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MANAGEMENT OF THE WATER SLIDE BROUGHT AND SALINE FLOW IN IRRIGATED RICE CULTIVATION IN THE SENEGAL RIVER DELTA

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ABSTRACT

The find for the optimal slide of water to bring to the plot is important in order to limit the recharge of the water table close to the surface. The slide of water brought into the plots is estimated from the reading of the water height before and after each irrigation series on limnimetric scales. Monitoring of the water surface and the salinity of the water and soil made it possible to assess the water balance and surface salt deposits. At the end of the irrigation period and the drainage of the water slide of the plot, the groundwater table reaches its maximum level and becomes sub-flush. The optimum slide of water to maintain in the plot in order to limit this groundwater recharge is between 10 and 12cm. On a 40 cm profile, the electrical conductivity is 3.5dS/m at the start of irrigation and 1.5dS/m in mid-season with, respectively, salt deposits of 1.62t/ha and 1.22t/ha, i.e. an average of 1.25t/ha. These deposits (1.25t/ha) would come from the water present in the plot (0.45t/ha) and from the capillary rise (0.8t/ha). The salt deposits would be more important in the root zone (between 30 to 40cm) with an average of 1.02t/ha.

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INTRODUCTION

Nearly 70% of freshwater resources are currently devolved to irrigated cultivation (Biswas, 1993), as tensions over water sharing around the world brighten up. In arid and semi-arid zones, irrigation makes it possible to remove the production constraint of seasonal rainfed agriculture subject to climatic hazards. It makes it possible to increase the surface emblaved and ensure food self-sufficiency. This irrigation in arid and semi-arid zones often poses a problem in the conservation management of land and groundwater, mainly linked to saline dynamics. In the same vein, irrigating puts the soil at risk of salinization (Ndiaye et *al*., 2008). These risks are all the more observed as the water inputs are not well defined. Previous work carried out in the Senegal river valley has shown that soil salinization is one of the major factors in the decline in agricultural productivity (Gning et *al*., 2012; Ndiaye et *al*., 2008).

It affects nearly 39% of agricultural land in arid regions of the world (Cheverry & Bourrie, 1998). This is due to the difference between the incoming solute flows (irrigation, rise by capillary action of the water tables) and the outgoing flows (percolation towards the water table linked to irrigation, basic water table flow, drainage) (Ndiaye et *al*. , 2008). In the Senegal river delta where irrigation for rice cultivation is done by submersion, a slide of water is maintained on the surface of the soil throughout the campaign. These large inflows of water can raise the water table and bring it close to the ground surface. In this area where the water table is salty in places and shallow (Gning et *al*., 2012). Strong evapotranspiration means that the difference between the leaching of salts under the effect of irrigation water inputs and the rise by cappillarity often results in an accumulation of a salt deposit on the soil surface (Ndiaye et *al*., 2008). A good understanding and quantification of the saline flow are therefore primordial when irrigating crops. A device for monitoring the water brought was set up and transfer modeling was carried out to estimate the quantities of salt in the profile. At the lower level of the plot, a simple water-soil-plant water balance model was calibrated and validated (Kaly et *al.*, 2016) in order to estimate the quantities of salt in a profile, ascending during capillary rise and descending during the flood irrigation phase over the entire crop cycle. The objective of this work is to propose a management of irrigation water during the crop cycle in order to facilitate the quantification of the salt flow in the agricultural plot and at the level of the root profile.

MATERIALS AND METHODS

Presentation of the study area: The Senegal river delta is part of the Senegalese-Mauritanian sedimentary basin located between 15° 30 and 16° 30 west longitude and between 16° and 17° north latitude (Fig. 1). The delta is a geographical entity of triangular shape. It is in the form of a vast low plain, limited in the North by the Senegal river, in the West by the Atlantic ocean, in the east by the Guiers lake system, in the South-West by dunes cords and in the South-East by the Ferlo valley (Fig. 1). The area of the delta is 4,343 km^2 and extends over a length of 250 km from Richard-Toll to Saint Louis, three quarters of which are located on the left bank of the Senegal river. The climate is of type Sahelian with rainfall in the order of 300 to 400 mm / year (Ndiaye et *al.*, 2008). A few depressions are naturally filled by the floods of the Senegal river. The main factors of soil formation are the frequency and duration of flooding by the flood (Raes et *al.*, 1995; Raes & Feyen, 1995). The soils of the delta have a texture ranging from coarse sand (old beads of banks) to clay (settling areas or basins). The delta is traversed by a fairly dense hydrographic network which includes the main branch of the Senegal river 1,800 km long, which has many outlets. These various outlets of the river as well as the Guiers lake allow the irrigation of the numerous agricultural perimeters by a complex system of open sky canals. Irrigated agriculture was practiced there before independence and developed with the construction of dams on the Senegal river (Diama in 1986 and Manantali in 1988) which allows the availability of fresh water and agricultural activities throughout the year. The drainage water from these perimeters is evacuated via canals and discharged into the natural depressions of Ndiaël, of Noar and Krankaye.

