English Version

Characteristics of the Nitrate leaching in intensive farming areas

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Abstract

The increase of the nitrate concentration (NO_3^-) in the water of underground drainage, and the increase in the contamination of the water table due to high rates of nitrogen fertilizers applied have occurred practically all over the world. NO_3^- leaching in agricultural areas is enhanced by the physical properties of the soil, by intense agricultural practices and by the high appropriation of water used in irrigation. The concentration of nitrate on water is a potential cause of damages to man and to the environment. Among the most common problems observed are the dysfunction of the thyroid gland, the production of nitrosamines, which generally cause cancer, and a decrease on the capacity of blood to transport Oxygen, also known as metahemoglobinemia, besides the impact on the various plants and environments. The increase in the leaching associated with the risks and impacts of the nitrate as soil and water pollutant shows the necessity of care on the nitrogen fertilizer management, due to the wide implications on the human and animal lives, besides the economic and environmental questions involved. The research on the nitrate leaching area has enabled the generation of new alternatives of agricultural management, with reduction of the impacts of the crop in intensive systems over the contamination of water sources; however, it is necessary to enlarge the knowledge and the generation of new technologies to apply in the intensive farming areas aiming a most appropriate management of the nitrogen in the system water-soil-plant.

Key-words: irrigation; protected cultivation; nitrogen; soil solution; water pollution.

Introduction

With the increase in the food demand it can be seen a growing advancement on the agricultural technicization. The management of the soil fertility with chemical fertilization, the intense cultivation in green houses and the increase in the use of irrigation and joint drainage are elements of great expression in this contest of agricultural expansion.

The benefits resulting from the intensive and technified agriculture are evident and aim the sustainability of food supply to the world. However, this process also generates numberless problems, especially in relation to the environment, emphasis on the water resources. Besides the direct use of water in agriculture, there is also the process of chemical element deposition in soil and water, which end representing a risk to the new crops and to human and animal health, since it not only reduces water quality, but also increases the difficulty of purification to consumption and still exposes people and animals to the direct consumption of polluted water.

Nitrogen (N) is one of the most present elements on the chemical fertilization applied on agriculture, widely used in intensive system cultivations as those practiced in greenhouse, where plants develop their cycle in an accelerated way and many times a year in the same place, depending almost exclusively on chemical fertilization, in which in the case of N, the supply from the atmosphere by rain is inexistent. Thus, the higher the application of this element on soil or substrate, the greater the possibility of generating residues and the higher the potential of soil and water pollution by nitrate leaching (NO_3^-).

In Brazil, the crop area with use of plasticulture in greenhouses present growth concomitant with the increase in urban growth, where the major cities are surrounded by a green belt with high greenhouse concentration. The irrigated perimeters spread throughout the countryside, with an accelerated proliferation of irrigation equipments, namely center pivot. The irrigated area nowadays is approximately 5 million hectares, with great potential of growth (ANA, 2009).

The aspects presented about the highest

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potential of pollution by chemical element leaching in irrigated areas and intensive farming areas as greenhouses cannot, however, reduce the importance of these production processes, since both irrigation and protected cultivation, which depends directly on the use of irrigation, enable increase in yield and collaborate to decrease the necessity of agricultural frontier expansion. Despite this, the negative impact of water use in irrigation is many times inferior to the impact caused by industrial and urban pollution. However, these are the three sectors that exert most pressure on the water sources on the planet.

In this context, the study and dissemination of knowledge about the effect of the management processes and use of inputs in agriculture and their potential of soil and water sources pollution is of major importance, because it may evidence the necessity and possibility of development of production process mechanisms 'cleaner' or environmentally less harmful.

Characteristics of the nitrate leaching process

Free nitrate in the soil solution is frequent. Since these ions are not adsorbed by the components of the soil fraction, reason why they move easily, they can be absorbed by roots and translocated to leaves and leached to underground springs (CORREA et al., 2006). Dynia and Camargo (1999) emphasize that the nitrate leaching is a physical phenomenon, favored by low energy involved in its adsorption to the soil particles and also by its great solubility in water.

