Environmental Challenges of Animal Agriculture and the Role and Task of Animal Nutrition in Environmental Protection* - Review -

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ABSTRACT : Animals are one of the important memberships of the food chain. The low-efficiency rule of nutrient transfer from one member to the next in the food chain determines the low efficiency of animal agriculture for human food. On the average, about 20% feed proteins and 15% feed energy can be converted into edible nutrients for humans. The rest proportion of feed nutrients is exposed to the environment. Environmental pollution, therefore, is inevitable as animal agriculture grows intensively and extensively. The over-loading of the environment by nutrients such as nitrogen, phosphorus from animal manure results in soil and water spoilage. The emission of gases like CH_2, CO_2, SO_2, NO, NO_2 by animals are one of the contributors for the acidification of the environment and global warming. The inefficient utilization of natural resources and the probable unsafety of animal products to human health are also a critical environmental issue. Improving the conversion efficiency of nutrients in the food chain is the fundamental strategy for solving environmental issues. Specifically in animal agriculture, the strategy includes the improvements of animal genotypes, nutritional and feeding management, animal health, housing systems and waste disposal programs. Animal nutrition science plays a unique and irreplaceable role in the control of nutrient input and output in either products or wastes. Several nutritional methods are proved to be effective in alleviating environmental pollution. A lot of nutritional issues, however, remain to be further researched for the science of animal nutrition to be a strong helper for sustainability of animal agriculture. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 3 : 423-431)*

Key Words : Food Chain, Animal Agriculture, Environment, Animal Nutrition

INTRODUCTION

The environmental issues related to modern animal agriculture are of global concerns and interests. The objective of animal agriculture has been shifted from one goal of high yield of animal products into the multiple goals including high yield of safe animal products, high utilization of natural resources and minimum environmental pollution. Animal nutrition plays an important role in realizing the new objective of animal agriculture. The role, however, may be limited because animal agriculture itself is a process of low efficiency of nutrient conversion and many other factors are related to the process. This overview is intended to explain the inevitability of environmental pollution by intensive animal agriculture and the dependence of alleviating environmental risk on all the related factors being taken into accounts at the same time, with emphasis on the role and future tasks of animal nutrition, one of the factors related to animal agriculture. The specific nutritional management for minimizing environmental pollution, which has been extensively reviewed in literatures (Backus, 1998; Kornegay, 1996; Kephart, 1996; Honeyman, 1993), will not be covered in this overview.

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* This paper was presented at 2000 APEC China Seminar on Public Health Issues in Animal Production/Animal Products which was held on October 15~19, 2000 in Beijing, P. R. China.

POSITION OF ANIMALS IN THE FOOD CHAIN

Plants and animals are the major and basic constituents in the food chain. Plants absorb solar energy and convert simple nutrients from soil and air into complex nutrients by photosynthesis. Animals and humans are unable to live on simple nutrients directly as plants do. Photosynthesis products are their fundamental food source (figure 1). Therefore, both animals and humans are consumers in the food chain.

Energy and nutrients are transferred relatively inefficiently from one member to the next in the food chain. The exchange efficiencies are only about 10% for energy and 25% for nutrients (Lanyon, 1996). Consequently, the number of organisms that can be supported by the food chain becomes less and less as each transfer is made along the food chain. It is estimated that only 1% of total solar energy reaching on the earth is captured by plants and only 5% of the captured energy is transferred into edible foods for humans. The number of people sustained directly by grains produced in one hectare land is five times as that by animal products after the grains are consumed by animals (Gillespie, 1987). Therefore, low efficiency of nutrient transfer down the food chain is a basic natural rule. "Eating lower on the food chain" is a way for greater energy efficiency. However, There are a large number of decomposer organisms in the food chain which are able to recycle the "wasted" nutrients back into the food chain (figure 1).

In terms of human food production, both plants and animals are food producers. Plants contribute 84% calories and 66% protein of total human food demands, animals cover the rest of the percentage (table 1). Despite the smaller proportion, animal products play a unique role in human life, which plant products can not.

