c</sup>	14.74 <sup>d</sup>	4.41 <sup>c</sup>	10.33 <sup>c</sup>	66.6 <sup>a</sup>





Fig. 5. Metabolic efficiency of bobwhites for partridgepea, sunflower, and giant ragweed seeds averaged for two 3-day periods. Quail were maintained at three different controlled environments.



at 30°C, 15 hours than at 1°C, 10 hours and 20°C, 10 hours. Total excretory energy did not change ( $P > 0.05$ ) with environment.

The efficiency of energy utilization was not different ( $P > 0.05$ ) under the environmental conditions studied. This agrees with the observations made by Case (1971) for bobwhites, but not with those of Kendeigh (1969a) for passerine species. An increasing trend in metabolic efficiency was noticed for quail on diets of sunflower and partridgepea but was not significant ( $P > 0.05$ ). Failure to show the significance of an 11 percent increase in the metabolic efficiency of quail for sunflower may be due to the small sample of quail used.

## METABOLIC EFFICIENCY, PHASE III

When total energy metabolized from food is less than energy expended, an individual will draw upon its body reserves to make up the deficit. As a result there is an elimination of waste products as uric acid passed with fecal matter. In feeding trials designed to determine the metabolic efficiency of quail on specific diets, the exogenous excretory energy that accompanies weight loss biases the results. This bias can be removed by using a correction factor which can be estimated by dividing total excretory energy produced by starving birds by weight lost. To employ this correction factor it is necessary to assume that the "caloric value of excreta is a direct reflection of the weight loss from tissue breakdown . . ." (Clement 1970:25) and that the average energy lost per gram of weight is the same for groups of experimental birds.

Methods

To calculate a correction factor for weight loss, nine birds were starved. Water was provided ad libitum throughout. Weights were recorded to 0.1 g daily and excreta collected at 3-day intervals. After the first three days of fasting, half of the surviving birds were returned to a diet of P-18 (ad libitum) in order to plot weight recovery rates. Half the quail continued to be deprived of food.

Excreta was prepared for analysis and caloric determinations made according to the procedures described in "Materials and Methods."

The correction factor for weight loss was calculated by dividing total weight lost into the total excretory energy.

Simple correlations were calculated for: (1) initial weight versus total weight loss and survival time (days), and (2) for survival time versus total

weight loss and weight loss/day.

### Results

One bird died at the end of two days of starvation, at 76.0 percent of its initial weight. Two more birds died on the third day. Three of the surviving six birds were provided with P-18; but, food was withheld from the other three survivors for another three days. At the end of six days the only surviving bird refused to eat and succumbed even after being force fed and removal from thermal stress. At death that bird weighed 112.0 g, 57.0 percent of its original weight.

Mean weight loss was 55.8 g/bird accompanied by an average of 7.1 g/bird of excrement. Excretory energy was 2.63 kcal/g with total excretory energy of 18.69 kcal/bird. A correction factor of 0.335 kcal/g of weight lost was calculated ( $18.69 \div 55.8$ ).

Mean initial weight of the nine birds was  $192.5 \pm 12.1$  g., the mean final weight (at death or when fasting terminated)  $136.6 \pm 12.4$  g, and the mean weight lost  $55.8 \pm 14.9$  g ( $28.9 \pm 6.79$  percent). While one bird survived six days of starvation, it died within 2 hours after the trial terminated, and for all practical purposes was considered to have died within the trial period. Six birds that died of starvation had a mean initial weight of  $192.8 \pm 14.2$  g, mean weight at death of  $133.0 \pm 13.2$  g and mean weight loss  $30.9 \pm 6.6$  percent ( $59.8 \pm 15.0$  g). A correlation of several variables from the six dead birds revealed no significant correlation ( $P > 0.10$ ) between initial weight and total weight lost ( $r = 0.61$ ), or survival time ( $r = 0.54$ ). Survival time was inversely correlated ( $P \leq 0.01$ ) with mean weight loss/day ( $r = -0.79$ ) and positively correlated ( $P \leq 0.01$ ) with total weight loss ( $r = 0.98$ ).

Birds recovered 12.9 g/3 days initially. This was reduced to 9.9 and 9.6 g/3 days during the next two 3-day periods, and finally to 3.5 g/3 days in the final observed period.

#### DISCUSSION

Even without food, quail were able to subsist for several days at low temperatures. Maximum survival under mean winter conditions in Kansas (1°C, 10 hours photoperiod) for healthy quail weighing 195 g would be approximately six days. Average survival as determined in my study time was three to four days.

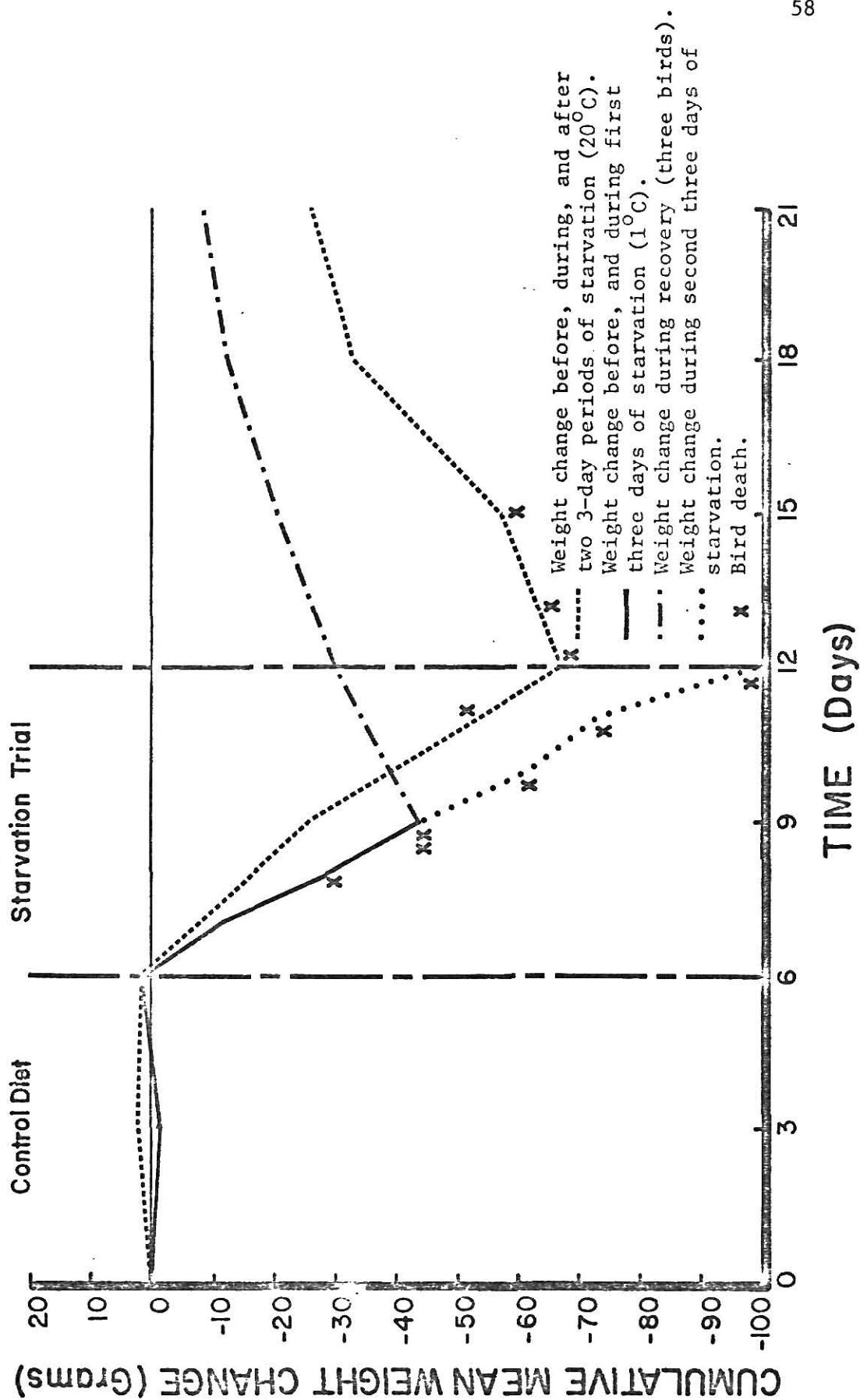
The correlation of initial weight to total weight loss ( $r = 0.61$ ) and survival time ( $r = 0.54$ ) was not significant ( $P > 0.10$ ) and failed to provide statistically significant evidence supporting the observations of Kendeigh (1945) that heavier (fatter) birds lose more weight and survive longer. A larger sample size would test this more precisely. Survival time was correlated with the tolerance of birds to lose a large amount of weight ( $r = 0.98$ ) at low daily rates ( $r = -0.79$ ) as suggested by Kendeigh (1945). Bird #323 was near average weight (192.2 g), but died during the second day of starvation after losing 24.3 percent of its body weight at a rate of 23.3 g/day. Bird #324, the lightest bird (180.5 g), lost 31.0 percent of its body weight (16.0 g/day) and survived 3.5 days. Bird #328 (195.9 g) had the greatest weight loss (42.8 percent) with the lowest rate (14.0 g/day) and survived the longest, 6 days.

