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A Practical Guide to Nutrition, Feeds, and Feeding of Catfish

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Contents

List of Tables

Preface

Almost 5 years have passed since the publication of the first edition of this report on the status of catfish nutrition and feeding. During that time, several studies have been completed that impact both feed formulation and feeding practices. These new data have been included in the present report. In addition, sections on feeding and feed manufacture have been expanded to include in a single source information that has appeared in other MAFES bulletins. Much of the information presented remains unchanged. As in the original report, certain sections are presented in more detail and are more technical than others. Hopefully, the information is practical I and is presented in a usable manner. As stated in the original report, the information presented is intended as a guide because the feeding of catfish, though based on sound scientific evidence, remains in part an "art" as much as a science.

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Introduction

Early catfish producers depended primarily on natural pond organisms to provide nutrients essential for fish growth. Fish production was often enhanced by the addition of fertilizers to pond water to stimulate the growth of natural food organisms. Prepared feeds, mixtures of feedstuffs processed into various forms, were used to supplement natural productivity. Supplemental feeds were largely steam-pelleted (sinking) feeds that provided protein and energy, but were generally deficient in micronutrients such as vitamins, minerals, and essential fatty acids. Requirements for some micronutrients were met from those present in feed ingredients and/or natural foods.

Supplemental feeds provided sufficient nutrition as long as fish were stocked at rather low densities (2,000-3,000/acre). As catfish culture became more intensive, with increased emphasis on high yield resulting in a three- to five-fold increase in stocking densities, the contribution of natural food decreased. Thus, feed quality and feeding practices became a critical issue. Nutritionally complete feeds that provided all known nutrients required by catfish as well as sufficient energy needed for their metabolism were developed and manufactured either by steam pelleting into sinking pellets or by extrusion to make pellets that would float on the water surface. To optimize profits, catfish producers must feed a nutritionally complete feed in a prudent manner to avoid waste. Nutrition, feeds, feed manufacture, and feeding of catfish are discussed in the following sections.

Nutrition

Nutrition is the process by which an organism takes in and assimilates food. Nutrition involves the ingestion, digestion, absorption, and transport of various nutrients throughout the body where the nutrients in foods are converted into body tissues an d activities. In addition, nutrition also includes the removal of excess nutrients and other waste products. Nutrition is a complex biological science. It is an inexact science because of the natural variability between individuals of a given species. Also o, nutrition is affected by sex, feed intake, dietary energy, nutrient interactions, nutrient availability, presence of toxins or mold in the diet, expected level of performance, desired carcass composition, and environmental factors.

The nutrition of catfish is similar to that of other animal species. That is, catfish require the same nutrients as other animals for normal metabolic function. However, the specified amount of a particular nutrient needed by catfish may differ from at of other animals. Nutrient requirements of catfish have been determined. A discussion of energy, nutrient requirements, and digest ion follows.

Energy

Energy, which is defined as the capacity to do work, is essential to life processes during all stages of an animal's life. Quantitatively, energy is the most important component of the diet, because animals generally eat to satisfy an energy requirement t. Feeding standards for many animals are based on energy needs. Considerable information exists on energy needs of ruminant animals; less is known about the energy requirements of nonruminant species, particularly fish.

Solar energy is the ultimate source of energy. It is stored by plants and is available to animals to the extent they are able to digest plant materials. Animals that consume plants store part of the ingested energy and thus become sources of energy for carnivorous species that consume them. Animals derive energy from oxidation of organic compounds ingested in food or from stored lipid, protein, and to a lesser extent stored carbohydrate. These compounds are catabolized to yield energy, which is usually expressed in calories (1 kcal = 1,000 calories). The average total caloric values for protein, lipid, and carbohydrate are 5.65 kcal, 9.45 kcal, and 4.15 kcal/g, respectively.

However, all of the calories inherent in these compounds are not available to the body. The amount available is dependent upon the digestibility of each component. For example, when the caloric values given above are corrected for human digestibility and for the calories present as nitrogen in protein, they become 4.0 kcal, 9.0 kcal, and 4.0 kcal/g for protein, lipid, and carbohydrate, respectively. These values are termed physiological fuel values (PFV's) and have been used as caloric values for various food components in studies with fish. Though PFV's are not exact measures of the usable energy in food for various fish species, they are useful estimates of available energy when no data exist on the energy requirements of a particular species. Total energy should be corrected to usable energy by applying the digestion coefficients determined with the animal of interest.

Utilization and Expression. Perhaps the most notable difference between the nutrition of fish and farm animals is in energy utilization. More specifically, less energy is required for protein synthesis in fish. Energy needs are lower for fish than for warm-blooded animals because fish do not have to maintain a constant body temperature and they expend less energy to maintain their position in space. Losses of energy in urine and gill excretions are lower in fish because most nitrogenous waste is excreted as ammonia instead of urea or uric acid, which are excreted by mammals and birds, respectively. Also, the heat increment or increase in energy cost associated with the assimilation of ingested food is less in fish.

Dietary energy should be expressed in a manner that reflects available (utilizable) energy. Gross energy, which is a measure of the heat liberated on complete oxidation of a compound, is not a practical indicator of usable energy because certain compounds are not as digestible as others. As an example, gross energy for starch and cellulose is similar but the digestible energy, defined as gross energy minus fecal energy losses, from starch for catfish is about 2.5 kcal to 3.0 kcal/g and essentially zero for cellulose. Since gross energy is of little practical value in expressing usable energy values for catfish, digestible energy is often used to express the dietary energy of catfish feeds. Metabolizable energy, digestible energy minus energy losses from the urine in livestock or urine and gills in fish, is used to express energy content of feeds for livestock. Theoretically, using metabolizable energy to express dietary energy may be more desirable than using digestible energy, since metabolizable energy is a more precise measure of available energy for metabolism. Also, metabolizable energy has been adopted by the National Research Council for use in formulating animal feeds. However, in a practical sense, there is little advantage in using metabolizable energy values rather than digestible energy values in formulating fish feeds because losses in digestion account for most of the variation in losses of gross energy. Also, energy losses through the gills and urine by fish are smaller than nonfecal losses in other animals, and these losses do not vary among feedstuffs as much as fecal losses.

Requirements. Energy requirements of catfish were largely neglected in the early stages of catfish feed development, primarily because an imbalance in dietary energy does not appreciably affect the health of the fish. Also, feed prepared from feedstuffs typically used in catfish feeds, such as soybean meal, corn, and fish meal, are unlikely to be extreme in respect to energy balance. As it turns out, these assumptions were more or less true. However, correct balance of dietary energy is an important consideration when formulating catfish feeds, because too much energy can result in a reduction in food intake and thus reduce nutrient intake. Also, excess dietary energy may result in an increased deposition of body fat. If the dietary energy level is too low, protein will be used for energy instead of tissue synthesis.

Energy requirements for catfish have been based on weight gain or on composition of gain and have been reported as a ratio of calories to dietary protein. Energy requirements for catfish are tentative because, in the various studies, dietary energy was generally estimated from metabolizable energy values of other species or calculated using PFV's. Also, feeding rates varied between studies, and in studies conducted in ponds, the contribution of natural food was not accounted for.

Based on current information, it appears that a digestible energy level of 8 to 9 kcal/g of protein is adequate for use in catfish feeds. Thus, a 32% protein feed should contain a digestible energy level of about 1,200 to 1,300 Kcal/lb of feed. Increasing dietary energy may result in increased weight gain, but body fat is also likely to increase. Energy requirements change with environmental temperature. Increasing the ratio of digestible energy to protein when environmental temperature deviates from optimum appears to be beneficial. Research is currently underway to more precisely define the energy requirements of catfish, particularly under extremes in environmental temperature.

Nutrients

Qualitatively, 40 nutrients have been identified as necessary for the normal metabolic function of catfish. The quantitative requirements for most nutrients have been identified for catfish (Tables 1-4).

Nutritional requirements for catfish have generally been based on studies with small fish conducted under conditions presumed to be near optimum, the requirement being based primarily on weight gain and feed efficiency. Presently, there is considerable interest in practical nutrient requirements for catfish. Studies are currently underway to more precisely define nutrient requirements of catfish under conditions that reflect commercial culture practices. Those data that are available are included in the following sections on the various nutrients.

Carbohydrates. Carbohydrates are compounds of carbon, hydrogen, and oxygen, which include sugars, starch, cellulose, gums, and other closely related compounds. Carbohydrates are the major constituent of plants, comprising 50% to 80% of the dry weight of various plants. They form the structural framework of plants and are the primary form of energy stored in seeds, roots, and tubers. Plants synthesize carbohydrates from solar energy, carbon dioxide, and water through the process of photosynthesis.

Animal tissues contain small amounts of stored carbohydrate. Glucose in the blood of animals is relatively constant at about 0.05% to 0.1%. Circulating glucose is utilized for energy and is replenished from stores of glycogen in the liver. Generally glycogen stores in the liver are small, representing only about 3% to 7% of liver weight in most animals. Excess ingested carbohydrate is converted to and stored primarily as lipid.

Although carbohydrates are the least expensive source of energy for use in animal feeds, their role in fish nutrition remains somewhat obscure. Enzymes for the major pathways involved in carbohydrate metabolism have been detected in several fish specie s. However, it appears that hormonal and metabolic control of carbohydrate metabolism in fish may differ from that of mammals.

The utilization of carbohydrate by catfish appears to differ depending on the complexity of the carbohydrate. Starch or dextrin (partially hydrolyzed starch) is used more efficiently by catfish than are sugars such as glucose or sucrose. It has generally been thought that catfish and certain other fish resemble diabetic animals by having insufficient insulin for maximum carbohydrate utilization. However, recent information has shown that insulin levels in fish are about the same as those found in mammals, which indicates that fish are not diabetic. Glucose is highly digestible by catfish, but apparently a large portion of the absorbed glucose is excreted.

