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AGRICULTURAL REUSE OF WASTEWATER AND GLOBAL WATER MANAGEMENT

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ABSTRACT

Agricultural reuse of wastewater has to be integrated into comprehensive land and water management plans taking into account water supply, wastewater collection, reclamation, and reuse. It may be incorporated, as a land treatment system, to the treatment cycle and considered as the nutrient recycling part of the loop. However, the water used for irrigation purposes has to meet the public health and agronomic quality requirements. Therefore, the treatment objectives and standards need to be clearly defined. This leads to reconsidering the treatment approach, the required treatment levels and processes, and the indicators that should be taken into account. A common approach to wastewater treatment and agricultural reuse has to be developed in order to define a reclaimed water quality that would be safe for each intended end use of the effluent, and acceptable in economic terms as well as the quality of the products coming from these wastewater reuse operations. Among the challenges that agricultural reuse operations have to overcome, planning and management are still major ones that require careful attention. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Agricultural wastewater reuse; integrated approach; wastewater management; wastewater planning; wastewater reclamation; water resources management.

INTRODUCTION

Agricultural wastewater reuse is an element of water resources development and management that provides innovative and alternative options for agriculture. Reuse of reclaimed water for irrigation enhances agricultural productivity: it provides water and nutrients, and improves crop yields. However, it requires public health protection, appropriate wastewater treatment technology and siting, treatment reliability, water management and public acceptance and participation. It must also be economically and financially viable.

Therefore, agricultural wastewater reuse addresses a number of questions that have to be answered before extensive wastewater reuse operations are implemented or in order to improve their performances. The questions that need to be addressed are the following: Is our approach to wastewater reclamation and reuse appropriate to agricultural reuse development? Is cost-effectiveness of agricultural water reuse well assessed? What is the place of agriculture in the wastewater treatment cycle? Are the treatment technologies used for agricultural wastewater reuse appropriate? Do public health water quality criteria depend on the state of development of the country? Are non-conventional approaches to wastewater reuse in agriculture safe? Which criteria and standards should be used for agricultural wastewater reuse? Are the actual institutional settings appropriate for a high reuse rate? Could increased users' associations participation improve the reuse rate and ensure a safe and efficient use of effluent? How can we improve effluent management for a safe reuse?

AGRICULTURAL REUSE DEVELOPMENT HAS TO BE INTEGRATED TO A WATER MANAGEMENT AND WASTEWATER REUSE APPROACH

Agricultural reuse development cannot be considered independently of water and land management. It is a wastewater reuse option which has to be included, with wastewater reclamation, in an overall planning effort for public health protection, environmental pollution control, and water resources management (Asano and Levine, 1996). An approach to water management and wastewater reuse integrating water supply, wastewater collection, reclamation and reuse needs therefore to be developed in which final water end uses would determine the choices to be made.

Wastewater reuse and water management units. Wastewater reuse is a water quality and resource management issue. It has therefore to be integrated into water management units or in a watershed approach because of the direct relationship between urban and agricultural areas established through agricultural wastewater reuse and the resulting water quality due to the different agricultural, domestic, and industrial activities. Wastewater quality needs also to be protected from different kinds of pollution sources. For that purpose, treatment at the source is required to minimize costs and environmental exposure to hazardous materials. Realistic regulations for the wastewater that is discharged by industries have to be set up to protect treatment plants and prevent the accumulation of potentially toxic compounds in the soil and groundwater aquifers. Enforcement of existing regulations is also required.

For a decentralized wastewater management. An approach based on water management units or watershed areas calls for a decentralized wastewater management. The implementation of a treatment plant leads to the production of an effluent in one given location when decentralized systems will lead to different treatment processes and consequently to different reuse options. Smaller amounts of wastewater flows will then be generated and more easily controlled. Transfers over lòng distances, due to the lack of available land around cities, may then be avoided. The technical, institutional and economic aspects of the question have still to be studied since they require the development of appropriate strategies and qualified bodies for local management of treatment and reuse projects (Tchobanoglous and Angelakis, 1996). Such projects could be designed in complement to classical centralized large-scale systems.