There are several important issues related to the food chain which people are or will be facing and have to deal with properly.

Whether the food chain goes well and efficiently is a main determinant of ecosystem equilibrium. The rapid increase of population and human activities requires the parallel increase of food production, which means the food chain will be over-loaded. The over-loaded food chain and the inefficiency of nutrient transfer in the chain will result in the inevitability of environmental deterioration and the deletion of unrenewable natural resources. Consequently, the food chain, and therefore together with the ecosystem equilibrium will be broken. Avoidance of such disastrous result is an extremely hard and long-term task.

Animals, as a consumer in the food chain, will compete with humans for food. There are some options to solve this problem. For example, animals as the member of food chain have to be kept, but animals as a human food producer could be limited so that the use of grains for animal consumption could be shifted to a direct consumption by humans. If the amount of animals raised have to be globally limited in general, either increasing productivity or utilizing high proportion of nutrients that are directly inedible to humans, or both are the right direction for animal agriculture to go. In this case it will be probably more difficult to solve environmental issue in animal agriculture than ever before.

As a human food producer, animals must be fed and managed in such a way that their products must be safe to human health. Food problems such as bovine spongiform encephalopathy (BSE), dioxin contamination, drug residues, mycotoxins, E. coli O157:H7 and salmonella must no longer appear. Animal agriculture will be subject to more strict legislative control (Bateman, 1998; Cooke, 1998; Thomas, 1998).

EFFICIENCY OF ANIMAL PRODUCTION

The position of animals in the food chain determines the low efficiency of animal production. For example, a 100-kg-liveweight pig consumes totally about 8 kg nitrogen, the amount retained in the body is less than 2.5 kg. Energy excreted into the environment accounts for 80-85% of total consumption, phosphorus for 70-80% and trace minerals for 95-98% (NRC, 1998).

For a dairy cow producing 22.7 kg of milk, about 35% of carbon and energy consumed are excreted as feces and urine, 40-44% as CO_2, 5% as CH_4. Only 18-20% of consumed carbon and energy is converted into milk (Van Horn, 1994). About 17.6 g carbon and 171.8 kcal energy are lost in form of methane per kg of milk production (Chandler, 1996).

Animals, as a food producer of humans, are characteristic of low efficiency to transfer feed nutrients into edible nutrients for humans. On the average, the efficiency is about 20% for proteins and 15% for energy (table 2). This means approximately 80% proteins and 85% energy consumed by animals will be exposed to the environment. When the amount of "exposed" nutrients exceeds the amount of "recycled" nutrients, environmental pollution is inevitable no matter how properly they are handled.

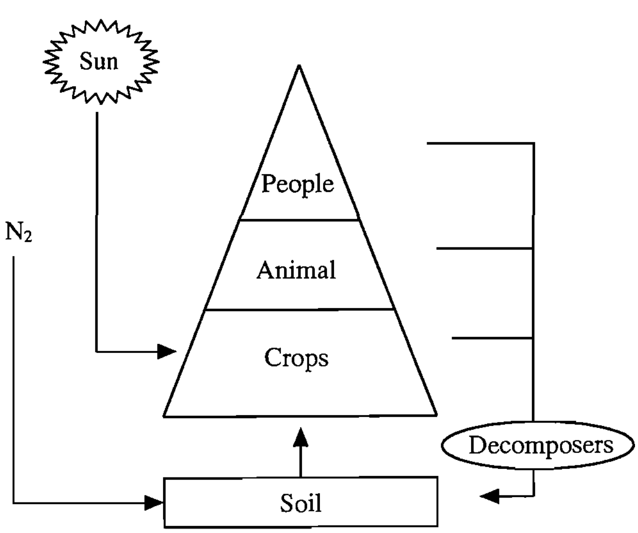

Figure 1. Primary food chain (Lanyon, 1996)

