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Review of Current Situation of Agricultural Non-Point Source Pollution and Its Prevention and Control Technologies

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Abstract: Agricultural non-point source pollution is one of the main causes of water pollution in China. Owing to its randomness, varying pollution discharge, and changes in pollution load, it is more difficult to control and prevent pollution from non-point sources than from point sources. The focuses of non-point pollution control are to clarify the current state of non-point agricultural pollution and to develop prevention and control technologies. This paper summarizes the causes and current state of agricultural non-point source pollution, and cites the uncontrolled fertilizer application and pollutant discharge from large-scale livestock and poultry farms as the main sources of agricultural non-point pollution. The existing mature non-point source pollution prevention and control techniques for crops and livestock industries are described. It also proposes the combination of source control, process control, and end treatment for the prevention of agricultural non-point source pollution. The corresponding prevention and control technologies for non-point source pollution should be adopted according to local conditions, to realize environmental, economic, and social benefits simultaneously.
Keywords: agricultural non-point source pollution; farmland nutrient runoff; pollutant discharge from livestock industry; prevention and control technology

1 Introduction

Point pollution and non-point source pollution are the two main causes of the deterioration of lake water quality. Point source pollution has been controlled to a great extent in recent years owing to the increased attention it has received. Non-point source pollution is gradually becoming the major form of pollution affecting water quality of lakes and rivers. Pollution from agricultural production is extensive and represents the largest threat to water systems [1,2]. Non-point source pollution resulting from agricultural activities has become the most difficult to control worldwide. The pollutants come from three major sources: livestock breeding and crop planting; waste generated by

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people living in rural areas and suburbs, including feces and urine containing COD, N, P, and pathogenic microbes and heavy metals; and soil erosion, runoff, or leaching by rainfall or irrigation carrying N, P, and pesticides into water bodies. The characteristics of agricultural non-point pollution include strong randomness, stochastic discharge locations, large temporal and spatial variations in pollutant load, relative hysteresis, fuzziness, and strong potential, which increase difficulty and complexity in monitoring, controlling, and managing of non-point source pollution [3].

Agricultural non-point source pollution has become a major threat to water safety in many countries. In the United States, the Environmental Protection Agency reported that agricultural non-point pollution is the greatest source of impairment of water bodies such as rivers and lakes, contributing to approximately two-thirds of the total pollutant load. In Denmark, 94% of N load and 52% of P load of 270 rivers are from agricultural sources. In certain farming watersheds in Ireland, 59% of total P comes from non-point source pollutants [4]. In Norway, 50% of total N and 30% of total P load in rivers derive from farm field management [5]. Agricultural non-point pollutants from Sweden contribute 40% of total P inflow to the load of the Baltic Sea [6]. In Holland, agricultural non-point pollution supplies 60% of N and 40% of P from the total amount of water pollution [7]. In Finland, lacustrine water quality has deteriorated by 20%, with agricultural pollution accounting for more than 50% of the total discharged N and P, especially in watersheds with higher proportion of farming input [8]. In the UK, agricultural non-point source pollution contributes to approximately 30%−50% of total P load [9].

In China, the state of agricultural non-point source pollution is more serious compared with those developed countries because of the higher fertilizer and pesticide utilization rates. According to the Bulletin of First National Survey of Pollutant Sources in China, the results from 2007, shown in Fig. 1, revealed that pollutants from agricultural discharge significantly affect water environment nationwide. Agricultural pollutants (from planting, livestock and poultry breeding, and aquaculture) were the main sources of total N and total P, and their discharges of 2.7046 and 0.2847 million tons, accounted for 57.2% and 67.4% of the total discharge, respectively. The COD discharge was 13.2409 million tons, accounting for 43.7% of the total amount. Mulch film, straw, and vegetables scraps are also considered sources of agricultural non-point pollutants, but they were excluded from this general survey.

