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THE INFLUENCE OF DIET COMPOSITION UPON GROWTH AND DEVELOPMENT OF SANDHILL CRANES

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ABSTRACT.—Experiments were conducted to evaluate the effect of protein, metabolizable energy, and sulfur amino acid content of five diets upon growth and development of captive Florida Sandhill Crane (*Grus canadensis pratensis*) and Greater Sandhill Crane (*G. c. tabida*) chicks raised under controlled conditions. A high protein (32%) diet resulted in faster growth than that obtained when a lower protein (24%) ration was supplied. Florida Sandhill Crane chicks fed a diet containing 2,160 kcal/kg grew significantly slower than chicks fed a ration containing 2,830 kcal/kg. Reducing the sulfur amino acid content of a ration containing 24% protein from 0.88% to 0.73% significantly slowed the growth of young cranes. A 17% incidence of leg disorders and a 25% incidence of wing abnormalities occurred between 7 and 28 days of age among Greater Sandhill Cranes fed a high protein diet. Florida Sandhill Cranes grew slower than Greater Sandhill Cranes irrespective of the type of ration they were provided and did not develop leg or wing abnormalities. Abnormalities invariably developed only in the most rapidly growing Greater Sandhill Cranes. Diets that promoted slower growth reduced the incidence of abnormalities. A ration formulated to contain a low (0.73%) sulfur amino acid level appeared to be the most suitable for slowing growth rates of captive-reared Sandhill Cranes and reducing the risk of abnormal wing or leg development.

The Endangered Wildlife Research Program at the Patuxent Wildlife Research Center is engaged in comprehensive research on Whooping Crane (*Grus americana*) and Sandhill Crane (*G. canadensis*) biology, captive production, and reintroduction techniques (Erickson 1968, 1976). Crane chicks reared from eggs taken from parents are susceptible to leg and wing abnormalities at this facility and other institutions (Carpenter et al. 1976, Kepler 1978, Archibald and Viess 1978). The abnormalities generally appear between 10 and 28 days of age. Wing abnormalities consist of unilateral or bilateral twisting of the wing feathers similar to a condition called "angel wing" in waterfowl (Francis et al. 1967). Most often the carpal bones twist or droop, resulting in the displacement of young primary feathers from the normal position. A slight rotation or bending of one leg, frequently occurring as early as 7–10 days of age, is usually the first indication of abnormal leg development. Shortly afterward, leg bones become twisted, sometimes slipping from the intertarsal joints. Since leg rotation and displacement of tibiotarsus or femur bones from joints can occur within 48 h in apparently normal individuals that are 18 to 28 days of age, leg disorders can develop rapidly. The condition, which in some respects resembles chondrodystrophy (perosis) in poultry, usually worsens to the extent that standing is no longer possible and death frequently follows.

Little is known about skeletal deformities among crane chicks in the wild; however, chicks raised by their parents in captivity appear to be less susceptible to wing and leg disorders than those raised from eggs collected from nests. No such deformities have occurred among 18 chicks recently parent-reared at the Patuxent facility. Preliminary tests of possible causes of leg disorders focused upon environmental factors such as floor surfaces, bedding materials, and pen design. The latter was considered since crane chicks are unusually aggressive (Littlefield and Ryder 1968, Drewien 1973) and active, and it was hypothesized that some leg disorders might result from injuries sustained striking enclosure surfaces. Altering environmental conditions reduced the incidence of leg disorders, particularly among Florida Sandhill Cranes (*G. c. pratensis*) when chicks were raised in pens containing 10–15 cm of sugarcane bedding. Leg disorders continued to occur, however, particularly among Greater Sandhill Cranes (*G. c. tabida*) and young Whooping Cranes raised under similar conditions.

