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EFFECTS OF VARIOUS COMBINATIONS AND NUMBERS OF LEAD:IRON PELLETS DOSED IN WILD-TYPE CAPTIVE MALLARDS

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Irwin was responsible for analyzing the data from the Phase I and Phase III studies and for preparing the initial drafts of these sections of this report. Sanderson was responsible for analyzing the data and preparing the reports for the remaining phases of the study. Sanderson was also responsible for the editing and final content of the entire report.

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CONCLUSIONS REGARDING THE USE OF LEAD:IRON SHOT FOR HUNTING WATERFOWL

Glen C. Sanderson

There is much still to be learned about the effects of ingested lead:iron shot in waterfowl, especially regarding the mechanisms that produce the results we observed. Nevertheless, on the basis of the data presented in the present report, I conclude that five No. 4 shot composed of no more than 40 percent lead and the corresponding percentage of iron (60 percent iron minus the percentage of trace elements) is relatively nontoxic for captive game-farm mallards on a diet of corn. Although the data indicate that shot of 42 percent lead would meet the guidelines proposed by the U. S. Fish and Wildlife Service for mortality and weight loss, I favor a slightly conservative position. In addition, the data are not precise enough to provide an accurate estimate of the effects of a 1 percent change in the amount of lead in the shot. There is, however, a sharp break in our observed data in the toxicity of five No. 4 pellets between 41 and 45 percent lead.

If we accept the guidelines proposed by the U. S. Fish and Wildlife Service of no more than 20 percent mortality 6 weeks postdosing and a maximum weight loss of 20 percent in excess of that for undosed controls 6 weeks postdosing--I have added changes in PCV's and Hb values 3 and 6 weeks postdosing that are no more than 20 percent in excess of those for undosed controls to my discussions--we find the following percentages of lead permitted in five No. 4 shot:

Factor	Percent decline	No. weeks postdosing	Sex	Percent Pb in five No. 4 shot
Mortality rate	20	6	M&F	42
Weight loss	20[a]	6	M	59
	20[a]	6	F	49
PCV	20[a]	3	M&F	32
	20[a]	6	M&F	52
Hb	20[a]	3	M&F	40
	20[a]	6	M	45
	20[a]	6	F	35

a/ In excess of the change in undosed controls.

Thus, the effects of 40 percent lead shot exceed the guidelines for mortality and weight loss. Shot that are 40 percent lead also meet or exceed the levels I have used to discuss PCV's 6 weeks postdosing and Hb values 3 weeks postdosing for males and females combined and 6 weeks postdosing for males. I am not particularly concerned that the estimating equations indicate only 32 percent lead in the shot for PCV's 3 weeks postdosing and 35 percent lead for females 6 weeks postdosing. By 6 weeks postdosing the allowance for PCV's was 52 percent lead, and for the Hb values at 6 weeks postdosing, the males were well above the arbitrary level chosen.

PHASE I. EFFECTS OF VARIOUS COMBINATIONS AND NUMBERS OF LEAD:IRON PELLETS DOSED IN WILD TYPE CAPTIVE MALLARDS ON THREE DIETS

METHODS

One thousand one hundred and forty game-farm mallards, 570 drakes and 570 hens, were obtained from the McGraw Wildlife Foundation, Dundee, Illinois, on 1 April 1975. All of these ducks were hatched during the last week of December 1974. The ducks were banded with metallic, numbered leg bands. The bands for males and for females were placed in separate containers and thoroughly mixed to insure that the numbers were randomly assigned to each duck. The ducks were then distributed according to predesignated band numbers among six large flight pens, 144' X 24' X 8' high, at Nilo Farms near Brighton, Illinois. Drakes and hens were penned separately in alternate pens. The pens were paired in such a way that one pen of drakes and one of hens received one of three diets. The three diets were: (No. 1) whole corn exclusively for the entire experiment, (No. 2) whole corn exclusively until 2 weeks after dosing and then free choice of both whole corn and a complete ration for 4 weeks, and (No. 3) a complete ration exclusively for the entire experiment. The corn was grown at Nilo Farms and the complete ration was Purina Game Bird Breeder Layena manufactured by Ralston Purina Company, St. Louis, Missouri. All feeds and water were given ad libitum.

On 14 and 15 May 1975 all ducks were dosed, according to their predesignated band numbers, in such a manner that each pen of birds received the same gamut of doses. There were a total of 19 doses, each with a replicate of 10 birds. The doses consisted of a no-dose control group and one, three, and five shot dose levels of six different types of shot. The six types of shot were commercial steel, commercial lead, and four types of lead:iron shot containing either 41, 45, 58, or 64 percent lead. More exact details of shot composition are given in Table 1, and the mean weights of the doses administered are given in Table 2. All shot were No. 4's. The doses were given orally via stomach tube.

At 2 days before dosing and at 21 and 42 days after dosing each duck was weighed and a blood sample was taken for packed cell volume (PCV) and hemoglobin concentration (Hb). The microhematocrit technique was used to determine PCV's and the cyanomethemoglobin technique using the Unopette collection system of Becton-Dickinson Company, Rutherford, New Jersey, was used to determine hemoglobin concentrations.

Necropsies were performed on all birds that died during the experiment. At 44 days after dosing, all surviving birds on the corn diet were decapitated and necropsied. At necropsy, the testes of each drake were weighed, the diameter of the largest ovarian follicle in each hen was measured, all gizzards were inspected for retained shot, and the thyroids of the controls and the birds dosed with commercial iron shot were weighed.

RESULTS AND DISCUSSION

There were no significant differences ($\underline{P} > 0.05$) among the body weights, PCV's, or Hb's of any of the doses at 21 or 42 days after dosing (Tables 3, 4, 5).

No significant differences were found between males and females for the parameters tested. Thus, the sexes were combined prior to analysis.

The lack of a difference between the sexes may be a result of the low response rates observed in this entire experiment. Other investigators have reported sex differences in the effects of lead poisoning in captive mallards. For example, Bellrose (1964) reported that captive male mallards ate more food in fall and winter than hen mallards and suffered a mortality that was only 50 percent of the rate for hens. In spring, hens ate more than drakes and the survival rate was more than twice as high in females as it was in males. The implication is that the difference in food consumption was responsible for the sex differences observed.

Mortality

The low toxic response was also shown by a low mortality rate. Although 21 ducks in all (1.8 percent) died during the experiment, only 13 were found to have lesions associated with lead poisoning (Table 6). Sixteen of the 21 deaths occurred in the pen of corn-fed drakes. Eleven of the 16 deaths in that pen had lesions associated with lead poisoning. Those included 7 of 11 ducks that were found to have lesions indicative of being pecked by other birds in the pen. Two ducks in the groups fed diet No. 2 died, and were found to have lesions associated with lead poisoning. One of those ducks was the only hen that died with lesions associated with lead poisoning. There was no lead-related mortality in the ducks fed diet No. 3. Mortality attributed to lead poisoning tended to show a direct relationship to the lead content of the shot and the number of pellets in the dose (Table 7); however, the expected strong inverse relationships between survival time and lead content of shot and dose level were not found (Table 7).

There was, however, an effect related to diet. Of the 13 ducks in which lead poisoning was a factor in their deaths, 11 were on diet No. 1, and 2 were on diet No. 2. The overall mortality rate (3.67 percent) for all ducks dosed with commercial lead or lead:iron pellets on diet No. 1 was significantly ($P < 0.001$) higher than the overall mortality rate (0.00 percent) for all ducks dosed with commercial lead or lead:iron pellets on diet No. 3. The difference in mortality rate between diet No. 1 and diet No. 2 (0.67 percent) was also significantly different ($P < 0.02$). The difference in mortality rate between diet No. 2 and diet No. 3 was not significantly different ($P > 0.10$). Thus, in spite of the extremely low rate of mortality experienced in this investigation, the increased toxicity of ingested lead in ducks on a diet of corn was apparent.

Of the 11 ducks on diet No. 1 in which lead poisoning was a factor in their death, one each was dosed with 5-58 and 3-64 pellets, two each with 3-100, three each with 5-64, and four each with 5-100 pellets. The only groups of dosed ducks on diet No. 1 to show significant differences ($P < 0.05$) in mortality rates when compared with groups dosed with the same number of shot of a different type were the groups dosed with 5-0, 5-41, and 5-45 shot, which had no mortality, as compared with ducks dosed with 5-100 pellets, which had 20.0 percent mortality. The only other significant difference ($P < 0.05$) found was the higher mortality rate for ducks dosed with 5-100 pellets (20.0 percent) as compared with ducks receiving 1-100 pellets (0.0 percent).

Thus, even with the confounding effects of the soil in the present experiment, ducks dosed with five pellets in the three groups with the lowest percentages of lead had a lower mortality rate than ducks dosed with five commercial lead pellets. Also, the increased effects of five commercial lead pellets as compared with one lead pellet were apparent.

Although it has been recognized for many years that diet and the rate of food consumption have profound effects on the toxicity of ingested lead in waterfowl, how these factors exert their influence is still a matter of some speculation and conflicting evidence. In our study we made no attempt to measure the rate of food consumption.

One of the first experimental studies of lead poisoning in ducks demonstrated some of the effects of diet on the toxicity of ingested lead. In an initial experiment with Pekin ducks it was obvious that lead pellets were not poisoning the ducks as expected. Thirteen ducks were then dosed with 25 No. 4 lead pellets; seven were placed on a corn diet and six on duck pellets. Six of the seven ducks on corn died within 17 days but only two of the six on duck pellets died within the same time. Additional experiments demonstrated that mallards on a diet of coontail and mixed grains were less susceptible to lead poisoning than ducks on mixed grains alone. Jordan and Bellrose (1950) concluded that diet was more important than the dose in lead poisoning in waterfowl. Results from wild mallards indicated that 60 to 80 percent of those ingesting one pellet would die if the ducks were on a diet of wild seeds.

In a follow-up study, Jordan and Bellrose (1951) supplemented whole corn diets in mallards with protein, calcium, phosphorus, calcium phosphate, or vitamin C. They concluded that the nutritional constituents alone did not account for the influence of diet on lead poisoning. A recent experiment confirmed these earlier conclusions. A basal diet of corn meal plus selected nutrients provided at levels commonly found in natural foods did not result in greatly reduced toxicity over that found in mallards fed only corn (Irwin et al. 1974). However, other results from the studies of Jordan and Bellrose (1951) indicated that the addition of egg albumen, oyster shell, calcium carbonate, and phosphorus powder reduced the degree of toxicity of lead in game-farm mallards by about 50 percent over a straight corn diet (Holmes 1975).

The effects of diet were also noted in a study of acid-fast intranuclear inclusion bodies in the proximal convoluted tubules of the kidneys. Acid-fast bodies were present in mallards fed one, two, three, or eight No. 6 shot while on a diet of corn but were not found in mallards fed one or three lead shot and fed duck pellets (Locke et al. 1966).

In an experiment with adult game-farm mallard drakes dosed with none, four, and eight No. 4 lead shot, and one group fed corn and the other an adequate diet, only lead-dosed birds on a corn diet lost a significant amount of weight. Also, although all lead-dosed birds showed some gross and microscopic lesions, they were more frequent in ducks fed only corn. The pellets eroded faster in the ducks on an adequate diet than in ducks fed corn, and the rate of lead excretion was higher in ducks on an adequate diet. Ducks on the adequate diet excreted about 88 percent of the lead they dissolved, whereas ducks fed corn excreted only about 54 percent of the lead eroded in their gizzards. The concentration of lead in the bones of dosed ducks fed corn was significantly higher than lead concentrations in bones of dosed ducks on the adequate diet (Irwin et al. 1974).

There was a negative correlation between lead concentration in bones and the percentage of eroded lead excreted in the ducks fed corn. This information suggests that the assimilation and deposition of lead in bone was directly related to the retention of lead. The apparent increased absorption of eroded lead and its subsequent deposition in bone in ducks on the corn diet compared with ducks on the adequate diet may have resulted from a calcium deficiency (Irwin et al. 1974, Six and Goyer 1970).

Perhaps the obviously calcium-deficient diet of corn also enhanced the toxicity of lead (Irwin et al. 1974, Six and Goyer 1970). The negative phosphorus balance in the ducks on a corn diet supports the hypothesis of Shelling (1932) that lead produced a phosphate deficiency. There was a correlation between fecal lead and phosphorus, suggesting that lead and phosphorus may combine into insoluble phosphates as happens with calcium, iron, and magnesium. These elements, when taken in large amounts, result in reduced absorption of phosphorus (Maynard and Loosii 1969).

Body Weight

The postmortem body weights--of the ducks that died of lead poisoning--of the ducks dosed with commercial lead shot tended to be lower than the postmortem weights of the ducks dosed with lead:iron shot (Table 8). This difference probably reflects the longer survival time of the ducks dosed with commercial lead shot. For some unknown reason, the survival times of the ducks that died in the groups dosed with 64 percent lead:iron shot were generally shorter than the survival times of the ducks dosed with commercial lead shot. The overall difference was not statistically significant ($\underline{P} > 0.05$).

The mean weights of surviving ducks in all groups were higher 6 weeks after dosing than they were when dosed (Table 3). Only the surviving ducks dosed with five commercial lead pellets each weighed less 3 weeks after dosing than they did when dosed. There were no significant differences in body weights caused by shot type or dose levels.

These results were not expected, because loss of body weight has long been recognized as one of the most common objective symptoms of lead poisoning in ducks. Emaciation was listed as the characteristic feature of lead poisoning by Quortrup and Shillinger (1941), who autopsied 3,000 wild birds (including 11 species of wild waterfowl) of which 259 had died of lead poisoning. Jordan and Bellrose (1950) reported severe loss of body weight as one of the most common objective symptoms of lead poisoning in ducks. Bellrose (1964) reported that waterfowl starving because of lead poisoning weighed only about 50 percent of normal. Twelve captive mallards that died an average of 22.4 days after dosing with lead lost an average of 43.4 percent of their preexposure body weight (Barrett and Karstad 1971). In another study, game-farm mallards on a diet of whole corn and dosed with eight No. 6 lead shot survived an average of 17 days after dosing and lost an average of 27 percent of the initial body weight (Irby et al. 1967). Anderson (1975) reported that wild scaups lost an average of 30 to 35 percent of their body weight before dying of lead poisoning in Illinois in the spring.

There was, however, no correlation in the body weights of swans with more than 100 pellets in their gizzards and those with 10 or less (Trainer and Hunt 1965). Seven captive Canada geese dosed with 10 or more pellets each suffered acute lead poisoning and died within 23 days (mean 10 days) after losing only 22 percent of the original body weight, whereas two geese dosed with 5 pellets each survived for an average of 55.5 days and lost 32 percent of their body weight (Cook and Trainer 1966). Another group of poisoned captive Canada geese lost 25 to 45 percent of their body weight and died 11 to 45 days after dosing (Sileo et al. 1973).

PCV and Hb

As with the body weights, there were no significant differences in the packed cell volume (percent) caused by shot type or dose levels (Table 4). In most cases, the values showed slight declines from dosing to 3 weeks after dosing to 6 weeks after dosing. In the three groups of ducks dosed with commercial lead pellets, the mean values 6 weeks after dosing were the same or slightly higher than they were 3 weeks after dosing. Thus, there was a slight indication that the commercial lead pellets caused a decline in PCV values at 3 weeks, but that by 6 weeks the values were recovering.

Hb values were generally about the same--or slightly lower--3 weeks after dosing as they were at dosing (Table 5). By 6 weeks after dosing Hb values of all groups except ducks dosed with 1-45 shot were higher than they were when the ducks were dosed. There were no significant differences caused by shot type or dose levels.

Several changes in the blood associated with lead poisoning have been reported. The hemoglobin content is low in lead-poisoned birds and poikilocytosis and anisocytosis are nearly always observed (Quortrup and Shillinger 1941). The erythrocytes in the peripheral blood in lead-poisoned mallards were reduced in size and in hemoglobin content and concentration. Production of defective erythrocytes and impaired release of the cells are probably the main sources of anemia (Bates et al. 1968), which is a common characteristic in lead-poisoned birds (Beer and Stanley 1965).

Gonads

There were no significant differences between the mean weights of the testes, the mean weights of the ovaries, or the mean diameters of the largest ovarian follicles with respect to dose in the ducks killed at the termination of the experiment (Table 9). There were no trends in the weights or sizes of the gonads. It appears that the protective effects of the soil, and perhaps the lateness of the season, combined to prevent any detectable effects of the dosed lead on the weights of the gonads.

It has been suggested that waterfowl might survive lead poisoning but retain enough lead in their systems to interfere with reproduction (Adler 1942). Dosing captive mallards with lead did not affect fertility or hatchability of eggs (Cheatum and Benson 1945, Elder 1954). In one study mallard hens dosed with 18 lead shot laid fewer eggs in a season than controls (Elder 1954), but in another study game-farm mallards dosed with three No. 6 lead shot laid as many eggs as controls (U. S. Fish and Wildlife Service 1976). So far as we know, studies have not been continued into the second generation, where the greatest effect of lead poisoning on reproduction in mice was found (Gullvag et al. 1975). Morgan et al. (1975) reported that in Japanese quail normal sexual development in males did not occur at 500 ppm lead in the diet, and weights of testes were reduced at 5 and 6 weeks of age in the birds that received 1,000 ppm lead. Lead acetate in a standard food mixture for 13 weeks at 0, 10, 20, and 50 ppm lead had no effect on the number of eggs laid by Japanese quail or the hatchability of the eggs (Gullvag et al. 1975). Drinnan (1966) and Pringle et al. (1968) found the gonadal areas of oysters to be particularly affected by lead. The high levels they found are in line with the findings in humans (Hardy 1966).

Thyroids

In an earlier study (Sanderson and Hurley 1974), small sample sizes indicated that dosing with commercial steel shot might result in enlarged thyroids, although no rationale for such a change was apparent. In order to test possible effects of steel shot on thyroids, we weighed the thyroids from the controls and from the ducks dosed with commercial steel shot and compared the weights.

There were no consistent differences in the weights of thyroids as related to the number of commercial steel shot dosed, and there were no significant differences between weights of thyroids of the controls and those of any of the groups dosed with steel shot (Table 10). The only significant differences found ($\underline{P} < 0.05$) were that thyroids of males dosed with five steel pellets weighed less than thyroids of females similarly dosed and that thyroids of males dosed with five steel pellets weighed less than thyroids of males dosed with one or with three steel pellets. However, there were no significant differences in the weights of thyroids of controls and those of ducks dosed with one, three, or five commercial steel shot for either males or females. In five of six comparisons between controls and ducks dosed with commercial steel shot, thyroids of dosed ducks weighed less than thyroids of controls. From the results of the present study, we conclude that ingestion of one, three, or five commercial steel pellets did not cause a significant difference in the weights of thyroids.

Retention of Different Types of Shot

Among the ducks killed at the termination of the Phase I study (those on diet No. 1), those dosed with steel shot were found to have the highest retention rate of shot (91.4 percent), those dosed with 45 percent lead:iron shot had 27.0 percent retention, and those dosed with the other types of shot had less than 6 percent retention (Table 11). The retention rate of steel shot was significantly ($\underline{P} < 0.001$) higher than the rates for any of the other types of shot, and the drakes were found to retain significantly more shot than hens ($P < 0.01$). There were no significant differences in the rates of retention that were related to the number of shot dosed nor among the retention rates of ducks dosed with commercial lead pellets and pellets of any combination of lead and iron. These results indicate that steel pellets are much more resistant to erosion in a duck's gizzard than pellets with 41 or more percent lead and the corresponding percentages of iron.

We had planned to measure the effect of diet on the erosion rates of the various types of shot. Because of the low response rate obtained, after 6 weeks--the planned end of the experiment--and after autopsying all surviving ducks on diet No. 1, we decided to use the ducks on diet No. 2 and diet No. 3 for additional experiments. We hoped to learn the reasons for the low rate of response in the initial experiment. Other experiments have demonstrated some of the effects of diet on the erosion and retention rates of dosed lead pellets.

Lead pellets in mallards on a high fiber diet eroded 46 percent of their initial weight within 20 days after dosing, whereas pellets in ducks on a low fiber diet eroded 62 percent of the initial weight in the same time. The rate at which pellets are released from the gizzard is partially dependent on size. Thus, pellets that erode more rapidly because of a particular diet might also be eliminated sooner, perhaps partially offsetting the effects of a higher rate of exposure to lead (Clemens et al. 1974).

In an experiment in which game-farm mallards were dosed with none, four, and eight No. 4 pellets, with one group fed corn and a second group given an adequate diet, the consumption of food declined after dosing only in the groups fed corn (Irwin et al. 1974). There was a significant correlation between amount of feed consumed and the erosion rate of the lead shot only in the ducks on the adequate diet, and a significant relationship between the amount of feed eaten and the rate of lead excretion only in the ducks on the adequate diet. The most obvious difference between the effects of ingested lead in ducks fed corn and ducks fed an adequate diet was the lead-induced anorexia in the former but not in the latter. Rate of food consumption was an important factor as was indicated by the correlation between it and the changes in body weight. The increased volume of soft food of the adequate diet passing through the gizzard may have caused an increase in the secretion of gastric juices and the greater erosion rate of the shot, such as was observed. The correlation between the erosion rate of the pellets and the rate of food consumption in birds fed the adequate diet supports this hypothesis. Perhaps the correlation between the amount of feed consumed and the rate of lead excretion was present only in ducks on the adequate diet because passage of normal amounts of ingesta through the gastrointenstinal tract continuously conveyed lead out of the ducks. The lead-induced anorexia in corn-fed ducks probably meant that the amount of ingesta was insufficient to carry the lead out of the birds. The experiment did not indicate how diet protects from the effects of ingested lead. It was clear, however, that anorexia in corn-fed ducks played a major role, but the reason for anorexia occurring only in the ducks on a corn diet was not known (Irwin et al. 1974).

One study indicated no correlation between the number of pellets in the gizzard and the rate of retention (Cook and Trainer 1966); our results from the present study agree with this conclusion. However, Irwin et al. (1974) found that on an adequate diet ducks dosed with eight shot eroded them significantly faster than ducks dosed with four lead pellets.

PHASE II. EFFECTS OF STRAIN OF DUCK AND SOURCE OF CORN

METHODS

Because of the low toxic response of the ducks dosed with lead:iron shot and with commercial lead shot in the Phase I experiment, we decided to try to determine the factor or factors responsible. Two simultaneous experiments were designed to test the effects of the soil, strain of duck, type of corn, time of year, water, and air.

The experiment to test the effects of strain of duck and type of corn was conducted at the Illinois Natural History Survey Field Station, Havana. Twenty adult game-farm mallard drakes were used: 10 were McGraw mallards (MM) used in the Phase I study and 10 were Whistling Wings mallards (WWM) from Hanover, Illinois. Five ducks of each strain were placed side by side in pens with wire floors. These pens were 30' X 6' X 2' (Jordan and Bellrose 1950:157). The ducks in one pen were fed corn from Nilo Farms and those in the other pen were fed corn from the Havana area.

The experiment to test the significance of the soil was conducted at Nilo Farms in one of the original experimental pens. Twenty male MM from the Phase I experiment were used in this experiment: 10 were placed on the ground and 10 were placed on wire in an adjacent pen. Each pen was 12' X 6' X 4'. All birds on this experiment were fed corn from Nilo.

All MM used in the present experiment were controls or ducks that had been dosed with one steel pellet or one pellet of lead and iron. They were all from Pen 3--males on corn for 2 weeks and then corn plus duck pellets. Each duck that had been dosed with one pellet of some combination of lead and iron was X-rayed to determine if any traces of the pellet remained in the gizzard. These ducks had been exposed to low levels of lead and iron, and we believed that by 6 weeks after the initial dosing any effect of lead or iron was insignificant.

Ducks on both tests were weighed, bled, and each was dosed with five No. 4 commercial lead shot on 1 July 1975. They were placed in the pens as described above and begun on their respective diets of either Nilo corn or Havana corn. Nine of the ducks at Nilo Farms were placed in a pen with a wire floor so that they did not have access to the soil and 11 were placed in an adjacent pen with no floor. The division of 9 and 11 ducks instead of 10 and 10 resulted from an error in placing the ducks in the pens after a very long, hot day.

All ducks were weighed and bled at weekly intervals, ducks that died were autopsied, and the shot was removed from their gizzards and weighed. The ducks surviving these tests at Havana were moved to Urbana, Illinois, on 16 July to make room for the Phase III experiment. The ducks surviving these tests at Nilo Farms were moved to Urbana on 23 July in order to remove all ducks from the pens at Nilo Farms. At Urbana, the ducks were placed in pens with wire floors, but a box of dirt from the holding pens at Nilo was placed in the pen with the ducks that were on the ground at Nilo.

RESULTS AND DISCUSSION

Effect of Soil on Lead Toxicity

Retention and Erosion of Pellets.--The 9 ducks held on wire at Nilo had a mean of 3.78 pellets in their gizzards at death compared with 1.82 pellets for the 11 ducks on the ground (Table 12). This difference was significant ($P < 0.05$); however, it is not clear from this experiment how the presence of soil influenced the retention of shot to the time of death in these ducks. The rate of passage of pellets was 1.11 percent per day for ducks on wire compared with 1.59 percent for ducks on the ground.

The individual pellets in the gizzards of all ducks on wire declined an average of 35.7 percent in weight compared with a 60.1 percent decline in the average weight of pellets in ducks on soil. This difference was not statistically significant ($P > 0.05$) because of the small sample sizes and high individual variation.

The ducks with access to soil had a much longer time to erode the pellets and pass them from the gizzard than the ducks on wire. The daily erosion rate was slightly higher (4.25 percent) in ducks on wire than in ducks on soil (3.87 percent). This higher daily erosion rate for ducks on wire occurred because the ducks with one or more pellets in their gizzards at death died an average of 17.9 days after dosing compared with 28.9 days for ducks on soil with one or more pellets in their gizzards at death (Table 12). Thus, there was more surface to erode because the shot in the gizzards of ducks on wire were larger at death than the pellets in ducks on soil. When only ducks that died before the end of the experiment are compared, the average daily erosion rate was 4.80 percent for ducks on soil compared with 4.25 percent for ducks on wire. Also, when a comparison is made only for the ducks that died by 30 days after dosing, we find an average daily erosion rate of 4.25 percent and an average of 19.3 days to death for ducks on wire compared with an average daily erosion rate of 5.42 percent and an average of 23.4 days to death for ducks on soil. The 35.7 percent erosion rate we found in ducks on wire in 17.9 days may be compared with an erosion rate of 46 percent in mallards on a high fiber diet within 20 days after dosing and 62 percent in 20 days for mallards on a low fiber diet (Clemens et al. 1974).

Without citing any supporting evidence, several investigators have reported that when grit is in short supply, lead pellets are more likely to be ingested and are retained longer in the gizzard than when grit is abundant (Osmer 1940, Rosen and Barnkowski 1960, and Beer and Stanley 1965). These same investigators reported that excess grit moved through birds quickly and carried any lead pellets with it. Recently Longcore et al. (1974) have presented experimental evidence indicating that the amount and type of grit affect the rate of erosion and rate of retention of lead pellets. Ingested shot eroded faster and were retained for a shorter time when grit was readily available. The overall result was a lower but faster mortality rate among ducks with access to grit than in ducks with no grit. Our data seem to support these earlier conclusions. We did not measure the grit in the gizzards of these ducks; however, the ducks on the soil had access to grit in the soil. The ducks on wire obtained no grit after this experiment was initiated, and at death they retained a higher percentage of the dosed pellets--and the pellets were larger--than the ducks on soil. The daily rate of voiding pellets was higher in ducks on the ground than it was in ducks on wire, but this difference may have been a result of the smaller mean size of the pellets at death in the ducks on soil.

Irwin et al. (1974) dosed game-farm mallards with none, four, and eight No. 4 lead pellets. Half of the ducks were fed corn and half were fed an adequate diet. The consumption of food declined after dosing only in the groups fed corn; however, there was a significant correlation between amount of feed consumed and the erosion rate of the lead shot only in the ducks on the adequate diet. In our study, both groups were fed corn and we did not measure food consumption. The ducks on soil were obviously in better physical condition than the ducks on wire. Thus, it is possible that the ducks on soil consumed more corn than the ducks on wire. If they did, one expected result would be a higher erosion and a higher passage rate of the lead pellets. Irwin et al. (1974) stated it was clear that anorexia in corn-fed ducks played a major role. Perhaps in our study the ducks on the ground obtained something from the soil that helped to maintain their appetites.

Mortality.--Although the mean number of days survived to 60 days after dosing was not significantly different in the two groups, the average for the ducks on wire was only 22.6 days compared with 40.0 days for ducks on soil. The most striking difference in the ducks on wire and on soil was the mortality rates at 30 days and at 60 days after dosing. At 30 days the rate was 88.9 percent for ducks on wire compared with 36.4 percent for ducks on the ground. At 60 days after dosing the rates were 88.9 percent for ducks on wire and 45.4 percent for ducks on the ground (Table 12). Both differences were statistically significant ($P < 0.003$).

We have found no previous studies that considered the effects of soil on the toxicity of ingested lead in ducks. Many of the effects of diet on lead poisoning that have been reported by other investigators appear similar to the results we found in this limited preliminary study. For many years it has been recognized that diet and the rate of food consumption have profound effects on the toxicity of ingested lead in waterfowl. How these factors exert their influence is still a matter of some speculation and conflicting evidence.

Body Weight.--Although the ducks on wire lost slightly more weight than the ducks on soil, the differences were not statistically significant (Table 13). The differential mortality rates between the two groups resulted in similar rates of weight losses in the surviving ducks. Only one duck on wire survived to 60 days after dosing compared with six on soil. The ducks that died first were among those with the highest rates of weight loss. Although the two groups had similar percentages of weight losses at death for ducks that died during the experiment (46.3 percent for ducks on wire compared with 42.8 percent for ducks on soil), the former group lost weight for only 22.6 days (average number of days to death) compared with 40.0 days for the latter group.

Ducks on soil erode and expel lead faster than ducks on wire, ducks on wire have a higher mortality rate after dosing with lead pellets than ducks on soil, and ingested soil has protective effects against lead toxicity in captive mallards. Thus, changes in body weights must be interpreted and evaluated with care if they are used to indicate responses to ingested lead in ducks on wire as compared with ducks on soil.

The weight losses we found in the present experiment for ducks that died of lead poisoning (approximately 45 percent in 23 to 40 days) are similar to losses reported by other investigators. Twelve captive mallards that died an average of 22.4 days after dosing with lead had lost an average of 43.4 percent of their preexposure body weight (Barrett and Karstad 1971). Another group of game-farm mallards dosed with eight No. 6 lead shot on a diet of whole corn survived an average of 17 days after dosing and lost an average of 37 percent of the initial body weight (Irby et al. 1967).

Seven captive Canada geese dosed with 10 or more pellets suffered acute lead intoxication and died within 23 days (mean 10 days) after losing only 22 percent of the original body weight, whereas two geese dosed with 5 pellets each survived for an average of 55.5 days and lost 32 percent of their body weight prior to death (Cook and Trainer 1966). Another group of lead-poisoned captive Canada geese lost 25 to 45 percent of their body weight and died 11 to 45 days after dosing (Sileo et al. 1973). Wild scaups lost an average of 30 to 35 percent of their body weight before dying of acute lead poisoning in Illinois in the spring (Anderson 1975).

PCV's.--The decline in PCV's was significantly greater ($P < 0.05$) at 9 and 15 days after dosing with five No. 4 commercial lead pellets in ducks on wire than in ducks on soil (Table 14). At 21 days after dosing the differences were as great as they were 15 days after dosing (42.1 percent vs. 25.3 percent, respectively, for ducks on wire and ducks on soil); however, because there were only five surviving ducks on wire, the difference was not statistically significant ($P > 0.05$).

In the present study, declines in PCV's were a more sensitive indicator than early mortality rates, mean number of days survived after dosing, or changes in body weights. In our Phase I study PCV's were measured prior to dosing and at 3 and 6 weeks after dosing in surviving ducks. There were no significant differences in the PCV's caused by shot type or dose levels (Table 4). There was a slight indication that the commercial lead pellets caused a decline in these values at 3 weeks postdosing but that by 6 weeks after dosing the values were recovering. If PCV's are used to indicate relative responses to lead toxicity in ducks, they should be taken about 7 and 14 days after dosing. By 21 days after dosing PCV values will be recovering in many surviving ducks. Also, after about 14 days the effects of mortality will tend to mask and confuse the results when the PCV's of the surviving ducks are used.

Effect of Strain of Duck and Source of Corn on Lead Toxicity

Retention and Erosion of Pellets.--There were no significant differences ($P > 0.70$ in all cases) among the four test groups of ducks--MM fed Nilo corn, MM fed Havana corn, WWM fed Nilo corn, and WWM fed Havana corn, all on wire--in the number of pellets in the gizzards at death. The mean number of pellets recovered at death ranged from 4.2 to 4.6 (Table 15). In the first part of the present study just discussed, ducks on wire had an average of 3.78 pellets in their gizzards at death and ducks on soil had only 1.82 pellets (Table 12).

All MM had an average of 4.3 pellets in their gizzards at death compared with 4.4 pellets in the gizzards of WWM ($\underline{P} > 0.80$). The ducks fed Nilo corn had an average of 4.5 pellets at death compared with 4.2 pellets in gizzards of all ducks fed Havana corn ($\underline{P} > 0.50$).

The average loss of weight per pellet at death ranged from 20.5 percent in the WWM-Nilo corn group to 38.3 percent in the MM-Nilo corn group (Table 15). There were no significant ($\underline{P} > 0.10$ in all cases) differences among these groups. The mean weight loss of each pellet at death was 32.5 percent for all MM compared with 21.6 percent for all WWM ($\underline{P} > 0.10$). Pellets in gizzards of ducks fed Nilo corn eroded 29.4 percent of their weight by the time the ducks died compared with an average loss of 24.7 percent for ducks fed Havana corn ($\underline{P} > 0.40$).

The daily rate of decline of weight of the pellets ranged from 1.3 percent for the WWM-Havana corn group to 2.4 percent for the MM-Nilo corn group and the MM-Havana corn group (Table 15). As with the other values related to erosion rate of the pellets, there were no significant differences ($\underline{P} > 0.10$ in all cases) among these groups.

The daily rate of weight loss of the pellets in gizzards of all MM was 2.4 percent compared with 1.7 percent for all WWM ($\underline{P} > 0.20$). Pellets in gizzards of ducks fed Nilo corn lost an average of 2.2 percent of their weight each day by the time the ducks died compared with 1.8 percent daily loss for ducks fed Havana corn ($\underline{P} > 0.50$). The daily erosion rate for all the ducks at Havana (Table 15) was 2.04 percent compared with 4.25 percent for ducks on wire at Nilo Farms (Table 12).

The MM on Nilo corn at Havana had a daily erosion rate of 2.4 percent (Table 15) and an average survival time of 19.4 days compared with 4.25 percent and an average survival time of 17.9 days for MM on Nilo corn at Nilo Farms (Table 15). This difference in the daily erosion rates was caused by one duck at Nilo Farms that died 1.5 days after dosing, at which time it had eroded 19.9 percent of the weight of the pellets in its gizzard. If this duck is not included, the daily erosion rates are the same for both groups. Clemens et al. (1974) reported a daily erosion rate of 2.3 percent in 20 days for mallards on a high fiber diet and 3.1 percent in 20 days for mallards on a low fiber diet.

Mortality.--The mean number of days to death for the four groups of ducks ranged from 11.6 for the WWM-Nilo corn group to 19.4 for the MM-Nilo corn group. There were no significant ($\underline{P} > 0.10$ in all cases) differences among these groups (Table 15). The MM survived an average of 16.3 days after dosing compared with 14.8 days for the WWM ($\underline{P} > 0.60$). Ducks fed Nilo corn survived an average of 15.5 days compared with 15.6 days for ducks fed Havana corn ($\underline{P} > 0.80$).

Fourteen days after dosing the mortality rate ranged from 20.0 percent in the WWM-Havana corn group to 60.0 percent in the WWM-Nilo corn group. None of these differences approached significance ($\underline{P} > 0.70$ in all cases). By 60 days after dosing all ducks in all four groups were dead. Only one duck (in the MM-Nilo corn group) survived for more than 30 days and it died 32 days after dosing. All MM suffered 50 percent mortality by 14 days after dosing compared with 40 percent mortality for the WWM ($\underline{P} > 0.90$). Ducks fed Nilo corn suffered 50 percent mortality by 14 days after dosing compared with 40 percent for ducks fed Havana corn ($\underline{P} > 0.90$).

The average number of days survived to 60 days after dosing for all ducks at Havana (Table 15) was 15.6 compared with 22.6 (Table 12) for ducks on wire at Nilo Farms. At 30 days after dosing the mortality rate was 88.9 percent for ducks on wire at Nilo Farms compared with 95.0 percent for all ducks at Havana. At 60 days after dosing the rates were 88.9 percent for ducks on wire at Nilo Farms and 100 percent for all ducks at Havana.

Body Weight.--By 7 days after dosing the MM-Nilo corn group had lost significantly ($P < 0.05$) more weight (17.1 percent) than the MM-Havana corn group (14.4 percent) (Table 16). This significant difference was one of only three found among some 86 comparisons made for these four groups of ducks, and the other significant differences noted under PCV's do not support the difference in body weight. There were no significant differences in body weights 14 days after dosing and in body weights at death among the four groups. Also, there were no significant differences ($P > 0.05$) in the rates of weight losses of the ducks 7, 14, and 21 days after dosing and at death for the MM compared with the WWM or for the ducks fed Nilo corn compared with the ducks fed Havana corn.

All ducks on the present experiment at Havana died during the experiment. Their average weight loss was 36.8 percent compared with 46.3 percent for the ducks on wire at Nilo Farms that died during the experiment. The ducks on wire at Nilo Farms lost weight over a slightly longer period than ducks at Havana. The average survival time for the ducks on wire that died prior to the end of the experiment at Nilo Farms was 17.9 days compared with 15.6 days for all ducks at Havana.

PCV's.--The declines in PCV's 7 days after dosing ranged from 44.1 percent in the MM-Nilo corn group to 57.3 percent in the MM-Havana corn group. None of these differences was significant ($P > 0.05$). By 14 days after dosing the PCV values of the surviving ducks had improved slightly. The declines ranged from 29.0 percent for the MM-Nilo corn group to 56.2 percent for the WWM-Havana corn group (Table 17). The difference between these two groups was the only significant ($P < 0.05$) one found among the PCV values for these four groups of ducks.

The decline for all MM 7 days after dosing was 49.9 percent compared with 53.2 percent for the WWM ($P > 0.60$). On the same date the decline for all ducks on Nilo corn was 43.9 percent compared with 57.2 percent for all ducks on Havana corn ($P > 0.05$). By 14 days after dosing the decline in PCV's for all surviving MM was 31.8 percent compared with 51.5 percent for all surviving WWM. This difference was the only significant one in PCV's at 14 days after dosing ($P < 0.05$). On the same date, the decline for all ducks on Nilo corn was 34.3 percent compared with 49.4 percent for all surviving ducks on Havana corn ($P > 0.10$).

These differences indicated that the WWM may be slightly more susceptible to the effects of lead toxicity than the MM. So far as the PCV values were concerned, the type of corn did not appear to be a factor. The one statistically significant difference in body weight indicated that Nilo corn resulted in a greater weight loss than Havana corn when the ducks were dosed with lead pellets. The PCV's of ducks on wire at Nilo Farms had declined 54.9 and 47.2 percent, respectively, 9 and 15 days after dosing (Table 14), whereas the declines for all ducks at Havana were 50.5 and 40.8 percent, respectively, 7 and 14 days after dosing (Table 17).

CONCLUSIONS

Significant differences were found in the number of pellets retained at death and in the mortality rates 60 days after dosing, and the declines in PCV's were significantly greater 9 and 15 days after dosing in ducks on wire compared with ducks on soil. Also, there were substantial, but not statistically significant, differences in the total amount of erosion from the pellets, the mean number of days the ducks survived after dosing, and body weights. Even though the sample sizes were small, all of the differences in the preliminary experiment indicated that ducks on wire were more susceptible to ingested lead pellets than ducks with access to soil.

