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Microbial, physical and chemical properties of irrigation water in rice fields of Southern Brazil

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ABSTRACT

This paper presents the results of the statistical analysis of microbiological, physical and chemical parameters related to the quality of the water used in rice fields in Southern Brazil. Data were collected during three consecutive crop years, within structure of a comprehensive monitoring program. The indicators used were: potential hydrogen, electrical conductivity, turbidity, nitrogen, phosphorus, potassium, calcium, total and fecal coliforms. Principal Component and Discriminant Analysis showed consistent differences between the water irrigation and drainage, as the temporal variation demonstrated a clear reduction in the concentration of most of the variables analyzed. The pattern of this reduction is not the same in the two regions – that is, the importance of each of the different variables in the observed differentiation is modified in two locations. These results suggested that the variations in the water quality utilized for rice irrigation was influenced by certain specific aspects of each rice region in South Brazilian – such as anthropic action or soil/climate conditions in each hydrographic basin.

Key words: agrosystems, irrigation, rice field, spatial variation.

INTRODUCTION

Water used for irrigation is a source of concern that has generated a great number of studies in developed countries, especially on water use in urban and semi-urban areas. Deficient water treatment systems increase the possibility of chemical and biological contamination both of drinking and irrigation water. The pollution of freshwater systems alters the quality of the water, or in other words, changes the characteristics that make the water suitable for the user´s needs. The problems of the quality of water are associated to non-sustainable agricultural techniques, inadequate animal husbandry practices and unsatisfactory methods for the treatment of domestic and industrial solid and liquid wastes (Crowther et al. 2002, Koukal et al. 2004, Evanson and Ambrose 2006, Chang 2008, Zhang et al. 2008).

The quality of water may be evaluated in terms of its physical, chemical and biological parameters. Polluted waters cannot support balanced ecosystems – in other words, systems and the environment interact in a manner positive for both.

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The quality of the water plays a fundamental role in this interaction by contributing to the maintenance of a balanced environment (Ntengwe 2006).

The cultivation of irrigated rice is widely considered to be one of the agricultural activities that consume most water. In Brazil approximately 11 tons/ha of rice are produced annually – of which 60% are produced in the state of Rio Grande do Sul (Sosbai 2010). The importance of water for this culture is associated to the increase in the availability of nutrients, the control of weeds and the regulation of the thermal alterations in the soil. The importance of water for the productivity of rice cultivation, various problems arise from irrigation especially the possibility of microbiological contamination due to the use of urban waters (Ensink 2004, Rhee et al. 2010), and the contamination of water resources by chemical substances used for fertilization of the soil and/or pest control (Macedo and Menezes 2004).

The chemical pollution caused by the drainage of irrigated water is the main economic problem in rice cultivation (Tongkasame 2007, Silva 2008). On the other hand, the cultivation of rice may act as a filter for chemical and biological pollutants present in the incoming water used for irrigation (Somura et al. 2009). In this context, the evaluation of the quality of the water supplied to the rice field for irrigation and of that same water when it is returned to the river are important aspects for a complete understanding of the real impact of this activity on the water resources.

This study was performed with the objective of evaluating the microbiological, physical and chemical quality of the water used for irrigation in rice field areas in Southern Brazil during three crop years. Specifically, this paper seeks to evaluate two fundamental aspects: a) the quality of the water used for irrigation and b) the quality of the water returned to the water source following its passage through the rice field; temporal and phenological variation in water quality were also analyzed.

MATERIALS AND METHODS

The Study Areas

To obtain the data for the analyses we selected two areas located in Southern Brazil (Fig. 1), as follows:

In the district of Camaquã – Rio Grande do Sul, located in the rice-growing region of the Inner Coastal Plain**,** the samples for evaluation of the water utilized in the local rice field were obtained from the Barragem do Arroio Duro (30°51’04”S and 51°48’44”W) – RS, a dam supplied with water from the Camaquã River which is the main source of irrigation water for an area of 19.600 ha;

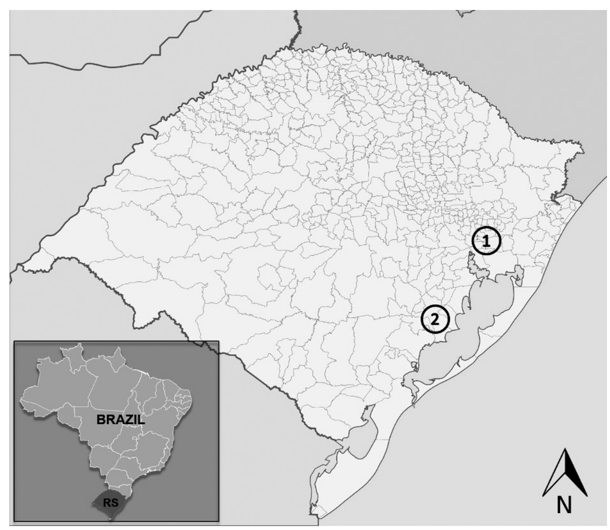

Figure 1 - Map of the water quality in the monitoring rice culture areas in South Brazil. (1) Cachoeirinha and (2) Camaquã/RS/Brazil.

In the district of Cachoeirinha, Rio Grande do Sul – situated, in the Outer Coastal Plain **-** the water used for irrigation is obtained directly from the Gravatai River. The samples analyzed were obtained from a 60 ha experimental area located in the *Estação Experimental do Arroz do Instituto Rio Grandense do Arroz - EEA/IRGA* (29º56’59,9” S and 51º07’23” W).

Basic Agricultural Activities

Two significant events at the beginning of the rice cultivation are fertilization and irrigation. Before sowing is performed, an analysis of the soil's chemical composition is conducted to identify the level of main nutrients, mainly phosphorus, potassium and nitrogen. The fertilizer applications offer the necessary quantities of these substances to sustain the productivity of the crop being consumed during its development, supplying the required quantity to the culture. The application of phosphorus and potassium occurs before sowing. Nitrogen is applied twice: in the sowing and before the flowering plants. The nitrogen applied per ha will depend on the amount of soil's organic substances available, varying between 10 and 60 kg/ha. The maximum value for potassium and phosphorus is 40 and 60 kg/ha, respectively. It is expected that all fertilizer will be consumed by rice plants. The rice field irrigation occurs a few days before the crop sowing; the floodwater is held at a 10 cm depth. This water level is sustained by periodic reposition during cultivation cycle.