Specific nutrient requirements of cranes are unknown; however, diets fed to cranes that developed disorders were specially formulated to contain ample amounts of nutrients (choline, nicotinic acid, biotin, folic acid, manganese, and zinc) whose deficiency is known to raise the incidence of perosis and other leg disorders in poultry. These nutrients were provided for the cranes at higher levels than those customarily used in diets for poults because young turkeys are more susceptible to leg disorders than other fowl. Results of this approach indicated that leg abnormalities were associated with rapid growth. Food intake was therefore restricted to a percentage of what would be consumed freely in an effort to regulate growth and control or prevent these conditions. A better method was sought because (1) this procedure is cumbersome and often unsuccessful (Kepler 1978) and (2) hunger, which is known to exacerbate conflicts among chicks (Quale 1976), increased the risk of injuries from fighting. This paper reports experiments that were undertaken to examine the influence of diets differing in protein, metabolizable energy (ME), and sulfur amino acid (SAA) content upon growth and development of Florida Sandhill Cranes (FSC) and Greater Sandhill Cranes (GSC). This work represents the first of its kind attempted with these species in captivity.

MATERIALS AND METHODS

GENERAL PROCEDURE

Spring trials were conducted over a period of several years with FSC and GSC chicks of both sexes. Eggs collected from nests of GSC at Grays Lake National Wildlife Refuge in Idaho represented the major source of chicks for these studies. Eggs for one trial were obtained from nests of FSC at Loxahatchee Wildlife Refuge in Florida. In addition, eggs from captive flocks of FSC and GSC maintained for production at the Patuxent Wildlife Research Center were used to supplement those obtained in the wild. Eggs were hatched by artificial incubation in forced-draft incubators.

The number of chicks (12–45) available for study differed each year, being subject to the source of eggs, the ability to collect eggs from nests in the wild, the hatchability of eggs, and post-hatching mortality. Chicks were raised in groups in 2.7 × 3.7 m community pens or individually in 1 × 2.5 m pens containing sugarcane bedding. Infrared heat lamps were used for supplemental heating. Food and water were supplied ad libitum. Many chicks required instruction for one to four days after hatching before learning to recognize food and eat unassisted. Chicks were provided with 12–14 hours of light each day. Aggressive behavior resulting in injury or mortality necessitated raising cranes individually or in groups composed of no fewer than six crane chicks and 6 to 10 like-size turkey poults.

Crane chicks were weighed shortly after hatching and every seventh day thereafter. The average weight of day-old FSC was 113 g and that for GSC chicks was 126 g. For cranes raised in community pens, the pen average was considered the experimental unit. Records were maintained for weight, food consumption, mortality, and the incidence of leg and wing abnormalities. One-way ANOVA (unbalanced design) was performed on data to test for significance (Snedecor and Cochran 1967) using a programmable calculator and differences between treatment means were evaluated using Kramer's extension of Duncan's multiple range test to group means having unequal numbers of replicates (Kramer 1956).

COMMUNITY PEN TRIALS

Crane chicks were introduced 24 h after hatching into community pens containing one-week-old Broad Breasted Bronze Turkey poults. The poults served (1) as an aid in teaching cranes to recognize and consume food, and (2) in reducing intraspecific fighting by penmates. Aggression diminished with increased bird density in pens and with time. Lighting was dimmed during the first two weeks of the trials as a further means of controlling aggression. All birds were debeaked shortly after hatching and periodically thereafter to prevent pecking and injury to one another. Chicks were distributed to maintain as little variation in age within pens as possible and none differed by more than six days in age.

EXPERIMENTAL DIETS

The composition of the experimental diets used in these studies is shown in Table 1. Diets 1, 2, 4, and 5 were fed to FSC in Experiment 1. Diets 1 and 4 were similar to those used for feeding poultry and contained common feed ingredients. Diet 1, containing 32% protein, could be expected to support rapid growth of pheasants, poults, and other species having a high protein requirement, while diet 4, containing 24% protein, could be expected to support moderate growth in these species. Vitamin and trace mineral supplements (Table 1) were specifically formulated to provide what was believed to be ample fortification of the rations.

