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## Using Wastewater as a Source of N in Agriculture: Emissions of Gases and Reuse of Sludge on Soil Fertility

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### 1. Introduction

Nitrogen is one of the essential elements most required by plants and, for this reason, large amounts are applied for agricultural production; as consequence, N is one of the nutrients that most impacts the environment. The use of nitrogenated fertilizers and the use of residual waters as sources of nutrients for crops have increased production remarkably; however, a large part of the N supplied by fertilizers or residual waters is not recuperated in the harvest, primarily due to losses through filtration to the ground, although there are also losses to the atmosphere that have an impact on the stratosphere and participate in the greenhouse effect (Bergstrom *et al.*, 2001; Oron, *et al.*, 1999).

The continuous growth of the world population, together with industrial and agricultural activities to increase the food supply, as well as consecutive drought during the last years, have caused the consumption of existing water resources; a phenomenon that reaches its greatest expression in arid and semiarid regions.

Therefore, any source of water that can be utilized and is financially profitable must be taken into account to promote a greater development in regions with limited sources of water. It is worth mentioning that treated residual water can be used for agriculture. However, the residual water supply is not always treated (Wang *et al.*, 2007, Kiziloglu *et al.*, 2007). independently of the nutrient contribution to crops, where N is one of the main ones.

### 2. Nitrogen transformations

Recently, a growing concern has come up regarding the ever more popular use of nitrogenated fertilizers, both chemical or organic, since they both (along with residual waters) are used for agricultural activities, significantly contributing to environmental pollution.

Nitrogen in the soil solution is subject to a series of transformations; part of that N is consumed by the crop, while another part suffers a series of loss processes outside the soil-plant system. In agro-ecosystems without erosion, the loss of N to the atmosphere occurs through the processes of denitrification and volatilization, while lixiviation is associated with contamination of water tables. The magnitude of each of these losses will depend on the environmental and crop management conditions in place.

The environment (soil, climate, among others) is not very changeable, but crop management, especially the nutrients added through residual waters, can be optimized with the goal of maximizing their utilization (Kiziloglu *et al.*, 2007; Duxbury *et al.*, 1993).

### 3. Residual waters as a source of nitrogen

Residual waters are a product, fundamentally, of a population's water supply, after being made impure through various uses. From the point of view of their origin, these waters are the combination of liquids or waste dragged by the water, from houses, commercial and institutional buildings, from industrial establishments, and from underground, superficial or precipitation water that may be added (DSEUA, 2000).

Residual water contains various pollutants: total and suspended solids, biodegradable organic material (OM) (animal fats, minerals and oils), non-biodegradable OM (detergents, pesticide and solvents), toxic substances (heavy metals), nutrients (N, P and K), and various types of chemical products and pathogenic agents (bacteria, virus and protozoans) (Domínguez-Mariana *et al.*, 2004).

#### 3.1 Nitrogen content in residual waters

Residual waters contain considerable amounts of N, which represents a benefit for agricultural activities and which can contribute to soils that are not very fertile (Agin *et al.*, 2005). It is necessary to take into consideration this contribution in N for the fertilization plan of a crop, in order to avoid excess quantities of N in the soil, since this excess can decrease production or quality in crops such as cotton, tomato for conserve, beet, potato, melon, apple and grapes (Bowder and Idelovitch, 1987).

Taking into account that residual water can have an N content of 20 to 40 mg L<sup>-1</sup>, a crop that through irrigation is applied a total of 5000 m<sup>3</sup> ha<sup>-1</sup>, receives 100 to 200 kg of N ha<sup>-1</sup>. These quantities can cover the N needs of a crop in many cases (Ramos, 1998).

In Saudi Arabia, Hussain *et al.* (1996) carried out applications of 300 kg N ha<sup>-1</sup> to the soil in wheat crops, from residual water with an N content of 207 mg L<sup>-1</sup>. Other N contents applied on the soil from residual water were 30 to 200 mg L<sup>-1</sup> (Oron *et al.*, 1991; Zekri and Koo, 1994). Hussain and Al-Jaloud (1998) carried out applications, by using waste water from aquaculture, equivalent to 150 kg ha<sup>-1</sup> of N.