Water Samples

The quality of irrigation water was monitored for three crop years (2006/07; 2007/08; and 2008/09). The water samples were obtained during the three phenological phases of the rice: vegetative (October and November); reproductive (December and January) and maturation (February and March). In each collection, samples were taken from four different points of the irrigation and the drainage water and each was processed and analyzed independently.

The values utilized to construct the data matrices correspond to the average values obtained for these points and represent the concentrations of the different variables analyzed in the water used to irrigate the rice field and the water returned to the river after its passage through the plantation on the day the samples were collected.

Samples having a volume of 100 ml of the water were submitted to an analysis of microbiological quality in the Laboratory of Microbiology and Toxicology at the *UNISINOS* University. Quality analysis of the water samples was performed using the method of pollution indicators that simultaneously establishes the concentrations of total and fecal coliforms. The quantity of contamination was determined by biochemical analysis using the Colilert® (IDEXX) method which makes use of defined substrate technology (Defined Substrate Technology – DST) and biochemical analysis (Clesceri et al. 1998). For the statistical analysis of the biotic data sampled it was converted into most probable numbers in 100 milliliters (NMP x 10^6/100 mL) and these were compared to the quality standards for classification/grading of water (CONAMA 2005).

The physical and chemical parameters analyzed were: potential hydrogen - pH, electrical conductivity –EC (μS/cm), turbidity – T (NTU) and the levels of total nitrogen –Tn (mg / L), phosphorus – P (mg / L), potassium - K^+ (mg / L) and calcium - Ca^{2+} (mg / L), measured at the moment of collection with a multi-parametric probe, and further analysis performed at the Soil Laboratory of *EEA/IRGA,* in Cachoeirinha/RS/Brazil. The procedures used to determine the various physical and chemical parameters were those set out by Tedesco et al. (1995). Some variables (P, N, K^+, Ca^{2+}) are estimated to define the quantities that should be added to soil to maintain productivity; the same variables are considered to estimate the possible environmental impact. Others parameters (pH, EC total and fecal coliforms) are analyzed to assess the quality of water used for irrigation.

Statistical Analysis

The spatial and temporal variations in the water quality utilized in irrigated rice fields during the three years of our study were analyzed by Principal Components Analysis (PCA) and Discriminant Analysis (DA). All the analysis used SPSS 19.0 e PC ORD 5.0 software. The data were transformed to $\log_{10}$ before analysis.

To determine the variation of the water quality, the results were organized into three banks of different data and analyzed separately. The first databank was utilized to evaluate the quality of both and quality of the water that returned to the river following its passage through the rice field. The matrix was constructed using the data obtained from the points of irrigation and drainage during the three crop years for all the variables. The second was applied in the analysis of the effects of the phenological phases of the plants on the quality of the water returned to the river, utilizing only the information obtained from the drainage points during the three crop years. For the PCA analysis we used a correlation matrix, because the variables are estimated in different units of measurement. Only autovalues greater that 1 were utilized as criteria for extraction of the principal components. The varimax rotation, was used to simplify the expression of a particular sub-space in terms of just a few major items each, the actual coordinate system is unchanged, as to facilitate the interpretation of the data generated by the principal component analysis.

The third database was used to evaluate the variation over time of the quality of the irrigation water using a matrix containing only the information obtained from the irrigation during the three agricultural years.

The discriminant analysis was applied to identify the variables that can best be used to differentiate the different groups analyzed. The variables of each principal component are correlated. The data was analyzed by the Stepwise Method in which the discriminant function is constructed step-by-step; at each step all the variables are evaluated to determine which contributed most to the discrimination amongst the groups. This variable is included in the model and the process starts again.

RESULTS

We monitored the quality of water used in rice cultivation for three consecutive crop years. The samples were collected at entry points into the fields and when the water exited the field and drained back into. The average values obtained for the irrigation water and for the drainage water in each phenological phase of the plants for the three crop years, Inner Coastal Plain and Outer Coastal Plain, for all the variables.

Variation in Quality of the Irrigation and Drainage Water

The matrices for this analysis were constructed utilizing data obtained for all the samples collected during the three crop years of the monitored rice plantations – that is, 137 for the Inner Coastal Plain and 136 for the Outer Coastal Plain.

Inner Coastal Plain - Camaquã

The Principal Component Analysis indicated the existence of four principal components which explain approximately 76% of the total variation (Table I). The average values of the variables included in the principal components are lower in the drainage water than in the irrigation water. The reduction in these values is greater for phosphorus, electrical conductivity and nitrogen, followed by potassium and calcium, which are included in the first and second components respectively and which explain more than 52% of the observed variation. The reduction in the total coliforms, *Escherichia coli*, and pH variables was found to occur with less intensity.

The separation of the points which were analyzed based on the first two components is shown in Figure 2, were observed a separation between use samples taken from the irrigation and drainage waters can be observed. The samples from the drainage water are mainly grouped on the left-hand side of the graph and those from the drainage water on the right side.

The discriminant analysis indicated nitrogen, pH, turbidity and total coliforms as the main variables

TABLE I
Matrix standardized coefficient, percentage of variance, eigenvalues, canonical correlation, and Wilks lambda for discriminant analysis variation in quality of irrigation and drainage water in Camaquã/RS/Brazil.

	Irrigation x Drainage	Years		Phases	
Parameters	DF1	DF1	DF2	DF1	DF2
N	0.449	0.706	- 0.270	0.789	- 0.529
T	0.555	-	-	0.487	0.433
EC	-	0.422	- 0.059	-	-
K^+	-	-	-	-	-
Ca^{+2}	-	- 0.152	0.850	-	-
P	-	0.279	0.639	-	-
pH	-	-	-	0.581	0.785
TC	- 0.413	-	-	-	-
E. coli	-	-	-	-	-
% variance	100	75.2	24.8	87.6	12.4
Eigenvalues	0.717	2.100	0.691	1.581	0.225
Canonical correlation	0.646	0.823	0.639	0.783	0.428
Wilks, Lambda	0.583	0.191	0.591	0.316	0.817

EC=electrical conductivity; TC=total coliforms; T=turbidity; DF=discriminant function.