Although catfish use carbohydrate effectively, there is no dietary requirement for carbohydrate. Carbohydrates are important dietary components as an inexpensive source of energy, as precursors for various metabolic intermediates, as an aid in pelletin g practical catfish feeds, and in reducing the amount of protein used for energy thereby sparing protein for growth.

A typical commercial catfish feed contains 25% or more soluble (digestible) carbohydrate. An additional 3 to 6% carbohydrate is generally present as crude fiber. Fiber is considered to be indigestible by catfish; thus, it is not desirable in catfish feeds because indigestible materials may "pollute" the water. However, there is always some fiber inherent in practical feed ingredients.

Lipid. The use of lipids (fats and oils) in catfish feeds is desirable because lipids are a highly digestible source of concentrated energy (containing about 2.25 times as much energy as does an equivalent amount of carbohydr ate), supply essential fatty acids, serve as a vehicle for absorption of fat-soluble vitamins, increase feed palatability, and serve as precursors for steroid hormones and other compounds. In their storage form, lipids affect the flavor for fish as well a s help maintain neutral buoyancy. The type and amount of lipid used in catfish diets are based on essential fatty acid requirements, economics, constraints of feed manufacture, and quality of fish flesh desired.

Essential fatty acids (EFA's) are fatty acids that cannot be synthesized in the animal's body; thus, they must be provided in the diet. EFA's are classified based on their chemical structure and are designated as either omega-3 (n3) or omega-6 (n6) fatty acids. In general, fish appear to require n3 fatty acids while land animals appear to require n6 fatty acids. This generalization does not always hold. Certain fish (including some species of tilapia and carp) apparently require both n3 and n6 fatty ac ids. EFA requirements for catfish and most other warmwater fish have not been precisely defined, but catfish apparently require a small amount of n3 fatty acids. It appears that 1 to 2% dietary linolenic acid (18:3 n3) is as good as 0.5 to 0.75% highly unsaturated fatty acids for normal growth, because catfish apparently elongate and desaturate linolenic acid to synthesize highly unsaturated fatty acids. The EFA requirement can be supplied by marine fish oil such as menhaden oil. Natural pond food organisms may also be a source of EFA. For example, plankton contain relatively high levels of EFA.

Catfish appear to have the ability to synthesize most of their fatty acids; thus, nutritionally there may be no "best" level of dietary lipid except that needed to provide EFA. Generally, weight gain and feed efficiency are depressed in aquatic species when fed diets containing 15% or more lipid. Catfish have been fed diets containing up to 16% lipid without conclusive evidence as to which level is best for optimum growth. Even so, there is likely an optimum level of lipid to be used in catfish feeds with respect to protein sparing, product quality, and constraints of feed manufacture.

Since lipid is a concentrated source of energy and can spare the more expensive protein, some lipid should be included in catfish diets. However, too much dietary lipid may result in excessive fat deposition in the visceral cavity and tissues that may adversely affect yield, product quality, and storage of processed products. Also, high-lipid feeds are difficult to pellet. If needed, supplemental lipid can be sprayed on to the finished feed pellet. Lipid levels in commercial catfish growout feeds rarely exceed 5 to 6%. About 3 to 4% of the lipid is inherent in the feed ingredients with the remaining 1 to 2% being sprayed on to the finished pellets. Spraying feed pellets with lipid increases dietary energy and aids in the reduction of "fines."

A mixture of vegetable and animal lipids has been used in commercial fish feeds. These were recommended over marine fish oils because high levels of fish oil may impart "fishy" flavors to the fish flesh. In addition, there is evidence that levels of menhaden oil as low as 2% of the diet reduce survival of catfish exposed to the bacterial pathogen *Edwardsiella ictaluri*. This is likely caused by the immunosuppressive effect of highly unsaturated n3 fatty acids. Catfish feeds manufactured in Mississippi are generally sprayed with catfish oil, which is a local product extracted from catfish offal. In some cases, menhaden oil or a mixture of catfish oil and menhaden oil is used. It may be wise to restrict menhaden oil to no more than 1% of the diet.

Protein and Amino Acids. Protein comprises about 70% of the dry weight of fish muscle. A continual supply of protein is needed throughout life for maintenance and growth. Catfish, like other animals, actually do not have a protein requirement, but require a source of nonspecific nitrogen and indispensable amino acids. Usually, the most economical source of these elements is a mixture of proteins in feedstuffs. Ingested proteins are hydrolyzed to release amino acids that may be used for synthesis of tissue proteins or, if in excess, utilized for energy. Use of protein for energy is expensive; thus, catfish feeds should be balanced to assure that adequate levels of nonspecific nitrogen, amino acids, and nonprotein energy are supplied in proper proportions.

The requirements for proteins and their structural components, amino acids, have been studied in catfish for several years. Yet there is still a debate as to which level of dietary protein provides for cost-effective growth. The level of dietary protein and amino acids needed for the most economical gain may differ as the costs of feed ingredients vary. In addition, it is difficult to set a level of protein that is optimum for all situations because of the factors that affect the dietary protein requirement of catfish. These include water temperature, feed allowance, fish size, amount of nonprotein energy in the diet, protein quality, natural food available, and management practices.

Most of the studies on protein requirements of fish have been based on weight gain and feed efficiency. Data from those studies indicate that the dietary protein requirement for catfish ranges from about 25 to 50% (Table 1). Recent studies have indicated that a protein level as low as 16% may be adequate for growout of catfish when the fish are fed full feed during the growing season. The rationale behind these studies is that the optimum dietary protein level is driven by economics as much as rate of gain. Thus, to maximize profits, the optimum dietary protein level should be changed as fish and feed prices change.

Although we speak of a protein requirement, it is more precise to formulate fish feeds on the basis of amino acid requirements. Nutritionally amino acids may be classified as indispensable (essential) or dispensable (nonessential). An indispensable ami no acid is one that the animal cannot synthesize or cannot synthesize in quantities sufficient for body needs; thus, it must be supplied in the diet. A dispensable amino acid is one that can be synthesized by the animal in quantities sufficient for maxima l growth. Most simple-stomached animals, including catfish, require the same 10 indispensable amino acids (Table 2). There are differences between the amino acid requirements among various species of animals as well as among fish species, but that would be expected since the relative proportion of structural proteins may vary between species as well as physiological needs for certain amino acids.

Although dispensable amino acids can be synthesized by catfish, there are certain advantages if they are provided in the diet. For example, if they are in the diet, energy is saved in their synthesis and some dispensable amino acids can partially replace an indispensable amino acid (cystine can replace about 60% of the methionine, and tyrosine can replace about 50% of the phenylalanine). Practical catfish feeds contain liberal amounts of dispensable amino acids inherent in the proteins of various feeds tuffs.

In a practical feed, amino acid requirements are best met by feeding a mixture of feedstuffs or by using a mixture of feedstuffs supplemented with amino acids. There has been much debate among fish nutritionists concerning the use of supplemental amino acids by fish. However, data indicate that amino acids are effectively used by catfish when supplemented into a practical feed. In practice, lysine (which is the first limiting amino acid in catfish feeds) will likely be the only supplemental amino acid used in commercial catfish feeds.

Vitamins. Vitamins are highly diverse in chemical structure and physiological function. They are generally defined as organic compounds that are required in small amounts in the diet for normal growth, health, and reproduction by one or more animal species. Some vitamins may be synthesized in the body in quantities sufficient to meet metabolic needs, and thus are not required in the diet.

Characteristic vitamin deficiency signs can be induced in catfish fed diets deficient in a particular vitamin, at least under experimental conditions (Table 3). Vitamin deficiencies are rarely encountered in natural populations of fish. Vitamin C and p antothenic acid deficiencies have been documented in commercially cultured catfish. The addition of sufficient levels of these vitamins to catfish feeds eliminate deficiency problems.

Qualitative and quantitative vitamin requirements for catfish have been fairly well defined (Table 3). Vitamin requirements for catfish have generally been determined with small rapidly growing fish. These values are considered to be sufficient to meet the needs of larger fish; however, vitamin requirements are affected by fish size, growth rate, stage of sexual maturity, diet formulation, disease, and environmental conditions. The interrelationships among these factors and the vitamin needs of fish have not been adequately defined.

Catfish feeds are generally supplemented with a vitamin premix that contains all essential vitamins in sufficient quantities to meet the requirement and to compensate for losses due to feed processing and storage (vitamin losses during storage are not a major factor in the Mississippi Delta and other places where feed is generally not stored for more than 2 to 3 days).

Vitamins present in feedstuffs are usually not considered during feed formulation because their bioavailability is not known, but they certainly contribute to the vitamin nutrition of catfish. Natural food organisms may also be a source of vitamins for catfish. Zooplankton collected from commercial catfish ponds contain all vitamins, some in relatively high concentrations (see natural foods under section on "feeding"). Although many nutritionists discount the contribution of natural foods to the nutrition of catfish, we have data that indicate that these foods may contribute to the micronutrient requirements of catfish.

We have conducted several studies on the growout of catfish in earthen ponds in which the fish were fed a diet with and without supplemental vitamins, and the results have consistently indicated no differences in any parameter measured. This is not to imply that supplemental vitamins are not needed in catfish diets. However, it may be that the concentrations of certain vitamins can be reduced or that certain vitamins can be removed from the vitamin premix without affecting fish performance. Studies are currently underway to determine practical vitamin requirements for catfish. Composition of vitamin premixes for use in practical catfish feeds are discussed under "feed formulation."