The effect of temperature is an important factor in the length of survival. Clements (1970) reported only one death for nine birds starved 6 days at 20°C, 10 hours photoperiod. Birds at 20°C lost more weight but



Fig. 6. Cumulative mean weight change of nine quail before, and during two 3-day periods of starvation at 1°C and 20°C, 10 hours photoperiod. After three days of starvation, three of the surviving quail at 1°C were fed P-18 ad libitum. Initial weight of quail at 20°C was 177.1 g, and at 1°C, 192.5 g.





more slowly (39.8 percent of initial body weight at a rate of  $11.8 \pm 4.5$  g/day) than birds at  $1^{\circ}\text{C}$  (30.9 percent of initial weight at a rate of  $16.8 \pm 3.4$  g/day) (Fig. 6). The correction factor was very similar at both temperatures, 0.336 kcal/g at  $1^{\circ}\text{C}$  and 0.356 kcal/g at  $20^{\circ}\text{C}$ .

Barrett and Bailey (1972) maintained pheasants on diets of high, medium, and low metabolizable energy to determine dietary effects on their general health and reproduction. There was a significant difference in weight of males on high and low energy diets, and this difference was positively correlated ( $r = 0.67$ ) with percent body fat. Male pheasants on the high energy diet had a mean of 32.1 percent fat, and those on the low energy diet had 3.7 percent fat on a dry weight basis. The percentage of protein was not reduced as much at lower body weight as was fat.

Birds with less than 5 percent fat contained 67.1 percent moisture in the body; while fat birds ( $> 25$  percent fat) had 58.7 percent moisture, indicating that fat deposits had less water than the mean for other body tissues. The composition of the total weight difference between heavy and light weight males was attributed to 16.7 percent protein, 34.4 percent water, and 48.9 percent fat.

If the difference in body composition between birds maintained in prime, and in near starving condition is similar to birds reduced from prime to starving condition, and data from pheasants is applicable to quail, then an estimate of the efficiency of utilization of body tissues (fat and protein) can be calculated. The values of Barrett and Bailey (1972) were used to calculate efficiency of body tissue metabolism on account of the controlled nature of their experiment and the presence of an estimate for percent protein metabolized. If 48.9 percent of the 59.6 g weight loss by starved quail consisted of fat with a gross energy of 9.54 kcal/g (Pritham 1968:353) then

278.04 kcal ( $.489 \times 59.6 \times 9.45$ ) could be produced by metabolizing it. Similarly 56.24 kcal ( $.167 \times 59.6 \times 5.65$ ) could be produced from 9.95 g of protein with an energy of 5.65 kcal/g (Pritham 1968:353).

For the sake of calculating minimum efficiency for fat metabolism, consider that all of the mean total excretory energy (18.69 kcal) produced by the six quail before death, was from fat metabolites rather than both fat and protein metabolites. The minimum metabolic efficiency for fat would be 93.3 percent ( $\frac{278.04 - 18.69}{278.04}$ ). Minimal efficiency of protein utilization would be 66.8 percent ( $\frac{56.24 - 18.69}{56.24}$ ).

It is known that fat is oxidized nearly completely to  $\text{CO}_2$  and  $\text{H}_2\text{O}$ , and that protein has large amounts of minerals and nitrogen as waste during metabolism. Excreta, therefore, would be largely metabolites from protein with a much smaller ratio from fat. The actual metabolic efficiency of protein should be close to the minimal value calculated and efficiency of fat metabolism would be higher than calculated. Pritham (1968:353) states that efficiency of fat metabolism was 94.3 percent and of protein metabolism was 70.8 percent. The calculated minimum values seem within reason. However, the total M.E. from 278.04 kcal of fat used with 94.3 percent efficiency plus 56.24 kcal of protein used with 70.8 percent efficiency would be 302.00 kcal/3 days. For quail with an existence requirement of 172 kcal/3 days, the energy derived from storage compounds would provide 5.2 days of survival. The quail in my study survived 3.8 days suggesting that the estimate of 48.9 percent of weight loss being due to fat metabolism might be high. Robel (1972) found that 193 g wild quail during the winter months near abundant food sources had 19.2 percent fat on a dry weight basis. This figure included adult and juvenile birds of both sexes, and is probably lower

than the fat content of inactive caged adult quail. Twenty-seven percent of the caged pheasants analyzed Barret and Bailey (1972) had greater than 25 percent body fat.

During December and January 28.8 percent of the quail collected by Robel (1972) had greater than 25 percent of dry body weight as fat. This indicates that the data obtained from pheasants for the composition of weight loss is reasonably applicable to caged quail, although it would appear that a lower percentage of weight lost by quail could be attributed to the metabolism of fat.

## EFFECTS OF GRIT

Based on the premises that quail would retain grit for long periods (Nestler 1949a) and that efficiency of seed utilization would be little affected without grit (Fritz 1937), no grit was provided during the experiments on metabolic efficiency.

Feeding trials involving partridgepea cast aspersions on these premises. Three birds fed this diet died, apparently of starvation, yet seed was present in both the crop and gizzard. Two birds had no grit in the gizzard at death and the third had one small piece (0.02 g). Another quail voided excreta during the second 3-day period which consisted almost entirely of whole seeds (Plate 1).

To test the validity of results from the metabolic efficiency studies, and to evaluate the effects of grit on the digestive ability of quail, a feeding trial was conducted.

## METHODS

The effects of quartz grit were tested on the digestibility of shrub lespedeza and partridgepea, on account of their hardness and availability.

Twelve quail were paired by weight. Commercial "fine" granite poultry grit was provided to one bird of each pair three days before all birds were placed on a diet of shrub lespedeza. Seed which passed through a 2.39 mm screen was used in conjunction with grit which would not pass through. The data collected from two consecutive 3-day periods were analyzed statistically.

Three control birds used in the first phase of the digestive efficiency experiment were provided with grit and P-18. Data from the second 3-day period was compared to data collected in the same period of the fifth and

sixth feeding trials of phase I when grit was not available.

Two quail, having been fed partridgepea without grit for two 3-day periods, were retained on this diet for an additional 3-day period, but provided with grit less than 2.39 mm in diameter. Seeds which were greater than 2.39 mm were used as feed.

During cage cleaning, spilled grit and seed were removed from excreta. Seed and grit were then separated through a 2.39 mm screen. Drying, grinding, and energy determination of excreta were completed as described in the Materials and Methods section of this report (pg 10).

At the end of the feeding trial, all quail except those on a diet of partridgepea were sacrificed and the gizzard examined for grit. Weight change, weight and total energy of food consumed, total excretory energy, M.E., metabolic efficiency and weight of grit in the gizzard at death were measured.

Passage of grit with excreta would lower the estimate of excretory energy/g calculated by caloric determination. Caloric values for excreta produced by birds with access to grit was corrected for the percentage calorimetric ash in excess of the mean percent ash in excreta of birds without grit. A second estimate of excretory energy from birds with grit was calculated using, as a correction factor, the percentage grit recovered after decanting ground excreta in carbontetrachloride (Korschgen 1969). Ashfree excretory energy of both seed and excreta was determined by subtracting the weight of ash after caloric determination from the sample weight (Golley 1961). These corrected and ashfree values for excretory energy were used to calculate three values for metabolized energy and efficiency.

Errors in determining ash content of substances may result using

calorimetric wastes (Paine 1964). To test whether the high temperatures produced during calorimetric determinations affect the weight of quartz (siliceous) grit, four samples were placed in a muffle furnace at 650°C. Two were removed and weighed after 4 hours and two after 24 hours.

The ash content of excreta produced by birds with and without grit, and the estimates of grit by calorimetric and decantation procedures were compared by T-test ( $\alpha = 0.05$ ), after Hartley's F-max test ( $\alpha 0.05$ ), for homogeneity of variance (Fryer 1966).

A two-way analysis of variance was conducted on the data collected from the quail fed shrub lespedeza to determine the effects of grit on each variable during different periods. Data from the second 3-day period for birds on diets of P-18 and shrub lespedeza were subjected to a two-way analysis of variance to determine if the effect of grit changed with different diets. A simple correlation analysis was conducted on second period data.