Table 1. Contributions of plant and animal products to the world food supply

Food source	Calories (%)	Protein (%)
Plant products	84	66
Cereals	49	43
Roots, tubers, pulses	10	10
Nuts, oils, vegetable fats	8	4
Sugar and sugar products	9	2
Vegetables and fruits	8	7
Animal products	16	34
Meat	7	15
Eggs	1	2
Fish	1	5
Milk	5	11
Other	2	1

(Pond, 2000)

IMPACTS OF ANIMAL AGRICULTURE ON THE ENVIRONMENT

The low efficiency of animal agriculture determines the inevitability of the negative impact of intensive animal agriculture on the environment. The negative impact includes, broadly speaking, three aspects (figure 2). First, animals themselves and the activity of animal agriculture produce wastes or manure (including feces, urine, sloughed hair and skin, waste substances such as feed, water, bedding), exhaled gases such as CO_2 and CH_4, noise, offensive odour, and dust on which there may exist pathogens and toxins to some extent, all of which are referred to as pollutants and directly contribute to the environment deterioration (Stehman, 1996). Secondly, animal agriculture consumes inefficiently the existing environmental resources. Theoretically, animals, together with other consumers, can delete the unrenewable resources. Renewable resources may be renewed at the rate not enough to meet the total needs. Thirdly, There exists a safety issue of animal products to human health.

Nutrients in manure are not balanced for crop requirements. Manure nitrogen is not adequate because ammonium nitrogen which accounts for approximately 50% of the total is easily lost by volatilization, and phosphorus and potassium exceed the crop requirements (Bannon, 1997). Application of manure at a rate to meet the nitrogen requirement of crops would result in the accumulation of phosphorus and potassium in soil. On the contrary, application of manure based on phosphorus and potassium requirements of crops would need large area of land to dispose the manure. When enough land is not available, the situation that heavy application of manure in a certain area must occur, which means the environmental pollution in that area is inevitable.

Water pollution is the biggest problem in animal agriculture because of the limited availability of freshwater and the long time of turnover of water in the globe (table 3). The most common impacts are nitrate contamination of groundwater, which is the primary source of drinking water for humans (Jacques, 1989), and phosphorus contamination of surface water, which is the primary source of fisheries, recreation, industry, and drinking in some area, and toxic metal contaminations.

Table 2. Conversion efficiency of feed nutrients into human food by animals

Species	Energy efficiency (%)	Protein efficiency (%)
Laying hens	18	26
Broilers	11	23
Turkeys	9	22
Dairy cows	17	25
Beef cattle	3	6
Hogs	14	14
Lambs	2	5

(Gillespie, 1987)

Table 3. Location and turnover time of the global freshwater resources

Storage location	% of total	Turnover time
Ice sheets and glaciers	85	8000 years
Ground water	14	280 years
Surface water	1	
Lake,, reservoirs	0.5	7 years
Soil moisture	0.3	1 years
Atmospheric vapor	0.05	3 month
Rivers	0.004	3.5 month

(Jacques, 1989)

Animals can emit a lot of gases like CH_4, CO_2, SO_2, NO, NO_2, which are believed to be associated with the acidification of the environment and global warming (greenhouse effect). The presence of CO_2 and CH_4 in the atmosphere results in the retention of solar radiation. CH_4, on the molecular basis, is sixty-five times more efficient in absorbing infra-red radiation than CO_2. The buildup of CH_4 in the atmosphere is considered to contribute 15% to the global greenhouse effect (Williams, 1994). It is estimated that the global methane emission from livestock industry accounts for 10-30% of total emission, some .counties reaching as

