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Comparing methods of water use by irrigation in the horticultural hydro system of the Niayes, Senegal

Mahécor DIOUF[1], Saliou NDIAYE[2], Ibrahima DIEDHIOU[2], El Hadji Bamba DIAW[1*],

[1]Laboratory of Science and Technology of Water and Environment (LaSTEE), Polytechnic School of Thies BP A10 Thiès, Senegal. (elhbdiaw@ept.sn*)

[2]University of Thiès, National School of Agriculture, Thiès, Senegal.

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Abstract: The water valorization methods' knowledge by the irrigation and their effects in the cultivated hydro-system of the Niayes in Senegal are a stake in the current context of the climate changes. The study was about three types of water valorization by irrigation in the Niayes hydro-system of Senegal: localized, sprinkling and manual irrigation. Comparative analysis of the different irrigation methods practiced in the study area shows that the drip (localized) irrigation is more water saver and offers more production, sprinkler irrigation as second and the traditional irrigation as third. To cover the vegetables crop cycle, the comparison between the localized irrigation and the sprinkler shows a difference of 24.5 millimeters, 6.23 millimeters between the sprinkler irrigation and the manual irrigation, 30.8 mm between the drip irrigation and the manual irrigation. The study of irrigation efficiency gave three grouped classes around 94.86% for the irrigation mode. The variance's analysis showed a highly significant effect at the 14.39% level. Comparison of averages showed that the drip irrigation gave the best yield with an average of 28.72 tons per hectare. Sprinkler irrigation yielded 24.44 tons per hectare and traditional irrigation with an average of 20.83 tons per hectare. However, the drop irrigation is not suitable around the study area because of the iron concentration, which is very high in some places. We recommend promoting drip irrigation in areas where the iron concentration is less than 2.5 mg / liter to reduce punctures on the Niayes aquifer.

Key words: irrigation, water, efficiency, horticultural crops, yield, Niayes

INTRODUCTION

Senegalese agriculture has an important place in the economic and social life of the country. It supports 73.8% of rural households[1] and is essentially family type. Agricultural production accounts for 45 to 50 % of primary sector output and 8 to 10 % of Gross Domestic Product (GDP)[2]. However, this sector is characterized by a general downward trend as a result of agricultural land degradation and declining rainfall. To respond to the increasing growth rate of the demand for food, irrigation is the essential way to develop the agricultural economy and particularly food security. It is an important strategic focus for agricultural production and food security in the country. Irrigation water accounts for 70% of the world's fresh water[3].

In Senegal, significant investments have been made in irrigation since independence, through several policies and strategies. For this purpose, major facilities are realized throughout the country.

The Niayes area is one of the best for horticultural in Senegal. Waters that can be mobilized are essentially from groundwater. They are threatened by salinity in some places due to strong demands for other purposes such as the establishment of factories [4]. They are also threatened by iron-laden waters in the area where the soil type is ferruginous tropical slightly leached[5]. Irrigated areas are generally small-sized ones, often less than one hectare. Irrigation water from these plots is captured by multiple filtering points (mini-boreholes) or traditional wells. The high demand for irrigation water poses a real threat to the groundwater. In addition, global hydrological models that have been used to estimate the fraction of irrigation water that contributes to groundwater recharge have shown a very low proportion [6-8]. In the early 1990s, the Gladima[9] and Faye[13] studies estimated flows extracted at more than 100,000 m^3/d, while renewable resources were estimated at 115,000 m^3/d.

Faced with this issue, the use of more water-efficient irrigation systems would be a good strategy to ensure ecological balance. A better water management will meet the challenge of food demand and increased income for producers. It is in that perspective that this research work proposes to analyse the "Comparison of the methods of valorization of water by irrigation in the horticultural hydro-system of the Niayes of Senegal". The purpose of this article is to promote the efficient and fair use of water among users, in order to preserve the environment.

MATERIALS AND METHODS

Présentations Of The Study Area: The study area is located on the northern coast of Senegal east of the national road N°2. It is located between latitudes 14°3' and 16° N and longitudes 16° and 17°5' W and covers an area of 2,00 km^2. The study area that extends from Dakar to Saint-Louis is characterized by a Sahelian climate under the influence of the maritime trade wind from the Azores anticyclone charged with moisture. The annual average of temperatures are around 25 °C [10].

The annual rainfall cycle observed in the area is characterized by a long dry season of more than nine months (November-July) and a short wet period of less than three months (August-October). The average annual precipitation in the study area over the period 1982-2017 is 300 mm. This area has always had alternating wet and dry periods[11]. During the last 30 years, this region has seen a global decrease in rainfall. This decline in rainfall is synchronous with the great generalized drought period observed in the Sahel, which began in the 1970s to the 1990s [12].