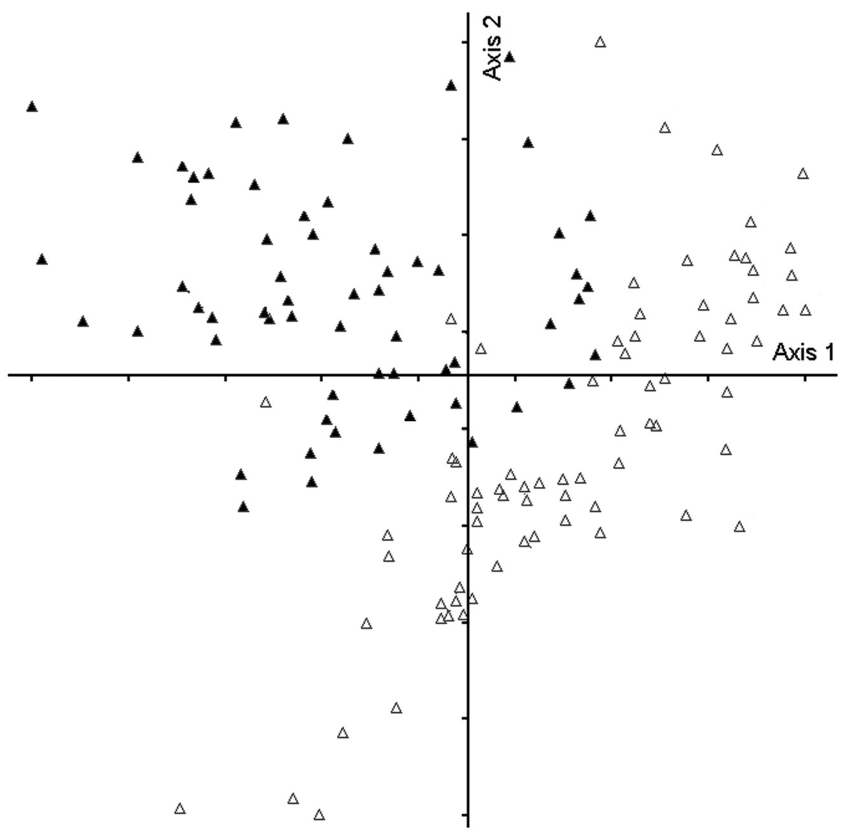

Figure 2 - Biplot graph showing the separation between irrigated and drainage sites in Camaquã/RS/Brazil.

that contribute significantly to differentiate samples of irrigation canals and drainage water on the Inner Coastal Plain - Table II, Fig. 3a). The values obtained for Wilks lambda ($p<0.001$) indicate that the model has good resolution capacity. The generated Discriminate Function explains 100% of what was observed, with a canonical correlation of 0.646. The Discriminate Function generated was correlated with total coliforms (-0.520), pH (0.586), turbidity (0.670) and nitrogen (0.559). The Discriminate Analysis Function correctly classified 84% of the samples originating in the irrigation water using the original data and 82.4% by the cross-validation process. For the samples from the drainage water the values are 76.1% and 73.9%, respectively.

Turbidity was indicated by discriminant analysis as an important parameter to differentiate the source of samples, as it has a_high value in drainage water. In Figure 3a we can see that the values of total coliforms presented large variations between the samples analyzed.

Outer Coastal Plain - Cachoeirinha

The Principal Component Analysis indicated the existence of four principal components which explain 77.53% of the total variances (Table III). The average values for the variables included in the two principal components are lower in the drainage water than in the irrigation water, and are more accentuated for those of the first component.

The separation of the points analyzed based on the first two principal components is presented in Figure 4 where good separation can be observed between the samples from the irrigation water and those from the drainage. The samples from the irrigation water are, for the most part on the left-hand side of the graph while those from the drainage water are mainly on the right-hand side.

The discriminant analysis indicated nitrogen, electrical conductivity, potassium, phosphorus and *E. coli* as the main variables that contribute significantly to the differentiation between the irrigation and drainage water (Table IV, Fig. 3b). The values obtained for Wilks lambda ($p<0.001$) indicate good resolution capacity in the model. The

TABLE II
Matrix standardized coefficient, percentage of variance, eigenvalues, canonical correlation, and Wilks lambda for discriminant analysis variation in quality of irrigation and drainage water in Cachoeirinha/RS/Brazil.

	Irrigation x Drainage	Years		Phases	
Parameters	DF1	DF1	DF2	DF1	DF2
N	0.969	0.62	0.673	-	-
T	-	0.316	0.684	1.003	0.111
EC	- 0.393	-	-	-	-
K^+	- 0.404	0.501	- 0.819	- 0.027	1.009
Ca^{+2}	-	-	-	-	-
P	0.468	-	-	-	-
pH	-	-	-	-	-
TC	-	-	-	-	-
E. coli	0.357	-	-	-	-
% variance	100	60.8	39.2	64	36
Eigenvalues	0.790	0.762	0.491	0.236	0.133
Canonical correlation	0.664	0.658	0.491	0.437	0.343
Wilks. Lambda	0.559	0.382	0.671	0.714	0.888

EC=electrical conductivity; TC=total coliforms; T=turbidity; DF=discriminant function.