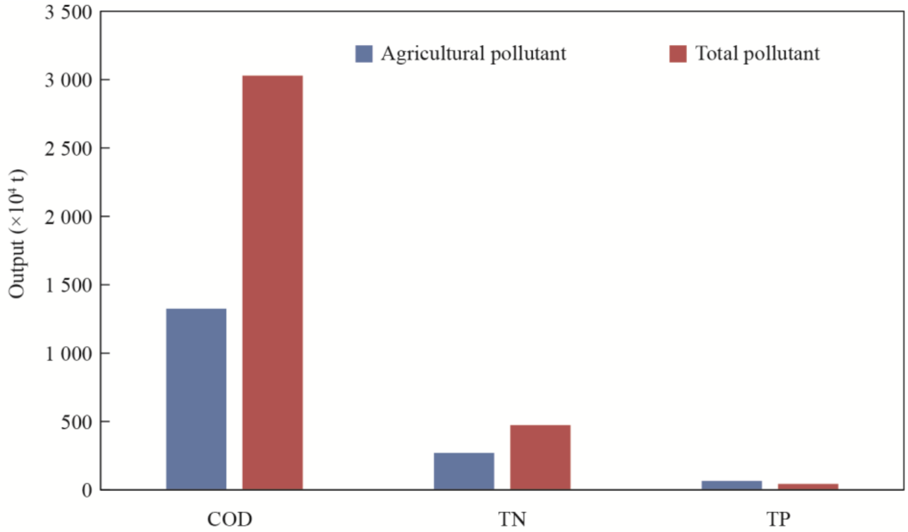

Fig. 1. Comparison of agricultural source pollutant discharge and total pollutant discharge.

2 The origin and current situation of agricultural non-point source pollution

2.1 Uncontrolled chemical fertilizer application

According to the *Chinese Rural Statistical Yearbook*, the sown area of vegetables and melons in China was 24.9303 million hectares in 2016, accounting for 14.8% of the total sown area; this reflects an increasing trend from 1978 to 2016 (Fig. 2). The sown areas of vegetables, fruit orchards, and tea plantations in 2016 were 5.67, 6.83, and 1.77 times greater than those in 1978, respectively. The survey and monitoring of agricultural non-point source pollution by the Ministry of Agriculture showed that planting systems including vegetables, orchards, and tea plantations are characterized by high fertilizer application rates and the consequent discharge of large amounts of effluents into water systems by runoff and leaching [10,11]. They are the most important source of agricultural non-

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point pollution from crop planting. The study by Zhang Weili et al. [1] indicated that in Dianchi Lake, Taihu Lake, Chaohu Lake, and the Three Gorges reservoir area, although vegetables, fruits, and flower fields account for only 15%–35% of the total sown area, their contribution to eutrophication in water bodies of watersheds was equivalent or greatly exceeded the contribution of grain crops, which account for 70% of the total sown area.

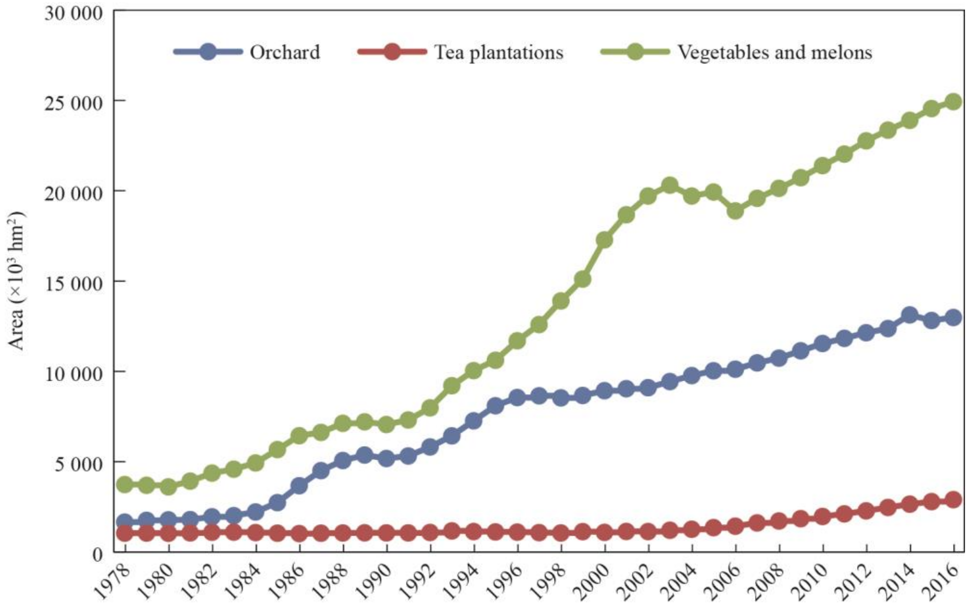

Fig. 2. Sown area of vegetables and melons, fruit orchards, and tea plantations in China.