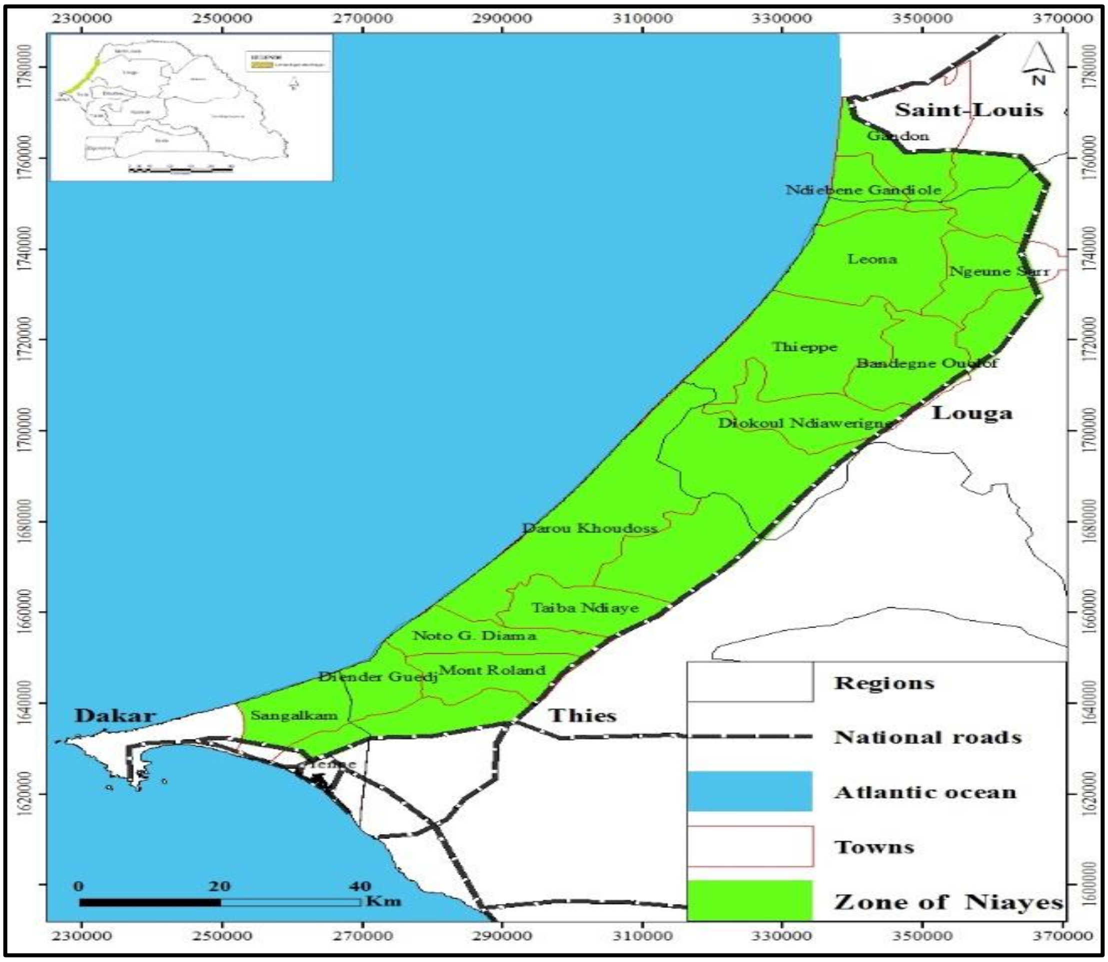

Figure 1: Area map of Niayes

The study area is composed of several types of soils:

- The subarid red brown soils inter ferruginous grades, whose ***A*** to forest horizon is more or less acidic and deep. The horizon ***B*** uniformly colored brown more or less dark and the horizon ***C*** rich in iron (usually granite or ferruginousstandstone);
- The weakly leached tropical ferruginous soils also called soil Dior of movable and permeable nature. This pedological unit is not very fertile because of a coarse sandy texture and a more and more acute degradation which is caused by the erosion especially aeolian (Harmattan). Nevertheless, Dior soils are very conducive to rainfed crops including cereals and oleaginous crops. This explains the preponderance of such speculation (millet, peanuts, cowpeas, etc.) in economic activities;
- Tropical ferruginous soils with little or no leaching with non-aligned ponds are formed on various materials. The superficial horizon is discolored more or less completely and becomes beige. Color, texture and structure variations are fast. The ***A*** horizon has a faded, sandy, massive upper level, followed by a more clayey ***B*** level with moderately colored fragmentary structure rich in spots and concretions;
- The raw mineral soils of contribution located at the edge of the littoral, bordered of a thick cord of dunes alive or semi fixed in the northwestern part of Senegal. These soils are generally located on

a fairly steep slope where the superficial layers are constantly trained, thus preventing soil formation. The vegetation cover is very insignificant. The profile is of type ***AC*** with a relatively young horizon ***A*** not very interesting for agriculture;

- Poorly evolved soils, young soils and are distinguished mainly by their low deterioration of minerals and low organic matter content. The peculiarity of this class is that the humic horizon is essentially composed of organic matter and that the parent rock is completely altered. These soils are little evolved because they undergo frequent sedimentary inputs. These soils can be interesting for agriculture if one manages to dominate the contributions by erosion.

The study area is located on the coast. It is geologically constituted by Quaternary sands. It contains the coastal aquifers which are among the most important freshwater resources of Senegal, commonly known as the Niayes aquifer or the Quaternary sands of the North coast. This sheet contained in the reservoirs of marine and continental sands is most often outcropping in inter-dune depressions (Niayes). The sand dunes resting on an impervious substratum between Kayar and Saint Louis contain a large free sheet directly fed by the rains. The water is generally of good quality except in the deltaic areas and some depressions with marine alluvium [13]. The aquifer is completely free, becomes semi-captive or captive in some very limited areas or reads and clay layers of 1 to 2 m have formed. Its depth varies from 3 to 150 m. The exploitable resources are estimated to 115,000 m^3/day.

Irrigation water at the level of the cultivated Niayes horticultural perimeters hydro-system is of underground origin. The capture works consist in filtering points (mini-drilling) and wells. The captured aquifer is that of the quaternary sands of the Senegal northern coast. It is a flush sheet, very productive with large flows. The depth of these catchment works is a function of its geographical position and varies from the sea to the mainland from 3 to 150 m.