Due to climatic factors, soil conditions and method of irrigation, slats dissolved on water can be accumulated on the soil profile or be carried to underground water (BARTON et al., 2006; RODRIGUES et al., 2007). Nitrate ions, since they are not retained in the solid phase of the soil, generally are dissolved in their solution, and can be leached in higher or lower degree, in function of the percolating of water all trough soil profile, reducing its availability to plants, with risks of contamination of surface and subsurface water.

Nitrate is considered the main form of nitrogen associated to water contamination by agricultural activities. According to Resende (2002), this occurs because it is weakly retained in the positive charges of colloids, tending to remain more in solution, mainly in the superficial soil layers, in which the organic matter accents the electronegative character of the solid phase (repelling the nitrate). In the soil solution, this element is very inclined to the leaching process and throughout the time it may have remarkable increase in its level in deep waters. To this author, the process of contamination depends, mainly, on the quantity of nitrate added to the soil, on the soil permeability, on the climate conditions (rainfall and irrigation) and on the depth of the water table. The excessive enrichment of the superficial water with nitrate causes the eutrophication of the springs.

The increase in the concentration of the mineral nitrogen $N\text{-}NO_3^-$ in the water of underground draining, and the increase of water table contamination due to high rates of nitrogen fertilizers application has been occurred practically worldwide. To Bakhsh et al. (2000), this fact happens due to the pursuit for ever great productivity without observing, generally, the consequent environmental impact. In this context, the effect of the rate of application of N, the productivity and the loss of $N\text{-}NO_3^-$ on the water of underground drainage must be quantified to search the appropriate economic development, and at the same time to ensure the sustainable development of the agricultural practices.

In normal condition it happens on the soil the process of nitrification, in which it is established an increase in the availability and absorption of nitrogen by plants, decrease on the N losses by denitrification and polluting effect on natural N. This process may be defined as a biological oxidation in which ammonium, from mineralization of the soil organic matter or from amide or ammoniac fertilizers is converted to nitrate by action of microorganisms on soil. Summarizing, the process can be divided in two phases, in which the first one the bacteria of the genus Nitrossomonas (NTS) act in the formation of nitrite and in the second the nitrate formation occurs by the action of bacteria of the genus Nitrobacter (NBT). In both cases, these nitrobateria are chemoautotrophic, fixing CO_2 with the energy obtained in these reactions which are obligatorily aerobic. The process occurs as follows:

$$2\,NH_4^+\;3O_2 \xrightarrow{NTS} 2\,NO_2^- + 2H_2O + 4H^+ \qquad (1)$$

$$2NO_2^- + O_2 \xrightarrow{NTB} 2NO_3^- \qquad (2)$$

According to Myrold (1998), nitrification occurs in two phases, in the first phase ammonia oxidizes and it is converted to hydroxylamine by the action of the enzyme ammonia monooxygenase (AMO). Later, hydroxylamine is converted to nitrite, with the participation of the enzyme hydroxylamine oxidoreductase (HAO).

$$NH_3 + O_2 + 2H^+ \xrightarrow{AMO} NH_2OH + H_2O \quad (3)$$

$$NH_2OH + H_2O \xrightarrow{HAO} NO_2^- + 5H^+ \quad (4)$$

In the second phase of nitrification there is the oxidation of nitrite to nitrate, with is performed with the participation of the enzyme nitrite oxidoreductase (NOR), which is:

$$2NO_2 + O_2 \longrightarrow 2NO_3^- \quad (5)$$

Management of nitrogen fertilization

Even though it is not the only responsible for the loss on the water quality, agriculture directly or indirectly contributes to the spring degradation. According to Phillips and Burton (2005), this can occur by the contamination of the water bodies by organic or inorganic, natural or synthetic substances, and still by biological agents. Widely used, most of the time inappropriately, the application of fertilizers, defensives and waste from intensive cattle is named as the main activities related to the loss of water quality on rural areas.

The knowledge of the availability of mineral N on soil during the crop cycle is of great importance to the performance of fertilization with N in the appropriated period and quantity. Nevertheless, it must be considered the existence of various factors which interfere on the availability of N released by the soil, as well as its absorption and assimilation by the pant. To Von Wirén et al. (1997) the use of N sources (NO_3^-, NH_4^+) available on the soil by plants is determined by environmental conditions and by the soil conditions to provide these two forms.