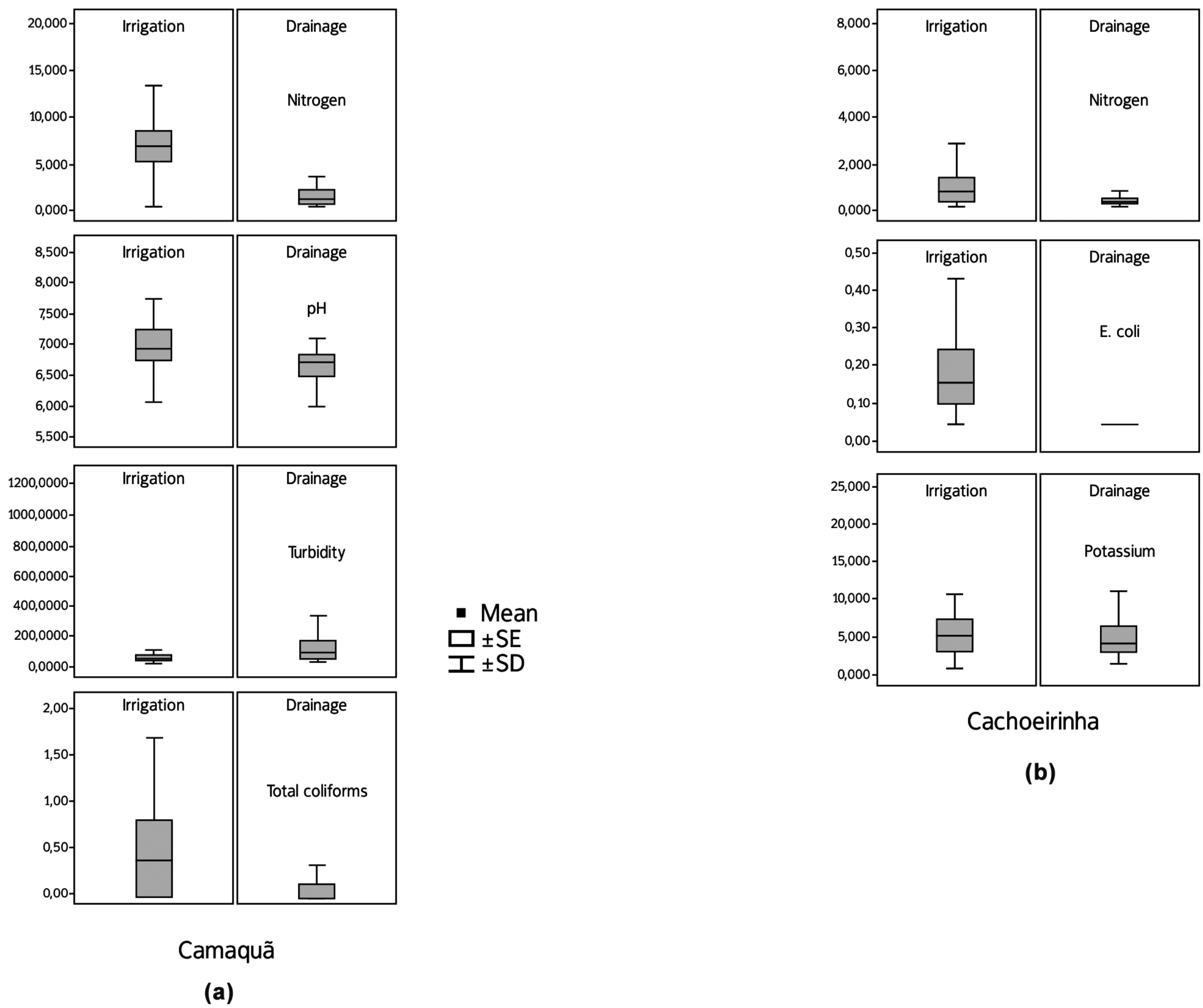

Figure 3 - Box-and-whisker plot representing the main discriminant variables between irrigation and drainage water quality. (**a**) Camaquã; (**b**) Cachoeirinha/RS/Brazil.

TABLE III
Partial and total variance explained by principal component analysis in Camaquã/RS/ Brazil. The variable has a correlation > 0.75 with the PCA.

PCA	Irrigation x Drainage	%	Cycles of culture	%	Phases of culture	%
1	P, N, EC	**31.258**	N, CE, P	**25.544**	CE, Ca, K, T	**38.861**
2	K^+, Ca^{+2}	**20.819**	TC, *E. coli*	**19.673**	pH	**14.193**
3	*E. coli*, TC	**12.952**	pH	**14.187**	P	**12.244**
4	pH	**11.858**	K	**11.682**	*E. coli*	**11.479**
% total		**76.879**		**71.080**		**76.781**

EC=electrical conductivity; TC=total coliforms; T=turbidity.