In Mexico, the use of residual water in Valle del Mezquital constitutes a regular practice; the volumes applied annually are between 10 000 and 20 000 m<sup>3</sup> ha<sup>-1</sup> with concentrations of 20 to 40 mg L<sup>-1</sup>, these applications represent dosages of 200 to 800 kg N ha<sup>-1</sup> year<sup>-1</sup>.

An additional problem caused by the N in residual waters is that the demand of the nutrient and water can possibly not coincide in time: in most crops, the N demand is low during the initial phase of cultivation, increases during the growth phase and is low again in the final phase of cultivation, once the plant has completed its development. An excess of N, in addition to being damaging to the plants, increases the NO<sub>3</sub><sup>-</sup> lixiviation and the pollution of underground waters (Ramos, 1998).

#### 3.1.2 The use of residual water in agriculture

The use of residual water in agriculture arose from the competition there is between cities and agriculture over the resource. The way to solve this situation was, initially, the use of water by cities, and later, its use in agriculture (Bouwer, 1992).

For Zekri and Koo (1994), the need to preserve the vital liquid, as well as the safe and economical disposal of residual water, are the factors responsible for the use of this water in agriculture, and its utilization is considered a viable option, with the advantages of being able to reduce the application of fertilizers and decrease the costs of production.

The use of water without treatment for irrigation is a popular practice in Mexico, where there are nearly 165,000 ha that are irrigated with  $51 \text{ m}^3 \text{ s}^{-1}$  of residual waters from the main cities (Alfaro, 1998).

According to data from the National Statistics and Information Institute (INEGI, Instituto Nacional de Estadística Geografía e Informática), the volume of residual water of urban origin was  $239 \text{ m}^3 \text{ s}^{-1}$  in 1002, out of which  $187 \text{ m}^3 \text{ s}^{-1}$  were channeled through drainage. On the other hand, in 2001, industries generated residual waters equivalent to  $5.39 \text{ km}^3$  annually ( $171 \text{ m}^3 \text{ s}^{-1}$ ).

Currently, it is estimated that out of the  $145\,605 \text{ L s}^{-1}$  of residual waters (urban and industrial) generated in the country, 41 495 correspond to Mexico City's metropolitan area, 7135  $\text{L s}^{-1}$  to Monterrey's metropolitan area and 5658  $\text{L s}^{-1}$  to Guadalajara's.

In Mexico, the use of urban residual water for agriculture has existed since more than 100 years ago in Valle del Mezquital, located in the state of Hidalgo, the place where the world's largest (100 000 ha) and most ancient agricultural area irrigated with residual water is located (DFID, 1998). Water from Mexico City and surrounding areas constitute the main source for agricultural/livestock development in the valley, which has a limited availability of first-use water (Flores *et al.*, 1997).

As was mentioned before, the total irrigated area in Valle del Mezquital is approximately 100 000 ha, and these are supplied with residual water ( $50\,000\,000 \text{ m}^3 \text{ year}^{-1}$ ) or a mixture of residual waters and rainwater. The total water application varies from 1500 to 2000  $\text{mm ha}^{-1} \text{ year}^{-1}$ , depending on the requirements of the crops, the soil texture, the depth and the availability of water throughout the year (Gutiérrez *et al.*, 1994).

In countries like Israel, the lack of drinking water has fostered the use of residual water in agriculture, making it one of the countries with the greatest use of residual waters to supply crops with the vital liquid. According to Harrosh (1993), two thirds of the residual water produced is recycled and 50% of the total volume of water is used for agriculture supply. The author mentions that in this country, they decided to develop an irrigation system of residual water onto soil, in order to cultivate. In the case of Australia, an increase of 100% has been registered for the use of residual water for irrigation of fruit trees in only 5 years (Snow *et al.*, 1999).

Research about the use of residual water in different countries in the world has produced different observations. For example, Vázquez-Montiel *et al.* (1995) indicate that the response of soy and corn to application of residual water is favorable, yet differences are observed in grain production and N absorption. The difference was due to the time and amount of water applied, and it was observed that the decrease in residual water application during the early growing stage stimulates N absorption.

