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Chemical alterations in soils fertirrigated with wastewater from swine facilities¤

Alteraciones químicas en suelos fertirrigados con aguas residuales porcícolas

Alterações químicas em solos fertirrigados com águas residuais suinicolas

José Antonio Rodrigues de Souza[1], Ing, Msc, PhD; Débora Astoni Moreira[1]*, Ing, Msc, PhD; Rafael Oliveira Batista[1], Ing, Msc, PhD; Jairo Alexander Osorio Saraz[2], Ing, Msc, PhD; Olga Lucía Zapata Marín[1], Adm Gest Amb, Msc.

[1] *Universidad Federal de Viçosa Brasil, Departamento de Ingeniería Agrícola.*

[2] *Universidad Nacional de Colombia – Sede Medellín, Departamento de Ingeniería Agrícola y de Alimentos.*

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Summary

The increasing size of swine farms poses an environmental risk to water bodies, considering that manure is generally applied to croplands without appropriate agronomic criteria. Objective: the present work aimed to evaluate various chemical changes occurring in soils fertirrigated with filtrated wastewater from swine facilities (FWS). Methods: 21 drainage lysimeters filled with Dystrophic Red-Yellow Latossoil were cultivated with tomato plants in protected environments, and fertirrigated with several doses of FWS, with and without fertilizer addition. Treatments were: T1: control (provided the recommended irrigation and fertilization needs for tomato plants). Treatments T2, T3, and T4, provided 100, 150, and 200% of recommended nitrogen (N), respectively, by adding filtered swine wastewater. Treatments T5, T6, and T7 provided equivalent N percentages with fertilizer addition. The experiment was conducted in a completely randomized design (seven treatments and three replications). Results: compared with initial conditions, an increase in the concentration of available phosphorus was observed, mainly in the superficial layers. The FWS addition resulted in increments in N concentration in the superficial layers, while chemical fertilizer application resulted in larger displacements in the soil profile. Conclusion: chemical fertilization was more effective than FWS for ionizing the soil solution.

Key words: *chemical alterations, fertirrigation, nitrogen, phosphorus.*

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* Corresponding author: Débora Astoni Moreira. Departamento de Ingeniería Agrícola y de Alimentos Universidad Federal de Vicosa – Brasil. E-mail: deboraastoni@yahoo.com.br

Resumen

El aumento en el tamaño de las granjas porcinas supone un riesgo ambiental para los cuerpos de agua, teniendo en cuenta que el estiércol se aplica generalmente a las tierras de cultivo sin adecuados criterios agronómicos. Objetivo: el presente trabajo tuvo como objetivo evaluar los diversos cambios químicos que ocurren en los suelos fertirrigados con aguas residuales de instalaciones porcícolas (FWS). Métodos: 21 lisímetros de drenaje llenos con Latosuelo distrófico rojo-amarillo fueron cultivados con plantas de tomate en ambientes protegidos, y fertirrigados con varias dosis de FWS, con y sin adición de fertilizante. Los tratamientos fueron: T1: control (proveía la irrigación y fertilización recomendada para las necesidades de las plantas de tomate). Los tratamientos T2, T3 y T4 suministraron el 100, 150 y 200%, respectivamente, del nitrógeno (N) recomendado, mediante la adición de las aguas residuales filtradas. Los tratamientos T5, T6 y T7 proporcionaron los mismos porcentajes de N mediante la adición de fertilizantes. El experimento se realizó en un diseño completamente al azar (siete tratamientos y tres repeticiones). Resultados: al comparar con las condiciones iniciales, se observó un aumento en la concentración de fósforo disponible, sobre todo en las capas superficiales. La adición de FWS resultó en incrementos en la concentración de N en las capas superficiales, mientras que la aplicación de fertilizantes químicos resultó en grandes desplazamientos en el perfil del suelo. Conclusión: la fertilización química fue más eficaz que el FWS para ionizar la solución del suelo.