Urban and agricultural development. Agricultural development poses the problem in terms of both water quality and land use. The percentage of urban population is rapidly increasing not only as a consequence of a significant increase in overall population, but also because of the rural populations migrating to urban areas. Construction of sewer networks and wastewater treatment plants has accelerated reclaimed water availability around cities: Tunis, for example, concentrates more than 60% of the country's effluent. Around cities, agricultural development is based on water availability, which usually is the main limiting factor. Peri-urban irrigated areas are mainly devoted to the production of eaten raw vegetables which may be a major constraint to reuse development in the case of crop restriction (when water quality does not meet the standards for unrestricted application). Agricultural reuse also needs to be considered in land use planning. Agricultural land availability is the second limiting factor, especially along sea shores. Transfer of water for reuse may then be required even though expensive.

In Tunisia, the 11 towns project in the Medjerda catchment area is an example of integrated watershed management. The Medjerda catchment area is the main source of irrigation and of drinking water for the Tunis, Cap Bon and Sahel regions. A sanitation programme to equip the 11 largest towns of this catchment area with sewerage networks and treatment plants in order to protect the Medjerda reservoir and, particularly, the Sidi Salem dam (450 Mm^3) from raw wastewater which flows into it, is under implementation. The project also includes household waste management and the creation of irrigated areas with reclaimed water. The treatment process includes phosphate removal to limit risks of eutrophication from the discharge of non-reused water.

COST-EFFECTIVENESS OF AGRICULTURAL WATER REUSE HAS TO BE BETTER ASSESSED

Selection of a reuse opportunity is not often made on a rational basis:

- Even though agricultural wastewater reuse is the major component of wastewater reuse strategies in arid and semi arid areas, other reuse opportunities (wetlands, afforestation, recreation, industry, etc.) should be equally assessed and the most cost-effective one should be selected. The question has to be considered case by case within water resources management plans.

- Cities have to choose between an outfall that would dispose of secondary treated effluent or a more complicated and often more expensive system of treatment and reuse that optimizes water use. However, assessment of cost differentials between treatment for reuse and water transfer and treatment for sea outfall, as well as the cost of providing additional quantities of fresh water is not always done. Non-reused effluent disposed through sea outfalls are expensive temporary solutions not without environmental impacts and difficult to accept in water-short areas. Improving the cost-effectiveness of treatment, distribution and reuse of effluent and acknowledgment of the costs of environmental degradation would allow us to reconcile local and national priorities (UNDP *et al.,* 1992).

On the other hand, social and economic benefits of agricultural wastewater reuse have also to be assessed. A cost-benefit analysis of reuse operations is required, which would evaluate the positive aspects (benefits related to the value of water, nutrients, improvement of the quality of receiving bodies, impacts on public health) as well as the negative ones (risks of aquifer pollution mainly by pathogens and organic trace elements) and would take into account the different existing alternatives and indirect gains (employment, etc). Economic implications of a reuse scheme, both in terms of costs (treatment, maintenance of treatment facilities, implementation of a distribution network, and cost-recovery mechanisms) and expected benefits have to be analysed. An integrated methodology to evaluate all aspects of reuse has still to be defined.

WHAT IS THE PLACE OF AGRICULTURE IN THE WASTEWATER TREATMENT CYCLE?

Wastewater application at sewage farms was an example of zero discharge based on the "assimilative" and "self-purification" power of soil (Bouwer, 1993). More stringent regulations imply the return to a zero discharge approach by reusing the wastewater and recovery of initial water quality. There are different ways to reach such a target:

1. To use technically proven wastewater processes. However, only few countries can afford such technologies which are not fully applicable everywhere due to socio-economic conditions. Such a choice is based on a conservative approach in which the role of the soil in the attenuation of contaminants is neglected (Chang *et al.,* 1995).
2. To adopt a step by step approach where agriculture is integrated, as a land treatment system, to the treatment cycle and is considered as the nutrient recycling part of the loop. The water used for irrigation purposes has to meet quality requirements. The soil as a bioreactor and its capacity to attenuate contaminants are taken into account. This approach in which no more wastewater disposal will take place but where instead agriculture is incorporated to municipal treatment needs a real partnership between rural and urban sectors (Juanico, 1993).

PUBLIC HEALTH AND AGRONOMIC QUALITY REQUIREMENTS FOR IRRIGATION

A wastewater treatment level and, consequently, a given water quality are required for a type of agricultural production. Agricultural wastewater reuse, even though widely admitted and integrated in some national water resources strategies, still brings up various questions and controversial viewpoints. The wastewater content in salt or micro-organisms limits the range of uses; wastewater may, in some cases, have a high salt load, which presents soil salinization and alcalinization risks if used for irrigation. Wastewater microbial composition imposes crop restrictions and constraints for the users. This means that all effluents cannot be used for agricultural purposes.