The application rates of N and P chemical fertilizers have increased continuously (Fig. 3), by 2.23 and 4.54 times, respectively, from 1980 to 2016. However, in response to national policies, the rates have stabilized or even declined slightly since 2014. In 2014, the Ministry of Agriculture issued a series of policies and measures to control agricultural non-point source pollution, such as the *Opinions on Taking Measures to Prevent and Control Agricultural Non-point Source Pollution*, and the *Action Plan for Zero Growth in the Application of Fertilizer by 2020* [12]. Under the guidance of existing policies, the amount of fertilizer applied to vegetables, melon crops, and fruit trees has decreased, although crop layout and farmland management still need to be optimized in order to realize food security and decrease N and P pollution in water systems.

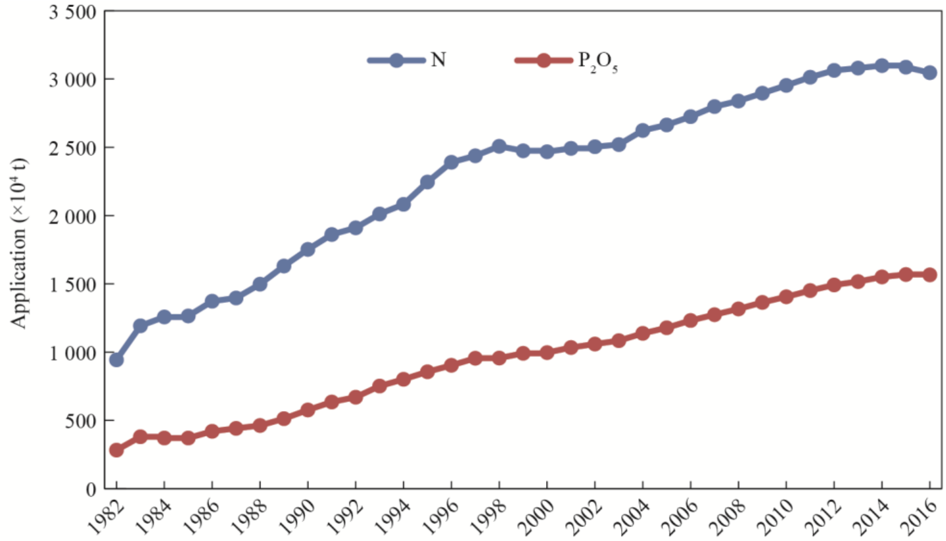

Fig. 3. Application rates of N and P chemical fertilizers in China.

2.2 Sewage discharge from large-scale livestock farming

The pollutants generated by livestock and poultry breeding are mainly sewage, solid feces, odorous gas, N, P, suspended matter, and pathogenic bacteria, among which COD, total N, and total P are the greatest pollutants.

The livestock industry has shown a steady increasing tendency in China (Fig. 4). In 2016, China was the biggest producer of both live and slaughtered pigs, accounting for approximately half of the world's total production. The poultry, beef, and mutton production also maintained a steady growth. The cattle stock at the end of 2016 was 106.679 million heads, among which beef cattle and cows accounted for 69.7% and 13.4%, respectively. The stocks of pigs, sheep, and poultry were 435.04 million, 301.12 million, and 5.90 billion, respectively. The slaughtered cattle, pigs, sheep, and poultry were 51.1 million, 685.02 million, 306.946 million, and 123730.01 billion, respectively. The total meat production was 85.378 million tons, of which the total tonnage of pork, beef, and mutton was 64.753 million, and pork had the biggest share with 52.991 million; beef, mutton, and fowl production reached 7.168, 4.594, and 18.882 million tons, respectively. The total egg production was 30.949 million tons. China's meat and egg production has long been the highest in the world, with meat consumption per capita reaching the level of medium-developed countries and egg consumption per capita reaching the level of developed countries.