METHODOLOGY

Water slide monitoring brought: Due to the hierarchy of the hydraulic system, the quantities of water brought to the plot are often difficult to estimate and in certain cases, this estimate could be made at the scale of the pumping station well upstream of the plots (SAED, 1999). As part of this study, the slide of water supplied is estimated from reading the water height before and after each irrigation series on limnimetric scales set up within each plot (ten plots in total). Water level readings are taken every day. To properly assess the water supply during irrigation, a blade reading is carried out the day before and after irrigation. However, it is still necessary to take into account a whole series of other parameters such as evapotranspiration, percolation or water losses by runoff at the level of the bunds to know the quantities of water available at the scale of the plot. could be used by crops.

Assessment of actual evapotranspiration by the lysimeter: The lysimeter is a device installed in the center of each plot. On this device, a square is adapted on one side. Its installation is done meticulously by reconstituting, as far as possible, the different horizons. The square is inclined at 25°C relative to the vertical thus, the unevenness read is dilated, and better precision obtained. This reading is taken three times in the week from sowing to harvest. After each reading the lysimeter is refilled and the reading of the standing water level is noted. To measure the quantity of water consumed over time by a soil covered with vegetation, which includes on the one hand the water transpired by the plant cover, on the other hand direct evaporation from the ground, the rates obtained are transformed into real evapotranspiration by multiplying them by the crop coefficients (kc) proposed by the FAO (Allen et *al.*, 1998). The coefficients, kc retained for rice cultivation are 1.15, corresponds to the growth phase (Kc, ini), 1.3 relating to the maturation phase (Kcb, mid) and 1.05 for the end of the crop cycle, after the first week of grain production (Kcb, end) (Doorenbos & kassam, 1979; Raes et *al.*, 1995).

Water slide available for plants: The water slide available for rice plants is calculated at the level of each plot. Indeed, it is quantified by making a difference between the quantities of water brought during irrigation and those lost by the phenomenon of percolation and evapotranspiration. From this result it is necessary to subtract the losses by runoff at the level of the bunds. As soon as the groundwater comes to the surface, it is necessary to eliminate the losses by percolation because the water content of the soil becomes important.

Monitoring of groundwater dynamics: The monitoring of the dynamics of the water table comprises three phases: 1) two months before the plots are flooded, 2) throughout the crop cycle, 3) and approximately two months after the end of irrigations (i.e. after rice harvest). A monitoring system has been set up to measure fluctuations in the groundwater table.

Measurement of electrical conductivity: Regular monitoring of the electrical conductivity (EC) of water and soil in the plots was carried out in order to study the evolution of the salinity of the irrigated perimeter during irrigation. Samples of the pasty solution from the soil of the plots were taken to depths of 10 cm and 40 cm using an auger and stored in sachets. These samples were analyzed using a soil / water ratio of 1/5 (Aubert, 1978) using a conductivity meter. The electrical conductivity of the irrigation water was measured.

Data processing: The simulation model of crops, movement and quantities of salts (water-soil-plant, AquaCrop) developed by Steduto et *al.*, 2009 was used in the form of a simple information program to simulate the quantities of salt brought by irrigation water and groundwater during the capillary rise to the level of the plot. The model simulates the movement of hydrosaline flow through saturated soil during irrigation. It predicts the distribution of salinity in the soil during irrigation doses and the dynamics of the groundwater table. In order to estimate the salt quantities with the model, the input data includes, on the one hand, parameters related to soil and hydraulic properties determined using the pedotransfer functions described by Saxton et *al.*, 1986 , and on the other hand, water-related parameters (water balance, quality). The first results produced in tabular form were analyzed using R statistical software version 3.0.1 (R development core team, 2013) and presented in the form of curves, diagrams and histograms.

RESULTS

Water slide brought by irrigation and its impact on the dynamics of the groundwater table: In the Senegal river delta during irrigated rice cultivation, the water losses observed are due either to the process of percolation and/or evapotranspiration.

