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REUSE OF TREATED WASTEWATER IN AGRICULTURE: SOLVING WATER DEFICIT PROBLEMS IN ARID AREAS (REVIEW)

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ABSTRACT
In the arid and semiarid areas, the availability and the management of irrigation water have become priorities of great importance. The successive years of drought, induced by climate change and population growth, increasingly reduced the amount of water reserved for agriculture. Consequently, many countries have included wastewater reuse as an important dimension of water resources planning. In the more arid areas wastewater is used in agriculture, releasing high resource of water supplies. In this context, the present work is a review focusing the reuse of treated wastewater in agriculture as an important strategy for solving water deficit problems in arid areas. Much information concerning the wastewater reuse in different regions of the world and in Morocco, the different wastewater treatment technologies existing in Morocco were discussed. The review focused also the fertilizing potential of wastewater in agriculture, the role of nutrients and their concentrations in wastewater and their advantages effects on plant growth and yield.
KEY WORDS: *wastewater, reuse, drought, fertilizing potential, agriculture*

INTRODUCTION

In recent years, the wastewater reuse has experienced very rapid growth with an increase in volumes of wastewater reuse in the order of 10-29% per year, in Europe, the United States and China, and up to 41% in Australia. The current daily volume of water used reaches a staggering 1.5-1.7 million m^3 per day in several countries, such as California, Florida, Mexico and China (Lazarova & Brissaud, 2007).

Reuse of wastewater is spread around the world with several types of recovery. There are thousands of projects using wastewater (Bixio *et al.,* 2008). Bixio *et al*. (2005) are classified different types of reuse in 4 categories 1) agricultural use, 2) urban and periurban use and replenishing the aquifer 3) industrial use, 4) mixed uses. Globally, the reuse of treated wastewater for agriculture, industry and domestic use cover respectively 70%, 20%, 10% of water demand (Ecosse, 2001), however, these proportions vary across regions of the world (Figure 1).

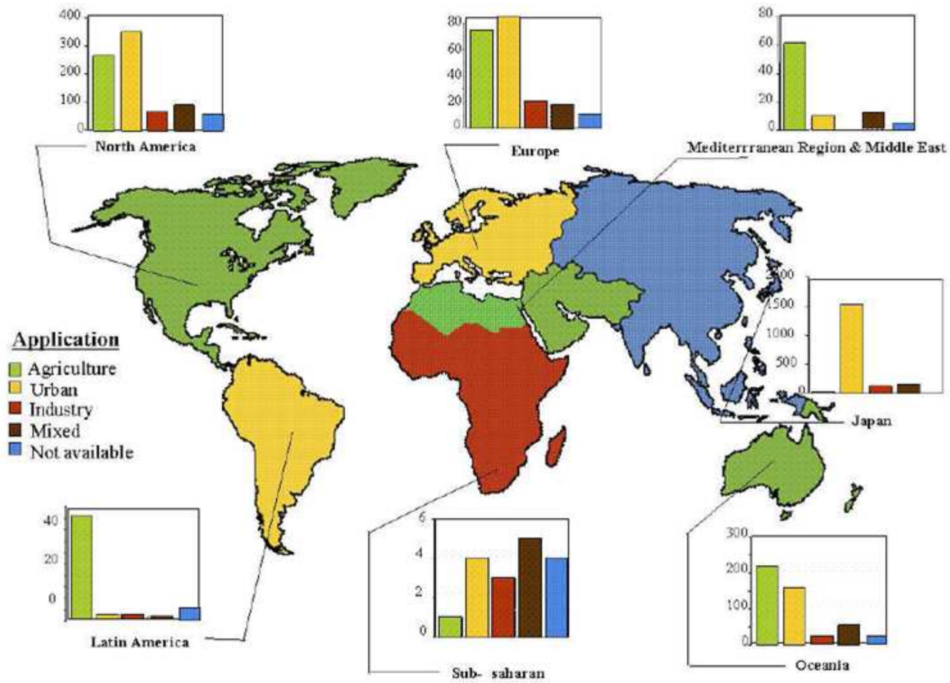

FIG.1. Aspects of wastewater reuse in different regions of the world (Bixio *et al*., 2005)

It is obvious, that the reuse of wastewater (raw or treated waste) has been promoted throughout the world, based on real experiences. In Latin America (Peasey *et al*., 2000), about 400 m^3/s of raw sewage flow into surface water and almost 500,000 hectares of farmland are irrigated with wastewater, mostly without packaging (Mexico -350000, Chile-16000, Peru and Argentina-5500-3700). In Mexico, irrigation with wastewater began in 1926 for irrigation of different crops. Thus, after more than 80 years, there are 40 departments that reuse wastewater, which only 11% are treated for irrigation of agricultural land with a total area of 350,000 hectares (Peasey *et al*., 2000).