There were only three statistically significant differences among the 86 comparisons made for the ducks used to test the strain of duck and the different corns, and these differences did not support each other. Thus, we concluded that the strain of duck and the source of corn were not important factors in the lack of significant differences among the groups of ducks on the Phase I study. The similarities in results from ducks on wire at Nilo Farms and from all ducks at Havana indicate that air and water were not important factors in the Phase I study.

PHASE III. EFFECTS OF VARIOUS COMBINATIONS AND NUMBERS OF LEAD:IRON PELLETS DOSED IN WILD-TYPE CAPTIVE MALLARDS ON A DIET OF CORN

METHODS

On 16 July 1975 the ducks fed the complete diet in the Phase I study were moved to the Illinois Natural History Field Laboratory at Havana. There, all the ducks except those dosed with the 41 percent lead:iron shot were put into four pens (30' X 6' X 2' high), with wire floors (1-inch mesh) to prevent access to the soil. In this experiment, drakes and hens were housed separately; five males per dose were held in each of two pens and five females per dose were held in each of two pens (that is, there were 10 drakes and 10 hens per dose). Only one diet, whole corn, was used. The ducks dosed with 41 percent lead:iron shot were housed in groups of five, sexes separately, in wire-covered pens 4' X 4' X 2.5'. In order to avoid overcrowding, these ducks were not placed in the four larger pens. The ducks dosed with 41 percent lead:iron shot were chosen because this shot was made by a different process from that by which the other lead:iron shot used in the experiment were made.

The ducks were weighed, bled, and dosed on 29 July 1975. The mean weights of the doses administered are given in Table 18. The ducks were given the same dosages as they received during the Phase I study, but a few missing ducks were replaced with ducks from the group fed diet No. 2 in the Phase I study. In addition to the procedures described for Phase I above, the birds in the Phase III study were weighed and bled at 7 days after dosing. The drakes and hens were killed for necropsy at 43 and 44 days, respectively, after dosing. At necropsy, livers, gonads, and shot remaining in the gizzards were weighed as well as the thyroids from the controls and all the iron-dosed ducks.

If the level of statistical significance is not specified in the text, assume the 0.05 level as the basis of acceptance or rejection.

RESULTS

At necropsy, it was discovered that some birds had more shot or had a different type of shot than was originally administered. These shot were probably ingested from the bottoms of the watering troughs. Ducks with altered doses and one duck that died of an *Escherichia coli* septicemia were eliminated from the experiment (Table 19).

We are aware that some ducks may have eliminated one or more shot and ingested one or more shot of the same or a different type either before or after eliminating the shot we dosed. These additional shot that may have been ingested no doubt were eliminated by dosed ducks and were then ingested from the bottom of the watering troughs. We make the assumption that a duck with the same number, or fewer, shot than were dosed had not ingested additional shot. We are aware that this assumption may not always be correct, but except for analyzing the lead content of each shot recovered from the gizzards (an impractical solution), we know of no way to be certain that the shot recovered from a gizzard were the ones we dosed in that particular duck. Ducks could be

X-rayed or fluoroscoped daily and the shot in their gizzards counted, but the additional stress resulting from this procedure would add an extra undesirable dimension to the experiment.

We recommend that in future studies a false bottom made of 1/4-inch-mesh hardware cloth or welded wire be placed in water troughs so that ducks cannot ingest shot that are voided in the water. The only way to be certain that one duck does not ingest shot eliminated from another duck is to place the ducks in individual pens. During the Phase VI study, one duck dosed with five No. 4 lead pellets on 15 September 1975 had six lead pellets in its gizzard when it died on 21 September 1975. Fifteen dosed lead pellets were missing at autopsy from the gizzards of other ducks in the same pen. This pen had a floor of 1-inch-mesh wire supported by wooden 2 x 4's. The only logical explanation is that one of the other ducks eliminated a shot that lodged on the narrow wooden floor support and that the shot was ingested by the duck whose gizzard contained six pellets at autopsy.

Retention Rate of Shot

Among the birds killed at the termination of the study, the ducks dosed with iron shot were found to have the highest retention of shot, 95.4 percent. Those dosed with the 45 percent lead:iron shot had the next highest retention. The groups dosed with 58 and 64 percent lead:iron shot had retained 61.9 and 58.0 percent, respectively, of the administered shot, and the 41 percent lead: iron group had the lowest shot retention, 18.3 percent (Table 20). There was no significant difference in the overall shot retention between drakes and hens.

Regression analyses of the shot recovery data yielded the following equation:

$$\underline{Y} = 0.5033 + 0.5500\underline{N} + 0.7463\underline{D} - 0.0005\underline{TP} - 0.0275\underline{T}$$

Where $\underline{Y}$ = number of shot recovered

$\underline{N}$ = number of shot in the dose

$\underline{D}$ = disposition; $\underline{D} = -1$ for survivors and $\underline{D} = 1$ for nonsurvivors

$\underline{T}$ = postdosing time to necropsy (days)

$\underline{P}$ = percent Pb composition of the shot by weight.

Those variables accounted for 54.3 percent of the variation in the number of shot recovered. All the regression coefficients were highly significant ($\underline{P} < 0.001$). The above regression indicated that there were different responses between the ducks that died and the surviving ducks with respect to retention of shot and that the number of shot administered and an interaction between time and percent Pb composition of the shot were important.

Erosion Rate of Shot

The amounts of shot eroded in the gizzards of the surviving ducks were generally greater than the amounts eroded in the ducks that died (Table 21). Because the erosion rates of the different shot in the survivors and the ducks that died were comparable (Table 22), the greater amount of shot eroded in the surviving ducks was probably a result of the longer time the shot spent in their gizzards. That assumption was supported by the regression analyses, in which the time to necropsy alone was found to account for 54 percent of the variation in the amount of shot eroded. The following equation was generated by regression analyses:

$$\underline{Y} = 3.070 + 3.085\underline{T} - 9.340\underline{R} + 0.524\underline{P}$$

Where $\underline{Y}$ = the mean weight loss per shot (mg)

$\underline{T}$ = the postdosing time to necropsy (days)

$\underline{R}$ = the number of shot recovered at necropsy

$\underline{P}$ = the percent Pb composition of the shot.

The inclusion of the $\underline{R}$ and $\underline{P}$ variables increased the explained variation to a total of 74.8 percent. All three regression coefficients were highly significant ($\underline{P} < 0.001$). The regression indicated that erosion of shot was directly related to time and Pb composition and inversely related to the number of shot retained in the gizzard.

The calculated amount of Pb eroded per shot by the ducks that died ranged from 32.3 mg for the 3-45 group to 126.2 mg for the 1-100 group (Table 21). The mean amounts of Pb eroded per shot by the survivors in the 58 and 64 percent lead:iron groups were 86.8 and 102.3 mg, respectively, compared with 82.4 mg for the ducks that died in the groups dosed with commercial lead shot. The mean amounts of Pb eroded by the survivors in groups dosed with 41 and 45 percent lead:iron shot were both 64.5 mg per shot.

The rates of shot erosion in the gizzards of the ducks that died ranged from 1.4 percent per shot per day for the 5-58 group to 3.2 percent per shot per day for the 3-45 group (Table 22). The rates of shot erosion in the groups of survivors ranged from 1.5 percent per shot per day for the 5-64 group to 2.3 percent per shot per day for the 1-41 group. Overall, the ducks that died did not erode shot at a significantly different rate from those that survived (1.9 and 2.0 percent per shot per day, respectively). There were no significant differences between the erosion rates of those that died and those that survived for any of the dosage groups.

Mortality Rate

The number of ducks that died in each treatment is given in Table 23. Mortality ranged from 0 percent in the controls, in ducks dosed with commercial steel shot, and in the 1-41 and 1-45 groups to 100 percent in the 5-100 group.

Mortality appeared to be directly related to the amount of Pb in the dose. There was no significant difference in the overall mortality rate with respect to sex.

We compared the mortalities of the different types of shot--with the three dose levels and sexes combined--by applying the proportions of ducks that died to the 95 percent binomial confidence limits. The ducks dosed with 58 percent lead:iron shot had a significantly lower mortality rate than ducks dosed with the commercial lead shot (Table 24). Ducks dosed with 41 or 45 percent lead:iron shot had significantly lower mortality than the groups receiving 58 percent lead:iron shot.

The mortality rates for the different doses are given in Table 25. The median effective times to 50 percent mortality (ET_{50}) with sexes combined ranged from 11.4 days for the 5-100 groups of ducks to 43.6 days for the 5-45 group and tended to be inversely related to the amount of Pb in the shot and the number of shot in the dose. The 1-64, 1-58, 3-45, and 1-45 groups, all the groups dosed with 41 percent lead:iron shot, those dosed with steel shot, and the controls had insufficient mortalities to calculate ET_{50}'s. Although the overall mean survival times of the drakes and hens, 21.8 and 20.0 days, respectively, were not significantly different, the ET_{50}'s of the hens in the 5-58, 3-64, and 5-100 groups were significantly shorter than for their corresponding groups of drakes. The cumulative mortality patterns for the different types of shot are illustrated in Figs 1-5.

Body Weight

Postdosing body weights tended to be inversely related to the amount of Pb in the dose (Table 26). At 1 week after dosing, the groups of ducks dosed with commercial lead shot had lost significantly more weight than the groups dosed with 58 and 64 percent lead:iron shot, and the latter two groups in turn had lost significantly more weight than the groups dosed with 41 and 45 percent lead:iron shot and steel shot. At 3 weeks after dosing, the groups dosed with commercial lead shot had continued to lose significantly more weight than the other groups. The groups dosed with 64 percent lead:iron shot had lost significantly more weight than the groups dosed with 58 percent lead:iron shot. The 58 percent lead:iron groups had lost significantly more weight than the 41 percent lead:iron and the steel shot groups, and the 45 percent lead:iron groups had lost significantly more than the steel shot groups. At 6 weeks after dosing, reductions in sample sizes because of mortality and the presence of recuperating ducks that had expelled their shot had partially distorted the earlier response pictures. The groups dosed with 64 percent lead:iron weighed significantly less than the other lead:iron and the steel shot groups. Both the 41 and 45 percent lead:iron groups had significantly lower weights than the groups dosed with steel shot.

Regression analyses of each of the three sets of data for postdosing body weights for all groups except those dosed with commercial lead shot and the control group yielded the following equations:

$$\underline{BW}_1 = 104.1145 + 0.8583\underline{BW}_o - 0.59\underline{L} - 38.5979\underline{S} + 0.8742\underline{PN}$$

($\underline{R}_T^{\ 2}$ = 86 percent, $\underline{R}_E^{\ 2}$ = 22 percent, C.V. = 4.4 percent)

$$\underline{BW}_3 = 98.5942 + 0.8450\underline{BW}_o - 0.49\underline{L}$$

($\underline{R}_T^{\ 2}$ = 64 percent, $\underline{R}_E^{\ 2}$ = 48 percent, C.V. = 10.1 percent)

$$\underline{BW}_6 = 403.8710 + 0.4953\underline{BW}_o - 0.41\underline{L} - 85.8269\underline{S}$$

($\underline{R}_T^{\ 2}$ = 50 percent, $\underline{R}_E^{\ 2}$ = 25 percent, C.V. = 11.2 percent)

Where $\underline{BW}_o$ = predosing body weight (g)

$\underline{BW}_1$ = body weight (g) at 1 week after dosing

$\underline{BW}_3$ = body weight (g) at 3 weeks after dosing

$\underline{BW}_6$ = body weight (g) at 6 weeks after dosing

$\underline{L}$ = amount of Pb in the dose (mg)

$\underline{P}$ = percent Pb composition of the shot

$\underline{N}$ = number of shot in the dose

$\underline{S}$ = sex; drakes = -0.5 and hens = 0.5

$\underline{R}_T^{\ 2}$ = the total amount of variation in the dependent variable that could be attributed to all the independent variables in each particular equation

$\underline{R}_E^{\ 2}$ = the amount of variation in the dependent variable that could be attributed to only the experimental doses as opposed to animal variables such as sex and covariants such as initial body weight.

The commercial lead shot groups were eliminated from the analyses of the body weight data--as well as the PCV and Hb data--because the inclusion of those groups tended to reduce the $\underline{R}_E^{\ 2}$ value.

All regression coefficients in the above three equations were highly significant ($\underline{P} < 0.01$). In all three regression analyses of body weights, the amount of Pb in the dose and the predosing body weights were indicated as the most important variables. Sex was a significant factor at 1 and 6 weeks after dosing but contributed little to the $\underline{R}_T^{\ 2}$ value (2 and 1 percent for $\underline{BW}_1$ and $\underline{BW}_6$, respectively). All three analyses indicated that postdosing weights were directly related to predosing body weight and inversely related to the amount of Pb in the dose.

The final body weights of the ducks that died in each group are given in Table 27. Multiple regression analyses of the final body weights of the ducks that died yielded the following equation:

$$\underline{Y} = 235.3705 - 1.4031\underline{D} + 0.4889\underline{BW_o} + 1.2053\underline{P} - 0.1434\underline{DP}$$

Where $\underline{Y}$ = the postmortem body weight (g)

$\underline{D}$ = the postdosing time to death (days)

$\underline{BW_o}$ = the predosing body weight (g)

$\underline{P}$ = the percent Pb composition of the shot.

The $\underline{R_T}^2$ value for the equation was 55 percent and all the regression coefficients were highly significant ($\underline{P} < 0.001$). This analysis indicated that the final body weight of the ducks that died from lead poisoning was directly related to the predosing body weight and the relative lead content of the shot and inversely related to the duration of the toxicosis.

PCV

Mean PCV's of each of the doses for each of the three postdosing times of blood sampling are presented in Table 28. In general, the PCV response, like the body weight response, was inversely related to the amount of Pb in the dose, but unlike the body weight response, the mean PCV values of many of the groups had returned to within the normal range by 6 weeks after dosing.

At 1 week after dosing, the groups of ducks dosed with commercial lead shot had significantly lower PCV values than the groups dosed with 58 and 64 percent lead:iron shot. The two latter groups in turn had significantly lower PCV values than the groups dosed with 41 and 45 percent lead:iron shot and the steel shot. At 3 weeks after dosing there was a tendency for the PCV values of the groups dosed with three and five shot of the 41, 45, 58, and 64 percent lead:iron shot to be lower than their respective levels at 1 week after dosing. At 3 weeks after dosing, the PCV values of the groups dosed with 64 percent lead:iron shot were significantly lower than those dosed with 58 percent lead:iron shot. The PCV values of the groups dosed with commercial lead shot and 58 percent lead:iron were significantly lower than the PCV values of those dosed with 41 percent lead:iron shot, and the PCV values of the 45 and 41 percent lead:iron groups were lower than the values of the groups dosed with steel shot. At 6 weeks after dosing, there were no significant differences among the PCV values of any of the groups.

Multiple regression analyses of the three sets of postdosing PCV data for all groups except those dosed with commercial lead shot and the control group yielded the following equations:

$$\underline{PCV_1} = -0.24102 - 0.126\underline{L} + 1.01957\underline{PCV_o} + 0.18696\underline{PN}$$

$$(\underline{R_T}^2 = 65 \text{ percent}, \underline{R_E}^2 = 55 \text{ percent, C.V.} = 13.2 \text{ percent})$$

$\underline{PCV}_3 = 6.01676 - 0.38\underline{L} + 0.91527\underline{PCV}_o$

($\underline{R}_T^2$ = 49 percent, $\underline{R}_E^2$ = 44 percent, C.V. = 18.8 percent)

$\underline{PCV}_6 = 25.20279 - 0.19\underline{L} + 0.47773\underline{PCV}_o$

($\underline{R}_T^2$ = 29 percent, $\underline{R}_E^2$ = 23 percent, C.V. = 11.8 percent)

Where $\underline{PCV}_1$ = PCV (%) 1 week after dosing

$\underline{PCV}_3$ = PCV (%) 3 weeks after dosing

$\underline{PCV}_6$ = PCV (%) 6 weeks after dosing

$\underline{PCV}_o$ = predosing PCV (%)

$\underline{L}$ = amount of Pb in the dose (mg)

$\underline{P}$ = the percent Pb composition of the shot

$\underline{N}$ = the number of shot in the dose.

All the regression coefficients in the above three equations were highly significant ($\underline{P} < 0.01$). In all three of the PCV regression analyses, the amount of the Pb in the dose was indicated as the most important independent variable. The three analyses indicated that the PCV responses were inversely related to the amount of Pb in the dose and directly related to predosing PCV.

Hb

The mean hemoglobin concentrations at 1, 3, and 6 weeks after dosing for the groups of ducks given the various doses are shown in Table 29. At 1 week after dosing, the groups of ducks dosed with the commercial lead shot had attained the lowest Hb observed during the entire experiment. That mean of 4.2 mg percent was significantly lower than the means of the groups dosed with 64 and 58 percent lead:iron shot. The latter two groups in turn had significantly lower Hb values than the groups dosed with 45 percent lead:iron shot, which, again in turn, had a significantly lower Hb value than the groups dosed with 41 percent lead:iron shot and steel shot. At 3 weeks after dosing the overall mean Hb value for the ducks dosed with 64 percent lead:iron shot was significantly lower than for the groups dosed with 45 and 41 percent lead:iron shot and commercial steel shot. Hb's for ducks dosed with commercial lead shot and 58, 45, and 41 percent lead:iron shot were significantly lower than Hb's of ducks dosed with commercial steel shot. The mean Hb value of the ducks dosed with commercial lead shot was also significantly lower than the value for the birds dosed with 41 percent lead:iron shot. At 6 weeks after dosing, the overall mean Hb for the ducks dosed with 64 percent lead:iron shot was significantly lower than that for ducks dosed with 41 percent lead:iron and with steel shot. The mean Hb for each group of ducks dosed with 58, 45, and 41 percent lead:iron shot was significantly lower than the Hb value of the birds dosed with steel shot.

The following three estimating equations were derived by multiple regression analyses of the postdosing Hb data of all groups except those dosed with commercial lead shot and the controls:

$$\underline{Hb}_1 = 20.76359 - 0.004928\underline{M} - 0.0037\underline{L} - 0.033815\underline{P}$$

$(\underline{R}_T^2 = 57 \text{ percent}, \underline{R}_E^2 = 44 \text{ percent}, \text{C.V.} = 20.5 \text{ percent})$

$$\underline{Hb}_3 = 14.34215 - 0.010\underline{L} - 0.00081\underline{P}^2 - 1.50697\underline{S}$$

$(\underline{R}_T^2 = 50 \text{ percent}, \underline{R}_E^2 = 48 \text{ percent}, \text{C.V.} = 25.5 \text{ percent})$

$$\underline{Hb}_6 = 13.18752 - 0.009\underline{L} - 0.02564\underline{SP}$$

$(\underline{R}_T^2 = 32 \text{ percent}, \underline{R}_E^2 = 28 \text{ percent}, \text{C.V.} = 25.5 \text{ percent})$

Where $\underline{Hb}_1$ = Hb (mg %) 1 week after dosing

$\underline{Hb}_3$ = Hb (mg %) 3 weeks after dosing

$\underline{Hb}_6$ = Hb (mg %) 6 weeks after dosing

$\underline{M}$ = mean weight of the shot in the dose (mg)

$\underline{L}$ = amount of Pb in the dose (mg)

$\underline{P}$ = the percent Pb composition of the shot

$\underline{IU}$ = the number of pellets in the dose

$\underline{S}$ = sex; drakes = -0.5 and hens = 0.5.

All the regression coefficients in the three equations were highly significant ($\underline{P} < 0.01$). As in the case of the PCV responses, in all three of the Hb regression analyses the amount of Pb in the dose was indicated as the most important independent variable. Sex was also a significant factor at each of the three sampling times but contributed little to the overall amount of explained variation in the Hb responses ($\underline{R}_T^2$). In all cases, the Hb response was inversely related to the amount of Pb in the dose.

Gross Symptoms

The prevalence of gross symptoms that occurred in the ducks that died is presented in Table 30. The symptoms most commonly noted were, in descending order of frequency, distension of the gall bladder with bile, bile-stained gizzard lining, emaciation, degeneration of the gizzard lining, hydropericardium, anemia, distension of the gizzard with feed, epicardial hemorrhages, and myocardial degeneration. All ducks dosed with lead:iron shot that died had a significantly higher incidence of distension of the gizzard with feed ($\underline{P} < 0.01$) than the ducks that died in the groups dosed with commercial lead shot. The higher incidence of this symptom may have been related to the longer course of the toxicosis of the ducks dosed with lead:iron shot and a recovery of the appetite of the ducks dosed with lead:iron shot. Ducks that died after dosing with commercial lead shot had a significantly ($\underline{P}<0.05$) higher incidence of degeneration of the gizzard lining than ducks that died after dosing with lead:iron shot.

At necropsy of the surviving ducks from both the Phase I and Phase III studies, the only recurring gross lesion noted was enlarged fatty livers indicative of fatty degeneration (Table 31). In the ducks of the Phase I study, fatty livers were noted in one duck dosed with steel shot, two ducks dosed with 45 percent lead:iron shot, six ducks dosed with 58 percent lead:iron shot, and three ducks dosed with 64 percent lead:iron shot. This lesion was not observed in any of the surviving ducks from the groups dosed with the 41 percent lead:iron shot, commercial lead shot, or the control group. Fatty livers were found in both drakes and hens, occurring more frequently in hens, but the difference in prevalence was not significant. In the surviving ducks of the Phase III study, fatty livers were found only in the drakes. The lesion was found in two drakes dosed with steel shot, seven dosed with 41 percent lead:iron shot, two dosed with 45 percent lead:iron shot, and one dosed with 58 percent lead:iron shot. It was not found in any of the ducks dosed with 64 percent lead:iron shot, commercial lead shot, or in the controls.

Liver

The mean liver weights of the ducks that died and the ducks that survived, with respect to sex and treatment, are given in Table 32. In general, the weights of the livers of the ducks that died were lower than in the survivors. No significant differences were found among the means of the liver weights of the mortalities with respect to type of shot administered. Within the survivors, there were no significant differences among the mean liver weights of the hens with respect to the type of shot administered, but mean liver weights of the drakes dosed with 41 percent lead:iron were significantly higher than those of the drakes dosed with the other types of lead:iron shot and steel shot. The greater weight of the livers of the surviving drakes dosed with the 41 percent lead:iron shot probably reflects the greater proportion of these birds that had fatty livers (Table 31).

Multiple regression analysis of liver weights of all the ducks yielded the following equation:

$$\underline{LW} = 33.27107 - 8.87871\underline{D} - 0.47073\underline{T} - 0.35315\underline{TS} + 0.00903\underline{BS}$$

Where $\underline{LW}$ = liver weight (g)

$\underline{D}$ = disposition; died = +1, survived = -1

$\underline{T}$ = time to necropsy (days)

$\underline{S}$ = sex; drakes = -0.5, hens = 0.5

$\underline{B}$ = predosing body weight (g).

All the regression coefficients in the above equation were highly significant ($P < 0.001$), but the total amount of variation in liver weight that could be attributed to the independent variables was only 32 percent. The most important factor in determining liver weight was disposition, that is, whether the birds died during the experiment. These data support the observation that the liver weights of the birds that died were lower than those of the survivors. Time to necropsy was the next most important factor and it may have reflected weight loss resulting from lead toxicity. Both the TS and BS interactions probably reflect the relatively higher weights of the surviving drakes at necropsy compared with those of the hens. The lack of a significant relationship between liver weight and Pb dosage indicates that liver weight is not a good criterion of toxicity in an experiment of 6 weeks duration.

Testes

The only significant finding in the data collected on gonad weights and sizes (Tables 33, 34) is that the testis weights of the surviving drakes dosed with the different lead:iron shot were inversely related to the amount of Pb in the dose ($P < 0.001$). The relation is given by the estimating equation $Y = 4.57566 - 0.00008L$. The amount of explained variation in the gonad weights that was accounted for by the L factor was only 20 percent.

Thyroids

There were no significant differences for each sex among the thyroid weights of controls and ducks dosed with iron shot (Table 35). Also, there were no significant differences between the thyroid weights of male and female controls and those of males and females dosed with comparable numbers of iron shot nor among the weights of thyroids of the various groups when males and females were combined.

DISCUSSION

Retention Rate of Shot

Of the ducks that survived to the end of the experiment 6 weeks after dosing, those dosed with commercial steel shot retained the largest percentage of the dosed shot (95.4 percent). During the Phase I study, ducks that survived to the end of the experiment after being dosed with commercial steel shot and placed on a diet of corn retained 91.4 percent of the shot (Table 11). Thus, access to soil did not result in a significant difference in the retention rate of commercial steel pellets. Ducks that survived to the end of the experiment after being dosed with commercial lead shot retained only 3.2 percent of the shot dosed in the Phase I study and 0.0 percent in the Phase III study. Only five ducks in this group survived in the Phase III study.

Although we did not test the differences for significance, all groups of ducks dosed with lead:iron shot during the Phase III study retained substantially higher percentages of the shot than ducks dosed with similar numbers of the same type of shot during the Phase I study. We conclude that access to soil during the Phase I study resulted in a lower retention rate of the lead:iron shot than during the Phase III study, but that there was no difference in the retention rates of ducks dosed with commercial steel shot or with commercial lead shot. Apparently, the commercial steel shot were too hard for the ingested soil and grit to cause a significant increase in the erosion rate of the shot and thus an increase in the expulsion rate. The erosion of the commercial lead shot, on the other hand, was so severe even in the absence of soil and grit that none was retained in the gizzards of surviving ducks 6 weeks after dosing.

Although there was no significant difference in the retention rates for drakes and hens on the Phase III study, the hens retained a slightly higher percentage of the dosed pellets than the drakes. The drakes retained significantly more shot than the hens during the Phase I study. A probable explanation for this sex difference in the two studies relates to the season. The earlier study was begun on 14 and 15 May 1975, whereas the later study was begun on 29 July 1975. During the earlier study many of the females were laying and presumably were ingesting more food than the males. Of the 13 ducks that died of lead poisoning during the Phase I study, only 1 was a female. Bellrose (1964) found that captive male mallards ate more food in fall and winter than hen mallards and suffered a mortality rate that was only 50 percent of the rate for hens. In spring, females ate more than males and the survival rate for females was more than twice as high as for males. In fall, juvenile mallards ate more than adults and had a survival rate several times that of adults. Irwin et al. (1974) found that only in ducks on an adequate diet was there a significant positive correlation between the amount of feed consumed and the erosion rate of lead shot.

The retention rates for nonsurviving ducks were higher in all cases than for surviving ducks. This difference is explained by the longer postdosing time to necropsy (<u>T</u>) for the surviving ducks and the significant effect of <u>T</u> on the number of shot recovered.

Although we did not test for significance among the various percentages of shot retained by each group, it appears that the shot that were 41 percent lead were retained at a significantly lower rate than any other shot dosed except commercial lead. The estimating equation indicated that Pb composition of the shot was inversely related to the retention rate. Thus, the shot that were 41 percent lead should have had the highest retention rate of any of the lead:iron shot. The 41 percent lead shot were made by a process different from that used to manufacture the other lead:iron shot dosed in this experiment. We did not pursue this apparent difference with these data because a separate study (Phase VIII) made to test the retention and erosion rates of the pellets as affected by the manufacturing process indicated no significant difference caused by the two methods of manufacture.

Erosion Rate of Shot

Of the ducks that survived to the end of the experiment, those dosed with steel shot had the lowest daily erosion rate (1.7 percent). In spite of the fact that the estimating equation showed that the Pb composition of the shot was directly related to the rate of erosion of the shot, surviving ducks that had been dosed with 41 percent lead shot had the highest daily erosion rate (2.2 percent) of any ducks dosed with lead:iron shot. None of the ducks dosed with commercial lead shot survived to the end of this experiment.

The estimating equation showed that the mean weight lost per shot was significantly ($P < 0.001$) higher in ducks with fewer shot recovered from the gizzard at necropsy. Irwin et al. (1974) reported that ducks on an adequate diet and dosed with eight shot eroded them significantly faster than ducks dosed with four lead pellets. We have no explanation for these observed differences in the two studies.

Mortality Rate

Guidelines established by the U. S. Fish and Wildlife Service (1976:263) for acceptable substitute shot call for less than 20 percent mortality to each sex 6 weeks after dosing with five No. 4 shot for ducks on a corn diet. Control ducks dosed with five No. 4 commercial lead pellets must suffer a mortality rate of 75 percent or more in the same period. These guidelines require 20 birds of each sex on each test and separate tests in winter and during the laying period. We used only 10 ducks of each sex for each test and our study was conducted between the laying period and winter. Of the lead:iron pellets we tested, only the results of those containing 41 percent lead met the proposed guidelines for mortality rate. The mortality rate was 10 percent for 10 males and 11 percent for 9 females. Eight males and nine females each dosed with five pellets containing 45 percent lead suffered 50 percent mortality by 6 weeks postdosing.

These data indicate a sharp break in the mortality rate between 41 and 45 percent lead when five No. 4 pellets are dosed per duck. If we assume that the relationship between percentage of lead and mortality rate from 41 to 45 percent lead is linear, we estimate from data in Table 23 that five No. 4 shot with 42 percent lead will cause a 20 percent mortality rate by 6 weeks postdosing.

Body Weight

The guidelines (U. S. Fish and Wildlife Service 1976:263) specify "No debilitating factor (e.g. immobility, excessive weakness or excessive weight loss, i.e. no more than 20 percent of undosed controls) caused by the proposed substitute shot." We assume that this statement means that ducks dosed with five No. 4 substitute shot must not lose an average in excess of 20 percent more weight than the average weight lost by undosed controls during a 6-week test. If our interpretation is correct, in the males dosed with five lead:iron shot, only those dosed with shot that were 41 percent lead or with shot that were 58 percent lead met the guidelines for weight loss (Table 27). Only two males dosed with 58 percent lead survived, so this group would be eliminated on the basis of a high mortality rate. Males dosed with five steel shot lost slightly less weight than controls, and none of the males dosed with five commercial lead pellets survived to the end of the experiment. All surviving females dosed with five lead:iron shot met the guidelines for weight loss; however, only four females dosed with five 45 percent lead shot, one dosed with five 58 percent lead shot, and none dosed with five 64 percent lead shot survived to the end of the experiment. Thus, all females dosed with five lead:iron shot, except those dosed with shot that were 41 percent lead, were eliminated because of high mortality rates. Females dosed with five steel pellets lost approximately the same percentage of their initial body weight as controls, and all females dosed with five commercial lead shot died prior to the end of the experiment (Table 27).

Undosed controls lost approximately 10 percent of their initial body weight. This loss of weight was probably caused by the stresses of handling for sham dosing, weighing, and taking blood samples, and by the diet of shelled corn.

Surviving male controls lost 10.1 percent of their initial body weight by 6 weeks postdosing and females lost 11.3 percent. Thus, to meet the proposed guidelines, males dosed with five No. 4 lead pellets could lose 30.1 percent and females dosed with five No. 4 lead pellets could lose 31.3 percent of their initial body weight by 6 weeks postdosing. If we use the estimating equation to estimate the amount of dosed lead required to cause a 30.1 percent weight loss in males and a 31.3 percent weight loss in females 6 weeks postdosing, we calculate 445 mg for males and 342 mg for females. If we prepare a graph from Table 18 showing the percentage of lead and the weight of lead in five No. 4 lead:iron shot, we can then estimate that in the present study males could have been dosed with five No. 4 pellets containing 52 percent lead and females with five No. 4 pellets containing 42 percent lead in order to meet the proposed guidelines for weight losses 6 weeks postdosing.

Ducks that die of acute lead poisoning lose less weight than ducks that die of subacute or chronic lead poisoning, and in some cases ducks that die of acute lead poisoning lose less weight than ducks that recover from chronic lead poisoning. Bellrose (1964) reported that waterfowl starving because of lead poisoning weighed only about 50 percent of normal. Twelve captive mallards that died an average of 22.4 days after dosing with lead lost an average of 43.4 percent of their preexposure body weight (Barrett and Karstad 1971). Game-farm mallards on a diet of whole corn and dosed with eight No. 6 lead shot survived an average of 17 days after dosing and lost an average of 27 percent of their initial body weight (Irby et al. 1967). Anderson (1975) reported that wild scaups lost an average of 30 to 35 percent of their body weight before dying of lead poisoning in Illinois in the spring. A group of captive Canada geese dosed with 10 or more pellets each suffered acute lead poisoning and died within 23 days (mean, 10 days) after losing only 22 percent of their original body weight, whereas two geese dosed with 5 pellets each survived for an average of 55.5 days and lost 32 percent of their body weight (Cook and Trainer 1966). These authors state (p. 3): "Acute cases lost approximately 19 percent of their original body weight, chronic cases 36 percent."

In the present experiment, 17 ducks died of what we called acute lead toxicosis. These 17 ducks lost from 12.2 to 51.6 percent (mean, 21.7 percent) of their initial body weight. They survived from 4 to 21 days (mean, 9.6 days) after dosing. Eighteen ducks died of acute to subacute lead toxicosis. Their loss of body weight ranged from 18.8 to 51.7 percent (mean, 35.2 percent). They died from 5 to 37 days (mean, 16.4 days) after dosing. The largest group (86 ducks) died of subacute or chronic lead poisoning. They lost from 27.9 to 55.9 percent (mean, 48.8 percent) of their initial body weight and survived from 11 to 42 days (mean, 24.2 days) after dosing.

Thus, ducks that die about 10 days or less after ingesting lead and that have lost about 20 percent of their body weight are victims of acute lead poisoning. Ducks that survive about 16 days after ingesting lead and lose about 35 percent of their body weight are in an intermediate stage between acute and chronic lead poisoning. Ducks that die of chronic lead poisoning live for about 25 days or longer after ingesting lead and after losing about 45 percent or more of their body weight. Ducks that survived to the end of our experiment lost as much as 38.8 percent of their initial body weight.

PCV's

There was a slight indication in the Phase I study that the commercial lead pellets caused a decline in PCV values 3 weeks after dosing but that by 6 weeks after dosing the PCV values were recovering (Table 4). After the Phase II study (Table 14), we concluded that if PCV's are used to reflect relative responses to lead toxicity in ducks, they should be taken about 7 and 14, and perhaps 21, days after dosing. Twenty-one days after dosing, PCV values were recovering in many surviving ducks, and by 14 days after dosing mortality masked many of the effects of lead toxicosis on the PCV's. In the present (Phase III) study there were several statistically significant difference in PCV values 1 and 3 weeks after dosing, but by 6 weeks after dosing there were no significant differences in the PCV values among any of the groups of surviving ducks.

We believe that up to about 14 days after dosing, PCV values are a more sensitive indicator of lead toxicosis than mortality rate, mean number of days survived after dosing, or changes in body weights. Morgan et al. (1975) reported that anemia in Japanese quail was more readily indicated by reduced Hb levels than by PCV's, but we prefer PCV values because they are faster and easier to determine and in our studies appeared to give more consistent results than Hb concentrations.

Surviving controls had PCV's that were 1.7 percent higher 3 weeks postdosing and 8.1 percent higher 6 weeks postdosing than on the date of dosing. Thus, an 18.3 percent decline in PCV's 3 weeks postdosing and a 11.9 percent decline 6 weeks postdosing represent declines 20 percent greater than the changes in the controls. Although PCV values are not included in the proposed guidelines, we have used the estimating equations to estimate the amount of dosed lead required to cause an 18.3 percent decline 3 weeks postdosing and a 11.9 percent decline 6 weeks postdosing. The respective amounts of lead are 266 mg and 447 mg; they are contained in five No. 4 shot of 32 and 52 percent lead, respectively.

Hb

Quortrup and Shillinger (1941) reported that the Hb content is low in lead-poisoned birds and poikilocytosis and anisocytosis are nearly always present. Bates et al. (1968) reported that the erythrocytes in the peripheral blood in lead-poisoned mallards were reduced in size and in Hb content and concentration. They believed that the production of defective erythrocytes and the impaired release of the cells were probably the main source of anemia, which Beer and Stanley (1965) reported as a common characteristic in lead-poisoned birds.

Although in the present study there were a few significant differences in Hb values 6 weeks after dosing--in contrast to the PCV values--there were many more significant differences 1 and 3 weeks after dosing (Table 29). As with the PCV's, the recovery of Hb values in surviving ducks after 3 weeks plus mortality make Hb values taken more than 3 weeks after dosing of little value for determining relative responses of ducks to varying amounts of dosed lead.

Surviving control males and surviving control females had Hb values that were 12.9 percent and 21.8 percent lower 3 weeks postdosing than at the time of dosing. Thus, a 32.9 percent decline in males and a 41.8 percent decline in females represent declines 20 percent greater than those in controls 3 weeks after dosing. Hb values were not included in the proposed guidelines. We used the estimating equations to estimate the amount of dosed lead required to cause a 32.9 percent decline in males and a 41.8 percent decline in females 3 weeks postdosing and a 33.5 percent decline in males and a 34.7 percent decline in females 6 weeks postdosing. These amounts are 329 mg for males and 329 mg for females, or five No. 4 shot containing 40 percent lead for the above results 3 weeks postdosing. For 6 weeks postdosing, the amounts are 374 mg for males and 293 mg for females, or five No. 4 shot containing 45 percent and 35 percent lead, respectively.

These figures may be compared with 42 percent lead shot for a 20 percent mortality rate 6 weeks postdosing, 52 percent lead in shot for males and 42 percent for females, respectively, to cause a 20 percent increase in loss of body weight 6 weeks postdosing, and 32 percent and 52 percent, respectively, lead in shot to cause a 20 percent increase in the decline of PCV's 3 and 6 weeks postdosing.

Gross Symptoms

Several studies summarize the gross symptoms often found in lead-poisoned ducks, geese, and swans. The symptoms usually listed include emaciation, prominent keel, lowered intake of food, bright green droppings, green diarrhea and sometimes a staining of the vent, fatigue, a tendency to seek isolation and cover, loss of the ability to fly, loss of the ability to hold the wings in a normal position, inability to stand or to walk steadily, enlarged and flabby heart, enlarged gall bladder, small gizzard, gizzard lining stained green or dark brown or black, stiff and easily peeled gizzard lining, patches of gizzard lining missing, impaction of the proventriculus, anemia, paleness of all tissues, absence of body fat, atrophy of striated muscles and internal organs, edematous heads in geese, discolored liver, small liver, severe enteritis, epicardial and endocardial hemorrhages, hydropericardium, myocardial infarction, infarction of gizzard and skeletal muscle, wing drop, lethargy, extreme weakness, birds resting on their sternums, and difficulty in movement (Quortrup and Shillinger 1941, Adler 1942, 1944, Jordan and Bellrose 1951, Bellrose 1959, Cook and Trainer 1966, Locke et al. 1967, Bates et al. 1968, Irwin 1975, and U. S. Fish and Wildlife Service 1976).

The enlarged fatty livers indicative of fatty degeneration occurred in 3.3 percent of 359 ducks necropsied in the Phase I study and in 5.6 percent of 212 ducks necropsied in the Phase III study. In Phase I of the study, 3 of 174 males (1.7 percent) and 9 of 185 females (4.9 percent) had fatty livers. In the Phase III study, 12 of 109 males (11.0 percent) and none of 103 females had fatty livers. The explanation for the difference in incidence of fatty livers between the sexes in the two studies is probably the same as for the differing retention rates of shot (see Retention Rate of Shot). The Phase I study was begun in May and the Phase III study was begun in July. During the earlier study the females were laying and no doubt consumed much larger amounts of shelled corn than the males. Males in the Phase III study probably consumed larger quantities of corn than the females. In the Phase III study there was a severe reaction to the dosed lead, and the lack of fatty livers in both hens and drakes dosed with the larger amounts of lead (Table 31) probably relates to anorexia caused by the lead. Thus, it appears likely that the incidence of fatty degeneration of the liver was positively correlated with the amount of shelled corn consumed.