Diet 2 was designed to test the effect of a reduced energy level on growth and development of FSC. The ME content of this ration was lowered to 2,160 kcal/kg compared to a level of 2,830 kcal/kg in diet 1 by incorporating wheat middlings, ground oats, and cellulose at the expense of corn meal. Diet 3 was similar to diet 2, but with less protein. It was designed to test the effect of a reduced energy level compared with a similar diet (diet 4) on growth and development of GSC in Experiment 2.

TABLE 1. Composition of experimental diets (%).

Diet	1	2	3	4	5
Ingredients					
Yellow corn meal	32.2	5.2	20.0	31.25	24.43
Soybean oil meal (49%)	37.0	37.0	21.0	19.0	31.5
Wheat middlings	3.0	10.25	12.0	12.0	12.0
Ground oats	—	10.0	11.5	11.5	11.5
Cellulose	—	9.25	9.25	—	—
Fish meal (60%)	8.0	8.0	6.0	6.0	—
Meat and bone meal (48%)	5.0	5.0	5.0	5.0	—
Alfalfa meal (17%)	2.5	5.0	5.0	5.0	5.0
Corn oil	3.0	1.0	1.0	1.0	3.32
Corn distillers solubles	3.0	3.0	3.0	3.0	3.0
Brewers dried yeast	2.5	2.5	2.5	2.5	2.5
Dried whey	1.25	1.25	1.25	1.25	1.25
Dicalcium phosphate	1.0	1.0	1.0	1.0	3.0
Limestone	0.5	0.5	0.5	0.5	1.5
Iodized salt	0.25	0.25	0.25	0.25	0.25
DL-Methionine	0.08	0.08	0.08	0.05	—
Vitamin mixture[a]	0.5	0.5	0.5	0.5	0.5
Trace mineral mixture[b]	0.25	0.25	0.25	0.25	0.25
Determined analysis					
Protein (N × 6.25)	31.8	32.0	24.6	24.8	24.3
Calculated analysis					
Protein	32.0	32.0	24.2	24.1	23.8
Metabolizable energy, kcal/kg	2,830.0	2,160.0	2,352.0	2,689.0	2,689.0
Methionine + Cystine	1.13	1.11	0.87	0.88	0.73
Lysine	1.95	1.33	1.33	1.30	1.32
Calcium	1.45	1.45	1.45	1.45	1.38
Available phosphorus	0.77	0.79	0.79	0.81	0.86

[a] Supplied the following in the diet (mg/kg): niacin, 66; calcium pantothenate, 11; riboflavin, 3.3; menadione sodium bisulfite, 2.2; biotin, 0.22; folic acid, 4.4; inositol, 138; ethoxyquin, 125; ascorbic acid, 110; p-aminobenzoic acid, 22; zinc bacitracin, 110; choline, 440; amprolium, 125; vitamin B_{12}, 0.0066; and (IU/kg): retinyl acetate, 16,550; cholecalciferol, 1,653; and α-tocopheryl acetate, 11, premixed in carrier.

[b] Supplied the following in the diet (mg/kg): $MnSO_4 \cdot H_2O$, 375.1; ZnO, 124.8; $FeSO_4 \cdot 7H_2O$, 99; $CuSO_4 \cdot 5H_2O$, 22; $Na_2MoO_4 \cdot 2H_2O$, 8.2; $CoCl_2 \cdot 6H_2O$, 1.7; Na_2SeO_3, 0.22, premixed in carrier.

Diets 1 and 5 also were fed to GSC in this experiment.

Diets 4 and 5 were each formulated to contain 24% protein and 2,689 ME kcal/kg. However, diet 5 was formulated to contain 0.73% SAA (methionine + cystine) by calculation, a level about 17% less than that in diet 4. This was the lowest SAA level that could be achieved in a 24% protein ration using customary feed ingredients. Methionine and cystine, both sulfur-containing amino acids, are indispensable nutrients for growing birds; hence, restricting their intake was considered a possible means for regulating growth. Diet 4 was designed for comparison with diet 1 as well as diet 5. Protein (6.25 × nitrogen content) in diets for each trial was determined by Kjeldahl analysis. ME values of the diets were calculated using ME values for feed ingredients that have been determined for poultry (Scott et al. 1976).