Palabras clave: *alteración química, fertilización por riego, nitrógeno, fósforo.*

Resumo

O incremento de tamanho das granjas de suínos supõe um risco ambiental para os corpos de água, tendo em conta que as fezes dos porcos aplicam-se geralmente em terras para culturas sem ter em conta critérios agronômicos adequados. Objetivo: este trabalho teve como objetivo avaliar a alteração química que ocorre em solos adubados com irrigação de água residuária de suinocultura filtrada (FWS). Métodos: 21 lisímetros de drenagem cheios com latossolo distrófico vermelho-amarelo foram cultivados com tomateiros em ambientes protegidos e fertirrigados com varias doses de FWS, com e sem adição de adubo químico. Os tratamentos foram: T1: controle (ministrou-se a irrigação e fertilização recomendada para as necessidades do tomateiro). Os tratamentos T2, T3 e T4 ministraram 100, 150 e 200%, respectivamente, do nitrogênio (N) recomendado, por médio da adição de águas residuais filtradas. Os tratamentos T5, T6 e T7 proporcionaram as mesmas percentagens de N por médio da adição de adubos químicos. O experimento se analisou com um modelo completamente aleatorizado (sete tratamentos e três repetições). Resultados: ao comparar as condições iniciais, observou-se um aumento na concentração de fósforo disponível, principalmente nas capas superficiais. A adição de FWS resultou em incrementos da concentração de N nas capas superficiais, enquanto a aplicação de adubos químicos resultou em grandes deslocamentos no perfil do solo. Conclusão: A adubação química foi mais eficaz que o FWS para ionizar a solução do solo.

Palavras chave*: adubação por irrigação, alteração química, fósforo, nitrogênio.*

Introduction

Until the 1970s, swine feces were not a major problem for pig farmers, since farm animal concentration was low and the soils had the capacity to absorb all nutrients present in the added manure. However, as production aiming to meet the population demand for pork meat increased, most farmers began to adopt a feedlot-type regimen, which consequently increased the volume of waste produced per unit of area. Waste started to leak into watercourses without previous treatment, becoming a pollution source for water bodies and a risk factor for animal and human health.

The pollutant capacity of swine waste is much higher than that of other animal species. The biochemical oxygen demand of swine feces from pregnant and lactating sows, averaging 196 kg live weight, varies from 170 to 380 g/day, while human waste averages 45 to 75 g/day (Perdomo *et al*., 1998).

Aware of the environmental damage caused by the discharge of wastewaters into water bodies and rising concerns regarding environmental quality, swine producers have begun seeking specific solutions for the treatment, placement, and reuse of residues.

In spite of the advantages in using swine manure as soil fertilizer as well as the existing reports pertaining to the chemical effects of soil deposition, most research does not consider agronomic criteria in order for the calculation of the film to be applied. Considering that plants play a vital role in the technical viability and sustainability of the treatment system, the present work aims at evaluating the chemical changes in a Dystrophic Red-Yellow Latossoil cultivated with tomato plants (*Lycopersicon esculentum* Mill).

Materials and methods

The experiment was conducted at the Lysimeter Station of the *Área Experimental de Hidráulica, Irrigação e Drenagem* (Experimental Area of Hydraulics, Irrigation and Drainage), at the Federal University of Viçosa (UFV) campus in Viçosa (MG, Brazil) from September 2007 to May 2008.

Twenty one drainage lysimeters were used in protected environments. Lysimeters were filled with Dystrophic Red-Yellow Latossoil previously air-dried, harrowed, sieved in a 0.004 m mesh sieve, acidity adjusted and homogenized up until the formation of the profile of 0.60 m. Table 1 presents the physical and chemical characteristics of the soil used to fill the lysimeters.

After the formation of four definite leaves, the saplings of tomato plants (*Lycopersicon esculentum* Mill; hybrid Fanny TY), were transplanted into furrows of 0.15 m depth, with 1.00 x 0.50 m spacing, totaling four plants per lysimeter.

The plants were conducted with a single stem, without tip pruning, without removing the first inflorescence, maintaining only six inflorescences per plant, which were vertically staked with polypropylene cord, starting the binding 10 days after transplanting (DAT), as recommended by Perdomo *et al*. (1998).