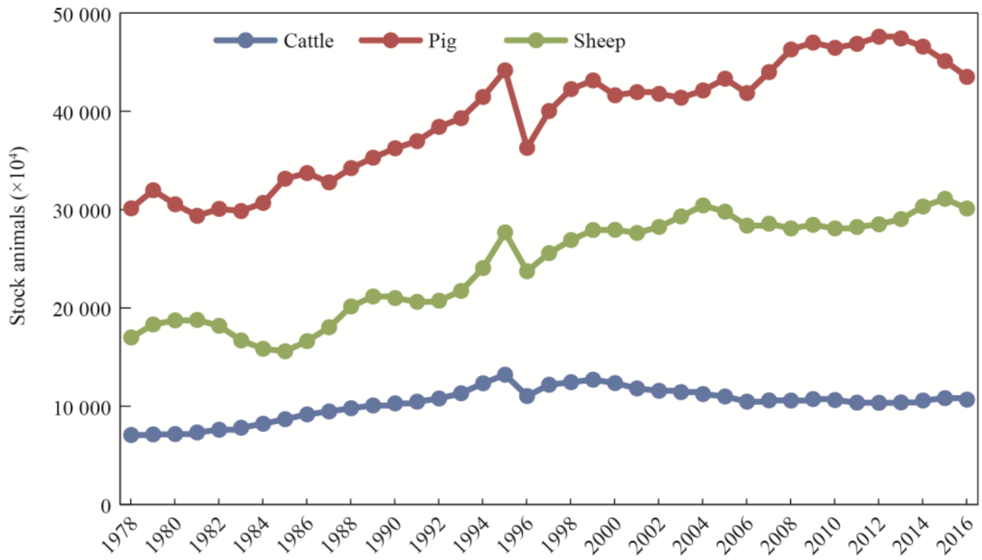

Fig. 4. Livestock and poultry amount at the end of year in China.

Concurrent with meat, egg, and milk production, the livestock and poultry breeding industries produce significant amounts of waste [3]. Especially with the emergence of large-scale breeding farms and breeding districts, it is difficult to effectively treat and make use of animal feces and urine and sewage from the breeding industry. Large-scale livestock farms located close to cities have less arable land on which to apply manure [1]. In some areas, the volume of excreta and sewage greatly exceeds the capacity of the fields. Thus, most are discharged in nearby water systems, causing water contamination. For a long time in the past, people prioritized development at the expense of environmental protection. With the expansion of breeding farms, the driving forces of limited labor supply and economic returns prompted an increasing number of farms to adopt water flushing or water soaking methods for feces disposal, which generated more sewage. The longer distance travelled by fecal water to reach crop fields also raised costs significantly. In this case, if there are insufficient funds, a large amount of fecal water might be discharged in situ, which aggravates environmental pollution and generates one of the major sources of agricultural non-point source pollution in China.

3 Prevention and control technology for agricultural non-point source pollution

The three types of mature technologies for prevention and control of agricultural non-point source pollution are source control, process interception, and end purification. Source control technologies reduce the amount of pollutants produced and discharged by farming through optimization of agricultural production processes, including clean planting and breeding technologies. Process interception technologies intercept, degrade, dispose, and utilize agricultural non-point source pollutants that emerge in the migration pathway through chemical, physical, and biological methods to reduce the volume discharged to water bodies, thus reducing agricultural non-point pollution. End purification technologies include integrated engineering methods to treat and purify pollutants after they are generated.

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3.1 Prevention and control technologies for non-point source pollutants from crop production

Regarding source control is the optimal choice to reduce pollution from crop production, assuming that it maintains crop yield and protects economic interests. Optimized agronomic management practices that enable highly efficient fertilization are used to control fertilizer and pesticide application rates, and to decrease soil disturbance and water outflow from fields. Based on traditional application methods, field management such as irrigation and tillage, and engineering approaches are combined for the comprehensive prevention and control of non-point pollution. This is a growing trend in current technologies to prevent and control pollution from crop production.

3.1.1 The high-efficiency fertilization technology

The widespread issues of excessive fertilizer use, improper ratio of basal and topdressing fertilization, and mismatch between application date and peak crop uptake period lead to low fertilizer use efficiency and high risk of nutrient loss. Thus, application dates and rates are optimized by split application according to crop type and growing seasons. They are combined with deep soil application of chemical fertilizers to increase the efficiency of N and P and decrease the risk of N and P runoff.