In the Valley of Amezquital, there is the largest project of wastewater reuse in the world with 83,000 hectares irrigated with raw sewage (Domínguez-Mariani *et al.,* 2004).

In the United States, since 1955, the wastewater is reused for landscaping purposes. In fact, besides irrigation of parks, golf courses and parks, artificial lakes were fed in whole or part by treated wastewater (Puil, 1998). In France, the reuse of treated water is undeveloped. This is mainly due to the abundance of water resources whose consumption does not exceed 24% of available resources (Lazarova &

Brissaud, 2007). Although in this country, the reuse of treated wastewater has started since the eighties, direct reuse of wastewater remained limited to a few special cases, particularly in the islands of Ré, Noirmoutier, Oléron and Porquerolles. A Noirmoutier, irrigation is carried out on 220 hectares of potatoes and zucchini. At Ars-en-Ré, sprinkler irrigation is performed on maize, sunflower and potato. Vegetable crops and orchards (peach, almond) are watered to the line or drip irrigation on a surface of 30 hectares of irrigation (Puil, 1998). The Clermont-Ferrand project is the most important event of reuse of treated wastewater in France. The perimeter has expanded to 580 acres, 8 municipalities with a total population of 17 000. In 1998, 150,000 m^3 of industrial and 440,000 m^3 of domestic sewage effluents and were used after treatment for agriculture. The main crops are corn, seed corn and beet. In general, almost all the other countries around the Mediterranean, from Spain to Syria, reuse of wastewater (treated and untreated) for various applications (Bixio *et al.,* 2005). Indeed, Mediterranean basin is a region where water scarcity is particularly felt. It is also one of the regions where agricultural reuse of urban waste is the most practiced. In some countries, this reuse has become the subject of a national policy such us Tunisia, Greece and Jordan (Rebhun, 2004, Tsagarakis *et al.,* 2004; Ammary, 2007; Bahri & Brissaud, 2002). In Tunisia, the TWW represent 4.3% of the available water resources for 1996, and they will reach 11% by 2030. In Israel, these waters represent 15% of available resources for the year 2000 and approximately 20% by 2010 (Kamizoulis *et al*., 2003). However, relative to the total water resources, wastewater volumes reconditioned represent approximately 7% in Tunisia, 8% in Jordan, 24% in Israel and 32% in Kuwait. However, the fraction of reused wastewater is highly variable, with the latter about 10% while the figures are 20 -30% in Tunisia, 85% in Jordan and 92% in Israel (Kamizoulis *et al.,* 2003).

Jordan, closer to its goal of recycling 100% of the wastewater, about 90% of the 73 million water meters cubic recovered on 19 wastewater treatment stations are now reused directly or indirectly in the industry, construction and agriculture.

REUSE IN ARID ENVIRONMENTS: THE RIGHT APPROACH TO WATER MANAGEMENT IN AGRICULTURE.

In arid and semi-arid regions, changes in precipitation accompanied by successive droughts generate long-term impacts on water availability for farmers (Khouri *et al.,* 1994; Farissi et al., 2014a). For this, quantitatively, the waste water is a source of water always available since the consumption of clean water does not stop (Pollice *et al*., 2004; Papaiacovou, 2001). Indeed, the treated wastewater can balance the natural cycle of water and conserve resources by reducing harmful emissions into the environment (Bouchet, 2008). In addition to environmental benefits, treated wastewater could have a positive economic impact on farmers. As a result of the high demand for water in the agricultural sector, the delivery of treated water to agricultural fields would decrease the negative impact caused by the use of clean water in irrigation

(Haruvy, 1997; Toze, 2006). In fact, irrigation can affect the economy of poor farmers, especially when the equality of access to land and water is absent (FAO, 2005). Therefore, the treated water could reduce all these expenses and would make less costly irrigation and scope of local farmers, allowing them to invest their money in crop diversification and to move towards a large agriculture added value and sustainable (Haruvy, 1997; Molinos-Senante, 2011). This would also increase the property value of irrigated land, making significant economic benefits to farmers. Even those responsible for sanitation and water treatment could benefit from selling price of treated water and derived products rather than direct discharge into the natural environment (Lazarova & Brissaud, 2007).