The treatments comprised the control (T1 – recommended tomato plant irrigation and fertilization) and fertirrigation with filtered swine wastewater, providing 100%, 150%, and 200% of the nitrogen dose recommended for tomato plants without additional fertilization (T2, T3, and T4) and with addition of fertilization (T5, T6, and T7), respectively. The experiment was conducted in a completely randomized design with seven treatments and three replications.

Wastewater from the swine facilities at the Department of Animal Science, UFV, was used for fertirrigations. Wastewater was conducted to a tank (339 h average hydraulic detention time). The effluents were submitted to a sequential filtering procedure by passing through 2 10-mesh stainless steel screens and 1 25-mesh stainless steel screen. The filtered swine manure (ARSF) was pumped into the wastewater reservoir of the lysimeter station to be used for fertirrigation.

Table 1. Physical and chemical analyses of the soil used to fill the lysimeters.

Characteristic	Value	Characteristic	Value
Texture class	Very clay-like	Clay (%)	75.00
Coarse sand (%)	10.00	Soil Specific Mass (kg dm^{-3})	0.98
Fine sand (%)	10.00	Specific Mass of the particles (kg dm^{-3})	2.64
Silte (%)	5.00	Total porosity (dm^3 dm^{-3})	0.63
pH	7.01	H+Al ($cmol_c$ dm^{-3})^d	0.80
P (mg dm^{-3})^a	0.90	SB ($cmol_c$ dm^{-3})	2.64
K (mg dm^{-3})^a	9.00	t ($cmol_c$ dm^{-3})	2.64
Na (mg dm^{-3})^a	5.50	T ($cmol_c$ dm^{-3})	3.44
P-rem (mg dm^{-3})^e	11.80	V (%)	76.72
Ca^{2+} ($cmol_c$ dm^{-3})^c	2.02	m (%)	0.00
Mg^{2+} ($cmol_c$ dm^{-3})^c	0.57	ISNa (%)	0.91
Al^{3+} ($cmol_c$ dm^{-3})^c	0.00	CO (dag kg^{-1})^b	0.52
N_T (mg kg^{-1})^f	817.00	MO (dag kg^{-1})^b	0.90

a - Mehlich-1 method; b - Walkley & Black method; c - KCl 1 mol L^{-1} method; d - $Ca(OAc)_2$ 0.5 mol L^{-1} method and - concentration of phosphorus in balance after agitation for 1 hour of the TFSA with $CaCl_2$ 10 mmol L^{-1} solution, containing 60 mg L^{-1} of P, in the relation 1:10; f – salicylic acid method.

In which: pH – hydrogenionic potential in water 1:2.5; P - available phosphorus; K – exchangeable potassium; Na – exchangeable sodium; P-rem – remaining phosphorus; Ca^{2+} - exchangeable calcium; Mg^{2+} -exchangeable magnesium; Al^{3+} - exchangeable acidity; H+Al – potential acidity; SB – sum of bases; t -capacity of effective cation exchange; T – cation exchange capacity at pH 7.0; V –index of saturation by bases; m – index of saturation by aluminum; ISNa – index of saturation by sodium; MO – organic matter, N_T – total nitrogen.

Table 2 presents the physical, chemical, and microbiological characteristics of the ARSF, while table 3 presents the chemical characteristics of the irrigation water.

To calculate the ARSF films, nitrogen was taken as the reference nutrient, whose films, necessary for applying the different percentages of nitrogen, were calculated by means of equation 1, recommended by the EPA (1981).

$$L_W = \frac{Cp\left(PR - ET\right) + 10\,U}{\left(1 - f\right)Cn - Cp} \quad (1)$$

in which:

Lw - application of annual laminae, cm year^{-1};

Cp - nitrogen concentration in the percolation water, mg L^{-1};

PR - local precipitation, cm year^{-1};

ET - evapotranspiration, cm year^{-1};

U - nitrogen absorption, kg ha^{-1} year^{-1};

Cn - nitrogen concentration in the wastewater, mg L^{-1}; and

F - nitrogen portion removed by denitrification and volatilization, adimensional.