There has been considerable interest among catfish researchers and catfish producers concerning the use of megadose levels of certain vitamins, particularly vitamin C, to enhance disease resistance in catfish. Early evidence indicated that high levels of vitamin C (10 times or more than the level needed for normal growth) reduced mortality from certain bacterial diseases affecting catfish. As a result some catfish producers fed a high-C feed, which contained about 900 mg vitamin C/lb, during late winter or early spring, presumably to enhance the immune system of catfish. More recent results from at least six studies do not show an advantage to using high levels of dietary vitamin C for disease resistance in catfish. Data from these studies indicate that catfish response to dietary vitamin C during disease challenge is an "all or none" type of response. That is, if vitamin C is not present, then mortalities are increased during disease challenge but if vitamin C is present in the diet mortalities are significantly reduced. Concentrations as low as 25 ppm vitamin C have been shown to enhance survival of catfish during challenge with the bacterium *Edwardsiella ictaluri*. There is evidence that the vitamin C requirement of catfish is as low as 15 ppm. Commercial catfish feeds manufactured in the Mississippi Delta generally contain about 100 ppm vitamin C in the final feed. This level can likely be reduced by at least 50% without detrimental effect on fish performance.

Minerals. The same minerals required for metabolism and skeletal structure of other animals are apparently required by catfish. Catfish also require minerals for osmotic balance between body fluids and their environment, some of which can be absorbed from the water. Minerals may be classified as macrominerals or microminerals, depending on the amount required in the diet. Macrominerals are required in relatively large quantities; microminerals are required in trace quantities . Mineral nutrition studies with fish are complicated by dissolved minerals found in the water. For example, a dietary calcium requirement can only be demonstrated in catfish reared in calcium-free water. In water containing sufficient calcium, catfish can meet their calcium requirement by absorption of calcium from the water. Fourteen minerals are considered to be essential for catfish. Although mineral studies with fish are difficult to conduct, deficiency signs and quantitative requirements for macro- and micro-minerals have been determined for catfish (Table 4).

Among macrominerals, phosphorus is particular important in fish feeds because fish require a relatively large quantity of the mineral in the diet. Feedstuffs, especially those of plant origin, are poor sources of biological available phosphorus, and fish do not obtain significant amount of phosphorus from pond water. As a result, catfish feeds are usually supplemented with phosphorus. Dicalcium and defluorinated phosphates are commonly used as phosphorus supplements in catfish feeds. Catfish growth dat a from both laboratory and pond studies have indicated that defluorinated phosphates have essentially the same nutritional value as dicalcium phosphate. Because defluorinated phosphates are much less soluble in water than dicalcium phosphate, their use in catfish feeds may reduce phosphorus levels in pond water, which may be beneficial in controlling phytoplankton density in pond water and reducing total phosphorus levels in pond effluents.

Plant feedstuffs are poor sources of phosphorus for animals. Approximately two-thirds of phosphorus in feedstuffs of plant origin is in the form of phytate, a bound form of phosphorus that is poorly available to fish. Studies have demonstrated that phytase enzymes can be used in animal feeds (including catfish) to release phytate phosphorus making it available for use.

Catfish feeds are typically supplemented with a trace mineral premix that contains all trace minerals in sufficient amounts to meet or exceed dietary requirements of catfish (composition discussed under "feed formulation"). However, there is evidence that supplemental trace minerals are not needed particularly in diets containing animal proteins. Research on practical mineral nutrition of catfish is ongoing.

Digestion

Digestion is generally thought of as a series of processes that take place in the gastrointestinal tract to prepare ingested food for absorption. These processes involve mechanical reduction of particle size and solubilization of food particles by enzymes, low pH, or emulsification. Once digestion has occurred, absorption (the uptake of small molecules from the gastrointestinal tract into the blood or lymph) may occur by diffusion, active transport, or by pinocytosis (engulfment).

Specific digestive processes have not been extensively studied in catfish, but digestion in catfish is presumed to be similar to that of other simple-stomach animals. The divisions of the digestive tract of catfish is similar to that of other simple-stomach animals and include the mouth, pharynx, esophagus, stomach, and intestine, as well as the accessory digestive organs pancreas, liver, and gall bladder. The pH of the stomach and intestine of catfish ranges from 2 to 4 and 7 to 9, respectively. The digestive enzymes trypsin, chymotrysin, lipase, and amylase have been identified in catfish intestines.

To formulate feeds, it is important to know the digestibility of feedstuffs to a particular species of fish. Digestibility coefficients provide an estimate of the usefulness of feedstuffs and of finished feeds.

Digestibility coefficients are more difficult to determine with fish than with terrestrial animals, because nutrients can be lost to the water from the feed or from fecal material collected from the water. Although determining digestibility coefficient s is problematic with fish, they have been determined for commonly used feed ingredients for catfish (Tables 5 - 9).

Protein digestibility coefficients for feedstuffs (Table 5) are useful in formulating feeds, but a more precise feed formulation can be derived if one uses amino acid availability (Table 6) as the basis for formulating feeds rather than digestible protein. For example, the protein digestibility of cottonseed meal to catfish is about 84%; whereas, the lysine availability is only about 66%. If feeds are formulated on a protein basis using cottonseed meal, a lysine deficiency may result. The major problem in formulating catfish feeds on an available amino acid basis is the lack of sufficient data.

Digestion coefficients for energy (Table 7) and lipid and carbohydrate (Table 8) have been determined for catfish. Lipids are particularly good energy sources for catfish. Starches are not digested as well as lipids by catfish, but the digestibility of starch by warmwater fish is higher than that of coldwater fish. The level of carbohydrate in the diet appears to affect starch digestion. Starch and dextrin digestion decrease as the dietary level of starch increases. The predominant sources of carbohydrate in catfish feeds are grain products, which are 60 to 70% digestible.

The availability of minerals from feedstuffs has not been studied to any extent in catfish. Phosphorus availability has been determined for various sources of phosphorus to catfish (Table 9). Generally, phosphorus from plant sources is only about 30-50% available to catfish; phosphorus from animal sources is about 40-80% available.

Feeds

Although natural food organisms may provide certain nutrients (particularly micronutrients such as vitamins and fatty acids), the contribution of pond organisms to the nutrition of intensively cultured catfish is generally considered to be small. Thus, the nutritional requirements of cultured catfish are met by using a complete feed, that is, a feed formulated to provide all required nutrients in the proper proportions necessary for rapid weight gain, high feed efficiency, and a desirable composition of gain. Feed cost represents about one-half of variable production costs in catfish culture; thus, careful consideration should be given to feed selection and use.

Feed Ingredients

No single feedstuff can supply all of the nutrients and energy required for optimum growth of catfish. Thus, commercial catfish feeds are comprised of a mixture of feedstuffs and vitamin and mineral premixes that provide adequate amounts of essential nutrients as well as the energy necessary for their utilization. The amount of each feed ingredient used depends on several factors including nutrient requirements, ingredient cost, availability of each ingredient, and processing characteristics. The effects of feedstuffs on feed manufacturing are discussed under "feed manufacture."

Protein Supplements. Feedstuffs containing 20% crude protein or more are considered protein supplements. Protein supplements may be classified as animal and plant proteins. Animal proteins used in animal feeds come from inedible tissues from meat packing or rendering plants, milk products, and marine sources. Those typically used in catfish feeds include fish meal, meat and bone meal, and blood meal. Animal proteins are generally considered to be of higher quality than plant proteins, primarily because of their superior complement of indispensable amino acids. Animal protein is essential in the diet of fry and small fingerling catfish. Fish meal prepared from whole fish appears to be a better protein supplement than other animal proteins. Fish meal does not appear to be essential in the diet of catfish after they reach a size of 6-7 inches. Fish meal can be completely replaced by meat and bone meal or meat and bone/blood meal in diets for growout catfish. There is also evidence that animal proteins can be completely replaced by plant proteins in catfish growout feeds without affecting growth and feed efficiency.

The primary plant protein sources used in catfish feeds are oilseed meals, such as soybean meal, cottonseed meal, and peanut meal. Certain other oilseed meals could be used, but are not generally available on a timely basis and at an economical cost per unit protein. Compared to animal proteins, most plant proteins are deficient in lysine and methionine, the two limiting amino acids in catfish feeds. Also, certain plant proteins contain toxins and antinutritional factors that may or may not be inactivated during processing of the meal. A brief description of various animal and plant protein sources that can be used in catfish feeds is given below as well as a summary of commonly used protein supplements (Table 10).

- Fish Meal. Fish meal is prepared from dried, ground tissues of undecomposed whole marine fish or fish cuttings such as menhaden, herring, or white fish. Fish meal contains 60 to 80% protein of excellent quality that is highly palatable to catfish. Since fish meal is a good source of essential amino acids, it is often used to supplement feeds containing plant proteins. Fish meal is also rich in energy, minerals, and essential fatty acids. It is used at levels up to 50% in catfish fry feeds, up to 12% in catfish fingerling feeds, and from 0 to 8% in catfish growout feeds.