Liver

There were no significant differences among the mean liver weights of four groups of three ducks each dosed with five No. 4 commercial lead pellets during Phase VII of the study. Half the ducks were on a diet of shelled corn and half were on a diet of duck pellets, and half were dosed daily with 10 g of soil (Table 48). The livers of ducks on a diet of corn and not dosed with soil weighed more than the livers of any other group. The ducks in this group died an average of 7.3 days after dosing with lead, so there was not time for their livers to lose much weight. In general, livers of lead-poisoned ducks are reduced in size (Coburn et al. 1951, Jordan and Bellrose 1951, Locke et al. 1967a, Bates et al. 1968); however, in our Phase VIII study the mean weights of livers of most dosed ducks were heavier than livers of undosed controls (Table 60). We have no explanation for the heavy livers in these dosed ducks.

In the present study (Phase III), weights of livers of nonsurviving ducks showed a direct relationship with the percentage of lead in the lead:iron shot and thus with the total amount of lead dosed (Table 32). No doubt this relationship is a result of the inverse correlation between the percentage of lead in the dosed pellets and the average time to death, after dosing, for the nonsurviving ducks. Among the survivors, the only significant difference was that the livers of males dosed with lead:iron shot containing 41 percent lead weighed more than the livers of the other groups of males. Nearly one-third of the males in this group had fatty livers. Thus, as with most of the factors considered in these experiments, the tendency for lead to have a direct effect on the liver is confounded by the effects of seasons and their differing influences on the total rate of food consumption and on the relative rates of food consumption by the sexes, the average postdosing survival time, diet, and the lead-induced results of anorexia. The general conclusion that lead toxicosis results in a reduction of liver size seems valid. However, Adler (1944) reported that the livers of lead-poisoned Canada geese were much larger than normal. Chupp and Dalke (1964) also reported enlarged livers in swans suffering from lead poisoning.

Thyroids

An earlier study (Sanderson and Hurley 1974) indicated that ingested commercial steel shot might cause enlarged thyroids in ducks. Our results from the present (Phase III) study and from the Phase I study (Table 10) both show that there were no consistent differences in the weights of thyroids related to the number of steel shot dosed nor were there any significant differences between weights of thyroids of the controls and any of the groups dosed with steel shot. Thus, we conclude that the ingestion of one, three, or five No. 4 commercial steel pellets has no significant effect on the weights of thyroids in captive game-farm mallards.

SUMMARY

Groups of 10 male and 10 female game-farm mallards were orally dosed with one, three, or five No. 4 shot of one of the following types: commercial steel shot, commercial lead shot, or lead:iron shot with mean Pb compositions of 41, 45, 58, or 64 percent by weight. There were also 10 male and 10 female undosed controls. The ducks were dosed on 29 July 1975 and the experiment was terminated 9 September 1975; however, surviving males were autopsied on 10 September and surviving females on 11 September. Data were collected on expulsion of shot, erosion of shot in the gizzard, mortality, body weight, PCV, Hb, gross lesions, and weights of liver, gonads, and thyroids (of some groups). The number of shot retained was directly related to the number of shot dosed and inversely related to time and the percentage of Pb in the shot. The ducks that died retained more of the dosed shot than those that survived. The difference is explained by the shorter time the former birds had in which to expel their shot. There was no significant difference between sexes with respect to the retention of dosed shot. The erosion of shot in the gizzards was directly related to time and the percentage of Pb in the shot, and inversely related to the number of shot present in the gizzard at necropsy. Ducks that died did not erode shot at a significantly different rate from the survivors. As expected, mortality tended to be directly related, and survival time tended to be inversely related to the percentage of Pb in the dose. Mortality ranged from 0 percent in controls, in the ducks dosed with steel shot, and in the 41 and 45 percent lead:iron groups dosed with one shot to 100 percent for the groups dosed with five commercial lead shot. $\underline{ET}_{50}$'s for both sexes combined ranged from 43.6 days for the ducks dosed with five 45 percent lead:iron shot to 11.4 days for the ducks dosed with five commercial lead shot. In general, body weight, PCV's, and Hb values were inversely related to the amount of Pb in the dose. The main sources or unaccounted for variation in the results were probably the high variation in the specific compositions of the individual types of lead:iron shot, variation arising from such unknown factors as times of expelling shot, which would result in unknown variation in the amount of the Pb exposure, and variation because of individual responses to Pb toxicity. The postmortem body weights of the ducks that died from lead toxicity were directly related to the predosing body weight and the Pb content of the shot and inversely related to the duration of the toxicosis. Among the ducks that died from lead poisoning, the frequency of gizzard impaction was significantly higher in the lead:iron dosed ducks than in those dosed with commercial lead shot, but the incidence of degeneration of the gizzard lining was significantly higher in ducks dosed with commercial lead shot. Enlarged fatty livers were a common finding at necropsy in the survivors of both the Phase I and Phase III studies. This condition was not observed in any of the controls or the ducks dosed with commercial lead shot. There was no significant

correlation between liver weight and Pb dose among ducks that died during this experiment. Livers of surviving hens showed no significant differences with respect to the type of shot dosed. Livers of surviving drakes dosed with 41 percent lead:iron weighed significantly more than livers of drakes dosed with other types of lead:iron and steel shot. Males dosed with 41 percent lead:iron shot had a higher percentage of fatty livers than any other group. The weights of testes of the surviving males dosed with the different types of lead:iron shot were inversely related to the amount of Pb in the dose. There were no significant differences in weights of thyroids of controls and ducks dosed with steel shot.

PHASE IV. EFFECTS OF SOIL ON EROSION RATE OF LEAD PELLETS IN THE GIZZARD AND ON SURVIVAL OF DUCKS DOSED WITH FIVE NO. 4 LEAD PELLETS

The erosion rates of pellets in the first ducks to die during the Phase II study at Nilo Farms indicated that soil might be acting to lessen the effects of ingested lead in ducks by slowing the rate of erosion of the pellets. The final analysis of the data from the Phase II study indicated the reverse condition--ducks on the ground (with access to grit?) eroded lead pellets in their gizzards significantly faster than ducks on wire. Before the end of the Phase II study, this Phase IV experiment was designed to determine the effect of soil on the erosion and retention rates of lead pellets and the effects of soil on toxicity of ingested lead in captive mallards.

METHODS

Twenty female and 20 male MM surviving from the Phase I experiment were moved from Nilo Farms to Urbana and placed in four pens with wire floors as follows: 10 females in a pen with a wire floor, 10 males in a pen with a wire floor, 10 females with a wooden box of dirt from the pens at Nilo Farms, and 10 males with a wooden box of dirt from the pens at Nilo Farms. The dirt was soaked with water at least twice daily and the ducks "puddled" extensively in the dirt.

All 40 ducks were weighed and bled (only PCV's were determined from the blood), and each was dosed with five No. 4 commercial lead pellets and placed on a diet of corn. Two males and two females from each of the pens were killed on the following schedule after dosing: 12 hours, 24 hours, 36 hours, 48 hours, and 168 hours (1 week). Body weights and PCV's were determined when the ducks were killed, and body weights at death were determined for ducks that died prior to the end of the experiment. The pellets were recovered, weighed, and the percentage erosion determined for each duck.

This study was conducted by Sarah S. Hurley with assistance from Margaret S. Shapiro and several individuals from the staff of the Illinois Natural History Survey. Dr. Hurley tabulated the data and wrote a preliminary report based on the study.

RESULTS AND DISCUSSION

Because of the small sample sizes imposed by the intensive nature of this study, and because two ducks of each sex were used in each group, the results were difficult to interpret. We assumed no differential responses caused by sex and combined the results for the sexes. Subsequent studies provided more extensive data on the effects of ingested soil on the rate of loss of body weight by ducks, on changes in PCV's, and on the rate of erosion from the shot. However, there are few data on changes in body weight and

PCV's of ducks and erosion rates from pellets from 12 hours to 168 hours (1 week) after dosing. Thus, it seems worthwhile to examine these data for what they contribute to our understanding of the short-term effects of ingested lead on ducks.

Body Weight

By 12 hours after dosing with lead pellets the ducks on wire had lost an average of 6.5 percent of their body weight compared with 7.9 percent for ducks on soil (Table 36). The surviving ducks did not again reach weight losses of this magnitude until 168 hours after dosing. Thus, it appears that the weight losses 12 hours after dosing with lead resulted from the stress of catching, weighing, bleeding, and dosing the ducks more than from the lead placed in their gizzards. The weight losses were similar (*P*>0.80) for ducks on wire and ducks with access to soil at all except the final test period during this 1-week experiment. By 168 hours after dosing, the ducks on wire had lost an average of 21.5 percent of their initial weight compared with 16.6 percent lost by the ducks on soil (*P*<0.05).

In the Phase II study we found no significant difference in weight loss between ducks on wire and ducks on soil 9 days after dosing with lead (Table 13). Those rates of weight loss were 28.0 and 26.4 percent, respectively.

PCV's

The ducks on wire showed a 4.4 percent increase in PCV's 12 hours after dosing compared with a 2.2 percent decline in the same time for ducks on soil (*P*<0.05) (Table 18). We have no explanation for the increase in PCV's of the ducks on wire. Three of the ducks showed increases, and the fourth had the same percentage as when it was dosed. The PCV values in all groups showed only modest changes until 48 hours after dosing, at which time they had declined 15.0 percent in the ducks on wire and 9.3 percent in the ducks on soil (*P*>0.40). One week after dosing only two of the four ducks on wire survived, and their average decline in PCV's was 58.2 percent compared with 39.6 percent for the three surviving ducks on soil (*P*>0.40). Although the difference in these means 1 week after dosing was substantial, it was not statistically significant because of the small sample size. In the Phase II study the decline in PCV's was significantly greater at 9 (54.9 percent and 41.4 percent) and 15 (47.2 and 31.2 percent) days after dosing in ducks on wire than in ducks on soil (Table 14).

Erosion Rate of Pellets

Although the erosion rates of pellets in ducks on wire and in ducks on soil did not show significant differences (*P*>0.20 in all cases) until 168 hours after dosing, the mean erosion rate was consistently higher in ducks with access to soil than in ducks on wire (Table 36). By 168 hours after dosing, ducks on wire had eroded 21.0 percent of the weight of the pellets dosed compared with 61.0 percent of the pellets dosed in ducks on soil ($P<0.02$). Thus, the initial indication from the earlier Phase II study that soil might cause a slower rate of erosion of ingested pellets was not confirmed. The results from the Phase IV study confirm the conclusions reached after the final analysis of the data from the Phase II study. Pellets in ducks with access to soil on the Phase II study eroded faster than they did in ducks on wire--60.1 percent in an average of 23.9 days and 35.7 percent in an average of 17.9 days, respectively (Table 12). This difference barely missed the 0.05 level of significance because of the small sample sizes and high individual variation.

The retention rate of the shot in the present experiment was 99 percent for ducks on wire and 96 percent for ducks on soil. One pellet was missing in one duck on wire 48 hours after dosing, and four pellets were missing from one duck on soil 168 hours after dosing. Thus, there was no clear indication in this limited study that the grit available from the soil in two of the pens carried the lead pellets through the ducks with excess ingested grit. Because these ducks were not X-rayed or fluoroscoped, we do not know when the two ducks passed the shot from their gizzards; however, all 30 ducks killed 36 hours or less after dosing contained all shot that had been placed in their gizzards.

CONCLUSIONS

Weight losses of ducks dosed with five No. 4 commercial lead pellets on 24 July were relatively modest until about 1 week after dosing. Even with the small sample sizes in this study, by 1 week after dosing the protective effects of ingested soil on loss of body weight were evident.

The PCV's of these ducks showed only modest declines 36 hours after dosing, but by 48 hours after dosing the declines were substantially greater. One week after dosing the PCV values were much lower than they were 48 hours after dosing. In the present study all surviving ducks were killed 1 week after dosing. Data from the present study, combined with data from the Phase II study (Table 14), suggest that the low point in PCV values in ducks dosed with five No. 4 commercial lead pellets occurred between 2 and 7 days after dosing and was probably about 7 days after dosing.

It is apparent from the results of the present study that ingested soil (grit?) results in a more rapid erosion rate of lead from pellets in the gizzard of ducks. It is unclear what effect, if any, the availability of grit from the soil we placed in the pens had on the rate of retention of dosed lead pellets to 1 week or less after dosing.

PHASE V. EFFECTS OF SOIL ON EROSION RATE OF LEAD PELLETS IN GIZZARDS AND ON SURVIVAL OF DUCKS 1, 2, AND 3 WEEKS AFTER DOSING WITH FIVE NO. 4 LEAD PELLETS

The objective of this study was to test the retention and erosion rates of lead pellets in ducks on wire and on soil at 1, 2, and 3 weeks after dosing. A secondary objective was to test the effects of access to soil on the toxicity of five No. 4 commercial lead pellets in mallards on a diet of corn.

METHODS

Sixty females from the Phase I study were placed in six pens with 10 ducks each on 4 August 1975. These ducks had been held in Urbana in a large holding pen with a dirt floor. Their diet was free choice shelled corn and Game Bird Breeder Layena (Ralston Purina Co.); however, on 4 August they were placed on a diet of shelled corn. Three pens each had a tray of soil taken from the pheasant holding pens at Nilo Farms, Brighton, Illinois; the other three pens had no soil available.

The ducks were weighed, bled, and dosed with five No. 4 commercial lead pellets each on 11 August 1975. Surviving ducks in pens 3 and 6 were killed on 18 August, surviving ducks in pens 4 and 9 were killed on 25 August, and surviving ducks in pens 5 and 10 were killed on 1 September. Survivors were also weighed and bled on 18 and 25 August and 1 September and all ducks that died in the pens were weighed. All shot were removed from the gizzards and weighed.

RESULTS AND DISCUSSION

Effect of Soil on Retention and Erosion Rates of Pellets

We have no data on the amount of soil ingested by ducks per day or whether ducks in captivity ingest more or less soil than wild ducks. When we placed soil in wooden trays 30 X 30 inches in the pens and soaked it twice daily with water, the ducks eagerly and almost always immediately "puddled" vigorously in the soil. It was obvious from an examination of the gizzards of ducks with and without soil available that ducks obtained much grit from the soil. In addition to the potential lead-binding capacity of the soil, ducks may obtain nutrients, minerals, or bacteria from the soil that have a role in the toxicity of lead in ducks.

Retention Rates of Pellets.--Direct comparisons of the numbers of pellets recovered from gizzards of ducks with soil available and of ducks on wire were made 1, 2, and 3 weeks after dosing (Table 37). As expected, there was a decline in the average number of pellets recovered from 1 to 2 to 3 weeks after dosing. There were no significant ($P \geq 0.05$) differences in the number of pellets recovered from the ducks on wire and from the ducks with access to soil 1, 2, and 3 weeks after dosing. Because of the relatively high mortality rates of the ducks without access to soil, the sample sizes for these groups were small. In all three weekly comparisons there were more pellets recovered from ducks on wire than from ducks with access to soil. Thus, were it not for the high mortality rate of the ducks on wire, there probably would have been significantly more pellets recovered from ducks on wire than from ducks with access to soil.

The percentage of shot expelled by about 1, 2, and 3 weeks after dosing and the daily expulsion rates at the same times were always higher in ducks with access to soil than in ducks on wire (Table 38). For example, ducks on wire that died within 7 days after dosing and ducks on wire that were killed 7 days after dosing expelled only 1.4 percent of the pellets placed in their gizzards in an average of 5.6 days (0.2 percent per day). Ducks with access to soil expelled 24.0 percent in an average of 6.8 days (3.5 percent per day). This difference was statistically significant ($\underline{P}<0.025$). Ducks on wire that died or were killed from 8 to 14 days after dosing expelled 26.7 percent of their pellets in an average of 13.2 days (2.0 percent per day) compared with 41.8 percent in 13.9 days (3.0 percent per day) for ducks with access to soil. This difference was not statistically significant ($\underline{P}>0.40$). Ducks on wire that died or were killed from 15 to 21 days after dosing had expelled 28.6 percent of the pellets, whereas ducks on soil had expelled 33.3 percent ($\underline{P}>0.70$).

These results indicate that one way soil may protect ducks from the effects of ingested lead is by an increased explusion rate of the pellets the first week after dosing. In the Phase II study the expulsion rate was 4.25 percent per day in an average of 17.9 days for ducks on wire and 3.87 percent per day in an average of 28.9 days for ducks on soil. Results of the present study indicate that the soil or grit obtained from the soil, or both, increases the expulsion rate of ingested lead pellets, as was reported by Osmer (1940), Rosen and Barnkowski (1960), Beer and Stanley (1965), and Longcore et al. (1974). Longcore et al. were the only investigators to present evidence for a more rapid expulsion rate of pellets when grit was abundant.

<u>Erosion Rates of Pellets</u>.--Both 1 (30.8 percent) and 2 weeks (25.6 percent) after dosing, ducks on wire had eroded significantly ($\underline{P}<0.05$ and $\underline{P}<0.01$, respectively) less lead than ducks on soil (52.4 and 64.2 percent, respectively). After 3 weeks only five ducks survived and the difference in the erosion rate was not significant between the two groups (Table 37).

We also made comparisons of the erosion rates of lead pellets in the gizzards of all ducks that died or were killed from 1 to 7, from 8 to 14, and from 15 to 21 days after dosing for ducks with access to soil and for ducks on wire (Table 38). The rates for ducks on wire were 21.0, 25.7, and 44.7 percent compared with 50.4, 55.2, and 68.8 percent for the same three periods in ducks with access to soil. The daily erosion rates were 4.1, 2.0, and 2.3 percent for ducks on wire and 7.4, 4.0, and 4.1 percent for ducks with access to soil. All differences between ducks on wire and ducks with access to soil were significantly different ($P<0.05$) except that the total erosion from pellets in ducks with access to soil was not significantly higher ($P>0.05$) 15-21 days after dosing than it was for ducks on wire (Tables 37, 38). For all ducks that died in the pens, there was no significant difference ($P>0.10$) between the daily erosion rate of 2.8 percent for ducks on wire and the 3.9 percent for ducks with access to soil; however, as will be discussed later, ducks with access to soil lived significantly longer after dosing than ducks on wire.

The possible protective effects of a more rapid expulsion rate of ingested pellets when ducks have access to soil must be balanced against the more rapid erosion rate of pellets in these ducks. The higher erosion rate would be expected to increase the early toxic effects of ingested lead in ducks with access to soil. Longcore et al. (1974) concluded that when grit was readily available the overall result was a lower but faster mortality rate among ducks than when ducks did not have grit available.

Effects of Soil on Lead Toxicity

Mortality Rate.--The mean number of days to death in a pen-by-pen comparison was significantly lower for ducks on wire (6.0 and 10.0) than for ducks on soil (6.8 and 13.9) 1 and 2 weeks after dosing (Table 37), but 3 weeks after dosing the difference was not significant. The average survival times for all ducks that died or were killed between 1 and 7, 8 and 14, and 15 and 21 days after dosing regardless of the pen they were in are shown in Table 39. These figures were calculated in order to compute the rate of expulsion and the rate of erosion of the shot. The differences between ducks on wire and ducks with access to soil were not significantly different for the three weekly periods.

The mortality rate from 1 to 7 days after dosing for all ducks that died in the pens was significantly higher (33.3 percent) for ducks on wire than it was for ducks with access to soil (3.3 percent) (Table 39). The mortality rates from 8 to 14 days after dosing for all ducks alive 8 days after dosing was higher (25.0 percent) for ducks on wire than for ducks with access to soil (10.0 percent), but the difference was not significant. The mortality rates from 15 to 21 days after dosing for ducks alive 15 days after dosing were not significantly different for ducks on wire (71.4 percent) and ducks with access to soil (77.8 percent). Jordan and Bellrose (1950) reported that their results indicated that 60 to 80 percent of wild mallards ingesting one lead pellet would die if the ducks were on a diet of wild seeds.

The mortality rate for ducks with access to soil was greatly influenced by an extremely severe winter storm 15 days after dosing. Eight of 16 surviving ducks died 15 days after dosing and another died the day after the storm; 6 of these 9 ducks that died had access to soil. If the winter storm had not occurred, most or all of these ducks would probably have survived to the end of the experiment.

In spite of the confounding effects of severe weather on mortality during the third week of the experiment, for the entire study ducks on wire suffered a significantly ($P<0.05$) higher mortality rate (63.3 percent) than ducks with access to soil (33.3 percent). Of the ducks that died in the pens, those on wire lived an average of 9.6 days after dosing compared with 14.3 days for ducks with access to soil ($P<0.02$). Also, after 1 week, 33.3 percent of the ducks on wire had died compared with only 3.3 percent of the ducks on soil (Table 39). This difference was highly significant ($P<0.005$). These mortality rates include only ducks that died in the pens. Ducks killed for autopsy 1, 2, and 3 weeks after dosing were not included in the mortality rates. If some of the ducks had not been killed for autopsy, no doubt the difference in mortality rates would have been even greater.

The mortality rate 1 week after dosing and the average survival rate for all ducks that died in the pens do not support the conclusions of Longcore et al. (1974). They concluded that the overall result of a readily available supply of grit (in the present study, soil and the grit it contained) was a lower but faster mortality rate among ducks with access to grit compared with ducks that had no grit.

Results of the present study also indicate some of the differing results expected between captive and wild birds. In spite of the readily available supply of food and water and moderate protection from the severe winter storm, several captive birds weakened by the dosed lead succumbed to the direct effects of the storm. Wild birds suffering from lead poisoning would be even more vulnerable to environmental factors than our captives were.

Barrett and Karstad (1971) dosed 45 captive mallards with varying numbers of No. 6 lead shot. The ducks were held in outdoor pens with wire floors and fed a diet of mixed grains. The 12 mallards that died during their experiment survived an average of 22.4 days after dosing. In another study 23 of 24 game-farm mallards died after they were dosed with eight No. 6 lead shot and fed a diet of whole corn. The average length of survival was 17 days. These ducks were in pens with wire floors and were given quartz grit (Irby et al. 1967).

Body Weight.--One, 2, and 3 weeks after dosing with five No. 4 commercial lead pellets, there were no significant differences in the loss of body weight between all ducks on wire and all ducks with access to soil (Tables 39, 40). As was pointed out in the Phase II report, ducks on wire suffer greater mortality than ducks on soil. Also, ducks that lose weight at a slower rate tend to survive longer than ducks that lose weight at a faster rate. Thus, it is difficult to determine the relationships between ingested soil and changes in body weights of ducks dosed with lead pellets. When daily rate of exposure to lead, protective action of the soil against lead toxicity, and different mortality rates are considered, it is not surprising that body weights alone are inadequate to reflect the toxic effects of ingested lead in ducks that have access to soil.

It is clear that ducks on wire that died during the present experiment lost less weight ($P<0.025$) than ducks on soil (30.5 vs. 41.5 percent) (Tables 39, 40). The explanation for this difference appears to be that the protective action of the soil permitted ducks to survive after a greater weight loss than was possible for ducks without access to soil. It appears that ducks dosed with lead, given a corn diet, and placed in pens with wire floors died of acute lead toxicity, whereas ducks under the same conditions except that they had access to soil died of chronic lead poisoning.

Of 45 captive mallards placed in pens with dirt floors, fed a diet of mixed grains, and dosed with varying numbers of lead pellets, 12 died of lead poisoning. These 12 lost an average of 43.4 percent of their preexposure body weight by the time they died (Barrett and Karstad 1971). A second group of game-farm mallards, on a diet of whole corn and dosed with eight No. 6 lead shot, lost an average of 37 percent of their initial body weight by the time they died. These ducks were in pens with wire floors and were fed quartz grit. All but one of the 24 dosed ducks died (Irby et al. 1967). The first experiment was conducted from June to August; the second from April through June. Air temperature is an important factor in the loss of body weight that a lead-poisoned duck will tolerate before death. According to Bellrose (1964), waterfowl starving because of lead poisoning weigh only about 50 percent of normal.

PCV's.--There were no significant differences in the changes in PCV's 1, 2, and 3 weeks after dosing for all surviving ducks on wire and with access to soil, regardless of their pen number (Table 39). Also, there were no significant differences in the daily rates of decline of PCV's of ducks on wire and those on soil. However, in every comparison--between groups, combined comparisons for all groups, and comparisons of all daily rates of change--at 1 week after dosing the declines were less in ducks on wire than in ducks with access to soil (Tables 39, 41).

The percentage decline 7 days after dosing was slightly greater (40.7) in ducks with access to soil than in ducks on wire (36.2) (Table 39). The PCV's in ducks on wire continued to decline through the third week (to 40.5 percent), whereas in ducks with access to soil the PCV's were improving slightly by the second week after dosing (to 37.8 percent the second week and to 26.6 percent by the third week in the two surviving ducks with access to soil). Thus, at both 2 and 3 weeks after dosing, the picture had changed and ducks with access to soil always had smaller declines in PCV's than ducks on wire. In the Phase IV study (Table 36) PCV's of ducks on wire showed a 4.4 percent increase 12 hours after dosing, whereas ducks with access to soil showed a 2.2 percent decrease for the same period.

In the Phase I study 55 ducks, each dosed with five No. 4 lead pellets, in the pheasant holding pens at Nilo Farms had PCV's of 43.6 percent 3 weeks after dosing (Table 4). These ducks were on three different diets; however, there were no significant differences in PCV's because of diet. Three weeks after dosing, the PCV's of ducks with access to soil on the Phase II study were 31.5 percent, and at the same time were 25.2 and 22.3 percent for two groups of ducks on wire (Tables 14, 17). Corresponding percentages 3 weeks after dosing in the present study were 33.1 and 27.5 percent, respectively, for ducks with access to soil and ducks on wire (Table 41). These values are in close agreement for the Phase II and Phase V studies and seem to indicate that ducks in pens with access to a tray of soil received less protection than ducks in the holding pens.

CONCLUSIONS

For the first week after dosing, ducks on wire expelled dosed lead pellets at a significantly lower rate than ducks with access to soil. The expulsion rates 2 and 3 weeks after dosing were not significantly different, but they were higher in ducks with access to soil. The present study clearly demonstrates that access to soil in a pen with a wire floor results in an accelerated erosion rate of lead pellets in a duck's gizzard for at least 3 weeks after the pellets are ingested. Changes in body weights and PCV's appear to be influenced by the protective effects of ingested soil or grit, or both, on the toxicity of ingested lead. However, the higher erosion and expulsion rates of pellets in ducks with access to soil and the higher mortality rate suffered by ducks on wire make it difficult to use changes in body weights and PCV values as measures of the protective effects of soil on ingested lead. The lower percentage of initial weight lost by time of death in ducks on wire compared with ducks with access to soil seems to indicate acute toxicity in the former group and more chronic responses in the latter group. A severe winter storm during the third week of this experiment had a major effect on mortality rates of the surviving ducks. Also, the surviving ducks in one-third of the pens were killed 1, 2, and 3 weeks after dosing to determine the retention and erosion rates of the dosed pellets. Even so, the results clearly demonstrate that the mortality rate is a useful indicator of the protective effects of access to soil when ducks have lead pellets in their gizzards.

PHASE VI. EFFECTS OF DAILY DOSES OF MEASURED AMOUNTS OF SOIL ON THE TOXICITY OF FIVE NO. 4 LEAD PELLETS IN GAME-FARM MALLARDS

The purpose of this study was to determine the effects of measured amounts of soil from the Nilo holding pens on the toxicity of dosed lead pellets in ducks.

METHODS

Forty male game-farm mallards from the Phase I study were placed 10 to a pen on a diet of corn, duck pellets, and water on 4 September 1975 in Urbana, Illinois. They were weighed, bled, and dosed with five No. 4 commercial lead pellets on 15 September 1975 and placed on a diet of shelled corn and water. They were dosed daily with either 0, 2.5, 5.0, or 10 g of soil taken from the pheasant holding pens at Nilo Farms, Brighton, Illinois.

Dr. Kenneth E. Smith, Analytical Chemist for the Natural History Survey, ran a Lead Absorption Profile on a sample of soil from the pheasant holding pens. At the PH of the soil (5.5), he found a maximum capacity for 1 g of soil to bind 12 mg of lead. This rate would be at a concentration of 200-300 ppm of lead--a concentration probably not found in the gizzard of a duck. At a concentration of 10-20 ppm of lead, perhaps a reasonable level in a duck's gizzard, the soil has the capacity to bind 6-7 mg of lead per gram of soil. Ducks with access to soil in the pens eroded 7.4 percent of five No. 4 commercial lead pellets per day for a week after dosing (Table 38). Five No. 4 commercial lead pellets weighed approximately 1,000 mg (Table 2). Thus, if a duck ingested 10 g of soil from the pens at Nilo Farms per day, the soil had the potential to bind virtually all of the lead eroded from five No. 4 commercial lead pellets per day. In any event, we concluded that the capacity of this soil to bind lead was great enough to have the potential of making a significant difference in the results when ducks that were dosed with lead and had access to soil were compared with ducks that had no access to soil. Thus, we chose the dose rates of soil because, theoretically, 10 g of soil daily had the capacity to bind all of the lead eroded daily from five No. 4 lead pellets in the presence of grit in the gizzard.

The ducks were weighed and bled weekly, and the survivors were necropsied 21 days after dosing. Lead pellets were removed from all ducks at autopsy, counted, and weighed. Grit was also removed from each gizzard, washed free of dirt and food material, air-dried, and weighed. Each dose of lead pellets was weighed to the nearest tenth of a mg prior to dosing.

Air-dried soil was weighed and packed in ½ oz gelatin capsules. The capsule was dipped in water, the duck was held with its neck extended vertically by an assistant, and the capsule inserted in the top of the esophagus with the use of an index finger that had also been dipped in water. The capsule was moved into the proventriculus by using a thumb and forefinger on the outside of the duck's neck. Capsules of this size (37 X 13 mm) were readily placed in the proventriculus in the manner described. These were the largest capsules we could find, but they were not large enough to hold 10 g of the soil from the pheasant pens. Thus, ducks dosed with 10 g of soil were given two capsules, each one with 5 g of soil.

At necropsy of ducks on the Phase V study it was apparent that there was a wide variation in the amount of grit in the various groups of ducks. As a result of this observation, and because the amount of grit in the gizzard may have a significant effect on the erosion rate of the pellets in the gizzard, on the capacity of the soil to bind lead in the duck, and on the effect of lead in the duck, we weighed the amount of grit (lead pellets were excluded) found in the gizzard of each duck in the 10 groups used in the Phase V and Phase VI studies (99 ducks total).

When these ducks were in the holding pens at Urbana they had access to grit from the soil and from the crushed rock that was used in an attempt to maintain sanitation around the automatic waterers in the pens. There is a potential for grit to be eroded and eliminated from the gizzard. Thus, the average number of days "off ground to death" (average number of days during which grit obtained from the holding pens could be eroded and eliminated) was determined.

In order to obtain an estimate of the average amount of grit in the gizzard of each duck when removed from the holding pen, we used the three groups of ducks on the Phase V study that had no soil in the experimental pens. One group survived an average of 13.0 days, one group 17.0 days, and the third group 23.3 days after removal from the soil (grit) (Table 42). We assumed that the differences in the mean weights of the grit 13.0, 17.0, and 23.3 days after removal from the source of grit indicated the mean rate of loss of grit and that the daily loss of grit was uniform. Thus, we calculated the weight of grit in the gizzards of each of these three groups of ducks when they were removed from the soil. We averaged the three weights obtained from the groups and assumed that this was the average amount of grit present in the other ducks when they were removed from the soil (1,849.67 mg).

We had an estimated beginning weight of the grit for each duck and a calculated daily rate of loss of grit (33.25 mg lost per day). We then calculated the weight of grit in the gizzard at death, assuming that no additional grit had been ingested. We determined the actual weight of grit in the gizzard at the death of each duck. We then determined the actual weight of grit at death in relation to the calculated weight. The difference in these two figures was an estimate of the relative amount of grit obtained by each group of ducks after they were removed from the holding pens and placed in the experimental pens. The method of calculation used required that the three groups of ducks from the Phase V study that had no soil in the experimental pens show no difference between the calculated and the actual amount of grit in their gizzards.

RESULTS AND DISCUSSION

Effect of Soil on Retention and Erosion Rates of Pellets

Retention Rates of Pellets.--The mean number of pellets recovered ranged from 3.3 for ducks dosed with 10 g of soil to 4.2 for controls and ducks dosed with 5 g of soil (Table 43). None of the differences among the four groups of ducks was significant ($P>0.05$). From the results of this study it does not appear that 10 g of soil daily had enough grit to cause an increase in the rate of expulsion of the pellets, as was suggested by Osmer (1940), Rosen and Barnkowski (1960), Beer and Stanley (1965), and Longcore et al. (1974).

Erosion Rates of Pellets.--The mean daily erosion rate was substantially and significantly ($P<0.05$) higher in ducks that were dosed with soil than in controls (Table 43). The erosion rate was positively correlated with the amount of soil dosed, except that ducks dosed with 10 g of soil daily had a lower (3.02 percent) daily erosion rate than ducks dosed with 5.0 g of soil (3.41 percent). Among the ducks dosed with soil, only the difference between the erosion rates for ducks dosed with 2.5 and 5.0 g of soil daily was significant.

The amounts of soil dosed in the present experiment resulted in higher daily erosion rates of the pellets than in controls. From our Phase V study there was an indication that ducks with free access to soil eroded lead from the pellets in their gizzards at a faster rate than ducks dosed with 2.5, 5.0, or 10.0 g of soil daily. The daily erosion rate for these three groups dosed with soil was 2.9 percent at a mean survival time of 14.6 days. One group of ducks with free access to soil in the Phase V study eroded 4.0 percent per day in an average of 13.9 days (Table 38).

Effects of Soil on Lead Toxicity

Mortality Rate.--The percentage mortality 1, 2, and 3 weeks after dosing and the mean number of days survived to 21 days after dosing are shown in Table 43. The small differences in mortality 1 week after dosing were not significant ($P>0.05$). By 2 weeks after dosing the ducks dosed with 2.5 and 5.0 g of soil daily had suffered 50 and 70 percent mortality, respectively, compared with the respective percentages of 30 and 33 for the controls and ducks dosed with 10 g of soil. These differences were not significant. By the end of the experiment 21 days after dosing, ducks dosed with 2.5 or 5.0 g of soil had suffered 100 percent mortality compared with 80 percent for controls and 55.6 percent for ducks dosed with 10.0 g of soil daily. The 100 percent mortality was significantly higher ($P<0.05$) than the 55.6 percent mortality.

The mortality rates of ducks in the present experiment indicated that the amounts of soil dosed did not provide as much protection as was obtained by ducks with free access to soil in a box in their pens. The ducks dosed with 10.0 g of soil daily suffered a lower mortality rate than ducks dosed with 2.5 and 5.0 g of soil but not lower than the rate for the controls. In the Phase V experiment, ducks with free access to soil in their pens survived longer and had a lower total mortality rate by 3 weeks after dosing than ducks on wire (Tables 38, 39).

In the present experiment, it appears that the amounts of soil dosed daily were enough to cause a higher daily erosion rate of dosed pellets than occurred in the controls. In ducks dosed with 2.5 or 5.0 g of soil, the protective effects of the soil were apparently not enough to offset the increased effects of the higher daily exposure to lead eroded from the pellets.

Body Weight.--The initial body weights and weights 1, 2, and 3 weeks after dosing are shown in Table 44. There were no significant differences in the changes in the body weights of surviving ducks by 1 week after dosing. By 2 weeks after dosing, the controls (the controls were dosed with lead pellets and were dosed daily with an empty capsule) had lost significantly ($P<0.05$) less body weight than the three groups dosed daily with soil. Ducks dosed with 10.0 g of soil daily had lost less weight (32.5 percent) than either ducks dosed with 2.5 g of soil (35.7 percent) or with 5.0 g of soil (42.0 percent). Only the difference between the ducks dosed with 10.0 g and those dosed with 5.0 g of soil were significantly different ($P<0.01$). By 3 weeks after dosing only six ducks survived so the body weights at this time have little meaning.

The fact that the controls had lost less body weight by 2 weeks after dosing than any of the three groups dosed with soil seems to indicate that the amounts of soil used in this experiment did not provide the degree of protection received by ducks that had free access to soil in a box in their pens. In the Phase V study (Tables 39, 40) there were no significant differences in body weights among ducks on wire and ducks with access to soil 1, 2, and 3 weeks after dosing. As was true for the mortality rate, it appears that the amounts of soil dosed caused an increase in the daily erosion rates of lead in the gizzards but did not offset the effects of the higher daily dosage levels of lead received by the ducks.

PCV's.--All PCV's (Table 45) indicate the severe effects of lead poisoning in ducks dosed with five No. 4 lead pellets while on a diet of corn. The only significant ($P<0.001$) difference occurred 1 week after dosing. The value for the controls (55.8 percent decline) had declined more than the value for ducks dosed with 5.0 g of soil daily (46.0 percent).

Results of the present experiment indicate that 5.0 or 10.0 g of soil dosed daily provided only slight protection from lead poisoning as indicated by the PCV's, and 2.5 g of soil provided no protection. In the Phase II and Phase V studies, when ducks had free access to soil from the ground or in their pens (Tables 14, 41) there were only slight differences in PCV's of ducks on wire and ducks with access to soil.

Grit

We estimated the amount of grit obtained by ducks with free access to soil in their pens on the Phase V study and the amount obtained from 2.5, 5.0 and 10.0 g of soil dosed daily in the present study. The three groups of ducks in the Phase V study had from 111 to 150 percent more grit in their gizzards than the calculated amounts (Table 42). The calculated amounts assumed that no additional grit was ingested after the ducks were removed from the holding pens and placed in pens with boxes of soil. The four groups of ducks in the present study had -12.2 percent (controls, no soil dosed or available), -5.3 percent (dosed with 2.5 g of soil daily), +15.1 percent (dosed with 5.0 g of soil daily), and +38.2 percent (dosed with 10.0 g of soil daily) in relation to the calculated amounts of grit. Thus, it appears that ducks with free access to soil in boxes in their pens ingested about three times as much grit as ducks obtained when they were dosed daily with 10.0 g of soil from the same source.

We do not know how much soil was ingested by ducks with free access to it because they may have selectively ingested grit from the soil. It is also possible that ducks with free access to soil ingested much more grit than our estimates indicate. Although they present no supporting evidence, Osmer (1940), Rosen and Barnkowski (1960), and Beer and Stanley (1965) reported that excess grit moves through birds quickly and carries any lead pellets with it.

Our data from the Phase V study showed a significantly higher expulsion rate of pellets 1 to 7 days after dosing for ducks with access to soil compared with ducks on wire (Table 38). After the first week the differences were not significant, but ducks with access to soil continued to pass their shot at a higher rate than ducks on wire. In the present study, surviving ducks were not killed until 3 weeks after dosing. Because of a low mortality rate by 1 week after dosing, we did not consider the expulsion rate. By 3 weeks after dosing the mean number of pellets recovered from ducks without access to soil was similar in the two studies--4.2 shot recovered an average of 15.2 days after dosing (Table 43) and 3.7 and 3.6 shot recovered 13.2 and 17.8 days after dosing (Table 38). In the Phase V study, we recovered 3.3 pellets from ducks with free access to soil an average of 17.0 days after dosing (Table 38). In the present study we also recovered 3.3 pellets from ducks dosed with 10.0 g of soil daily an average of 16.7 days after dosing. Our data indicate that at least by 3 weeks after dosing lead pellets, the amount of grit ingested by ducks with free access to soil compared with ducks on wire had no effect on the retention rates of the dosed lead pellets. Although our data are not conclusive, they provide an indication that free access to soil or dosing with 2.5, 5.0, or 10.0 g of soil daily results in a slightly higher expulsion rate of shot by 3 weeks after dosing.

PHASE VII. THE INFLUENCE OF SOIL AND DIET ON THE AMOUNT OF LEAD EXCRETED DAILY IN GAME-FARM MALLARDS DOSED WITH FIVE NO. 4 LEAD PELLETS

The effects of diet on lead poisoning in waterfowl have long been reported in the literature. During the present project we have conducted several experiments to determine some of the effects of free access to soil and of measured doses of soil on the retention and erosion rates of dosed lead pellets, on mortality rates of dosed ducks, on body weights, and on PCV's. The next logical step appeared to be an experiment to determine the amount of ingested and eroded lead that is excreted on a diet of duck pellets (Layena) plus soil, corn plus soil, pellets alone, and corn alone. Of course, the difference between the amount of lead eroded from the lead shot and the amount excreted determines how much lead is retained in the duck--not necessarily in forms or locations that cause lead poisoning.