## RESULTS

Grit that quail obtained in the hatchery before confinement in a controlled environment chamber was brown and easily distinguished from the white quartz grit fed during this experiment. Post-mortem examination showed that some grit was retained by most birds throughout the nine months of experimentation. Three control birds, fed only pelletized P-18, had retained  $0.41 \pm 0.15$  g and added to it only  $1.10 \pm 0.08$  g of quartz grit. Six birds that had been deprived of grit retained  $0.05 \pm 0.08$  g. Five of those birds had almost no grit ( $< 0.03$  g) but one bird had one large piece, 0.22 g. Six birds given access to grit in the last feeding trial retained some native grit,  $0.09 \pm 0.07$  g, but had consumed far more quartz grit,  $1.55 \pm 1.10$  g.

Significantly more ( $P \leq 0.05$ ) grit (and ash) was contained in the excreta voided by quail with access to grit. No difference ( $P > 0.05$ ) was detected between the estimates of grit determined by decantation and calorimetric methods.

Grit passed during the first period from quail fed shrub lespedeza varied between 0.03 and 9.56 ( $\bar{x} = 3.47$ ) percent of excreta (by weight), significantly lower ( $P \leq 0.05$ ) than during the second period, 0.31 to 24.14 ( $\bar{x} = 11.04$ ) percent as determined from calorimetric ash. Grit recovered by decanting excreta was generally lower than, but not different ( $P > 0.05$ ), from calorimetric estimates. Decanted grit in the first period, 2.41 percent (0.41 to 6.84 percent), was less ( $P \leq 0.05$ ) than in the second period, 7.12 percent (0.21 to 17.59 percent) of excreta weight.

There was no significant difference ( $P > 0.05$ ) between percentage ash in the excreta of control birds, with or without grit. It was assumed that little or no grit was passed. Decantation validated this assumption.

Calorimetric estimates for grit passage by two quail fed partridge-pea were 32.62 and 12.03 percent of excreta weight, while the estimates from the decantation of excreta from the same two birds were 25.87 and 12.12 percent, respectively.

A test of the decantation procedure by mixing a known amount of ground grit with grit-free excreta had 100 percent recovery.

Samples of grit incinerated at  $650^{\circ}$  had negligible (0.002%) weight loss after 4 and 24 hours.

The correlation analysis (Table 12) indicated that there was no significant relationship ( $P > 0.05$ ) between efficiency and amount of grit in the gizzard.



Significant differences ( $P \leq 0.01$ ) were found between the first and second period for all variables except efficiency and between diets of P-18 and shrub lespedeza for all variables except weight change and gross energy consumed (Table 13). Figure 7 gives the mean weight of quail before and during the feeding trial. No significant differences ( $P > 0.05$ ) attributed to the effect of grit were detected in any of the variables except M.E. from partridgepea.

The means for variables measured from quail on diets of P-18 and shrub lespedeza for both grit treatments were almost identical (Table 14) within periods.

The weight and gross energy of partridgepea consumed increased 27.8 percent when grit was made available to the quail. Metabolized energy increased between 82.1 and 85.5 percent, and metabolic efficiency between 3.9 and 8.3 percent when grit was available. Only the increase in M.E. was significant ( $P \leq 0.05$  to  $P \leq 0.01$ ).

## DISCUSSION

Quail demonstrated their ability to retain grit for long periods of time. Experimental birds fed whole seeds retained less grit ( $0.07 \pm 0.07$  g) than control birds ( $0.41 \pm 0.15$  g) on a diet of P-18 mash. This agreed with the effect of diet on retention time described by Hollingsworth et al. (1965). It is doubtful if the small amount of grit retained by birds fed whole seeds had any functional value.

Quail on a diet of shrub lespedeza with grit had more grit ( $P \leq 0.05$ ) in the gizzard at death ( $1.64 \pm 1.14$  g) than birds fed P-18 with grit ( $0.51 \pm 0.12$  g). About 6 percent grit was passed in the excreta of birds fed whole seeds with grit, while those fed P-18 with grit had negligible grit passage.

Table 12. Simple correlation matrix showing relationship among the sixteen variables considered in determining the effect of grit on digestive efficiency in the second 3-day period of a feeding trial.

Variable	1	2	3	4	5	6	7	8
1. Weight Change								
2. Food Cons.	-0.02							
3. Energy Cons.	-0.02	1.00**						
Total Excretory Energy:								
4. Corrected	0.12	0.84**	0.84**					
5. Ashfree	0.12	0.84**	0.84**	1.00**				
6. Decanted	0.12	0.86**	0.86**	0.99**	0.99**			
Metabolized Energy:								
7. Corrected	-0.29	0.20	0.20	-0.36	-0.37	-0.32		
8. Ashfree	-0.29	0.09	0.09	-0.45	-0.47	-0.41	0.99**	
9. Decanted	-0.32	0.18	0.18	-0.36	-0.36	-0.34	0.97**	0.96**
Efficiency:								
10. Corrected	-0.24	-0.58*	-0.58	-0.93**	-0.93**	-0.89**	0.68*	0.75**
11. Ashfree	-0.24	-0.57*	-0.57	-0.92**	-0.92**	-0.88**	0.68*	0.76**
12. Decanted	-0.26	-0.63*	-0.63	-0.94**	-0.94**	-0.94**	0.62*	0.69*
13. Gizzard Grit	-0.10	-0.21	-0.21	0.04	0.06	-0.08	-0.42	-0.44
Variable	1	2	3	4	5	6	7	8
Efficiency:								
10. Corrected	0.65*							
11. Ashfree	0.65*	1.00**						
12. Decanted	0.65*	0.98**	0.97**					
13. Gizzard Grit	-0.22	-0.24	-0.28	-0.05				
Variable	9	10	11	12				

\* Significant ( $P \leq 0.05$ )

\*\* Significant ( $P \leq 0.01$ )

Table 13. F-ratios and error variance from a two-way unequal subclass analysis of variance for the effects of grit on the variables affecting seed metabolism by bobwhites. Comparison I: the effects of grit on the metabolism of shrub lespedeza in the first and second 3-day periods. Comparison II: the effects of grit on the metabolism of P-18 and shrub lespedeza in the second 3-day period. Comparison III: the effects of grit on the metabolism of partridgepea.

Source	Df	Weight Change	Feed Consumed	Gross Energy Consumed	Corr. <sup>a</sup>	Ashfree Dec. <sup>b</sup>	Corr. <sup>a</sup>	Ashfree Dec. <sup>b</sup>	Corr. <sup>a</sup>	Ashfree Dec. <sup>b</sup>	Corr. <sup>a</sup>	Ashfree Dec. <sup>b</sup>
Comparison I												
Period	1	61.4**	39.6**	39.6	21.5**	21.1**	21.2**	23.4**	31.2**	25.3	3.8	3.8
Grit	1	2.6	0.6	0.6	0.1	0.1	0.3	0.8	1.1	0.3	0.2	0.0
Period x Grit	1	0.3	0.5	0.5	0.5	0.4	0.7	0.1	0.2	0.0	0.2	0.5
Error Variance	20	11	44	888	455	523	441	280	403	275	0.002	0.002
Comparison II												
Seed	1	0.1	9.8**	0.1	34.4**	24.0**	178.3**	72.1**	37.3**	260.9**	91.8**	604.2**
Grit	1	0.1	1.1	0.1	0.2	0.2	0.5	0.8	1.1	0.3	0.0	0.1
Seed x Grit	1	0.7	0.6	0.6	0.3	0.2	0.5	0.2	0.3	0.0	0.0	0.1
Error Variance	17	124	24	450	378	442	354					
Comparison III												
Grit	1	0.2	0.3	0.3	0.0	0.0	0.0	49.6*	11.8	201.5**	0.1	0.1
Error Variance	2	31	181	3631	3991	4373	3841	21	67	7	0.047	0.045

<sup>a</sup>Total energy values of excreta from birds with grit, corrected for ash in excess of mean ash in excreta from birds without grit.

<sup>b</sup>Corrected for grit recovered from decantation of excreta.

\*\*Significantly different at  $\alpha = 0.05$ .

Significantly different at  $\alpha = 0.01$



Table 14b. Means at variables measured to determine effect of grit on energy utilization.

		<u>Metabolized Energy (kcal/3 days)</u>		<u>Metabolic Efficiency (kcal/3 days)</u>			
		Corrected	Ashfree	Decanted	Corrected	Ashfree	Decanted
Shrub Lespedeza	Period 1, no grit	93.2±6.8	111.7±8.2	93.1±6.8	56.95±2.0	58.81±1.9	56.88±1.9
	Period 1, grit	89.2±6.8	106.6±8.2	90.6±6.8	55.09±2.0	56.36±1.9	55.67±1.9
	Period 2, no grit	128.6±6.8	160.9±8.2	128.3±6.8	52.10±2.0	56.21±1.9	51.99±1.9
	Period 2, grit	120.3±6.8	148.9±8.2	123.3±6.8	52.19±2.0	55.78±1.9	53.64±1.9
P-18	Period 2, no grit	181.5±5.8	201.2±6.5	-----	74.10±2.0	72.58±1.9	-----
	Period 2, grit	178.3±8.3	197.7±9.2	-----	73.55±2.9	72.09±2.7	-----
Partridge	Period 2, no grit	38.4±3.2	34.3±5.8	38.4±1.9	40.02±15.4	36.7±15.7	40.1±15.1
	Period 3, grit	70.7±3.2	62.5±5.8	75.6±1.9	45.60±15.4	40.68±15.7	48.47±15.1

These differences may be related to seed hardness and the necessity for an abrasive to remove hard seed coats; but, the insignificant change in metabolic efficiency in the presence of grit makes this relationship tenuous. Birds fed whole seed had almost no grit in the gizzard, and the consumption and passage of large amounts of grit may have been a compensatory action. Nestler (1946) found that quail given access to grit after a period of deprivation consumed 1.5 g/day initially, but only 0.8 g/day after a period of time.