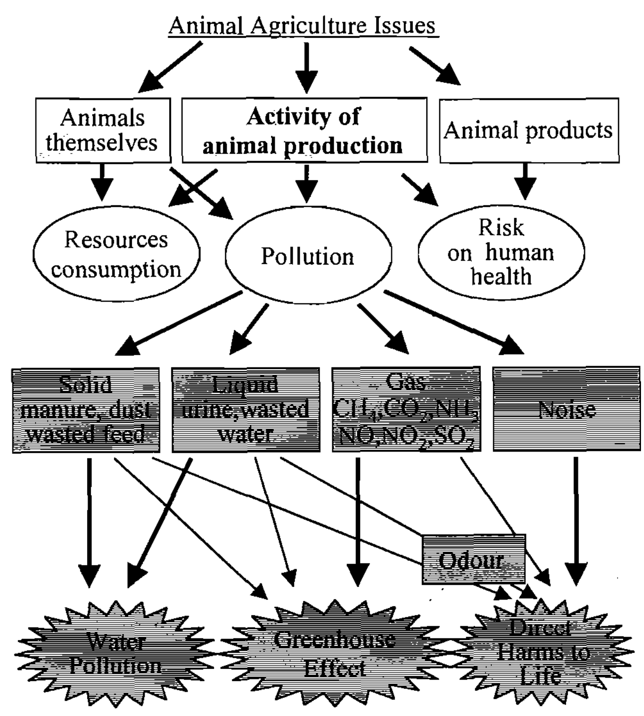

Figure 2. Impacts of animal agriculture on the environment

methane emission from livestock industry accounts for 10-30% of total emission, some counties reaching as high as 50% (Van't Klooseter, 1998).

It should not be neglected that the environmental pollution within animal housings may be more severe than that outside housings. Workers who are exposed to animal housings are prone to health problems resulting from toxic gases and pathogen-containing dust. Animal health and productivity are also affected by the pollution. Therefore, more attention should be paid by priority to workers and animals within housings from standpoints of human and animal welfares and animal productivity.

Animals of different species or different physiological conditions have different potentials for environmental pollution. In order to make calculations and comparisons, animal population unit (APU) and animal pollution equivalent (APE) are employed by Taiganides (1987). APU is defined as 100 kg of total live weight (TLW) of animals. APE is a pollutant parameter based on the biochemical oxygen demand (BOD) of the waste compared to the BOD of human waste. 1 APE is defined as 0.075 kg BOD. Table 4 shows the APE of each head animal and each APU for different species of animals. The larger the physical size of animals, the higher the APE for each head animal; while the smaller the physical size of animals, the higher the APE for each APU.

THE FUTURE EXISTENCE OF ENVIRONMENTAL POLLUTION FROM ANIMAL AGRICULTURE

Environmental issues from animal agriculture will continue to exist or even to be more serious simply because animal agriculture will continue to exist and be developed although animal agriculture is characteristic of low efficiency. Several reasons may support this idea. First, animals are the important membership of ecosystem. Animals are not only the contributor of environment pollution, but also a protector of the environment. There are a large array of processing byproducts and inedible food wastes from plant products. If these byproducts were not utilized by animals as feeds, they would contribute to disposal problems and environmental pollution. Second, animals consume enormous quantities of harvested and grazed forages which is of little nutritional value to humans and is produced in the area of little economic value for other agricultural activities. So animal agriculture itself is also a way to increase transfer efficiency of the food chain and utilization efficiency of natural resources. As a result, animal agriculture has much higher conversion efficiency in terms of human edible nutrients than of total nutrients (table 5).

Table 4. Animal population units (APU) and the water pollution equivalents (APE)