Nitrogen is absorbed by roots on the form of NO_3^- or in an ion ammonium (NH_4^+), which is incorporated in amino acids in the root itself or in the aerial part of plant. Thus, NO_3^- is the most available form of N in aerated agricultural soils where nitrification is not inhibited. Sparks (1995) describes that to N in the form of ammonium (N-NH_4^+), leaching is reduced by the adsorption of this cation on the complex of negative charges of the soil, although the capacity of adsorption of N-NH_4^+, according to the lyotropic series, is lower in relation to other cations, as Ca and Mg.

The use of sources of mineral N available on the soil by plants is determined by environmental conditions and, mainly, by soil conditions to provide these two forms. In this sense, NO_3^- is the most available form of N on aerated agricultural soils where nitrification is not inhibited (VON WIRÉN et al., 1997).

To Resende (2002) the exception of the effect of erosion which carries fertilizers and organic waste to the waterways, the excessive movement of nitrate to the springs occurs naturally due to an imbalance between rates of mineral nitrogen supply (nitrate or ammonium) in soil and capacity of vegetation coverage to absorb and assimilate nutrients, converting it to organic forms. Thus, when there is nitrate in soil in quantity above the amount that a particular culture can take, it increases the leaching to deeper layers not explored by the root system.

The average efficiency of the nitrogen (N) use in cereals is only 33%. Considering the 67% of N which are not used, Raun and Johnson (1999) estimate the occurrence of an annual loss of 15.9 billion dollars in nitrogen fertilization. In accordance with Catarella and Duarte (2004), nitrogen, despite being the nutrient most required in quantity, has a complex management and recommendation. The increase in the use and cost of nitrogen fertilizers is a growing preoccupation in several countries, and now also in Brazil. In this contest, Keenky (1982) define the ideal management of the nitrogen fertilization as the one which can satisfy the crop necessity with the minimum of environmental risk.

To be absorbed by plants the plants the organic N must be mineralized to form NH_4^+, this ion, by its turn, when passing through the nitrification process in soils oxidized is rapidly transformed to the form of NO_3^-. This way, there might be in soil much more nitrate that the absorption capacity by plants, and the exceeding leached easily in the profile (COSTA et al., 2004). A good example of nitrate release potential to the soil solution is fertilization with urea $CO(NH_2)_2$, which is one of the main types of nitrogen formulated fertilizers applied in agriculture, which presents 45% of nitrogen (N) soluble in water. In soil, the nitrogen of the urea is transformed in gaseous ammonia (NH_3) and nitrate NO_3^-. In the region of Campos Gerais in the state of Paraná, Piovesan et al. (2009) observed that the quantities of P, K e N-NH_4^+ lost, in relation to the applied, are comparatively lower to N-NO_3^-, confirming the potential of N-NO_3^- leaching, even in clay soil with predominance of kaolinite and gibbsite in the clay fraction. In relation to the Brazilian soils, as Latossolo, Araújo et al. (2004) verified that even with doses considered normal of nitrogen fertilizers and in Latossols clayey, where high levels of iron oxides and gibbsite occur, the NH_4^+ and NO_3^- leaching is a reality. This implies in more care in the management of nitrogen fertilization due to the enormous economic and environmental implications involved.

An important area of the management of fertilization is the current alternative of the use of wastewater. Coavilla et al. (2010) describe that the contamination of the soil and the underground and superficial water in areas with water reuse is closely linked to the characteristics of the wastewater and the properties of retention and transmission of water and solutes in soil, which can limit its appliance. Considering the results of several researches, Sampaio et al. (2010) observe that since it is a technique of disposition that reduces the cost of treatment and brings benefits to agriculture, the use of wastewater, as for instance from the pig farming, in fertigation of crops has aroused the interest of the farmers. Although, this water, when applied over the soil support capacity, may cause soil and underground water contamination trough nutrient leaching.