Large differences in the grit requirements of individual birds was observed. Of six birds fed shrub lespedeza with grit, four birds had  $1.33 \pm 0.26$  g, one bird had 0.63 g, and another had 3.86 g of grit in the gizzard at death. Grit in the gizzards of these birds was significantly ( $P \leq 0.05$ ) correlated to the amount of grit passed in the excreta ( $r = 0.86$  based on decanted grit,  $r = 0.89$  based on calorimetric ash). Hollingsworth et al. (1965) observed similar variability in grit consumption and passage in poultry. Vance (1971) showed that pheasants lacking essential elements had increased grit requirements. Bobwhites used in my experiments were maintained on a "balanced diet"; and, it is doubtful that mineral deficiencies would develop in less than six days on a diet of shrub lespedeza. Whether the differences in consumption by grit by these birds was due to individual differences or mineral deficiencies in the diet was not ascertained.

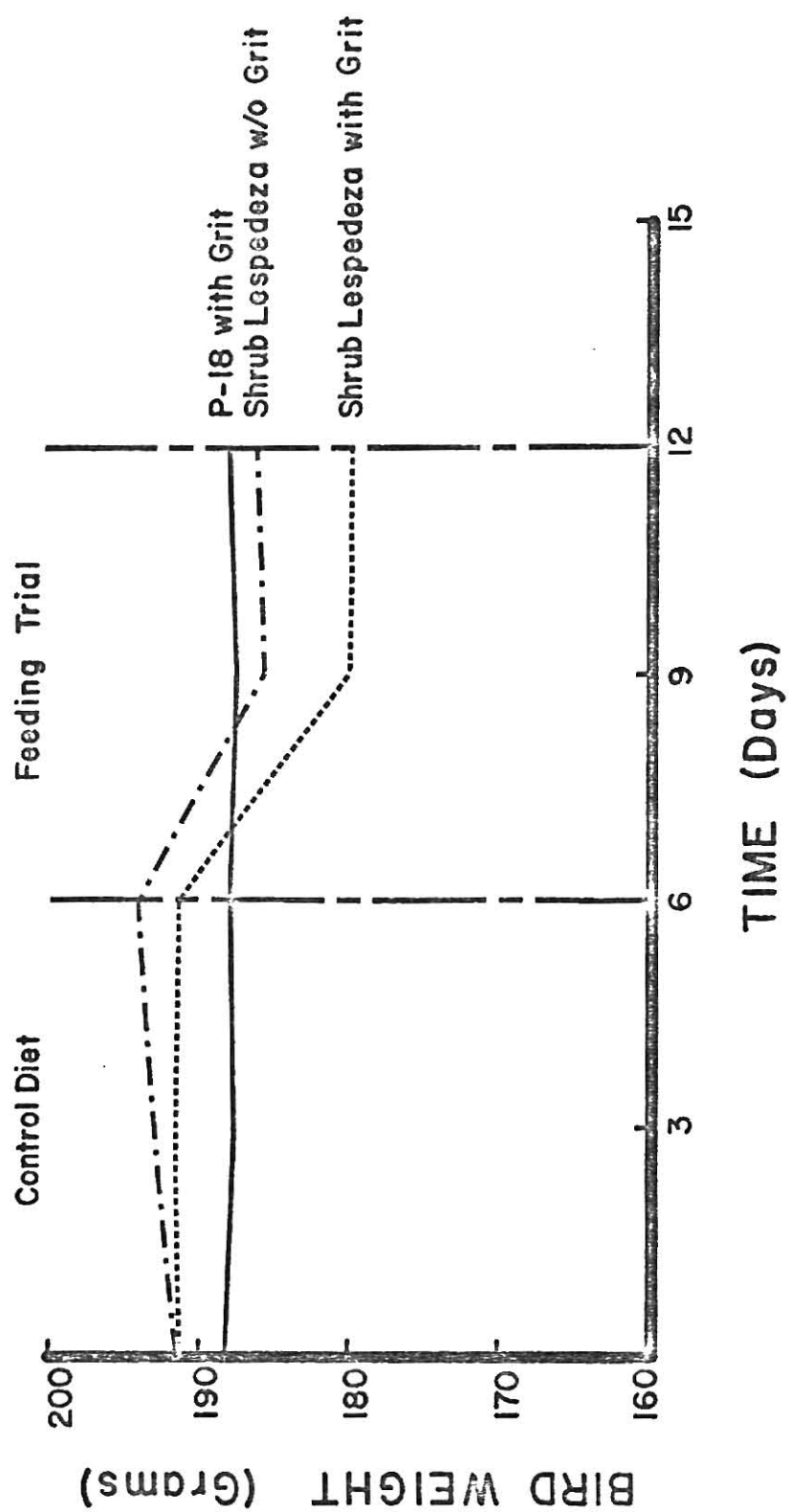
Access to grit resulted in no change in any of the measured variables for birds fed P-18 and shrub lespedeza. F-ratios calculated from the mean squares of the analysis of variance (Table 13) for grit are generally small indicating no effects due to grit.

The two quail on a diet of partridgepea did, however, show large differences in feed consumption, M.E., and metabolic efficiency (Table 14) when grit was



Fig. 7. Weight changes of twelve quail on a diet of shrub lespedeza, six with grit, six without grit, and three quail on a diet of P-18 and grit, preceeding and during two 3-day feeding trials to test the effect of grit on metabolic efficiency. Birds were maintained at 1°C, 10 hours photoperiod and sacrificed after the study.





available. Only the increase in M.E. based on total excretory energy corrected for gut passage was significant ( $P \leq 0.05$  to  $P \leq 0.01$ ). I believe that the failure to show significant differences in most of these variables was related to the lack of power due to small sample size, rather than to an actual lack of effect due to grit. An experiment with larger sample size would more accurately assess the grit effects.

Bird #327 consumed much more partridgepea without grit than did bird #326; however, it also passed most of these seeds in an undigested state (Plate 1). Given access to grit, the weight of food consumed by bird #327 did not increase, but that of bird #326 more than doubled. Very few seeds from either bird remained unground after consumption with grit. The total excretory energy was essentially the same with grit (97 kcal/3 days) as without (96 kcal/3 days), and this in combination with increased energy intake when grit was available resulted in greater M.E. ( $P \leq 0.05$  for corrected M.E. values) and higher metabolic efficiency.

The efficiency of energy utilization by bird #327 increased from 18.8 percent without grit to 36.7 percent with grit present; however, the efficiency of bird #326 dropped from 57.8 to 51.6 percent when grit was available. It appears that bird #327 was unable to break the hard seed coats without grit, resulting in near maximum food consumption but low metabolic efficiency. Bird #326 was able to grind the seed without grit, but presumably with difficulty. This manifested itself in peak metabolic efficiency but low consumption. Once grit was available, birds were apparently able to grind seeds more effectively. Bird #327 increased its metabolic efficiency. Bird #326 increased its plane of nutrition, but sacrificed some efficiency of energy utilization as was suggested by Kendeigh (1969a).

The difference between the two methods for determining grit passage in excreta were not significantly different; although, the decantation estimate was lower for all but one bird. It was expected that a greater error would be incurred by the decantation process due to small particles of grit being decanted off; however, a test of this method by mixing ground grit in grit-free excreta had complete grit recovery. A homogenous mixture of discrete grit and excreta particles cannot accurately simulate the intimate association of excreta with grit produced by a bird. It is possible that grit particles enveloped in fecal matter could have sufficiently reduced specific gravity to be decanted off. Grinding excreta before decantation was believed to reduce this error. To completely and accurately remove the bias of grit passage in excreta, ashfree energy determinations could be used.