Propose rational and sustainable water resources management methodologies of a region supposes that one is able:

- to apprehend the variability of these water resources for nested time and space scales;
- to separate natural and anthropogenic factors from this variability;
- understand the mechanisms involved;
- Describe the interactions between the different processes that produce or participate in this variability in the study area.

In the study area, productive water is enhanced by various forms: sprinkler irrigation, drip irrigation, manual irrigation (spraying, catch basin, etc.). The drip irrigation system offers many advantages. It is a system adapted to different types of soil and adapts well to the relief of the area. It is very water efficient with an irrigation efficiency greater than 90%. The adoption of this irrigation system contributes to the management of the Quaternary sand table subject to saline intrusion. It allows a suitable irrigation of crops.

Method: The trial was conducted in twelve plots of horticultural production at the villages of Cayar, Notto, Gabar and Galdamel, in the Niayes area. The methodology adopted for this study is based on standard calculations of reference evapotranspiration, plant water requirements, and management of irrigation patterns. An irrigation monitoring sheet is developed for assessing the water needs of the crop. The determination of the specific water requirements takes into account the sowing date, the length of the cycle, the type of soil, the cultural coefficient at the different phenological stages. Added to these parameters are regional parameters such as effective rain and potential evapotranspiration. The calculation of effective rainfall is based on the USDA-SCS method. The FAO CROPWAT 8 program is mainly used to assess crop water requirements. FAO CROPWAT is a decision-facilitating tool for irrigation planning and management, developed by FAO's Land and Water Development Division. This program offers fairly simple tools for estimating water requirements.

Experimental apparatus: The experimental setup adopted is the complete randomization with three treatments using three irrigation modes (drip, sprinkler, manual) and twelve repetitions. Each treatment or irrigation method is applied on a piece of land of 1000 m^2. Observations and measurements were carried out at the level of each treatment according to the position of the elementary plot (1000 m^2) to detect the effects of the irrigation method and the uniformity of distribution of the water on the plot:

- The amount of water supplied to cover the water needs of the crops;
- Irrigation efficiency;
- The average yield of the tomato crop.

The objective is to determine at the end of the season the quantity of water used, the irrigation efficiency and the total production at the level of each production plot.

In order to make this comparison, we adopted the device described below. The area reserved for the trial is 0.3 ha for each producer. This area is divided into three plots of 1000 m^2 each: plot I to which the T1 is assigned, plot II to which the T2 is assigned and plot III to which the T3 treatment is assigned. The spacing between the elementary plots was set at 1 m. This device is repeated twelve times with twelve promoters in the Niayes area. Statistically, this device can be analyzed as a complete randomization with a three-level and twelve-repeat treatment. Indeed, this device is not, strictly speaking, a completely random device, because due to practical constraints, the subplots are not distributed randomly. However, since there is no difference in fertility between plots, the device can be statistically analyzed as a completely random device.

Monitoring and collecting field data: A comprehensive survey was conducted in 2014 to identify the structure of family farms based on an initial list of ninety-two (92) farmers supported by the Program of Support for the Economic Development of Niayes (PADEN). This survey focused on the crops grown, their areas and irrigation techniques practiced (manual, sprinkler or localized). A typology has been developed through a principal component analysis. The choice of farms and the variables that are the subject of this typology is conditioned by the approval of horticultural sub-projects that will lead to a change in the production system: from manual irrigation to modern irrigation (drip or sprinkler).

In this work, we considered that the irrigated area is constituted by the family farms. The typology represents a model based on the mobilization of knowledge from the field, integrating the diversity of farms to build a technical reference.

Method of calculating irrigation water demand at the scale of the perimeter: The water consumption of a crop depends essentially on the importance of solar radiation reaching its foliage. This energy is provided by natural sunshine. Considering the vegetative period of 145 days and its different phases, to which the values of the cultural coefficient kc are assigned, according to the subdivision: (initial phase 30 j with kc=0.6, development phase 40 j with kc=0, 8; transit phase of mid-season 45 days with kc=1.15 and the final phase 30 days with kc=0.7). These data will make it possible to calculate the maximum evapotranspiration (ETM). Tomato is an crop that partially occupies the soil surface. In micro-irrigation, water is provided individually to the plants and the watered area is very limited in comparison with surface irrigation or sprinkling. For the latter, the entire area not covered by the foliage is moistened by watering and water loss is inevitable. In this case, we use the ETM values that incorporate these losses, whereas in the case of micro-irrigation, we took into account a coefficient of reduction kr at 80%. This coverage coefficient is multiplied by the values of the ETM to obtain the ETM*, specific to the micro-irrigation.

Materials

Plant material: The tomato is a tropical vine of the family Solanaceae, belonging to the genus Solanum which includes more than 1300 species. The plant produces bunches of fleshy fruits every third leaf, during naturally indeterminate growth. Tomato is a popular fruit that has adapted to mass consumption in all regions of the world[14]. The plant is grown in the open field or under cover. The species has some botanical varieties, including the "cherry tomato" and several thousand cultivated varieties[15] . Of great economic importance, it is the object of numerous scientific researches. It is considered a model plant in genetics. It gave birth to the first genetically transformed variety authorized for consumption. The tomato is a cold-sensitive plant, perennial in hot climate, usually annual. It is a plant with indeterminate growth, but there are varieties with fixed growth. The tomato flower is actinomorphic with pentamer symmetry. The chalice has five green sepals. This calyx is persistent after fertilization and remains at the top of the fruit[16] . These fleshy fruits are berries normally with two boxes, sometimes three or more, with very numerous seeds. They are very varied in size, shape and color. The cultivated tomato is a plant with neutral days, whose flowering is indifferent to photoperiodism, which allowed its adaptation in various latitudes.