RESULTS AND DISCUSSION

EXPERIMENT 1

Body weights of FSC fed four diets in five separate trials are shown in Figure 1. A total of 71 birds are represented, 56 of which were raised individually and 15 in community pens. Diet 1, formulated for rapid growth of poults and pheasants, also supported rapid growth of FSC. Cranes fed a low energy diet (diet 2) or 24% protein diets (diets 4 and 5) grew more slowly than those fed diet 1. Cranes fed diet 5 required approximately seven additional days from 14 to 49 days of age to achieve weights comparable to those fed diet 1. Body weight and feed utilization values obtained at 21 and 28 days of age from FSC grown individually are shown in Table 2. Values for these periods are of interest because physical abnormalities, if any, invariably appear before four weeks of age. Cranes fed diet 1 weighed significantly more than those fed other diets (ANOVA: 21 days, $F = 10.96$, df = 3,52, $P < 0.05$; 28 days, $F = 10.01$, df = 3,52, $P < 0.05$). Cranes fed diet 5 weighed 32% less than those raised on diet 1 at four weeks of age. Reducing the SAA content of a ration containing 24% protein from 0.88% (diet 4) to 0.73% (diet 5) significantly slowed the growth of FSC (ANOVA: 21 days, $F = 10.96$, df = 3,52, $P < 0.05$; 28 days, $F = 10.01$, df = 3,52, $P < 0.05$). Weights of cranes fed a low energy ration (diet 2) were not significantly different (ANOVA) at four weeks of

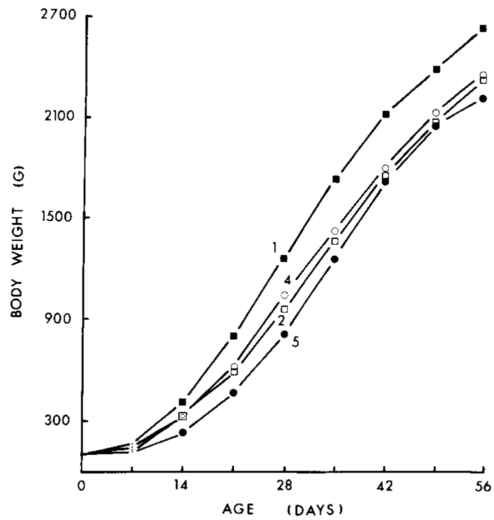

FIGURE 1. Average weight of young Florida Sandhill Cranes fed four diets differing in nutrient composition (Experiment 1). Cranes (n = 71) were fed two high protein (32%) diets (1; n = 20, closed squares), (2; n = 20, open squares), and two 24% protein diets (4; n = 15, open circles), (5; n = 16, closed circles), described in Table 1.

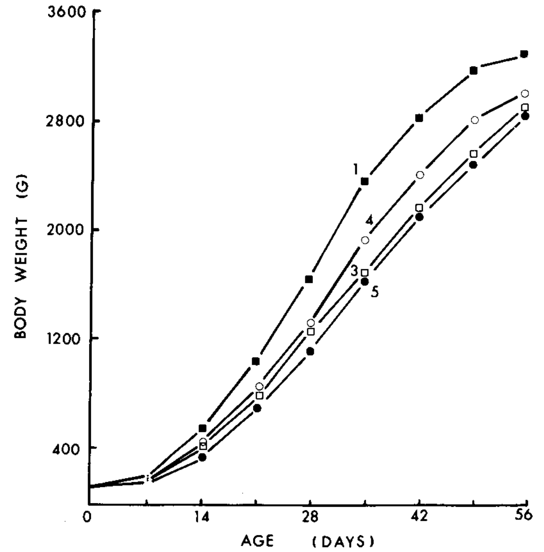

FIGURE 2. Average weight of young Greater Sandhill Cranes fed four diets differing in nutrient composition (Experiment 2). Cranes (n = 130) were fed a high protein (32%) diet (1; n = 28, closed squares) and three 24% protein diets (4; n = 23, open circles), (3; n = 38, open squares), (5; n = 41, closed circles), described in Table 1.