3.1.2 Soil testing and fertilization formula technology

According to the soil test results and the nutrient demands of the crop, a fertilization formula can be provided, in which the amounts, ratios, and forms of the main nutrients are recommended. Appropriate amounts, application dates, and methods for N, P, K, and micronutrients fertilizers are suggested, and the fertilizers should be easy for processing and molding. This technology is more effective but has higher costs.

3.1.3 Regional field nutrient management technology

Detailed knowledge on the regional distribution of soil nutrients is obtained through a combination of traditional agronomic techniques and modern technologies such as GPS and GIS, in addition to a comprehensive analysis of digital information about soil, social economic conditions, and meteorology. Based on these aspects, a special fertilizer that fits local major crop rotation practices and soil types is developed. The fertilizer is suitable for application in intensive crop production areas.

3.1.4 Plant nutrient diagnosis technology for fertilization

This technology diagnoses crop nutrient deficiency by plant analysis during the growing season. As a result, fertilizers are applied at the correct time and rate to meet the demand for optimal growth based on crop nutrient stress at that time.

3.1.5 Nutrient balance window technology

Based on nutrient input and output, the nutrient balance of the field is analyzed. After the basic input and output data are collected and the richness or deficit of field nutrients is evaluated, the data are entered into the Fertilizer Expert System based on the planned types of crops to be planted. The results of plot nutrient balance and soil texture, planting season, target yield, and nutrient balance indicators are given, as well as recommendations such as application rates, form of fertilizer partition, and proper application methods.

3.1.6 Technology on balanced fertilization of organic and inorganic fertilizers

The application of nitrogen fertilizer through organic manure is essential to achieve high and stable yields at lower costs. This not only meets the crop nutrition demand, but also increases soil fertility and decreases the loss of N and P.

3.1.7 New fertilizers and crop specific fertilizer technology

The newest fertilizers are mainly slow-release and controlled-release types that are produced based on local soil, crops, and weather conditions. They normally use coating materials to control the release rate of nutrients in line with the rate of crop demand for nutrients within the entire growing cycle, in order to increase fertilizer's use efficiency and decrease nutrient leaching and volatilization.

The formula for crop-specific fertilizer not only contains N, P, and K depending on soil fertility and crop need, but also various micronutrients based on soil nutrient-limiting factors, which combine macro control with micro adjustment for individual crop needs in different regions. The specific fertilizer formula contains various kinds of nutrients such as N, P, K, Ca, Mg, S, Fe, and B. The total nutrient content is usually as high as 40%–50% to meet the demand for normal crop growth. Overall, the utilization efficiency of specifically formulated fertilizers is approximately 10−15% greater than traditional ones. They also decrease N and P losses significantly.

3.1.8 Management technology for water and fertilizer integration

Fertigation supplies the appropriate nutrients, dissolved in water, through an irrigation system according to nutrient demand and soil and climate conditions in different growing phases, in order to precisely supply fertilizers for direct uptake by root systems. All fertilizers used in fertigation must be either completely water-soluble or liquids. The micronutrients must be water soluble or in chelatable form. Drip irrigation, and sprinkler or infiltration irrigation can be used to save water and fertilizers, reduce N and P losses, and increase their utilization efficiency when adopting water and fertilizer integration.

3.1.9 Tillage technologies for water and soil conservation

This includes no tillage, less plowing, intercropping, straw mulching, etc. The major aims of these farming technologies are to control soil erosion by wind and water; decrease agricultural non-point source pollution; promote soil fertility, drought-resistance, and water-saving capabilities; reduce energy consumption; lower production costs; and increase production efficiency. Intercropping can be advantageous due to the different nutrient needs of different crops. It adequately utilizes soil nutrients, reduces pollution caused by residual nutrients, adjusts the ratios of soil nutrients, and prevents soil consolidation and salinization.