Production plots: The production plots is composed of twelve horticultural perimeters of twelve promoters in the Niayes area. The promoters of the series A are Villages of Cayar, the promoters of the series B of the village of Notto, the promoters of the series C are villages of Galdamel and Gabar.

Figure 2: Irrigation mode

Irrigation equipment: Localized irrigation is characterized by a localized, frequent and continuous supply of water using reduced flow rates at low pressures. Only the fraction of the soil harvested by the roots is continuously moistened. The drip irrigation network is made of a head station and a distribution network. The latter is composed of feeder pipes and irrigation areas. Each sector is controlled by a valve and includes ducts or ramps bearing distributors. The ramps are connected to a ramp gate. Supply lines and ramp doors are PVC, DN 50-60 mm. The ramp gates are equipped with departures, placed at variable distances between 20 to 30 cm. The distribution is made through PEFD ramps with built-in drippers. The distance between two drippers is ten (10) cm. Irrigation is performed at the water tower. Each sector is dominated by a valve. The head equipment is made of filtration station, fertigation and a volumetric meter. Sprinkler irrigation reproduces the artificial phenomenon of rain, controlling the intensity and height of precipitation. This technique requires medium to high pressure conditions (from 1.5 to 4.5 bars at the head of the network). At the level of the sprinkler, the centerpiece of the device, a nozzle creates a jet and directs it towards the spoon. The movable arm is activated by the jet. The return spring causes the return of the movable arm and thus ensures the rotation of the sprinkler. The sprinklers are Sprinkler type with a span of 12 m and placed 0.6 m above the ground. The distance between two ramps is ten (10) meters. Ramps and ramps' supports are PVC DN63PN6. The head equipment is composed of a filtration station and a volumetric meter. Manual irrigation with catch basins relies on the use of low or medium flow motor pumps, buried piping, storage ponds and watering cans or buckets. The pump feeds the basins through a buried pipe network. Irrigation is done manually. The head equipment consists of a volumetric meter. Spear irrigation is also noted in the areas of Cayar, Notto, Mborro and Lompoul. It is done through a continuous water jet of PVC or HDPE piping. The head equipment consists of a volumetric meter.

DATA USED

Data related to water: The data used are diverse. They include the data collected in the field (peak duration, volume pumped per season, the inventory of producers in the Niayes zone, the areas cultivated, cultivated speculations), the CROPWAT crop and soil parameters files, rainfall, temperature, soil types.

Soil data: Soil samples taken during irrigation monitoring were used for different perimeters soil analysis. These analyses concern the moisture rates at the field capacity and the permanent wilting point, the apparent density and the texture of the soil, the content of organic matter by carrying out a particle size analysis by the method of Pipette of Robinson. These analyzes required samples taken from twelve different sites at two depths of 0-20 and 20-45 cm and were used for particle size analysis.

Data related to culture: The CROPWAT software already includes in its basic files the parameters of a certain number of crops. These parameters concern the crop coefficients, the different vegetative stages durations, the root depths, etc. The yields of each production are collected.

Data from the literature was used to supplement the data contained in CROPWAT crop parameter files and those collected during the two monitoring campaigns.

The figure 3 below summarizes the intrinsic characteristics of the plant material.

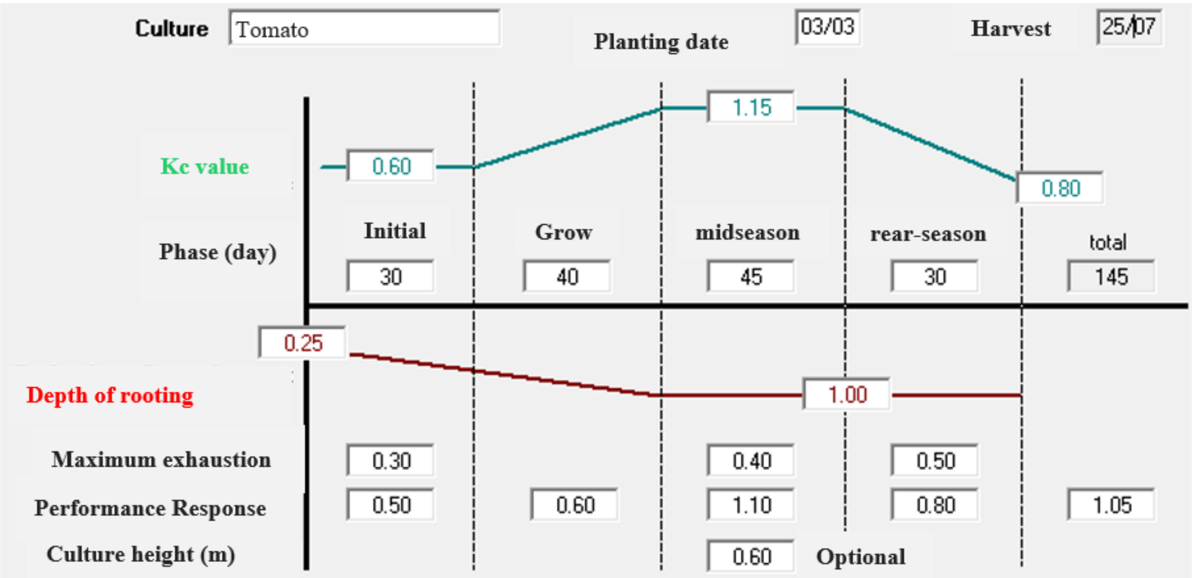

Figure 3: Intrinsic characteristics of the plant material

RESULTS AND DISCUSSIONS

The table 1 below summarizes the results of the analysis of variance of the various parameters studied. The detailed analysis of the results is presented in the following paragraphs.