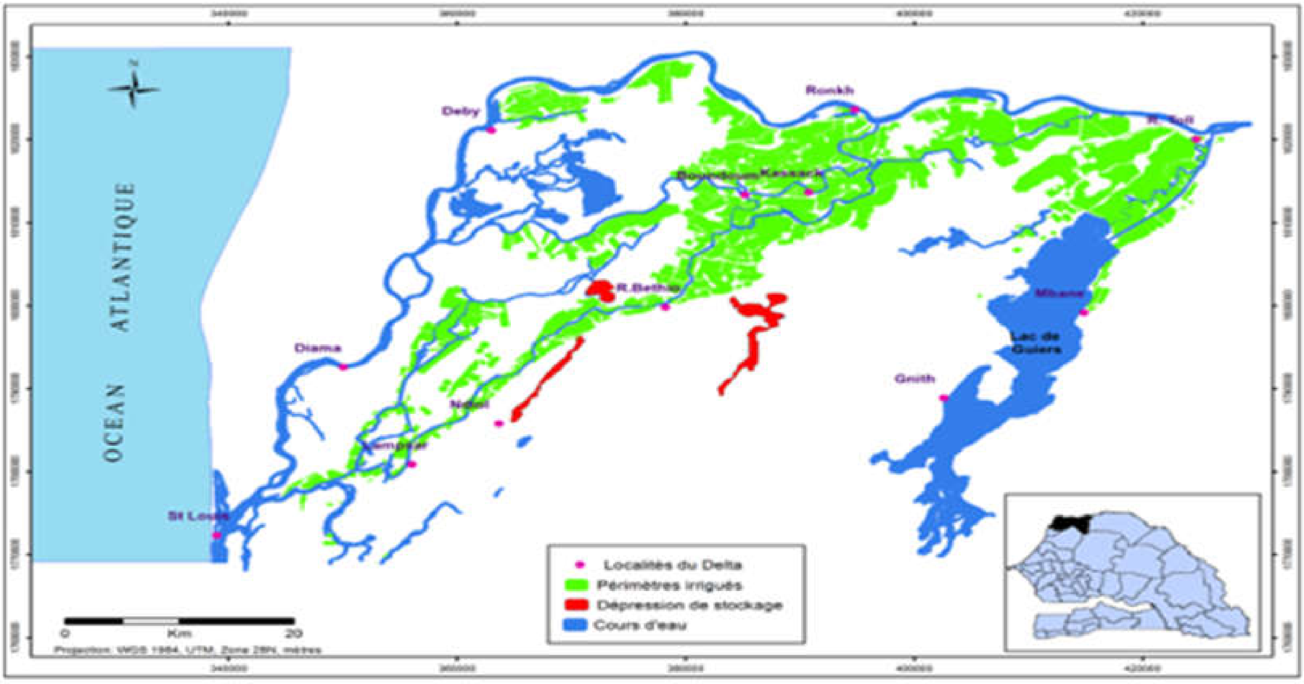

Figure 1. Location map of the Senegal river delta

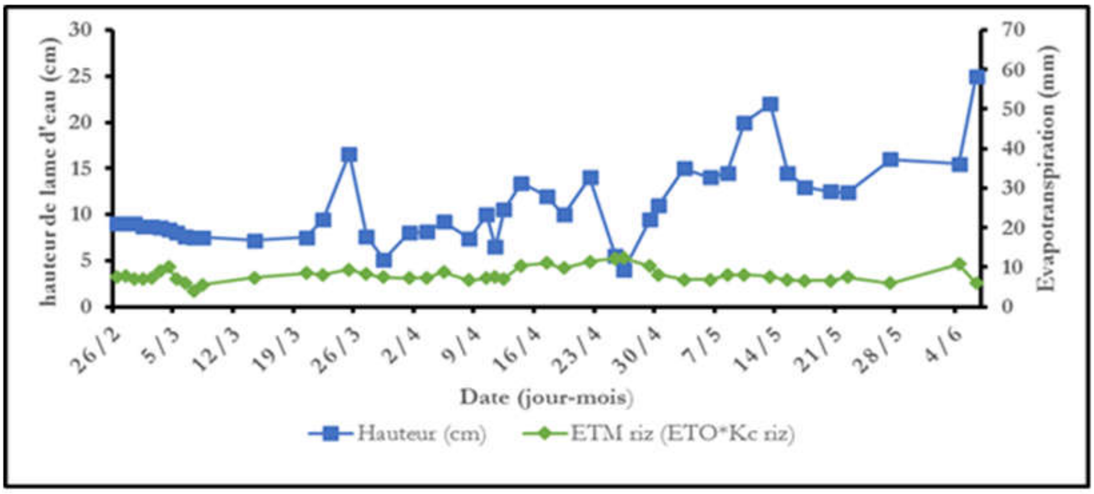

Figure 2. Evolution of the cumulative water slide and the evapotranspiration of the cumulative rice