As a strategy to reduce the nitrate loss to soil and enable better use of wastewater, Aita and Giacomini (2008) describe that the addition to the soil of organic matter with elevated C/N relation, as the cereal cultural waste, may stimulate the absorption of N-NO_3^- by the microbial biomass, maintaining the N temporarily in the organic form and decreasing the losses of N-NO_3^- to the environment. The authors found efficiency in the application of pig manure on the oak straw as a strategy to stimulate the microbial immobilization of N, reducing the process of NO_3^- leaching on soil. However, the quantities of N-NO_3^-, and its soil percolation increased rapidly after the application of the manure, mainly in the 80 m^3 ha^{-1} doses, indicating that the management of soil fertilization with the use of biofertilizers offers risks similar to the chemical fertilization.

Behavior of the nitrate on the soil system soil-waste-plant

Characteristics concerning soil

According to Spitz and Moreno (1996), the main factors that influence in the loss of nitrate to the environment are rainfall, temperature, rate of fertilizers application, planting practices and drainage management practices. Although some of these are factors that occur naturally, and thus they are incontrollable, there are those which involve some human interaction and which can be managed to minimize the pollution of N, maintaining the benefit of the fertilizer. However, it must be observed the especial and temporal variability in the physical, chemical and biological properties of the soil, of nonlinear nature of return, as transport of contaminants, associated to the factor of climate uncertainty and complexity of soil properties.

Correa et al. (2006) and Phillips and Burton (2005) reported that, in elevated appropriation of water, the rage of ion leaching is higher in sandy soils. For being in general poor in organic matter, these soils, as well as the substrates of agricultural use have low capacity to retain nitrate, which, free in solution, will be subjected to leaching to the deeper layers. Andrade et al. (2009) verified that in irrigated fields, the nitrate leaching was enhanced by the physical properties of the soil, by agricultural intensive practices and by the elevated appropriation of water applied on the irrigation.

In the soils in which predominates clay of permanent charges, the capacity of nitrate retention is almost nil. By contrast, soils in which predominate minerals of variable charges (as latossolos) may present considerable capacity of nitrate retention (DAVIS et al., 2000). In evaluations in the tropical soil, Dynia (2000) verified that nitrate presents pronounced mobility, with accumulation of the ion between 220 and 460 cm of depth, in sandy soil, which demonstrates presence of this element in places well below the root zone of exploration of most crops.

Characteristics concerning protected cultivation and irrigation management

Irrigation plays an important role in the expansion of the agriculture yield, which enables the development of many regions of the globe. However, Cruz et al. (2003) considered that the practice of irrigation, associated to the irregular regime of rain and to the high rages of evaporation in the dry regions or in a system of protected cultivation, tend to increase the level of salt in soil and in water.

Before these factors, there is theoretically greater vulnerability to the contamination of the water table in irrigated areas, protected cultivation or regions with uneven distribution of rainfall. This hypothesis is justified because, in the period of drought, there is an increase in the frequency of irrigation, in the appliance of nitrogen fertilization trough fertigation and in the excess of the percolated depth of the irrigation water. To Oliveira (1993) the risk of contamination of the underground water with nitrate is also high in regions where there is high rainfall levels or occurs the application of excessive depth of wastewater and the soil presents high permeability.

The major potential problems of nitrate leaching are in areas of intensive cultivation, irrigated areas and drained areas, besides exploitation of wetlands. The intensive exploration of these areas with high dosages of fertilizers presents high risks of environmental imbalance with pollution by NO_3^-. Even if they do not represent the exact concept of intensive cultivation, the irrigated areas are associated to levels of high agricultural technology and are constituted of situations that demand high water quantities, and where there is application of chemical fertilization with macronutrients and, frequently, fertigation with nitrogen fertilization. They are important members of the crop management, representing, by contrast, high potential of pollution by chemical element leaching, especially those with great mobility in soil and water, as nitrates.

The protected cultivation system represents classic conditions to exploration in intensive agriculture, in which the use of chemical fertilizers, irrigation and application of management technologies are performed continuously aiming at a maximum enhancement of the production. This form of cultivation is an efficient alternative to the expansion of the agricultural frontiers and the period of cultivation of the agricultural crops.