METHODS

We had facilities to hold 12 ducks in individual cages with a pan under each cage. The individual wire cages were 24" X 16" X 14" (height). Twelve female MM from the Phase I study were randomly placed in individual cages on 10 October 1975. They were fed corn, Layena, and water until 21 October, when they were weighed, bled for PCV determinations, and each was dosed with five No. 4 commercial lead pellets. On the date of dosing, half the ducks were placed on a diet of shelled corn (C) and water and the other half on a diet of Layena (P) and water. Half of the ducks on each diet were dosed daily with 10 g (10) of soil from the pheasant holding pens at Nilo Farms, Brighton, Illinois, and each control was dosed daily with an empty gelatin capsule (0). Thus, C-0 = ducks on a corn diet and not dosed with soil, and P-10 = ducks on a pellet diet and dosed daily with 10 g of soil.

Dr. Kenneth E. Smith, Analytical Chemist, Illinois Natural History Survey, ran lead absorption profiles on the corn (ground) we fed to the ducks, on the Layena pellets, and on topsoil and subsoil from the holding pens at Nilo Farms. The cation exchange capacities in mg Pb/g material were as follows: ground corn, 10 (6.0); Layena, 20 (10.0); topsoil, 11.5 (4.5); and subsoil, 8.5 (4.0). The numbers in parentheses represent the amount of lead 1 gram of each material might realistically be expected to sorb in a duck's gizzard with a concentration of 10-20 ppm lead in the gizzard contents. Although the feed materials sorb more lead than these soil samples, much of the material in the food is probably ultimately absorbed by the ducks and is not excreted directly. Most of the soil ingested is probably excreted directly and might be expected to carry with it the lead that had been sorbed on it.

Five No. 4 commercial lead pellets weigh approximately 1,000 mg (Table 2). During the first week after dosing, one group of ducks on a corn diet eroded 7.4 percent of the pellets (by weight) per day (Table 37). Thus, ducks on a corn diet and with access to soil would be exposed to approximately

70 mg of eroded lead per day for the first week after dosing. Ten grams of soil dosed daily would have a theoretical capacity to sorb approximately 45 mg of lead or about 60 percent of the lead we expected would be eroded each day during the first week after dosing in ducks on a corn diet and dosed with lead.

A simple plywood tray lined with heavy plastic held in place by glass-headed map pins was placed under each cage. These plastic sheets were removed at approximately the same time each morning. The feces were dried on the plastic sheet on a bench under a heat lamp, searched for expelled pellets, ground, and placed in a glass bottle until analyzed for total content of lead. The plastic sheets were washed and dried and were ready to be replaced under the same cage as on the previous day immediately after a second sheet was removed with its daily feces. Whole grains of corn, if any, were picked out of the feces after drying. Any residues of duck pellets on the plastic sheet were analyzed with the feces. An analysis of the duck pellets revealed only 0.4 ppm of lead. The corn had <1 ppm lead and the topsoil from the pheasant holding pens had 2.3 ppm of lead. The feces from each surviving duck were analyzed for their total content of lead on a daily basis.

The ducks were weighed and bled for PCV determination at the start of the experiment (21 October 1975) and at weekly intervals. All surviving ducks were killed 3 weeks after dosing. At autopsy each duck was weighed, the liver and gonads were weighed, and the shot remaining in the gizzard were counted and weighed. The grit was removed from the gizzard, washed, dried, and weighed. The weight of any shot in the gizzard was not included with the weight of the grit.

RESULTS

Effect of Soil on Retention and Erosion Rates of Pellets

Retention Rates of Pellets.--One of the 15 shot (6.7 percent) administered to the three C-0 ducks (5 apiece) was expelled in an average survival time of 7.3 days for this group (Table 46). The expelled shot was found in the feces on the day the duck died, 7 days after dosing. Because it was not found in the feces, a second shot missing from this same duck was assumed to have been completely eroded or eroded to such a degree that it was overlooked in the dried feces. It seems unlikely that such pellets were overlooked in the feces because they should have been apparent when the feces were analyzed for lead. If we had not examined the feces of this duck for lead pellets, we would have assumed that both missing pellets had been expelled.

The expulsion rate was 20.0 percent in 17.0 days for the three C-10 ducks. One shot that weighed 112.9 mg was found in the feces 20 days after dosing. The four remaining shot in this duck each weighed an average of

112.0 mg when the duck was killed 21 days after dosing. Two shot that weighed an average of 110.1 mg each were recovered from the feces of another C-10 duck 11 days after dosing. This duck had only one pellet (weight, 95.3 mg) in its gizzard when it died on the last day of the experiment, 21 days after dosing. If we had not examined the feces for shot, we would have assumed that this duck expelled four shot instead of two and would have calculated an expulsion rate of 33.3 percent instead of 20.0 percent.

We recovered only 6 of the 15 dosed pellets from the gizzards of the P-0 ducks. Five pellets in one duck weighed an average of 47.9 mg each, whereas one pellet in another duck weighed only 0.9 mg. Because we found no pellets in the feces of these ducks, we assume that all missing pellets had been completely dissolved by the ducks. We also recovered only six pellets from the gizzards of the P-10 ducks. Three pellets in one duck weighed an average of 19.0 mg each and three pellets in the gizzard of another duck weighed an average of 13.6 mg each. Again, we found no pellets in the feces of these ducks.

Thus, unless ducks are fluoroscoped or X-rayed frequently after dosing or are held in individual pens and the feces examined daily, it will often not be possible to determine whether dosed pellets have been expelled or eroded. If ducks are held in groups on soil, in a pen with a solid floor, in a pen with a water tank, or even in a pen with a wire floor that rests upon narrow wooden supports, some ducks may ingest lead pellets that are expelled by other ducks (see Phase III study).

Although the sample sizes were small and we attempted no statistical tests, it is apparent that dosing 10 g of soil daily had little effect on the expulsion rate of Pb shot in ducks on either a corn or duck pellet diet (Table 46). The retention rates of pellets 21 days after dosing were affected little, if at all, by dosing with 10 g of soil daily in this experiment. The substantial effects of a diet of duck pellets on the retention rate, as compared with a diet of corn, can be at least partially explained by differential erosion rates, the next topic of discussion (Table 46).

Erosion Rate of Pellets.--The mean amount of lead dosed per duck in each group, the mean amount recovered from the gizzard at death, and the mean amount of lead eroded are shown in Table 47. The mean amount of lead eroded per duck prior to death was 277.8 mg for C-0 ducks, 553.0 mg for C-10 ducks, 994.6 mg for P-0 ducks, and 1,024.9 mg for P-10 ducks (Table 47).

In these tests, diet was more important than soil in the total amount of lead eroded in the gizzards. Although the mean amount of lead eroded was slightly higher in the P-10 group than in the P-0 ducks, the difference was not statistically significant ($P>0.80$). The mean survival times were identical for these two groups of ducks. Although the P-10 group eroded slightly more total lead and had a slightly higher daily erosion rate, these differences were not significant ($P>0.50$). Thus, we conclude that the addition of 10 g of soil daily with a duck pellet diet in this experiment did not add to the already increased erosion rate of the lead shot that was caused by the diet of pellets.

In a direct comparison of the effects of corn and pellets with no soil available or dosed, P-0 ducks eroded 3.6 times as much lead (277.8 mg vs. 994.6 mg, $P<0.005$). The daily erosion rates were not significantly different ($P>0.25$) (Table 47). The mean number of days to death after dosing was longer ($P<0.001$) for the P-0 group, and their daily erosion rate was 47.4 mg compared with 40.8 mg for the C-0 group. Thus, the initial daily erosion rate had to be much higher for the P-0 group than for the C-0 group.

In a comparison of the two groups fed shelled corn, the C-0 group eroded only 277.8 mg of lead compared with 553.0 mg by C-10 ducks, but the difference was not statistically significant ($P>0.05$). This increased total erosion was probably caused by the soil (grit) and by the longer survival time of the C-10 group, even though the relative survival times (7.3 days compared with 17.0 days) were not significantly different ($P>0.05$) (Table 46). There were no significant differences in the daily erosion rates for these two groups of ducks (Table 47). The similar daily erosion rates in the two groups are no doubt explained by a higher initial erosion rate in the C-10 group followed by a progressively lower erosion rate as the pellets became progressively smaller in the gizzards. Thus, the similar daily erosion rates for the entire period after dosing for two groups with differing survival times actually indicate a higher initial erosion rate for the group that lived longer (C-10).

The P-10 ducks eroded much more (1,024.9 mg) lead than the C-0 ducks (277.8 mg, $P<0.001$) or the C-10 ducks (553.0 mg, $P<0.02$). The P-0 ducks also eroded more (994.6) lead than the C-0 ducks ($P<0.005$) or the C-10 ducks ($P<0.05$). Except for these differences and the higher ($P<0.025$) daily erosion rate in the P-10 ducks than in the C-10 ducks, there were no significant differences in the erosion rates of the four groups (Table 47). The P-0 and P-10 ducks had 21.0 days to erode lead compared with an average of 17.0 days for the C-10 group ($P>0.30$). The C-0 ducks had a mean of only 7.3 days to erode their lead ($P>0.05$ for the C-10 ducks and $P<0.001$ for the P-0 and P-10 ducks). Although the daily erosion rates were significantly different only for the C-10 and P-10 ducks, these rates must be examined with the knowledge of the differences in the time available for the pellets to erode in the gizzards of each group of ducks.

The differences in the total amount of lead eroded in the various groups of ducks can be explained by a higher initial erosion rate caused by the pellet diet and by the dosing with soil, by a slightly higher overall daily erosion rate of lead in some groups, and by a longer survival time for some groups. The pellet diet increased the erosion rate more than the daily dosing with 10 g of soil for ducks on a corn diet.

As we have reported in previous phases of our current project, the addition of soil usually results in a more rapid erosion rate of dosed pellets when ducks are fed corn. For the present study, the daily rate was 3.8 percent for the C-0 ducks compared with 3.1 percent ($P>0.60$) for the C-10 ducks (Table 47). This seemingly higher erosion rate in ducks with no soil resulted because the C-0 ducks lived an average of 7.3 days after dosing compared with 17.0 days for the C-10 ducks, as noted above.

We made no attempt to measure food consumption in our studies. Irwin et al. (1974) found a significant positive correlation between the amount of food consumed and the erosion rate of lead shot in game-farm mallards on an adequate diet (see section on Mortality, Phase I, this report). The most obvious difference they reported between the effects of ingested lead in ducks fed corn and ducks fed an adequate diet was the lead-induced anorexia in the ducks fed corn.

Grit.--There were no significant differences in the mean weights of grit taken from the gizzards of these four groups of ducks at death. These ducks had no access to grit after they were removed from the holding pen on 9 October 1975, except for the grit obtained from 10 g of soil dosed daily in half of the birds during the experiment. The C-0 and P-0 ducks had obtained no grit for an average of 19.3 and 33.0 days, respectively, on the dates of their death.

The average weights of the grit taken from the gizzards give little indication that the C-10 and P-10 ducks obtained grit from the dosed soil. The C-0 ducks had an average of 14.4 g of grit in their gizzards, but gizzards of C-10 ducks contained only 10.5 g. Gizzards of P-0 ducks averaged 24.0 g of grit compared with 27.8 g for P-10 ducks (Table 48). There is an indication that ducks on a corn diet (12.4 g of grit) eroded or expelled grit more rapidly than ducks on a pellet diet (25.9 g of grit). Even with these small sample sizes, the difference approached significance ($P = 0.08$).

Other than the Phase I study, where only ducks on the corn diet were killed for autopsy, we did not feed a pellet diet to ducks during the experimental period of any of our studies. If there is a significant difference between the retention rates for grit in ducks on a corn diet and ducks on a pellet diet, we have no explanation for the difference or the possible resultant effect on toxicity of ingested lead pellets. It does appear odd that ducks on a corn diet would erode or expel, or both, grit faster than ducks on a pellet diet while retaining a greater percentage of the lead pellets in their gizzards (Table 46) and eroding those pellets more slowly than the pellet-fed ducks.

Effects of Soil on Lead Toxicity

Mortality.--The C-0 ducks suffered 100 percent mortality compared with 33.3 percent for the C-10 ducks. All six ducks on the pellet diet survived to the end of the experiment (Table 46). The mean number of days each group lived after dosing was 7.3 for the C-0 group, 17.0 for the C-10 ducks, and 21.0 for both the P-0 and P-10 groups. The only significant difference was between the C-0 ducks and the P-0 and P-10 ducks.

Thus, as many previous published studies and our own earlier studies on the present project have shown, lead poisoning is more severe on a corn diet than on a more complete diet. This differential response occurs in spite of the fact that, as our studies show, ducks on a more complete diet and with soil are exposed to a much greater daily dose of eroded lead than ducks on a corn diet and no soil. Note the direct relationship between the mean weight of lead eroded prior to death (Table 47) and the mean number of days survived after dosing with lead (Table 46). In a comparison of corn versus pellets and corn versus corn and 10 g of soil daily, it seems obvious that pellets provide much more protection from dosed lead than soil does. In fact, with respect to the mortality rate, we have been unable to show that pellets plus soil are significantly better for ducks than pellets alone. The mortality rate for all ducks on a corn diet was 66.7 percent compared with 0.0 percent for all ducks on a pellet diet.

These data are of limited value for average survival times as affected by diet and soil. They are important in the interpretation of most other factors in the present study--amount and rate of loss of body weight, weight of the liver and gonads, erosion and expulsion rates of pellets from the gizzard, amount of grit in the gizzard, and rate and total amount of lead excreted.

Body Weight.--The changes in body weights of surviving ducks indicate a slightly lower daily reduction in the C-10 ducks (2.2 percent) than in the C-0 ducks (2.6 percent). Because the C-10 ducks lived much longer than the C-0 ducks, the C-10 ducks lost more body weight (37.3 percent) than the C-0 ducks (19.1 percent) (Table 49). As we reported in the Phase V study, these weight changes indicate acute lead poisoning in lead-dosed ducks on a diet of corn and chronic lead poisoning in lead-dosed ducks on a diet of corn and dosed daily with 10 g of soil. The small sample sizes and differential mortality rates must be noted when weight changes of these ducks are considered.

Both groups of ducks on the pellet diet weighted slightly more at the end of the experiment than they did at the start. This fact probably indicates that the conditioning period in the small cages was inadequate. The ducks were caught from the large holding pen on 9 October and placed in one of the pens used for the Phase IV study. They were caught again on 10 October, weighed, and placed in the individual pens. Their weights had stabilized by 21 October when they were dosed; however, they had not regained the weight lost after 10 October. The P-0 ducks gained 4.4 percent in body weight from 21 October to 11 November compared with 5.1 percent for the P-10 ducks for the same period. With weight changes as with mortality rates, there was little difference between pellets and pellets and soil and a much larger difference between corn and pellets. All ducks on a corn diet lost an average of 2.4 percent per day compared with a gain of 0.2 percent per day for ducks on a pellet diet.

Changes in body weights on a weekly basis and in the final weights of ducks that died during the experiment are shown in Table 50. The two groups of ducks on a corn diet lost 12.8 (C-0) and 11.1 (C-10) percent of their body weight by 1 week after dosing. Only two of the ducks in the C-0 group survived to the seventh day and one of those died on the seventh day. The last duck in the C-0 group died on the ninth day after dosing, so comparisons were not possible 2 and 3 weeks after dosing. The C-0 ducks lost significantly more weight by 1 week after dosing than either the P-0 (+1.6 percent, $P<0.02$) or the P-10 (+2.8 percent, $P<0.005$) ducks (Table 50). The C-10 ducks lost more weight by 1 week after dosing than the P-0 ducks or the P-10 ducks ($P<0.05$). The weight patterns were similar both 2 and 3 weeks after dosing. The weight changes were similar between the P-0 and P-10 ducks 1, 2, and 3 weeks after dosing--weight gains ranged from 1.6 to 5.1 percent. Although the differences between these two groups were not significant, they were consistent in that in all cases the P-10 group gained slightly more weight than the P-0 group.

The daily weight losses to death, including two in the C-10 group that survived to the end of the experiment, were not significantly different ($P>0.60$) in the two groups on the corn diet--1.9 percent for the C-0 ducks and 2.2 percent for the C-10 ducks. The daily weight losses were the same (0.2 percent) for both groups on the pellet diet, but the rates of daily weight losses were significantly lower for both groups on pellets than for both groups on corn ($P<0.025$ or less).

The C-0 ducks lost only 13.2 percent of their body weight by the time they died, indicating acute lead toxicity and a relatively short survival time after dosing. The C-10 duck that died (9 days after dosing) lost 26.4 percent of its body weight, but the two surviving ducks in this group lost 37.3 percent of their weight by the end of the experiment. The total weight change for the three ducks in the C-10 group (33.6 percent loss) was significantly ($P<0.05$) higher than for the C-0 ducks (13.2 percent loss) (Table 50). The C-0 ducks lost significantly ($P<0.005$) more total weight than the P-10 ducks (5.1 percent gain) but not significantly ($P>0.10$) more than the P-0 ducks (4.4 percent gain). The C-10 ducks lost significantly ($P<0.05$, $P<0.005$, respectively) more total weight than the P-0 and the P-10 ducks.

It appears that weight changes induced by lead are slightly more sensitive to the effects of diet and soil than the physical parameters such as erosion rates of lead pellets, excretion rates of lead in the feces, and retention rates of lead in the duck. Especially note the consistency of the significant differences in weight changes between the C-10 and the P-0 groups. Although there were some differences in these two groups in the earlier parameters discussed, they were not as consistent as the weight changes.

PCV's.--One week after dosing there was little difference in the PCV's in surviving C-0 and C-10 ducks (Table 51). The second week after dosing none of the C-0 ducks survived. The mean PCV values declined sharply for both groups of ducks on the corn diet from dosing to 1 week later (45.6 and 48.7 percent). The declines were much less for ducks on the pellet diet--11.4 and 5.0 percent, respectively, for P-0 and P-10 ducks--than they were for ducks on the corn diet. At 1 week after dosing, PCV's of all surviving ducks on the corn diet had declined 47.2 percent compared with 8.2 percent for all ducks on the pellet diet (Table 50). As with other factors, the PCV's indicate that pellets provide more protection than soil for ducks dosed with lead. However, in the present study, PCV's indicated some added protection when 10 g of soil was dosed daily in ducks on a diet of pellets.

Although two ducks in the C-0 group survived to 1 week after dosing, one of the two died before a blood sample was taken. Thus, we have only one PCV value for the C-0 group and it shows a 45.6 percent decline by 1 week after dosing. The C-10 group had significantly greater declines in PCV values at 1 week after dosing (48.7 percent) than either the P-0 (11.4, $\underline{P}<0.05$) or the P-10 (5.0 percent, $\underline{P}<0.02$) groups. The differences were similar 2 and 3 weeks after dosing except that the difference between C-10 and P-0 at 2 weeks after dosing was not significant ($\underline{P}>0.05$). As with the weights, differences in PCV's were not significant between the P-0 and P-10 groups, but in all cases the P-10 ducks were "better" than the P-0 ducks. The percentage differences in PCV's were slightly larger between these two groups than were the differences in body weights.

Weights of Livers and Gonads.--There were no significant differences among the mean weights of the livers and gonads of the four groups of ducks in this experiment (Table 48). The livers and gonads of the C-0 group weighed more than these organs in any other group, and if the sample sizes had been larger, the difference would probably have been significant. Livers of lead-poisoned ducks are reduced in size (Jordan and Bellrose 1951, Coburn et al. 1951, Locke et al. 1967a, Bates et al. 1968). Thus, the heavier livers and gonads in the C-0 ducks are probably a further indication that these ducks died of acute lead poisoning before these organs had time to lose much weight. The C-0 ducks also lost significantly less body weight prior to death than the C-10 ducks (Table 50).

Lead Excretion in the Feces

The background level of lead in the feces of each duck is shown for 21 October, before the ducks were dosed with lead pellets (Table 52). This amount ranged from a low of 0.06 mg to a high of 3.99 mg. Twenty-four hours after dosing with lead pellets, the lead in the feces had increased from 25-fold for the C-10 group to 403-fold for the P-10 ducks. The mean amounts of lead excreted each day for the surviving ducks in each group are also shown in this table.

As we noted earlier in the present report, the total amount of lead eroded was not significantly different between the C-0 and the C-10 ducks and between the P-0 and P-10 ducks (Table 47). There was, however, significantly more lead eroded in the gizzards of ducks on the pellet diet (1.3 times the daily rate for ducks fed corn) than in gizzards of ducks on the corn diet, and the C-10 ducks actually eroded almost twice as much lead as the C-0 ducks. Previous studies on this project have shown that ducks with free access to soil eroded lead much faster, on a diet of corn, during the first and second weeks after dosing than ducks without access to soil (Tables 37, 38).

Differences in the excretion of lead in the feces could be influenced by the amount of lead eroded in the gizzards, but it does not appear probable that all of the differences noted were caused by differing amounts of eroded lead available to be excreted.

The pattern of excretion of lead in the feces for all surviving ducks is shown in Fig. 6. There was a sharp increase within 24 hours of dosing with lead pellets followed by lower levels for 3 days, an increase on the fifth day, sharp decreases for 2 days, and then a gradual decrease until the termination of the experiment 21 days after dosing. Excretion patterns for the four groups of ducks are shown in Fig. 7. In general, P-0 ducks had the highest excretion rate, followed closely by P-10 ducks. The third highest rate was found in C-10 ducks. C-0 ducks had the lowest excretion rate.

The small sample sizes are a problem with this study, but they were made necessary by the time and effort involved in collecting and analyzing the feces for lead on a daily basis. Also, for many aspects other than excretion rates of lead in the feces, we have data based on larger sample sizes--for example, daily erosion rates of lead, mean survival time, changes in body weight, and changes in PCV's as influenced by diet and soil.

The total amount of lead excreted per duck prior to death was significantly less ($\underline{P} < 0.05$) for the C-0 group (83.4 mg) than for the other three groups. The C-10 ducks also excreted significantly less (319.7 mg, $\underline{P} < 0.05$) than either the P-0 group (762.7 mg) or the P-10 ducks (590.4 mg) (Table 53). The difference in the total amounts excreted by the P-0 and P-10 ducks was not significant.

The daily amount of lead excreted per duck followed the same general pattern as the total amount eroded (Table 52), but none of the differences was significant. The daily excretion rate for the C-0 ducks was 12.7 mg compared with 19.9 mg for C-10 ducks, 36.3 mg for P-0 ducks, and 28.1 mg for P-10 ducks. In the present study, 10 g of soil dosed daily did not cause a significant increase in the amount of lead excreted per day, in the total amount of lead eroded, or in the daily erosion rates prior to the death of the ducks, probably because of the small sample sizes and the longer survival times of the ducks on a pellet diet and ducks on a corn diet that were dosed with soil.

We chose to examine the lead excreted the second day after dosing to give the ducks time to adjust to the dosed lead. On this day the C-0 group excreted significantly less lead than any of the three other groups (Table 53). The C-0 group excreted 19.2 mg per duck compared with 62.2 mg for the C-10 group ($\underline{P} < 0.005$), 89.7 mg for the P-0 group ($\underline{P} < 0.01$), and 47.4 mg for the P-10 group ($\underline{P} < 0.05$). From this comparison, it appears clear that either 10 g of soil dosed daily with a diet of corn or a diet of pellets as contrasted with a diet of corn resulted in a much higher excretion rate of lead in the feces (Table 52).

On the second day after dosing there was no significant difference ($\underline{P} > 0.05$) in the amount of lead excreted by the C-10 group and the P-10 group--in fact, the C-10 ducks excreted more lead (62.2 mg) than the P-10 ducks (47.4 mg) (Table 53). We have no explanation for this difference. The total amount of lead eroded by the P-10 ducks was nearly twice the amount eroded by the C-10 ducks. Thus, it appears unlikely that more eroded lead was available for excretion in the C-10 ducks on the second day after dosing. Data presented in Table 52 show that all three ducks in the C-10 group excreted uniformly high levels of lead on the second and third days after dosing. These were the only 2 days among the first 10 days after dosing that the C-10 ducks excreted more lead than the P-10 ducks (Fig. 7).

The P-0 group excreted significantly more ($\underline{P} < 0.05$) lead (89.7 mg) on the second day after dosing than the P-10 group (47.4 mg) (Table 53). Also, on 8 of the first 10 days after dosing the P-0 group excreted more lead than the P-10 group (Table 52). From this information, it appears that the addition of 10 g of this soil daily to a diet of pellets inhibits the excretion of lead. Perhaps something in the soil binds the lead and is absorbed by the duck so that the bound lead is retained with the soil-bound component. We would anticipate that the erosion rate on the second day would be higher in the P-10 ducks than in the P-0 ducks because of the soil and grit. Thus, it seems that something other than the amount of eroded lead available for excretion is the explanation for the differing rates of excretion of lead among the four groups of ducks.

The next point at which we examined the lead excretion in detail was the sixth day after dosing, chosen because it was the last day on which all ducks in the experiment were alive (Table 52). The excretion rates for both groups of ducks on the corn diet were lower than they were on the second day, but the rates were higher for both groups on the pellet diet. Only the rate for the C-10 group was significantly different ($\underline{P} < 0.05$) from what it was on the earlier date (Table 53).

On the sixth day the C-0 group excreted only 2.4 mg of lead, but this amount was not significantly ($\underline{P} > 0.05$) lower than the 29.8 mg excreted by the C-10 ducks (Tables 52, 53). No doubt the lack of significance was a result of the small sample sizes and the individual variability of the ducks. The excretion for the C-0 group was significantly lower than in the P-0 group (102.2 mg, $\underline{P} < 0.025$) and in the P-10 group (58.3 mg, $\underline{P} < 0.01$). These results indicate that a pellet diet increased the rate of excretion of lead in the feces more than 10 g of soil added daily to a diet of corn.

Although the differences in the amount of lead excreted on the sixth day were substantial among the remaining three groups of ducks, these differences were not statistically significant (Table 53). Ducks on the pellet diet excreted more lead than the C-10 group, and P-0 ducks excreted more lead than P-10 ducks.

The total amount of lead excreted from the time of dosing to the sixth day was in the same relative order as the amounts excreted on the second and sixth days; the C-0 group excreted significantly less lead during this period than the other three groups (Table 53). The amount of lead excreted by 6 days after dosing--when all ducks in both groups were surviving--was more than three times higher in the C-10 group than in the C-0 ducks. After most of the pellets have eroded in ducks with longer survival times, there is little lead left to erode. Thus, when average daily erosion (or excretion) rates include ducks that survive longer, the figures mask probable higher initial rates. By the end of the experiment (21 days after dosing) P-0 and P-10 ducks had eroded approximately 94 percent of the weight of the lead dosed (Table 47).

The excretion rates can be obtained on a daily basis from individual ducks; however, in order to determine daily erosion rates in the same ducks, the pellets would have to be removed from the gizzards, weighed, and replaced daily in the individual ducks. Nord (1941) developed a technique for removing pellets from the gizzard of a live duck, but the frequent handling and removal procedures would add stress and a new dimension to a study using his technique.

Although the average survival times of the C-0 and C-10 groups were not significantly different ($P > 0.05$)--probably because of the small sample sizes--other studies (Table 37) have shown that access to soil provides substantial protection from lead toxicity for ducks on a diet of corn. From the present study it appears that this protection is derived primarily from some effect of the soil other than an increase in the excretion rate of lead in the feces. This effect may be physiological or it may result from some binding action of soil elements retained in the duck that prevents the retained lead from adversely affecting the duck.

A comparison of a corn diet (C-0) with a pellet diet (P-0) for erosion rates of lead pellets shows differences similar to the ones found between the C-0 and C-10 groups except that the P-0 groups eroded significantly ($P < 0.005$) more lead than the C-0 group and also survived significantly ($P < 0.005$) longer (Tables 46, 47). Even though the erosion rate and the total amount of lead excreted are higher in the P-0 group than in the C-0 group, the daily excretion rates in the two groups were not significantly different ($P > 0.05$). Perhaps larger samples would have demonstrated significant differences in these areas if they exist; however, results of the present study seem to indicate that the protection afforded by the pellet diet over the corn diet comes primarily from some physiological effect in the duck and not from an increase in the daily excretion rate of lead in the feces.

Folic and humic acids are expected to be abundant in soils high in organic matter (such as soil from the pheasant holding pens at Nilo Farms) and would show a preferential binding of lead compared with clay in the soil. Lead bound to clay would be excreted with the feces. Lead bound by the pellet diet would probably not be bound to the acids mentioned above. These acids with bound lead could be absorbed by ducks. Lead thus absorbed would not be in the ionic state and could not interfere with the formation of hemoglobin. The greater amount of lead that remains in ducks on pellets, on pellets plus soil, and on corn plus soil has much less adverse effects on ducks than the much smaller amount of lead that remains in ducks on a corn diet and no soil.

Eroded Lead Retained by the Duck

In a relatively short-term experiment such as this one (21 days), perhaps the most important item to examine is the amount of lead retained by the duck.

The erosion rate may have an influence on the amount of lead retained, but the excretion rate could counteract the effect of the rate of erosion. The survival time of each duck would be a factor in the amount of lead excreted. Lead could also be absorbed by the duck, have an adverse effect, and be excreted within 21 days or less. The amount of lead retained by each duck was calculated by subtracting the lead excreted in the feces prior to death from the lead eroded from the lead shot in the gizzard.

The C-0 ducks retained 194.4 mg compared with 233.3 mg for the C-10 group, 231.0 mg for the P-0 ducks, and 434.5 mg for the P-10 group (Table 53). The only significant difference was between the C-0 and P-10 groups ($\underline{P} < 0.02$). The group with the lowest daily erosion rate, the lowest daily excretion rate, and the shortest survival time retained the smallest amount of lead. The P-10 group retained more than two times as much lead as the C-0 group and survived about three times as long after dosing (all three P-10 ducks were killed 21 days after dosing). The high retention rate for the P-10 ducks resulted from the highest daily erosion rate and the second highest daily excretion rate.

The amount of lead retained per day from dosing to death presents a different picture. Although none of the differences was significant, the C-0 ducks (20.2 mg) and the P-10 group (20.7 mg) retained similar daily amounts. Because of a likely higher erosion rate early in the experiment, the P-10 ducks probably retained more lead per day during that period than the C-0 ducks. The last C-0 duck died 9 days after dosing. The C-10 (13.2 mg) and the P-0 (11.0 mg) ducks retained only slightly more than half as much lead on a daily basis as the other two groups; however, they each retained 1.2 times as much total lead as the C-0 group. The P-10 ducks retained 2.2 times as much total lead as the C-0 group and 1.9 times as much as the two other groups.

The C-0 ducks excreted only 30.0 percent of the lead that was eroded in their gizzards (Table 53). The C-10 and P-10 groups excreted nearly 58 percent of the eroded lead, and the P-0 ducks excreted 76.7 percent of the eroded lead. Irwin et al. (1974) found that ducks on an adequate diet excreted about 88 percent of the lead they dissolved, whereas ducks fed corn excreted only about 54 percent of the lead eroded in their gizzards.

CONCLUSIONS

We conclude that 10 g of soil daily in ducks on a diet of corn and dosed with five No. 4 commercial lead pellets provide substantial protection from the effects of lead poisoning. A diet of duck pellets provides much better protection than a diet of corn alone and more protection than corn plus 10 g of soil daily. Pellets plus 10 g of soil daily provided the most protection in these tests, but pellets plus this amount of soil were not significantly better than pellets alone except for PCV's.

As can be seen from the survival data (Table 46) and from the data on body weight and PCV's (Table 50), lead toxicity was most severe in the C-0 group followed by the C-10, P-0, and P-10 groups. Although all parameters presented in Table 50 were either "better" for the P-10 ducks than for the

P-0 ducks or were equal for the two groups, the differences were slight and none was significant.

These data indicate that the major reasons for the differences in reaction to lead that were observed in these ducks must be some factor(s) additional to the differences in the total and daily erosion rates of lead in the gizzards, the total and daily amounts of lead excreted in the feces, and the total and daily amounts of lead retained in the ducks. The ducks that eroded the least lead on a daily and total basis (C-0), excreted the least lead on a daily and total basis, and retained the least lead on a total basis were most severely affected by lead poisoning. On a daily basis, the C-0 ducks retained more lead than the C-10 and P-0 groups, and the P-10 ducks retained only slightly more. The P-10 ducks had the highest total and daily erosion rates for lead, the second highest total and daily excretion rates (only the P-0 group was higher), the highest total and daily retention rates for lead, and showed the least adverse reactions to lead poisoning.

PHASE VIII. EFFECTS OF THE "OLD" AND THE "NEW" PROCESS ON THE TOXICITY OF LEAD:IRON SHOT IN CAPTIVE GAME-FARM MALLARDS DOSED WITH FIVE 47:53 NO. 6 PELLETS

INTRODUCTION

The closest duplication we had on the Phase III study was 40:60 lead: iron pellets made by the "old" process (OP) and 45:55 pellets made by the "new" process (NP). The results appeared to indicate that the method of manufacture had a significant effect on the toxicity of the shot to waterfowl. Thus, it seemed worthwhile to test possible differences caused by the method of manufacture.

METHODS

At our request the Canadian Wildlife Service contacted the National Research Council of Canada (NRC), and the NRC agreed to supply enough shot to run this series of tests. The NRC had a supply of No. 6 pellets manufactured by the old process on hand. Shot made by the new process is approximately 47 percent lead unless steps are added to increase or decrease the amount of lead. Thus, NRC provided enough No. 6 OP pellets of approximately 47 percent lead, No. 6 NP pellets of approximately 47 percent lead, and No. 6 pellets of approximately 47 percent lead made by the new process and then flamed (NP-F) to remove the lead film, if such a film were present on the shot.

The ducks for this experiment were survivors of the Phase I study. They were removed from the holding pens in Urbana, Illinois, on 18 November 1975 and placed in nine pens with wire floors in Urbana. They were given duck pellets, shelled corn, and water until the date of dosing. They were weighed, bled for PCV determinations, and dosed on 23 December 1975. After dosing, the ducks were placed on a diet of shelled corn and water. They were weighed and bled 1, 3, and 6 weeks after dosing. All surviving ducks were weighed and bled on 3 February 1976, at the end of the experiment, 6 weeks after dosing. All shot remaining in the gizzards at death were recovered and weighed. The experimental ducks and the controls were autopsied on 4 February and on 5 February 1976, respectively.

The densities and percentages of lead, iron, tin, and zinc in the various types of shot are shown in Table 54. The design of the experiment is also shown in this table. Because only a limited number of ducks were available, we used 10 male control ducks and 10 male ducks each dosed with three No. 6 pellets of three types and 10 male ducks dosed with five No. 6 pellets of the same three types. Because 6 male and 12 female ducks remained after these ducks were dosed, 3 males and 6 females were each dosed with one OP pellet and 3 males and 6 females were each dosed with one NP pellet.

RESULTS AND DISCUSSION

Mortality

There were no significant differences in mortality rates caused by the method of manufacture of the shot. All ducks were alive 1 week after dosing, and only three had died (one in each of three groups) by 3 weeks after dosing (Table 55). By the end of the experiment the mortality rates ranged from zero for controls and the ducks dosed with one shot each to 20 percent for all the ducks dosed with three shot each and 47 percent for all ducks dosed with five shot each. One of the controls died 23 days after dosing from causes unrelated to the experiment and was therefore removed from consideration.

All controls and all ducks dosed with one pellet survived to the end of the experiment (42.0 days). There were no significant differences in mean survival times among the controls and all three groups of ducks dosed with 3 pellets each (Table 55). The average survival time for ducks dosed with 5 OP or with 5 NP-F pellets was significantly less than for controls. Ducks dosed with 5 NP shot did not have a significantly ($\underline{P} > 0.05$) shorter survival time (37.1 days) than the controls.

These tests were not designed to test the toxicity of these shot in relation to controls. We found, however, that both the 5 OP and the 5 NP-F groups had significantly shorter mean survival times than controls. Although No. 6 pellets were used in this experiment instead of No. 4 pellets used in the other experiments, mortality was 30, 50, and 60 percent for the three groups dosed with five shot. Thus, from this study it appears that pellets with 47 percent lead are relatively toxic for ducks on a diet of corn.

Changes in Body Weight

All groups except those in pen No. 6 (1 OP) gained a slight amount of weight during the first week after dosing (Table 56). Ducks in pen No. 6 lost a slight amount during the same period. These slight weight gains indicate that the ducks probably should have been conditioned longer before they were dosed. By the third week all surviving ducks except the controls (pen No. 2) had lost from < 0.1 to 12.4 percent of their initial weight. Weights of controls remained essentially unchanged. By the end of the experiment 6 weeks after the ducks were dosed, all surviving ducks had lost weight. The loss of weight by the controls from the third to the sixth week was probably caused by the extremely cold weather during this period (the ducks were held in outdoor pens) and by the diet of shelled corn.

Comparisons of weight changes from dosing to 1, 3, and 6 weeks after dosing were made for all surviving ducks to determine whether the method of manufacture of the shot had an effect on the weight changes (Table 57). Comparisons were made within each group dosed with the same number of shot and between each group and the controls. Comparisons were not made among the ducks dosed with different numbers of shot.

Statistically significant differences ($\underline{P} < 0.05$) in weight changes were found in only four instances involving the different types of shot (Table 57). At 1 week ducks dosed with 1 NP shot had gained 2.6 percent, whereas those dosed with 1 OP shot had lost 0.7 percent ($\underline{P} < 0.05$). Ducks dosed with 3 NP shot had lost < 0.1 percent of their initial weight by 3 weeks after dosing compared with 5.2 percent for ducks dosed with 3 OP shot ($\underline{P} < 0.05$).

By the end of the experiment these weight losses were 4.7 and 11.4, respectively ($P < 0.02$), whereas ducks dosed with 3 NP-F had lost 13.5 percent of their initial weight ($P < 0.05$, compared with 3 NP ducks).

In 9 of 24 possible cases, controls either gained significantly more or lost significantly less weight than ducks dosed with shot (Table 57). For example, 1, 3, and 6 weeks after dosing, ducks dosed with 1 OP shot had lost more weight than controls ($P < 0.005$, 0.01, and 0.02, respectively). Three and 6 weeks after dosing, ducks dosed with 3 OP shot had lost more weight than controls ($P < 0.025$). Three weeks after dosing, ducks dosed with 5 OP shot ($P < 0.001$) and ducks dosed with 5 NP shot ($P < 0.05$) had lost more weight than controls. Both 3 and 6 weeks after the start of the experiment, ducks dosed with 5 NP-F shot had lost more weight than controls ($P < 0.01$ and < 0.025, respectively). Thus, each type of pellet caused one or more groups of surviving ducks to lose significantly more weight than controls at one or more periods.

It is interesting that 9 of 13 significant differences in weight losses found in this study involved shot made by the old process. In all nine of these cases involving the OP shot, ducks dosed with it lost more weight than the group with which they were compared, but only four of these comparisons were with ducks dosed with other shot types. The other five comparisons were with the controls. If we ignore significance, in 11 of 15 comparisons between OP shot and other types, ducks dosed with OP shot lost more weight than ducks dosed with the same number of shot of other types.

Significant differences in weight changes were not found between most of the groups compared. Thus, we conclude that the method of manufacture of the pellets tested caused no significant differences in the weight changes of the ducks studied. As with the mortality rates, the consistently greater weight losses of dosed ducks compared with controls indicates the toxicity of these No. 6 lead:iron pellets to ducks.

Changes in PCV Values

Except for one group (3 NP), in which an increase of 9.6 percent occurred, most groups of ducks showed relatively small changes in PCV values from dosing to 1 week later (Table 58). Two other groups showed increases and the remaining six groups showed decreases. By 3 weeks after dosing, all groups except the controls and the 3 NP group showed decreased PCV values. The two increased values at 3 weeks were only slightly above the levels observed on the date of dosing, but the decreases ranged from 1.1 percent (1 OP) to 25.2 percent (5 OP). All surviving ducks at the end of the experiment had higher PCV values than they did 3 weeks after dosing. Except for the 3 NP group, which had a 9.9 percent increase over the level at dosing, all ducks dosed with three or five pellets had PCV's that were from 5.5 to 14.4 percent lower than they were when the ducks were dosed.