In 1973, the World Health Organization (WHO) proposed relatively stringent guidelines: the quality of the effluent to irrigate crops to be consumed raw had to be high and close to water supply quality. These recommendations were based on the concept of "zero risk". To achieve such a level implies very important investments. Few countries have developed reuse projects in compliance with these guidelines. The epidemiologic approach for health risks assessment allowed an evolution of the wastewater reuse guidelines. In 1989, new guidelines were issued by WHO for aquaculture and non-potable urban uses. They take into account the treatment process, the irrigation system, the exposed group, and the crops to be irrigated. This new set of guidelines is controversial but has allowed a real development of wastewater reuse.

Concerning the chemical guidelines, the FAO quality criteria (salinity, sodium adsorption ratio, nitrogen, toxic and trace elements) determine the degree of suitability of a given effluent for irrigation (Ayers and Westcot, 1985). The classification of saline water has been reconsidered on the basis of research and practical observations (Kandiah, 1990). WHO has also undertaken a study on chemical guidelines related to human health for wastewater reuse in irrigation (Chang *et al.*, 1995). This study, which takes into account non-organic and organic trace elements, developed a methodology based on the acceptable daily human intake for different pollutants and on the food chain transfer of pollutants via the waste-soil-plant-human route. This type of approach is promising to derive site- and case-specific numerical limits.

Countries where reuse is developing on a rational basis, within an organized institutional setting, have elaborated and implemented regulations and precise standards. In other countries, it is just referred to as health standards. Schematically, two categories of countries are distinguished: those which have adopted a set of public health water quality criteria close to the WHO guidelines (1989), that means that reuse is practiced with a low level of risk, and those which elaborated regulations close to the California's Title 22 effluent reuse standards with minimum risk levels. However, there is a wide variety of situations with different regulations and standards that are often independent of the country's development state. Experiences gained in different countries will help develop a common approach to wastewater treatment and agricultural reuse based on the documentation and evaluation of existing practices in order to define a quality of reclaimed water that would be safe for each intended end use of the effluent, and acceptable in economic terms as well as the quality of the products coming from these wastewater reuse operations (Marecos do Monte *et al.*, 1996; Bontoux, 1997). This requires a new set of technology-based standards that combines the technology that must be adopted, the extent of wastewater treatment that is required for a specific use, the irrigation methods and the crops. A methodology needs also to be developed for setting microbial and chemical limits.

WASTEWATER TREATMENT

Before designing a wastewater treatment plant, the final end uses of the water should be first considered. The treatment objectives and standards need then to be clearly defined. This will lead to reconsidering the treatment approach, required treatment levels and processes, and the indicators that should be taken into account. It may also reduce conflicts of interest between wastewater producers and users due to the objectives difference among each group. But reuse has so far not been considered as an objective sufficiently important to modify our approach to treatment and disposal practices. Conventional technology has been adopted for treating wastewater independently of the type of reuse. The performance criteria that are appropriate for a given type of reuse are generally not carefully considered.

Appropriate treatment technology. It is said that developing countries need reliable low cost, low technology methods. However, what is required is to utilize appropriate technologies that are suitable to a particular socio-economic context; these may be "conventional" appropriate technologies or advanced or sophisticated "appropriate" technologies, which require supporting industries and logistics or innovated technological solutions. It has to be affordable, operable, and reliable (Kreissl, 1997). Low technologies often consistently reach the standards and should not be under-estimated. Using a combination of different high and low technology solutions (Dodds *et al.*, 1993), depending on local conditions, the siting, etc. will help to solve the problem in a sustainable and environmentally sound manner.

Treatment objectives and criteria. In industrialized countries, a common approach to treatment of drinking water was adopted at the end of the 19th and beginning of the 20th century with the introduction of filtration and chlorination. The recent adoption of standards for other chemical contaminants is not without created problems since it requires regular water quality monitoring and additional treatment steps. The cost of complying with more stringent standards is not affordable for many countries and makes it unfeasible (Nash, 1993).