3.1.10 Technology for cropping system adjustment and layout optimization

This is a macro-control measure to rearrange the layout of cropping systems in a region, according to the adaptation of different crops and potential occurrence of agricultural non-point pollution in different soils, climates, and terrains. The crops with higher nutrient requirements such as vegetables and flowers are preferentially grown in areas with lower risk of pollution. In high risk areas, legumes, grain crops, or forests can be planted, since they need fewer nutrients and are more environment-friendly [13]. Through this technique, it is possible to decrease the dependence of agricultural production on chemical fertilizers and effectively control agricultural non-point source pollution.

3.1.11 Hedgerow technology

A hedgerow is a line of closely-spaced woody plants or shrubs that form a narrow buffer strip between plant populations. The density of the strip is airtight on the ground or near the ground. Normally, perennial and valuable woody or herb plants are planted on soil ridges or slopes to control soil erosion as well as increase income. There are two options: economic hedgerow + grain crops; and economic hedgerow + economic crops.

3.1.12 Buffer belt technology

Before farmland tailwater goes into artificial wetlands or into a tributary of a river, buffer belts (approximately 10 m wide) are established at equal intervals (200 m) in crop fields along the direction of the river or its tributary. No N or P fertilizers are applied to the buffer belts. Aquatic plants with economic value such as rice, reeds, and calamus are planted in the belt. These plants grow depending on the N and P from upstream runoff, resulting in the reuse of N and P resources. The crops in the belt are harvested normally, which not only provides economic returns but also enhances the development of crude processing of agricultural products.

3.1.13 Ecological interception technology

This technology involves growing aquatic plants that can effectively bioaccumulate N, P, and pesticides from existing drainage furrows, ponds, and wetlands under local terrain conditions. It is coordinated with engineering measures to intercept, adsorb, and degrade pollutants. Control of agricultural non-point pollution and improvement of water quality can be achieved by ecological interception. The ecological interception must consider local conditions in order to scientifically choose the plants and other disposal processes for purification according to the local terrain, type of crops and their layout, precipitation, furrows for irrigation and drainage, etc.

Considering the control management methods of all these fertilization techniques, 1–10 items belong to source control technology while 11–13 items belong to process prevention or end management. In a given district, these techniques to control non-point pollution should complement each other. They are essential to decrease N and P pollution from farmlands into water bodies to the greatest extent.

3.2 Prevention and control technology for pollution from livestock and poultry breeding

Source control technologies for pollution prevention and control of livestock and poultry breeding are mainly

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achieved by a clean breeding to reduce wastewater discharge, including raising pigs in ecological fermentation beds, and using feed optimization technology, amongst others. Process prevention and control technologies to decrease pollutants include manure collection and storage, and the process of feces dry cleaning. Finally, manure resource utilization and sewage disposal can be included as end management technologies.

3.2.1 Pig breeding in ecological fermentation bed

The ecological fermentation bed is a new and eco-friendly breeding mode with the following characteristics: water, feed, and labor savings; higher disease resistance; improved pork quality; increased breeding benefits; and zero pollution [14]. It is suitable for a midsize hoggery. Zero-discharge ecological breeding houses require the reconstruction of existing piggeries and cushion preparation. The cushion consists of sawdust, pulverized cotton stalks (leaves of tree or weed), nutrient additives, and a certain amount of water fermented by microbial strain to eliminate dung pollution. It is a technical solution to prevent the environment pollution and promote scaled pig breeding.

3.2.2 Livestock and poultry excrement collection and storage technology

Commonly, households that engage in livestock breeding have large herds of animals that are widely dispersed. During the rainy season, casually stacked excrement may highly pollute surface water. The construction of a rainproof manure collection and storage facilities is necessary to prevent environmental pollution by manure during storage. The manure undergoes a series of anaerobic, aerobic, and facultative degradation processes when placed in a storage pool for a period before application in the field. When applied to the arable land, it can increase soil organic matter content and improve soil structure, infiltration rate, and plough ability to enhance water holding capacity and reduce soil erosion. Fecal fluid as a water source supplies water to meet plant growth needs. The direct return of manure to the field after being stored for a period is the most economical and effective handling solution for livestock breeding by households.

3.2.3 Dry collection process

Dry collection is the process of treating dry picked feces and sewage separately. The solid feces are converted into organic fertilizer, and sewage quantity can be reduced by 70% compared with water flushing or soaking processes. The COD content decreases by 90% and suspended solids by 95% in sewage.