Animal	Description and age	Mean TLW kg/animal	APU/animal	No. of animal/APU	APE	
					/animal	/APU
Beef cattle	Cows 2 y and older	500	5	0.2	8.5	1.7
	Heifers 1-2 y old	400	4	0.25	6.8	1.7
	Feeder calves	200	2	0.5	3.4	1.7
	Steers 1 y and older	300	3	0.33	5.1	1.7
Dairy cattle	Cows 2 y and older	700	7	0.14	16.8	2.4
	Heifers 1-2 y old	500	5	0.2	12	2.4
	Heifer calves	300	3	0.33	7.2	2.4
Pigs	Piglets	10	0.1	10	0.3	3.0
	Growers	40	0.4	2.5	1.2	3.0
	Porkers	70	0.7	1.4	2.0	2.8
	Gilts, sows and boars	100	1.0	1.0	2.9	2.9
Poultry	Pullets-not laying	1	0.01	100	0.05	5.0
	Pullets-laying	1.5	0.015	67	0.07	4.7
	Hens-laying	2	0.02	50	0.10	5.0
	Broiler	1	0.01	100	0.05	5.0
	Ducks	2	0.02	50	0.10	5.0
	Turkey-heavy	7	0.07	14	0.34	4.8
Turkey	light	4	0.04	25	0.19	1.2
Sheep	Lambs-ewe and ram	40	0.4	2.5	0.48	1.2
	Wethers	50	0.5	2	0.60	1.2
	Ewes-1 y and older	80	0.8	1.2	0.96	1.2
	Rams	100	1.0	1.0	1.2	1.2

(Taiganides, 1987)

Table 5. Inputs and returns of animal agriculture

Product	Total energy and protein				Human edible energy and protein			
	Energy		Protein		Energy			
	Input* Mcal	Return %	Input kg	Return %	Input Mcal	Return %	Input kg	Return %
Milk	19960	23.1	702	28.8	4555	101.1	111.5	181.4
Beef	20560	5.2	823	5.3	1869	57.1	39.9	108.8
Swine	1471	23.2	66	37.8	588	58.0	29.0	86.0
Poultry	23.2	15.0	1.2	30.0	11.2	31.0	0.48	75.0

* Inputs are calculated as digestible energy and digestible protein and include cost of maintaining breeding herds and flocks.
(Pond, 1995)

Third, animal products are valuable food for human health. In the developing countries consumption of animal products has been steadily increasing as their economic status improves. Even in the developed countries in which the per-capita consumption of total protein tends to plateau as family incomes rise, animal protein consumption continues to rise (figure 3).

It is reasonably believed that animal agriculture will continue to be developed to meet the increasing demands for humans. It is also predicted that a number of changes will take place in animal agriculture in such aspects as the distribution and size of animal farms, the shift of feed resources from conventional to more nonconventional, animal facilities and management model, waste disposal, animal welfare and legislative supervision on the whole process. Therefore, environmental pollution and the endeavors against the pollution will not only continue but also tend to be more intense in the future.

STRATEGIES FOR ALLEVIATING ENVIRONMENTAL POLLUTION

The activity of the food chain and its member is a matter of ecological, economical, technical and social issues. The essence of alleviating environmental pollution is to combine all the issues into the activity of the food chain or its member and make them well balanced and harmoniously developed, which is the exact concept of sustainability. Maintaining the sustainability of agriculture (including crop and animal agriculture) is one of the greatest challenges for the humans in the coming decades.

In order to reach this goal, more and more artificial strategies are applied to increase the energy and nutrient transfer efficiency nowadays (figure 4). Crops are grown in one location, animals raised in another, and humans live far away from crop and animal agriculture sites. At the same time, fertilizers and renovated farming systems are applied for greater crop production, animals do not live directly on crop produces, instead on commercial feed from feed mills which can balance the nutrient demands by animals and nutrient supplies by crops according to the achievements of the science of animal nutrition and feeds, and people, on the processed products from crops and animals by food processing industries.

In terms of animal agriculture, the most important way is to make itself to be sustainable (table 6).

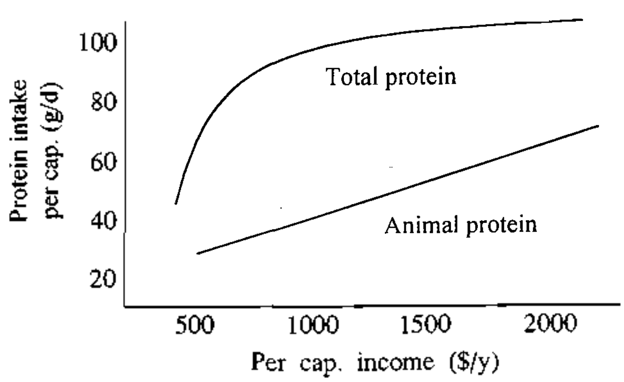

Figure 3. Animal food consumption (Pond, 2000)