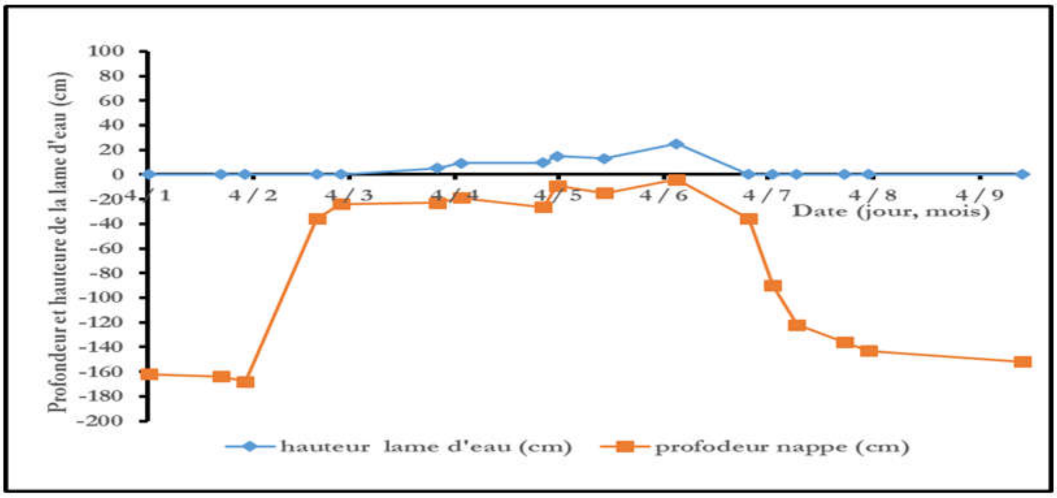

Figure 3: Evolution of groundwater as a function of surface water during irrigation

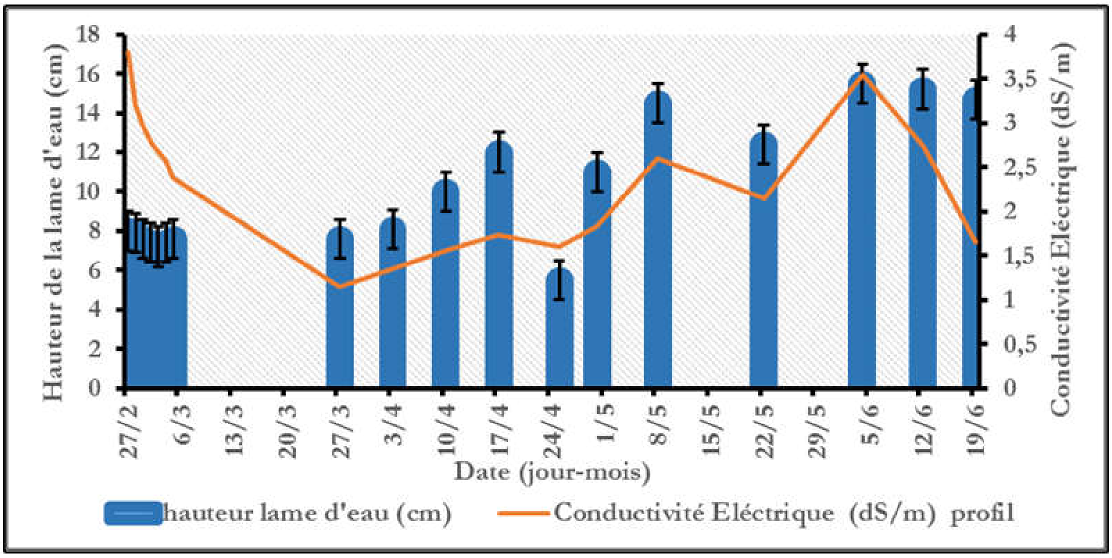

Figure 4. Evolution of the electrical conductivity of the soil as a function of the water slide brought