age from those fed diet 5. The feed/weight gain value for cranes fed diet 2 was significantly higher than others (ANOVA, F = 17.37, df = 3,36, $P < 0.01$). None of the FSC raised in this experiment developed leg disorders or wing abnormalities.

EXPERIMENT 2

Growth responses of GSC (n = 130) fed four diets in five separate trials (Fig. 2) were similar to those obtained with FSC. GSC fed diet 1 grew more rapidly than those fed the other diets. Lowering the protein and ME levels (diets 3 and 4) resulted in reduced growth compared to that achieved with a high protein diet. Cranes fed diet 5 weighed the least at all ages. Body weights obtained at 21 and 28 days of age from GSC raised in community pens are shown in Table 3. Feed utilization values are from comparable birds raised individually. Cranes fed diet 1 weighed significantly more than those fed diet 3 or diet 5 (ANOVA: 21 days, F = 7.05, df = 3,10, $P < 0.01$; 28 days, F = 7.59, df = 3,10, $P < 0.01$). I found no significant differences in weights (ANOVA) among groups fed 24% protein rations with differing ME and SAA levels. Feed/weight gains for cranes fed diet 5 were significantly higher than those obtained with diet 1 (ANOVA, F = 2.89, df = 3,43, $P < 0.05$).

I found growth rates of young cranes highly variable, differing as much as 100% or more in some instances among chicks raised within a treatment during a single trial. Gains of 15 GSC and 14 FSC raised individually on diet 4, for example, were 1,151 g and 931 g (SD = ±409 g and 300 g, respectively) at 28 days of age. Sex and genetic differences may account for some of this variability. In addition, chicks differed widely in the time required before adjusting to a captive environment and learning to recognize and consume food. Some

TABLE 2. Influence of dietary protein, metabolizable energy, and sulfur amino acid levels on growth and feed utilization of Florida Sandhill Cranes (Experiment 1).

Diet number	Nutrient content: Protein (%)	ME (kcal/kg)	SAA (%)	Body weight (g)[a]: 21 days	28 days	Feed/gain[b] (28 days)
1	32	2,830	1.13	797 ± 38^{a} (16)	1,266 ± 59^{a} (16)	1.82^{c} (15)
2	32	2,160	1.11	607 ± 53^{b} (12)	917 ± 66^{bc} (12)	2.89^{a} (8)
4	24	2,689	0.88	647 ± 45^{b} (14)	1,082 ± 68^{b} (14)	2.33^{b} (9)
5	24	2,689	0.73	486 ± 22^{c} (14)	865 ± 39^{c} (14)	2.12^{bc} (8)

[a] Values represent the mean ± SEM for the number of individuals shown in parentheses. Means within a column not followed by the same letter superscript are significantly different by ANOVA ($P < 0.05$) followed by Kramer's extension of Duncan's multiple range test.
[b] Values represent the mean for the number of individuals shown in parentheses. Means not followed by the same letter superscript are significantly different by ANOVA ($P < 0.01$) followed by Kramer's extension of Duncan's multiple range test. The pooled SEM was ±0.08.

TABLE 3. Influence of dietary protein, metabolizable energy, and sulfur amino acid levels on growth and feed utilization of Greater Sandhill Cranes (Experiment 2).