Shrub lespedeza was chosen because it was the hardest of the seeds available. It turned out, however, to be a poor seed with which to test the effects of grit. The seed coat is not "hard" but leathery and when the seeds are placed in a moist area (the crop) they imbibe water, becoming very soft and easily crushed, with or without grit. Jensen and Korschgen (1947) found that Korean lespedeza and showy partridgepea were proportionally lower in the gizzard than in the mixed seed diet placed in the crop, indicating that they were easily ground. I believe that ease of grinding is true for shrub lespedeza but not for partridgepea when fed alone. The large numbers of whole seeds passed by bird #327, as well as post-mortem observations on dead quail fed partridgepea support this belief. The seed coat of partridgepea is hard and does not soften appreciably when moistened. It takes more than 70 lbs. to crack the coat of partridgepea and about 25 lbs. to squash dry, "hard" lespedeza (Bisset and Hartowicz unpublished).

Grit was only of value in grinding hard seeds. A more accurate estimate of the value could be obtained from a study using a balanced statistical design with partridgepea or whole corn as a diet.

## RATE OF FOOD PASSAGE

Energy demands of homeotherms at temperatures below the thermoneutral range, necessitate procurement of greater quantities of energy by increasing consumption, increasing metabolic efficiency of available energy, or by morphological adaptations. Results of the digestive efficiency study (Phase I & II) indicate that all comparable seeds, except ragweed and partridgepea, were consumed in greater amounts at 1°C, 10 hours, than at 20°C, 10 hours, or 30°C, 15 hours photoperiod. Metabolic efficiency of bobwhites also increased for four of the six seed species used in phase I.

Very little has been written about the rate of passage of food through quail, and nothing comparing rates at different temperatures. McFarland and Freeland (1959) measured the time for food passage through coturnix quail and Boyd (1970) did a similar study with bobwhite, both at thermoneutral temperatures. Leopold (1953) found that California quail (Lophortyx californica) on nutritionally poor diets had greater gut length than those on nutritious diets. Davis (1961) found an increase in the gut length of rufous-sided towhees during winter. Greater gut length allowed a longer time for food passage, resulting in greater digestive breakdown.

A pilot study was conducted to determine if increased nutritional volumes of bobwhite kept under approximately mean northeastern Kansas winter conditions were accompanied by a change in rate of passage, compared to that of quail maintained under mean summer conditions.

## METHODS

Food passage rate studies were conducted with eight bobwhite acclimated to 20°C with 15 hours light/day and four acclimated to 1°C and 10 hours light.

One trial was attempted using the 48 x 25 x 13 cm polypropylene cages,

but this proved unsatisfactory due to accumulation of excreta. Birds were transferred to small wire bird cages, 26 x 17 x 25 cm, with removable bottoms and elevated floors of 12.7 mm hardware cloth. A stack of papers, each with bird number and removal time, was placed in the bottom of each cage. At the beginning of the trial a gelatin capsule with 200 mg of chrome sesquioxide ( $\text{Cr}_2\text{O}_3$ ) marker was placed into the esophagus of each bird.

Ad libitum feeding of pelletized P-18 was allowed after capsule insertion. The number of excreted pellets, color, and whether of cecal origin or not were recorded each half hour throughout the photoperiod, except near the end of the trial when only hourly records were kept. The top paper from each cage was removed hourly and the excreta allowed to air dry. This procedure made possible the verification of color and cecal evacuations under better light conditions than existed in the environmental chambers.

Powdered chrome sesquioxide was selected as a marker due to its bright color and insoluble, undigestible nature. Two hundred milligrams were placed in #2 and #4 gelatin capsules. Number 2 capsules were used initially as suggested by McFarland and Freeland (1959). Discrepancies in results arose and #4 capsules, used by Boyd (1970) were employed in remaining trials in addition to #2 capsules.

Three trials were conducted at 20°C, 15 hours, with capsules inserted at different times in relation to feeding. Insertion took place at the beginning of the photoperiod before normal feeding began, after two hours of normal feeding, or after two days of fasting but before feeding. Capsules were placed in birds maintained at 1°C, 10 hours only before normal feeding.

## RESULTS

The bright color of the dye was very easily distinguished in the first

part of the experiment when the feces portion of excreta changed from normal color to green. The green faded to grey-green, then brown as time progressed. No sudden disappearance of color described by McFarland and Freeland (1959) or Boyd (1970) was observed. It was after this observation that I decided to use both capsule sizes so that results would be directly comparable to the above mentioned papers.

Table 15 presents the results from this experiment. Due to the gradation of color from green to normal, the final symbols denoting the presence of color were placed in an arbitrary manner. No statistical analysis was conducted because of small sample size, large variability, and the arbitrary nature of some observations.

At 20°C dyed excreta was generally observed in 1-2 hours after ingestion. In each of the marking regimes, at least two of eight birds passed marked excreta within 1 hour after capsule insertion. When the capsule was inserted before normal feeding, all but one bird had voided marked excreta at 2 hours. No colored excreta was passed by this last bird until 4.5 hours. All birds given the capsule after 2 hours feeding passed dyed excreta by 1.5 hours. Birds starved for 48 hours exhibited a great deal of variability in time of first passage. Two birds passed marked excreta at 1 hour, one took 6 hours, and another more than 12 hours.

The mean number of intestinal excretory pellets from birds at 20°C, 15 hours was  $5.78 \pm 0.85$  pellets/hour when quail were fed normally, and  $3.94 \pm 0.73$  pellets/hour when fed after two days of starvation.

Although the final observance of color was arbitrary, excreta was generally completely normal color 12 hours after first appearance of the dye at 20°C. Many of the birds passed normal colored excreta before this

Table 15. Times of passage of indicator dye through the alimentary tract of bobwhites maintained at 20°C, 15 hours and 1°C, 10 hours photoperiod. Different capsule sizes and times of capsule insertion in relation to regular feeding were used.

	Insertion	Cap.	½	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
322	20°C	#2	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
324	15 hrs	"	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
323	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
333	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
330	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
332	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
329	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
305	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
331	1°C	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
328	10 hrs	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
325	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
315	"	"	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-
322	20°C	#2	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
330	15 hrs	"	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
332	"	"	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
324	"	"	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
329	"	#4	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
305	"	"	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
323	"	"	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
333	"	"	-	-	+	+	+	+	+	+	+	+	+	+	-	-	+	-
322	"	#2	0	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
330	"	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
332	"	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
324	"	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
329	"	#4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
305	"	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
323	"	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
333	"	"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

- Normal Excreta      + Dye Present      \*Cecal Feces Present      <sup>1</sup>Dye Passed During Night  
 0 No Excreta Voided



time. It was not quantified, but the intensity of the color indicated that most dye and thus ingesta was passed between 2 and 6 hours after food consumption.

Rate of passage at 1°C, 10 hours was considerably more rapid than at 20°C, 15 hours photoperiod. At 1°C, 10 hours three of four birds passed marked excreta within 1 hour of marking and intestinal feces was completely free of dye at 4 hours. For the fourth bird, colored excreta appeared at 1.5 hours and was absent at 6.5 hours. Feces having passed into the cecae retained some color until 7 hours after marking. Birds excreted  $7.70 \pm 1.47$  pellets/hour in this environment.

The feces of cecal origin was readily distinguished by its fine homogeneous nature, in contrast to granular rectal feces (Sturkie 1965:284). Some of this "cecal" feces was entirely from the cecae while other was combined with intestinal feces. The cecae were generally evacuated several times per day; and, it often appeared as though only part of the cecal contents were evacuated at one time. Occasionally two very large cecal pellets would be voided in a short period, suggesting complete evacuation of both cecae. Color was observed last in the cecal evacuations, often appearing several hours after intestinal feces had become normal.

#### DISCUSSION

Due to small sample size and variable results of this experiment, most of the postulates are tenuous at best, and in need of further study.

The rate of passage, hourly excretion and ratio of intestinal to cecal feces were apparently the same for birds given the capsule before or after feeding. This may indicate that there is no change in the gut motility as

feeding progresses. It could also indicate that both capsules went directly into the proventriculus or into the crop. It was expected that the capsule insertion before feeding would go to the proventriculus and the one inserted after feeding would be stored in the crop (Marshall 1961:419), resulting in a difference in rate of passage. The unnaturalness of forcing a capsule into the esophagus could easily disrupt this cycle.

Variability in time of food passage through starved birds indicated that some capsules, particularly the large ones, were stored in the crop then passed through the rest of the digestive tract at a later time. This was the only evidence that there was a difference in rate of passage based on the size of ingested material.

The most noticable and consistent difference was the environmental effect. At 1°C and 10 hours photoperiod ingesta was passed through the alimentary canal between one-half and six hours, while at 20°C, 15 hours complete food passage occurred between one and twelve hours after consumption. These observations support the speculation by Kendeigh (1969), Davis (1955), and Zimmerman (1965) that reduced efficiency at lower temperatures or shorter photoperiod may have been due to increased rate of food passage.

The rapid passage of dye strongly suggests that it is the rate of passage, not an intestinal volume change, which facilitates the increased consumption at lower temperatures.