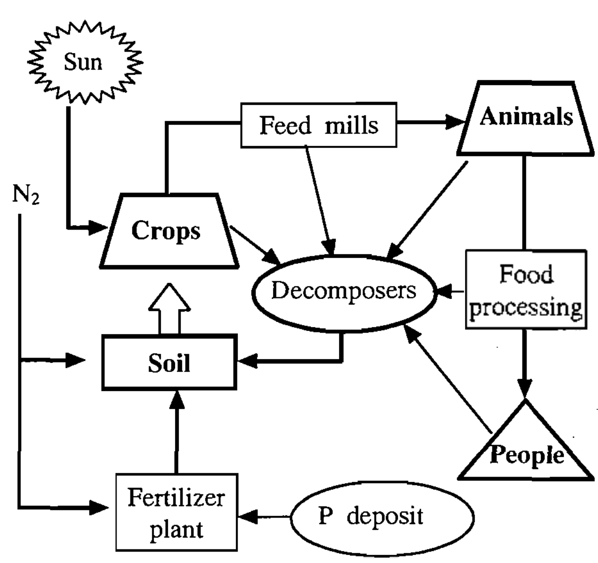

Figure 4. Remodeled food chain (Based on Lanyon, 1996)

Technically, the solutions for environmental issues include enhancing animal genetic potential of production by breeding and selection, improving performance and feed conversion efficiency of animals by nutritional managements, improving animal health by veterinary managements and developing proper waste disposal programs. Any animal farms that either exist already or are going to be built have to take into account all the aspects related to environmental risks such as animal species or breeds and density raised, feed requirements, manure output, nutritional managements, facility for manure collection and treatments, where and how to dispose manure, land area needed for application. Only when the comprehensive actions are taken could the environmental risks be minimized.

The role of biotechnology in alleviating environmental pollution needs to be emphasized. Biotechnology has been playing and will continue to play an important role in the following aspects related to animal agriculture.

At first, more and more genetically modified crops are or will be available for animal feeds. Many of the disadvantages of these original crops, for example, high content of anti-nutritional factors, low content of lysine, can be overcome by biotechnology in various extents (Anderson, 1998). These new crops have higher nutritional value and feeding value than their original breeds (Anderson, 1998).It is much easier than before to balance a diet when they are used as feed ingredients The amount of excretion, therefore, is expected to be declined considerably.

Secondly, recombinant DNA technology can produce mass quantities of biologically active proteins for animal agriculture, such as hormones, enzymes, amino acids, vaccines. When used as feed additives or growth promotants or disease preventers, animal health and the efficiency of animal agriculture or the quality of products can be improved, while environmental loading, decreased dramatically.

Thirdly, transgenic technology can not only help to elucidate the molecular mechanisms of nutrient metabolism, making it possible to meet exactly nutrient requirements for animal agriculture, but also produce animals with particular metabolic functions. A good example is that transgenic pigs that have high blood growth hormone (GH) level and, moreover, express GH in peripheral tissues in addition to in the pituitary gland have been produced (Pond, 2000). Many nutritional disorders may be eliminated or at least alleviated by gene therapy. Therefore, transgenic animals have tremendously high genetic potential for production.

At last, biotechnology can directly play a role in waste disposal. Great break-throughs in the purification of animal wastes and farm environment, and the recycling of animal wastes as plant fertilizers or animal feeds will be made in the near future by means of biotechnology.

It should be clear that the successful application of all the strategies does not mean, at least in the present, that the inefficiencies of nutrient transfer in the food chain can be reversed. Indeed, the more extensive and intensive the animal agriculture and human activities are, the larger the amount of wasted nutrients is, and the higher the risk of environment deterioration would be. At the same time, It should be remembered that comprehensive manipulations have to be employed to minimize environmental risk but not all manipulations are cost effective in terms of animal agriculture.