Wastewater treatment cannot be based on the same approach as water supply because of the variety of existing reuse opportunities. Wastewater treatment must be linked to the type of reuse. The general approach adopted up to now is based on producing an effluent in compliance with water quality discharge requirements. Treatment plants are designed with no concern for reuse and there are no guarantees for the quantity or quality of the effluent. Reuse is generally considered in a second step. It is rarely the starting point. For agricultural reuse, conventional treatment plants, such as activated sludge processes, are generally designed for pollution control with BOD and SS removals as main objectives and the standards for these parameters are often higher than required; on the contrary, these conventional systems are ineffective to remove helminth eggs, bacteria or viruses. So, the approach to treatment generally adopted is not how to make the best use of the water components which means, first, how to keep nutrients and get rid of micro-organisms and the undesirable components, and, second, what would be the most appropriate technology for such a target. The application of performance criteria that describe the desired effects on human health (reduced exposure to pathogens), environment (ecosystems to be protected), and human activity (agriculture, in the specific case) would be a more innovative approach (Krauss and Boland, 1997). The setting of water-quality objectives depending on the type of reuse has to be the result of a balance between what is desirable from an environmental and public health point of view and what is feasible from a technical and economic point of view. The Mexican approach to the question is therefore a good example.

Mexico City and the Mezquital Valley. The City of Mexico produces 74.5 m^3/s (including stormwater) of sewage used downstream in the Mezquital Valley located 50 km north of the Valley of Mexico. Irrigated agriculture is the main activity of the Mezquital Valley where wastewater is used to irrigate around 90,000 ha of forage crops and consumed raw vegetables. Because of the high incidence of water-borne diseases in that area, attempts are made to treat the wastewater in order to produce a safe effluent, which could benefit agriculture, at an economic cost. The approach adopted to treat wastewater is (Jiménez *et al.*, 1997):

- how to comply with Mexican regulations for reclaimed water reuse which for unrestricted irrigation requires a helminth egg concentration less than 1/l and coliforms concentration less than 1000/100 ml, and
- how to keep the wastewater nutrient content to a level that could satisfy crop requirements.

For that purpose, several pilot tests based on an advanced primary treatment plus filtration and disinfection are being compared.

The Mexican case is interesting for the following reasons:

- the approach is innovative: the target is to produce an effluent that could be used safely in agriculture which could make the best use of the nutrients. The starting point is the use of the water and the nutrients;
- the economic aspect of the question is also taken into account.

PLANNING, COORDINATION, AND MANAGEMENT

The planning and management of agricultural reuse operations need to take into account institutional, organizational, legal, regulatory, socio-economic, policy pricing, environmental, and technical aspects. The complexity of the systems is such that the implementation of wastewater reuse operations is still a big challenge.

Planning and coordination

Institutional settings. An important degree of planning and coordination is required for a safe reuse program but not often reached. Storage, allocation, timely availability of effluent for reuse, and means of cost recovery, are also important issues that need to be addressed. Storage requires additional infrastructures that may be difficult to finance when rate of wastewater reuse is low. The willingness to pay for water is related to availability of water in quantity and quality. These issues require also cooperation among agencies and sectors that often perceive their interests to be conflicting, such as health, municipal wastewater treatment, irrigation water distribution, etc. Skills and administrative responsibilities are also often spread over different governmental offices. To ensure efficient agricultural wastewater reuse, cross-sectoral collaboration is required at the national and local levels. Perceptions of interdependence have to be strengthened. A complete wastewater discharge, treatment, and reuse system requires an integrated view, and adapted legislation and institutional structures. An interagency coordination and control of water use or an institutional body or executive committee empowered to properly regulate and enforce standards and procedures for wastewater reuse (monitoring - information - enforcement of the regulations, ...) might be required (UNDP *et al.*, 1992).

Water users' associations. Institutional and organisational measures between the wastewater treatment agency and the reclaimed water users guarantying a water quantity and quality level need also to be identified. The approach generally adopted for agricultural wastewater reuse schemes has been a top-down planning approach. Participatory approaches based on water users' associations are developing and may be a way to ensure safe and efficient use of effluent, on the one hand, and to increase the reuse rate through a more demand driven reuse, on the other hand. However, coordination among the different agencies involved in reuse operations is still a big issue and another approach to the question may have to be set up.

Wastewater irrigation management

Agricultural water reuse requires the application of multiple barriers to ensure a safe reuse. After treatment, it has to be based on appropriate irrigation management that includes storage, distribution and application methods. These different steps may provide additional treatment or prevent contamination.

Storage. The use of reclaimed water for agriculture requires both seasonal and long-term storage. Storing reclaimed water, in reservoirs or aquifers, leads to more reliable supplies (meet peak demands), water quality improvement, an increase in the rate of reuse, and a better protection of water bodies. Building reservoirs in which a few days effluent production can be stored would allow matching daily variations in irrigation water demand, increasing the reliability of water supply, and upgrading water quality to meet guidelines for unrestricted irrigation. On the other hand, as demand for irrigation water is mainly during the dry season, seasonal storage during the non-irrigation period would increase reclaimed water reuse and prevent coastal waters contamination.