In this system it is possible to use devices of climate control, although, it is indispensable the availability of irrigation to the water supply of plants. This water supply by irrigation facilitate the occurrence of salinization on the topsoil, due to the movement of chemical compounds present on the soil solution of the topsoil layers, which occur in consequence of the upward movement by water evaporation. To avoid this process of salinization, the management in protected crops is established considering the realization of periodic irrigation, in which are applied depths able to wash the soil profile conducting the concentrated soils to layer distant from the root system, which enhances the process of nitrate leaching (except the cases in which the drainage is conducted to tanks of effluent management, which is unusual). The other aspects of leaching are similar to those which occurred in conventional cultivation.

In irrigated or drained areas the initial losses occur soon after the soil saturation, moment in which nitrate, mineralized during the aerobic phase (NO_3^-), is denitrified to NO_2 and N_2, gaseous. On the other hand, NH_4^+ which is formed by mineralization of the organic matter or applied in the form of ammonia fertilizer is stable in the small area of the soil to be nitrified by aerobic microorganisms. The NO_3^- formed in the nitrification process can spread to small areas and be denitrified by the anaerobic microorganisms to NO_2 and N_2 (SOUSA and LOBATO, 2004). It is presented the following relation:

$$24\ NH_4^+ + 48O_2 \rightarrow 24\ NO_3^- + 24\ H_2O + 48\ H^+ \quad (6)$$

$$24\ NO_3^- + C_5H_{12}O_6 + 24H^+ \rightarrow 12\ N_2 + 30CO_2 + 42H_2O \quad (7)$$

In research in irrigated area, Andrade et al. (2009) observed that the levels of nitrate, in well water directed influenced by irrigated agriculture exceed significantly the maximum limits in the current legislation in Brazil to human consumption and also in relation to the classification of the water bodies. The optimization of water resources and of nitrogen fertilizers can be improved with the adoption of an irrigation management appropriated to the type of soil of the cultivated area.

Regarding to the irrigated areas, where the movement of water on the soil-plant system is more intensive, it is important to consider the information presented by Sousa and Lobato (2004), who describe that the total loss of N in soil is 43% from the denitrification and 29% are lost in form of nitrate leaching, process that is more accentuated in conditions of high soil humidity. In the same way Wolschick et al. (2008) verified that in years of high precipitation the loss of N by leaching on soil can achieve 30%.

Among the methods that enable the controlled application of fertilizers through irrigation systems, the located application by drip irrigation presents the advantage of reducing the loss of N by leaching, since the depth of application is better controlled and in general it is applied smaller and more frequent water depths, which enables the portioning of the nitrogen fertilization, and appliance of higher doses in the periods in which the use by the crop will be larger. However, even in these conditions, there is a necessity of performing irrigation with larger depth with determined frequency, aiming to wash the excess of salt to areas more distant to the root system of the crop. In this case, the joint action with a drainage system may enable a most efficient control of the effluent, and the application of techniques which minimize the leaching.

Effects and risks of nitrate

The contamination of underground water with nitrate is a concern. Nitrate is an ion that promotes the appearance of algae and other water plants in superficial water bodies, which affects the quality of the water for domestic use, recreation and can decimate the population of fish by eliminating the Oxygen on the water. Michovej and Rechcigl (1995) emphasize that water with concentration of nitric N ($N\text{-}NO_3^-$) above 3 mg L^{-1} is considered contaminated, and in this case the cost of removal of the ion NO_3^- by ion chance or other treatment method is high.

Facing the risk that it represents, the concentration of nitrate in water to human consumption must not exceed 10 mg L^{-1} of $N\text{-}NO_3^-$, according to the limits adopted by the National Council for the Environment (CONAMA) and the Ministry of Health (BRAZIL, 2001). These limits are the same adopted in several countries, as currently by the United States Environmental Protection Agency – USEPA. Data presented by Muñoz-Carpena et al. (2002) and Chowdary et al. (2005) showed that in areas explored with irrigated agriculture, the concentration of $N\text{-}NO_3^-$ in the water table, some times, exceed 200 mg L^{-1}.