As with body weights, comparisons of changes in PCV values from dosing to 1, 3, and 6 weeks were made for all surviving ducks. Statistically significant differences ($P < 0.05$) in changes of PCV values were found in only five instances involving different types of shot (Table 59). In only two of the five were the differences in the same groups that showed significant differences in changes in body weights. These were the 3 OP group (-10.4 percent) compared with the 3 NP group (+2.5 percent) 3 weeks after dosing ($P < 0.02$) and the 3 NP group (+9.9 percent) compared with the 3 NP-F group (-14.4 percent) 6 weeks after dosing ($P < 0.05$).

The 3 OP ducks (-1.3 percent) showed a greater decline in PCV values than the 3 NP group (+9.6 percent) 1 week after dosing ($P < 0.05$). The 3 NP-F group showed greater declines 1 and 3 weeks after dosing (-1.5 and -15.9 percent, respectively) than the 3 NP group (+9.6 and +2.5 percent, respectively) ($P < 0.05$, < 0.01, respectively). The PCV values for the 3 NP group were significantly higher than the values for the 3 OP group at two of three times and higher than the values for the 3 NP-F group at three of three times (Table 59). Much of the increase in the 3 NP group was caused by a single duck that had an exceptionally low value (34 percent) on the date of dosing. This value increased to 50 percent 1 week later. Thus, the relatively small sample sizes no doubt influenced the results. Whereas 9 of 13 statistically significant differences in weight changes found in this study involved shot made by the old process, only 5 of 15 statistically significant differences in changes in PCV's involved shot made by the old process.

Because of a lack of consistency in the results from one group to another, the small number of significant differences found, and little correlation between significant differences in changes in body weights and differences in changes of PCV values, we conclude that the method of manufacture of the pellets tested had no consistent significant effect on the PCV values of the ducks studied.

Of 24 possible comparisons between controls and ducks dosed with pellets, 10 differences were statistically significant. Controls always showed increases in PCV values and the dosed ducks always showed decreases (Table 59). These results support the findings on mortality rates and changes in body weights and indicate the toxicity of these pellets to ducks, especially when five pellets were dosed. In five of nine possible comparisons of PCV's between controls and ducks dosed with five pellets, the PCV's of dosed ducks declined significantly more than in controls.

Organ Weights

Liver.--The livers of 3 NP ducks weighed (22.07 g) significantly ($P < 0.02$) more than livers of 3 OP ducks (17.58 g). There were no other significant differences in mean weights of livers among groups dosed with the same number of pellets (Table 60). Other than the females, which had livers that weighed significantly less ($P < 0.001$ and < 0.02, respectively) than livers of male controls, the mean weights of livers of most dosed ducks were heavier than livers of controls. Only weights of livers of 3 NP ducks (22.07 g) were significantly ($P < 0.02$) different from weights of controls (18.20 g). We have no explanation for the heavy livers in dosed ducks that survived to the end of the experiment. All groups retained from 84.0 to 100 percent of the dosed shot at death (Table 61), and all 46 males that lived to the end of the experiment retained at least one dosed shot.

The mean weight of livers of the 9 controls (18.20 g) was highly significantly ($P < 0.001$) heavier than the mean weight (12.59 g) of livers of all 20 dosed male ducks that died during the experiment, but was not significantly ($P > 0.25$) different from the mean weight of livers of the dosed ducks that lived to the end of the experiment. The mean weight of livers of the male ducks that died during the experiment was highly significantly ($P < 0.001$) lower than the mean weight of the livers of the 46 male ducks that lived to the end of the experiment (20.38 g). Livers of lead-poisoned ducks are reduced in size (Jordan and Bellrose 1951, Coburn et al. 1951, Locke et al. 1967a, Bates et al. 1968).

Testes.--The mean weights of testes of surviving ducks were not significantly ($P > 0.05$) different from the mean weights of testes of controls (Table 42). The only significant ($P < 0.05$) difference within groups dosed with the same number of pellets was the lighter (0.86 g) weight of 3 NP-F ducks compared with 3 NP ducks (4.29 g). As was true for the livers, the mean weight (3.20 g) of testes of all dosed ducks that survived to the end of the experiment was highly significantly ($P < 0.001$) heavier than the mean weight (0.52 g) for all dosed ducks that died during the experiment.

Spleen.--There were no significant ($P > 0.05$) differences in mean weights of spleens among groups dosed with the same number of pellets (Table 60). Only spleens of the 1 OP group had a mean weight (1.11 g) that was significantly different ($P < 0.02$) from the mean weight (0.32 g) of spleens of controls. The mean weight (0.34 g) of spleens of all dosed ducks that survived to the end of the experiment were highly significantly ($P < 0.001$) heavier than the mean weight (0.10 g) of spleens of all dosed ducks that died during the experiment.

Retention and Erosion Rates of Pellets

Retention Rates.--Within groups dosed with the same number of pellets, only the 3 OP group (86.7 percent) and the 3 NP-F group (100.0 percent) had statistically significant ($P < 0.025$) differences in the percentage of shot recovered from the gizzards (Table 61). Although the 5 OP group (88.0 percent) had a lower recovery rate than the 5 NP-F group (94.0 percent), the difference was not significant ($P > 0.40$). Thus, we conclude that the method of manufacture of these three types of shot was not a significant factor in the percentage of pellets retained in the gizzards during these experiments.

Erosion Rate.--There were no significant ($P > 0.05$) differences in the total weight eroded from pellets among groups dosed with the same numbers of pellets (Table 61). The daily rate of erosion of pellets in the gizzard was significantly ($P < 0.005$ and < 0.01, respectively) higher in the 5 OP group (2.2 percent) than in the 5 NP (1.8 percent) and the 5 NP-F (1.8 percent) groups. These were the only significant differences in the daily erosion rates among groups dosed with the same number of shot. The OP shot had a higher daily erosion rate than NP shot for ducks dosed with one pellet, but OP shot had the lowest daily erosion rate for ducks dosed with three pellets each (Table 61).

Impaction

The present study showed that all ducks that died that had been dosed with lead:iron shot had higher incidences of distention of the gizzard with feed than the ducks that died in the groups dosed with commercial lead shot (Table 30). Hanson and Smith (1950:159) reported: "Food impaction is the result of lead poisoning, which often causes paralysis of the digestive tract in Canada geese and other waterfowl." In several of our studies we noted that ducks that died 8 days or sooner after dosing seldom had corn in the esophagus, proventriculus, or gizzard. Only 1 of 17 ducks that died from 4 to 8 days after dosing had corn in its gizzard (Table 62) and none showed any impaction. All ducks listed in Table 62 were held in cages with wire floors and were on a diet of shelled corn. Thus, if corn was not present, the esophagus, proventriculus, and gizzard were essentially devoid of food. They sometimes contained a few green leaves from plants that grew under the pens and bits of debris and feathers picked up in the pens.

Ducks that died from 9 to 39 days after dosing with lead sometimes had corn in the esophagus, and corn was usually present in the proventriculus and gizzard. A few ducks died with their heads in the receptacles holding the corn and with corn in their mouths. Perhaps after 8 days the anorexia caused by the dosed lead was lessening and several of the dosed ducks were again eating corn.

In many cases the corn present in the esophagus, proventriculus, and gizzard was in small amounts and there was no indication of impaction. In other instances the ingested corn became impacted, presumably because of paralysis of the digestive tract. The largest number of grains of corn we found in the respective sections was 55 grains in the esophagus of a duck that died 17 days after dosing, 65 grains in the proventriculus of a duck that died 17 days after dosing, and 27 grains in the gizzard of a duck that died 9 days after dosing. The esophagus of one duck, the proventriculi of three ducks, and the gizzards of five ducks were impacted with feathers.

There was little difference in the presence of corn or in the impaction rates among three 10-day periods beginning 9 days after dosing (Table 62). The presence of corn and the impaction rate were lowest in the esophagus and highest in the gizzard.

All but 20 of the 87 ducks examined had been dosed with five No. 4 commercial lead shot. Twenty ducks had been dosed with either three or five No. 6 shot that were approximately 47 percent lead and the corresponding percentage of iron (Phase VIII). The impaction rate in the esophagi of ducks dosed with lead:iron shot (15.0 percent) was significantly higher ($\underline{P} < 0.005$) than the rate for ducks dosed with commercial lead shot (0.0 percent). There were no significant ($\underline{P}>0.50$) differences in the impaction rates in proventriculi of ducks dosed with lead:iron shot (10.0 percent) and ducks dosed with commercial lead shot (13.4 percent). Impaction of gizzards of ducks dosed with lead:iron shot (35.0 percent) was significantly higher ($\underline{P}<0.005$) than in gizzards of ducks dosed with commercial lead pellets (10.4 percent).

It seems reasonable that the higher impaction rates of the esophagi and gizzards of ducks dosed with lead:iron shot in relation to those dosed with commercial lead shot are related to the longer average survival time of ducks dosed with lead:iron shot (see Phase III). Apparently, the appetites of the ducks dosed with lead:iron shot returned more often than those of ducks dosed with commercial lead shot. Of the ducks dosed with lead:iron shot, 90.0 percent had corn in the esophagus, proventriculus, or gizzard compared with 58.2 percent of the ducks dosed with commercial lead pellets. Perhaps, even though their appetites returned, their digestive tracts were still at least partially paralyzed and impaction of the ingested corn occurred. We have no explanation for the higher, but nonsignificant, impaction rate in the proventriculi of ducks dosed with commercial lead shot.

CONCLUSIONS

The method of manufacture of the three types of pellets tested showed no significant effects on the mortality rate or on the average survival time to the end of the experiment. Significant differences in changes in weight were not found between most of the groups tested. Although OP shot were involved in most of the significant differences demonstrated in the changes in weight, we conclude that the method of manufacture of the pellets tested caused no significant differences in the weight changes of the ducks studied. PCV values also failed to demonstrate any consistent significant differences caused by the type of shot dosed. Mean weights of livers, testes, and spleens did not show consistent differences as a result of the type of shot dosed. The method of manufacture of the shot did not consistently affect the percentage of pellets recovered, the weight of pellets eroded, or the mean percentage of the pellets eroded per day. There was a slight tendency for the OP shot to erode faster than the NP and the NP-F pellets. In direct comparisons between OP pellets and the other types, the OP pellets showed a higher erosion or disappearance rate 12 of 15 times. In only 3 of 12 cases were the differences statistically significant. Although the OP pellets may have a tendency to erode slightly faster than the other types, the difference, if real, had little effect on the toxicity to ducks when five or fewer pellets were dosed.

All biological parameters measured indicated that five No. 6 lead pellets of approximately 47 percent lead and the corresponding percentage of iron caused what we consider an unacceptable level of toxicity when dosed in game-farm mallards on a diet of corn.

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Table 1. Composition of the different types of shot used--Phase I and Phase III.

Nominal Pb-Fe content of lead:iron shot	Number of shot analyzed	Mean composition values (percent by weight)						Density (g/cc)
		Pb	Range	Fe	Range	Other	Range	
40-60	5	41.4	36-47	56.6	53-61	2.0	0-5	8.13
50-50	6	45.0	42-47	51.2	50-53	3.8	0-6	8.91
60-40	12	58.0	48-64	35.2	31-40	6.8	2-19	9.24
70-30	12	63.8	43-75	26.6	19-46	9.5	0-19	9.46
Commercial steel shot		0.05		99.95[a]				
Commercial lead shot		97.1						

[a] This value was derived by exclusion of Pb content only and will include other impurities such as carbon.

Table 2. Weights of the doses of the different types of shot--Phase I.

Dose[a]	Mean dose weights (mg)	±1SD[b]
Controls	0.0	
1-0	152.3	1.57
3-0	455.1	3.43
5-0	758.5	3.97
All-0	455.3	
1-41	158.9	8.82
3-41	480.1	15.7
5-41	802.1	28.2
All-41	480.3	
1-45	166.5	3.40
3-45	497.2	14.2
5-45	834.2	9.24
All-45	499.3	
1-58	175.4	7.76
3-58	524.7	14.3
5-58	880.5	20.2
All-58	526.8	
1-64	194.2	10.4
3-64	581.5	20.1
5-64	964.5	52.7
All-64	580.1	
1-100	213.6	13.5
3-100	632.9	20.6
5-100	1,065.0	28.4
All-100	637.2	

[a] The first number in the dose code indicates the number of shot in the dose. The second number indicates the approximate percentage composition of Pb (by weight).

[b] Standard deviation of the mean. Corresponding sample sizes were all 60.

Table 3. Body weights (g) of ducks in each group--Phase I.

Dose[a/]	Time: Before dosing[b/]	Time: Three weeks after dosing	Time: Six weeks after dosing
Controls	1127 (60)[c/]	1142 (59)	1139 (59)
1-0	1101 (59)	1114 (60)	1131 (60)
3-0	1109 (60)	1147 (60)	1176 (60)
5-0	1091 (60)	1122 (60)	1138 (59)
All-0	1100 (179)	1127 (180)	1149 (179)
1-41	1125 (60)	1143 (58)	1162 (57)
3-41	1128 (60)	1149 (60)	1157 (60)
5-41	1122 (60)	1142 (60)	1173 (60)
All-41	1125 (180)	1145 (178)	1164 (177)
1-45	1103 (60)	1132 (59)	1150 (59)
3-45	1109 (60)	1136 (60)	1155 (60)
5-45	1121 (60)	1149 (59)	1175 (59)
All-45	1111 (180)	1139 (178)	1160 (178)
1-58	1132 (60)	1153 (58)	1168 (58)
3-58	1107 (60)	1122 (60)	1146 (60)
5-58	1121 (60)	1134 (59)	1154 (58)
All-58	1120 (180)	1136 (177)	1156 (176)
1-64	1131 (60)	1160 (58)	1167 (57)
3-64	1101 (60)	1105 (59)	1131 (59)
5-64	1109 (60)	1153 (57)	1182 (57)
All-64	1114 (180)	1139 (174)	1160 (173)
1-100	1103 (60)	1114 (60)	1130 (60)
3-100	1095 (59)	1103 (58)	1155 (58)
5-100	1105 (60)	1082 (55)	1139 (54)
All-100	1101 (179)	1100 (173)	1142 (172)

a/ See footnote a/ in Table 2.

b/ Ducks were first weighed on 12-13 May and were dosed on 14-15 May 1976.

c/ Numbers in parentheses indicate sample size.

Table 4. Packed cell volume (percent) of blood in ducks in each group--Phase I.

Dose[a/]	Time: Before dosing[b/]	Three weeks after dosing	Six weeks after dosing
Controls	47.5 (60)[c/]	45.4 (59)	44.3 (59)
1-0	47.5 (59)	46.5 (60)	45.7 (60)
3-0	46.2 (60)	45.0 (60)	44.9 (60)
5-0	47.3 (60)	45.5 (60)	45.0 (59)
All-0	47.0 (179)	45.7 (180)	45.2 (179)
1-41	47.3 (60)	45.4 (58)	45.0 (57)
3-41	48.0 (60)	45.7 (60)	45.0 (60)
5-41	45.9 (60)	45.3 (60)	44.9 (60)
All-41	47.1 (180)	45.5 (178)	45.0 (177)
1-45	47.3 (60)	45.3 (59)	44.6 (59)
3-45	46.8 (60)	45.8 (60)	45.1 (60)
5-45	47.2 (60)	45.7 (59)	44.8 (59)
All-45	47.1 (180)	45.6 (178)	44.8 (178)
1-58	47.6 (60)	45.9 (58)	44.1 (58)
3-58	47.0 (60)	46.0 (60)	45.5 (60)
5-58	46.5 (60)	44.7 (59)	45.3 (58)
All-58	47.1 (180)	45.5 (177)	45.0 (176)
1-64	46.7 (60)	45.3 (57)	44.4 (57)
3-64	47.5 (60)	44.9 (59)	44.8 (59)
5-64	46.9 (59)	44.1 (57)	45.0 (57)
All-64	47.0 (179)	44.8 (173)	44.7 (173)
1-100	46.0 (60)	45.3 (60)	45.3 (60)
3-100	47.9 (59)	43.9 (58)	45.6 (58)
5-100	48.5 (60)	43.6 (55)	44.8 (54)
All-100	47.4 (179)	44.3 (173)	45.2 (172)

[a/] See footnote [a/] in Table 2.

[b/] Ducks were first bled on 12-13 May and dosed on 14-15 May 1976.

[c/] Numbers in parentheses indicate sample size.

Table 5. Hemoglobin concentrations of blood (mg %) in ducks in each group--Phase I.

Dose[a]	Time		
	Before dosing[b]	Three weeks after dosing	Six weeks after dosing
Controls	18.0 (60)[c]	18.0 (58)	18.9 (55)
1-0	18.0 (59)	17.8 (57)	18.9 (59)
3-0	17.7 (60)	17.8 (57)	18.9 (56)
5-0	17.8 (60)	17.7 (56)	18.8 (59)
All-0	17.8 (179)	17.8 (170)	18.9 (174)
1-41	17.9 (59)	18.4 (57)	18.9 (53)
3-41	18.2 (60)	17.8 (57)	18.3 (58)
5-41	17.7 (60)	17.4 (59)	18.5 (56)
All-41	17.9 (179)	17.9 (173)	18.5 (167)
1-45	18.2 (59)	17.0 (57)	18.1 (58)
3-45	17.7 (58)	17.5 (58)	18.7 (59)
5-45	18.0 (59)	17.5 (57)	18.5 (59)
All-45	18.0 (176)	17.4 (172)	18.4 (176)
1-58	17.6 (60)	17.7 (56)	18.2 (57)
3-58	18.1 (60)	18.8 (60)	18.9 (58)
5-58	17.9 (59)	16.9 (59)	19.0 (57)
All-58	17.8 (179)	17.8 (175)	18.7 (172)
1-64	17.4 (60)	17.0 (57)	18.5 (55)
3-64	17.9 (60)	17.7 (58)	18.6 (57)
5-64	17.7 (60)	17.4 (56)	18.9 (51)
All-64	17.7 (180)	17.4 (171)	18.6 (163)
1-100	17.7 (59)	16.6 (58)	17.8 (59)
3-100	17.8 (59)	16.8 (56)	19.3 (55)
5-100	17.9 (57)	17.0 (55)	18.1 (54)
All-100	17.8 (175)	16.8 (169)	18.4 (168)

[a] See footnote [a] in Table 2.

[b] Ducks were first bled on 12-13 May and dosed on 14-15 May 1976.

[c] Numbers in parentheses indicate sample size.

Table 6. Diagnosed etiology of mortality in ducks in the applicable groups--Phase I.

Diet[a]	Sex	Dose[b]	Bird number	Days to death	Diagnosis
1	M	1-41	1016	15	Pecking[c]
1	M	1-45	1046	16	Pecking[c]
1	M	1-58	1076	12	Pecking + enteritis[c]
1	M	5-58	1097	17	Pecking + lead poisoning
1	M	1-64	1108	14	Predation[c]
1	M	1-64	1106	21	Pecking[c]
1	M	3-64	1114	5	Pecking + lead poisoning
1	M	5-64	1129	5	Lead poisoning
1	M	5-64	1128	10	Pecking + lead poisoning
1	M	5-64	1127	14	Pecking + lead poisoning
1	M	5-100	1159	14	Lead poisoning
1	M	3-100	1145	8	Lead poisoning
1	M	3-100	1141	17	Pecking + lead poisoning
1	M	5-100	1160	11	Pecking + lead poisoning
1	M	5-100	1154	18	Pecking + lead poisoning
1	M	5-100	1152	19	Lead poisoning
1	F	1-58	2076	5	Killed by drakes[c]
2	M	1-41	1394	2	Pecking[c]
2	M	5-100	1348	22	Lead poisoning
2	F	1-64	2294	13	Lead poisoning
3	F	5-100	2539	13	Septicemia[c]

[a] Diet No. 1 consisted of whole corn, exclusively; diet No. 2 consisted of corn for 2 weeks and then a choice of corn or commercial duck pellets for the remainder of the experiment; diet No. 3 consisted of duck pellets, exclusively.

[b] See footnote [a] in Table 2.

[c] These birds were excluded from the mortality data.

Table 7. Mortality of ducks on each dose with respect to diet[a/]--Phase I.

	Diet No. 1			Diet No. 2			Diet No. 3			All diets combined		
Dose[b/]	Number of ducks	Number dead	Percent mortality	Number of ducks	Number dead	Percent mortality	Number of ducks	Number dead	Percent mortality	Number of ducks	Number dead	Percent mortality
Controls	20	0	0	20	0	0	20	0	0	60	0	0
1-0	20	0	0	19	0	0	20	0	0	59	0	0
3-0	20	0	0	20	0	0	20	0	0	60	0	0
5-0	20	0	0	20	0	0	20	0	0	60	0	0
All-0	60	0	0	59	0	0	60	0	0	179	0	0
1-41	19	0	0	20	0	0	20	0	0	59	0	0
3-41	20	0	0	20	0	0	20	0	0	60	0	0
5-41	20	0	0	20	0	0	20	0	0	60	0	0
All-41	59	0	0	60	0	0	60	0	0	179	0	0
1-45	19	0	0	20	0	0	20	0	0	59	0	0
3-45	20	0	0	20	0	0	20	0	0	60	0	0
5-45	20	0	0	20	0	0	20	0	0	60	0	0
All-45	59	0	0	60	0	0	60	0	0	179	0	0
1-58	18	0	0	20	0	0	20	0	0	58	0	0
3-58	20	0	0	20	0	0	20	0	0	60	0	0
5-58	20	1	5 (17.0)[c/]	20	0	0	20	0	0	60	1	2 (17.0)
All-58	58	1	2 (17.0)	60	0	0	60	0	0	178	1	1 (17.0)
1-64	18	0	0	20	1	5 (13.0)	20	0	0	58	1	2 (13.0)
3-64	20	1	5 (5.0)	20	0	0	20	0	0	60	1	2 (5.0)
5-64	20	3	15 (9.7)	20	0	0	20	0	0	60	3	5 (9.7)
All-64	58	4	7 (8.5)	60	1	2 (13.0)	60	0	0	178	5	3 (9.4)
1-100	20	0	0	20	0	0	20	0	0	60	0	0
3-100	20	2	10 (12.5)	20	0	0	20	0	0	60	2	3 (12.5)
5-100	20	4	20 (15.5)	20	1	5 (22.0)	19	0	0	59	5	8 (16.8)
All-100	60	6	10 (14.5)	60	1	2 (22.0)	59	0	0	179	7	4 (15.6)

a/ See footnote a/ in Table 6.

b/ See footnote a/ in Table 2.

c/ Numbers in parenthesis are mean survival days.

Table 8. Postmortem body weights of ducks that died of lead poisoning on each dose--Phase I.

Dose[a/]	Mean body weights at death[b/] (percent of initial wt)
1-0	(0)
3-0	(0)
5-0	(0)
All-0	(0)
1-41	(0)
3-41	(0)
5-41	(0)
All-41	(0)
1-45	(0)
3-45	(0)
5-45	(0)
All-45	(0)
1-58	(0)
3-58	(0)
5-58	71.7 (1)
All-58	71.7 (1)
1-64	78.8 (1)
3-64	99.0 (1)
5-64	83.5 (3)
All-64	85.7 (5)
1-100	(0)
3-100	84.2 (2)
5-100	62.4 (5)
All-100	68.6 (7)

[a/] See footnote [a/] in Table 2.

[b/] Numbers in parentheses indicate number of birds that died.

Table 9. Weights of testes and ovaries and diameters of largest ovarian follicles in ducks fed diet No. 1 (corn)--Phase I.

Dose[a]	Mean weight of testes (g)		Mean weight of ovaries (g)	Mean diameter of largest ovarian follicle (mm)
	Nonsurvivors	Survivors	Survivors	Survivors
Controls	(0)[b]	4.3 (10)	0.9 (10)	4.3 (10)
1-0	(0)	2.0 (10)	1.6 (10)	6.0 (10)
3-0	(0)	2.5 (10)	1.3 (10)	5.1 (10)
5-0	(0)	1.9 (10)	1.2 (9)	4.3 (9)
All-0	(0)	2.1 (30)	1.4 (29)	5.2 (29)
1-41	(0)	3.0 (9)	1.3 (9)	4.8 (9)
3-41	(0)	1.2 (10)	1.2 (10)	4.9 (10)
5-41	(0)	3.6 (10)	0.8 (10)	3.6 (10)
All-41	(0)	2.6 (29)	1.1 (29)	4.4 (29)
1-45	(0)	2.9 (9)	1.1 (10)	5.8 (10)
3-45	(0)	3.9 (10)	3.0 (10)	5.8 (10)
5-45	(0)	2.8 (10)	0.9 (9)	3.9 (9)
All-45	(0)	3.2 (29)	1.7 (29)	5.2 (29)
1-58	(0)	1.6 (9)	0.6 (9)	3.9 (9)
3-58	(0)	2.9 (10)	1.0 (10)	4.5 (10)
5-58	(0)	2.9 (8)	1.0 (9)	5.2 (9)
All-58	(0)	2.4 (27)	0.9 (28)	4.5 (28)
1-64	(0)	2.3 (8)	1.6 (10)	5.8 (10)
3-64	(0)	2.6 (9)	2.1 (10)	5.8 (10)
5-64	3.8 (2)	4.0 (7)	0.8 (10)	4.4 (9)
All-64	3.8 (2)	2.9 (24)	1.5 (30)	5.4 (29)
1-100	(0)	2.5 (10)	2.6 (10)	6.1 (10)
3-100	7.1 (1)	4.4 (8)	0.6 (10)	3.2 (10)
5-100	5.9 (2)	2.7 (6)	0.7 (10)	3.9 (10)
All-100	6.3 (3)	3.2 (24)	1.3 (30)	4.4 (30)

[a] See footnote [a] in Table 2.

[b] Numbers in parentheses indicate sample size.

Table 10. Mean weights of the thyroids of controls and of ducks dosed with commercial steel shot, on No. 1 (corn)--Phase 1.

Dose[a]	Mean weight of thyroids (mg) Males	N	Females	N
0	58.70ab[b]	10	59.63c	9
1-0	56.11a	10	58.86c	9
3-0	55.16a	10	70.29c	10
5-0	44.44b	10	52.55c	8

[a] See footnote [a] in Table 2.

[b] Means not underlined by the same line are significantly different ($P < 0.05$). Means in columns followed by different letters are significantly different ($P < 0.05$) from each other.

Table 11. Number of shot recovered at necropsy from the gizzards of ducks fed diet No. 1 (corn)--Phase I.

Dose[a/]	Nonsurvivors Mean	Nonsurvivors Percent retention	Survivors Mean	Survivors Percent retention
1-0			0.8 (20)[b/]	80.0a[c/]
3-0			2.6 (19)	86.0a
5-0			4.8 (19)	96.8a
All-0			2.7 (58)	91.4A
1-41			0.0 (18)	0.0b
3-41			0.3 (20)	10.0b
5-41			0.2 (20)	3.0b
All-41			0.2 (58)	5.0B
1-45			0.3 (19)	26.3b
3-45			1.0 (20)	35.0b
5-45			1.1 (19)	22.1b
All-45			0.8 (58)	27.0B
1-58			0.1 (18)	11.1b
3-58			0.2 (20)	5.0b
5-58	3.0 (1)	60.0	0.3 (19)	5.3b
All-58	3.0 (1)		0.2 (57)	5.8B
1-64			0.0 (18)	0.0b
3-64	0.0 (1)	0.0	0.1 (19)	1.8b
5-64	4.3 (3)	86.0	0.1 (17)	1.2b
All-64	3.2 (4)		0.1 (54)	1.2B
1-100			0.0 (20)	0.0b
3-100	2.0 (2)	66.7	0.2 (18)	5.6b
5-100	4.0 (4)	80.0	0.1 (16)	2.5b
All-100	3.3 (6)		0.1 (54)	3.2B
All drakes			0.8 (164)	27.2
All hens			0.6 (175)	19.0

a/ See footnote a/ in Table 2.

b/ Numbers in parentheses indicate sample size.

c/ Means followed by the same lower case letter are not significantly different ($P > 0.05$). Means followed by different capital letters are highly significantly different ($P < 0.001$).

Table 12. Rate of erosion of lead pellets and percentage mortality 60 days after dosing ducks on a diet of corn--one group in a pen with a wire bottom and one group on soil. Ducks dosed 1 July 1975--Phase II.

Band number	Wt of 5 No. 4 commercial lead pellets (mg)	Number of Pellets at death	Wt of pellets at death (mg)	Percent decline in wt of pellets	Number of days to death[a]	Percent decline in wt of pellets/day[b]	Percent mortality 60 days after dosing
			NO SOIL AVAILABLE				
1207	1,057.5	5	740.4	30.0	9	3.3	
1209	1,016.7	3	283.2	53.6	26	2.1	
1238	1,034.3	4	534.6	35.4	26	1.4	
1239	1,043.7	0	-----	----	61	---	
1240	1,086.0	5	524.6	51.7	17	3.0	
1264	1,035.4	3	475.6	23.4	26	0.9	
1292	1,029.8	5	776.6	24.6	22	1.1	
1293	1,057.5	5	741.3	29.9	1.5	19.9	
1297	1,070.7	4	537.0	37.3	16	2.3	
Mean		3.78a		35.7c	22.6d 17.9[c]	4.25e	88.9f
			ON SOIL				
1202	1,024.9	1	99.8	51.3	26	2.0	
1208	1,017.3	1	11.6	94.3	61	1.5	
1231	1,048.9	0	-----	----	61	---	
1234	1,046.7	5	373.4	64.3	12	5.4	
1235	1,065.2	5	882.9	17.1	1.5	11.5	
1237	1,063.3	1	57.5	73.0	33	2.2	
1263	1,063.0	0	-----	----	61	---	
1266	1,071.9	0	-----	----	61	---	
1268	1,056.8	2	12.1	97.1	61	1.6	
1291	1,004.6	0	-----	----	61	---	
1298	1,058.1	5	811.3	23.3	8	2.9	
Mean		1.82b		60.1c	40.0d 28.9[c]	3.87e	45.4g

Note: All ducks were McGraw mallards, all corn was from Nilo, and all ducks were housed at Nilo from treatment until 23 July when the survivors were moved to Urbana, Illinois. All ducks were males. The diet was changed to corn and pellets on 8 August 1975. See Tables 13 and 14 for additional data on these ducks.

[a] All surviving ducks were killed 31 August 1975, but mean numbers of days to death were calculated on the basis of 60 days maximum survival.

Table 12 - continued.

Table 12. Continued - page 2.

b/ Percent decline in weight of pellets based on 61 days for ducks that survived to the end of the experiment.

c/ Ducks with one or more pellets in their gizzards at death.

Note: Means in vertical columns not followed by the same letter are significantly different from each other ($P < 0.05$).

Table 13. Body weights of male mallards dosed with five No. 4 commercial lead pellets on 1 July 1975--corn diet--Phase II.

Band number	Body weight (g) 25 June	10 July	16 July	24 July	30 July	6 Aug.	18 Aug.	31 Aug.	At death	Date of death
					NO SOIL AVAILABLE					
1207	1130	790							790	10 J[a]
1209	1180	960	800	710					540	27 J
1238	1260	910	790	730					550	27 J
1239	1340	950	960	1030	1100	1140	1380	1160	1160	31 A[b]
1240	1180	840	730						680	18 J
1264	1260	940	810	730					530	27 J
1292	1250	850	720	630					580	23 J
1293	1340								1010	3 J
1297	1180	800	630						580	17 J
Mean	1235.6	880.0	777.1	766.0					657.5[c]	
Percent change[d]		-28.0	-37.2	-39.3	-17.9	-14.9	+3.0	-13.4	-46.3[c]	
					ON SOIL					
1202	1270	840	740	640					500	27 J
1208	1500	930	820	800	800	820	1250	1300	1300	31 A[b]
1231	1220	1010	930	940	910	940	1230	1260	1260	31 A[b]
1234	1300	970							830	13 J
1235	1360								1020	3 J
1237	1400	1050	950	850	710				550	3 A
1263	1580	1150	970	950	880	840	1410	1420	1420	31 A[b]
1266	1410	930	810	790	800	800	1260	1350	1350	31 A[b]
1268	1240	930	820	780	690	670	1130	1170	1170	31 A[b]
1291	1490	1310	1300	1290	1180	1140	1390	1440	1440	31 A[b]
1233	1360								930	9 J
Mean	1375.4	1013.3	917.5	880.0	852.8	868.3	1278.3	1323.3	766.0[c]	
Percent change[d]		-26.4	-33.8	-36.6	-39.3	-38.3	-9.1	-5.9	-42.8[c]	

Survivors were placed on a diet of corn plus game bird pellets on 7 August. See Tables 12 and 14 for additional data on these ducks.

[a] J = July, A = August.

[b] The surviving ducks were killed on 31 August.

[c] Mean of ducks that died prior to 31 August.

[d] Comparisons were based on the initial weights of only those ducks surviving on the date the comparison was made.

Note: There were no significant differences ($P > 0.05$) between ducks on soil and ducks with no soil available for the percentage change in body weight at 9, 15, and 23 days after dosing; for body weight at death for ducks that died during the experiment; or for percent body weight lost per day for ducks that died during the experiment.

Table 14. PCV's of male mallards dosed with five No. 4 commercial lead pellets on 1 July 1975--corn diet--Phase II.

Band number	PCV 25 June	10 July	16 July	22 July	30 July	6 Aug.	18 Aug.	31 Aug.
NO SOIL AVAILABLE								
1207	44							
1209	46	22	17	10				
1238	42	14	23	27				
1239	45	29	35	37	40	42	42	45
1240	43	26	21					
1264	39	17	27	27				
1292	49	11	19	25				
1293	38							
1297	39	17	17					
Mean	42.8	19.4	22.7	25.2				
Percent change[a/]		-54.9a	-47.2c	-42.1e	-11.1	-6.7	-6.7	0.0
ON SOIL								
1202	44	21	31	30				
1208	43	23	27	31	32	32	40	42
1231	40	25	32	35	37	40	46	45
1234	40	27						
1235	40							
1237	39	19	19	23	26			
1263	40	27	27	29	26	21	45	47
1266	44	25	30	33	35	38	45	47
1268	41	21	28	33	33	28	48	49
1291	46	33	39	38	42	45	47	44
1298	41							
Mean	41.6	24.6	29.1	31.5	33.0	34.0	45.2	45.7
Percent change[a/]		-41.4b	-31.2d	-25.3e	-21.2	-19.7	+6.7	+7.9

Survivors were placed on a diet of corn plus game bird pellets on 7 August. See Tables 12 and 13 for additional data on these ducks.

[a/] Comparisons were based on the initial values of only those ducks surviving on the date the comparison was made.

Note: Means in vertical columns followed by different letters are significantly different ($P < 0.05$).

Table 15. Rate of erosion of lead pellets and percent mortality 60 days after dosing of two strains of birds on corn from two sources--Phase II.

Band number	Strain of duck[a/]	Source of corn	Wt of 5 No. 4 commercial lead pellets dosed 1 July 1975 (mg)	Number of pellets at death	Wt of pellets at death (mg)	Percent decline in wt of pellets at death	Number of days to death	Percent decline in wt of pellets per day	Percent mortality 60 days after dosing	Percent mortality 14 days after dosing
1201	MM	Nilo	1,054.7	5	942.7	10.6	13	0.8		
1203	MM	Nilo	990.1	5	430.0	56.6	32	1.8		
1204	MM	Nilo	1,045.4	2	214.7	48.6	23	2.1		
1205	MM	Nilo	1,044.8	5	622.3	40.4	7	5.8		
1270	MM	Nilo	1,048.7	5	676.0	35.5	22	1.6		
Mean			1,036.7	4.4		38.3	19.4	2.4	100.0	40.0
2712	WWM	Nilo	1,036.4	5	871.5	15.9	7	2.3		
2713	WWM	Nilo	1,036.8	5	859.7	17.1	6	2.8		
2714	WWM	Nilo	1,018.1	4	698.4	14.2	22	0.6		
2783	WWM	Nilo	997.2	4	456.1	42.8	16	2.7		
2784	WWM	Nilo	991.0	5	867.2	12.5	7	1.8		
Mean			1,015.9	4.6		20.5	11.6	2.0	100.0	60.0
1236	MM	Havana	1,036.0	5	944.4	8.8	6	1.5		
1261	MM	Havana	983.9	5	606.4	38.4	18	2.1		
1265	MM	Havana	1,077.3	4	575.1	33.3	10	3.3		
1295	MM	Havana	1,079.5	5	880.7	18.4	5	3.7		
1296	MM	Havana	1,073.8	2	282.0	34.3	27	1.3		
Mean			1,050.1	4.2		26.6	13.2	2.4	100.0	60.0
2715	WWM	Havana	1,043.3	5	920.6	11.8	24	0.5		
2719	WWM	Havana	1,036.7	4	718.2	13.4	18	0.7		
2720	WWM	Havana	1,030.9	5	868.1	15.8	17	0.9		
2786	WWM	Havana	1,020.3	3	317.8	48.1	17	2.8		
2787	WWM	Havana	1,031.0	4	780.0	24.3	14	1.7		
Mean			1,032.4	4.2		22.7	18.0	1.3	100.0	20.0

Table 15 - continued.

Table 15. Continued - page 2.

[a] MM = McGraw Mallard. WWM = Whistling Wings Mallard. All ducks were in pens with wire bottoms at Havana, Illinois, from dosing until 16 July when the survivors were moved to Urbana, Illinois. All males.

Note: There are no significant ($P > 0.05$) differences among the means listed in this table.

Table 16. Body weights and percentage change of body weight of surviving ducks 1, 2, 3, and 4 weeks after dosing and percentage change at death of two strains of ducks on a diet of corn from two sources--Phase II.

Band number	Strain of duck	Source of corn	Body weight (g) 1 July	8 July	15 July	24 July	30 July	At death	Date of death	Percent wt change at death
1201	MM	Nilo	1140	960				810	14 July	-28.9
1203	MM	Nilo	1330	1070	930	790	710	650	1 Aug	-51.1
1204	MM	Nilo	1090	920	680	540		540	24 July	-50.4
1205	MM	Nilo	1130	940				940	8 July	-16.8
1270	MM	Nilo	1120	920	760			550	23 July	-50.9
Percent change[a]				-17.1a	-33.3c	-45.5	-46.6	-39.6d		
2712	WWM	Nilo	950	740				740	8 July	-22.1
2713	WWM	Nilo	1100					890	7 July	-19.1
2714	WWM	Nilo	1070	920	780			530	23 July	-50.5
2783	WWM	Nilo	990	840	660			620	17 July	-37.4
2784	WWM	Nilo	920	690				690	8 July	-25.0
Percent change				-19.1ab	-30.2c			-30.8d		
1236	MM	Havana	1060					880	7 July	-17.0
1261	MM	Havana	1020	880	710			530	19 July	-48.0
1265	MM	Havana	1130	970				880	11 July	-22.1
1295	MM	Havana	1230					1070	6 July	-13.0
1296	MM	Havana	1110	940	820	680		500	28 July	-55.0
Percent change				-14.4b	-28.3c	-38.7		-31.0d		
2715	WWM	Havana	1040	860	750	610		490	25 July	-52.9
2719	WWM	Havana	1040	850	690			520	19 July	-50.0
2720	WWM	Havana	940	810	580			490	18 July	-47.9
2786	WWM	Havana	950	790	750			610	17 July	-35.8
2787	WWM	Havana	940	730	550			550	~~15 July~~	-41.5
Percent change				-17.7ab	-32.5c	-41.3		-45.6d		

[a] Compared with initial values of ducks surviving on the dates indicated. Ducks were dosed on 1 July with five commercial lead pellets each, and were held in wire pens at Havana, Illinois, until 16 July when the survivors were moved to Urbana, Illinois. All males.

Note: Means in the vertical columns followed by different letters are significantly ($P < 0.05$) different.

Table 17. PCV's and percentage change of PCV's of surviving ducks 30 days after dosing of two strains of ducks on a diet of corn from two sources--Phase II.