Table 6. Requirements for sustainable animal agriculture

Reduce input/cost
Increase output/productivity
Reduce environmental burden/cost
Maintain safety
Improve quality
Increase awareness and confidence
Maintain competitiveness
Compatible with other industry

ROLES AND TASKS OF ANIMAL NUTRITION IN SOLVING ENVIRONMENTAL ISSUES

Animal agriculture has negative impacts on the environment in many aspects. Animal nutrition plays a role in 1) improving utilization efficiency of natural resources by animals, 2) controlling nutrient intake and excretion by animals, and 3) ensuring the safety of animal products to humans. All the three roles lie during animal agriculture rather than pre- or post-production. The ultimate goal of animal nutrition science is to make animal agriculture to go well under such nutritional management system that is, in general, environmentally, economically, and socially sound.

Based on the current knowledge of animal nutrition science, the following options can be taken to reduce the environmental pollution by animal agriculture.

1. Figure out the accurate nutrient requirements of the specific genotypes of animals.
2. Apply the most precise database of nutrient availabilities of feedstuffs for animals.
3. Use new feed ingredients with high availability of nutrients.
4. Formulate diets based on bio-available nutrients rather than total nutrients to just meet the needs of animals.
5. Reduce crude protein level by applying ideal

protein principle or supplementing synthetic amino acids.
6. Supplement diets with feed enzymes, especially phytase, polysacchridases and proteases.
7. Use growth promoters
8. Improve feed processing facilities and technology
9. Apply phase feeding and sex-split feeding systems
10. Execute all the regulations and laws concerning feed hygiene, food safety and environmental protection
11. Recycle animal manure as animal feeds

Nitrogen and phosphorus excretions can be decreased up to 50% by the above strategies. However none of the above aspects is clearly understood up to now. There is a long way for the science of animal nutrition to go to realize its ultimate goal.

Understanding nutrient metabolism and its efficiency in animal body in molecular basis is the prerequisite to improve utilization efficiency of nutrients. Very little has been known in this area up to now. Animal nutrition must be transferred from traditional population level into a new branch of molecular level to brighten the black hole of nutrient metabolism within animal body (figure 5).

Nutrient requirements of animals need to be refined and reevaluated. The current nutrient requirements are established mainly based on the optimum performance of animals, with little care about the environmental loading. As shown in figure 6, as nutrient intake increases, animal performance enhances and reaches a plateau at the level of B. But when nutrient intake reaches a certain level (A), further increase would result in a gradual decrease of the marginal utility of performance, and dramatic increase of environmental loading although the absolute performance continues to rise. Nutritionists need to discuss this question: which point (A or B or a point between A and B) as shown in figure 6 is the reasonable nutrient recommendation taking all the three factors of animal performance, environmental risk and resource utilization into account? In other words, do we need to match nutrient allowances to the genetic potential of animals or to balance the genetic potential with environmental pollution potential and utilization efficiency of resources? Even though the optimum absolute performance is still considered as the criterion for establishing nutrient recommendation, the current recommendation based on performance has to be reevaluated because some experiments show that the recommendation for some nutrients may be higher than (B in figure 6) needed for optimum performance (Keshavarz, 1999; Satter, 1999).

Establishing the accurate database of available nutrient contents in feed ingredients is important for alleviating environmental risk. Feed evaluation in the future should focus on the improvement of methodology and the refinement of the current data of nutritional values on the basis of nutrient availability. It is very likely that the proportion of nonconventional feeds and genetically modified crops for animal feeds will be increased to a large extent. Data for these feeds are almost exclusively deficient at the present time. Nutritional evaluations on these new feed resources will be the predominant task for feed scientists in the near future.