Sawwam (1992), working with chrysanthemum, found a greater number of inflorescences in plants irrigated with residual water, and an increase in the content of chlorophyll, Fe and Zn; however, the content of other nutrients (K, Mn and Cu), was not affected. In corn, it has been found that the concentration of P in plants irrigated with residual water is greater, as are those of N, Ca, Mg, Na and K (Al-Nakshabandi *et al.*, 1997).

Studies by Hussain *et al.* (1996) have proven that the high production in treatments with high dosages of N can be attributed to a better physiological growth and a greater utilization

of nutrients, as compared with the control. When evaluating wheat yield, they found a response between 6.19 and 6.87 Mg ha<sup>-1</sup> with the application of residual water, indicating that the nutrients present in water can be enough for an optimal growth of the crop.

Al-Nakshabandi *et al.* (1997) and Oron *et al.* (1991) also observed an increase in yields when applying residual waters, indicating that the production is favored with the sole application of waste water.

Kiziloglu *et al.* (2007) reported an N increase of 0.18% in the soil, at a depth of 30 cm, and a greater yield in the cultivation of cabbage irrigated with residual water, as compared to the yield obtained with irrigation water.

When evaluating the efficiency in N use (ENU) of residual water, Hussain *et al.* (1996) found that it is favored when N is not applied to the soil, and that it decreases with the application of nitrogenous fertilizer; they also mentioned that estimating EUN is important in order to determine the relationship between the input and the output and to save in the use of inorganic fertilizer. Oron *et al.* (1999) found that the efficiencies vary from 35 to 64%; the highest values correspond to treatments irrigated with treated residual water, due to the quantity of P, K and other lesser elements contained in the water.

With this information, we can clearly see that the agronomic and economic benefits of using residual waters in irrigation are evident, for they increase productivity (Al-Nakshabandi *et al.*, 1997), thanks to the high levels of N, P and K (Pescod, 1992), and therefore, can be applied for agricultural production (Magesan *et al.*, 1998). According to Jenssen and Vant (1991), the use of N and P from residual water in agriculture can reduce the use of fertilizers in 15%.

In addition to what has been described, it has been observed that mineralization of N in the soil irrigated with residual waters is a fast process, with the liberation of the greater part of the N applied, which remains available for absorption by the plant. Also, the OM in residual water has the capacity of retaining water and giving the soil structure (Oron *et al.*, 1999).

### 3.1.3 Economic value of residual waters

As has been discussed, residual waters constitute an alternative to be used in agriculture because of the nutrient content present, in available forms, for crops; an important factor of its use is the possibility of reducing the production costs because of the decrease in inputs.

Assuming a cost of N equivalent to urea (\$1675 MX pesos Mg<sup>-1</sup>), the application of urban residual water for crop production represents savings, as is indicated by the following cases: in Saudi Arabia, the 300 kg N ha<sup>-1</sup> applied to wheat crops by Hussain *et al.* (1996), represent \$ 502.5, the 200 kg N ha<sup>-1</sup> applied by Oron *et al.* (1991), correspond to \$ 335, and the applications done by Hussain and Al-Jaloud (1998), represent USD \$ 251.25 (for the 150 kg N ha<sup>-1</sup>).

The application of residual water in Valle del Mezquital represents an investment per hectare that varies from \$335.00 MX pesos, for a dosage of 200 kg N, to \$1340.00 MX pesos with applications of 800 kg N ha<sup>-1</sup> (Hernández *et al.*, 1993).

### 3.1.4 Disadvantages and environmental impact of residual waters

As has been seen, the use of residual waters in agriculture is a common practice, since the OM present improves soil conditions and plant productivity. However, it contributes in a parallel manner to the contamination of soil, plants and the environment, putting human health, in general, at risk (Cuenca, 2000).



In spite of these advantages, their use can be restricted by the high content of salts, heavy metals, bacteria and virus that can be present in residual waters (Zekri and Koo, 1994), reason why developed and developing countries have decided to establish rules for their use.