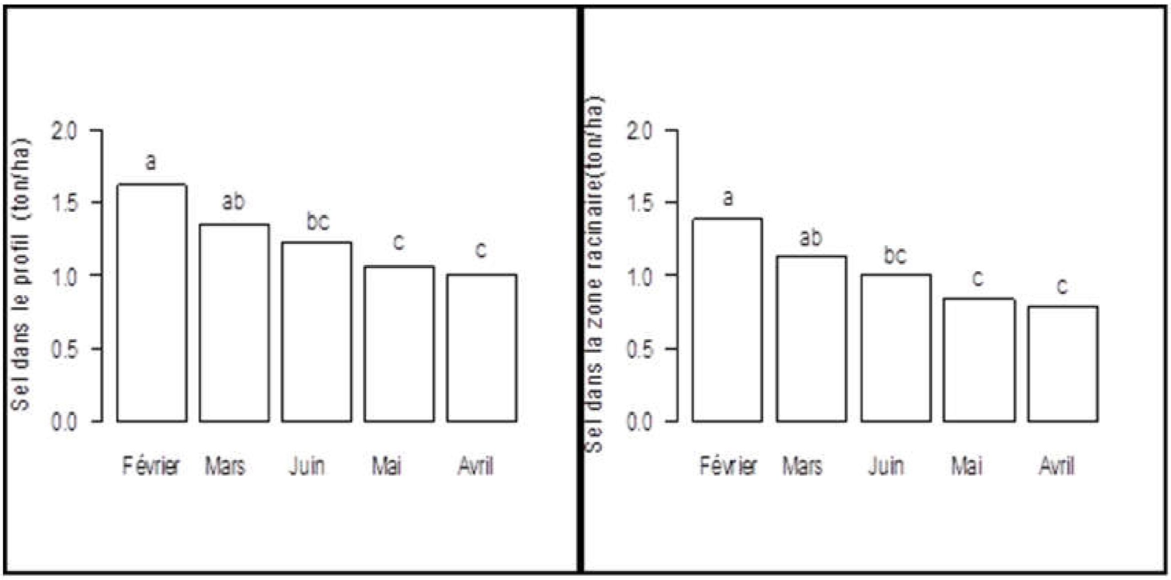

Figure 5. Quantity of salt estimated in the profile (A) and in the root zone (B) depending on the months

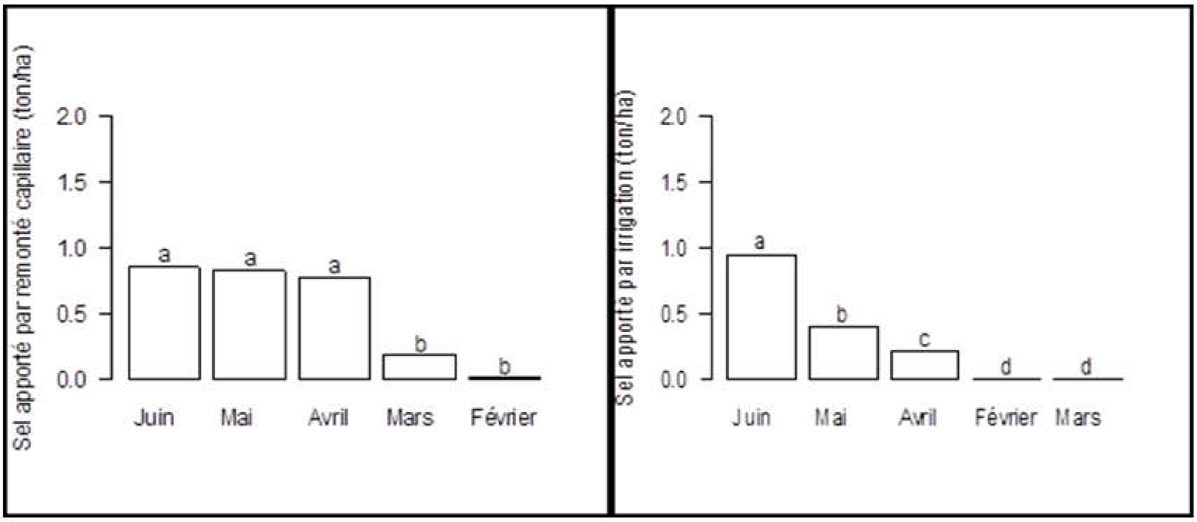

Figure 6. Quantity of salt brought to the profile by capillary rise in groundwater (6C) and by irrigation waters (6D) depending on the months