Diet number	Nutrient content: Protein (%)	ME (kcal/kg)	SAA (%)	Body weight (g)[a]: 21 days	28 days	Feed/gain[b] (28 days)
1	32	2,830	1.13	1,051 ± 48[a] (4)	1,654 ± 70[a] (4)[c]	1.84[a] (8)
3	24	2,352	0.87	777 ± 39[b] (5)	1,210 ± 58[b] (5)	2.00[ab] (8)
4	24	2,689	0.88	796 ± 114[ab] (2)	1,236 ± 132[ab] (2)	2.03[a] (12)
5	24	2,689	0.73	711 ± 76[b] (3)	1,184 ± 122[b] (3)	2.14[b] (19)

[a] Values represent the mean ± SEM for the number of replicates (shown in parentheses) which contained a total of 88 individual GSC. Means within a column not followed by the same letter superscript are significantly different by ANOVA ($P < 0.01$) followed by Kramer's extension of Duncan's multiple range test.
[b] Values represent the mean for the number of individuals shown in parentheses. Means not followed by the same letter superscript are significantly different by ANOVA ($P < 0.05$) followed by Kramer's extension of Duncan's multiple range test. The pooled SEM was ±0.04.
[c] Approximately 17% of the GSC fed diet 1 developed leg disorders and about 25% developed wing abnormalities.

chicks did not begin eating much until four days after hatching and they tended to weigh less for several weeks than comparable chicks that began eating regularly within 24 h after hatching.

An effort was made to raise roughly equal numbers of cranes on each of the experimental diets; however, whether a chick was reared individually or in a community pen was primarily a consequence of the time the egg hatched. A chick was assigned to a community pen when 10 or more were expected to hatch within a six-day period. As a result, 88 GSC were reared in community pens and 42 were raised individually. At least two diets were compared in each trial; however, not all diet combinations were tested in community pen trials. When examining the performance of groups fed diets 4 and 5 (Table 3), in particular, one must note that body weight data for birds fed diet 4 were compiled in two trials, neither of which was conducted during the same season as any of the three replicates comprising the responses to diet 5.

Considerable variation in growth occurred occasionally within and between trials in a manner that appeared to be independent of the diet or other experimental conditions. Replicate gains for GSC raised on diet 5 in community pens, for example, were 854 g (SD = ±253, $n = 8$) and 1,040 g (SD = ±307, $n = 7$) in one trial and 1,273 g (SD = ±233) when six birds were raised on the diet during the succeeding season. This variability as well as the fact that no direct comparison of diets 4 and 5 was conducted with GSC in community pens in a single trial masked actual differences in the performance of cranes fed these diets when the results from all community pen trials were combined (Table 3). I found that cranes fed diet 5 consistently grew 15–25% slower than those fed diet 4 when chicks were fed the diets in the same trial. This difference is apparent when responses of individual FSC and GSC obtained within the same trial are compared (Table 4). FSC fed diet 5 containing 0.73% SAA weighed significantly less than those fed diet 4 containing 0.88% SAA in Trial 1 (ANOVA, $F = 7.11$, df = 1,9, $P < 0.05$). A similar significant response (ANOVA, $F = 17.72$, df = 1,13, $P < 0.01$), in which GSC fed diet 5 weighed 26% less than those fed diet 4 at 28 days of age, was obtained in Trial 2. These results clearly demonstrate that a ration containing a low level of SAA is effective in reducing growth rates of Sandhill Cranes.

Cranes supplied diet 2 and diet 3 spent long periods each day consuming feed. This was not the case with cranes fed the other diets. Although FSC fed diet 2 ate somewhat more than those supplied the other diets, feed consumption was not markedly different from that of FSC fed diet 1 or diet 4. Consumption of diets 1 and 3 by GSC that were raised individually was quite uniform (2,578 g and 2,631 g per bird) at four weeks of age. Cellulose combined with high levels of ground oats and wheat middlings in diets 2 and 3 contributed to the rations having a low density as well as low ME values. I observed that these diets were difficult for crane chicks to eat; therefore, the long periods they spent feeding probably were a

TABLE 4. Influence of a reduced sulfur amino acid level in the diet upon growth of Sandhill Cranes.