Table 1: Results of the analysis of variance

Sources of variation	ddl	Sum of squares	Middle square	F of Fisher	Pr > F
Quantity of water consumed	2	1086347.785	543173.892	530.356	< 0,0001
Irrigation efficiency	2	8320.881	4160.441	765.952	< 0,0001
Production	2	3.736	1.868	23.774	< 0,0001

EFFECT OF IRRIGATION MODE ON WATER NEEDS: THE water quantities measurements result to cover the vegetative cycle for the various treatments are presented in the figure 4 below. The irrigation mode has a significant effect at the 1 ‰ threshold on the amount of water distributed to the plot to cover the water needs of the crop. The comparison of the average amounts of water distributed at the plot level shows that the drip irrigation requires less water with a quantity of 707.85 mm compared to 1,028.33 mm for the sprinkling and 1,110.50 mm for the peasant practice (Manual irrigation). At the scale of the cultivated plot, for the same promoter and the same speculation, the quantities of water used to cover the crop cycle varies from one irrigation mode to another.

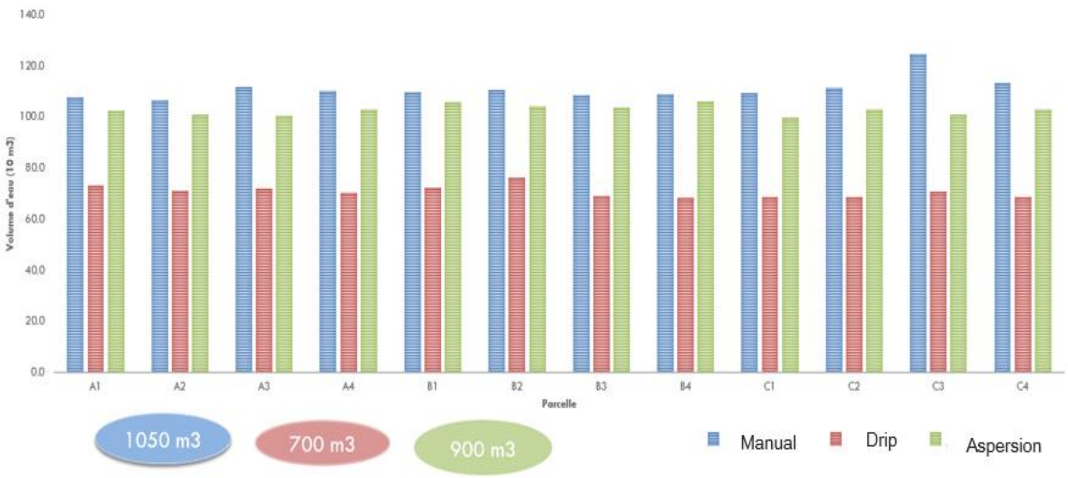

Figure 4: Water quantities measurements

Comparison of the means at the promoter scale shows a small variation of these amounts of water from one promoter to another. Manual irrigation (peasant practice) uses more water with a maximum of 124.5 mm compared to 76.4 mm for the drip irrigation.

This difference in the quantities of water distributed to satisfy the same water needs of the crop is explained by the way water is distributed to the plot. Indeed, for the drip irrigation mode, the distribution of water is localized (on the crop lines) whereas for the two others types (sprinkler and manual), the whole plot is moistened. In addition to the water needs of the crop, water is provided to water uncultivated parts. Also, it is very difficult to control the moistening of the soil with manual irrigation.

The comparative analysis of the different irrigation methods reveals a significant effect of the irrigation method on the water quantity consumed to cover the crops' needs. The table below shows the observed differences resulting from the comparison of the three irrigation modes with a 95% confidence interval.

Table 2: Comparative analysis of the different irrigation methods

Modalities	Difference	Reduced Difference	Critical value	Pr. > Diff	Significant
Manual ~ drip	402.649	30.819	2.454	< 0,0001	Yes
Manual ~ sprinkler	82.167	6.289	2.454	< 0,0001	Yes
Sprinkler ~ drip	320.483	24.530	2.454	1.000	Yes

The comparison between the drip irrigation and the sprinkler irrigation shows a difference of 24.5 mm versus 6.23 mm between the sprinkler irrigation and the manual one. The biggest difference is observed by comparing the drip irrigation to the manual irrigation which gives a difference of 30.8 mm. These results corroborate with the recommendations of the FAO which estimates the drip irrigation is more water efficient followed by the sprinkler. The comparison of the average amounts of water used to cover the water needs of the crops reveals three different groups. The ranking and grouping of non-significantly different groups and the distribution around the mean reveals three groups. The averages observed and grouped into classes are 1110 mm for the sprinkler irrigation (a), 1028 mm for the traditional irrigation (b) and 707 mm for the drip irrigation (c).

Effect of irrigation mode on plot irrigation efficiency: The figure below shows the effect of the irrigation mode on the efficiency of water use at the plot. The analysis of Figure 5 showed a maximum efficiency of 98% observed in plot B4 (drip irrigation mode) against a minimum of 54% observed in plot C3 (manual irrigation / peasant practice).