- Meat and Bone Meal. Meat and bone meal is the rendered product from beef or pork tissues and should not contain blood, hair, hoof, horn, hide trimmings, manure, or stomach and rumen contents except in amounts as may be unavoidable during processing. Meat and bone meal contains approximately 50% crude protein. Its protein quality is inferior to whole fish meal because it contains less lysine and the consistency of the product may vary considerably. It is good source of minerals. Its high ash content may limit its use because of possible mineral imbalance. The maximum level recommended for catfish feeds is 15%.
- Blood Meal. Blood meal is prepared from clean, fresh animal blood, excluding hair, stomach belchings, and urine except in trace quantities that are unavoidable. It contains 80 to 86% crude protein and is an excellent source of lysine. It is deficient in methionine. Levels up to 5% can be used in catfish feeds.
- Meat and Bone/Blood Meal Blend. Special products are available for use in catfish feeds that are mixture of meat and bone meal and blood meal. The two feedstuffs are mixed to give the desired nutritional characteristics. Generally, the blend mimics the nutritional profile of menhaden fish meal and provides 60-65% protein. Blended products are an excellent protein source for use in catfish feeds and are generally used to replace fish meal.
- Catfish Offal Meal. Catfish offal meal is prepared from catfish processing waste, primarily heads, frames, and visceral organs. The product contains approximately 50% protein. It is of better nutritional quality than meat and bone meal, but not as goo d as menhaden fish meal. It is highly palatable to catfish; however, it is seldom used in catfish feeds because it is not available in adequate amounts throughout the growing season.
- Poultry Byproduct Meal. Poultry byproduct meal is made up of ground, rendered or clean parts of the carcass of slaughtered poultry. It contains heads, feet, underdeveloped eggs, and visceral organs but does not contain feathers. The product contains approximately 59% good quality protein, but it is seldom used in catfish feeds because it is not available on a regular basis at a reasonable cost per unit of protein.
- Hydrolized Poultry Feathers. Hydrolyzed poultry feathers prepared by the treatment under pressure of clean, undecomposed feathers from slaughtered poultry. At least 75% of the protein should be digestible as measured by pepsin digestion. It is high in protein (85%), but protein quality is not as good as other animal protein sources. Although amounts up to 5 to 10% can be used in catfish feeds, it is rarely used.
- Solvent-Extracted Soybean Meal. Dehulled, solvent-extracted soybean meal is prepared by grinding the flakes after removal of the oil from dehulled soybeans by solvent extraction. Dehulled, solvent-extracted soybean meal contains 48% protein and is the predominant protein source used in catfish feeds. It has the best amino acid profile of all common plant protein sources and is highly palatable and digestible to catfish. Antinutritional factors are destroyed or reduced to insignificant levels with heat that is applied during the extraction process. Levels of soybean meal up to 60% have been used in commercial catfish feeds without detrimental effect.
- Heated, Full-Fat Soybean Meal. Full-fat soybean meal is prepared by grinding heated full-fat soybeans. The meal contains 39% protein and 18% fat. It is rarely used in catfish feeds because of its high fat content. A limited amount can be used in catfish feeds as long as the total fat level in the finished feed does not exceed about 6%.
- Solvent-Extracted Cottonseed Meal. Solvent-extracted cottonseed meal is obtained by grinding the cake remaining after the oil has been solvent extracted. The product generally contains 41% protein but must not contain less than 36% protein. It is highly palatable to catfish but is deficient in lysine. Cottonseed meal contains free gossypol and cylcopropenoic acids, which can be toxic; however, levels of these

chemicals in commonly available cottonseed meal are generally well below toxic levels. Level s of cottonseed meal should not exceed 30% of the feed for catfish unless supplemental lysine is used. Cottonseed meal is generally used in catfish feeds at a level of 10 to 15%.

- Peanut Meal. Peanut meal is obtained by grinding shelled peanuts, with the oil removed either mechanically or by solvent extraction. Solvent-extracted peanut meal contains 48% protein and the mechanically extracted product contains 45% protein. Peanut meal is highly palatable to catfish and contains no known antinutritional factors. It is deficient in lysine. Levels used in catfish feeds are restricted to 15 to 20% without lysine supplementation. Peanut meal is seldom used in catfish feeds because of its sporadic availability.
- Distillers' Dried Grains with Solubles. Distillers' dried grains with solubles are the primary fermentation residues, after removal of the alcohol by distillation, from the yeast fermentation of cereal grains. The product contains approximately 27% protein and is highly palatable to catfish. Levels up to 25 to 30% can be used in catfish feeds. If higher levels are used, supplemental lysine may be needed.
- Sunflower Meal. Sunflower meal is prepared by grinding the residue remaining after mechanical or solvent extraction of the oil from sunflower seeds. Dehulled sunflower meal is prepared from sunflower seed after the hull is removed. Solvent-extracted sunflower meal contains about 44% protein. The hulls are not easily removed so the meal contains around 13% fiber. Higher levels of fiber are found in meals that are not dehulled. Sunflower meal can be used in catfish feeds to replace part of the soybean meal. Its low lysine content and high level of fiber limit its usefulness in catfish feeds. A level of up to about 20% without lysine supplementation is acceptable for catfish feeds.
- Canola Meal. Canola meal is prepared from a special rapeseed by solvent extraction to remove the oil. Compared to typical rapeseed meal, canola meal is low in glucosinolates and erucic acid, which may be detrimental to fish growth. Canola meal contain s about 38% protein and is relatively low in lysine as compared to soybean meal, but lysine content in canola meal is higher than other oilseed meals. It is palatable to catfish and can be used at levels up to about 20 to 25% without supplemental lysine. It is seldom used in catfish feeds because of lack of availability.

Energy supplements. Energy supplements are feedstuffs that contain less than 20% crude protein. These include grain and grain byproducts, and animal fat or vegetable oil. Energy sources typically used in commercial catfish feeds include corn, corn screenings, wheat grain, wheat middlings, rice bran, milo, animal fat, and fish oil.

- Corn Grain and Corn Screenings. Corn and corn screenings are used interchangeably in commercial catfish feeds as a relatively inexpensive source of energy. Corn grain (whole corn) is ground prior to use. Corn screenings are obtained in the cleaning of corn and include light and broken corn grain. Cooking improves energy digestibility of corn for catfish. Corn contains a yellow pigment, xanthophyll, which, at high levels, has been shown to accumulate in catfish giving the flesh a yellowish coloration that is undesirable to consumers. Corn grain or screenings have been used in catfish feeds up to 45% of the feed without adverse effects. The digestible energy value of corn grain and corn screenings for catfish is about 1,150 kcal/lb.
- Wheat Grain. Wheat is a good source of energy for catfish, but is generally more expensive than corn. As a result, wheat grain has been used sparingly (2-5%) in catfish feeds, primarily for its pellet-binding properties. Wheat grain has a digestible energy value of about 1,160 kcal/lb for catfish.
- Wheat Middlings. Wheat middlings are fine particles of wheat bran, shorts, germ, flour recovered from milling wheat grain. Depending on cost, wheat middlings are used to replace corn or corn screenings levels up to about 25% in catfish feed. In humid areas (such as the Mississippi Delta), using levels greater than 25% may cause the feed to become sticky resulting in clumping of feed pellets and

handling problems. Low levels (2-5%) are often used to improve pellet binding. Wheat middlings have a digestible energy value of about 950 kcal/lb for catfish.

- Rice Bran. Rice bran is the bran layer and germ of rice grain with hulls or broken rice at levels only that are unavoidable in milling rice grain. It is high in fat and fiber, which limits its use in catfish feeds. Rice bran can be used in catfish feeds at levels of 3 to 5%. Rice bran has a digestible energy value of about 970 kcal/lb for catfish.
- Milo. Milo is chemically similar to corn, but somewhat higher in protein (11%). Milo is generally substituted for corn on weight-for-weight basis in catfish feeds. Energy value is assumed to be about same as corn for catfish. When milo is substituted for corn the feed is darker and more dense. Some varieties have high tannin concentration in seed coat and are not as palatable for certain animals. There are some unverified reports of decreased palatability when milo is substituted for corn in catfish feeds. Research with catfish conducted at the Delta Branch Experiment Station (DBES) did not demonstrate a difference in fish performance fed feeds containing either corn or milo.
- Animal and Plant Fats and Oils. Animal and plant fats and oils are highly concentrated sources of energy as well as a source of essential fatty acids. Animal fats used in catfish feeds include catfish offal oil, beef tallow, poultry fat, and menha den fish oil. Tallow is not recommended for use in winter feeds because it is a saturated fat. Plant oils can be used, but animal fats are generally preferred because they are generally less expensive. Currently catfish offal oil and menhaden oil are the two predominant oils used in commercial catfish feeds. There is evidence that levels of menhaden oil from about 2% or higher may reduce disease resistance in catfish. Often, the two are blended in equal parts or in a ratio of 75% catfish oil to 25% menhaden en oil. Supplemental fat is generally sprayed on the finished feed pellets at a rate of 1.5 to 2%, primarily to reduce feed dust ("fines"). Fats and oils have a digestible energy value of around 4,000 to 4,200 kcal/lb for catfish, depending on t he particular fat.

Premixes. Vitamin and mineral premixes are generally added to catfish feeds. They should be formulated to meet nutrient requirements and manufactured using digestible nutrient sources. Specifics of vitamin and mineral premixes used in catfish feeds are given below.

- Vitamins. Vitamin requirements of catfish have been fairly well studied. Catfish require a dietary source for 14 vitamins for proper metabolic function and normal growth. Most commercial feedstuffs used in catfish feeds contain vitamins, but the amount is often limited and the bioavailability of vitamins from feedstuffs is not known. Thus, commercial catfish feeds are supplemented with a vitamin premix that provides vitamins in quantities necessary to meet dietary requirements, including losses due to feed processing. Vitamins commonly added to commercial catfish feeds and the amounts recommended are given in Table 11. Recent data on vitamin stability during feed processing (Table 12) may allow a reduction in the amount of certain vitamins added to catfish vitamin premixes.
- Minerals. Although there have been a limited number of studies on the mineral requirements of catfish, particularly under typical rearing conditions, catfish appear to require the same minerals as other animals. Mineral studies with fish are complicated by the fact that fish can absorb certain minerals from the water. For example, catfish can meet their calcium requirement by absorption of calcium from water, if the water contains a sufficient amount of calcium.