The use of residential waters for crop irrigation has increased in several communities, although some factors that limit the use of residual waters for irrigation include the following (Bhatnagar *et al.*, 1992:

1. water availability at the time of irrigation
2. water quality according to the standards of use
3. disease transmission potential
4. accumulation of toxic substances

This is demonstrated by Cortés (1989), who points out that residual waters can be considered unhealthy at the time they reach the parcel, because they exceed the limits of microbe contamination suggested in Engelberg, Switzerland (1995) which should be of no more than 1000 fecal coliforms per 100 ml of water, and should not have more than one helminth L<sup>-1</sup> of water (WHO, 1989).

The presence of these microorganisms in residual waters, soils and fruits, as is the case of coliforms (*Escherichia coli* and *Klebsiella pneumoniae*), *Pseudomonas* spp, and helminth eggs (*Ascaris lumbricoides* and *Trichuris trichuria*), among others, which cause real and potential risks to public health.

In Mexico, the specific and non-specific sources of residual water discharges that come from population centers, industry and agriculture, exercise a heavy pressure over most of the superficial bodies of water; 29 monitored hydrologic regions, out of a total of 37, reach an acceptable category of water quality. Out of the total load of oxygen biochemical demand (OBD), 89% is concentrated in just 15 basins, and almost 50% specifically in the Pánuco, Lerma, San Juan and Balsas rivers, causing heavy contamination in them (INEGI, 2001).

Organochloride pesticides stand out since 1948, because of the application of considerable amounts of these on crops in the region. Due to their intense use, they are widely distributed in the high region of the Gulf of California.

#### 4. Denitrification: N<sub>2</sub>O emission in wheat irrigated with residual water

Denitrification is considered the most important mechanism for N, No and N<sub>2</sub>O volatilization during the N cycle in agro-ecosystems (Mosier, 2001; Oenema *et al.*, 2001; Aulakh *et al.*, 1998). Bouwman (1990) has estimated that N<sub>2</sub>O emissions from the soil are approximately 90% of the total of this gas' emissions. N<sub>2</sub>O is produced by microorganisms' biological activity.

The efficient use of urban residual waters for crops is an agronomic, economic and environmental necessity (Yadav *et al.*, 2003; Toze. 2006). The nitrogen applied to crops as fertilizer is not completely taken up by them. One of the mechanisms through which N is lost and its efficiency decreases, when applied to crops, is denitrification, which consists of the liberation of N oxides from the soil to the atmosphere. The latter negatively affects the producer's economy and can also affect the environment. One of the gases released is N<sub>2</sub>O. This is a gas that increases the greenhouse effect with concentrations of 0.6 - 0.9 μLm<sub>3</sub>/-year (Prinn *et al.* 2000) and contributes to the ozone layer's thinning (Aulakh *et al.*, 1998). The International Panel on Climate Change (IPCC, 2001) reports that 44% of the global emission of 16.2 Tg N<sub>2</sub>O N yr<sup>-1</sup> is anthropogenic; out of this fraction, it is estimated that 46% comes from agricultural activities.

Magesan *et al.* (1998) indicate that approximately 2 kg N ha<sup>-1</sup> from residual water are lost to denitrification, data that differ from those presented by Zheng *et al.* (1994), who estimate that approximately 16% of the nitrified N can be converted to N<sub>2</sub>O. For Barton *et al.* (1999), based on the rates of denitrification in New Zealand soils that are irrigated with residual water, losses over denitrification are 2.4 kg N ha<sup>-1</sup> year<sup>-1</sup>, which corresponds to less than 1% of the N supplied by residual water. The same authors point out that under lab conditions, the denitrification potential can be of 13.4 kg N ha<sup>-1</sup> year<sup>-1</sup>; when comparing the results, they mention that the low emission is due mainly to the soil conditions, which do not favor the process, indicating that emissions to the environment can be higher than 200 kg N ha<sup>-1</sup> yr<sup>-1</sup>. Similarly, the combination of muds from residual waters and nitrogenated fertilizer can make the emission of N<sub>2</sub>O increase, when the NO<sub>3</sub><sup>-</sup> and C applied are available (Rochette *et al.*, 2000; van Groeningen *et al.*, 2004).