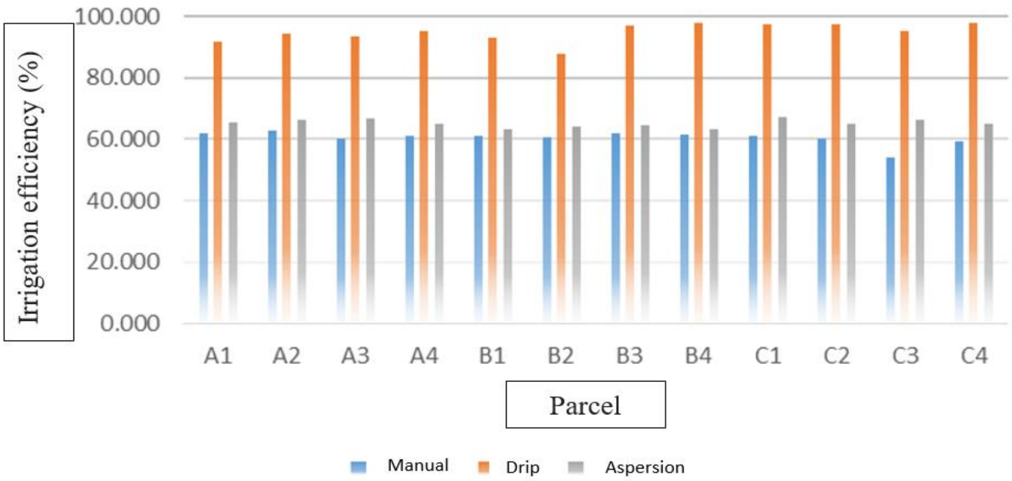

Figure 5: Effect of irrigation mode on plot irrigation efficiency

The analysis of the variance reveals a highly significant effect at the 1 ‰ threshold. This observed difference is explained by the treatment. It appears that at the level of the treatments, water is brought to the root surface of the plant for the drip irrigation. On the other hand, for the sprinkler irrigation, the distribution of water is done through nozzles (sprinkler) which reproduce the artificially the rain in the cultivated plot. For peasant practice (manual irrigation), various forms are observed. The form chosen for this study is the spear. The pressurized water is distributed to the plot through PVC and/or HDPE pipes. The humidification is done on all the parcel until rushing. This constitutes huge water losses in the plot. The comparison of averages, the classification and grouping of significantly different groups gives three classes with averages of 94.86 for the drip irrigation (a), 65.26 for the sprinkler irrigation (b) and 60.45 for the manual irrigation (c). The figure 6 below shows these classes grouped into non-significantly different groups.

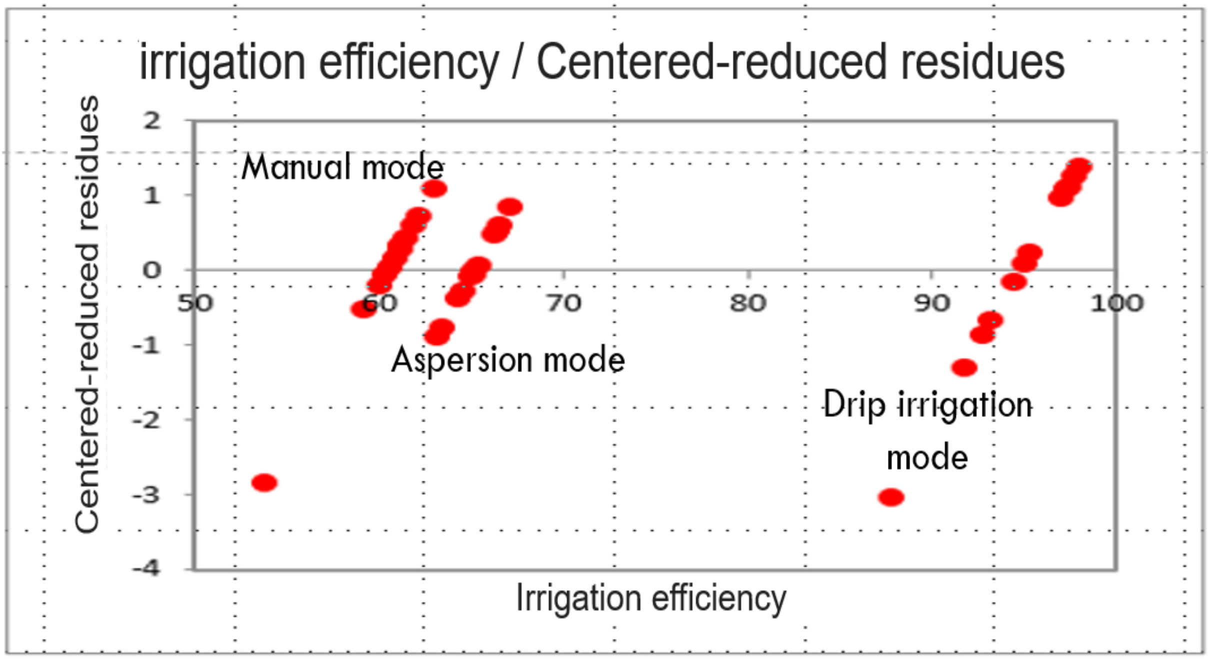

Figure 6: Comparison of averages

Effect of irrigation mode on production / yield: The schema below shows the effect of irrigation mode on production. The peak of production is observed at plot B1 with a quantity of 3.5 tons (drip irrigation) against a minimum of 1.7 at plot C4 (manual irrigation).