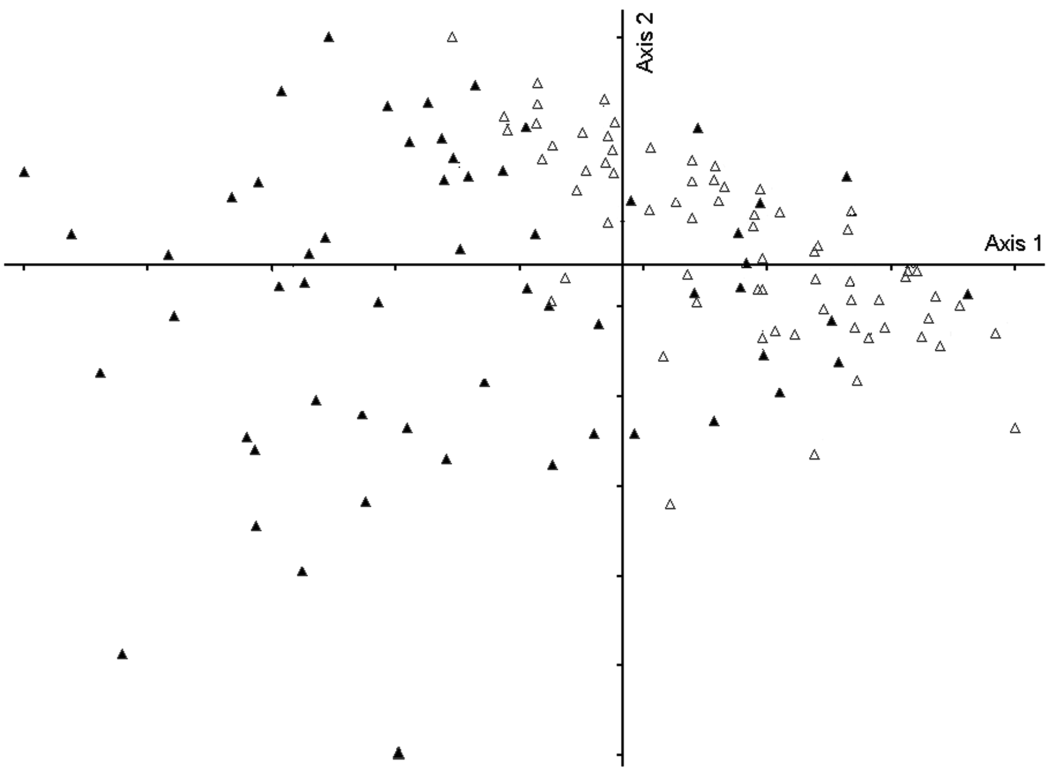

Figure 4 - Biplot graph showing the separation between irrigated and drainage sites in Cachoeirinha/RS/Brazil.

TABLE IV
Partial and total variance explained by principal component analysis in Cachoeirinha/RS/Brazil. The variable has a correlation > 0.75 with the PCA.

PCA	Irrigation x Drainage	%	Cycles of culture	%	Phases of culture	%
1	EC, K^+, pH, Ca^{+2}	**45.97**	P, Ca, EC, K	**48.88**	EC, pH	**33.574**
2	*E. coli,* TC	**13.34**	*E. coli,* TC	**14.093**	*E. coli,* TC, T	**19.047**
3	P	**10.444**			P	**11.857**
4	T	**7.759**				
% total		**77.539**		**62.973**		**64.477**

EC=electrical conductivity; TC=total Coliforms; T=turbidity.

generated Discriminant Function explains 100% of what was observed, with a canonic correlation of 0.644. The generated discriminating function was correlated with nitrogen (0.969), electrical conductivity (-0.393), potassium (-0.404), phosphorus (0.468) and *E. coli* (0.357). The discriminating function classified correctly 76.5% of the sample from the irrigation water utilizing the original data and 75% by the cross-validation process. For the samples from the drainage water the values are 91.2% and 89.7% respectively.

The three variables presented lower values in the water drained back to the water source. The variation in the concentration of *E. coli* between the samples is more accentuated than that observed for potassium and phosphorus (Fig. 3b).

Phenological Phases of the Plants and Temporal Variation of the Quality of the Water

The matrices for this analysis were constructed from data on the samples taken from the drainage water during our three-year observation of the rice field. During this period 69 samples for the Inner Coastal Plain and 68 from the Outer Coastal Plain were obtained.

Inner Coastal Plain

The PCA indicated the existence of four principal components which explain approximately 76% of the total variation (Table I). When the variations in the quality of the water are compared during the phenological phases of the rice plants, it will be seen that the greater part of the variations are explained by the reduction in the values of the electrical conductivity, calcium, potassium and turbidity of the first (vegetative) to the third (maturation) phases which are correlated with the first principal component (which explains 38% of the variances). The values registered for the pH variable were lower in the reproductive phase than in the vegetative and maturation phases. The values registered for the phosphorus and *E. coli* variables also show a reduction, that is, they are greater in the vegetative than in the maturation phases of the plant growth.

The discriminant analysis indicated that the variants which contributed most significantly to the differentiation were nitrogen, turbidity and pH (Table II, Fig. 5a). The values obtained for the Wilks, Lambda ($p<0.001$) indicated that the model has good resolution capacity. The first discriminate function explains 87.6% of the variance and has a high canonic correlation of (0.783), but presents a more accentuated relation with nitrogen (0.789) and turbidity (0.487). The second function explains 12.4% of the variation with a correlation 0.785 with the pH. The discriminant functions correctly classified 92.9% of the samples obtained in the vegetative phase, 52.2% in the reproductive phase and 85% in the maturation phase. This classification shows that 43% of the samples from the reproductive phase are included in the maturation phase. The values obtained with the cross-validation method were 88.0%, 52.2% and 85%, respectively. Only the pH average values increased between the vegetative and maturation phases, although in the vegetative phase we observed a great variation in the values obtained for the pH. The average values of turbidity and nitrogen decreased in the vegetative and the reproductive phases (Fig. 5a).

Outer Coastal Plain

The PCA indicated the existence of three principal components which explain approximately 64.47% of the total variance (Table III). When the variations in the quality of the water are compared during the phenological phases of the rice, it can be observed that the majority are explained by variations in the values of the electrical conductivity, pH, phosphorus, and total coliforms. These present higher values in the reproductive phase - in the maturation phase, although they show some reduction, the values are still greater than those in the vegetative phase. The concentrations of *E.coli* are the same in the vegetative and maturation phases, but are higher in the reproductive stage.

The discriminant analysis designated that the variants which contributed most significantly to the differentiation between the three phenological phases of the rice were turbidity and potassium (Table II, Fig. 5b). The values obtained for the Wilks lambda ($p<0.001$) indicate that the model has good resolution. The first discriminate function explains 64% of the variance and has a canonic correlation of (0.437), in addition to presenting a more accentuated relation with turbidity (1.0). The second function explains 36% of the variation with a correlation of 1.0 with Potassium. The discriminant functions correctly classified 66.7% of the samples obtained in the vegetative phase, 50.0% in the reproductive phase and 42% of those from the maturation phase. The values obtained with the cross-validation method were 63%, 50% and 42% respectively. These results indicate a greater similarity in the values obtained for the different variables in the three phenological phases of the rice of the Outer Coastal Plain. Turbidity is higher in the maturation phase, while the concentration of potassium is lower (Fig. 5b).

Temporal Variation in the Quality of the Water: Crop Years

The matrices for this analysis were constructed from the data obtained with the samples collected from the irrigation water during the three crop years in which we monitored the rice. During period we obtained 69 samples on the Inner Coastal Plain and 68 on the Outer Coastal Plain.