## MANAGEMENT IMPLICATIONS

"Irrespective of what may be the full role of a specific food in the life history of quail..., to be of greatest value as a winter staple it must have plenty of utilizable protein, carbohydrate and fat... must be heat producing and energy giving, whether it is perfectly balanced or not" (Errington 1936:357). Few areas in the north central states have more than two or three kinds of winter staple foods, and a reduction in any one of these can result in heavy mortality. Effective management of quail in areas where food may be a major limitation on population size is to maintain or improve the supply of winter food. This same idea of management with staple rather than preferred foods was expressed by Davison (1942).

Errington (1936) considered few of the many food items consumed by quail to be wholly sufficient by themselves.

The value of a monospecific diet of seeds as energy sources for quail can be related to metabolized energy, after a period of adaption. The use of metabolized energy as a basis of comparison places emphasis on the palatability of the diet, the seed energy and the efficiency with which seed energy is utilized. From the energy metabolized in the second 3-day period, only sorghum (174.11 kcal/3 days) and corn (168.34 kcal/3 days), of all the seeds used in this study, provided enough energy to meet the existence requirement of bobwhite maintained under Kansas winter conditions. A diet of sunflower (125.68 kcal/3 days), shrub lespedeza (118.34 kcal/3 days), and hemp (111.76 kcal/3 days) did not provide the full existence energy, but did sufficiently reduce weight loss so as to be considered important energy sources for quail. The value of prostrate lespedeza (91.59 kcal/3 days) was less than that of shrub lespedeza. Two of three quail fed prostrate

lespedeza were able to survive 12 days; but, it is doubtful if they could have survived much longer. Acorn (77.43 kcal/3 days), switchgrass (45.17 kcal/3 days), partridgepea (22.06 kcal/3 days) and ragweed (13.04 kcal/3 days) were low quality seeds for energy. Quail had large weight losses and several died on some of these diets.

The order of palatability of these seeds, judged by the weight of each consumed when presented separately but ad litibum, was essentially the same as their order of metabolic value, except that hemp was preferred over shrub lespedeza which, in turn, was preferred over sunflower.

Nestler (1949a) found that a diet of 19 to 25 percent protein was necessary to maintain body weight during breeding, but survival, body weight, and food consumption during the winter were as good on diet of 9 to 11 percent protein as those with greater amounts. All of the seeds used in this study, except switchgrass and possibly acorns from red oak, had sufficient protein (Table 15) for winter existence of quail. Other seeds, except corn and sorghum, had ample protein to meet breeding requirements.

Corn and sorghum both have extensive acreage within the range of the bobwhite (Handley 1936; Baumgartner et al. 1952). For this reason, if no other, they were ranked as major food items in most food habits studies. In preference tests (Michael and Beckwith 1955), sorghum was ranked as #1, cracked yellow corn was #15 and whole yellow corn was #39 of 58 seed species. Corn was valuable as a food source because of the large amounts of carotene, a vitamin A precursor (Nestler, 1949a). While these seeds have comparatively low energy (Table 17), they were consumed in large amounts and metabolized with high efficiency (Table 3) providing the full existence energy requirements of quail. The fact that these two species have "outstanding food value"

(Errington 1936:358) was confirmed by my study.

Western ragweed and common ragweed were ranked as being most important by Baumgartner et al. (1952), third in importance by Korschgen (1948) and Robel (1969) and of lesser importance by Davison (1942). Handley (1936) stated that giant ragweed was used extensively where it grew in abundance, but Robel (1969), Korschgen (1948), and Baumgartner et al. (1952) showed that it was utilized only to a limited extent and much less than the other two species. Seeds of giant ragweed had high energy value (5,680 kcal/g), and this energy was retained throughout the winter (Robel and Harper 1965). On account of the very low consumption of giant ragweed, I considered it to be a poor plant for management and a low ranking winter staple food. If common and western ragweeds have about the same seed energy and efficiency of metabolism by quail as giant ragweed, then these two seeds would be a very important source of energy owing to their greater consumption by quail. Reduced availability of ragweed seeds in winter (Robel and Slade 1965) would seriously reduce their value as winter staple foods.

Sunflower was another consistently important food item, although its utilization was reduced in winter (Baumgartner et al. 1952; Robel 1969) due to the unavailability of seeds (Robel and Slade 1965). In Kansas, where sunflower is abundant, Robel (1969) showed that it was the food with the highest frequency of consumption (36.9 percent) and second largest volume consumed (13.9 percent). It was rated by Michael and Beckwith (1955) as 39th of 58 seed species in order of preference by bobwhite. The quail in my study did not metabolize enough energy from sunflower seeds during the period studied to meet existence requirements, but the weight lost by birds was not great and an increase in weight was noted during the third 3-day

period (Table 7). I considered it to be an important energy source, but it is doubtful that it could be called a winter staple food.

Acorn mast, considered by Errington (1936) to be an important winter feed, was also found to be very important by Davison (1942) and Korschgen (1948). Baumgartner et al. (1952) considered it to be important only in eastern Oklahoma, but added that it was variable, with a good crop produced every third year. The amount of acorn consumed by quail in captivity was low, but metabolic efficiency was good. Metabolized energy from red oak acorns was about half of the existence energy required by quail maintained under winter conditions.

Grasses, particularly of the genus *Panicum*, were generally ranked among the ten most important food items (Davison 1942; Baumgartner et al. 1952; Robel 1969), but are not considered to be winter staple foods. The weight of seed consumed and M.E. by quail fed switchgrass were very low (Table 2). The importance of grasses lies partially in the fact that they seed early in the year and seeds are available through most of the summer. They are also important in the diets of young quail in areas where grass seed is abundant (Handley 1936). Switchgrass was rated 6th on preference (Michael and Beckwith 1955), well before sunflower, yet my quail consumed it in considerably smaller amounts than sunflower. I can offer no explanation for this discrepancy.

Hemp is not generally considered to play an important part in the diets of quail. Crops of Kansas quail (Robel 1969) contained 1.3 percent hemp by volume and 4.4 percent by frequency between September and April. In the northwestern prairie of Missouri it comprised 4.6 percent by volume of the diet (Korschgen 1948). A diet of hemp provided the greatest intake energy to quail

of the seeds studied; however, low efficiency of utilization resulted in only a moderate amount of energy metabolized (Table 2). Hartowicz (pers comm) found an average of 500-600 seeds/sq. ft. using seed traps in hemp patches during seed fall. At the same time, only 150 seeds/sq. ft. were found outside traps. By January there were almost no seeds remaining on the surface.

Hartowicz and Eaton (1971) considered the effect that an eradication program for hemp could have on farm game. Giant ragweed, sunflower and common ragweed were ranked as first, third, and sixth most frequent broad-leaved plants found in association with hemp. Indiscriminate methods used to control hemp could affect these important food and cover species.

Legumes have long been recognized for their value to wildlife management. Handley (1936) listed the reasons which make these attractive to bobwhites. They support abundant insect life and grow on well drained soil, both important for young quail. They provide dense cover desired by quail, with clear areas for passage beneath the canopy. They produce a bounteous supply of food and enrich the soil so that other important food plants, such as ragweed and sunflower, can flourish and produce a more abundant and varied diet.

Different legumes show considerable variation in their utilization and preference by quail. Thunberg lespedeza (L. thunbergii), bicolor lespedeza (L. bicolor) and common lespedeza (L. striata) were 11th, 14th and 31st in order of preference respectively, and showy partridgepea was 24th (Michael and Beckwith 1955). In eastern and central Oklahoma, common lespedeza and Korean lespedeza (L. stipulacea) were very important, yet sericea lespedeza (L. cuneata) was used only slightly (Baumgartner et al. 1952). Nestler (1949b)

found that bicolor lespedeza was used four times as much as L. juncea and twice as much as showy partridgepea.

Korean lespedeza was the most important food in the Ozarks of Missouri (Korschgen 1948). Murray (1948) attributed a 106 percent increase in the quail population of one area to the planting of fallow fields with this seed and corn. Korean and common lespedeza were also the most abundant seed used in the southeastern states, with showy partridgepea and L. servicea used to a lesser extent (Davison 1942). Partridgepea is an important constituent of the winter diet of Kansas quail (Robel 1969), with maximum utilization in January.

In addition to their preferred use by quail, lespedezas have other important advantages (Davison 1945). Bicolor lespedeza can be established by seeding or setting out 1 year plants; it lives many years without re-establishment; can withstand discing, burning, cutting, or use by rabbits; and it is attractive in appearance. It is used by many other species, including deer, rabbits, doves, and passerine birds. It is a very dependable source of food in all seasons. Seed accumulates on the ground over the years with few seeds removed by rodents. Seed drops between October and February, with 5 percent to 10 percent remaining on the stalk after February 1 (Haugen and Fitch 1955). Korean lespedeza, an annual, and bush clover (L. virginica), a perennial, thrive well on poor eroded soils and do not mature until late in the fall (Harris and Drew 1943).