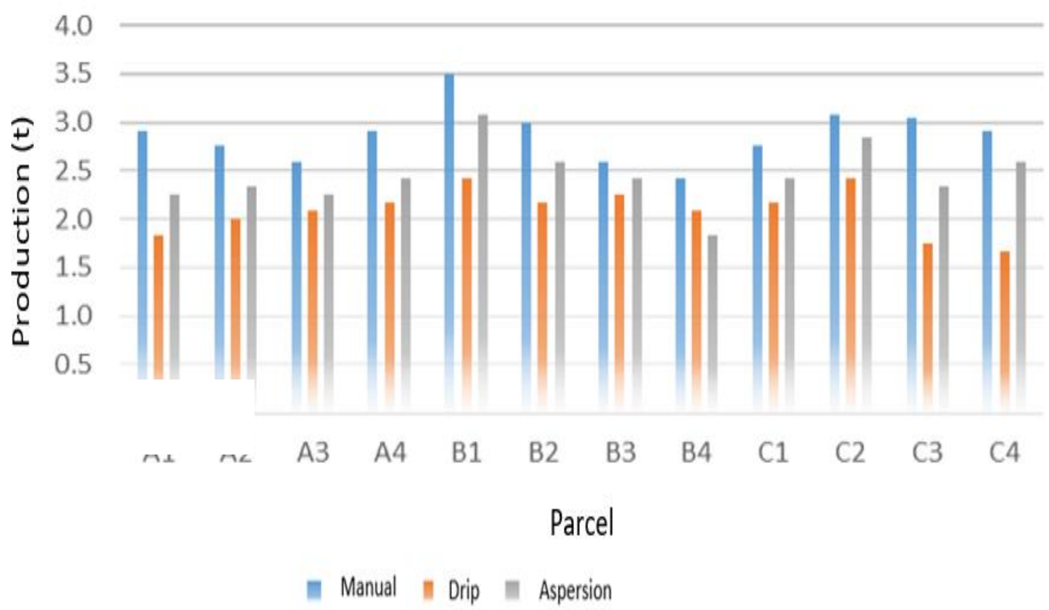

Figure 7: Effect of irrigation mode on production / yield

These values correspond to yields ranging from 17 T/ha for the manual irrigation mode against 35 T/ha for the drip irrigation mode. Concerning this parameter, the analysis of the variance showed a highly significant effect at the 1 ‰ threshold. Comparison of averages showed that the drip irrigation gave the best yield with an average of 28.72 tons per hectare. Sprinkler irrigation yielded 24.44 tons per hectare and traditional irrigation with an average of 20.83 tons per hectare.

This difference is explained on the one hand by the water of distribution pattern in the plot and on the other hand by the adoption of fertigation. Indeed, the drip irrigation offers the possibility of fertigation unlike other irrigation methods.

Irrigation water as well as fertilizers are brought to the roots of the plants, at same time. For sprinkler and manual irrigation, fertilizers are added to the pane at the plot level. Irrigation water leads to the leaching of some of the fertilizers thus reducing the fertilizers' efficiency. The difference in production between sprinkler irrigation and manual irrigation is due to drainage of part of the fertilizer during spraying. In addition, manual irrigation causes soil compaction thus reducing the tubers correct development.

Comparison of means, classification and grouping of non-significantly different groups give three classes with averages of 28.72 T/ha (drip irrigation), 24.44 T/ha (spray) and 20.83 T/ha (manual irrigation). The figure below shows these classes grouped into non-significantly different groups.

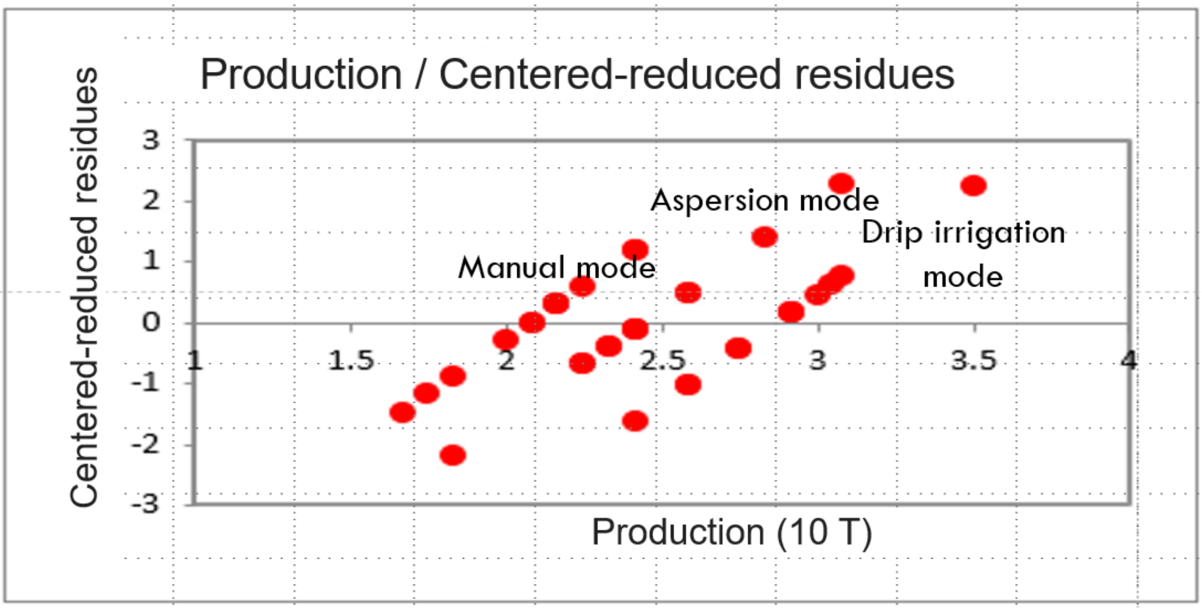

Figure 8: Groupings of groups not significantly different

The results above show that the drip irrigation is more water efficient and offers the best performance. However, it is not suitable throughout the study area due to the hydro chemical characteristics of the groundwater in some places. Thus, the recommendation of a productive water mode of valorization for the irrigation requires a prior knowledge of a number of parameters like the concentration of iron and limestone. The first mentioned is the essential parameter, which guides the choice of an irrigation mode adapted to the small parcels of the Niayes.