Band number	Strain of duck	Source of corn	PCV 1 July	PCV 8 July	PCV 15 July	PCV 24 July	PCV 30 July	Date of death
1201	MM	Nilo	42	20				14 July
1203	MM	Nilo	48	25	26	24	9	Alive
1204	MM	Nilo	37	31	27	18		24 July
1205	MM	Nilo	44					8 July
1270	MM	Nilo	35	14	30	22		23 July
Percent change[a/]				-44.1a	-29.0b	-46.2	-81.2	
2712	WWM	Nilo	46					8 July
2713	WWM	Nilo	49					7 July
2714	WWM	Nilo	55	25	37	26		23 July
2783	WWM	Nilo	43	29	23			17 July
2784	WWM	Nilo	50					8 July
Percent change				-43.6a	-42.1bc	-52.7		
1236	MM	Havana	42					7 July
1261	MM	Havana	36	17	26			19 July
1265	MM	Havana	39	17				11 July
1295	MM	Havana	44					6 July
1296	MM	Havana	41	15	23	31		28 July
Percent change				-57.3a	-35.8bc	-24.4		
2715	WWM	Havana	52	27	16	13		25 July
2719	WWM	Havana	49	20	24			19 July
2720	WWM	Havana	54	20	21			18 July
2786	WWM	Havana	46	23	26			17 July
2787	WWM	Havana	51	18				15 July
Percent change				-57.0a	-56.2c	-75.0		

[a/] Compared with initial values of ducks surviving on the dates indicated. Ducks were dosed on 1 July with five commercial lead pellets each, and were held in wire pens at Havana, Illinois, until 16 July when the survivors were moved to Urbana, Illinois. All males.

Note: Means in the vertical columns followed by different letters are significantly ($P < 0.05$) different.

Table 18. Mean weight of doses and amounts of lead and iron given to each group of ducks--Phase III.

Dose[a]	Mean weight of doses (mg)	±1 SD[b]	Calculated mean weight of Pb in dose (mg)[c]	Calculated mean weight of Fe in dose (mg)[c]
1-0	152.8	2.07	0.1	152.6
3-0	456.0	3.43	0.2	455.5
5-0	759.5	5.82	0.4	758.7
ALL-0	456.1		0.2	455.6
1-41	158.1	7.62	65.4	89.5
3-41	488.4	9.09	202.2	276.5
5-41	793.8	16.2	328.6	449.3
ALL-41	480.1		198.8	271.7
1-45	165.9	4.21	74.7	85.0
3-45	494.1	21.4	222.3	253.0
5-45	834.2	9.34	375.4	427.1
ALL-45	498.1		224.1	255.0
1-58	171.4	6.28	99.4	60.3
3-58	528.3	18.4	306.4	185.9
5-58	875.5	20.9	507.8	308.2
ALL-58	525.1		304.5	184.8
1-64	197.4	9.84	126.0	52.5
3-64	585.4	18.0	373.5	155.7
5-64	977.0	23.4	623.3	260.0
ALL-64	586.6		374.2	156.0
1-100	216.1	15.8	209.9	
3-100	641.8	26.6	623.2	
5-100	1072.1	34.6	1041.0	
ALL-100	643.3		624.7	

[a] See footnote [a] in Table 2.

[b] One standard deviation of the mean. Corresponding sample sizes were all 20.

[c] Mean Pb and Fe values used for these calculations are given in Table 1.

Table 19. Number of ducks eliminated from the various doses because of altered doses[a/] or bacterial infection--Phase III.

Dose[b/]	Nonsurvivors			Survivors			All ducks		
	Drakes	Hens	Sexes combined	Drakes	Hens	Sexes combined	Drakes	Hens	Sexes combined
Control	1	2[c/]	3	1	1	2	2	3	5
1-0	0	1	1	2	2	4	2	3	5
3-0	0	0	0	1	4	5	1	4	5
5-0	0	0	0	1	1	2	1	1	2
1-41	0	0	0	0	0	0	0	0	0
3-41	0	0	0	0	1	1	0	1	1
5-41	0	0	0	0	1	1	0	1	1
1-45	0	1	1	1	0	1	1	1	2
3-45	1	0	1	1	2	3	2	2	4
5-45	2	1	3	0	1	1	2	2	4
1-58	0	0	0	1	0	1	1	0	1
3-58	1	1	2	1	0	1	2	1	3
5-58	0	1	1	0	0	0	0	1	1
1-64	1	0	1	0	2	2	1	2	3
3-64	0	0	0	0	0	0	0	0	0
5-64	0	0	0	0	0	0	0	0	0
1-100	0	1	1	2	2	4	2	3	5
3-100	1	0	1	0	0	0	1	0	1
5-100	0	0	0	0	0	0	0	0	0

a/ Ducks that ingested additional shot from the pens during the experiment.

b/ See footnote a/ in Table 2.

c/ One hen died with an *E. coli* septicemia.

Table 20. Number of shot recovered at necropsy from the gizzards of ducks on each dose--Phase III.

	Nonsurvivors		Survivors	
Dose[a]	Mean number	Percent retained	Mean number	Percent retained
1-0	(0)[b]		1.0 (15)	100
3-0	(0)		2.8 (15)	93.3
5-0	(0)		4.7 (18)	93.3
All-0	(0)		2.9 (48)	95.4
1-41	(0)		0.2 (20)	20.0
3-41	1.0 (1)	33.3	0.4 (18)	14.8
5-41	4.0 (2)	80.0	1.0 (17)	20.0
All-41	3.0 (3)	64.4	0.5 (55)	18.3
1-45	(0)		0.8 (18)	77.8
3-45	3.0 (1)	100	2.5 (15)	84.4
5-45	3.9 (8)	77.5	3.4 (8)	67.5
All-45	3.8 (9)	80.0	1.9 (41)	78.2
1-58	1.0 (1)	100	0.6 (18)	61.1
3-58	2.9 (10)	96.7	2.3 (7)	76.2
5-58	4.0 (16)	80.0	1.7 (3)	33.3
All-58	3.5 (27)	86.9	1.1 (28)	61.9
1-64	1.0 (3)	100	0.7 (14)	71.4
3-64	2.6 (17)	88.2	1.0 (3)	33.3
5-64	3.9 (17)	78.8	1.0 (3)	20.0
All-64	3.1 (37)	84.9	0.8 (20)	58.0
1-100	0.7 (12)	66.7	0.0 (3)	0.0
3-100	2.5 (17)	82.3	0.0 (2)	0.0
5-100	4.3 (20)	87.0	(0)	
All-100	2.8 (49)	80.4	0.0 (5)	0.0
All drakes	3.0 (63)		1.5(101)	
All hens	3.2 (62)		1.5 (96)	

[a] See footnote [a] in Table 2.

[b] Numbers in parentheses indicate sample size.

Table 21. The weights of shot eroded in the gizzards of ducks on each dose--Phase III.

Dose[a]	Mean amount eroded per shot (mg) Nonsurvivors	Survivors	Mean calculated amount of Pb eroded per shot (mg) Nonsurvivors	Survivors
1-0	(0)[b]	118.2 (15)		0.06
3-0	(0)	112.9 (15)		0.06
5-0	(0)	109.3 (18)		0.05
All-0	(0)	113.2 (48)		0.06
1-41	(0)	155.7 (20)		64.5
3-41	118.4 (1)	158.7 (18)	49.0	65.7
5-41	118.1 (2)	152.6 (17)	48.9	63.2
All-41	118.2 (3)	155.7 (55)	48.9	64.5
1-45	(0)	151.8 (18)		68.3
3-45	71.7 (1)	142.2 (15)	32.3	64.0
5-45	102.6 (8)	126.7 (8)	49.2	57.0
All-45	99.2 (9)	143.4 (41)	44.6	64.5
1-58	118.9 (1)	155.4 (18)	69.0	90.2
3-58	66.9 (10)	129.0 (7)	38.8	74.8
5-58	42.8 (16)	162.9 (3)	24.8	94.5
All-58	54.5 (27)	149.6 (28)	31.6	86.8
1-64	108.7 (3)	169.0 (14)	69.3	107.8
3-64	67.2 (17)	154.7 (3)	42.9	98.7
5-64	67.1 (17)	125.2 (3)	42.8	79.9
All-64	70.5 (37)	160.3 (20)	45.0	102.3
1-100	130.0 (12)	(0)	126.2	
3-100	83.4 (17)	(0)	81.0	
5-100	59.1 (20)	(0)	57.4	
All-100	84.9 (49)	(0)	82.4	

[a] See footnote [a] in Table 2.

[b] Numbers in parentheses indicate sample size.

Table 22. Mean erosion rates of shot in the gizzards of ducks on each dose--Phase III.

Dose[a]	Nonsurvivors mg/shot/day	Nonsurvivors Percent/shot/day	Survivors mg/shot/day	Survivors Percent/shot/day
1-0	(0)[b]		2.7 (15)	1.8
3-0	(0)		2.6 (15)	1.7
5-0	(0)		2.5 (18)	1.6
All-0	(0)		2.6 (48)	1.7
1-41	(0)		3.6 (20)	2.3
3-41	3.1 (1)	1.9	3.6 (18)	2.2
5-41	4.5 (2)	2.8	3.5 (17)	2.2
All-41	4.0 (3)	2.5	3.6 (55)	2.2
1-45	(0)		3.5 (18)	2.1
3-45	5.1 (1)	3.2	3.3 (15)	2.0
5-45	2.9 (8)	1.7	2.9 (8)	1.7
All-45	3.2 (9)	1.9	3.3 (41)	2.0
1-58	3.1 (1)	1.8	3.6 (18)	2.1
3-58	2.9 (10)	1.6	2.9 (7)	1.7
5-58	2.4 (16)	1.4	3.8 (3)	2.1
All-58	2.6 (27)	1.5	3.4 (28)	2.0
1-64	4.4 (3)	2.2	3.9 (14)	2.0
3-64	3.0 (17)	1.6	3.6 (3)	1.8
5-64	3.2 (17)	1.7	2.9 (3)	1.5
All-64	3.2 (37)	1.7	3.7 (20)	1.9
1-100	6.1 (12)	2.9	(0)	
3-100	5.0 (17)	2.3	(0)	
5-100	4.5 (20)	2.1	(0)	
All-100	5.0 (49)	2.4	(0)	
Total	3.8(125)	1.9	3.3(197)	2.0

[a] See footnote [a] in Table 2.

[b] Numbers in parentheses indicate the number of ducks that had shot in their gizzards at necropsy.

Table 23. Number of ducks that died on each dose--Phase III.

Dose[a/]	Drakes			Hens			Sexes combined		
	Number ducks	Number dead	Percent mortality	Number ducks	Number dead	Percent mortality	Number ducks	Number dead	Percent mortality
Controls	8	0	0	7	0	0	15	0	0
1-0	8	0	0	7	0	0	15	0	0
3-0	9	0	0	6	0	0	15	0	0
5-0	9	0	0	9	0	0	18	0	0
All-0	26	0	0	22	0	0	48	0	0
1-41	10	0	0	10	0	0	20	0	0
3-41	10	0	0	9	1	11	19	1	5
5-41	10	1	10	9	1	11	19	2	10
All-41	30	1	3	28	2	7	58	3	5
1-45	9	0	0	9	0	0	18	0	0
3-45	8	0	0	8	1	12	16	1	6
5-45	8	4	50	8	4	50	16	8	50
All-45	25	4	16	25	5	20	50	9	18
1-58	9	0	0	10	1	10	19	1	5
3-58	8	7	88	9	3	33	17	10	59
5-58	10	8	80	9	8	89	19	16	84
All-58	27	15	56	28	12	43	55	27	49
1-64	9	1	11	8	2	25	17	3	18
3-64	10	8	80	10	9	90	20	17	85
5-64	10	7	70	10	10	100	20	17	85
All-64	29	16	55	28	21	75	57	37	65
1-100	8	8	100	7	4	57	15	12	80
3-100	9	9	100	10	8	80	19	17	89
5-100	10	10	100	10	10	100	20	20	100
All-100	27	27	100	27	22	81	54	49	91
Total	164	63	38	158	62	39	322	125	39

a/ See footnote a/ in Table 2.

Table 24. The 95 percent binomial confidence limits[a] for the proportions of ducks that died, with respect to percentage of Pb in the shot--Phase III.

Dose[b]	Drakes	Hens	Sexes combined
Controls	0.0000-0.3694	0.0000-0.4096	0.0000-0.2180
All-0	0.0000-0.1157	0.0000-0.1195	0.0000-0.0604
All-41	0.0084-0.1723	0.0082-0.2209	0.0104-0.1394
All-45	0.0455-0.3610	0.0585-0.3579	0.0777-0.2880
All-58	0.3254-0.7055	0.2448-0.6281	0.3224-0.5878
All-64	0.3572-0.7355	0.5060-0.8527	0.5239-0.7726
All-100	0.7722-0.9915	0.5646-0.8971	0.7269-0.9263
Total	0.2939-0.4420	0.2705-0.4146	

[a] Calculations of confidence limits from Statistical Tables for Use with Binomial Samples (Mainland et al. 1956).

[b] See footnote [a] in Table 2.

Table 25. Survival time and median effective time to 50 percent mortality for ducks on each dose--Phase III.

	Drakes			Hens			Sexes combined		
Dose[a]	Mean survival time (days)	ET_{50}	95% confidence limits of ET_{50}	Mean survival time (days)	ET_{50}	95% confidence limits of ET_{50}	Mean survival time (days)	ET_{50}	95% confidence limits of ET_{50}
Controls	(0)[b]			(0)			(0)		
1-0	(0)			(0)			(0)		
3-0	(0)			(0)			(0)		
5-0	(0)			(0)			(0)		
1-41	(0)			(0)			(0)		
3-41	(0)			38.0 (11)			38.0 (5)		
5-41	20.0 (10)			35.0 (11)			27.5 (10)		
1-45	(0)			(0)			(0)		
3-45	(0)			14.0 (12)			14.0 (6)		
5-45	36.5 (50)	40.8	30.2-55.3	33.5 (50)	46.2	19.8-107	35.0 (50)	43.6	35.8-53.2
1-58	(0)			38.0 (10)			38.0 (5)		
3-58	23.1 (88)	23.2	17.7-30.4	26.7 (33)	53.2	1.2-2320	24.1 (59)	33.2	26.1-42.3
5-58	22.7 (80)	23.1	19.3-27.8	13.9 (89)	13.2	10.0-17.3	18.3 (84)	18.8	16.8-21.1
1-64	26.0 (11)			25.0 (25)			25.3 (18)		
3-64	26.2 (80)	26.7	24.1-29.6	20.3 (90)	18.4	14.5-23.3	23.1 (85)	23.5	21.5-25.7
5-64	22.7 (70)	26.6	17.3-40.9	20.5(100)	16.2	12.5-21.1	21.4 (85)	20.9	17.9-24.3
1-100	20.2(100)	20.1	15.8-25.6	22.7 (57)	32.6	12.4-85.4	21.1 (80)	25.1	21.5-29.3
3-100	17.3(100)	14.2	11.1-18.2	18.4 (80)	19.3	16.2-22.9	17.8 (89)	17.6	15.9-19.5
5-100	15.0(100)	14.1	12.4-16.0	11.5(100)	7.7	5.2-11.3	13.2(100)	11.4	10.0-13.0
Total	21.8 (38)			20.0 (39)					

[a] See footnote [a] in Table 2.

[b] Numbers in parentheses indicate percent mortality.

Table 26. Postdosing mean body weights (g) of ducks on each dose adjusted for the covariant of predosing weights--Phase III.

Dose[a/]	Postdosing time 1 week	3 weeks	6 weeks
Controls[b/]	1,028 (15)[c/]	989 (15)	952 (15)
1-0	987 (15) ab[d/]	971 (15) a	914 (15) a
3-0	1,000 (15) a	991 (15) a	937 (15) a
5-0	992 (18) ab	985 (18) a	939 (18) a
All-0	993 (48) x[d/]	982 (48) v	930 (48) x
1-41	998 (20) ab	930 (20) ab	869 (20) ab
3-41	1,006 (19) a	956 (19) a	879 (18) ab
5-41	1,003 (19) a	912 (18) abc	803 (17) ab
All-41	1,002 (58) x	933 (57) vw	852 (55) y
1-45	1,018 (18) a	976 (18) a	925 (18) a
3-45	986 (16) ab	902 (15) abc	836 (15) ab
5-45	1,003 (16) a	810 (16) bcd	765 (8) ab
All-45	1,003 (50) x	899 (49) wx	861 (41) y
1-58	1,004 (19) a	957 (19) ab	916 (18) a
3-58	947 (17) abcd	770 (13) cde	776 (7) ab
5-58	922 (17) bcde	739 (8) cde	817 (3) ab
All-58	959 (53) y	853 (40) x	876 (28) xy
1-64	967 (17) abc	861 (16) abcd	800 (14) ab
3-64	962 (20) abc	728 (15) de	744 (3) ab
5-64	906 (19) cde	693 (12) e	630 (4) b
All-64	945 (56) y	768 (43) y	760 (21) z
1-100	887 (15) de	686 (8) de	800 (3) ab
3-100	874 (19) e	686 (7) de	819 (2) ab
5-100	873 (14) de	624 (1) abcde	(0)
All-100	878 (48) z	682 (16) z	807 (5) xyz

[a/] See footnote [a/] in Table 2.

[b/] The controls were excluded from the statistical analyses in order to employ a factorial design, which incorporated the dose levels. The iron-dosed groups were considered the control groups because an initial analysis indicated that they did not differ significantly from the controls.

[c/] Numbers in parentheses indicate sample size.

[d/] Means in each column followed by a common letter were not significantly different ($P > 0.05$). Letters "a" through "f" were used for comparison of the groups dosed with different types of shot with respect to the individual dose levels; letters "v" through "z" were used for comparison of the groups dosed with the different types of shot with all dose levels combined.

Table 27. Final body weights[a/] of ducks that died and of ducks that survived on each dose--Phase III.

Dose[b/]	Nonsurvivors Mean	Survivors Mean	Survivors: Mean percent weight lost, Males	Survivors: Mean percent weight lost, Females
Controls	(0)[c/]	89 (15)	10.1 (8)	11.3 (7)
1-0	(0)	88 (15)		
3-0	(0)	90 (15)		
5-0	(0)	89 (18)	8.6 (9)	12.8 (9)
All-0	(0)	89 (48)		
1-41	(0)	81 (20)		
3-41	50 (1)	82 (18)		
5-41	54 (2)	75 (17)	23.4 (9)	26.3 (8)
All-41	53 (3)	80 (55)		
1-45	(0)	89 (18)		
3-45	79 (1)	80 (15)		
5-45	52 (8)	71 (8)	33.7 (4)	23.9 (4)
All-45	55 (9)	82 (41)		
1-58	49 (1)	87 (18)		
3-58	54 (10)	76 (7)		
5-58	61 (16)	76 (3)	18.2 (2)	22.1 (1)
All-58	58 (27)	84 (28)		
1-64	51 (3)	76 (14)		
3-64	59 (17)	70 (3)		
5-64	58 (17)	59 (3)	38.8 (3)	(0)
All-64	58 (37)	72 (20)		
1-100	50 (12)	79 (3)		
3-100	59 (17)	75 (2)		
5-100	64 (20)	(0)	(0)	(0)
All-100	59 (49)	77 (5)		

[a/] Weights are expressed as a percentage of the predosing weight.

[b/] See footnote [a/] in Table 2.

[c/] Numbers in parentheses indicate sample size.

Table 28. Postdosing mean packed cell volume (percent) of blood in ducks on each dose adjusted for the covariant of predosing values--Phase III.

Dose[a]	Postdosing time: 1 week	3 weeks	6 weeks
Controls[b]	42.6 (15)[c]	44.6 (15)	45.5 (15)
1-0	42.4 (15) a[d]	45.1 (15) a	45.9 (15) a
3-0	43.0 (15) a	45.7 (15) a	46.0 (15) a
5-0	42.5 (18) a	44.7 (18) a	45.4 (18) a
All-0	42.6 (48) x[d]	45.1 (48) w	45.7 (48) x
1-41	41.7 (20) a	42.3 (20) abc	43.8 (20) a
3-41	42.6 (19) a	39.7 (19) abc	41.9 (18) a
5-41	42.6 (19) a	37.4 (18) abcd	39.9 (17) a
All-41	42.3 (58) x	40.0 (57) x	42.0 (55) x
1-45	41.5 (18) a	43.2 (18) ab	44.4 (18) a
3-45	40.6 (16) ab	35.4 (15) abcde	40.4 (15) a
5-45	38.6 (16) ab	29.5 (16) bcde	36.5 (8) a
All-45	40.2 (50) x	36.3 (49) xy	41.4 (41) x
1-58	38.4 (19) ab	38.8 (19) abc	39.1 (18) a
3-58	32.3 (17) bcd	28.5 (13) cde	38.5 (7) a
5-58	28.6 (17) cde	26.6 (8) bcde	42.4 (3) a
All-58	33.3 (53) y	33.0 (40) y	41.9 (28) x
1-64	36.4 (17) abc	34.4 (16) abcde	40.8 (14) a
3-64	31.6 (20) bcd	23.2 (15) e	36.9 (3) a
5-64	23.6 (19) de	23.0 (12) de	32.6 (3) a
All-64	30.2 (56) y	27.4 (43) z	38.7 (20) x
1-100	23.6 (15) de	30.0 (8) abcde	44.2 (3) a
3-100	23.1 (19) de	29.3 (7) abcde	43.1 (2) a
5-100	21.3 (14) e	20.6 (1) abcde	(0)
All-100	22.6 (48) z	29.1 (16) yz	43.8 (5) x

[a] See footnote [a] in Table 2.

[b] See footnote [b] in Table 26.

[c] Numbers in parentheses indicate sample size.

[d] See footnote [d] in Table 26.

Table 29. Postdosing mean hemoglobin concentrations (mg %) in ducks on each dose--Phase III.

Dose[a]	Postdosing time: 1 week	3 weeks	6 weeks[b]
Controls[c]	13.0 (15)[d]	13.6 (15)	13.4 (15)
1-0	13.0 (15) ab[e]	14.0 (15) ab	13.0 (15) ab
3-0	13.3 (15) ab	14.3 (15) a	13.1 (15) ab
5-0	12.8 (18) ab	13.8 (18) ab	13.8 (18) a
All-0	13.0 (48) w[e]	14.0 (48) w	13.3 (48) x
1-41	12.9 (20) ab	12.4 (20) abc	12.8 (20) ab
3-41	13.3 (19) a	11.6 (19) abcd	11.7 (18) ab
5-41	12.9 (19) ab	10.6 (18) abcde	11.0 (17) ab
All-41	13.0 (58) w	11.6 (57) x	11.9 (55) y
1-45	12.1 (18) ab	12.9 (18) ab	12.5 (18) ab
3-45	11.9 (16) ab	9.5 (15) abcde	10.8 (15) ab
5-45	10.9 (16) abc	7.9 (16) cde	9.5 (8) b
All-45	11.6 (50) x	10.2 (49) xy	11.4 (41) yz
1-58	10.8 (19) abc	11.4 (19) abcd	12.0 (18) ab
3-58	8.1 (17) cde	7.1 (13) de	9.9 (7) ab
5-58	6.6 (17) def	6.8 (8) cde	11.4 (3) ab
All-58	8.6 (53) y	9.1 (40) yz	11.4 (28) yz
1-64	9.7 (17) bcd	9.5 (16) abcde	11.0 (14) ab
3-64	8.2 (20) cde	5.9 (15) e	10.0 (3) ab
5-64	5.2 (19) ef	5.8 (12) e	8.0 (3) b
All-64	7.6 (56) y	7.2 (43) z	10.2 (20) z
1-100	4.6 (15) ef	7.9 (8) bcde	12.5 (3) ab
3-100	4.4 (19) f	7.7 (7) bcde	12.4 (2) ab
5-100	3.7 (14) f	13.9 (1) abcd	(0)
All-100	4.2 (48) z	8.2 (16) yz	12.5 (5) xyz

[a] See footnote [a] in Table 2.

[b] Only the means for samples from 6 weeks were adjusted for initial hemoglobin concentrations because these were the only hemoglobin data for which that covariant was significant ($P < 0.05$).

[c] See footnote [b] in Table 26.

[d] Numbers in parentheses indicate sample size.

[e] See footnote [d] in Table 26.

Table 30. Frequency of gross symptoms in ducks that died with respect to the type of shot dosed--Phase III.

Gross symptom	Dose[a/]											
	All-41		All-45		All-58		All-64		All-Pb:Fe		All-100	
	Number	Percent[b/]	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Number dead	3		9		27		37		76		49	
Emaciation	2	67	9	100	22	81	31	84	64	84	36	73
Hydro-pericardium	2	67	5	55	9	33	21	57	37	49	29	59
Epicardial hemorrhages	1	33	0	0	2	7	5	13	8	10	10	20
Myocardial degeneration	1	33	0	0	0	0	1	3	2	3	6	12
Gall bladder distended with bile	2	67	9	100	26	96	32	86	69	91	46	94
Gizzard lining stained with bile	3	100	8	89	26	96	30	81	67	88	46	94
Degeneration of gizzard lining	2	67	3	33	16	59	20	54	41	54	37	75
Gizzard ditended with feed	0	0	5	55	8	30	9	24	22	29	2	4
Tissues generally pale (anemia)	0	0	2	22	7	26	5	13	14	18	12	24

a/ See footnote a/ in Table 2.

b/ Percent of ducks that died.

Table 31. The frequency of fatty degeneration in the livers of surviving ducks fed whole corn with respect to sex, type of shot, and dose--Phase III.

Dose[a/]	Phase I			Phase III		
	Drakes	Hens	Both sexes	Drakes	Hens	Both sexes
Controls	0 (10)[b/]	0 (10)	0 (20)	0 (8)	0 (7)	0 (15)
1-0	0 (10)	0 (10)	0 (20)	1 (8)	0 (7)	1 (15)
3-0	0 (10)	0 (9)	0 (19)	0 (9)	0 (6)	0 (15)
5-0	1 (10)	0 (9)	1 (19)	1 (9)	0 (9)	1 (18)
All-0	1 (30)	0 (28)	1 (58)	2 (26)	0 (22)	2 (48)
1-41	0 (9)	0 (9)	0 (18)	3 (10)	0 (10)	3 (20)
3-41	0 (10)	0 (10)	0 (20)	1 (10)	0 (8)	1 (18)
5-41	0 (10)	0 (10)	0 (20)	3 (9)	0 (8)	3 (17)
All-41	0 (29)	0 (29)	0 (58)	7 (29)	0 (26)	7 (55)
1-45	0 (9)	1 (10)	1 (19)	1 (9)	0 (9)	1 (18)
3-45	0 (10)	1 (10)	1 (20)	1 (8)	0 (7)	1 (15)
5-45	0 (10)	0 (9)	0 (19)	0 (4)	0 (4)	0 (8)
All-45	0 (29)	2 (29)	2 (58)	2 (21)	0 (20)	2 (41)
1-58	0 (9)	2 (9)	2 (18)	1 (9)	0 (9)	1 (18)
3-58	1 (10)	1 (10)	2 (20)	0 (1)	0 (6)	0 (7)
5-58	1 (9)	1 (10)	2 (19)	0 (2)	0 (1)	0 (3)
All-58	2 (28)	4 (29)	6 (57)	1 (12)	0 (16)	1 (28)
1-64	0 (8)	0 (10)	0 (18)	0 (8)	0 (6)	0 (14)
3-64	0 (9)	1 (10)	1 (19)	0 (2)	0 (1)	0 (3)
5-64	0 (7)	2 (10)	2 (17)	0 (3)	(0)	0 (3)
All-64	0 (24)	3 (30)	3 (54)	0 (13)	0 (7)	0 (20)
1-100	0 (10)	0 (10)	0 (20)	(0)	0 (3)	0 (3)
3-100	0 (8)	0 (10)	0 (18)	(0)	0 (2)	0 (2)
5-100	0 (6)	0 (10)	0 (16)	(0)	(0)	(5)
All-100	0 (24)	0 (30)	0 (54)	(0)	0 (0)	0 (0)
Total	3(174)	9(185)	12(359)	12(109)	0(103)	12(212)

[a/] See footnote [a/] in Table 2.

[b/] Numbers in parentheses indicate sample size.

Table 32. Mean liver weights (g) of ducks on each dose--Phase III.

Dose[a]	Nonsurvivors			Survivors		
	Drakes	Hens	Sexes combined	Drakes	Hens	Sexes combined
Controls[b]	(0)[c]	(0)	(0)	22.1 (8)	15.2 (7)	18.9 (15)
1-0	(0)	(0)	(0)	19.0 (8)	20.1 (7)	19.5 (15)
3-0	(0)	(0)	(0)	21.6 (9)	15.2 (6)	19.0 (15)
5-0	(0)	(0)	(0)	22.5 (9)	18.1 (9)	20.3 (18)
All-0			(0)	21.1 (26)b[c]	17.9 (22)a	19.7 (48)a
1-41	(0)	(0)	(0)	34.0 (10)	15.0 (10)	24.5 (20)
3-41	(0)	6.8 (1)	6.8 (1)	29.0 (10)	15.5 (8)	23.0 (18)
5-41	14.6 (1)	7.5 (1)	11.0 (2)	32.7 (9)	20.5 (8)	27.0 (17)
All-41			9.6 (3)a[d]	31.8 (29)a	16.9 (26)a	24.8 (55)a
1-45	(0)	(0)	(0)	23.2 (9)	17.7 (9)	20.4 (18)
3-45	(0)	24.2 (1)	24.2 (1)	20.3 (8)	19.7 (7)	20.0 (15)
5-45	8.6 (4)	7.4 (4)	8.0 (8)	18.2 (4)	22.6 (4)	20.4 (8)
All-45			10.9 (9)a	21.1 (21)b	19.4 (20)a	20.3 (41)a
1-58	(0)	8.9 (1)	8.9 (1)	24.9 (9)	19.7 (9)	22.1 (18)
3-58	12.0 (7)	12.3 (3)	12.1 (10)	16.3 (1)	19.4 (6)	18.9 (7)
5-58	11.5 (8)	20.5 (8)	16.0 (16)	22.2 (2)	19.8 (1)	21.4 (3)
All-58			14.3 (27)a	23.6 (12)b	19.6 (16)a	21.2 (28)a
1-64	13.1 (1)	20.1 (2)	11.1 (3)	18.0 (8)	17.8 (6)	17.9 (14)
3-64	9.7 (8)	16.8 (9)	13.4 (17)	17.2 (2)	16.6 (1)	17.0 (3)
5-64	16.5 (7)	16.0 (10)	16.2 (17)	16.4 (3)	(0)	16.4 (3)
All-64			14.5 (37)a	17.5 (13)b	17.6 (7)a	17.5 (20)a
1-100	10.3 (8)	8.3 (4)	9.6 (12)	(0)	17.4 (3)	17.4 (3)
3-100	17.9 (9)	16.3 (8)	17.1 (17)	(0)	25.5 (2)	25.5 (2)
5-100	13.7 (10)	20.6 (7)	17.1 (17)	(0)	(0)	(0)
All-100			15.3 (46)a	(0)	20.7 (5)a	20.7 (5)a
Total			14.4(122)			21.1(212)

[a] See footnote [a] in Table 2.

[b] The controls were not included in the statistical analyses.

[c] Numbers in parentheses indicate sample size.

[d] Means followed by the same letter were not significantly different ($P > 0.05$).

Table 33. Weights of testes of drakes in each group--Phase III.

Dose[a]	Nonsurvivors	Survivors
Controls	(0)[b]	3.7 (8)
1-0	(0)	4.9 (8)
3-0	(0)	3.1 (9)
5-0	(0)	6.7 (9)
All-0	(0)	4.9 (26)
1-41	(0)	4.7 (10)
3-41	(0)	3.3 (9)
5-41	2.1 (1)	1.4 (9)
All-41	2.1 (1)	3.2 (28)
1-45	(0)	4.8 (9)
3-45	(0)	1.9 (8)
5-45	0.5 (4)	0.9 (4)
All-45	0.5 (4)	3.0 (21)
1-58	(0)	3.6 (8)
3-58	0.7 (7)	1.5 (1)
5-58	0.9 (8)	1.1 (2)
All-58	0.8 (15)	3.0 (11)
1-64	0.9 (1)	2.2 (8)
3-64	1.1 (8)	0.8 (2)
5-64	1.0 (7)	0.9 (3)
All-64	1.1 (16)	1.7 (13)
1-100	0.8 (8)	(0)
3-100	1.9 (9)	(0)
5-100	1.3 (10)	(0)
All-100	1.3 (27)	(0)

[a] See footnote [a] in Table 2

[b] Numbers in parentheses indicate sample size.

Table 34. Diameters of largest ovarian follicles in hens that died and weights of ovaries of hens that survived in each group--Phase III.

Dose[a]	Nonsurvivors Mean diameter of largest follicle (cm)	Survivors Mean weight of ovary (g)
Controls	(0)[b]	0.30 (7)
1-0	(0)	0.24 (7)
3-0	(0)	0.30 (6)
5-0	(0)	0.31 (9)
All-0	(0)	0.29 (22)
1-41	(0)	0.26 (10)
3-41	0.2 (1)	0.27 (8)
5-41	0.1 (1)	0.34 (8)
All-41	0.1 (2)	0.29 (26)
1-45	(0)	0.26 (9)
3-45	0.3 (1)	0.24 (7)
5-45	0.1 (4)	0.22 (4)
All-45	0.1 (5)	0.24 (20)
1-58	0.1 (1)	0.26 (9)
3-58	0.2 (3)	0.28 (6)
5-58	0.2 (7)	0.20 (1)
All-58	0.2 (11)	0.26 (16)
1-64	0.2 (2)	0.20 (6)
3-64	0.1 (9)	0.20 (1)
5-64	0.2 (10)	(0)
All-64	0.2 (21)	0.20 (7)
1-100	0.1 (4)	0.23 (3)
3-100	0.1 (8)	0.20 (2)
5-100	0.2 (7)	(0)
All-100	0.1 (19)	0.22 (5)

[a] See footnote [a] in Table 2.

[b] Numbers in parentheses indicate sample size.

Table 35. Thyroid weights (mg) of controls and of ducks dosed with iron shot--Phase III.

Dose[a]	Drakes $\bar{X} \pm 1$ SD	Hens $\bar{X} \pm 1$ SD	Both sexes $\bar{X} \pm 1$ SD
Controls	67.7 12.4 (8)[b]	72.9 14.5 (7)	70.1 13.2 (15)
1-0	80.9 24.6 (7)	58.4 13.8 (6)	70.5 22.8 (13)
3-0	100.7 56.5 (9)	68.5 19.2 (6)	87.8 47.2 (15)
5-0	73.9 20.0 (9)	67.4 12.4 (7)	71.1 16.9 (16)

a/ See footnote a/ in Table 2.

b/ Numbers in parentheses indicate sample size.

Table 36. Comparison of the erosion rates of commercial lead shot at various intervals after dosing with one group of ducks on wire and one with access to soil. All ducks dosed with five pellets on 24 July 1975 and fed a diet of corn--Urbana, Illinois--Phase IV.

Band Number	Body wt (g) At Dosing	Body wt (g) Hours after Dosing	Percent wt lost	PCV (%) At Dosing	PCV (%) Hours after Dosing	Percent PCV change	Wt of shot dosed	Wt of shot at death	Percent wt of shot eroded	Wt of liver (g)
				ON WIRE						
		12			12					
1307-M[a/]	1180	1170	0.8	38	40	+5.3	1084.8	1049.6	3.2	20.42
1366-M	1400	1120	20.0	39	41	+5.1	1066.3	1032.2	3.2	24.81
2302-F	870	850	2.3	46	46	0.0	1068.7	1012.1	5.3	16.20
2309-F	1080	1050	2.8	41	44	+7.3	1076.7	1045.4	2.9	21.74
Mean			6.5a			+4.4g			3.6m	
		24			24					
1304-M	1180	1130	4.2	42	41	-2.4	1114.8	1006.7	9.7	18.13
1363-M	1400	1370	2.1	41	41	0.0	1028.7	933.5	9.2	25.02
2310-F	980	950	3.1	42	42	0.0	1097.4	1060.6	3.4	18.32
2349-F	910	870	4.4	41	40	-2.4	1105.3	1059.9	4.1	16.77
Mean			3.4b			-1.2i			6.6n	
		36			36					
1196-M	1210	1160	4.1	44	44	0.0	1044.5	978.6	6.3	28.86
1324-M	1040	1030	1.0	45	46	+2.2	1072.5	703.9	34.4	31.75
2279-F	1010	940	6.9	39	33	-15.4	1086.3	1047.5	3.6	21.60
2321-F	1140	1050	7.9	43	41	-4.6	1035.5	987.3	4.6	27.92
Mean			5.0c			-4.4j			12.2o	
		48			48					
1262-M	1110	1050	5.4	37	30	-18.9	1011.4	806.9	20.2	25.52
1407-M	1180	1080	8.5	44	42	-4.5	1098.8	758.0[b/]	13.8	17.71
2293-F	950	880	7.4	41	34	-17.1	1047.8	932.3	11.0	21.11
2332-F	1030	950	7.8	41	33	-19.5	1074.8	937.9	12.7	23.42
Mean			7.3d			-15.0k			14.4p	
		168			168					
1244-M	1240	950[c/]	23.4	47	--[c/]	--	1030.4	630.8[c/]	38.8	41.74
1271-M	1080	930	23.1	45	14	-68.9	1058.8	821.6	22.4	27.53
2246-F	1060	840	20.8	42	22	-47.6	1126.9	1029.6	8.6	20.25
2338-F	910	740[d/]	18.7	44	--[d/]	--	1070.7	919.4[d/]	14.1	25.55
Mean			21.5e			-58.2 1			21.0q	

Table 36 - continued.

Table 36. Continued - page 2.

ON SOIL

		12			12					
1302-M	1050	1040	1.0	46	43	-6.5	1053.6	1025.7	2.6	18.03
1308-M	1500	1150	23.3	45	46	+2.2	1125.1	1051.7	6.5	25.70
2238-F	820	780	4.8	43	42	-2.3	1072.1	1035.3	3.4	12.16
2307-F	1130	1100	2.6	43	42	-2.3	1059.4	997.4	5.8	24.81
Mean			7.9a			-2.2h			4.6m	
		24			24					
1224-M	1280	1250	2.3	40	39	-2.5	1075.4	1004.0	6.6	29.43
1319-M	1020	1010	1.0	50	44	-12.0	1070.6	1007.5	5.9	15.72
2239-F	1040	980	5.8	43	43	0.0	1096.5	960.7	12.4	18.13
2320-F	1060	1010	4.7	39	40	+2.6	1118.2	755.2	32.5	22.20
Mean			3.4b			-3.0i			14.4n	
		36			36					
1343-M	1210	1190	1.6	52	50	-3.8	1095.7	779.3	28.9	26.14
1352-M	1130	1060	6.2	44	41	-6.8	1040.0	858.4	17.5	30.57
2191-F	890	820	7.9	39	37	-5.1	1057.9	868.2	17.9	19.46
2205-F	1000	960	4.0	46	46	0.0	1102.2	775.3	29.6	17.03
Mean			4.9c			-3.9j			23.5o	
		48			48					
1284-M	1210	1150	5.0	43	41	-2.3	1082.0	673.1	37.8	22.55
1345-M	1070	960	10.3	39	39	0.0	1028.8	923.2	10.3	16.76
2234-F	1030	950	7.8	41	38	-7.3	1075.7	930.6	13.5	22.03
2255-F	960	900	6.2	40	29	-27.5	1077.5	849.2	21.2	26.20
Mean			7.3d			-9.3k			20.7p	
		168			168					
1227-M	1260	1000	20.6	44	16	-63.6	1078.8	576.4	46.6	24.39
1199-M	1120	950	15.2	42	22	-47.6	1087.4	280.5	74.2	23.38
2224-F	1000	860 e/	14.0	38	-- e/	--	1071.8	457.6 e/	57.3	31.75
2270-F	1150	960	16.5	40	37	-7.5	1086.2	73.7 f/	66.1	27.29
Mean			16.6f			-39.6 1			61.0r	

a/ M = male, F = female.

b/ Four shot in gizzard.

c/ Died 144 hours after dosing.

d/ Died 108 hours after dosing.

e/ Died 132 hours after dosing.

f/ One shot in gizzard.