For the soils in Valle del Mezquital, Vivanco *et al.* (2001) reported amounts of N released through denitrification of 158 a 231 kg N<sub>2</sub>O ha<sup>-1</sup> año<sup>-1</sup>.

Mora-Ravelo *et al.* (2007) reported that the N<sub>2</sub>O emission was 279 kg ha<sup>-1</sup> in wheat irrigated with residual waters, taking into consideration that in greenhouse conditions, N losses in gas form have been 5 to 10 times greater than those generally reported in the field, in agricultural soils (Daum and Schenk 1998), Así Likewise, Jianwen *et al.* (2005) point out that the N<sub>2</sub>O emissions in wheat crops depend on the degree of development of the plant. This is generally accepted from two mechanisms for the flow of this gas in plants: N<sub>2</sub>O derived from the soil that is transported by plants and N<sub>2</sub>O that is directly produced by plants during N assimilation. In this study, losses because of denitrification were high, which can also be due to the phenological stages of wheat.

In face of the data exposed, we consider necessary the development of appropriate management and monitoring practices that allow a better control of the resource (Bouwer, 1992). According to Snow *et al.* (1999), it is necessary to predict and measure the concentration and distribution of elements applied in residual water, depending on the depth of the soil, since the application of waste water increases the concentration of NO<sub>3</sub><sup>-</sup> in the profile.

From the environmental point of view, reutilization of residual waters offers positive aspects such as the more rational utilization of the water resource and irrigation in areas where water resources are scarce, favoring the recuperation of desert lands (Crook, 1984). However, it is important to mention that until today there is only information of the damaging effect on health of microorganisms present in residual water (Zekri and Koo, 1994; DSEUA, 2000), and that the efficiency of N use is restricted to plants taking it up from NH<sub>3</sub><sup>+</sup> oxidation, which must be oxidized through nitrifying bacteria to NO<sub>3</sub><sup>-</sup> (Luna *et al.*, 2002). Therefore, it is necessary to establish the importance of microorganisms present in the residual water on the efficient use of N.

## 5. Biosolids as improvers of agricultural soils

Biosolids are the subproduct of the activity of purification of residual waters, which is a combination of physical, chemical and biological processes that generates huge volumes of highly decomposable organic muds. In order to ease their management, they are subjected to processes for thickening, digestion and dehydration, thus acquiring the category of biosolids: muds that are rich in organic matter, nutrients, microorganisms, water and heavy metals (Cuevas *et al.*, 2006; Vélez, 2007).

Biosolid production from the treatment of residual waters is not new in the world, for reports are known from the 19<sup>th</sup> Century, and by 1921, there were commercial options from the transformation of biosolids in agricultural fertilizers. The elimination of muds in a treatment plant constitutes a problem of utmost importance in our days, which is why there is the general tendency to reduce, recycle or reuse them rationally in order to protect the environment (Seoanez, M and Angúlo, I.1999).

The tendency in organic residue management is recycling, and therefore, during the last years it has been promoted, taking into account its agricultural value as fertilizer or rectifier in the soil, for there is a general consensus among experts that many of the problems that affect soils (erosion, the dependency on chemical products and organic, mineral and microbe shortages) could decrease to a great extent with the recycling of these compounds (Ceccanti and Masciandaro, 1999; Garcia *et al.*, 1999; Masciandaro *et al.*, 2006).

The benefits of mud utilization from treatment plants in agricultural activities is due to various components, such as humic acid, microorganisms and nutrients (N, P, K), which can be employed as agricultural fertilizers. However, the agricultural use of muds can be limited by the presence of substances that are potentially toxic, such as heavy metals, pathogens and residual chemical molecules.

During the last decades, the production of urban muds has increased remarkably. The reutilization and disposal of residual muds has become an issue of great interest throughout the world. In an attempt to improve its acceptance, systems have been developed to transform residual muds into a substance similar to humus ("humification" or transformation of residual muds).

Although many of the traditional cleaning technologies for contaminated soils and water have proven to be efficient, they are usually very expensive and of intensive labor. In the case of contaminated soils, they normally require specific *in situ* techniques to minimize the secondary environmental effects; in the case of residual water, the cost-efficacy relation is always a problem in decision making. Phytoremediation offers a cost-effective option that is non-intrusive, respectful of the environment and a safe alternative to conventional cleaning techniques. This technique was widely used in artificial wetlands for residual water treatment, as a promising field in China (Zhang *et al.*, 2007).