Furthermore, the reuse of treated wastewater showed several advantages. In fact, this irrigation water has increased the harvest of vegetables from poor people who cannot afford to buy fish and meat (Sheikh, 1998). Therefore, this increase has resulted in a positive impact on dietary population and income of farmers (Agunwamba, 2001).

OVERVIEW OF THE CONVENTIONAL WATER RESOURCES IN MOROCCO

Water resources in Morocco are facing problems of quantity and quality. These resources are limited due to the semi-arid to the arid climate in most of the territory, with episodic droughts and suffer on deterioration in their quality by their runoff on different limestone rocks spread over the Moroccan territory (XinShen and Roe, 2000) Morocco's water resources are highly variable with annual volume of precipitation over the entire territory between 50 and to 400 billion m^3 estimated to average 150 billion m^3. The potential availability of water in average year is about 29 billion m^3 of which about 19 billion m3 are formed by surface water (CSEC, 2001).

The renewable water resources are estimated in average year by some 30 billion m^3, of which 20 billion m^3 are mobilized under acceptable economic conditions (FAO AquaStat, 2005). The volume of renewable water per capita is currently at about 1,000 m^3 per capita situating Morocco at the limit of poverty in water, considered limit from which pressures on water resources begin to manifest (International Development Research Centre, 2008). At the horizon 2020, given population growth, the volume of water that would be available per capita will drop to about 750 m^3 per capita per year (Yacoubi & Belghiti 2002; Jemali & Kefati, 2002; Bzioui, 2004).

The chronic water scarcity is thus becoming a permanent situation that can no longer be ignored while drawing the strategies and policies concerning the management of water resources in Morocco. In this context and to support the development of the country, Morocco has long been committed to mastery of these water resources through the implementation of 128 large dams with a total capacity of around 17 billion m^3 and thousands of boreholes and wells capturing groundwater (Doukkali, 2005).

AGRICULTURE IN MOROCCO: THE GREAT CHALLENGE OF WATER DEMAND

Morocco is a predominantly arid and desert country despite its Atlantic coast. These weather conditions make irrigation a key technical requirement which economic and social benefits are undeniable. The day after the country's independence, irrigation was a privileged way of agricultural development and has received special attention from the authorities (Doukkali, 2005).

Today, the irrigation sector is the largest consumer of water in Morocco. Indeed, it consumes nearly 88% of the volume of water regularized. Morocco has a total area of 446,500 km^2; the cultivable area is 8 million hectares or 18% of the total land area. The potential of perennial irrigation is currently estimated at 1,364,250 hectares, or nearly 16% of the utilized agricultural area, to this must be added about 300,000 ha of seasonally irrigable land and by spreading flood waters (Administration du Génie Rural, Direction du Développement et de la Gestion de l'Irrigation, mars 2005).

This large water deficit on the one hand and increasing demand for agricultural products on the other, are two factors among others who are behind the development of irrigation in all regions of Morocco. Scarcity and limited potential of natural water resources are a limiting factor for the development of irrigated crops. Considerable efforts are being made in the inventory, the mobilization and management of water resources.

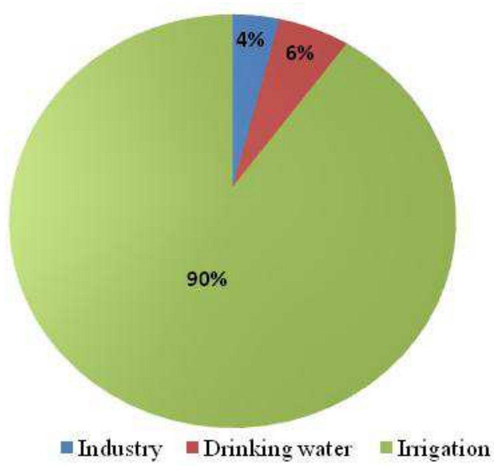

FIG. 2. Water resources consumption in Morocco

STATE WASTEWATER AND TRENDS

Wastewater potential in Morocco

During the 20th century, Morocco has experienced a very high population growth which had the effect of increasing the demand for potable water in urban areas and, subsequently, the rate of connections to the drinking water system, consequently that of the wastewater. With the expansion of urban areas and the expansion of sewerage networks, the annual volume of wastewater discharged has increased (Jemali and Kefati, 2002).