Note: Mean values for the same time periods that are followed by the same letter are not significantly different ($P > 0.05$).

Table 37. Rate of erosion of five No. 4 commercial lead pellets dosed in female mallards on 11 August 1975--corn diet--comparison of ducks with and without soil available in the pen--Phase V.

Band number	Pen number	Weight of pellets dosed (mg)	Weight of pellets recovered (mg)	Number of pellets recovered	Percent wt of pellets eroded	Number of days to death	Percent wt of pellets eroded per day
			NO SOIL AVAILABLE				
2259	6	1059.6	820.7	5	22.5	6	3.8
2298	6	1078.2	965.0	5	10.5	5	2.1
2327	6	1065.4	962.0	5	9.7	6	1.9
2330	6	1046.2	760.7	5	27.3	5	5.4
2362	6	1049.8	935.7	5	10.9	5	2.2
2372	6	1091.8	947.8	5	13.2	5	2.6
1585	6	1011.9	855.0	5	15.5	7[a]	2.2
2194	6	1129.0	632.6	5	44.0	7[a]	8.8
2212	6	1092.8	749.0	5	31.5	7[a]	6.3
2353	6	1099.0	742.3	4	32.4	7[a]	4.6
$\bar{x}$[b]				4.8	30.8a	6.0f	4.0k
			ON SOIL				
2370	3	1085.2	565.1	4	34.9	5	7.0
2199	3	1042.1	289.8	5	72.2	7[a]	10.3
2200	3	1077.2	338.6	3	47.6	7[a]	6.8
2222	3	1066.9	-----	0	----	7[a]	---
2230	3	1068.0	526.6	5	50.7	7[a]	7.2
2286	3	1079.3	111.8	2	74.1	7[a]	10.6
2300	3	1070.8	463.8	5	56.7	7[a]	8.1
2303	3	1066.2	514.0	5	51.8	7[a]	7.4
2339	3	1077.6	621.4	4	27.9	7[a]	4.0
2377	3	1090.2	676.2	5	38.0	7[a]	5.4
$\bar{x}$				3.8	52.4b	6.8g	7.4 l
			NO SOIL AVAILABLE				
2210	9	1050.3	806.8	5	23.2	4	5.8
2237	9	1059.6	894.6	5	15.6	4	3.9
2308	9	1063.8	810.7	5	23.8	4	5.9
2266	9	1049.0	758.8	5	27.7	14[a]	2.0
2271	9	1096.6	894.4	5	18.4	14[a]	1.3
2278	9	1031.5	239.2	2	42.0	14[a]	3.0
2289	9	1069.8	172.1	1	19.3	14[a]	1.4
2358	9	1060.5	842.1	5	20.6	14[a]	1.5
2361	9	1096.1	949.6	5	13.4	7	1.9
2371	9	1027.6	571.0	4	44.4	11	4.0
$\bar{x}$				3.6	25.6c	10.0h	3.1m

Table 37 - continued.

Table 37. Continued - page 2.

Band number	Pen number	Weight of pellets dosed (mg)	Weight of pellets recovered	Number of pellets recovered	Percent wt of pellets eroded	Number of days to death	Percent wt of pellets lost per day
				ON SOIL			
2208	4	1064.9	-----	0	----	14[a]	---
2242	4	1091.0	56.2	2	87.1	14[a]	6.2
2252	4	1037.8	617.4	5	40.5	14[a]	2.9
2257	4	1096.8	403.4	3	38.7	14[a]	2.8
2272	4	1078.5	894.3	5	17.1	13	1.3
2274	4	1084.5	199.4	5	81.6	14[a]	5.8
2305	4	1038.1	-----	0	----	14[a]	---
2322	4	1073.6	138.2	5	87.1	14[a]	6.2
2335	4	1150.8	-----	0	----	14[a]	---
2368	4	1066.1	211.8	2	50.3	14[a]	3.6
$\bar{X}$				2.4	64.2d	13.9i	4.1m
				NO SOIL AVAILABLE			
2260	10	1053.1	174.6	1	17.1	12	1.4
2265	10	1096.6	908.4	5	17.2	15	1.1
2284	10	1125.7	105.8	2	76.5	21[a]	3.6
2288	10	1051.2	489.0	5	53.5	17	3.1
2312	10	1063.0	830.9	5	21.8	13	1.7
2345	10	1094.7	570.2	3	13.2	15	0.9
2355	10	1099.9	879.6	5	20.0	13	1.5
2364	10	1062.0	162.8	3	74.4	21	3.5
2366	10	1076.5	906.3	5	15.8	15	1.0
2380	10	1093.7	165.6	2	62.1	21[a]	3.0
$\bar{X}$				2.3	71.0e	16.3j	2.1n
				ON SOIL			
2203	5	1094.5	279.2	3	57.5	20	2.9
2204	5	1081.4	533.1	5	50.7	16	3.2
2213	5	[illegible]	[illegible]	5	45.7	15	3.0
2218	5	1039.2	147.7	4	82.2	15	5.5
2269	5	1080.4	131.0	5	87.9	15	5.8
2282	5	1047.6	638.8	5	39.0	14	2.8
2326	5	1089.8	-----	0	----	15	---
2331	5	1059.8	419.9	5	60.4	15	4.0
2375	5	1088.5	-----	0	----	21[a]	---
2376	5	1088.8	19.8	3	97.0	21[a]	4.6
$\bar{X}$				1.5	78.7e	16.7j	4.0p

Table 37 - continued.

Table 37. Continued - page 3.

[a] Surviving ducks in Pens 3 and 6 were killed 7 days after dosing, surviving ducks in Pens 4 and 9 were killed 14 days after dosing, and surviving ducks in Pens 5 and 10 were killed 21 days after dosing. See Tables 38 and 39 for additional data on these ducks.

[b] The first two means in each row include only ducks killed for autopsy.

Note: Means in various vertical columns for the same weekly periods that are followed by different letters are significantly different ($P < 0.05$).

Table 38. Comparison of the effects of ingested soil on retention and erosion rates of pellets by 1-, 2-, and 3-week periods for female mallards--corn diet--dosed with five No. 4 commercial lead pellets on 11 August 1975--Phase V.

Number of days after Dosing[a]	Mean number of days to death[a]	Soil in pen	Number of pellets re-covered	Percentage of dosed shot expelled			Percentage weight of dosed shot eroded		
				Total	Per day	Sample size	Total	Per day	Sample size
1-7	5.6	No	4.9c	1.4e	0.2g	14	21.0i	4.1q	14
1-7	6.8	Yes	3.8d	24.0f	3.5h	10	50.4j	7.4r	9
8-14	13.2	No	3.7	26.7	2.0	9	25.7k	2.0s	9
8-14	13.9	Yes	2.9	41.8	3.0	11	55.2m	4.0t	8
15-21	17.8	No	3.6	28.6	1.4	7	44.7	2.3u	7
15-21	17.0	Yes	3.3	33.3	1.8	9	68.8	4.1v	7
0-death[b]	9.6a	No	4.5	9.5	0.7	19	23.6n	2.8	19
0-death[b]	14.3b	Yes	4.1	18.0	1.4	10	48.7p	3.9	9

[a] Ducks that died regardless of the pen they were in plus ducks that were killed.

[b] Only ducks that died in the pens; ducks killed for autopsy were not included.

Note: Means in vertical columns for each period that are followed by different letters are significantly different ($P < 0.05$).

Table 39. Comparison of the effects of ingested soil on weight loss, decline in PCV's, and mortality rates by 1-, 2-, and 3-week periods for female mallards--corn diet--dosed with five No. 4 commercial lead pellets on 11 August 1975--Phase V.

Number of days after dosing[a/]	Soil in pen	Percentage loss of body weight			Percentage loss of PCV			Mortality[b/]	
		Total	Per day	Sample size	Total	Per day	Sample size	Percent[c/]	Sample size
1-7	No	16.0	2.6	30	36.2	5.2	21	33.3c	30
1-7	Yes	16.8	2.4	30	40.7	5.8	29	3.3d	30
8-14	No	34.3	3.8	16	41.2	2.9	12	25.0	16
8-14	Yes	33.0	3.2	20	37.8	2.7	18	10.0	20
15-21	No	40.2	5.0	7	40.5	1.9	2	71.4	7
15-21	Yes	43.6	4.8	9	26.6	1.3	2	77.8	9
0-death[d/]	No	30.5a	3.5	18				63.3e	30
0-death	Yes	41.5b	3.0	10				33.3f	30

[a/] All ducks in any group that were alive during any part of each period were included for the appropriate number of days, except that PCV's were taken only for ducks surviving 7, 14, and 21 days after dosing.

[b/] This figure includes only ducks that died in the pens, but surviving ducks in Pens 3 and 6 were killed 7 days after dosing, surviving ducks in Pens 4 and 9 were killed 14 days after dosing, and surviving ducks in Pens 5 and 10 were killed 21 days after dosing.

[c/] Of the 30 ducks alive on wire on day 1, 33.3 percent had died by day 7; of the 16 ducks alive on wire on day 8, 25.0 percent had died by day 14; of the 7 ducks on wire alive on day 15, 71.4 percent had died by day 21; and of the 30 ducks alive on wire on day 1, 63.3 percent died of lead poisoning. The remainder were killed either 7, 14, or 21 days after dosing with lead.

[d/] Only ducks that died in pens; ducks killed for autopsy were not included.

Note: Means in vertical columns for each period that are followed by different letters are significantly different ($\underline{P}<0.05$).

Table 40. Comparative weight changes in female mallards dosed with five No. 4 commercial lead pellets on 11 August 1975--corn diet--one group with soil in the pens and the other with no soil available--Phase V.

Band number	Body weight (g)					Percent body weight change			
	11 Aug.	18 Aug.	25 Aug.	1 Sept.	At death	18 Aug.	25 Aug.	1 Sept.	At death
NO SOIL AVAILABLE									
2259	900				740				-17.8
2298	1010				850				-15.8
2327	1020				860				-15.7
2330	940				790				-16.0
2362	1010				780				-22.8
2372	1000				810				~~-19.0~~
1585	870	670				-23.0			
2194	780	620				-20.5			
2212	1050	1020				- 2.8			
2353	1020	820				-19.6			
$\bar{X}$						-16.5			-17.8
ON SOIL									
2370	1000				790				-21.0
2199	840	690				-17.8			
2200	920	750				-18.5			
2222	940	760				-19.1			
2230	980	800				-18.4			
2286	930	740				-20.4			
2300	970	820				-15.5			
2303	940	750				-20.2			
2339	830	690				-16.9			
2377	1060	880				-17.0			
$\bar{X}$						-18.2			-21.0
NO SOIL AVAILABLE									
2210	1070				780				-27.1
2237	820				690				-15.8
2308	900				790				-12.2
2266	860	720	460			-16.3	-45.6		
2271	1100	870	750			-20.9	-31.2		
2278	1000	880	710			-12.0	-29.0		
2289	870	720	510			-17.2	-41.4		
2358	980	840	720			-14.3	-26.5		
2361	1020	810			810	-20.6			-20.6
2371	830	680			470	-18.1			-43.4
$\bar{X}$						-17.0	-34.9		-23.8

Table 40 - continued.

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Table 40. Continued - page 2.

				ON SOIL					
2208	880	740	640			-15.9	-27.3		
2242	870	860	710			- 1.1	-18.4		
2252	1090	900	600			-17.4	-45.0		
2257	1110	890	760			-19.8	-31.5		
2272	1010	820			670	-18.8			-33.7
2274	1000	870	700			-13.0	-30.0		
2305	1020	830	730			-18.6	-28.4		
2322	1050	910	750			-13.3	-28.6		
2335	830	750	660			- 9.6	-20.5		
2368	900	700	560			-22.2	-37.8		
$\bar{X}$						-13.0	-29.7		-33.7
				NO SOIL AVAILABLE					
2260	830	640			430	-22.9			-48.2
2265	1030	910	740		700	-11.6	-28.2		-32.0
2284	880	900	730	600		+ 2.3	-17.0	-31.8	
2288	930	860	640		470	- 7.5	-31.2		-49.5
2312	870	710			470	-18.4			-46.0
2345	810	660	540		520	-18.5	-33.3		-35.8
2355	920	720			460	-21.7			-50.0
2364	900	900	750	490		0.0	-16.7	-45.6	
2366	870	690	500		470	-20.7	-42.5		-46.0
2380	950	820	770	560		-13.7	-18.9	-41.0	
$\bar{X}$						-13.3	-26.8	-39.5	-43.9
				ON SOIL					
2203	980	760	610		530	-22.4	-37.8		-45.9
2204	900	780	540		500	-13.3	-40.0		-44.4
2213	920	750	540		520	-18.5	-41.3		-43.5
2218	880	780	520		500	-11.4	-40.9		-43.2
2269	980	810	590		540	-17.3	-39.8		-44.9
2282	900	710	490		490	-21.1	-45.6		-45.6
2326	840	710	500		470	-15.5	-40.5		-44.0
2331	960	800	560		490	-16.7	-41.7		-49.0
2375	1010	850	680	650		-15.8	-32.7	-35.6	
2376	1060	860	730	620		-18.9	-31.1	-41.5	
$\bar{X}$						-17.1	-39.1	-38.6	-45.1
Grand mean									
No soil available						-15.1a	-30.1b	-39.5c	-30.5d
On soil						-16.7a	-34.7b	-38.6c	-41.5e

See Tables 37 and 41 for additional data on these ducks.

Note: Means in vertical columns followed by different letters are significantly different ($P < 0.05$).

Table 41. Comparative changes in PCV's in female mallards dosed with five No. 4 commercial lead pellets on 11 August 1975--corn diet--one group with soil in the pens and the other with no soil available--Phase V.

Band number	PCV (%) 11 Aug.	18 Aug.	25 Aug.	1 Sept.	Percent change in PCV 18 Aug.	25 Aug.	1 Sept.	Percent change in PCV per day 18 Aug.	25 Aug.	1 Sept.
					NO SOIL AVAILABLE					
2259	40									
2298	45									
2327	44									
2330	44									
2362	43									
2372	47									
1585	48	22			54.2			7.7		
2194	38	37			2.6			0.4		
2212	53	37			30.2			4.3		
2353	44	35			20.4			2.9		
$\bar{X}$	44.6	32.8			26.8a			3.8j		
					ON SOIL					
2199	43	26			39.5			5.6		
2200	42	30			28.6			4.1		
2222	41	25			39.0			5.6		
2230	44	17			61.4			8.8		
2286	46	28			39.1			5.6		
2300	41	18			56.1			8.0		
2303	44	25			43.2			6.2		
2339	44	25			43.2			6.2		
2370	42									
2377	39	19			51.3			7.3		
$\bar{X}$	42.6	23.7			44.6a			6.4j		
					NO SOIL AVAILABLE					
2210	39									
2237	45									
2308	44									
2266	40	27	31		32.5	22.5		4.6	1.6	
2271	44	27	33		38.6	25.0		5.5	1.8	
2278	45	30	32		33.3	28.9		4.8	2.1	
2289	46	34	19		26.1	58.7		3.7	4.2	
2358	38	24	26		36.8	31.6		5.3	2.2	
2361	43	14			67.4			9.6		
2371	47	24			48.9			7.0		
$\bar{X}$	39.0	25.7	28.2		40.5b	33.3e		5.8k	2.4p	

Table 41 - continued.

Table 41. Continued - page 2.

ON SOIL										
2208	39	31	29		20.5	25.6		2.9	1.8	
2242	44	26	33		40.9	25.0		5.8	1.8	
2252	47	26	29		44.7	38.3		6.4	2.7	
2257	47	32	31		31.9	34.0		4.6	2.4	
2272	43	29			32.6			4.6		
2274	45	33	31		26.7	31.1		3.8	2.2	
2305	42	28	28		33.3	33.3		4.8	2.4	
2322	50	28	24		44.0	52.0		6.3	3.7	
2335	46	21	31		54.3	32.6		7.8	2.3	
2368	41	29	35		29.3	14.6		4.2	1.0	
$\bar{X}$	44.4	28.3	30.1		35.8b	31.8e		5.1k	2.2p	
NO SOIL AVAILABLE										
2260	45	33			26.7			3.8		
2265	46	34	22		26.1	52.2		3.7	3.7	
2284	44	35	23	29	20.4	47.7	34.1	2.9	3.4	1.6
2288	49	29	24		40.8	51.0		5.8	3.6	
2312	44	23			47.7			6.8		
2345	40	15	19		62.5	52.5		8.9	3.8	
2355	45	38			15.6			2.2		
2364	45	33	26		26.7	42.2		3.8	3.0	
2366	41	18	20		56.1	51.2		8.0	3.6	
2380	49	26	34	26	46.9	30.6	46.9	6.7	2.2	2.2
$\bar{X}$	44.8	28.4	24.0	27.5	37.0c	46.8f	40.5h	5.3m	3.3q	1.9s
ON SOIL										
2203	43	33	25		23.2	41.9		3.3	3.0	
2204	46	12	23		73.9	50.0		10.6	3.6	
2213	44	28	20		36.4	54.5		5.2	3.9	
2218	43	16	25		62.8	41.9		9.0	3.0	
2269	48	33	25		31.2	47.9		4.5	3.4	
2282	43	13			69.8			10.0		
2326	41	36	28		12.2	31.7		1.7	2.3	
2331	47	31	18		34.0	61.7		4.9	4.4	
2375	48	21	31	35	56.2	35.4	27.1	8.0	2.5	1.3
2376	42	33	30	31	21.4	28.6	26.2	3.1m	2.0	1.3
$\bar{X}$	40.7	25.6	25.0	33.0	42.1c	43.7f	26.6h	6.0	3.1q	1.3s
Grand mean										
No soil available					36.2d	41.2g	40.5i	5.2n	2.9r	1.9t
On soil					40.7d	37.8g	26.6i	5.8n	2.7r	1.3t

See Tables 37-40 for additional data on these ducks.

Note: Means in vertical columns followed by the same letter are not significantly different ($\underline{P} > 0.05$).

Table 42. Actual and calculated weight of grit in gizzards of game-farm mallards in relation to the number of days with no grit available and in ducks dosed with 2.5, 5.0, and 10.0 grams of soil daily--Phases V and VI.

Phase of study	Number of ducks dosed	Sex	Average number of days after dosing to death[a]	Average number of days off ground to death	Average wt of grit in gizzard at death (mg)	Soil in pen	Wt of soil dosed daily (g)	Assumed wt of grit in gizzard when removed from soil (mg)	Calculated wt of grit in gizzard at death	Actual wt of grit in gizzard in relation to calculated wt (%)
V	10	F	6.0	13.0	1410.5	No	0	1842.75[b]	1401.5	0
V	10	F	10.0	17.0	1309.8	No	0	1875.05	1309.8	0
V	10	F	16.3	23.3	1056.5	No	0	1831.22	1056.5	0
V	10	F	6.8	13.8	2936.0	Yes[c]	0	1849.67[d]	1390.8	+111.1
V	10	F	13.9	20.9	2888.2	Yes	0	1849.67	1154.7	+150.1
V	10	F	16.7	23.7	2362.3	Yes	0	1849.67	1061.6	+122.5
VI	10	M	15.2	26.2	859.01	No	0	1849.67	978.5	- 12.2
VI	10	M	13.9	24.9	967.7	No	2.5[e]	1849.67	1021.7	- 5.3
VI	10	M	13.1	24.1	1206.8	No	5.0	1849.67	1048.3	+ 15.1
VI	9	M	16.7	27.7	1283.8	No	10.0	1849.67	928.6	+ 38.2

a/ Includes ducks killed for autopsy. Each duck in these experiments was dosed with five No. 4 lead pellets.

b/ Calculated by assuming that rate of loss of grit from 13.0 to 23.3 days after removal from the soil was uniform-- = 33.25 mg average weight of grit lost per day after removal from soil.

c/ A wooden box 30" X 30 inches about half filled with topsoil from the pheasant holding pens at Nilo Farms, Brighton, Illinois, was placed in each pen. The soil was soaked twice daily with a hose and replenished when needed.

d/ Average of three figures obtained in b/.

e/ These ducks were dosed daily with weighed amounts of soil in 1/4-oz gelatin capsules. The soil was from the same source as in c/.

Table 43. Effects of daily measured doses of soil on the mortality rate of male game-farm mallards each dosed with five No. 4 commercial lead pellets on a diet of corn and water and held in pens with wire floors. The soil was from the pheasant holding pens at Nilo Farms, Brighton, Illinois. Also shown are the mean rate of erosion of shot per day and the mean number of shot recovered from the gizzard--Phase VI.

Dose[a/]	Date of dosing	Number of ducks dosed	Percent mortality after dosing: 1 wk	2 wks	3 wks	Mean days survived to 3 wks after dosing[b/]	Mean wt of shot eroded per day (%)	Mean number of shot recovered
Controls	22 Sept.	10	0.0a	30.0b	80.0cd	15.2e	1.31f	4.2i
2.5 g soil	15 Sept.	10	10.0a	50.0b	100.0d	13.9e	2.28g	3.8i
5.0 g soil	15 Sept.	10	10.0a	70.0b	100.0d	13.1e	3.41h	4.2i
10.0 g soil	15 Sept.	9	11.1a	33.3b	55.6c	16.7e	3.02gh	3.3i

a/ Each duck, including controls, was dosed with one 1/4-oz gelatin capsule, except that ducks dosed with 10 g of soil were dosed with two capsules because one capsule would not hold 10 g of soil.

b/ All surviving ducks were killed 3 weeks after dosing.

Note: Means in each column that are not followed by the same letter are significantly ($P < 0.05$) different.

Table 44. Effects of daily measured doses of soil on loss of body weight of male game-farm mallards each dosed with five No. 4 commercial lead pellets on a diet of corn and water and held in pens with wire floors. The soil was from the pheasant holding pens at Nilo Farms, Brighton, Illinois--Phase VI.

Dose[a/]	Date of dosing 15 Sept. mean body wt (g)	1 wk after dosing 22 Sept. 75 Number alive	Mean body wt (g)	Percent change	2 wks after dosing 29 Sept. 75 Number alive	Mean body wt (g)	Percent change	3 wks after dosing 6 Oct. 75[b/] Number alive	Mean body wt (g)	Percent change
Controls[c/]	1111.0	10	933.0	-15.82a	7	818.6	-26.60b	2	660.0	-38.01e
2.5 g soil	1135.0	9	951.1	-16.00a	7	735.7	-35.73cd	0		
5.0 g soil	1123.0	9	922.2	-17.29a	6	650.0	-42.00c	0		
10.0 g soil	1158.9	8[d/]	968.8	-16.41a	6	776.7	-32.50d	4	682.5	-41.47e

[a/] Each duck, including controls, was dosed with one 1/4-oz gelatin capsule, except that ducks dosed with 10 g of soil were dosed with two capsules because one capsule would not hold 10 grams of soil.

[b/] Surviving ducks were killed on 6 October 1975.

[c/] Because of an error, the controls were dosed with lead pellets on 22 September 1975. Thus, the dates for 1, 2, and 3 weeks after dosing are 1 week later than the dates listed for the controls.

[d/] Because of an error, only nine ducks in this group were dosed.

Note: Means in each column that are not followed by the same letter are significantly ($P < 0.05$) different.

Table 45. Effects of daily measured doses of soil on PCV's of male game-farm mallards each dosed with five No. 4 commercial lead pellets on a diet of corn and water and held in pens with wire floors. The soil was from the pheasant holding pens at Nilo Farms, Brighton, Illinois--Phase VI.

	Date of dosing 15 Sept.	1 wk after dosing 22 Sept. 75			2 wks after dosing 29 Sept. 75			3 wks after dosing 6 Oct. 75		
Dose[a/]	Mean PCV (%)	Number alive	Mean PCV (%)	Percent change	Number alive	Mean PCV (%)	Percent change	Number alive	Mean PCV (%)	Percent change
Controls	41.4	10	18.2	-55.76a	7	25.1	-44.87c	2	21.5	-49.39d
2.5 g soil	43.4	9	17.7	-59.80ab	6	28.7	-34.38c	0		
5.0 g soil	44.4	9	23.8	-46.05b	4	21.8	-51.09c	0		
10.0 g soil	42.4	8	20.5	-51.81ab	6	23.8	-43.70c	4	16.5	-61.03d

a/ All footnotes are the same as in Table 44.

Table 46. Number of shot recovered, percent mortality, and average survival of 12 game-farm mallards as affected by diet and by daily doses of 10 g of soil--Phase VII.

Diet and dose[a]	Number of shot recovered[b]	Percent shot expelled	Percent shot retained in gizzard	Percent shot 100% eroded in gizzard	Percent mortality	Mean number of days to death[c]
C-0	14	6.7	86.7	6.7	100.0	7.3a
C-10	13	20.0	66.7	13.3	33.3	17.0ab
P-0	6	0.0	40.0	60.0	0.0	21.0b
P-10	6	0.0	40.0	60.0	0.0	21.0b

Note: Three ducks in each group; each duck was dosed with five No. 4 commercial lead pellets.

[a] C-0 = corn diet, no soil. C-10 = corn diet, 10 g soil dosed daily. P-0 = pellet diet, no soil. P-10 = pellet diet, 10 g soil dosed daily.

[b] Including shot recovered from feces.

[c] All surviving ducks were killed 21 days after dosing. Means in this column not followed by the same letter are significantly different ($\underline{P}<0.05$).

Table 47. Mean amounts of Pb dosed, recovered, and eroded by female game-farm mallards as influenced by diet and soil. Ducks were dosed with five No. 4 commercial lead pellets on 21 October 1975--Phase VII.

Diet and Dose[a/]	Mean wt Pb dosed per duck (mg)	Mean wt per shot dosed (mg)	Mean wt Pb recovered per duck (mg)	Mean wt per shot recovered (mg)[b/]	Mean wt Pb eroded per duck by death (mg)[c/]	Mg lead eroded per day[d/]	Mean total percent Pb eroded[d/]	Mean percent lead eroded per day[d/]
C-0[e/]	1075.4	215.1	797.7	182.7	277.8a	40.8ab	25.8a	3.8ab
C-10	1086.4	217.3	533.4	123.1	553.0a	33.9a	50.8a	3.1a
P-0	1074.7	214.9	80.1	40.0	994.6b	47.4ab	91.2b	4.4ab
P-10	1057.6	211.5	32.7	16.4	1024.9b	48.8b	98.2b	4.6b

Note: Figures in the last four vertical columns not followed by the same letter are significantly different ($P < 0.05$).

[a/] See Footnote [a/], Table 46.

[b/] At death and including shot recovered in feces prior to death (see [e/]).

[c/] The figures in this column are based on the assumption that all missing shot were completely eroded. They were probably so badly eroded that when passed in the feces they were overlooked upon visual examination of the dried feces.

[d/] Data include all surviving ducks, and all surviving ducks were killed 21 days after dosing.

[e/] One shot recovered in feces of one C-0 duck on day of death, 7 days after dosing. One shot recovered in feces of one C-10 duck, 20 days after dosing. Two shot recovered in feces of another C-10 duck, 11 days after dosing. This latter duck had only one pellet (weight, 95.3 mg) in its gizzard when it was killed 21 days after dosing.

Table 48. Weight of livers, gonads, and grit from 12 female game-farm mallards as influenced by diet and 10 g of soil dosed daily. Each duck was dosed with five No. 4 lead pellets on 21 October 1975--Phase VII.

Diet and dose[a]	Mean weight of liver (g)	Mean weight of gonads (g)	Mean weight of grit (g)
C-0	22.9	0.7	14.4
C-10	14.8	0.5	10.5
P-0	16.6	0.4	24.0
P-10	16.6	0.3	27.8

Note: Means in vertical columns are not significantly different ($P>0.05$).

[a] See Table 46.

Table 49. Body weights of 12 game-farm mallards held in individual pens as affected by diet and by daily doses of soil after dosing with five No. 4 commercial lead pellets each. Surviving ducks only, on the last date weighed--Phase VII.

Diet and dose[a]	Mean body weight (g)						Body weight lost (%)	Body weight lost per day (percent)
	10 Oct.	15 Oct.	21 Oct.[b]	28 Oct.	4 Nov.	11 Nov.[c]		
C-0	1213.3	1023.3	1023.3	830.0[d]			-19.1[d]	-2.6[d]
C-10	1143.3	953.3	953.3	850.0	745.0[d]	615.0[d]	-37.3[d]	-2.2[d]
P-0	1060.0	910.0	910.0	923.3	930.0	943.3	+ 4.4	+0.2
P-10	1070.0	953.3	966.7	993.3	1006.7	1016.7	+ 5.1	+0.2

[a] See Table 46.

[b] Date dosed.

[c] All surviving ducks were killed 21 days after dosing.

[d] Two surviving ducks. Weight changes are calculated by comparing the final weights with the initial weights of the same two ducks.

Table 50. Mean percentage change in body weight and in PCV from the date of dosing (21 October 1975) to 1, 2, and 3 weeks after dosing and to death[a] in captive female game-farm mallards as influenced by diet and soil. Each duck was dosed with five No. 4 commercial lead pellets--Phase VII.

Diet and Dose[a]	Mean percentage change in body weight					Mean percentage change in PCV		
	to 28 Oct.	to 4 Nov.	to 11 Nov.	to death[b]	per day[b]	to 28 Oct.	to 4 Nov.	to 11 Nov.
C-0	-12.8a	-----[c]	-----[c]	-13.2a	-1.9a	-45.6ab	-----[c]	-----[c]
C-10	-11.1a	-23.9	-37.3a	-33.6b	-2.2a	-48.7a	-41.8a	-37.5
P-0	+ 1.6b	+ 2.4a	+ 4.4ab	+ 4.4ac	+0.2b	-11.4bc	-13.2ab	-13.0a
P-10	+ 2.8b	+ 4.1a	+ 5.1b	+ 5.1c	+0.2b	- 5.0c	- 3.6b	+ 0.6a

Note: Figures in vertical columns not followed by the same letter are significantly different ($P < 0.05$).

[a] See footnote [a], Table 46.

[b] Data include all surviving ducks, which were killed 21 days after dosing.

[c] No surviving ducks.

Table 51. PCV's of 12 game-farm mallards held in individual pens as affected by diet and daily doses of soil after dosing with five No. 4 commercial lead pellets each--Phase VII.

Diet and dose[a/]	Mean PCV (%)			
	21 Oct.[b/]	28 Oct.	4 Nov.	11 Nov.
C-0	45.7	25.0[c/]		
C-10	49.7	25.3	33.5[d/]	30.0[d/]
P-0	49.3	43.7	42.7	42.7
P-10	46.3	44.0	44.7	46.7

Note: Three ducks in each group.

a/ See Table 46.

b/ Date dosed.

c/ One surviving duck.

d/ Two surviving ducks.

Table 52. Daily amounts (mg) of Pb excreted by captive game-farm mallards as influenced by diet and soil. Feces were collected on 21 October 1975 prior to dosing each duck with five No. 4 lead pellets--Phase VII.

Diet and dose[a/]	Band number	Lead dosed (mg)	Lead recovered (mg)	Lead eroded (mg)	Date (October 1975)											Total
					21	22	23	24	25	26	27	28	29	30	31	
C-0	2369	1070.7	771.3	299.4	0.22	99.6	25.2	9.77	12.6	5.78	0.30[b/]					
	2275	1076.7	664.4	412.6	0.19	8.22	26.5	7.32	3.75	5.42	2.95	0.21				
	2314	1078.8	957.3	121.5	0.23	4.15	5.77	4.97	2.97	7.38	4.10	11.1	1.59	0.57		
	Mean	1075.4	797.7	277.8	0.21	37.3	19.2	7.35	6.44	6.19	2.45	5.66	1.59	0.57		83.4
C-10	2217	1088.5	333.5	755.0	0.24	67.0	64.1	51.7	32.4	23.8	10.2	8.33	7.83	8.18	6.13	
	2360	1062.3	705.9	356.4	0.07	27.7	63.8	27.6	6.21	25.9	47.9	7.39	17.6	25.4	5.48	
	2381	1108.4	560.7	547.7	3.99	11.4	58.8	62.2	60.7	61.3	31.4	25.3	3.63	8.29	5.78	
	Mean	1086.4	533.4	553.0	1.43	35.4	62.2	47.2	33.1	37.0	29.8	13.7	9.69	14.0	5.80	
					Date (November 1975)											
					1	2	3	4	5	6	7	8	9	10	11	
C-10	2217				5.04	3.18	10.1	10.6	0.43	2.25	2.59	2.30	2.22	1.24		
	2360															
	2381				4.94	3.40	4.79	7.29	3.29	5.28	5.50	6.12	2.75	7.29	5.25	
	Mean				4.99	3.29	7.44	8.94	1.86	3.76	4.04	4.21	2.48	4.26	5.25	319.7
					Date (October 1975)											
					21	22	23	24	25	26	27	28	29	30	31	
P-0	2240	1061.4	0	1061.4	0.28	28.2	72.2	95.9	84.2	139	145	87.2	56.3	32.9	54.0	
	2291	1072.3	239.4	832.9	0.06	29.2	84.8	5.50	58.5	48.4	52.5	21.4	25.5	23.8	24.1	
	2329	1090.5	0.9	1089.6	0.15	78.6	112	71.2	100	143	109	18.5	14.9	40.8	33.0	
	Mean	1074.7	80.1	994.6	0.16	45.3	89.7	57.5	80.9	110	102	42.4	32.2	32.5	37.0	

Table 52 - continued.

Table 52. Continued - page 2.

					Date (November 1975)											
					1	2	3	4	5	6	7	8	9	10	11	
P-0	2240				56.3	29.0	9.79	3.11	20.6	1.27	1.12	1.08	0.91	1.06	1.39	
	2291				31.6	25.8	22.2	22.0	2.73	1.03	1.45	6.85	3.77	2.61	11.0	
	2329				26.7	20.8	18.5	14.2	21.0	12.5	3.39	8.23	4.55	6.03	4.83	
	Mean				38.2	25.2	16.8	13.1	14.8	4.93	1.99	5.39	3.08	3.23	5.74	762.7
					Date (October 1975)											
					21	22	23	24	25	26	27	28	29	30	31	
P-10	2295	1092.0	57.4	1034.6	0.52	256	36.5	28.2	46.6	85.1	41.0	26.9	44.4	18.7	18.0	
	2498	1031.8	0	1031.8	0.13	50.6	57.3	39.7	41.8	101	53.6	29.1	38.7	23.9	25.4	
	2263	1049.1	40.8	1008.3	0.23	44.8	48.3	35.2	31.7	60.4	80.2	27.2	30.9	25.3	18.3	
	Mean	1057.6	32.7	1024.9	0.29	117	47.4	34.4	40.0	82.2	58.3	27.7	38.0	22.6	20.6	
					Date (November 1975)											
					1	2	3	4	5	6	7	8	9	10	11	
P-10	2295				20.4	16.4	8.00	9.52	5.91	10.5	8.53	6.78	10.1	10.3	12.0	
	2498				13.2	16.0	7.26	7.19	4.44	12.1	5.08	4.15	2.16	1.69	0.88	
	2263				14.2	17.4	12.5	7.28	4.72	12.4	9.14	16.2	9.60	5.14	9.74	
	Mean				15.9	16.6	9.25	8.00	5.02	11.7	7.58	9.04	7.29	5.71	7.54	590.4

Note: Because samples at higher concentrations were diluted prior to analysis, all results are presented to three significant figures.

a/ P-0 = Diet of pellets and not dosed with soil.

P-10 = Diet of pellets and dosed with 10 g of soil daily.

C-0 = Diet of yellow shelled corn and not dosed with soil.

C-10 = Diet of yellow shelled corn and dosed with 10 g of soil daily.

b/ The last figure for each duck indicates the last date the duck was alive.

Table 53. Mean amount of lead eroded, excreted in feces, retained, and mean number of days to death by captive female game-farm mallards as influenced by diet and soil. Each duck was dosed with five No. 4 commercial lead pellets on 21 October 1975--Phase VII.

Diet and dose[a/]	Mg Pb excreted per duck after dosing					Mg eroded Pb retained in duck[b/]	Mg eroded Pb retained per day[b/]	Percent eroded Pb excreted[c/]
	2nd day	6th day	Total, days 1-6	excreted	Per day			
C-0	19.2	2.4a	78.9	83.4	12.7a	194.4a	20.2a	30.0
C-10	62.2ab	29.8ab	244.7a	319.7	19.9a	233.3ab	13.2a	57.8
P-0	89.7a	102.2b	485.7a	762.7a	36.3a	231.9ab	11.0a	76.7
P-10	47.4b	58.3b	379.3a	590.4a	28.1a	434.5b	20.7a	57.6

Note: Figures in vertical columns not followed by the same letter are significantly different ($P < 0.05$). In the second and third columns, figures not underlined by the same line are significantly different.

a/ See Table 46.

b/ Data include all surviving ducks, and all surviving ducks were killed 21 days after dosing.

c/ See Tables 47 and 52 for total amount of lead eroded.

Table 54. Number and type of pellets dosed in game-farm mallards to study possible differences in toxicity caused by the method of manufacturing the pellets--Phase VIII.

Number or type of pellets	Number of ducks						Composition (%)			
	"Old" Process		"New" Process							
			Flamed		Not Flamed					
	Males	Females	Males	Females	Males	Females	Pb	Fe	Sn	Zn
0	10[a]	0	10[a]	0	10[a]	0				
1	3	6	0	0	3	6				
3	10	0	10	0	10	0				
5	10	0	10	0	10	0				
			Density							
Old Process			9.10±0.10 g/cc				46	53	0.5	0.5
New Process--Flamed			9.14±0.20 g/cc				47.2	51.8	0.5	0.5
New Process--not Flamed			9.26±0.22 g/cc				47.2	51.8	0.5	0.5

Note: In pens with wire floors (no grit available) on diet of shelled corn and water.

[a] Same controls, thus only 88 ducks were used.

Table 55. Relative survival of captive game-farm mallards dosed with 1, 3, and 5 lead:iron pellets manufactured by three different processes. Ducks were dosed on 23 December 1975 with No. 6 pellets of approximately 47 percent lead and 52 percent iron--Phase VIII.

Pen number	Number of pellets dosed	Type of pellet[a/]	Number of ducks dosed[b/]	Percent mortality 30 Dec.	13 Jan.	4 Feb.	Mean number of days to death[c/]
2	0		10	0.00	0.00	0.00[d/]	42.0a[e/]
6	1	OP	9	0.00	0.00	0.00	42.0aA
1	1	NP	9	0.00	0.00	0.00	42.0aA
8	3	OP	10	0.00	0.00	20.00	39.2aB
4	3	NP	10	0.00	0.00	10.00	41.3aB
10	3	NP-F	10	0.00	10.00	30.00	36.1aB
3	5	OP	10	0.00	10.00	60.00	32.5 C
5	5	NP	10	0.00	0.00	30.00	37.1aC
7	5	NP-F	10	0.00	10.00	50.00	35.7 C

a/ NP = New Process. Made starting with high grade iron ore.

OP = Old Process. Made starting with lead and steel particles.

NP-F = New Process-Flamed. Pellets made by the new process and then flamed to remove the lead coating, if present.

b/ All males except 3 males and 6 females each in pens 1 and 6. There were not enough ducks available to dose with three different numbers of pellets. Thus, ducks in pens 1 and 6 were not part of the basic design of this experiment.

c/ To 6 weeks after dosing.

d/ One duck died 23 days after dosing. Because its death was not related to this experiment, it was eliminated from consideration.

e/ Means followed by the letter "a" in this column are not significantly ($P > 0.05$) different from the mean for the controls. Within each group dosed with the same number of shot, means followed by the same capital letter are not significantly different ($P > 0.05$). Comparisons were not made among groups dosed with different numbers of shot.

Table 56. Mean body weights of captive game-farm mallards dosed with 1, 3, and 5 lead:iron pellets manufactured by three different processes--Phase VIII.