  In addition to typical needs for minerals, catfish also require minerals for osmotic balance between the body fluid and their environment. If 5% or more animal protein is included in catfish feeds, supplemental trace minerals are generally not necessary. Since most growout feeds for catfish generally contain low levels of animal protein, a trace mineral premix is commonly added to commercial catfish feeds (Table 11). Trace mineral mixes are commonly manufactured using inorganic sources because of their lower cost.

There are reports that in poultry diets minerals that are bound to organic compounds, such as proteins, peptides, or amino acids (chelated minerals) are more available than inorganic minerals. A recent study with catfish at Auburn University showed that zinc methionine was more available than zinc sulfate, and feeding zinc methionine to catfish improved disease resistance against *Edwardsiella ictaluri*. In contrast, a study conducted at this station showed zinc methionine was no better than zinc sulfate for improving growth and increasing bone zinc of channel fish. In addition, research conducted by USDA researchers at Auburn also showed no benefit in using zinc methionine in catfish diets. This aspect of mineral nutrition requires further research ch prior to making a generally statement as to use of organic minerals in catfish feeds.

Feed Formulation

Catfish feeds have generally been based on a fixed formula with little use of a least-cost approach as is used in other animal industries. In the past, fixed formulas were used because of the lack of sufficient nutritional information. Presently, nutritional data are available to allow the nutritionist to formulate catfish feeds on a least-cost basis. The primary constraint limiting the use of least-cost programs for formulating catfish feeds is that relatively few feedstuffs are available that can b e used in catfish feeds. Many feedstuffs are unsuitable for use in catfish feeds because of their poor nutritional content or because of manufacturing constraints. Nutrient levels recommended for practical catfish feeds are given in Table 11.

To use a least-cost computer program to formulate feeds, the following information is needed: (**1**) cost of feed ingredients; (**2**) nutrient concentrations in feedstuffs; (**3**) nutrient requirements; (**4**) nutrient availability from feedstuffs; and (**5**) nutritional and nonnutritional restrictions. There are several constraints that inhibit the widespread use of least-cost formulation of catfish feeds in addition to the lack of a sufficient number of suitable feedstuffs. These include a lack of knowledge of the nutrient levels that result in maximum profit as opposed to levels that maximize weight gain, a lack of capacity to store large number of different ingredients at the feed mills, and the logistics of obtaining a wide assortment of feedstuffs on a timely basis. A limited form of least-cost feed formulation is used to formulate catfish feeds. Cottonseed meal, milo, and meat and bone meal are often used to replace a part of soybean meal, corn, and fish meal, respectively depending on cost.

Examples of restrictions placed on nutrients and feed ingredients for least-cost formulation of catfish feeds are presented in Table 13. Examples of formulations for commercial catfish feeds used for food fish are give n in Table 14.

Feed Manufacture

Feed manufacturing involves the processing of mixtures of feedstuffs and feed additives into a usable form. There are several goals and considerations in feed manufacturing, some of which are nutritional and some of which are nonnutritional. Typically the primary goal is to increase profits of animal production by maximizing the nutritional value of a feedstuff or a mixture of feedstuffs. Depending on the animal species, this process may range from a simple reduction of particle size to forming feed pellets through steam pelleting or extrusion. Catfish feeds are unique compared to feeds used for terrestrial animals grown for food because catfish feeds must be pelleted, water stable, and generally made to float on the water surface. Thus most commercial catfish feeds are manufactured by extrusion. If a particular feed additive will not withstand the rigors of extrusion, the feed may be manufactured by steam pelleting into a sinking pellet.

Catfish feed manufacturing involves the reduction of particle size, addition of moisture, heat treatment, and high pressure. Thus, the value of certain feedstuffs or feed additives may be lowered during feed processing. However, the overall process should result in a final product of proper form that meets nutrient specifications. The manufacturing process may also improve digestibility, inactivate certain undesirable substances present in feedstuffs, reduce the occurrence of molds and bacteria, and improve palatability. Nutritional and nonnutritional factors that must be considered in manufacturing catfish feeds as well as feed manufacturing practices and quality control are discussed in the following sections.

Nutritional Considerations

All animals, including catfish, require protein, vitamins, minerals, lipids, and energy for normal growth and other physiological functions. Because the nutrient contribution from natural food organisms is considered to be minimal in intensive catfish farming, nutrients and energy are provided primarily by prepared feeds. The primary goal in processing feedstuffs into a feed is to maximize the nutritional value of various feed components to meet nutrient requirements.

Nutrient requirements for catfish have been fairly well defined. In formulating and manufacturing catfish feeds, it is essential that the finished feed meet nutrient requirements and be in a form that is readily consumable and is digestible. Feed processing may have a profound effect on certain nutrients and little effect on others. It may make certain nutrients more available and others less available. However, the feed manufacturing process should produce a feed pellet of good quality with the least amount of detrimental effects on the nutrients present.

Nonnutritional Considerations

Although nutritional considerations are of prime importance, nonnutritional factors often influence the composition of the final product. The logistics of procuring and storing feedstuffs and feed additives are primarily nonnutritional considerations. In general, feed ingredients must be available on a consistent basis, be easily handled in the manufacturing process, be able to withstand the rigors of the manufacturing process, and be economical. These characteristics are the primary reason that soybean meal and corn have been the main feedstuffs typically used in catfish feeds. Peanut meal and cottonseed meal are often priced economically and could be used in catfish feeds, but their use is limited not only because of nutritional deficiencies but also because they are not available on a consistent basis during the catfish growing season.

Even if a large number of feedstuffs were available for use in catfish feeds, lack of ingredient storage bins would limit their use. Most catfish feed mills, even high volume mills, have storage bins for only six or seven feedstuffs. Storage is limited and feedstuffs are used rapidly; thus, they must be replenished almost on a daily basis.

When formulating catfish feeds, the feed manufacturing process must be considered because there is an interrelationship between feed formulation and feed manufacturing. For example, extrusion requires that at least 25% of the feed be composed of grains or grain milling byproducts for proper gelatinization and expansion necessary for good pellet stability and float. This is generally not a problem, but the type and amount of grain or grain milling byproducts that are used may be affected by humidity in the air.

Levels of wheat middlings up to 25% can generally be used except at high air humidity where the level may be reduced to 10 to 15% and the amount of corn grain increased to avoid making the feed too sticky and difficult to handle. Also, cottonseed meal at high levels slows the extrusion process.

High-fat feedstuffs, such as rice bran, are generally limited to 5 to 10% of the feed because high levels of fat make the feed more difficult to pellet or extrude, at least with the equipment commonly used to manufacture catfish feeds in the southeastern United States.

Supplemental fat is sprayed on the finished catfish feeds to reduce feed dust ("fines"). Highly fibrous feedstuffs must be limited to rather low levels because high levels of fiber reduce pellet quality.

Another consideration during catfish feed manufacture is that the conditions of high temperature, pressure, and moisture encountered during pelleting and extrusion destroy certain nutrients and improve the availability of others. Vitamins are particularly sensitive to destruction; thus, catfish feeds are normally overfortified with vitamins to account for losses during feed manufacture. Energy digestibility of starch appears to be enhanced by the extrusion process.

Manufacturing Processes

Catfish feeds are manufactured in modern feed mills specifically designed for manufacturing fish feeds. Regardless whether a feed is floating or sinking, the general scheme of feed manufacture is the same. Whole grains are ground through a hammer mill prior to batching. The feed ingredients are batched, weighed, mixed, and then reground. After regrinding, mixed feed ingredients are either extruded or steam pelleted and then cooled or dried, fat coated, and stored for loadout. During preparation for loadout the feed is screened to remove "fines" and then loaded into trucks for bulk delivery or bagged. Operation of the various phases of feed manufacture are controlled by operators from a control center.

Receiving and Storage. Feedstuffs and other ingredients are either received at the mill by rail or by truck. Rail is generally more economical. Feedstuffs are unloaded from the railcars or trucks and transferred to storage houses or bins. As feedstuffs are needed, they are moved by conveyers or screws to the appropriate section of the feed mill for processing.

Grinding, Batching, and Mixing. Whole grains (corn, wheat, etc.) are ground through a number 7 screen in a hammermill prior to batching and mixing. During batching, feedstuffs are moved into a hopper above the mixer and weighed prior to mixing. After batching, the batch is dropped into a mixer and mixed for a predetermined time (usually 1.5 to 3 minutes). After mixing, the feed mix is ground through a smaller screen (number 4 or 6) depending on the type of feed being manufactured . After regrinding, the feed mixture is moved into hoppers above the extruders or the pellet mill.

Steam Pelleting. Steam-pelleted (sinking) feeds are manufactured by using moisture, heat, and pressure to form ground feed ingredients into larger homogenous feed particles. Steam is added to the ground feed ingredients to increase the moisture level to 15 to 18% and temperature to 160° to 185°F. Steam helps to gelatinize starches, which bind the feed particles together. The hot "mash" is then forced through a pellet die in a pellet mill. Die size is dependent on the size of pellet desired. The pellets exit the die at about 10% moisture; thus, require little drying but must be cooled.

Steam-pelleted feeds are generally less expensive to manufacture than extruded feeds because less energy is expended in their manufacture. Also, less destruction of nutrients occurs during steam pelleting as compared to extrusion.

Extrusion. Extrusion cooking is a process that involves the plasticizing and cooking of feed ingredients in the extruder barrel by a combination of pressure, heat, and friction. Fish feed ingredients are a mixture of starchy and proteinaceous materials that are moistened to form a "mash." The "mash" may be preconditioned in a conditioning chamber for 3 to 5 minutes, during which moisture is added in the form of steam (water can also be injected) to increase the moisture level of the "mash" to about 25%. During this period, the "mash" is cooked as moisture penetrates the feed particles.