Significant amounts of pollutants from domestic sources are discharged into natural receiving environments, annual volumes of wastewater discharges cities have raised sharply over the past three decades. The figure 3, present the production of wastewater in Morocco by the entire urban that was estimated in 1990 to 210 million m^3, in 1999 to 500 million m^3 and reach 750 million m^3 in the year 2012 (Mandi & Ouazzani, 2013; Rifki, 2013). Reffouh (2007) and Lahlou (2007), believes that this volume could reach 900 million m^3 in 2020.

Despite the large amount of wastewater annually, the number of treatment plants who are in office remains low (Jemali and Kefati, 2002). Carrying in large urban centers, most of the population has a sewerage network with a connection rate of up to 75%, whereas in small towns the network connection remains low and does not exceed 35% (Yacoubi, 1999).

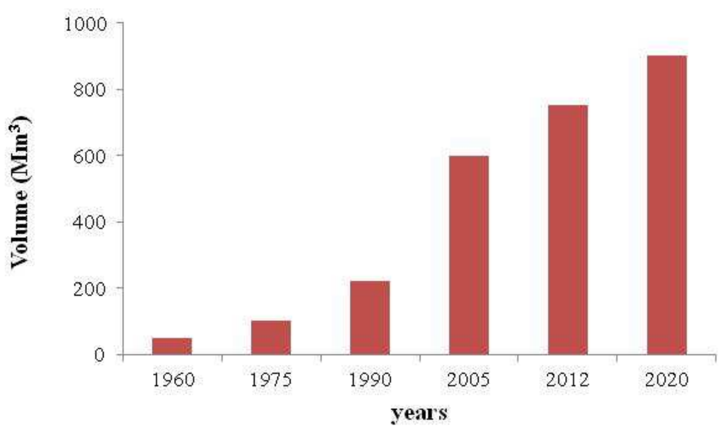

FIG. 3. Evolution of rejected wastewater volumes (mm^3/year)

Wastewater Treatments

There are several channels with different types of treatment, but the choice of treatment processes should be adequate from point of view of climate, the expected applications and the cost of investment (Werther and Ogada, 1999). These processes require a consistent set of treatments performed after pretreatment such as screening, and degreasing. We distinguish intensive processes including activated sludge, biological drives and trickling filters and extensive processes with lagoons and infiltration-percolation.

Since 1958, sixty of wastewater treatment stations (WWTP) were built in Morocco, but in 1994 the vast majority is down or is not connected to the network for various reasons: inadequacy of the treatment system to local conditions, faulty design of structures, lack of maintenance, management problems (lack of budget, lack of competent technical staff), lack of planning in the short and long term.

In 2004, only 8% of wastewater is treated, the rest is discharged directly into the sea (52%), the water system (32%) and septic systems, causing serious pollution of the coastline, rivers and groundwater. This wastewater treatment rate was increased in 2012 to 28% (Rifki, 2013).

In 2009, over 100 WWTPs are mainly installed in small and medium towns in the interior of the Moroccan country. They used a variety of technologies such as activated sludge, ponds, drainage and stabilization ponds and infiltration filters (Figure 4), but the lagoon technology remain the most used in the country due to their low cost, simple maintenance and adaptation to climate conditions of this areas (Mandi, 2012). For this purification systems, more than half are not functional for many reasons: technical, financial and human (Mandi, 2012). Such situation shows not only delay that the country combined in this domain, but also contamination risks about receiver environment in general and water resources in particular. Therefore, to protect water resources and reduce the pollution, a national sanitation and sewage program is developed to improve sewerage collection, the treatment of both industrial and domestic wastewater, and increase the reuse.