This method considered Cp as 10 mg L^{-1} (CONAMA, 2008), null PR-ET (handling in a greenhouse and evapotranspiration reposition), U equivalent to 400 kg ha^{-1} (tomato plant cultivated in a greenhouse, vertically staked (CFSEMG, 1999), f equivalent to 20% (Matos, 2007), and Cn achieved in bimonthly evaluations.

The complementary chemical fertilization was calculated by subtracting from P and K values (CONAMA, 2008). The amount of these nutrients comes from the different films of the ARSF applied.

Therefore, 261.10, 229.80 and 181.4 g furrow^{-1} of "super-simple" and 49.70, 40.90 and 32.70 g furrow^{-1} of potassium chloride were added to the soils under treatments 5, 6, and 7, respectively. In the soils submitted to the control treatment, 100 g furrow^{-1} of ammonium sulfate, 375 g furrow^{-1} of "super-simple," and 69 g furrow^{-1} of potassium chloride were added.

Table 2. Physical, chemical, and microbiological characteristics of filtered swine wastewater (FWS) used for fertirrigation.

Characteristics	Values	Characteristics	Values
pH	7.43	K_T (mg L^{-1})	162
CE (μS cm^{-1})	3.403	Na (mg L^{-1})	40
N_T (mg L^{-1})	480	COT (dag kg^{-1})	0.12
N-NO_3^- (mg L^{-1})	0.44	MO (dag kg^{-1})	0.20
N-NH_4^+ (mg L^{-1})	0.30	Ca + Mg (mmol$_c$L^{-1})	4.40
Cl (mg L^{-1})	181.40	DBO (mg L^{-1})	89
Alcalinity (mg L^{-1} de $CaCO_3$)	1954	DQO (mg L^{-1})	370
P_T (mg L^{-1})	139	RAP ((mmolL^{-1})$^{-1/2}$)	2.81
ST (mg L^{-1})	1067	RAS ((mmolL^{-1})$^{-1/2}$)	1.18
SST (mg L^{-1})	126	CT (MPN/100 mL)	13.4x10^5
SVT (mg L^{-1})	381	CF (MPN/100 mL)	4.1x10^5

In which: pH – hidrogenionic potential; CE – electrical conductivity; N_T – total nitrogen; N-NO^{3-} - nitrogen in nitrate form; N-NH_4^+ - nitrogen in ammoniacal form; Cl - chloride; P_T – total phosphorus; ST – total solids; SST - solids in total suspension; SVT – total volatile solids; K_T – total potassium; Na - sodium; COT – total organic carbon; MO – organic matter; Ca+Mg – calcium plus magnesium; DBO - biochemical oxygen demand; DQO – chemical oxygen demand; RAP - Potassium adsorption ratio; RAS - Sodium adsorption ratio; CT - total coliforms; CF – thermo tolerant coliforms; MPN most probable number.

Table 3. Chemical characteristics of irrigation water.

pH	CE	DQO	N_T	K_T	Na	Cl	Alc	Ca+Mg	RAS	RAP
	μS cm^{-1}			mg L^{-1}			mg L^{-1} de $CaCO_3$	mmol$_c$L^{-1}	(mmol$_c$L^{-1})$^{-1/2}$	
7.44	70.40	9.80	3.47	2.63	3.83	1.00	26.00	0.58	0.31	0.13

In which: pH - hidrogenionic potential; CE – electrical conductivity; DQO – chemical oxygen demand, N_T – total nitrogen l; K_T – total potassium; Na - sodium; Cl - chloride; Alc – total alkalinity, Ca+Mg – calcium plus magnesium, RAS - sodium adsorption rate; RAP - potassium adsorption rate.

The meteorological variables necessary for determining the evapotranspirometric demand were obtained using a greenhouse-installed Davis automatic station. Reposition of tomato plants' evapotranspirometric demand was determined considering the evapotranspiration (ETc), obtained by multiplying the reference evapotranspiration (ET0) by the plant cultivation coefficients (Kc; Moreira, 2002), the shaded area percentage, the localization coefficient proposed by Keller *et al.*, 1990, and the efficiency of the application system.

Irrigation water and fertirrigation application were carried out by dripping using a 0.016 m-diameter polyethylene hose with emitters spaced 0.50 m (one emitter per plant) and 1.90 L h^{-1} flow, with 10 MPa operating pressure.