Recently, research has revealed the advantages of bioremediation and particularly phytoremediation, as very promising, in view of its low costs. With this, technological options keep increasing, allowing us to think that the use of biosolids in agricultural lands could become a sustainable alternative if they are managed in a responsible manner.

Biodegradation contributes to recycling in soils, in water and in the atmosphere, of different nutrients and minerals that sustain life. Thus, carbon and nitrogen cycles are essential in nature. In the last years it has been recognized that biodegradation can also be applied to potentially toxic residues, and the technique has been developed to detect and increase the natural *in situ* biorecuperation.

Phytoremediation, for example, builds wetlands that can be a respectful alternative for the environment, in cleaning residual waters, based on solid scientific research. Using different trees, shrubs and grass species to cancel, degrade or immobilize harmful chemical products can reduce the risk of contaminated water at a low cost (Weis and Weis, 2004; Shankers *et al.*, 2005). There are reports that indicate that some species can accumulate certain heavy metals, although the plant species vary in their capacity to eliminate and accumulate heavy metals (Rai *et al.*, 1995).



In fact, biorecuperation or bioremediation, and particularly rhizofiltration or phytoremediation, could be a good solution for the feared metals, to convert them into less toxic forms, or simply recuperate them to recycle them.

Bioremediation includes the utilization of biological systems, enzymatic complexes, microorganisms or plants, to produce ruptures or molecular changes of toxic elements, contaminants and substances of environmental importance in soils, waters and air, and to generate compounds of lesser or no environmental impact. These degradations or changes usually occur in nature, although the speed of these changes is low. Through an adequate manipulation, these biological systems can be optimized to increase the speed of change and, thus, use them in sites with a high concentration of contaminants.

Recently, phytoremediation has been imposed as an interesting technology that can be used to bioremediate sites with a high level of contamination. Basically, phytoremediation is the use of plants to "clean" or "remediate" polluted environments, due in great measure to the physiological capacity and biochemical characteristics that some plants have to absorb and retain contaminants such as metals, organic complexes, radioactive compounds, petrochemical elements and others.

As an alternative, in Italy, experiments have been performed with natural technologies for mud treatment, with the goal of reducing costs of investment and eliminating the practical maintenance costs of the system, through stabilization of muds by the process of phytomineralization and biological conditioning when preparing tecnosuoli for agricultural and environmental use (Ceccanti and Masciandaro, 2006).

For example, with the use of *Phragmites australis*, a rhizomatose plant from the Poaceae family that has interesting characteristics for its use in phytoremediation or phytostabilization of nitrogen, phosphorous, organic compounds and heavy metals in water (Marrs and Walbot, 1997; Peruzzi *et al.*, 2010).

## 6. Conclusions

Research on the relationship between the wastewater and bacteria involved in N dynamics have been conducted separately. Some studies have reported on an individual crop nutrition with nitrogen fertilizer or the N contributed by wastewater highlighting the advantages and disadvantages of using them.

However, these studies do not consider the microbiological, which has a role based in the cycle of N. Each of these variables properly can provide important information which could help in future studies to handling the dynamics of N increasing agricultural productivity and minimize environmental impact by deepening the interaction between employment and bacteria wastewater participants N. losses

The fitotratamiento phytotreatment sludge process by opening the door to a kind of new concept of intervention, ensuring close the cycle of sludge directly to purification.

The product obtained with this treatment is pre-humified and therefore fit to be subjected to a composting process to develop a matrix to be addressed in different uses (agricultural and environmental).

The process has enabled a reduction in the average volume of over 90%, thus significantly reducing the cost of sludge management.

The final product is found to comply with the legal parameters for the production of compost soil mixed.

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The steady increase in industrialization, urbanization and enormous population growth are leading to production of huge quantities of wastewaters that may frequently cause environmental hazards. This makes waste water treatment and waste water reduction very important issues. The book offers a collection of studies and findings concerning waste water treatment, minimization and reuse.

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