Inner Coastal Plain

The PCA indicated the existence of four principal components that explain approximately 71% of the total variances (Table I). The variables correlated with the first two principle components, present a concentration increase over the three crop years – in total, these two components explain 45% of the observed variation. The variables of the third and fourth components show a reduction in the values over the three crop years evaluated in this study. The results show that, over the three years, there was an increase in the quantity of residual material returned to the Camaquã River especially of nitrogen, phosphorus and enterobacterias

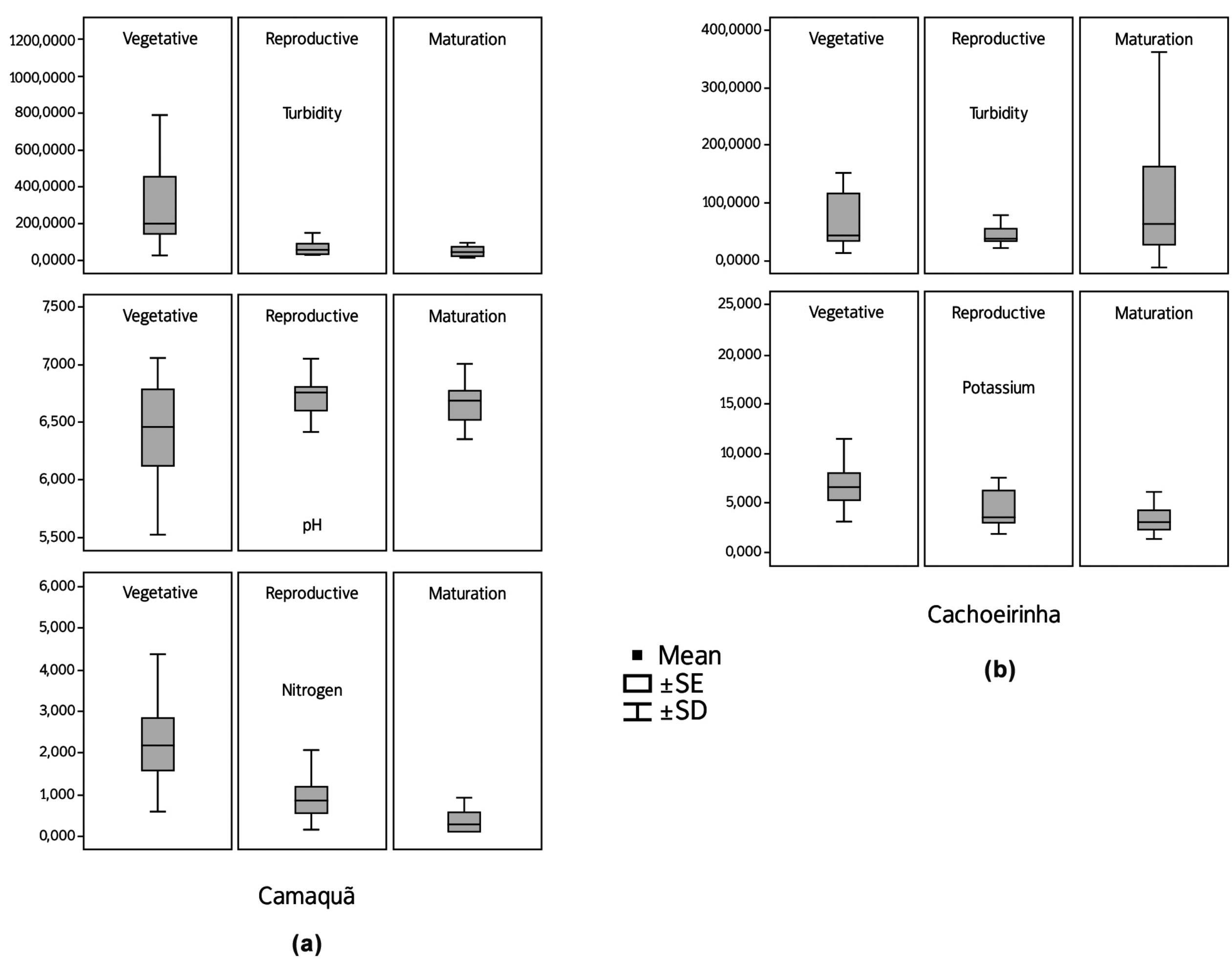

Figure 5 - Box-and-whisker plot representing the main discriminant variables between rice cultures phases. (**a**) Camaquã; (**b**) Cachoeirinha/RS/Brazil

(associated to the increase in the values of total coliforms and *E. coli*) and the electrical conductivity which also increased. In addition, the results indicate a reduction in the values of pH and potassium correlated with the third and fourth components respectively, which taken all together explain 26% of the variation observed.

The discriminant analysis indicated that the highest variants that contributed most significantly to the differentiation between the three years were nitrogen, electrical conductivity, calcium and phosphorus (Table II, Fig. 6a). The values obtained for the Wilks lambda ($p<0.001$) show that the model has good resolution capacity. The first discriminate function explains 75.2% of the variance and has a high canonic correlation (0.823), in addition to presenting a more accentuated relation with nitrogen (0.706) and with the electrical conductivity