Fertirrigations considered reposition of 100, 150, and 200% of daily ETc for treatments receiving 100, 150, and 200% N, respectively, by means of the ARS films, thus making the plants' most needed nutrients available in a timely manner.

After transplanting the saplings, fertirrigation started with daily applications of ARSF films, which concluded 68 days after transplant (DAT), then totaling 114.29, 171.43, and 228.58 mm, corresponding to 100, 150, and 200% of the N required, calculated in equation 1. After this period only water was applied to replace the evapotranspirometric demand by the plants. Thus, when clean water is prevented from passing through polyethylene lines during ARSF application period, biofilm formation and, consequently clogging of drippers, are reduced (Batista, 2007).

Soil samples were collected in each lysimeter during transplanting (0 DAT), in the middle (60 DAT), and end (120 DAT) of the tomato plant cycle using a Dutch auger 0.10 m far from the plant stem, in the strips of 0.18-0.22; 0.38-0.42, and 0.56-0.60 m depths, except for the samples used to determine electrical conductivity of the saturated soil-paste extract (CEes). These were collected in the 0-0.20 m layer, during periods 44, 77, and 112 DAT, corresponding to the formation of the first and sixth inflorescences and final phase of the plant cycle. These samples were identified and analyzed for CEes, phosphorus (P), and total nitrogen at the Soil Fertility and Soil Physics Laboratory of the Soils Department at UFV (Embrapa, 1997).

Results

Effects on electrical conductivity

When the applications of ARSF films were finished (68 DAT) films of irrigation water totaling 97 mm were applied, yielding an ETc of 211.62 mm. It was verified that even with the application of 200% of the ETc daily, the films were not enough to produce effluents in the lysimeters and subsequently guarantee that the entire ARSF was available for the plants.

According to the classification proposed by Embrapa (1997), due to the low electrical conductivity and the sodium adsorption ratio, the water used for irrigation presented high risk of sodicity and no risk of soil salinization, while the ARSF presented a high risk of salinization. However, regarding the potential to cause reduction in the soil infiltration capacity, these guidelines should not be used for ARSF because they do not include the solid organic elements contained in the wastewater.

Table 4 presents the soil electrical conductivity in different periods in the 0-0.20 m layer for the different treatments.

Table 4. Electrical conductivity of the saturation extract (CEes, dS m^{-1}) and respective average tests in several evaluation periods for the 0-0.20 m layer.

TRAT	DAT		
	44	77	112
1	4.42Aa	4.79Aa	2.20Ab
2	2.52Db	3.90Ba	1.76Ac
3	2.64Db	4.03Ba	1.72Aa
4	3.21Cb	4.42ABa	1.87Ac
5	3.94ABb	4.13Ba	2.01Ac
6	3.70BCa	4.43ABa	2.13Ab
7	3.45BCb	4.33ABa	1.85Ac

Averages followed by at least one same lower case letter in the lines indicate that for the treatment (TRAT) the evaluations at the time (DAT) do not differ according to the Tukey test at 5% of probability.

In table 4, it can be observed that the CEes increased with the increase in the ARSF films applied. However, when the chemical fertilization was added, the opposite behavior occurred. The treatments that received the smallest ARSF films but the highest quantities of additional chemical fertilization presented the highest CEes. Treatment 1 verifies that the chemical fertilization was generally more effective in increasing the CEes of the soil than the ARSF. This fact may be associated to the presence of ions, which take part in organic chains or are complexed/chelated. In this condition they are not detected by the conductivimeter electrode.

The application of ARSF films during transplanting (68 DAT) and their suppression after this period when only irrigation water was applied, and the end of the chemical fertilization (90 DAT), carried out in treatment 1, were responsible for the salinity reduction observed in the evaluation performed 112 DAT.

Phosphorus

Figure 1 presents phosphorus variations available with depth and time in the treated soils. It can be noted that P concentration presented a negative linear relation with depth and a quadratic relation with time, except for the soils in treatments 1, 2, and 5, which had a positive linear relationship. It is also observed that compared to the initial conditions, there was an increase in available P concentration, mainly in the superficial layers.