The value of bicolor lespedeza was assessed by Rosene (1956). Where food is abundant it is of little value, but in areas where food is the limiting control on quail populations, bicolor patches can be very important and in winter tend to attract and concentrate quail.



VA-70 shrub lespedeza used in my study has been selected for early maturity in Virginia. It is considered to provide excellent food and cover for quail, the large seeds remaining on the ground for 12-24 months with little use by rodents or non-game species (R. D. Lippert pers comm). It was readily consumed by quail (43.8 g/3 days) and provided a moderate amount of metabolized energy (118.34 kcal/3 days). With consideration given to the cover offered by this species and, if seeds are retained on the stalk (as with bicolor lespedeza) during critical period when snow prevents normal feeding, then shrub lespedeza could provide a very important and possibly staple winter diet. Prostrate lespedeza offers similar potential as a management species, however, it was not utilized as much (22.7 g/3 days) as shrub lespedeza, and provided less M.E. (71.72 kcal/3 days). Studies at Purdue University indicate that prostrate lespedeza is nearly as nutritious as a balanced diet, however, birds in Missouri lost weight when fed this seed for a period of time (R. D. Lippert per comm).

The value of the partridgepea seems to be somewhat less than that of lespedeza to management. They have lower winter availability, especially after the first year, and require more care in cultivation (Haugen and Fitch 1955). They grow very well and produce numerous seeds the first year of establishment, but fail to re-establish themselves on eroded soil in the second year (Harris and Drew 1943). Although important as food in many areas (Robel 1969, Handley 1936) when quail are given a choice, many species of lespedeza are preferred (Nestler 1949b, Michael and Beckwith 1955). Partridgepea was consumed less (3.3 g/3 days) and metabolized less efficiently (52.1 percent) than either species of lespedeza studied. On the basis of my metabolic efficiency studies, I considered it a poor species of plant for use in quail habitat management. Robel (1969), however, found that partridgepea

was used extensively as a winter food in Kansas, indicating that wild quail may more readily accept it than did captive quail.

Grit appears to be of mechanical value to quail only on diets of hard seeds such as partridgepea. Quail fed diets of soft food, shrub lespedeza and pelletized P-18, had no advantage in metabolic efficiency incurred by providing grit. With a diet of mixed seeds it is believed that hard seeds will take over the function of grit when grit is not available (Beer and Tidyman 1942). Making grit accessible to wild quail does not appear to be necessary as a management practice.

## CONCLUSIONS

1) It was possible to rank the metabolic value of seeds to quail using the metabolized energy derived after ad libitum feeding. Corn and sorghum provided the full existence energy required by quail under controlled mean winter conditions. Sunflower, shrub lespedeza, and hemp did not provide full existence energy, but were considered important energy sources for quail. Reduced availability of sunflower and hemp during the winter greatly lowers their value as winter foods. Shrub lespedeza may prove valuable as both an energy source and cover during winter. Prostrate lespedeza was less valuable than shrub lespedeza, providing about half the energy necessary for winter existence of quail. On account of low M.E., acorn, switchgrass, partridgepea and giant ragweed were of little use as winter food. Western and common ragweed seeds may yield large amounts of energy to quail if they have energy content similar to giant ragweed and are used as efficiently by quail.

2) Metabolic efficiency and M.E. generally increased for bobwhites maintained at 1°C, 10 hours photoperiod when compared with these factors for birds maintained at 20°C, 10 hours and 30°C, 15 hours. Increased M.E. was necessary to meet greater energy requirements at 1°C, 10 hours.

3) Starved quail survived an average of 3.8 days (maximum 6 days) before death. A mean weight loss of 55.8 g (28.9 percent of original body weight) was accompanied by 18.69 kcal of excreta produced. A factor of 0.335 kcal/g weight loss was used to correct the total excretory energy, M.E. and metabolic efficiency of exogenous energy due to metabolism of body tissue.

4) Minimum efficiency of body fat and protein metabolism were calculated to be 93.3 and 66.8 percent, respectively, assuming that 48.9 percent of the weight lost during starvation was fat and 16.7 percent was protein metabolism.

5) Survival at 1°C, 10 hours photoperiod was a function of the birds ability to lose large amounts of weight slowly, rather than the initial weight of the bird. Greater percentage weight loss at 20°C, 10 hours resulted in longer survival, than at 1°C, 10 hours photoperiod.

6) Use of grit with diets of soft food (shrub lespedeza and P-18) provided no increase in the consumption, M.E., or metabolic efficiency. Data from two quail fed partridgepea, without, then with grit, indicated large differences in weight of food consumed, M.E. and metabolic efficiency. Only M.E. corrected for the passage of grit with excreta was considered significant ( $P < 0.05$ ).

7) The rate of food passage through the alimentary tract was considerably faster at 1°C, 10 hours photoperiod than at 20°C, 15 hours photoperiod. At 1°C, 10 hours normal time for complete food passage was between 0.5 and 5 hours after consumption, while at 20°C, 15 hours, passage occurred between 1.0 and 12 hours. After two days of starvation, the rate of passage for the first particle of food consumed was variable; but, the overall rate was essentially the same as for normal feeding. Insertion of a capsule of marking dye at different times in relation to feeding indicated no differences in rate of food passage.

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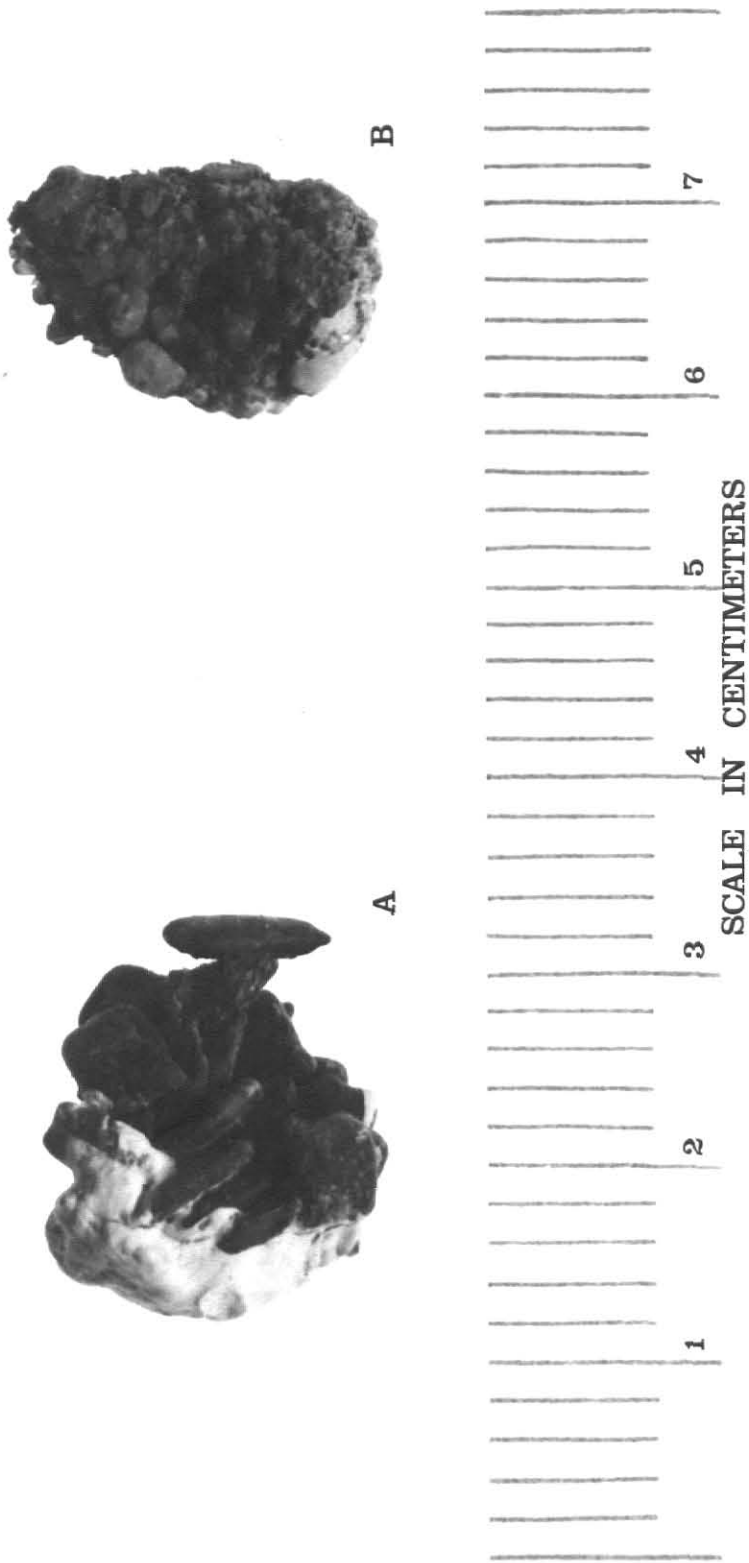
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## APPENDIX



Plate 1: Excreta from bird #327 on a diet of partridgepea; A showing passage of whole seeds without grit (Period 2), and B showing ground condition of seeds with grit available (Period 3).