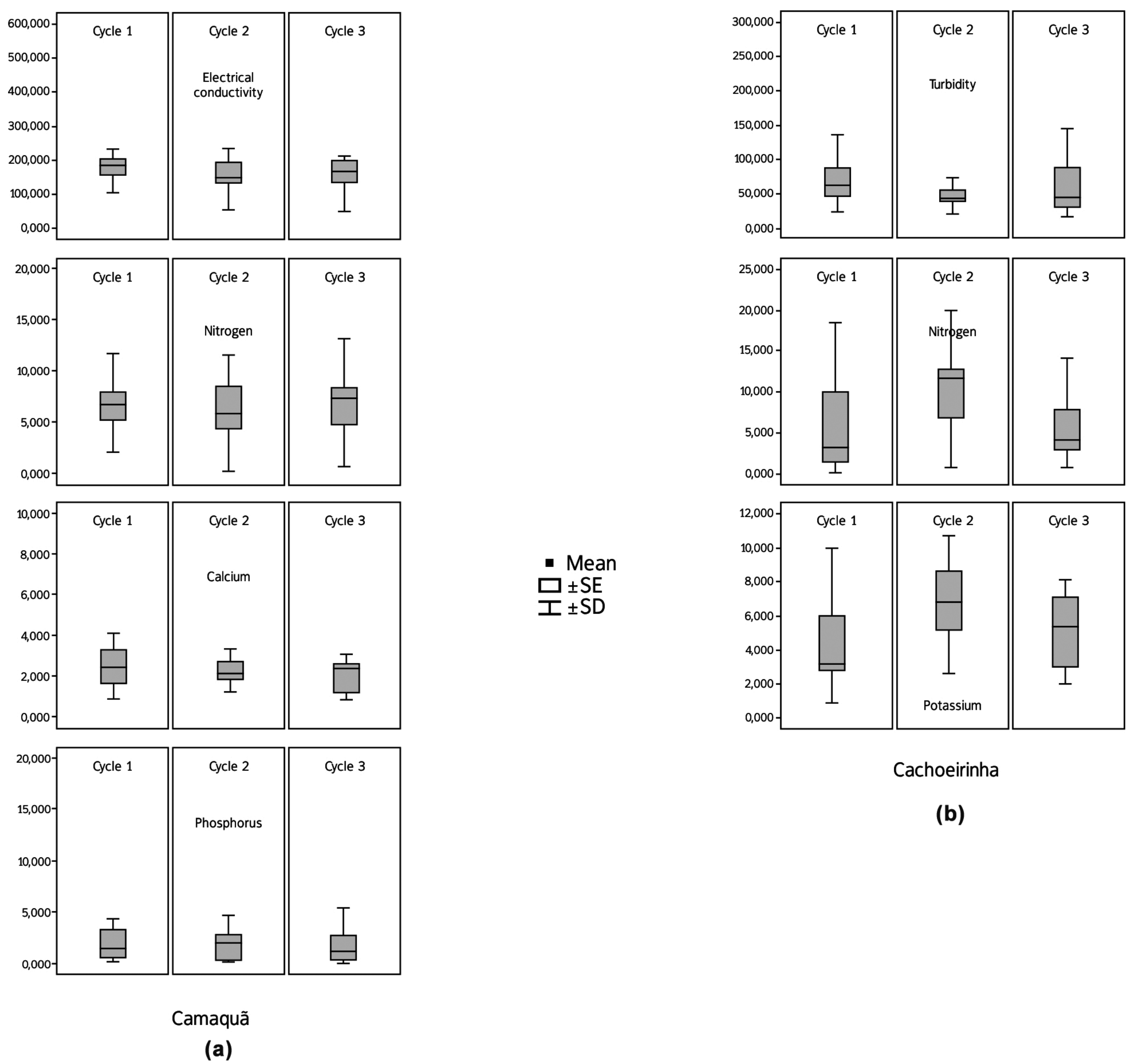

Figure 6 - Box-and-whisker plot representing the main discriminant variables between cycles of rice for 3 years. (**a**) Camaquã; (**b**) Cachoeirinha/RS/Brazil.

(0.422). The second function explains 25.8% of the variation with a correlation with calcium (0.850) and phosphorus (0.639). The discriminant functions correctly classified 90.9% of the samples from the first year, 87% from the second and 79.2% from the third year. The values obtained with the cross-validation method were 86.4%, 87% and 75% respectively.

The values of these variations oscillated during the years and are lower in the second year (2007/2008) for the electrical conductivity, nitrogen and calcium. Only the phosphorus average was higher in the second year.

Outer Coastal Plain

The PCA indicated the existence of two principal components that explain 62.97% of the total variance (Table III). All variables presented reductions in concentration over the three crop years. Among the variables, only turbidity demonstrated an increase in value during the three years of our study.

The discriminant analysis indicated that the main variants that contributed most significantly to the differentiation between the three years were nitrogen, turbidity and phosphorus (Table IV, Fig. 6b). The values obtained for the Wilks lambda ($p<0.001$) indicate that the model has good resolution capacity. The first discriminate function explains 60.8% of the variance and has a canonic correlation of 0.658 presenting correlation with nitrogen of 0.62, with turbidity of 0.316 and with potassium of 0.501. The second function explains 39.2% of the variation with a correlation with nitrogen of 0.673, with turbidity of 0.684 and with potassium of -0.819; the discriminant functions correctly classified 76.2% of the samples from the first year, 75% from the second and 68.2% from the third year. The values obtained with the cross-validation method were 76.2%, 75% and 65.2% respectively.

The alterations of the concentrations of these variables were accentuated between the crop years with the higher values occurring in the second year for all of them.

DISCUSSION

The main focus of this study was to compare the chemical, physical and biological quality of the water supplied to rice field irrigation and, especially, that of the water returned to the supply source after its passage through the cultivation. The results of this research demonstrate that after the water had irrigated the plants, there was a clear reduction of the concentration of the variables analyzed in the surplus water returning to the source. This reduction was observed in the two rice-growing regions studied. The only exception was turbidity. The irrigation and drainage water were consistently differentiated by Principal Component and Discriminant Analysis using microbiological, physical and chemical parameters studied.

The pattern of the reduction observed was not the same in the two locations, as different variables were highlighted as being the ones that contributed to the differentiation between the irrigation water and that returned to the rivers in the two rice-growing regions of Rio Grande do Sul/ Brazil. Nitrogen was the only variable detected by the discriminant analysis that showed a reduction in both regions. Even so, the average percentage of classification of the samples as coming from the irrigation or the drainage water - based on the Discriminant Analysis by the cross-validation method- was 74% for the two rice cultivation regions in RS. These results indicate that, in spite of the reduction in the concentration of the majority of the variables analyzed in the water returned to the river after passing through the rice plantation, specific aspects of each location may influence the process as well.