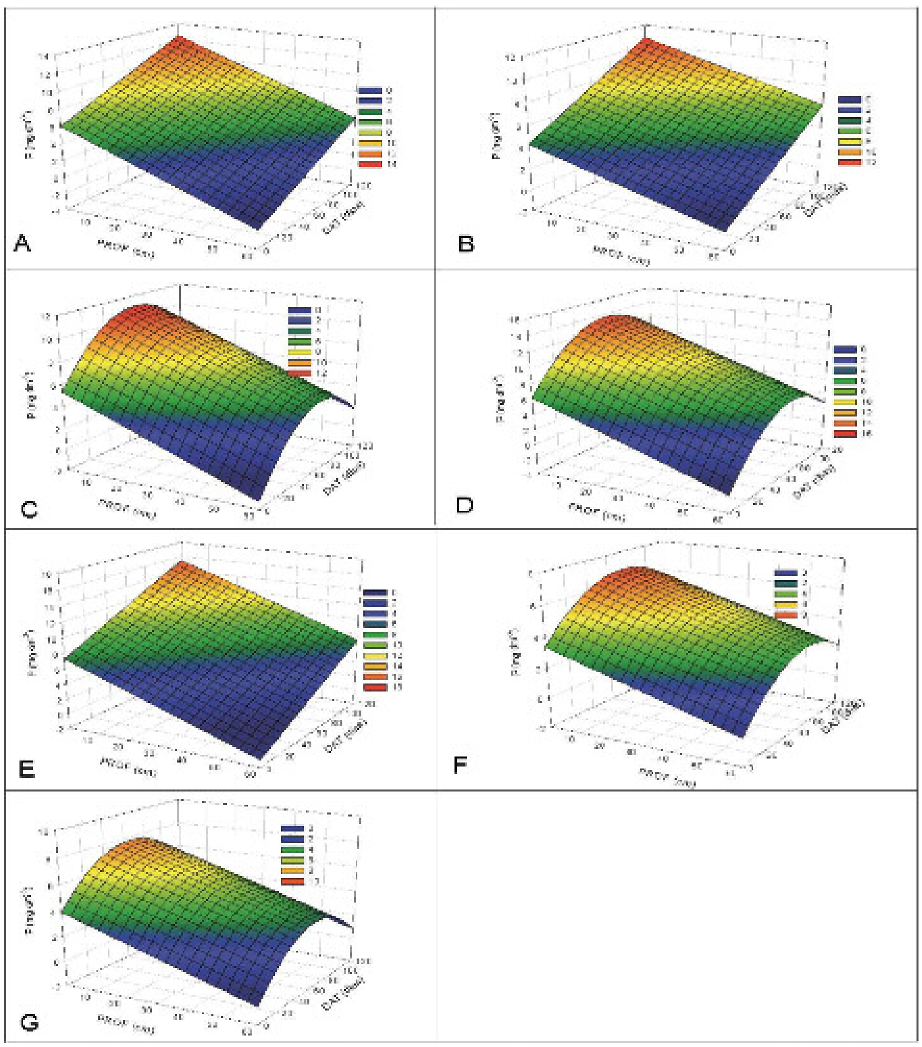

Figure 1. Variation in available P concentration in the soil profile, according to the depth (PROF) and days after transplanting (DAT) in the soils submitted to treatments 1 (A), 2 (B), 3 (C), 4 (D), 5 (E), 6 (F), and 7(G).

According to Ayers *et al*. (1991) and Scalopi *et al*. (1986), the low P concentration available in the lower layers is due to the low mobility of this nutrient, which is probably adsorbed by the soil particles and absorbed by the plants while the remaining is precipitated. For Ceretta *et al*. (2005), the available P content usually tends to decrease with depth, following the content of soil organic matter.

The application of daily ARSF films during transplanting until 68 DAT and its suppression after this period may have been responsible for the quadratic effect on time, while the positive linear behavior observed in the soils under treatments 2 and 5 may have been a consequence of the virus symptoms presented by the tomato plants cultivated in these soils, which hindered their development and yield, thus causing lower absorption of this nutrient.