Preconditioning may improve flavor development and feed digestibility, reduce extruder barrel wear, and allow for increased volume through the extruder. After preconditioning, the "mash" enters the extruder, which is a jacketed barrel that contains a rotating screw. Temperatures in the extruder generally range from 190° to 300 °F and are generated from friction in the extruder.

The superheated mixture is then forced through a die (about 3 to 6 mm in diameter for catfish feeds) located at the end of the extruder barrel. The die restricts product flow, thus causing development of the necessary pressure and shear. The die is al so used to shape the product (extrudate) passing through it. As the product passes through the die, a sudden reduction in pressure results in the vaporization of part of the water in the mixture and the feed pellets expand.

The moisture level of the pellets leaving the extruder is higher (18-21%) than that of steam-pelleted feed; thus, extruded pellets must be dried at high temperatures for longer periods of time.

Drying and Cooling. Some moisture is lost by flash evaporation as the feed pellet exits the die and by evaporative cooling after the feed pellets are exposed to air. Steam-pelleted feeds exit the die near a moisture level of 10% and require cooling but little drying. Extruded feeds also lose moisture by flash evaporation and evaporative cooling (about 2%), but require additional drying since they contain 20% or so moisture as they enter the dryer. Extruded fish feeds should be dried to a moisture content of 8 to 10%. At this level of moisture, the shelf life of the product is extended. Drying is generally accomplished using a multi-stage dryer, which has different temperature zones. For extruded catfish feeds, drying time is around 30 minutes. Temperatures range from 275° to 300°F.

Fat Coating, Storage, Screening, and Delivery. After drying, extruded catfish feeds are normally passed through a fat coater, which applies a thin layer of fat to the pellet surface. Fat coating helps reduce feed dust. After fat coating, the product is stored in bins awaiting loadout. Just prior to bulk loadout or bagging, feed pellets are screened to remove fines. Some feed mills may also screen the feed pellets after drying prior to fat coating and again after fat coating prior to storage for load-out. Fines are reclaimed and used as a feed ingredient. Almost all commercial catfish feeds are delivered to the farm in bulk by truck. Some feed is bagged.

Pellet Grinding or Crumbling. Feeds of a small particle size (flours, meals, or crumbles) are needed for feeding catfish fry and small fingerlings. Flour or meal-type feeds are usually prepared by either reducing the particle size of a pelleted feed by grinding and screening to the appropriate size, or by finely grinding feed ingredients to a particle size of less than 0.5 mm and mixing the ground ingredients. Crumbles are usually prepared by crushing (crumbling) pelleted feeds and screening for proper size. If flour or meal-type feeds are prepared by pelleting and then regrinding to the proper particle size instead of simply grinding and mixing, water-soluble nutrients are less likely to be lost to the water. Supplemental fat sprayed on the surface of meal or crumbled feeds improves water stability and floatability as well as reduces nutrient losses to the water.

Quality Assurance

Stringent quality-control methods are required to consistently manufacture high quality feeds that provide essential nutrients in an available form at the proper proportions and levels needed for body maintenance, growth, or reproduction at a reasonable le cost. Catfish feed mills have a continuous and comprehensive quality-assurance program in place whereby various quality-control methods are employed to ensure that all feeds produced are of highest quality. To be effective, a quality-assurance program must be the responsibility of all those involved from top management down. Thus, such a program should encompass all aspects of feed production from feed formulation to the final feed.

Feed Formulation. Catfish feed formulations are based on nutrient requirements established by research conducted at various state and federal agencies. Nutrient requirement data are updated frequently to ensure current data are available for formulating least cost feeds. Nutrient profiles of feedstuffs are continually updated based on actual assays conducted over a number of years on feedstuffs used and on information supplied by various suppliers of feedstuffs. Feeds a re generally formulated to meet nutrient requirements at an economical cost. A safety margin is used to account for variations in the nutrient content of feed ingredients.

Ingredients. The purchasing agent ensures that high-quality ingredients are available on a timely basis at a reasonable cost by having an understanding of feed ingredients and by knowing which suppliers can consistently provide ingredients as needed. Working with the nutritionist and the production manager, the purchasing agent establishes and uses ingredient specifications to ensure that ingredients meet the standards desired. Ingredients are inspected for color, odor, and texture prior to acceptance. Although subjective, visual and sensory inspection provides useful information on the quality of ingredients prior to use. An in-house test for moisture or toxins may be performed. Samples are taken for chemical analysis. Analyses are conducted to determine if ingredients meet specifications. Also, analyses may be conducted to determine presence of toxins, pesticides, or heavy metals. Since chemical tests lag behind ingredient use, a particular ingredient will be used prior to receiving the analytical results. However, if specifications are not met, a deficiency claim is filed with the supplier. In addition to ensuring quality by inspecting ingredients, ingredient inventories are maintained, which provides information o n the amount of an ingredient used over a certain time period. This can be used to check and correct errors in the manufacturing process.

Manufacturing. Quality control measures continue during each phase of production to ensure that a feed containing the proper nutrient content with desirable physical characteristics is produced. Ingredients are ground , batched, and mixed, reground, extruded, dried, and fat-coated prior to shipping. All equipment used is selected to produce a quality product. Equipment is continually checked and maintained at proper specifications. Since a uniform mix is essential, mix is checked periodically by assaying for particular vitamins or other micronutrients.

Finished Feed. The finished product is routinely assayed for moisture, protein, fat, and fiber, and periodically for selected micronutrients to ensure nutritional value. Each batch of feed is checked for physical characteristics including floatability.

Feeding

Although considerable research has been conducted on feeding catfish, feeding is far from an exact science. It is a highly subjective process that differs greatly among catfish producers. Basically, there does not appear to be one "best" method for feeding catfish, particularly considering that numerous factors (most of which cannot be controlled) affect feeding.

Even though catfish have been cultured for many years, there is still considerable variation in feeding practices on commercial catfish farms. Computer programs, which generally determine feeding rate based on a percentage of fish body weight, are available and are used by some catfish producers. Feeding a prescribed amount of feed based on fish biomass in a particular pond works best when the biomass in each pond is known and a fairly accurate estimate of feed conversion can be made. However, since most catfish producers do not clean-harvest but rather remove only harvestable size fish and replace harvested fish with fingerlings, after several harvests and restockings it is difficult to accurately determine biomass. In fact, many catfish producers judge their inventory by the amount of feed fed. As a result, catfish are generally fed once daily to what is commonly called satiation; i.e., feeding the fish all they will ingest in a reasonable period of time. However, feeding to satiation is highly subjective and is often difficult to achieve in ponds containing a high standing crop of fish without adversely affecting water quality.

A typical catfish production scheme includes feeding fish in various stages of their life cycle in an aquatic environment that varies widely in temperature and in quality. In addition, disease and environmental stressors often impact feeding activity. Thus, to maximize production and profits, catfish should be fed a feed that meets their nutritional requirements using a feeding strategy that is adapted to the specific culture conditions at any given time. That is, under normal conditions catfish should typically be fed daily as much feed as they will consume without adversely affecting water quality. However, depending on water temperature and other water quality parameters and on the health of the fish, it may be prudent to restrict the daily feed allowance or to feed less frequently. How much to feed and the frequency of feeding are decisions that must be made daily by catfish producers based on each pond of fish. No two ponds of fish are exactly alike, and, as a result, feeding behavior in individua l ponds may differ greatly or feeding activity in a particular pond may vary greatly from day to day.

A general discussion of the contribution of natural foods and of feeding practices and feeds for fry, fingerling, food, and brood catfish is presented below. The recommendations given should be considered as guidelines because no single feed or feeding method is suitable for all circumstances.

Natural Foods

Because of the high level of nutrients introduced by feeding, commercial catfish ponds are fertile and normally contain large numbers of organisms including phytoplankton, zooplankton, and invertebrates such as insects and crustaceans. Many of these organisms are high in protein and other essential nutrients and may contribute to the diet of pond-raised catfish (Table 15).

The degree that natural food organisms contribute to the nutrition of intensively grown channel catfish is still relatively unclear. While some commercially cultured fish that feed low on the food chain (such as tilapia and silver carp) make excellent gains on natural foods, channel catfish require prepared feeds for maximum yields, except for newly stocked catfish fry, which appear to meet their nutrient requirements from natural food organisms.

Although natural food organisms are abundant in most catfish ponds, their contribution to growth of stocker-size fish has been generally thought to be minimal. For example, studies conducted at Auburn University estimated that only 2.5% of the protein requirement and 0.8% of the energy needed for catfish grown in intensively-fed ponds was obtained from natural food. However, we have conducted studies in which low-protein foods (16%) provided for good growth of catfish stocked at 10,000 per acre.

The major contribution of natural food organisms to the nutrition of commercially cultured catfish may be from nutrients that are required in trace amounts such as vitamins, minerals, and essential fatty acids. Recent studies with catfish have shown that while vitamin deficiencies could be produced by feeding catfish purified diets devoid of various vitamins in aquaria under controlled laboratory conditions, the same deficiencies could not be produced in catfish raised in ponds and fed practical feeds lacking a supplement of a specific vitamin. Thus, the vitamin requirement was met either from vitamins naturally occurring in feedstuffs, from natural food organisms, or from a combination of the two.

Studies have also been conducted with minerals and essential fatty acids with similar results. These data indicate that catfish benefit from consuming natural food organisms. To investigate this topic further, research is continuing at DBES to evaluate nutrient profiles of phytoplankton and zooplankton commonly present in commercial catfish ponds.