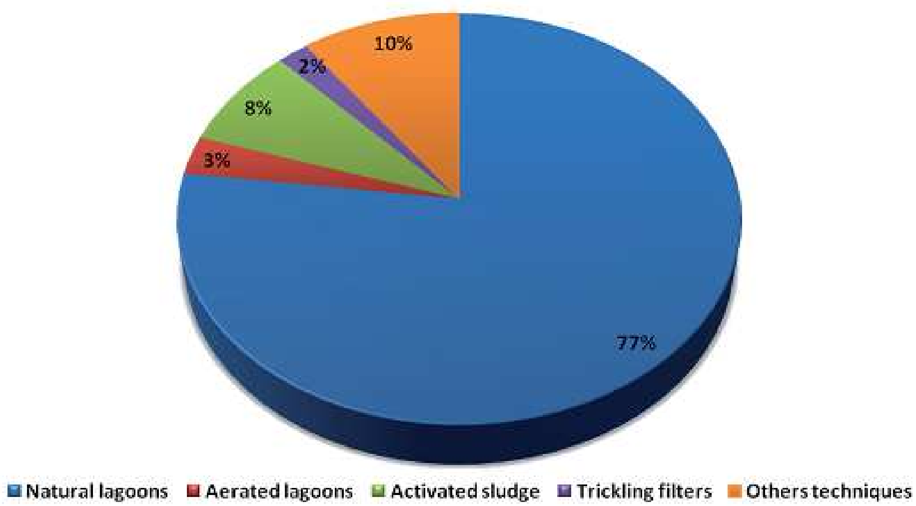

FIG. 4. Distribution of different kind of wastewater treatment technologies existing in Morocco (Makhokh and Bourziza, 2011).

Reuse of treated wastewater

Cope with water deficit, high population growth, rapid urbanization and high economic growth rates experienced by some arid climate countries such as Morocco; wastewater can be considered a significant source of water and elements fertilizers. The reuse of wastewater in agriculture can relieve the water traditional resources that can't longer meet the needs of intensive agriculture and reduce the water deficit (Nigim *et al*., 2002; Dadi, 2010).

In Morocco, wastewater reuse has been practiced for decades in many cities, particularly in large urban centers such as Meknes, Fez, Marrakech, Taza and Oujda. This has become important because of the arid climate in most parts of the country, but also the interest it represents about the addition of fertilizers to irrigated plots (Fatta *et al*., 2005). It should also be noted that the use of this water for agriculture will protect water resources against the pollution generated by urban sewage (Personne *et al*.,1997; Howard *et al.,* 2003; Taylor, 2004; Oren *et al*., 2004; Eladdouli *et al.,* 2009a; 2009b).

Currently, issues relating to the quality of the resource have been little considered: The sanitation sector is experiencing a long delay and more than 90% of wastewater is discharged into the environment (30% hydrographic network; soil and subsoil 27%, 43% sea (Bzioui, 2007) without any treatment.

A part of the raw water discharged by continental cities is reused in agriculture. It irrigates 7,235 ha in areas of horticulture, forage crops, tree crops and cereals (Report on water resources in Morocco, 2004).

The works of El Halouani (1995), Bouhoum & Amahmid (2002), Choukr-Allah (2005) on the reuse of raw wastewater in agriculture in Morocco, showed that different cultures are considered by this practice, namely, forage crops, grain crops, the orchards and vegetable crops. Until now, 80 Mm^3 of TWW was reused in agriculture in morocco, which presents 45% of the total volume of TWW (Table 1).

The use of these treated wastewater touch agriculture (currently covering an area of about 550 hectares and will reach 4,000 hectares in 2020), watering golf courses and green areas, groundwater recharge and recycling in industry. Regarding the low level of wastewater use in agriculture, it is necessary to note that despite the interest shown early by the Department of Agriculture for the reuse of treated wastewater for agricultural purposes, efforts have not been followed for a rapid transition from experimentation to the real application .

According to Belaid (2010), the use of treated wastewater would benefit the whole of society, the environment and evacuators. The use of TWW not only increases the efficient use of the water resource itself and the value added per unit volume of water, but it also relieves the level of substances water courses. Even for evacuators, the process is clearly positive. It allows them to organize the evacuation of more effective and easier than is often possible in arid countries where water points are generally remote and have little water. At the same time wastewater suppliers can obtain financial revenues that would not exist without the use of treated wastewater.

TABLE 1. Treated and reused waste water in Morocco (2010)

Raw sewage (Mm^3/year)	**Treatment levels**	**Treated wastewater**		**Reused wastewater**		**Used for**
		Mm^3/year	%	Mm^3/year	%	
700	Primary	37	5	0	0	Agriculture,
	Secondary	84	12	47	56	green spaces,
	Tertiary	56	8	33	59	groundwater
	Total	177	25	80	45	recharging and industry

Collecting wastewater and the removal of housing, sanitation networks ensure the health protection of individuals and contribute to improving the quality of life (Mara, 2001). However, their reuse in agriculture, without and without monitoring the quality of water treatment, may present health risks to human health, livestock and the environment (Seidu *et al.*, 2008). It is therefore essential to ensure that prior purification will aim to achieve a quality suitable for irrigation of agricultural land, in accordance with standards established by WHO for this purpose. The type of treatment process will depend on the nature of the waste water, climate and the respected discharge standards (Delanoüe and Proulx, 1986), or, in the case of reuse in agriculture, against standards reuse. These standards should focus on protection of human health through the consumption of agricultural products irrigated with treated wastewater (Salgot and Huertas, 2006).