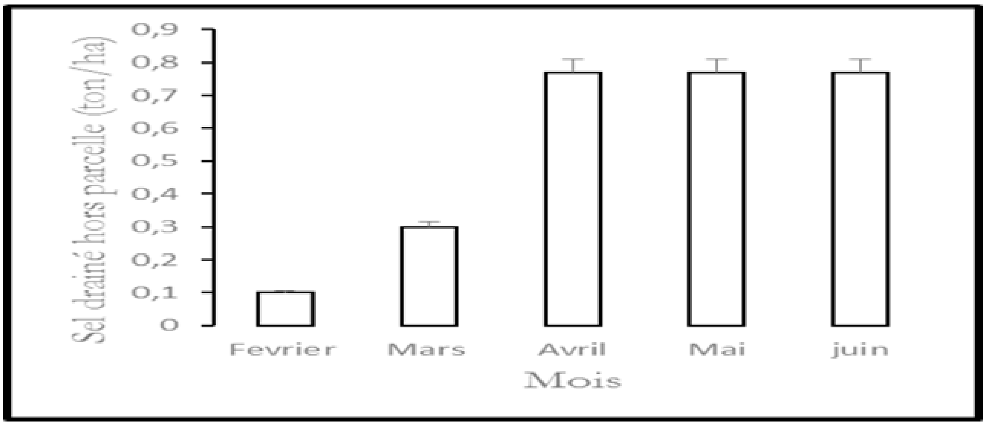

Figure 7. Quantity of salt evacuated by drainage waters

The water slide brought during irrigation remained largely above the evapotranspiration of the rice, therefore sufficient to cover the water requirements of the rice (fig. 2). At the end of the crop cycle a large quantity of water was brought to the plots to prepare for future harvests. This amount of water brought would contribute to the arrival of groundwater to the surface and would undoubtedly influence the electrical conductivity of the profile. Monitoring the water slide at the plot scale in rice growing and in flooded conditions has particular advantages for better management of hydro-agricultural developments.

The bunds which surround the plots make that their irrigated water storage capacity is very large and minimizes losses downstream. However, the permanent presence of water in the plots promotes infiltration and thus contributes to recharging the groundwater with water. To observe the relationship that exists between the inflows of water in irrigated rice cultivation and the movements of the groundwater in the Senegal river delta, a device for monitoring the water slide and the dynamics of the groundwater table at the level plots have been put in place. The water losses observed by infiltration cause the water table to change during the campaign. This same trend is noted on all plots in cultivation irrigated by submersion (flooded plots).

Variability of electrical conductivity depending on the water slide brought: Sampling the saturated pasty solution of the profile during the dry off-season campaign allowed us to observe the evolution of the electrical conductivity as a function of the water slide (fig. 4). The measurement of the conductivity of a solution is directly related to the salinity of the area. The results show that the electrical conductivity is high in the first days of irrigation (3.5 dS/m) and decreases at the end of irrigation (1.5 dS/m). On contact with the soil surface in the plots, the electrical conductivity of the irrigation water increases. This increase is presumably due to the dissolution of the salts which had remained trapped in the superficial sediments of the soil after the evaporation of the water brought in at the end of the cycle of the previous campaign. These salts will then be dissolved by the irrigation water and carried down to depth by the percolation front. This would explain the drop in electrical conductivity noted during submersion. The peaks in electrical conductivities observed during the campaign could be explained by the rise of water from the water table to the topographic surface, which would directly influence the salinity of the water slide at these dates.

Hydrosaline dynamics: The water-soil-plant model makes it possible to determine the saline flows brought into the profile by the irrigation water and during the capillary rise of water from the water table. The model differentiates the quantities of salt trapped in the profile and in the root zone (fig. 5). Knowledge of the physical characteristics of the soil, of the soil structure and of the salinity (electrical conductivity: 3.5 to 1.5 dS/m), as input data for the model, makes it possible to quantitatively estimate the salts during of capillary rise. The results made it possible to see the monthly evolution of the quantities of salts in each compartment of the profile, but also to follow the evolution of salinity during the campaign. The amounts of salt recorded in the profile (0 to 40 cm) are very high at the start of the cycle (February-March), relatively low between the months of May and April, and become high at the end of the irrigation (June) (fig. 5.A).

As soon as the water table is exposed, the quantities of salts recorded in the profile become important. This scenario is identical to that observed in the root zone (0 to 30 cm) (fig. 5.B). The variance analysis carried out on the results of salt deposits accumulated in the profile (0-40cm) and in the root zone shows that the amounts of salt were distributed into four groups according to the monthly averages during the campaign, group a (February), group ab (March), group bc (June) and group c (May = April) (Figure 5A and B). The monthly averages of the amounts of salt with the same letter are statistically identical. When groundwater rises by capillary action, the amounts of salt brought to the profile are low during the first months of irrigation (February-March), they increase after the first two months (fig. 6C). This same scenario is observed with irrigation water (fig.6D). A comparison between the quantities of salts brought by irrigation water and that brought by groundwater during capillary rise in a profile of 0 to 40 cm was made. It emerges from this comparison shows that the quantities of salts brought by irrigation water are lower than those of groundwater except for the month of June (fig. 6D). The analysis carried out on the results of the quantities of salt brought by irrigation water to the plots differentiates four groups; group a (June); group b (May); group c (April) and group d (February = March) (figure 6D). Deposits are important in June corresponding to the dates when the water table is sub-outcropping occasioning an accumulation of salt in the superficial part of the plot (figure 6D). Analysis of variance ranks the amounts of salt based on the statistical mean.