Warm Weather Feeding

Fry. Newly hatched catfish fry, which are only about ¼-inch in length, are usually held in indoor troughs and tanks for about 10 days before release into outdoor nursery ponds. Initially, catfish fry use their yolk sac a s an energy and nutrient source. Once the yolk sac is absorbed (approximately 3 to 5 days after hatching), fry begin to seek food, and should be fed frequently. In the hatchery, fry should be fed finely ground meal or flour-type feeds (Table 16) containing 45 to 50% protein supplied primarily from fishmeal at a daily rate equal to about 25% body weight divided into 8 to 10 equal feedings.

It is difficult to effectively feed catfish fry recently stocked into large nursery ponds. The tiny fish spread out over the pond and are relatively weak swimmers so they are not able to move rapidly to areas where manufactured feeds are offered. The b est way to ensure good growth and survival of newly stocked fry is to make sure that plenty of natural food is available in the fry nursery pond when the fish are stocked. Natural foods for channel catfish fry include insects, insect larvae, and zooplankt on (microscopic crustaceans). Insects and zooplankton eat plant material in the pond, so to produce them in abundance you must either increase natural plant production within the pond by fertilization or apply the plant material directly to the pond. Regardless of how you manage the pond for increased production of natural foods, it is important to plan ahead because time is needed for the population of insects and zooplankton to become established in the pond.

The simplest way to prepare the pond for stocking fry is to use a chemical fertilizer to stimulate a bloom of phytoplankton (the microscopic plants that give water the green color). The phytoplankton bloom then serves as food for insects and zooplankto n. Start fertilizing the pond about 3 weeks before stocking the fry so that ample time is available for development of a bloom. High-phosphorus liquid fertilizers are the most effective fertilizer materials for catfish ponds. Typical analyses for these fertilizers are 10-34-0 and 13-18-0. Apply about a half gallon of liquid fertilizer per acre every other day for 10-14 days or until a noticeable bloom develops. After the bloom develops, continue fertilizing the pond once or twice a week for 3-4 weeks after the fry have been stocked. By that time, the fry (now small fingerlings) should be feeding on manufactured feed and fertilization is no longer necessary.

Fertilizing ponds with chemical fertilizers does not always produce a good bloom, and a more dependable way to produce abundant natural food is to apply organic material directly to the pond. The organic material serves as a direct food source for insects and zooplankton, and also slowly decomposes to release plant nutrients that stimulate development of a phytoplankton bloom. Good organic fertilizers include alfalfa pellets, cottonseed meal, or any high-quality hay.

Start applying the organic material about 2 weeks before stocking fry. Apply the material twice a week at 100 to 200 pounds per acre. After stocking the fry, reduce the rate to 25 pounds per acre once or twice a week.

Adding liquid chemical fertilizer at a half gallon per acre once or twice a week in addition to the organic fertilizer will produce even more rapid and dependable results. Stop fertilizing the pond when the fingerlings begin vigorously accepting manufactured feed.

Even though fry presumably meet their nutrient needs from natural food organisms, they should be fed once or twice daily using finely ground feed at a rate equal to 25 to 50% of fry biomass. Since the feed serves primarily to fertilize the pond, it is not necessary to feed a high-protein feed as is used in the hatchery. Fines from regular 28 or 32% growout feeds are suitable for catfish fry during this phase. Some catfish producers do not feed the flour-type feeds, but feed a pelleted or crumbled feed, which is largely uneaten but breaks up in the water and serves to keep the pond fertile. After a few weeks, the fry will have grown into fingerlings of 1 or 2 inches in length and will come to the pond surface seeking food.

Fingerlings. Initially, small fingerlings (1-2 inches) should be fed once or twice daily to satiation using a crumbled feed or small pellets (1/8-inch diameter) containing 35% protein (Table 16), part of which should be supplied by fishmeal, meat and bone/blood meal, or a mixture of the two protein sources. Some catfish producers feed fingerlings the same feed they feed to fish for growout. Fingerlings consume large feed pellets by nibbling on the feed after the pellets soften and begin to break up in the water. Fingerlings appear to grow well using this feeding strategy, but nutrient losses, especially micronutrients, are likely due to leaching of nutrients because of the extended time the pellet is in contact with the water.

Food Fish. Catfish grown for food are usually stocked as advanced fingerlings of about 5-6 inches in length (about 50-60 lb/1,000 fish). They are generally fed a floating feed of approximately 5/32- to 3/16-inch diameter containing 28 to 32% protein (Table 17). As fish size increases feed consumption as percentage of body weight decreases and feed conversion increases (Tables 18 and 19). Because catfish are generally cultured using a multiple-batch production system in which several sizes of fish are present in the pond, it is recommended that they be fed to satiation. Offering as much feed as possible (without wasting feed) provides a better opportunity for the smaller, less aggressive fish to receive feed. Satiation fee ding appears to be particularly important when catfish are fed less frequently than on a daily basis. Although it is recommended that catfish typically be fed as much feed as they will consume, at high standing crops of fish it may be impossible to satiate the fish and maintain water quality at an acceptable standard. As a rule of thumb, feeding rates should not exceed what can be assimilated by organisms in the pond. This is difficult to judge, but generally long-term average feed allowance should not exceed 100 to 120 lb/acre/day. However, exceeding this rate for a few days should be okay. Overfeeding should be avoided since wasted feed increases production cost by increasing feed conversion (Table 20). Also, uneaten feed contributes to deterioration of water quality.

The best time of day to feed is still debated, but the point is more or less academic. On large catfish farms, the time fish are fed is largely dictated by the logistics required to feed large numbers of ponds in a limited time period. As a result, man y catfish producers start feeding early in the morning as soon as dissolved oxygen levels begin to increase. Some catfish producers and scientists argue that it is best to begin feeding midmorning or early afternoon. A study conducted in ponds at this station showed no significant differences in weight gain, feed consumption, feed conversion, and survival among catfish fed to satiation at 8:30 a.m., 4:00 p.m., and 8:00 p.m. There were also no differences in emergency aeration time among treatments. However, feeding late afternoon or at night in large commercial catfish ponds is not recommended because it may not be possible to aerate a commercial catfish pond as can be done in a small experimental pond. Peak oxygen demand generally occurs about 6 hours after feeding. If dissolved oxygen levels are particularly low at this time and aeration is insufficient, fish may be stressed or die. Generally, it appears most practical to begin feeding in the morning as the dissolved oxygen begins to increase.

Broodfish. Catfish brood stock is usually fed the same feed used for growout. Some catfish producers prefer feeding sinking feeds because broodfish are often hesitant to feed at the surface. However, because brooders gene rally feed slowly, sinking pellets may disintegrate before they can be consumed. Some catfish producers supplement commercial feeds for broodfish with live or frozen forage fish, such as golden shiners. It is recommended that catfish brooders be fed a typical 28 to 32% protein feed once daily. The feeding rate should be about 0.5 to 1% fish body weight.

Winter Feeding

Although catfish eat inconsistently at water temperatures below 70 °F, a winter feeding program appears to be beneficial to prevent weight loss and maintain fish health. Research has shown that significant increases in weight gain can be obtained in fish fed during the winter months as compared to those that are not fed. This appears to be particularly true with fingerlings. The health aspect of winter feeding is less well defined, but logically one would expect fish fed during the winter to be in better condition and perhaps more resistance to disease-causing organisms than fish that were not fed. However, there is some evidence with large catfish that nonfed fish are more resistant to challenge with *E. ictaluri*. Regardless of research dat a, catfish producers do not feed during the winter months. Often fish are not fed in the winter because inclement weather may prevent access to pond levees. However, some catfish producers simply do not see any benefit to winter feeding. It has been shown that weight gain of catfish not fed during the coldest winter months catches up with that of fish fed during the winter months when satiate feeding is resumed in the spring and summer. Even though some catfish producers choose not to feed for various rea sons, considering potential weight gains and health benefits, we feel that it is prudent to follow a winter feeding program on commercial catfish farms. The following sections provide guidelines to consider in winter feeding of catfish.

Fingerlings and Food Fish. Several schedules for winter feeding of fingerlings and food fish have been suggested. Generally, all schedules are such that water temperature dictates feeding frequency. A typical winter feeding schedule is shown in Table 21. Since most production ponds contain mixed sizes of fish at any given time, the feeding schedule chosen should be based, in addition to water temperature, on the number of small fish in the pond. These require higher feeding rates and more frequent feedings. The type of feed that should be fed during the winter has not been precisely defined. A typical growout floating feed containing 28 or 32% protein is sufficient. A 25% protein slow- sink feed (Table 22) is also available and is preferred by some producers. Either of these feeds will provide sufficient nutrition for overwintering catfish.

Broodfish. While it is important throughout the year to ensure broodfish receive adequate nutrition, it is especially important during the winter months. It is at this time of the year that eggs, which were produced by females the previous summer after spawning, are developing yolks and maturing. This process requires that broodfish receive adequate nutrition on a regular basis, which makes winter feeding of broodfish important.

Feeding rates and frequencies used in winter feeding of broodfish, as with fingerlings and growout fish, are based on water temperature. A suggested schedule is shown in Table 21. Regardless of the specific schedule chosen, the feeding rate should not be restricted too much since the more aggressive male broodfish may outcompete females for feed and resulting in restricted egg maturation.

The most common broodfish ration used in the winter is the same feed used to feed fingerlings and growout fish, either a 28 or 32% protein floating pellet. If broodfish appear to be reluctant to feed at the surface, the 25% slow-sink feed can be used. Some catfish producers also stock forage fish (e.g. fathead minnows) into ponds to ensure that adequate food is available during the winter.

Feeding Diseased Fish

Feeding diseased fish may be difficult because fish that are sick eat poorly, if at all. However, offering medication through the feed is generally the only method available to treat bacterial infections. As with most any subject concerning catfish, there is considerable debate over the efficacy of medicated feeds (feeds containing antibiotics) and the best method to treat diseased fish. There are catfish producers who do not feed during outbreaks of certain diseases or those who limit feed to every other day. Not feeding during disease outbreaks appears to be as effective as feeding medicated feeds.