Diet number	Nutrient content: Protein (%)	ME (kcal/kg)	SAA (%)	Body weight (g)[a] (28 days): FSC (Trial 1)	GSC (Trial 2)
4	24	2,689	0.88	1,124 ± 58 (5)	1,558 ± 86 (7)
5	24	2,689	0.73	912 ± 54 (6)	1,147 ± 53 (8)

[a] Values represent the mean ± SEM for the number of individuals shown in parentheses. Means are significantly different by ANOVA ($P < 0.05$, Trial 1; $P < 0.01$, Trial 2).

TABLE 5. Growth of Sandhill Cranes fed diets formulated for rapid and slow growth.

Age in days	Diet 1 Body weight (g)[a] GSC	FSC	Difference (%)	Diet 5 Body weight (g)[b] GSC	FSC	Difference (%)
7	195	164	16	160	123	23
14	533	418	22	344	232	32
21	1,037	804	22	692	468	32
28	1,653	1,265	23	1,145	832	27
35	2,380	1,735	27	1,658	1,271	23
42	2,840	2,137	25	2,123	1,739	18

[a] Values represent the mean for 26 GSC and 20 FSC, compiled in four trials.
[b] Values represent the mean for 42 GSC and 16 FSC, compiled in four trials.

consequence of the diets' consistency. These diets also tended to become compacted in the bills of the birds. Diet 5 did not have these undesirable characteristics and appeared to be a better ration for controlling growth.

I found that 17% of the GSC fed diet 1 developed leg disorders between 7 and 28 days of age and that 25% of the birds developed abnormal wings. Two GSC raised on diet 4 (9% incidence) developed leg disorders whereas only one bird from more than 40 that were raised on diet 5 developed a leg disorder. Wings on six rapidly growing GSC fed diet 3 developed abnormally (16% incidence); however, fewer abnormal wings (6% incidence) occurred among those GSC raised on diets 4 and 5. Physical abnormalities always developed only in the most rapidly growing cranes.

I concluded that the calcium and phosphorus content of diets fed to cranes was not a factor contributing to leg abnormalities. Evidence for this belief was that (1) physical deformities did not resemble rickets or other signs associated with a deficiency or imbalance of these minerals in other avian species, (2) tibia ash values from cranes that developed normal or abnormal legs were similar, and (3) tibia ash values from cranes were similar to those from poultry fed rations containing adequate and balanced amounts of calcium and phosphorus. Furthermore, in an eight-week trial (not shown) using a 24% protein diet closely resembling diet 4 (Table 1), cranes grew normally and showed no signs of rickets or abnormalities when fed three rations formulated to contain 1.2%, 0.9%, and 0.6% calcium and 0.63%, 0.63%, and 0.47% available phosphorus, respectively (Serafin, unpubl.).

Comparison of growth data for chicks fed diets 1 and 5 in four trials (Table 5) shows that FSC grew considerably slower than GSC irrespective of the type of ration fed. Since none of the FSC developed physical abnormalities, slower growth rates may have protected these birds from the risk of developing abnormalities. GSC, on the other hand, appear to have a genetic capacity for more rapid growth that may predispose some individuals to physical abnormalities. Wing abnormalities may result from rapid feather growth placing stress on tendons and ligaments associated with the carpal joint. Restraining wings to the body for several days when they begin twisting usually corrects the condition, supporting the belief that weight stress may be a causative factor. Leg disorders may be the result of rapid weight gain that cannot be supported by the very long legs of this species. The proximal ends of the tibiotarsus and tarsometatarsus, the distal portion of the tibiotarsus, and the intertarsal and tibio-femoral joints could be expected to be relatively weak in young, rapidly growing birds and subject to deformation from weight stress. The availability of a diet promoting rapid weight gain may be the principal reason why leg disorders occur in captive-reared cranes.