Pen number	Number and type of pellet	Mean body weight (g) 23 Dec.	30 Dec.	13 Jan.	3 Feb.	Percent change body weight to 30 Dec.	13 Jan.	3 Feb.
2	0	1136.7 (9)	1157.8 (9)	1137.8 (9)	1073.3 (9)	+1.9	+0.1	-5.6
6	1 OP	1107.8 (9)	1100.0 (9)	1076.7 (9)	1006.7 (9)	-0.7	-2.8	-9.1
1	1 NP	1094.4 (9)	1123.3 (9)	1083.3 (9)	1010.0 (9)	+2.6	-1.0	-7.7
8	3 OP	1219.0 (10)	1222.0 (10)	1155.0 (10)	1091.2 (8)	+0.2	-5.2	-11.4
4	3 NP	1166.0 (10)	1187.0 (10)	1161.0 (10)	1108.9 (9)	+1.8	-0.1	-4.7
10	3 NP-F	1151.0 (10)	1159.0 (10)	1101.1 (9)	1007.1 (7)	+0.7	-4.5	-13.5
3	5 OP	1218.0 (10)	1218.0 (10)	1056.7 (9)	982.5 (4)	0.0	-12.4	-15.5
5	5 NP	1183.0 (10)	1213.0 (10)	1067.0 (10)	1077.1 (7)	+2.5	-9.8	-12.3
7	5 NP-F	1210.0 (10)	1215.0 (10)	1111.3 (9)	1056.0 (5)	+0.4	-8.7	-16.0

Note: See Table 55 for explanation of type of shot and percentage mortality by each date. Ducks were dosed on 23 December 1975. Numbers in parentheses for 23 December indicate the number of ducks dosed in each group; numbers in parentheses for other dates indicate the number of surviving ducks.

Table 57. Changes in body weights in surviving ducks at 1, 3, and 6 weeks after dosing with 1, 3, or 5 shot manufactured by three different processes--Phase VIII.

Pen number	Number and type of pellet	1 week: Number of ducks	1 week: Percent change	1 week: P	3 weeks: Number of ducks	3 weeks: Percent change	3 weeks: P	6 weeks: Number of ducks	6 weeks: Percent change	6 weeks: P
1	1 NP	9	2.6		9	-1.0		9	-7.7	
6	1 OP	9	-0.7	<0.05	9	-2.8	>0.25	9	-9.1	>0.40
1	1 NP	9	2.6		9	-1.0		9	-7.7	
2	Controls	9	1.9	>0.60	9	0.1	>0.25	9	-5.6	>0.05
6	1 OP	9	-0.7		9	-2.8		9	-9.1	
2	Controls	9	1.9	< 0.005	9	0.1	<0.01	9	-5.6	<0.02
4	3 NP	10	1.8		10	< -0.1		9	-4.7	
8	3 OP	10	0.2	>0.10	10	-5.2	< 0.05	8	-11.4	< 0.02
4	3 NP	10	1.8		10	<-0.1		9	-4.7	
10	3 NP-F	10	0.7	> 0.30	9	-4.5	>0.10	7	-13.5	< 0.05
8	3 OP	10	0.2		10	-5.2		8	-11.4	
10	3 NP-F	10	0.7	>0.60	9	-4.5	>0.80	7	-13.5	>0.60
4	3 NP	10	1.8		10	< -0.1		9	-4.7	
2	Controls	9	1.9	> 0.90	9	0.1	> 0.50	9	-5.6	> 0.10
8	3 OP	10	0.2		10	-5.2		8	-11.4	
2	Controls	9	1.9	> 0.05	9	0.1	< 0.025	9	-5.6	< 0.025
10	3 NP-F	10	0.7		9	-4.5		7	-13.5	
2	Controls	9	1.9	> 0.10	9	0.1	> 0.20	9	-5.6	> 0.05
3	5 OP	10	0.0		9	-12.4		4	-15.5	
5	5 NP	10	2.5	> 0.20	10	-9.8	> 0.70	7	-12.3	> 0.70
3	5 OP	10	0.0		9	-12.4		4	-15.5	
7	5 NP-F	10	0.4	> 0.90	9	-8.7	> 0.40	5	-16.0	> 0.80
5	5 NP	10	2.5		10	-9.8		7	-12.3	
7	5 NP-F	10	0.4	> 0.10	9	-8.7	> 0.90	5	-16.0	> 0.60
3	5 OP	10	0.0		9	-12.4		4	-15.5	
2	Controls	9	1.9	> 0.30	9	0.1	< 0.001	9	-5.6	> 0.05
5	5 NP	10	2.5		10	-9.8		7	-12.3	
2	Controls	9	1.9	> 0.60	9	0.1	< 0.05	9	-5.6	> 0.10
7	5 NP-F	10	0.4		9	-8.7		5	-16.0	
2	Controls	9	1.9	> 0.10	9	0.1	< 0.01	9	-5.6	< 0.025

Table 58. Mean PCV's of captive game-farm mallards dosed with 1, 3, and 5 lead:iron pellets manufactured by three different processes--Phase VIII.

Pen number	Number and type of pellet	PCV's (%) 23 Dec.	30 Dec.	13 Jan.	3 Feb.	Percent change in PCV's to 30 Dec.	13 Jan.	3 Feb.
2	0	49.1	50.1	49.7	49.8	+2.1	+1.1	+1.4
6	1 OP	49.2	49.8	48.4	48.8	+2.0	-1.1	-0.2
1	1 NP	50.2	49.2	46.2	49.1	-1.9	-8.2	-2.1
8	3 OP	49.8	49.0	44.6	46.9	-1.3	-10.4	-5.5
4	3 NP	44.6	48.4	45.4	48.2	+9.6	+2.5	+9.9
10	3 NP-F	50.4	48.8	42.3	43.0	-1.5	-15.9	-14.4
3	5 OP	48.4	47.5	36.2	45.8	-1.8	-25.2	-6.2
5	5 NP	48.1	45.6	36.4	43.8	-4.8	-24.4	-9.1
7	5 NP-F	48.1	47.9	38.1	43.2	-0.3	-20.2	-9.1

Note: See Table 55 for explanation of type of shot and percentage mortality by each date. Ducks were dosed on 23 December 1975.

Table 59. Changes in PCV values in surviving ducks at 1, 3, and 6 weeks after dosing with 1, 3, or 5 shot manufactured by three different processes--Phase VIII.

Pen number	Number and type of pellets	1 week			3 weeks			6 weeks		
		Number of ducks	Percent change	P	Number of ducks	Percent change	P	Number of ducks	Percent change	P
1	1 NP	9	-1.9		9	-8.2		9	-2.1	
6	1 OP	9	2.0	>0.10	9	-1.1	>0.05	9	-0.2	>0.90
1	1 NP	9	-1.9		9	-8.2		9	-2.1	
2	Controls	9	2.1	<0.025	9	1.1	<0.02	9	1.4	>0.10
6	1 OP	9	2.0		9	-1.1		9	-0.2	
2	Controls	9	2.1	>0.90	9	1.1	>0.40	9	1.4	>0.60
4	3 NP	10	9.6		10	2.5		9	9.9	
8	3 OP	10	-1.3	< 0.05	10	-10.4	<0.02	8	-5.5	> 0.10
4	3 NP	10	9.6		10	2.5		9	9.9	
10	3 NP-F	10	-1.5	<0.05	9	-15.9	<0.01	7	-14.4	<0.05
8	3 OP	10	-1.3		10	-10.4		8	-5.5	
10	3 NP-F	10	-1.5	> 0.30	9	-15.9	>0.30	7	-14.4	>0.10
4	3 NP	10	9.6		10	2.5		9	9.9	
2	Controls	9	2.1	> 0.10	9	1.1	>0.70	9	1.4	> 0.30
8	3 OP	10	-1.3		10	-10.4		8	-5.5	
2	Controls	9	2.1	>0.05	9	1.1	< 0.02	9	1.4	> 0.05
10	3 NP-F	10	-1.5		9	-15.9		7	-14.4	
2	Controls	9	2.1	>0.10	9	1.1	< 0.01	9	1.4	<0.005
3	5 OP	10	-1.8		9	-25.2		4	-6.2	
5	5 NP	10	-4.8	> 0.40	10	-24.4	>0.90	7	-9.1	>0.70
3	5 OP	10	-1.8		9	-25.2		4	-6.2	
7	5 NP-F	10	-0.3	> 0.50	9	-20.2	>0.40	5	-9.1	>0.50
5	5 NP	10	-4.8		10	-24.4		7	-9.1	
7	5 NP-F	10	-0.3	> 0.30	9	-20.2	>0.60	5	-9.1	
3	5 OP	10	-1.8		9	-25.2		4	-6.2	
2	Controls	9	2.1	>0.05	9	1.1	< 0.001	9	1.4	<0.005
5	5 NP	10	-4.8		10	-24.4		7	-9.1	
2	Controls	9	2.1	>0.05	9	1.1	< 0.005	9	1.4	>0.05
7	5 NP-F	10	-0.3		9	-20.2		5	-9.1	
2	Controls	9	2.1	>0.25	9	1.1	< 0.005	9	1.4	< 0.01

Table 60. Mean weights of livers, gonads, and spleens of captive game-farm mallards dosed with 1, 3, and 5 lead:iron pellets manufactured by three different processes--Phase VIII.

Pen number	Number and type of pellet	Mean weight liver (g)				Mean weight testes (g)				Mean weight spleen (g)			
		Alive	Number alive	Died	Number died	Alive	Number alive	Died	Number died	Alive	Number alive	Died	Number died
2	0	18.20a	9	34.50	1	5.23a	9	5.30	1	0.32a	9	0.80	1
6[a]	1 OP	19.83aA	3		0	6.96aA	3		0	1.11A	3		0
1[a]	1 NP	19.24aA	3		0	3.91aA	3		0	0.28aA	3		0
8	3 OP	17.58aC	8	11.30	2	2.15aAB	8	0.74	2	0.28aB	8	0.12	2
4	3 NP	22.07B	9	13.50	1	4.29aA	9	0.72	1	0.29aB	9	0.14	1
10	3 NP-F	19.34aBC	7	11.37	3	0.86aB	7	0.58	3	0.26aB	7	0.12	3
3	5 OP	17.80aD	4	13.58F	6	2.53aC	4	0.54D	6	0.28aC	4	0.11E	6
5	5 NP	24.68aD	7	11.57F	3	4.52aC	7	0.39D	3	0.43aC	7	0.09E	3
7	5 NP-F	20.33aD	5	13.08F	5	2.18aC	5	0.40D	5	0.29aC	5	0.08E	5
1[b]	1 NP	15.02E	6		0				0	0.26aD	6		0
6[b]	1 OP	15.79E	6		0				0	0.26aD	6		0

Note: Means followed by the letter "a" in the same column were not significantly ($P < 0.05$) different from the mean for the controls. Within each group dosed with the same number of shot, means followed by the same capital letters are not significantly different. Comparisons were not made among groups dosed with different numbers of shot.

a/ Males only--three in each pen.

b/ Females only--six in each pen.

Table 61. Percentage of pellets recovered 6 weeks after dosing or at death in captive game-farm mallards dosed with 1, 3, and 5 lead:iron pellets manufactured by three different processes. The total amount of the pellet eroded and the daily erosion rates are also shown--Phase VIII.

Pen number	Number and type of pellet	Percentage of pellets recovered	Weight of pellets eroded (%)	Weight of pellets eroded per day[a] (%)	N
2	0				9
6	1 OP	88.9 A	89.0 E	2.1 K	9[c]
1	1 NP	100.0 A[b]	82.5 E	1.9 K	9[c]
8	3 OP	86.7 C	78.6 F	2.0 L	10
4	3 NP	93.3 BC	73.8 F	2.0 L	10
10	3 NP-F	100.0 B	70.9 F	2.1 L	10
3	5 OP	88.0 D	69.5 G	2.2 N	10
5	5 NP	84.0 D	66.5 G	1.8 M	10
7	5 NP-F	94.0 D	66.4 G	1.8 M	10

a/ The ducks were killed for autopsy 43 days after dosing.

b/ Within each group dosed with the same number of shot, means followed by the same capital letters are not significantly different ($P > 0.05$). Comparisons were not made among groups dosed with different numbers of shot.

c/ Three males and six females in each pen. The results are combined for both sexes in this table.

Table 62. Impaction of esophagus, proventriculus, and gizzard in ducks dosed with lead--Phase VIII.

Days survived after dosing	Sample size[a]	Esophagus				Proventriculus				Gizzard			
			Impacted with				Impacted with				Impacted with		
		Corn present (%)	Corn (%)	Feathers (%)	Corn and feathers (%)	Corn present (%)	Corn (%)	Feathers (%)	Corn and feathers (%)	Corn present (%)	Corn (%)	Feathers (%)	Corn and feathers (%)
[illegible]-8	17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	0.0
9-18	49	6.1	0.0	2.0	0.0	32.6	10.2	4.1	2.0	75.5	2.0	6.1	4.1
19-28	12	25.0	8.3	0.0	0.0	41.7	8.3	0.0	0.0	83.3	0.0	0.0	0.0
29-39	9	11.1	11.1	0.0	0.0	55.6	11.1	11.1	0.0	66.7	0.0	22.2	0.0
Total	87	8.0	2.3	1.1	0.0	29.9	8.0	3.4	1.1	62.1	1.1	5.7	2.3

[a] Ducks that died prior to the end of the respective experiments--Phases IV, V, VI, VII, and VIII. All ducks (67) from the Phase IV, V, VI, and VII studies were dosed with five No. 4 commercial lead shot. Eight ducks from the Phase VIII study were dosed with five No. 6 shot (47:57, lead:iron) and 12 were dosed with three shot.

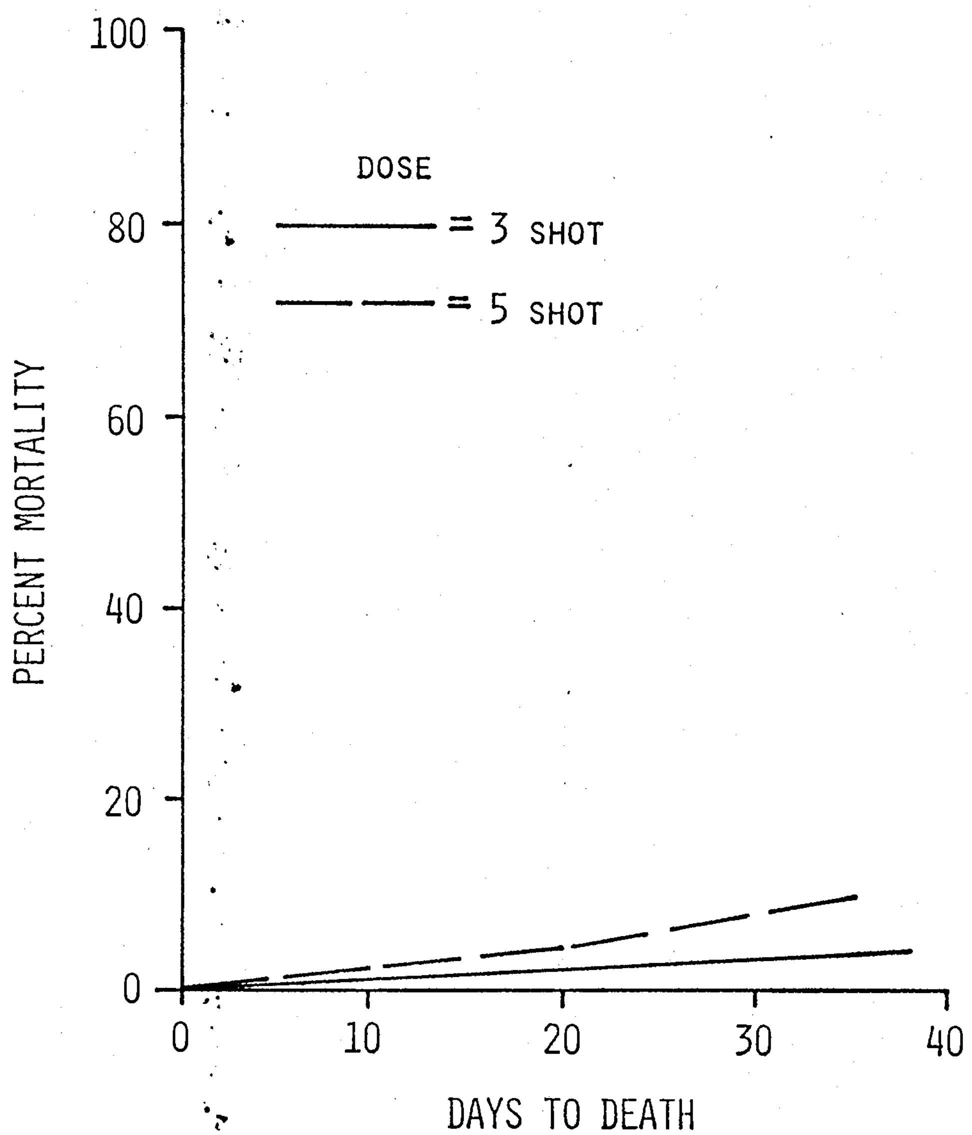

Fig. 1. Cumulative mortality in ducks dosed with lead:iron shot containing 41.4 percent Pb--Phase III.

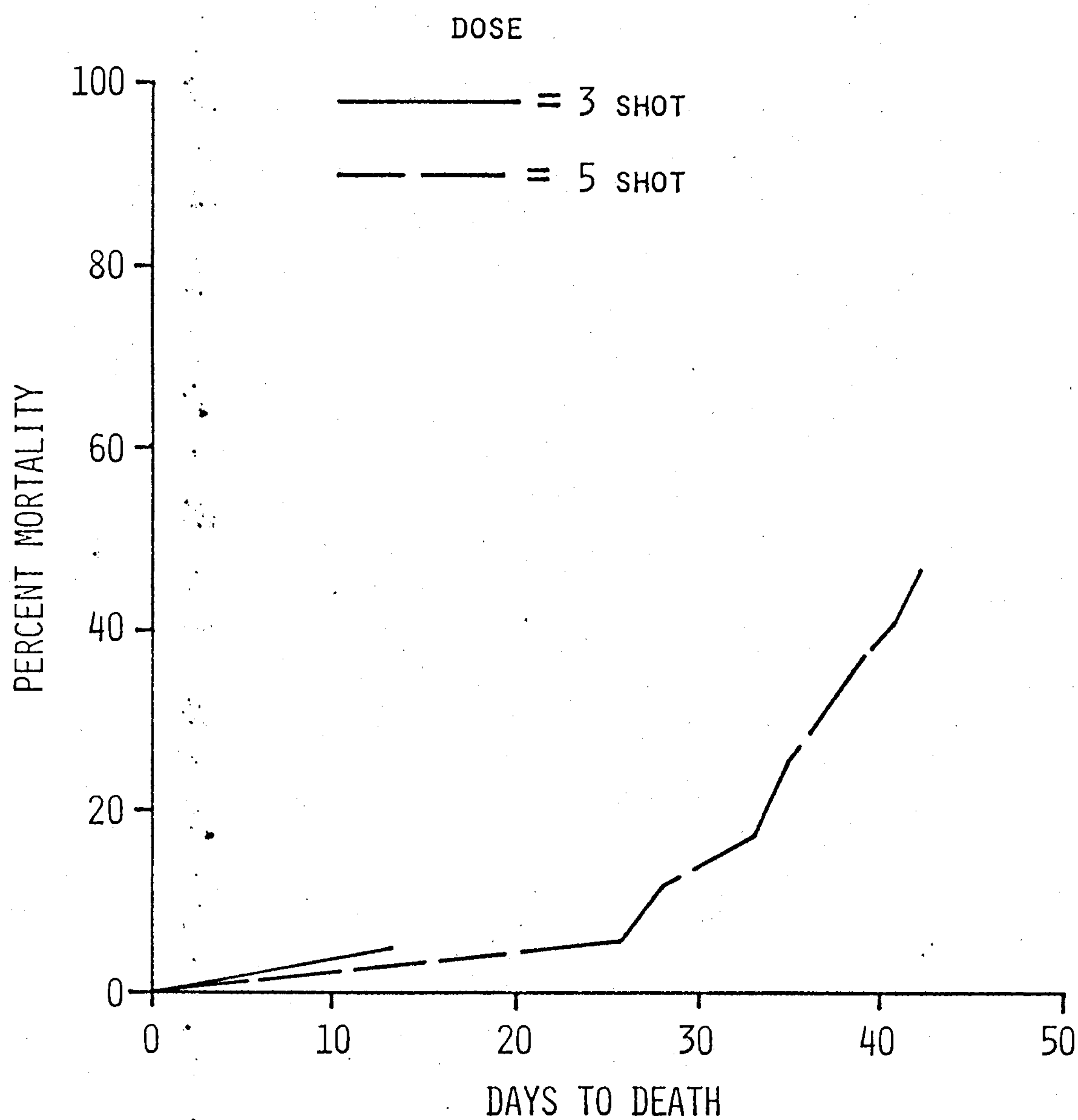

Fig. 2. Cumulative mortality in ducks dosed with lead:iron shot containing 45 percent Pb--Phase III.

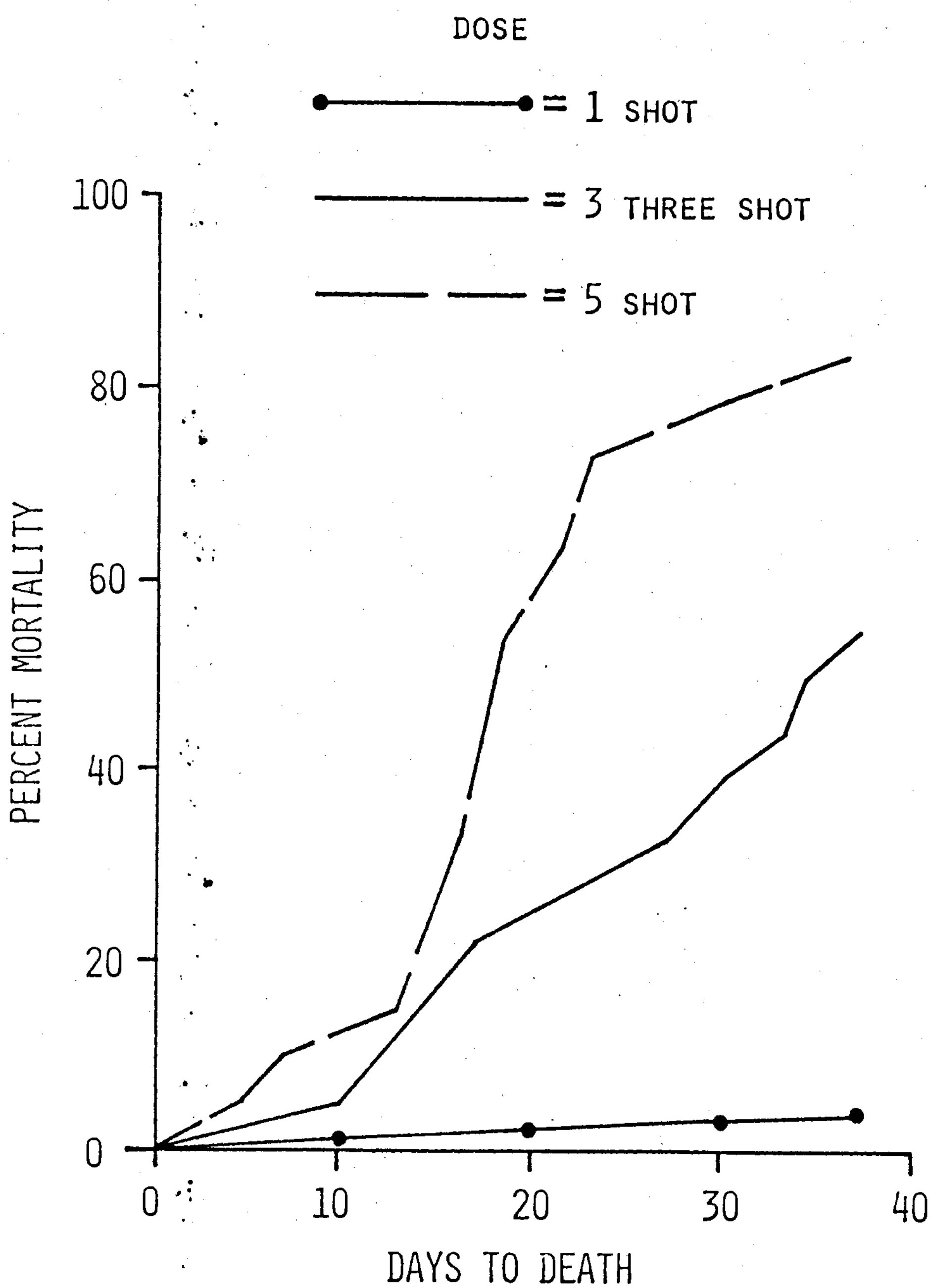

Fig. 3. Cumulative mortality in ducks dosed with lead:iron shot containing 58 percent Pb--Phase III.

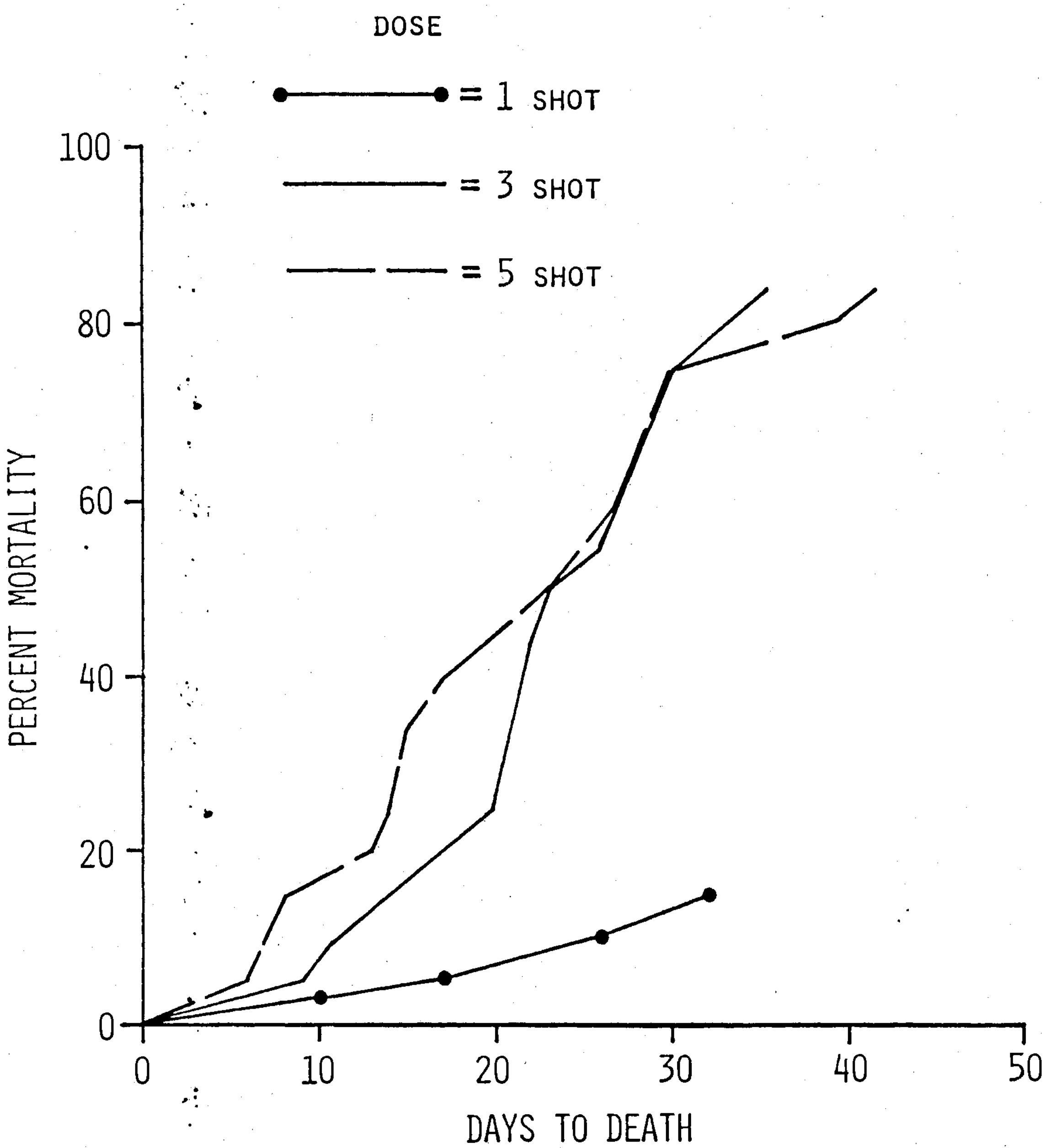

Fig. 4. Cumulative mortality in ducks dosed with lead:iron shot containing 63.8 percent Pb--Phase III.

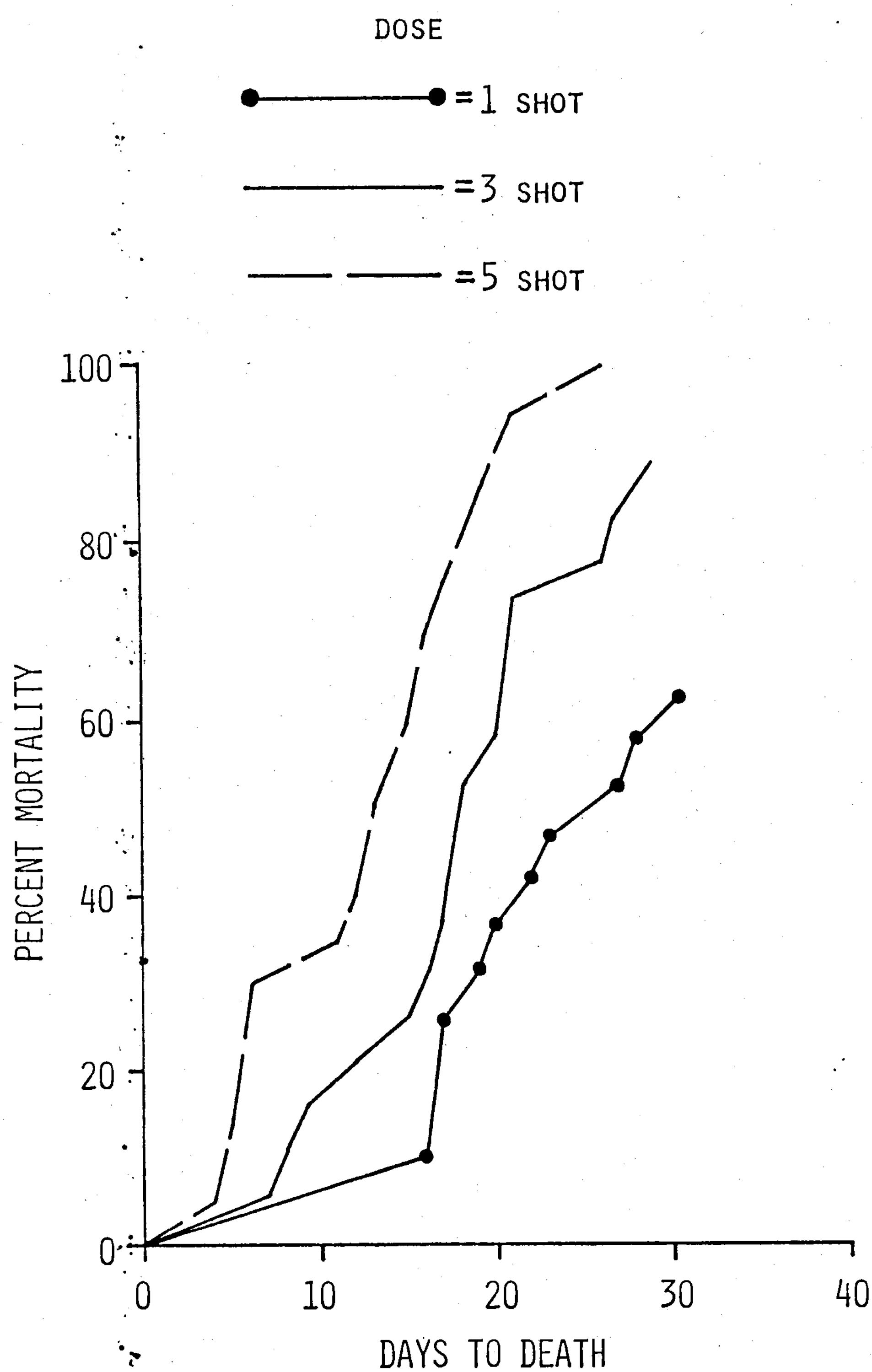

Fig. 5. Cumulative mortality in ducks dosed with commercial lead shot--Phase III.

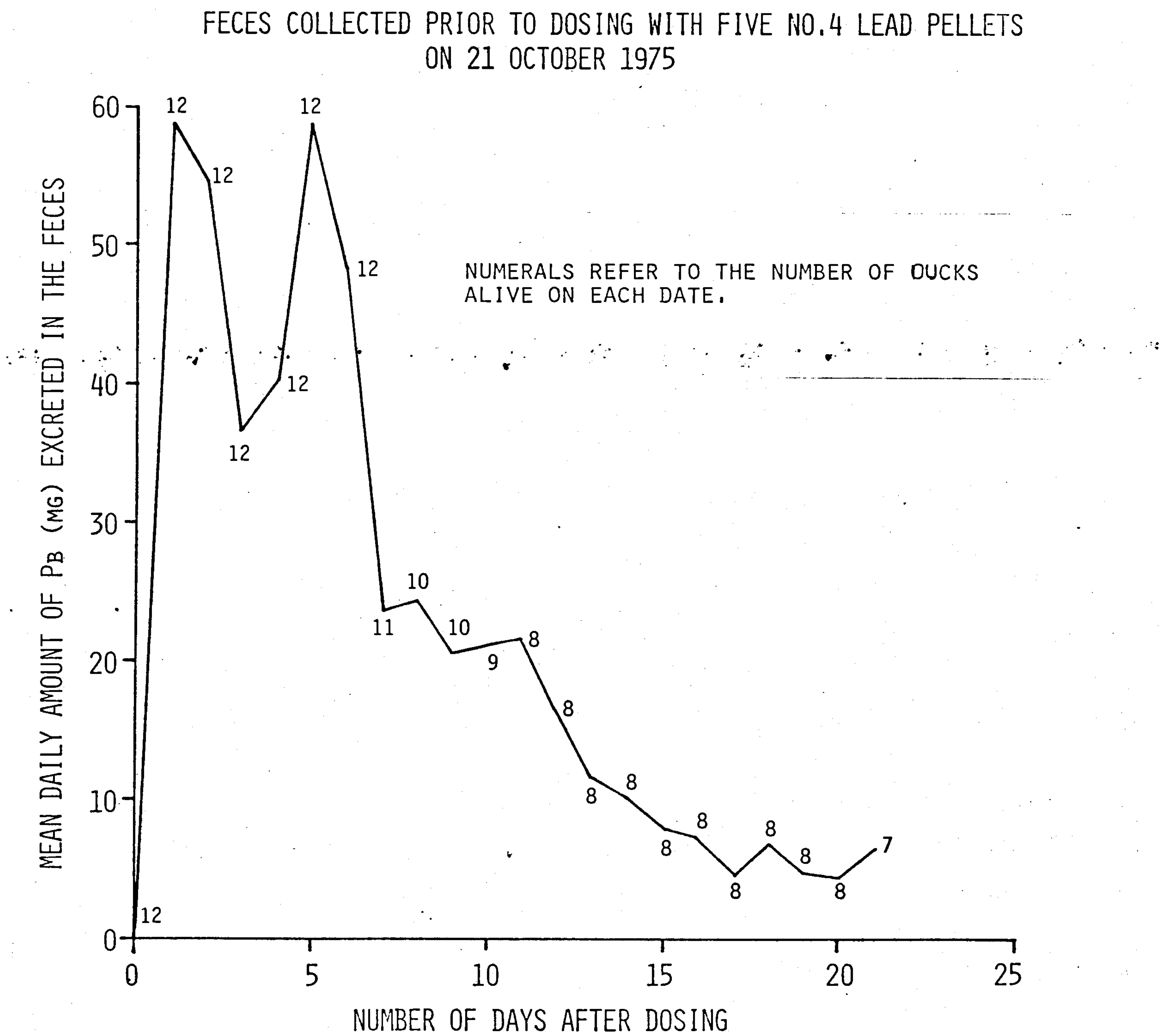

Fig. 6. Amount of lead excreted daily by female captive game-farm mallards in relation to date of dosing with five No. 4 commercial lead pellets--Phase VII (see Table 52).

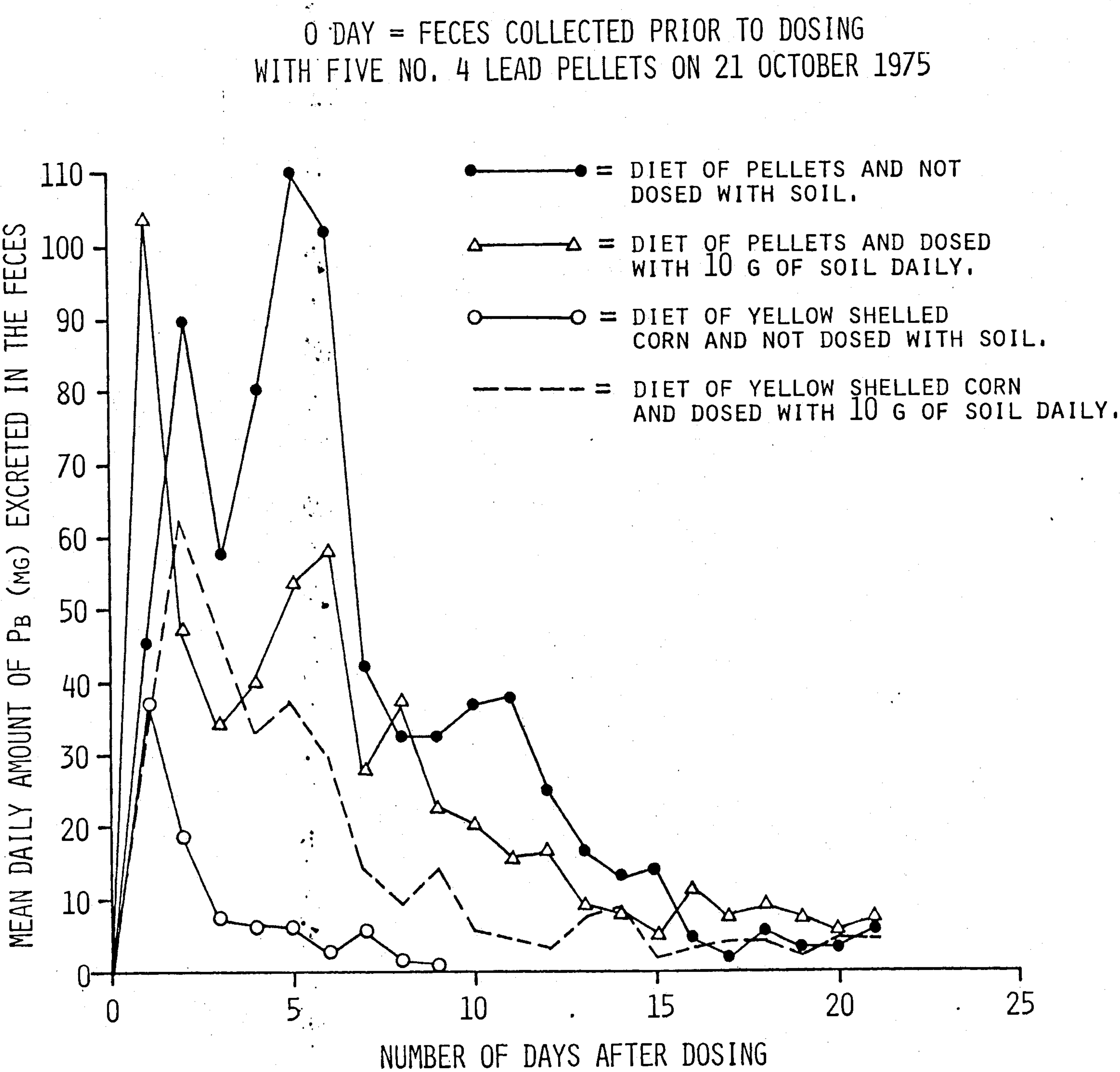

Fig. 7. Amount of lead excreted daily by female captive game-farm mallards as influenced by diet and soil--Phase VII (see Table 52).