Tomé (1997) studied the effects of applying various ARS films in soil cultivated with maize and, according to King *et al*. (1985), Freitas *et al.* (2004), Montavalli *et al.* (2002), Queiroz *et al*. (2004), and Oliveira (2006), soils cultivated with forage plants also presented increases in available P concentration in the superficial layers and achieved higher values when the highest films were applied.

At the end of the experimental period, at the depth of 0.10 m, reductions were observed in available P concentrations, compared to the control and the reductions of 10.85, 30.98, 17.05, 54.20, and 59.20% were obtained in treatments 2, 3, 4, 6, and 7, respectively. A 25.63% increase was observed in the soils of treatment 5. Thus, the highest ARSF films provided increments in P absorption by the plant, except for the soils in treatments 2 and 5 because of disease symptoms. The films were intensified by the nutrient balance via the fertilization addition.

Regarding the interpretation of P availability suggested by CFSEMG (1999), the plots of soil showed very low P availability prior to the experiment. After the experiment the soils had low (treatments 6 and 7), average (treatment 3), good (treatments 1, 2, and 4), and very good (treatment 5) P availability, as measured at a depth of 0.10 m.

Nitrogen

Figure 2 shows variations in total N concentration according to soil depth and time. It can be observed that in the soils of those treatments where ARSF was applied, N concentration showed a negative linear relation with depth and a quadratic relation with time, except for the soils under treatments 2 and 5, whose relation was linear positive. For soil in treatment 1, a quadratic relation with depth and a linear positive relation with time were observed.

The predominance of organic nitrogen (99%) added to the soils under ARSF application may have been responsible for the increase in the concentration of this nutrient in the superficial layers, while the quadratic effect on time may be related to the ARSF application until 68 DAT and its suppression after this period.

The positive linear relation with time, observed in soils under treatments 2 and 5, is probably related to the virus symptoms presented by the tomato plants cultivated in these lysimeters, which resulted in a lower development of the plants and consequently lower values for plant growth, dry matter production, fruit nutrient concentration and yield.

The use of ammonium sulfate as a source of N in treatment 1 resulted in a high mobility of this element in the soil. The liming and application of irrigation films may have caused the quadratic effect observed with the depth in the soil profile, favoring NH_4^+ and NO_3^- displacement. The variation in time may have been caused by the split application of N, according to CFSEMG’s (1999) suggested recommendations for tomato plants.

Scalopi (1986) analyzed the alterations caused by ARS application in soil cultivated with natural pasture (Berwanger *et al.,* 2008) by applying ARS in the arable soil for eight consecutive years, observing low N mobility in the soil profile, and achieving higher values in the superficial layers, which were increased by ARS addition.

It can also be observed that the maximum N concentration values in soils receiving ARSF occurred in the higher layers, following the application of all the films, except for the soils under treatments 2 and 5, in which the maximum values occurred at the end of the experimental period. In the soils under treatment 1, the maximum value was also observed at the end of the experimental period, but in the lower layers, which indicates a higher tendency of groundwater contamination.

At the end of the experimental period, an increase in N concentration at a depth of 0.10 m was observed for soils under treatments 1, 2, 3, 4, 5, 6, and 7 (11.00, 36.17, 13.83, 26.00, 27.21, 4.41, and 9.77%, respectively) compared to the initial conditions. Therefore, it is possible to argue that except for soils submitted to treatments 2 and 5, higher ARSF films provided higher increases in N concentration, with lower values observed when complementary fertilization was used, which, due to nutrient balance, favored higher plant absorption.

According to Dal Bosco *et al*. (2008), one of the problems with fertilization is the unbalanced use of nitrogen and potassium, which causes damage to agricultural production.