Drainage has for role essential to leaching salty soils and to evacuate excess irrigation water. Evacuation of the waters is carried out by intermediary the drainage channels located downstream of the plots. The drainage of the plots is left to the appreciation of each farmer. A drainage water recovery system has been installed downstream of the plots. On each sample we determined the electrical conductivity for each volume. At the start of the campaign, the quantities of salt evacuated are very low (February-March), while they increase and remain constant throughout the campaign (fig. 7). The Knowledge the quantities of salt present in the drainage water would allow planning to be carried out in order to limit the process of infiltration and accumulation of salt at the level of the superficiels horizons. The analysis carried out shows that there are no significant differences from April to June (Figure 7).

DISCUSSION

In the Senegal river delta special attention should be paid to the problems associated with the management of the water slide during irrigation. The quantities of water brought during irrigation by farmers remained largely sufficient to cover the needs of the crops throughout the campaign. Therefore surplus water is lost either by evapotranspiration or by infiltration and/or percolation. It would be good to redefine the water slide to be brought in order to limit these losses by percolation. Indeed a large part of these unused quantities of water are lost in flooded culture by percolation would participate in recharging the groundwater. Our results show that the groundwater table would have gone from 162 cm on the date of February 18 to 36 cm on the date of February 22, that is to say after four days that the plots were flooded to prepare for sowing. Impoundment the water lasts a maximum of four days for all the plots. After this period of set ting the water, a part would be lost by percolation, would reach the groundwater table and would lead cause its rise towards the superficial zones. Indeed, the upwelling of the water table is an ineluctable phenomenon as soon as irrigation is practiced (Samba, 1998). The roof of the water table has a speed of rise, four days after the flooding of the plots, of approximately 32 cm/day or 1.3 cm/h for Hollaldé soils, that is to say at more than 50 % of clay. This speed of ascent little important of the water table would be linked to character permeable of the clayey superficial layer which cracks after periods of strong evaporation. Ndiaye et *al.* (2008) had found that the speed of rise of the water table roof is estimated at around 25 cm/day for Hollaldé soils at the end of irrigations. This rise in the water table is strongly linked to the rhythm of crops carried out on the plot, which is more important in double cropping than in single cropping (Ndiaye et *al*., 2008). These differences can arise from the hydrodynamic properties. Loyer & Diallo (1979) and Le Brusq (1980), having carried out permeability measurements by infiltration according to the Muntz method, had found values of 1.1 cm/h after an infiltration duration of 3 hours. Our results corroborate those found by Loyer & Diallo (1979) during their work at the level of the Ndelle-NDiaye cuvette. After the period of flooding of the plots and during irrigation, the speed of rise of the groundwater table fluctuantes between 1.3 cm/h and 0.06 cm/h. The fluctuation of the water table at the level of the irrigated perimeters would be linked to the quantities of water brought into the plot. The waters trapped by the bunds which delimit the plots by preventing downstream water losses by runoff thus cause infiltration processes and at the same time the arrival of the water table on the surface by capillary rise. Samba (1998) during this work in the Senegal river delta showed that the practice of irrigation by submersion, especially in rice cultivation, quickly provokes a recharge of superficial water tables which would become flush. During the ascent of the water table rises, a salty flow is entrained to the surface and part of it remains trapped in the root zone of plants. However, to properly map the salinity rate of the plots, the electrical conductivity of the irrigation water and saturated pasty solutions in the profile was measured on the different dates during the campaign (February to June). We note that in the first days of flooding of the plots, the electrical conductivity is 3.5 dS/m, it will then decrease by leaching with the process of drainage of the plots. So as our results show, as soon as the water table is flushed with, peaks in electrical conductivity are noted at the profile level.