The average weights of FSC raised on diet 1 were 418 g and 804 g at 14 and 21 days of age (Table 5). Weights of GSC that developed leg disorders exceeded these values in every instance, further suggesting that very rapid weight gain places young cranes in jeopardy of developing leg abnormalities. This view gains support from findings by Archibald and Viess (1978) that (1) restricting feed intake and (2) exercising young cranes reduces weight gains and lessens the incidence of leg disorders.

A nutritionally-related disease or diet-associated unsatisfactory performance of livestock and poultry often is attributed either to an inadequate or excessive amount of a nutrient in the diet or to an improper balance of nutrients. I formulated diets for these experiments so as to include all nutrients known to be required by birds and supplied them in amounts that exceeded the needs of poults and other species that have demanding nutrient requirements. Although nutrient requirements and their optimal balances for satisfactory performance of cranes are unknown, there was no suggestion from the results of feeding cranes the diets that the amounts of nutrients supplied or their balances were unsatisfactory.

The concept that overconsumption of a balanced ration may contribute to or cause skeletal disorders in birds has received little attention in the past. Recent work, however, has shown that the incidence of a condition termed "twisted leg" in pheasants, peafowl, emus, turkeys, and other fowl (Nairn and Watson 1972), was reduced when feeding was restricted (Haye and Simons 1978). Similarities between leg abnormalities in cranes and the twisted leg syndrome are striking. Overfeeding has been shown to be involved with bone disorders such as osteochondrosis, hypertrophic osteodystrophy, and hip dysplasia in Great Dane and other giant breeds of dogs (Lust et al. 1973, Hedhammar et al. 1974). Protein and energy both promote rapid growth and there is growing evidence that overfeeding either of these to genetically predisposed animals can lead to skeletal disorders in cattle and horses (Stromberg 1979, Hintz and Kallfelz 1981). This also appears to be the case with cranes. Diets with lowered levels of protein and energy slowed growth and reduced the risk of GSC developing skeletal disorders. Diet 5 appeared better in this respect. Therefore, I recommend this diet or one similarly composed containing no more than 24% protein, 2,689 ME kcal/kg, and 0.73% SAA, as a desirable ration for raising Sandhill Cranes in captivity, based on an evaluation of my findings and available knowledge of crane nutrition.

FSC which grew more slowly than GSC and did not develop skeletal abnormalities, are nonmigratory and inhabit a region having a warm climate with ample food supplies for a long period. GSC, which are slightly larger than FSC when fully grown (Walkinshaw 1973), traditionally nest and raise young in northern latitudes having a cooler climate and a much shorter growing season for food supplies (Walkinshaw 1973, Drewien and Bizeau 1974). GSC at Grays Lake National Wildlife Refuge raise their young during a season averaging about 135 days, beginning around June 1 and lasting until fall migration commences in early to mid-October (Drewien 1973, Drewien and Bizeau 1974, 1978). A genetic capacity for rapid growth, which would make possible the maximum utilization of food supplies during this period, would seem to favor GSC under these conditions, but would be of less value to nonmigratory FSC inhabiting a warm climate. GSC in the wild could be expected to expend more energy finding food than chicks raised in captivity and would probably seldom have a plentiful supply continuously, as did the chicks in these studies. Thus, the observed physical abnormalities may be a phenomenon occurring only in young cranes with a genetic predisposition for rapid growth when the birds are raised in captivity with ample, high quality diets.

Young Whooping Cranes appear to be extremely susceptible to leg disorders when hand-raised in captivity (Kepler 1978). Parent-reared chicks in Wood Buffalo National Park, located in a sub-arctic climate in the Northwest Territories of Canada, generally hatch about June 1 and begin migrating southward in mid-September (Kuyt 1976, 1977). They are thus subject to an even shorter growing season (approximately 112 days) than GSC chicks raised at Grays Lake National Wildlife Refuge. Whooping Cranes, which are somewhat larger than GSC when fully grown, may also have a genetic capacity for rapid growth that is beneficial in the wild, but which also may jeopardize individuals reared in captivity with abundant, nutritionally balanced diets.

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