In Tunisia, the absence or insufficiency of storage was reported as one of the limiting factor for wastewater reuse development. Thus, the storage of reclaimed water in existing dams (not used for water supply) or in newly built reservoirs is under consideration for all agricultural reuse projects as well as underground storage and different storage opportunities were also investigated. It was found that storage may not be feasible in all situations and requires careful attention in order to prevent water quality degradation. Water salinity is a major constraint that limits the reuse opportunities. Blending reclaimed water with conventional waters may reduce water salinity and the amout of water required for the leaching fraction, prevent soil salinization, allow the irrigation of a wider range of crops and lead to important fresh water savings. This, however, requires careful operation and management in order to keep water quality within acceptable limits. The economic opportunity of such an operation has also to be clearly proven. On the other hand, alternate use of fresh and brackish water depending on the crop development stage may not be feasible because of the need for additional storage infrastructure. Concerning groundwater recharge with reclaimed water, it seems that suitable sites are limited for different reasons: underground storage is often not feasible because of a shallow groundwater level, the use of the groundwater for water supply, the bad quality of the reclaimed water in terms of salinity and the potential impacts on the aquifer quality. So, water quality studies related to storage systems (deep or shallow reservoirs, wastewater alone or blended with conventional water, storage system management, etc.) are still needed.

Irrigation management. In arid and semi arid areas, sewage effluents are often salt-affected for various reasons, such as the seepage of brackish/sea water into the sewerage network, the location of treatment plants, the proportion of industrial water compared to the domestic, and finally water supply quality (Bahri, 1995). This implies specific management measures such as the selection of agricultural crops resistant to lower water quality, the selection of the most appropriate irrigation and drainage techniques (application of a leaching fraction, etc.), the adoption of specific cropping techniques, etc. (Ayers and Westcot, 1985; Pettygrove and Asano, 1985; Kandiah, 1990). Water and salt leaching requirements need to be known more precisely to avoid water losses and more studies on solute transport have to be conducted to prevent groundwater pollution. In Mediterranean areas, permanent leaching does not improve yields much. By an appropriate scheduling of leaching (autumn or winter during the rainy period), less water is needed to obtain a good leaching efficiency. However, the major problem is generally first to improve water use efficiency. This may be achieved through a more accurate knowledge of crop water requirements for irrigation scheduling and the use of water saving application methods such as drip irrigation systems. These systems would be, when filtration is adequately performed, the safest way of using reclaimed water and preventing microbial contamination. However, such systems cannot be used in several cases such as extensive crops (alfalfa, wheat, etc.) and golf courses. Where reuse schemes are aimed at achieving maximum economic returns, studies are also still required to determine optimal cropping patterns and sequences.

Fertilization. The quantification of nutrients supplied by effluents is rarely done in the reuse areas. Effluent composition needs to be regularly monitored in order to estimate how much nutrients they supply and how much should be supplemented in order to match crop requirements. Farmers often do not take into account the amount of nutrients supplied by the effluents or by the soil. High amounts of residual nitrogen may still be available in the soil at the end of the vegetation period that constitute a risk of N leaching. Research is needed in this field to achieve nutrients savings and recycling and to prevent over-fertilization problems and groundwater pollution (Bouwer, 1990).

CONCLUSION

Wastewater management should be integrated into the global water cycle. It should be an integral component in water resources management. As for conventional water resources, reclaimed water requires us to devise a strategy for management and optimal use at different scales: catchment-, farm-, and plot-level.

Agricultural wastewater reuse has also to overcome several challenges:

- A source control program has to be set up for water quality protection.
- A methodology needs to be developed for setting microbial and chemical limits.
- Our approach to wastewater treatment has to be refocused so as to develop innovative technologies, especially energy-saving processes, which allow the achievement of appropriate technologies.
- Future reuse projects will also depend on a better planning and management of reuse operations. This means that the way technical, socio-economic, regulatory and environmental factors are taken into account has to be improved; a better institutional and organizational setting is also required. Technical and administrative aspects need also further study, along with empirical research for specific applications. Codes of good agricultural practices for agricultural reuse could assist farmers in reusing reclaimed water. Education, information, and training of farmers may also play an important role in promoting these practices aiming to achieve higher agricultural production without adverse impacts on the environment.

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