The quality of the water of a river is influenced by various factors, such as the edaphoclimatic, atmospheric conditions and anthropogenic effects (Bricker and Jones 1995). The concentration of pollutants is also influenced by the variation of the hydrological processes of the hydrographic basin itself, however, the industrial pollution and that deriving from the agricultural areas may be relatively constant (Papatheodorou et al. 2006, Giridharan et al. 2009). These aspects may explain the absence of a pattern in the reduction of the concentration of the same variable in the two rice-growing regions analyzed in this study

Analyzing the results of the variation of the water quality over the phenological phases of the plants using the discriminant analysis basis, we observed that only the turbidity results were common to the two regions analyzed. In *both* regions an increase in the levels of turbidity was observed during the phenological phases, at the plants. Another important point is that the capacity of discrimination between the samples taken at different phases on the Inner Coastal Plain is superior by 85% to the vegetative and maturation phases. On the other hand, at the Outer Coastal Plain, the capacity of discrimination was less defined. The variables: electrical conductivity and the pH, showed a reduction in concentration *between* phases at the Inner Coastal Plain and an increase in the value of these parameters from the vegetative to the maturation phases in the Outer Coastal Plain. The highest values for these two variables were observed in the reproductive phase. These results also indicate that the two systems analyzed present distinct characteristics, which influence, in specifically different ways, the concentration of the variables herein analyzed.

When the quality of the river water utilized for irrigation over the three crop years is analyzed, once again the absence of a common pattern between the two regions is observed. In the analysis of the discriminant, only nitrogen is highlighted for the two rice-growing regions and the capacity for discrimination of the samples for each crop year by the cross-validation method is greater for the Inner Coastal Plain (82% average) than on the Outer Coastal Plain (72%). We find a reduction in the concentration of the majority of the variables highlighted by the principal components on the Inner Coastal Plain and an increase in the variables highlighted for those of the Outer Coastal Plain.

Considering the biological quality of the water, the reductions observed in the *E. coli* concentrations, changed the water returned to the river into water of Class 1, while that utilized for irrigation on the Inner Coastal Plain was classified as Class IV and that of the Outer Coastal Plain as Class II – according to the respective CONAMA - 537/05 legislation. Furthermore, a reduction of the nutrients in the water returned to the river was observed. Water of Class 1 is proper for: human consumption (after simple treatment), the protection of aquatic communities, recreation with primary contact, such as swimming, water skiing and diving, irrigation of green plants that are eaten "*in natura*" and of fruits which grow close to the ground and are eaten uncooked, without removal of the skin in addition to the protection of aquatic communities in Native Brazilian Territories. Water Class II is destined for human consumption after conventional treatment and should otherwise have the same characteristics as Class 1. Class IV water may only be used for navigation and landscape harmony in accordance with CONAMA 537 of 2005.

The reduction of the microbiological variables is explainable by various factors, as for example, filtration by the plants, fixation in the sub-soil or on the plants, predators, antibiosis and/or greater exposure to ultraviolet radiation (Souza and Tundisi 2003, Almeida 2007). For the pH, phosphorus, potassium and nitrogen variables this reduction is relevant, as high levels of these substances can be prejudicial to aquatic ecosystems (Smith 2003, Kim and Oh 2006, Sharma et al. 2008, Tepavitcharova 2009).

The reduction observed in the concentrations of the calcium, phosphorus and nitrogen from the vegetative phase or the maturation phase - especially on the Inner Coastal Plain- indicates that a portion of these nutrients is used in the metabolism of the growing plants.

A considerable part of the reduction in the concentration of some variables during the crop years on the Outer Coastal Plain can be explained by the construction of Sewage Treatment Plants (ETEs) in the region of the Rio Gravatai Hydrographic Basin where the water supply for the Estação Experimental do Arroz/IRGA originates. On the Inner Coastal Plain we observed an increase in the concentrations of some variables during the three crop years analyzed and this may be the result of the constant growth of human activity in this region.

An important question must be mentioned is the “filtering process” can be efficient? Since the analyzed bacteria and substances may be being accumulated in the soil. Even if the accumulation rate is minimal, this possibility has not yet been adequately addressed in rice fields. This question must be carefully approach to analyze the risk to human health.

CONCLUSIONS

In this study we analyzed the quality of the water supplied for irrigation of rice field and the water that was returned to the water supply source in two regions in Southern Brazil. The results demonstrated some important aspects:

1. With the exception of turbidity, all the other variables showed reductions of the concentrations after the passage through the rice field.
2. The biological quality of the water drained back into the water source after passage through the cultivation could be classified as Class 1.
3. Even with the temporal variation in the concentration of some variables, irrigation and drainage of water, these are coherent and differentiated by analysis.
4. The two locations analyzed do not present a pattern of variation in the concentration of similar parameters, that is, different components undergo significant alterations in concentration independently of the others.
5. A relevant point for programs of management and control of water quality used in rice field that becomes clear in this study is that the parameters that undergo alterations between the irrigation and drainage water, and between the phenological phases of the plants, vary from one region to another. Therefore, from a management point of view, studies intended to support measures to improve water quality should be prepared for specifically identified water systems.

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RESUMO

Este artigo apresenta os resultados da análise estatística dos parâmetros microbiológicos, físicos e químicos relacionados à qualidade da água utilizada em campos de arroz no sul do Brasil. Os dados foram coletados durante três anos agrícolas consecutivos, dentro da estrutura de um programa abrangente de monitoramento. Os indicadores utilizados foram: potencial de hidrogênio, condutividade elétrica, turbidez, nitrogênio, fósforo, potássio, cálcio, coliformes totais e fecais. Componente Principal e Análise Discriminante indicaram diferenças consistentes entre a água de irrigação e de drenagem, da mesma forma a variação temporal demonstrou uma clara redução na concentração da maioria das variáveis analisadas. O padrão desta redução não é o mesmo nas duas regiões - isto é, a importância de cada uma das diferentes variáveis nas duas localizações é alterada. Estes resultados sugerem que as variações na qualidade da água utilizada para a irrigação do arroz foi influenciada

por alguns aspectos específicos de cada região do arroz no sul do Brasil - como ação antrópica ou as condições de solo/clima em cada bacia hidrográfica.

Palavras-chave: agrossistemas, irrigação, campo de arroz, variação espacial.

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