A

B

SCALE IN CENTIMETERS

Table 16. Nutritional analysis of experimental seeds or related species, expressed as percentages.

	Moisture	Protein	Fat	N-free Extract	Fiber	Ash	
<u>Panicum virgatum</u>	5.78	8.50	3.40	51.21	26.55	4.56	Spinner & Bishop (1950)
<u>Cassia nictitans</u>	7.08	33.21	3.35	44.73	6.80	4.88	" "
<u>Lespedeza virginica</u>	10.14	26.65	3.45	36.92	19.34	3.41	" "
<u>Ambrosia trifida</u> <sup>3</sup>	7.29 3.20	20.11 18.80	23.52 23.60	16.45 20.73	29.52 29.70	3.11 3.97	" Korschgen (1964)
<u>A. artinisifolia</u> <sup>1</sup> <sup>2</sup>	12.18 11.82 7.08	15.14 18.23 22.77	8.89 8.54 12.52	23.24 31.83 22.79	36.48 24.71 31.69	4.07 4.87 3.37	" " Korschgen (1964)
<u>Helianthus annuus</u> <sup>3</sup>	7.29 4.86	20.11 19.50	23.52 26.10	16.45 16.08	29.52 30.20	3.11 3.44	Spinner & Bishop (1950) Korschgen (1964)
<u>Zea mays</u>	13.50	10.50	3.29	68.91	2.48	1.32	"
<u>Quercus palustris</u>	11.60	4.99	17.60	51.91	12.20	1.70	"
<u>Sorghum vulgare</u>	9.88	12.20	3.65	64.68	5.93	3.66	"
<u>Cannabis sativa</u>	8.75	18.0 21.51	33.0 30.41	15.89	18.84	4.60	Mayer & Poljakoff-Mayber (1963) Winton & Winton (1932)

<sup>1</sup>Fall samples<sup>2</sup>Winter samples<sup>3</sup>Values as quoted in Spinner and Bishop 1950. Identical values suggest a possible misprint.  
No values available for Lespedeza japonica, L. daurica, or Quercus rubra.

Table 17. Caloric values, percent moisture, and percent ash in the seeds used in the study of the metabolic efficiency of bobwhites. Other reported caloric values are included for comparison.

Species	Caloric Value (kcal/gm)	Percent Moisture	Percent Ash	Reported Caloric Values	
Sorghum ( <u>Sorghum vulgare</u> )	4.304±0.051	6.83±0.45	1.57±0.27	<u>S. vulgare</u> <u>S. vulgare</u>	3.935-4.366 4.017 Robel (unpublished) Long (1934)
Corn ( <u>Zea mays</u> )	4.511±0.037	9.31±0.48	1.81±0.34	<u>Z. mays</u> <u>Z. mays</u>	4.317 4.415 Kendeigh and West (1965) Long (1934)
Acorn ( <u>Quercus rubra</u> )	5.199±0.020	32.81±7.30	1.74±0.25	<u>Q. palustris</u> <u>Q. alba</u> <u>Q. shumardii</u>	5.073 5.222 4.166 Clements (1970) Smith (1971) Smith (1971)
Shrub lespedeza ( <u>Lespedeza japonica</u> )	5.025±0.030	10.85±4.51	3.22±0.46	<u>L. stipulaceae</u>	4.965 Kendeigh and West (1965)
Hemp ( <u>Cannabis sativa</u> )	5.562±0.082	8.08±1.15	4.85±0.42	<u>C. sativa</u>	5.890 Long (1934)
Blackwell switchgrass ( <u>Panicum virgatum</u> )	4.520±0.012	9.74±1.25	6.02±0.34	<u>P. capillare</u> <u>P. dicatomiiflorum</u>	4.700 4.647 Kendeigh and West (1965)
Prostrate lespedeza ( <u>Lespedeza daurica</u> )	4.949±0.035	8.86±0.06	2.46±0.49		
Sunflower ( <u>Helianthus annuus</u> )	6.041±0.017	6.65±0.13	2.41±0.34	<u>H. annuus</u> <u>H. annuus</u> <u>H. annuus</u> <u>H. annuus</u>	5.575 5.619 5.824-6.061 6.759 Johnson and Robel (1968) Johnson and Robel (1968) Robel and Harper (1965) Long (1934)



Table 17 (cont'd)

Species	Caloric Value		Percent		Reported Caloric Values	
	(kcal/gram)	Value	Moisture	Ash		
Giant ragweed ( <u>Ambrosia trifida</u> )	5.680±0.202		8.29±0.06	2.75±0.28	<u>A. trifida</u> <u>A. trifida</u> <u>A. trifida</u> <u>A. trifida</u> <u>A. trifida</u>	5.175 5.420 5.802 5.132 5.689 Johnson and Robel (1968) Johnson and Robel (1968) Kendeigh and West (1965) Robel and Harper (1965) Robel and Harper (1965)
Partridgepea ( <u>Cassia fasciculata</u> )	4.638±0.021		9.60±0.00	2.68±0.27	<u>C. fasciculata</u>	4.547 Derksen (unpublished)
Control diet (P-18)	4.276±0.019		6.04±1.07	5.92±0.79	Control diet	4.294 Case (1971)

METABOLIC EFFICIENCY OF BOBWHITE (COLINUS VIRGINIANUS)  
FOR SEVERAL IMPORTANT DIETARY SEEDS,  
WITH OBSERVATIONS ON THE EFFECTS OF GRIT  
AND RATE OF FOOD PASSAGE

by

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B.Sc., Laurentian University, 1970

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AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

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As part of a long range study concerning habitat management for bobwhite (Colinus virginianus) in Kansas and the bioenergetics of bobwhites, a series of experiments was conducted at different environmental conditions to determine the metabolic efficiency of important or potentially valuable food items.

Research was done at 1°C and 10 hours photoperiod. Thirty adult male bobwhites were housed in modified 48 x 25 x 13 cm polypropylene cages within a controlled environment chamber. Twelve of these birds were used in a latin square design experiment to measure the metabolizable energy and efficiency of sorghum (Sorghum vulgare), corn (Zea mays), acorn (Quercus rubra), hemp (Connabis sativa), VA-70 shrub lespedeza (Lespedeza japonica), and Blackwell switchgrass (Panicum virgatum). Three additional birds, maintained on a balanced diet (P-13), were used as controls. Cursory studies were done with spare birds fed sunflower (Helianthus annuus), giant ragweed (Ambrosia trifida), partridgepea (Cassia fasciculata) and prostrate lespedeza (L. daurica).

Grit effects were studied using 12 birds placed into two groups according to weight and fed shrub lespedeza. One group received grit, the other did not. Control birds fed mash and grit and two birds fed partridgepea with grit were also used.

The rate of passage of a pelletized diet at two environmental conditions was determined by inserting encapsulated chrome sesquioxide ( $\text{Cr}_2\text{O}_3$ ) into the esophagus of quail and observing the time for its appearance in the excreta.

Corn and sorghum were the best seeds studied, having both high efficiency and metabolized energy (M.E.). These, in addition to shrub lespedeza on account of its winter availability, are suitable for winter staple food.

Hemp, sunflower and possibly western and common ragweeds were considered important energy sources for quail, but, reduced availability during the winter impedes their use as winter management species.

Giant ragweed, acorn, partridgepea and switchgrass were consumed in small amounts and provided little M.E. These were considered poor seeds for quail management. Prostrate lespedeza was of more value than these seeds, but provided less M.E. than sunflower, shrub lespedeza and hemp. It may be of some use as cover.

Metabolic efficiency of quail for whole seeds generally increased in a more stressing environment (1°C, 10 hours light compared to 20°C, 10 hours and 30°C, 15 hours). However, the metabolic efficiency for a pelletized balanced diet was unchanged.

Fasting quail can survive little more than six days at maximum. Fat and protein used with a minimum of 92.82 percent and 64.51 percent respectively. A factor of .335 kcal/g of weight lost was the estimate of the energy derived from tissue breakdown. This factor was used to correct fecal energy, metabolizable energy and efficiency for those birds that lost weight.

Grit did not increase the efficiency of utilization of mash or shrub lespedezea. Insufficient data were collected for partridgepea to be conclusive. Quail retain grit for long periods (9 months), but the length of time seems dependent upon diet and seed harshness.

Mash passed through alimentary tract much faster at 1°C, 10 hours than at 20°C, 15 hours photoperiod. Considerable variability in the time for the first appearance of the dye was observed for birds that had been starved for two days before feeding.