3.2.4 Compost technology by livestock and poultry manure

This technology is divided into aerobic and anaerobic based on environmental conditions. Both undergo transformation by microbes but under separate aerobic or anaerobic conditions to decompose organic matter, and then form humus, which is easily absorbed by crops. The anaerobic composting process takes longer, whereas aerobic composting is a highly efficient fermentation process with high temperatures and a shorter cycle. The organic matter is decomposed completely so that the danger is relatively low, which has contributed to its popularity.

3.2.5 Technology on fertilizer made by livestock and poultry waste

Livestock and poultry manure contain a large amount of organic N, P, K, and micronutrients, which provide essential nutrients for crop growth for a longer time when applied to soil. The conversion of livestock and poultry manure into fertilizer, and their return to the field are the most common and effective way to use this resource. It not only decreases environmental pollution but also promotes crop growth. It is suitable for breeding farms with adequate adjacent farm fields, especially in regions with intensive vegetable planting that need more nutrients.

3.2.6 Natural disposal technology

Livestock and poultry feces and sewage from breeding farms are treated mainly by natural disposal systems such as oxidation ponds and artificial wetlands [15], usually after anaerobic treatment. These require lower investment and have reduced operating costs. Moreover, complex engineering systems are not required. They are suited for areas that are far from cities, with higher air temperature, and with shallows, wasteland, woodland, or lowland as sites of natural disposal systems. When applied in the US and Australia, feces and sewage are directly placed in oxidation ponds without anaerobic pretreatment. Multistage oxidation ponds are used to increase the sewage stagnation duration and processing efficiency.

3.2.7 Engineering treatment technology

Owing to the lack of available fields to dispose of feces and sewage, livestock and poultry farms located in suburbs need to adopt engineering treatment technologies. These occupy less land but require more investment and have higher operating costs. Anaerobic or aerobic decomposition, or a combination of both, can be chosen according to local conditions. This is suitable for large-scale breeding farms that generate large amounts of sewage due to the use of the water flushing method for cleaning.

3.2.8 Technology for medium- and large-scale methane engineering

This technology is mainly used by rural breeding farms to supply clean energy to local residents. It includes a fermentation pond and corresponding facilities for preprocessing, methane usage, manure treatment, etc. [16]. The methane pond is the site of anaerobic decomposition of organic matter. Preprocessing facilities include deposition, regulation, metering, material loading and unloading, and stirring facilities. Methane gas utilization facilities include purification, storage, transport and distribution, and utilization facilities. Methane manure utilization facilities include biogas residue and biogas slurry integrated usage facilities.

4 Summary of agricultural non-point source pollution prevention and control

Crop planting and livestock and poultry breeding are the two major sources of agricultural non-point pollution. The current approaches for pollution prevention and control combine source control, process prevention and control, and end management.

Regarding crop planting, the introduction of 4R technologies (right source, right rate, right time, and right place) put forth by the International Plant Nutrition Institute (IPNI) enables the precise application of fertilizers and pesticides. The optimization of agronomic management measures enables the control of fertilizer and pesticide application rates, reduction of water consumption and discharge, and control of agricultural non-point pollution from the beginning. The trend of the technological development, aimed at prevention and control of non-point pollution, is to combine field management and engineering measures such as irrigation and tillage based on traditional fertilization techniques.

With regard to livestock and poultry breeding, based on the principles of reduction, safe treatment, and resource recycling, the number of herds is determined by the availability of nearby arable land and water resources. The adoption of clean breeding technology is recommended for the reduction of manure discharge from the breeding process. The excreta of livestock and poultry are resources for organic fertilizers and biological energy production with a mature technology. The government should promote the use of this agricultural resource.

The control of agricultural non-point source pollution is a long-term and challenging task. Under the guidance of associated policies and regulations issued by central or local governments, the corresponding technology to prevent and control non-point pollution should be adopted according to local conditions, with emphasis on: the combination of protection and development; agronomy control and engineering management; source control, process prevention, and end management; policy guidance and ecological compensation; and scientific and technological support, and technology transfer. This pollution control not only emphasizes scientific feasibility but also considers predictions in order to achieve sustainable environmental, social, and economic benefits.

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