The $N\text{-}NO_3^-$ leaching from the agricultural areas has become a risk to public heath, once in concentrations superior to 10 mg L^{-1} in underground water may develop metahemoglobinemia, also known in Brazil as syndrome of the "blue baby" (FENG et al., 2005). In relation to this effect Zublena et al. (2001) described that babies younger than six months old have bacteria on the digestive tract which reduce nitrate to nitrite, and may have poisoning. When nitrite reaches the bloodstream, there is a reaction with hemoglobin forming the compound methemoglobin, which reduces the blood capacity to transport Oxygen. In this situation, the child can suffer asphyxia, staying with a bluish skin, especially around the eyes and the mouth. The disease is lethal when 70% of the hemoglobin of the body is converted to methemoglobin.

Still concerning the effects of the excess of nitrate in soil and contamination of the water resources, Galaviz-Villa et. al. (2010) describe that nitrates and nitrites dissolved in underground water are indirectly consumed by human beings, in who they cause negative effects to health. Among the problems most commonly observed there is the dysfunction of the thyroid gland, production of nitrosamines (which generally cause cancer), besides the decrease on the blood capacity to transport oxygen (metahemoglobinemia).

To plants and plant production, Cano et al. (2007) emphasize that an excess of fertilization with nitrogen may cause multiple agronomical inconvenient which are widely defined, influencing on the fruit and plant quality, as hollow fruit, floral abortion, reduced resistance to frost, among others. The authors also point out that regarding to the environmental effects nitrates contribute to an increase in the greenhouse effect and degradation of the ozone layer.

Perspectives of the research

Nowadays, in Brazil, the major focus of concern with nitrate seems to be the management of wastewater, as well as effluent of the agricultural activities, as the pig farming. Besides these, it is verified studies in irrigated areas and protected cultivation, and, with less intensity, in plantations conducted in opened field. In other countries the problems associated with nitrate are various and distributed in all continents. One of the places with higher concentration of crop in intensive systems due to generalized use of irrigation and protected cultivation in greenhouses is the region Southeast of Spain. Studies show that in this place the elevated levels of production are accompanied with problems with nitrate leaching on soil and water. About this, Becerra and Bravo (2010) report that the actuation of the research on the leaching area has enabled the generation of great knowledge directed to the agricultural management, with reduction of the impacts of the cultivation in intensive systems under the contamination of water sources by nitrate.

Regarding to the advances in research it is observed in literature a wide range of information that show high financial investment and experimenting in nitrate leaching; however, it is also evident the necessity of scientific and technological improvement in this area, aiming at greater environmental sustainability and security, especially concerning human health.

At present the trend observed is the use of mathematic models to predict the transport of water and solutes, which represent an alternative of research grant and a possibility of practical application on the agricultural and environmental management, considering the specificities of different locations and characteristics of management in areas of intensive agriculture. For instance we can cite Gallardo et al. (2009) who present a mathematic model which proves to be effective in the evaluation of the N losses in cultivation in substrate. Thompson et al. (2009) demonstrate the efficiency of the model to estimate the regional losses of nitrate, appropriated not only to cultivation in soil but also in substrates.

Overall Considerations

In a general way the data of the research verified in literature demonstrate the occurrence of significant impacts on the nitrate leaching over the water resources and environment and highlight expressive risks of occurrence of problems in human heath which may be caused by this ion.

Even though this is a problem that has been studied long time, there is an eminent necessity of knowledge improvement, considering that new variables are being constantly inserted on the system. This is the case of new processes of management and reuse of wastewater, new inputs and fertilizers with nitrogen bases, expansion of protected cultivation and irrigation areas, cultivars with different levels of extraction and utilization of N, alteration on the global climate, particularly water regime and temperature, besides the soil weathering, which are elements that chance the process of nitrate movement and leaching.

Both nitrogen fertilization and use of irrigation are important factors that present great participation on the agricultural productivity. Thus it is necessary continuous studies, with aim at the development of management strategies associated to sustainability with minimum risk to environment and to human an animal lives, with reduction of the application rage, optimization of the use by plants and slowdown in the movement of the nitrate in soil, together with management practices more technified and less striking. It is essential that the information and awareness about this problem are increasingly present on the routine of the people responsible for the area of production and development of products, especially fertilizers.

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