The electrical conductivity (EC) of submersion water is a function of the evolution of the irrigation water slide. Ndiaye et *al.* (2008) during their work on the same cuvette led to the same result. Elsewhere for the simulation of salt deposits on the surface of the soil, a culture model was used. From the start of the irrigations until the end, the model estimated, on the one hand, the quantities of salt accumulated by capillary rise in the profile and in the root zone, and on the other hand, that accumulated in the different strata during the percolation of irrigation water which quickly reaches the groundwater table. The values of the salt deposits at the different layers vary according to the depths in the direction to reach the bed of the groundwater table. Whatever the depth considered, a quantity of salt is mobilized at the level of the sediments or from the water table. The accumulated amounts of salt are on average 1.62 t/ha (hot off-season) at the profile level for an electrical conductivity of 3.5 dS/m at the start of irrigation under rice cultivation. They decrease and reach on average 1 t/ha for an electrical conductivity of 1.5 dS/m in mid-season.

But when irrigations are stopped this quantity increasing slightly and increases to 1.22 t/ha for predominantly clay soils, encountered in the Ndellé cuvette. The average amount of salt trapped in the sediments at a profile of 40 cm for a hot off-season campaign would be 1.25 t/ha. Previous studies have shown that in the delta area, salt inputs would average 1.4 tonnes per hectare under irrigated rice cultivation (Engelhard & Ben Abdallah, 1986). In the logic of the method, of these quantities of salt (1.25 t/ha) recorded at the profile level during the campaign, 0.51 t/ha would come from irrigation water and 0.81 t/ha from capillary rise. From these results we can say that the salinization of the lands of the Senegal river delta would be due in part to the process of capillary rise. When irrigation is stopped, the salt washed away during the fluctuation of the water table remains trapped in level the sediments (pores) of the superficial layers of the soil. Ndiaye et *al.* (2008) had concluded that in situation in a shallow water table and with high evapotranspiration, the difference between the leaching of salts under the effect of water inflows and upwelling by capillarity often leads in an accumulation of salt deposition in the profile. Raes et *al.* (1995) during their work in the Ndellé-Ndiaye cuvette showed that the salt intake is of the order of 1 to 4 t/ha. This salt intake is function on the cropping intensity, the type of soil, the depth and the degree of salinity of the water table. These deposits are important at a depth of 30 cm, that is to say at the level of the root zone (1.02 ton/ha) undoubtedly linked in large part to the zone of permanent fluctuation of the groundwater in rice cultivation irrigated by submersion.

Of our results we can say that the concentration of hydrosaline fluxes is important in the root zone compared to the amounts recorded overall the entire profile. Knowing the quantities of salt brought by the irrigation water and those brought during the capillary rise, we can say that the salinity of the lands of the Senegal river delta would be entirely linked to the rise of water from the groundwater during flooded crops. The purpose of drainage downstream of the plot was to evacuate excess water and at the same time leach the superficial layer. During rice cultivation, the soil is saturated with water overall the profile, causing a important rise in its level in equilibrium with the irrigation water slide. Evacuation of salts is therefore essential in rice cultivation. The drainage makes it possible to evacuate the quantities of salt present at the level of the surperficial layers brought by the irrigation water and the capillary rise. During our work we found that the average quantities of salts present in the drained water at a volume of 75.3 mm with an electrical conductivity of 0.9 dS/m, would be 0.73 t / ha. Raes et *al* (1995), according to on their measurements on a water slide of about 80 mm, estimated the amount of salt evacuated to be 0.5 t/ha, admitting an EC of the slide of 1 dS/m. The quantities of salt brought into the profile during irrigations (1.25 t/ha) remain much higher than those drained from the plots (0.73 t/ha). It would be interesting to discuss a new technique for desalination of plots during agricultural activities.

Conclusion

The constraints of irrigated agriculture, of the rice growing more precisely, are numerous, complex and interdependent. The model answered the question relating to the height of the slide to add to limit any dynamics from the water table towards the surface. In the actuel conditions of development, of setting value, the profitability of producers initiatives will be increasingly optimal with this defined the water slide limiting the degradation of plots by the salinization process. What is generally called salinization groups together several degradation mechanisms: salinization, sodization and alkanization, which are three different phenomena. These mechanisms are the basis of the main soil degradation observed in the Senegal river delta during flooded cultivation. This is the concentration of neutral salts in the soil profile, in sufficient quantity to affect its agronomic abilities (increase in osmotic pressure causing water stress in the plant). The problems posed do not depend only on the quality of the brought water, but also on the water regime, depending on whether there is drainage or water concentration on the spot. Determining the real water needs of crops remains essential in order to correct the imbalances in the movements of the water table. One technique that seems to be effective in limiting the rise is the deep rebatement of the groundwater.

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