Medicated Feeds. Antibiotics can be administered to large populations of fish through the feed. Medicated feeds have been used to treat diseased fish for a number of years in other aquaculture industries (i.e. salmon and trout) and are currently accepted as the only viable alternative to treat systemic bacterial infections of catfish. Two antibiotics, Romet® (sulfadimethoxine-ormetroprim, Hoffmann-La Roche, Nutley, NJ) and Terramycin® (oxytetracycline, Pfizer, Inc ., New York) are registered by the Food and Drug Administration (FDA) to treat bacterial infections of catfish through their incorporation into feeds.

Romet is registered for control of enteric septicemia of catfish (ESC) and has also been shown to be effective in treating motile aeromonad septicemia (MAS) caused by *Aeromonas hydrophila* and systemic columnaris infections. Romet-medicated feed (Table 22) is fed at a feeding rate (dependent on the formulation of Romet used) sufficient to deliver 2.3 grams of antibiotic/100 pounds of fish/day. Romet was originally formulated to contain 66.6 pounds of Romet-30® ; premix/ton of finished feed and delivered the required dosage of antibiotic when fed at a rate of 0.5% of fish body weight daily. However, because of palatability problems, the amount added was reduced to 33.3 pounds per ton of feed and the feeding rate increased to 1% fish body weight daily.

Data from a recent study conducted at the DBES, indicated that the effectiveness of treating ESC with Romet could be increased by feeding a reduced concentration of antibiotic formulation at a greater rate -- both adjusted to deliver the required legal level of antibiotic. The reason for the increased effectiveness of this feeding strategy was speculated to be because of the increased availability of medicated feed to larger numbers of sick fish. Thus, catfish feed mills in the Mississippi Delta currently manufacture Romet-medicated feed using 11.1 pounds of Romet-30/ton of feed. This feed is fed at a rate of 3% body weight daily or fed to satiation. Romet is heat stable, so it can be used in a floating feed. Research at the DBES indicated that the level el of fish meal should be increased to 16% to improve the palatability of feeds containing Romet to catfish.

Romet is registered by the FDA to be fed at the prescribed rate for 5 consecutive days. If the majority of fish affected by the disease in the pond are fingerlings, feeding smaller feed size (crumbles or 1/8-inch diameter pellets) is usually suggested. This recommendation is based on results obtained in the aforementioned study, which showed that ESC-infected fingerlings fed medicated feed of reduced pellet sizes had better survival than those fed regular size medicated feed. If mortality does not decrease after treatment, additional sick fish should be diagnosed. An additional 5-day period of medicated feed may be prescribed. A 3-day mandatory withdrawal period is required before fish can be slaughtered.

Terramycin is a broad-spectrum antibiotic, which is registered by the FDA to treat MAS infections. Terramycin has also been shown to be effective in treating other aeromonad infections, ESC, and systemic columnaris infections. The most common feed formulation currently used contains 50 pounds of Terramycin TM 100® premix/ton of finished feed. The resulting medicated feed contains 2.5 grams of antibiotic/pound of feed and when fed at 1% of body weight/day delivers 2.5 grams antibiotic/100 pounds of fish/day.

Terramycin medicated feed is usually manufactured only as sinking pellets. The antibiotic is heat-labile and does not withstand the high temperatures required to make floating pellets. However, research to develop a "cold" pelleting process t o make floating Terramycin feed is ongoing.

Based on field observations, Terramycin-medicated feed is primarily recommended to treat systemic columnaris infections or ESC infections caused by strains of *E. ictaluri* that are resistant to Romet (see below). Terramycin is registered to be d for 7 to 10 consecutive days. A 21-day withdrawal period is required before fish are slaughtered and processed.

Considerations. Several important considerations should be taken into account when treating fish with medicated feed. An accurate diagnosis of the specific disease(s) affecting the fish population must first be obtained if effective treatment is expected. In many cases, fish are infected with multiple disease agents. For example, fish with a systemic ESC infection may also have a concurrent systemic or external columnaris infection coupled with a parasitic infection. In these situations, the choice of treatment should be made only after careful consideration of the results of an accurate diagnosis.

Another important factor producers must consider is bacterial resistance. Some strains of bacteria causing diseases in catfish are resistant to currently available antibiotics, i.e., the bacteria causing the disease will not be killed by application of the antibiotic. To avoid problems associated with bacterial resistance, a sensitivity test of the bacteria in question should always be obtained. In a sensitivity test, the infective bacteria are cultured under laboratory conditions and exposed to available antibiotics. If the bacteria are not affected by the antibiotic, they are resistant and an alternate treatment strategy is recommended. Sensitivity tests are routinely conducted by fish disease diagnostic laboratories.

Resistance of bacteria to antibiotics may result from indiscriminately feeding medicated feed or from using feeding schedules not prescribed by the FDA. It is important to remember that once a bacterial strain becomes resistant to an antibiotic, it may be impossible to treat future disease outbreaks due to the lack of effective legal antibiotics.

When using medicated feed, every effort should be made to ensure that fish consume the feed and receive the proper dose of antibiotic. Several practices can help ensure that fish consume feed. Fish should be submitted for diagnosis as soon as any poten-------- tial problems are observed. If disease outbreaks are allowed to progress for a long period of time, fish may be too weak to feed and treatment with medicated feed will prove useless. Fish should be fed when dissolved oxygen concentrations are relatively high. Feeding fish more than once a day and feeding over a large portion of the pond rather than in one area may also help increase consumption of medicated feed.

When treating fish with medicated feed, losses of fish may not immediately subside. Even if detected early, bacterial diseases may affect a portion of the fish in a pond to an extent that they will not consume feed. These fish normally will continue to die during and after the treatment period, but the remaining fish in the pond that consume medicated feed have a good chance for recovery.

Effect of Feeds on Sensory Quality of Processed Catfish

Flavor. Commercial feeds composed of oilseed meals, grains, and animal products generally have little influence on flavor quality of farm-raised catfish. A study was conducted at the USDA Agricultural Research Service, Southern Regional Research Center, New Orleans, LA, and the USDI Fish and Wildlife Service, Fish Farming Experiment Laboratory, Stuttgart, AR, to evaluate the effects of feed ingredients on flavor quality of farm-raised catfish. Commonly used feed ingredients were substituted individually into semipurified experimental diets at levels commonly used in commercial feeds. The diets were fed to catfish under laboratory conditions for two months and fish were evaluated for flavor quality by a trained panel using quantitative sensory techniques. Results showed no significant differences in flavor among fish fed different experimental diets.

High levels of dietary marine fish oil may give catfish a 'fishy' flavor that is undesirable, but catfish fed feeds containing 2% menhaden oil (this level is rarely exceeded in growout feeds for catfish) have no distinct 'fishy' flavor. Off-flavor problems of farm-raised catfish are predominantly influenced by phytoplankton, some of which can excrete certain metabolites that are absorbed by fish. Phytoplankton growth is related to feed input, so increased feeding rates may affect fish flavor indirectly by influencing phytoplankton growth.

Appearance. Consumer acceptance of farm-raised fish depends mainly on the color of the flesh. The preferred color of catfish flesh is white. At high dietary levels, the yellow pigment xanthophyll has been shown to concentrate in catfish giving the flesh a yellowish coloration that is undesirable. Corn gluten meal is limited as a feed ingredient because of its high concentration of xanthophyll. Corn and corn screenings contain the pigment, but it is present at concentrations that are not problematic. Other than this, feeds appear to have little effect on appearance of catfish flesh.

Fattiness. The amount of body fat found in catfish is influenced by several factors including dietary protein level and energy/protein ratio, feeding rate, and fish size and age. Regardless of fish age and feeding rate, a s dietary protein level decreases and the energy/protein ratio increases, body fat increases. Regardless of dietary protein and energy levels, fish fed to satiation generally contain more fat than fish fed at restricted levels. Presently body fat of catfish is higher than it was 20 or 30 years ago because catfish are fed more liberally today.

There is evidence that feeding synthetic compounds, such as Ractopamine® and carnitine may reduce body fat in catfish. Ractopamine is a so-called repartitioning agent that can repartition fat to synthesize protein, while carnitine is a natural compound that acts as a catalyst for fat metabolism. However, these compounds have not been approved for use by FDA.

A major concern about fattiness of catfish is that increasing fat in edible tissue may reduce the shelf life of frozen fish. However, a cooperative study involved several universities has shown that body fat content has little effect on frozen keeping quality of catfish products.

Compensatory Growth

After a period of feed deprivation or restriction, animals have the potential to compensate or 'catch up,' resulting in increased growth rate after full feeding is resumed. This phenomenon is called compensatory growth. It is well documented that compensatory growth occurs in mammals and it also appears to occur in fish. A study conducted at Auburn University indicated that catfish had the ability to make up weight gain following a 3-week restricted feeding regimen where fish were fed every third day during the summer. Another study at Auburn University showed that catfish which were not fed during the winter months of December, January, and February could make up for the weight loss if the fish were fed as much as they would consume the following spring and summer. These studies clearly indicate that catfish exhibit compensatory growth. This is of practical importance, because fish are often either not fed during the winter or fed infrequently because of factors such as inclement weather, holidays, hunting season, etc. However, it should be noted that these studies were conducted at relatively low standing crops with fish of a single size class. In the typical multiple-batch system used to raise catfish, the results may differ.

Although compensatory growth does occur, it should not be taken as a substitute for good feed management. That is, one should not assume that severely restricting feed or not feeding at all will always be compensated for by compensatory growth. It is t herefore recommended that catfish be fed daily during the growing season when culture conditions allow for it.