Feeding system is one of the factors influencing nutrient conversion efficiency. Many studies indicate phase feeding is effective to reduce nutrient excretion. Liquid feeding is superior to solid feeding in terms of environmental risk. All these feeding systems, and other possible systems need to be further studied.

The efficacy and the mechanisms of feed additives for animal agriculture and their possible impacts on

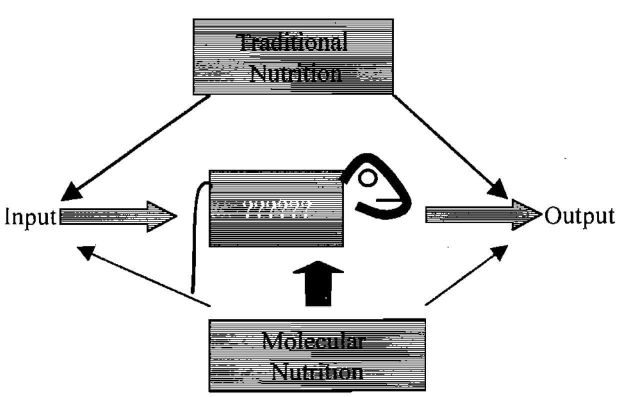

Figure 5. Rlationships between nutrition and nutrient metabolism

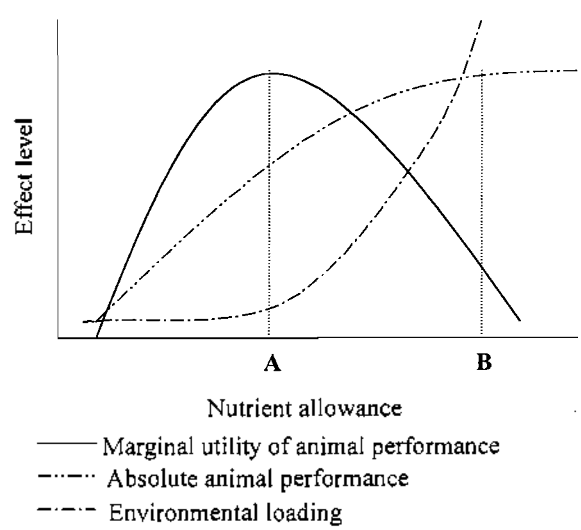

Figure 6. Relationships of nutrient allowance with animal performance and environmental risk

environment protection remain to be evaluated. Feed additives are classified into two categories according to their effects. One is those which have efficacy of promoting animal performance or improving product quality and have little detrimental impact on human health and the environment. The other one is those which have both efficacy of promoting animal performance or improving product quality and detrimental potential on human health and the environment. Most of the current commonly-used additives belong to the second category, such as antibiotic, arsenic, high level of inorganic copper and zinc. It is predicted that these additives will be under more strict control and eventually prohibited for food-producing animals in the globe. The most significant consequence of prohibiting these additives is a noticeable reduction of animal performance and animal resistance to diseases. Nutritionists have to seek alternative products or methods to keep the similar animal performance to that in the present, when the second category of additives is still employed widely.

There are increasing legislative constraints on animal agriculture, some of which have close relationships with nutritionists (Cooke, 1998; Thomas, 1998). For example, the ban of antibiotics as growth promotants, the prohibition of bone meal or even other animal proteins as animal feeds in European Union, the increasing outdoor feeding of some animals to meet the animal welfare are all great challenges for nutritionists to improve further the production level and efficiency by the same nutritional programs employed before theses laws are brought into action.

CONCLUSION REMARKS

The environmental issue resulting from animal agriculture originates from the low efficiency of nutrient transfer along the food chain and is beyond a technical issue. Many options, however, are indeed available, from the technical standpoints, to alleviate environmental risks by animal agriculture to a certain extent. The application of science and technology in animal nutrition is no doubt one of the most important options in the present. The future progress of science and technology in animal nutrition in the area of nutrient metabolism, nutrient requirement, nutritional evaluation of feedstuffs and the application of metabolic modifiers, will play much greater role in the sustainability of future animal agriculture.

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