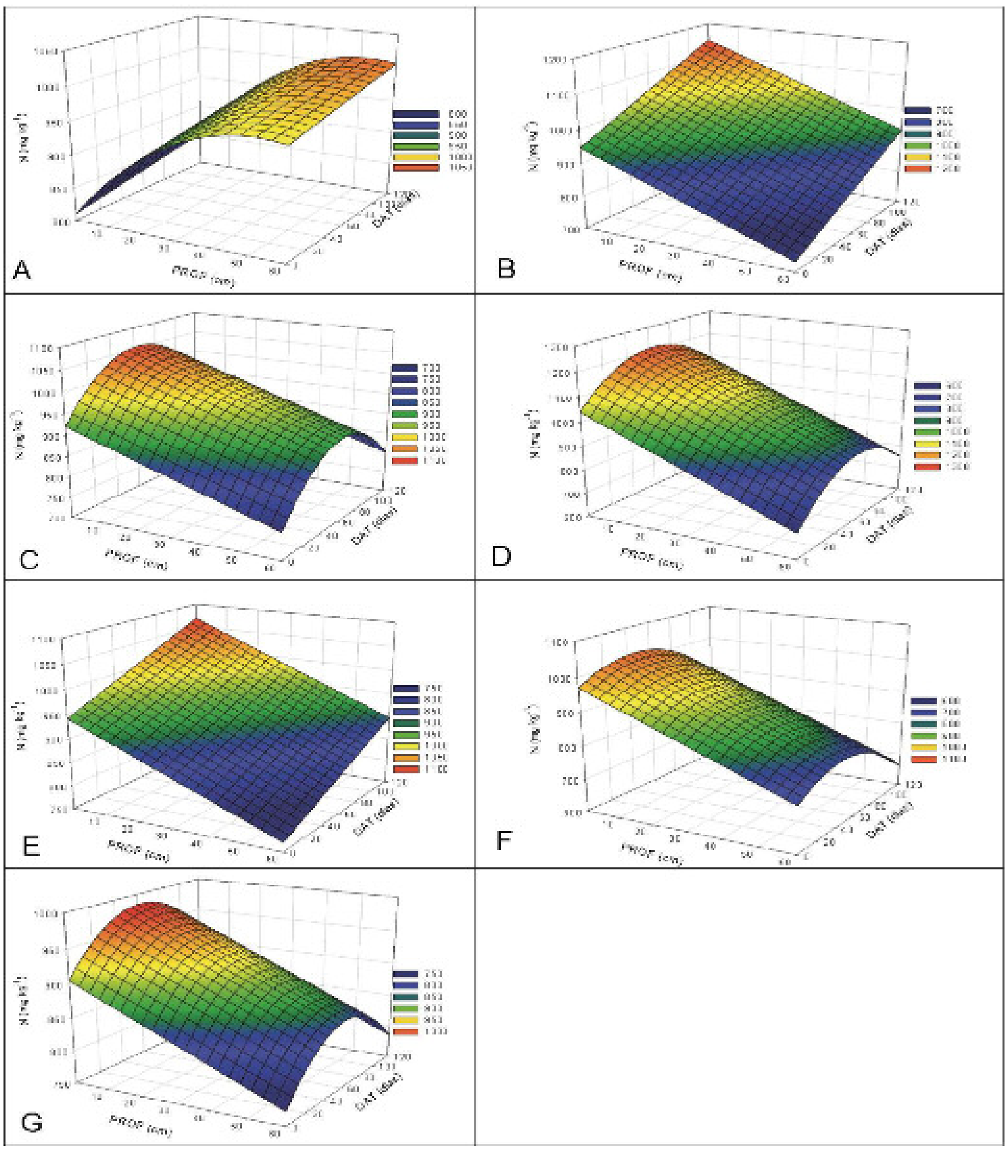

Figure 2. Nitrogen concentration variations in the soil profile, according to depth (PROF) and days after transplanting (DAT), in soils under treatments 1 (A), 2 (B), 3 (C), 4 (D), 5 (E), 6 (F), and 7(G).

Discussion

Under the experimental conditions used, it can be concluded that chemical fertilization was more effective for ionizing the soil solution than the wastewater from filtered swine manure (ARSF). The soils receiving lower ARSF films and higher amounts of chemical fertilization had higher CEes values. Compared to the initial conditions, there was an increase in the concentration of available P, mainly in the superficial layers. The addition of ARSF resulted in increased N concentration in the superficial layers, while chemical fertilization resulted in a higher displacement in the soil profile.

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