Proposal for a method of valorization of productive water by irrigation: The reduction of water withdrawal by the use of water-efficient irrigation methods contributes to maintain the balance of the Niayes ecosystem.

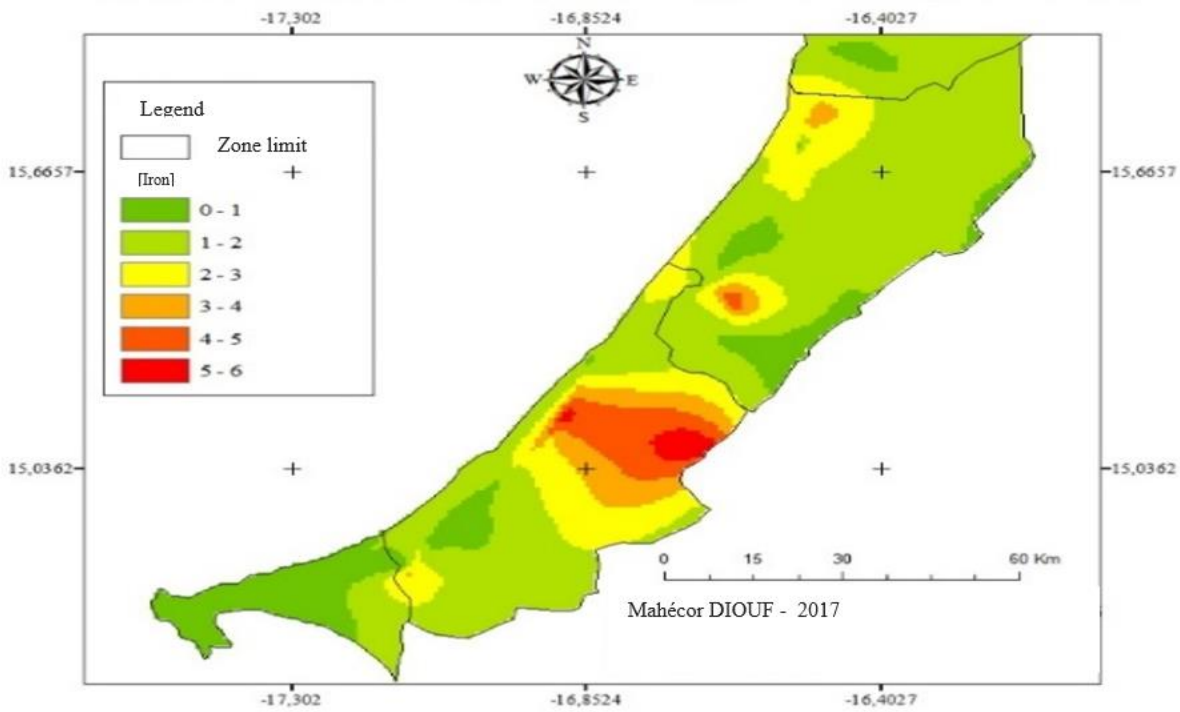

Figure 9: Spatial distribution of iron

However, the use of drip irrigation is not feasible throughout the study area because of high Fe concentrations in places. The spatial distribution of iron is not homogeneous in the area. Figure 10 shows:

- zones with a very high concentration of iron ([Fe] between 4.27 and 5.86 mg/l (Mboro, Ndeukou);
- areas of high concentrations ([Fe] between 3.47 and 4.26 mg/l) (Diambolo, Santhiou Ndong, Muril and Teureul);
- areas with averages concentrations ([Fe] between 2.68 and 3.46 mg/l), (Potou, Thioukougne, Keur Koura, Gorom, Ndiar Lémou);
- zones of low concentrations ([Fe] between 1.08 and 2.27 mg/l) like the majority of the regions of Louga and Saint-Louis;
- areas of very low concentration ([Fe] between 0.26 and 1.09 mg/l): most of the Dakar region, the Diender zone, Ngadiaga, Kébémer, Kab Gaye, Rao Peulh, Thieppe etc.

The higher the iron concentration, the better the drip irrigation is because of clogging causing obstruction of holes and burns of plant necks. When iron concentrations exceed 3 mg/l, water becomes very aggressive for mechanical equipment. Drip irrigation is recommended in areas where the Fe concentration is less than 2.5 mg/l. Conversely, we recommend the use of sprinkler irrigation.

CONCLUSION

From the results obtained in this study, it can be concluded that:

- Irrigation by drip compared to sprinkler and manual irrigation modes allows a clear reduction of punctures on the water table with losses lower than 5.2% against 34.7% for sprinkling and 39.5% for the mode of irrigation.

- The drip irrigation gave the best yields with an average of 29 T/ha against 24.44 and 20.8 T/ha respectively for spray irrigation and manual irrigation.

These results show that the drip irrigation is more water efficient followed by the sprinkler irrigation and the manual irrigation. Also, the drip irrigation offers more yield than other irrigation methods followed by sprinkler irrigation. However, the drip irrigation method is not suitable throughout the study area because of the iron content of the water table in some areas.
Drip irrigation has resulted in better distribution of water to the plot, which was favorabe to the better development of the culture.

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*** Corresponding author: El hadji Bamba DIAW,**

Laboratory of Science and Technology of Water and Environment (LaSTEE), Polytechnic School of Thies BP A10 Thiès, Senegal. (elhbdiaw@ept.sn*)

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