This weakness in celerity can be attributed to several factors, including the difficulty of establishing an institutional and legal instruments accepted by all stakeholders as well as rules of sharing the costs of wastewater treatment between municipalities (producers) and users (farmers).

National Water Strategy was approved by the government in 2010, it considers that the wastewater reuse is an important resource in unconventional water and its value should be placed in the context of integrated resource management water nationwide.

The Green Morocco Plan

The Green Morocco Plan adopted in 2008, highlighted the structural water deficits in most of the major agricultural production areas and considered the scarcity of water resources as a major constraint to agricultural development.

To address the challenge of water scarcity, the Green Morocco Plan and the National Water Strategy consider the management of water demand and water efficiency as a priority strategic scope for sectors water and agriculture.

In this context of growing scarcity of conventional water resources, both water and agriculture strategies consider mobilizing resources unconventional water including desalination of seawater and reuse of treated wastewater as an additional resource to help alleviate local water deficits.

FERTILIZING POTENTIAL OF WASTEWATER

Role of nutrients and their concentrations in wastewater

Plant growth requires a supply of macronutrients (nitrogen, phosphorus and potassium) and trace nutrients. The nitrogen is involved in the synthesis of amino acids. It promotes the growth of plant tissue, making it an important factor of yield (Amin, 2011). The nitrogen present in the wastewater from urban areas, whose main source is urine, is found primarily in the ammonium and organic forms (Omenka, 2010). But, it is absorbed by plants only in mineral form, mainly nitrates. About 13 to 15 grams of nitrogen per person is rejected daily and 1/3 of which is in ammonium form and 2/3 in organic form. The Nitrogen deficiency causes significant yield reductions, hence the need to provide, if necessary, nitrogen supplements in the form of mineral fertilizers (Farissi *et al*., 2014b). However, the nitrogen excessive amounts could affect negatively the growth and yield, particularly on fruit and vegetable crops. This causes plant overgrowth that delays fruit maturity and quality deteriorates (Ayers & Westcot, 1985). This phenomenon is frequently observed in the case of agricultural reuse of wastewater, when they have not been the subject of prior treatment may reduce nitrogen loading (Chiou, 2008).

Phosphorus is a cellular component and an energy carrier (Bargaz *et al.,* 2012). As a cellular component, it participates with the nitrogen to plant growth, especially root growth. It also promotes flowering, fruit set and seed formation (Soltner, 1996). It is mainly found in domestic wastewater. It is present as a mineral consisting essentially of orthophosphate (HPO_4^{2-}, $H_2PO_4^-$, $H_3PO_4^-$) and, in smaller amounts, organic form.

Potassium is required for photosynthesis and protein synthesis. It also allows the plant to drought tolerance (Farissi *et al.,* 2013). A deficiency or excess of potassium increases the sensitivity of the plant parasitism (Soltner, 1996). It is in mineral form K^+ in wastewater.

Micronutrients or trace elements are cofactors of many enzymes (He *et al.,* 2003). They are used in relatively small amounts compared to the three major nutrients N, P, K Nitrogen, phosphorus and potassium are naturally present in soil, but an exogenous supply may be necessary to achieve the expected crop yields. Complementary inputs are generally done through synthetic fertilizers. These are expensive and often inaccessible to small market farmers in poor countries (Latrach et al., 2014c) who are thus frequently tempted to take advantage of the nutrients in the wastewater.

The concentration of macronutrients wastewater has a daily and seasonal variability (Vazquez-Montiel *et al*., 1996). It is also dependent on the nature and treatment applied. These are usually classified into four categories which refer mainly to the type of pollutants covered (Vazquez-Montiel *et al*., 1996):

- Preliminary treatment or pre-treatment designed to remove solid waste relatively large sizes.
- The primary treatments concern the reduction of suspended matter which part is under biodegradable organic form.
- Secondary treatment; they are intended to supplement the reduction of organic waste, to reduce the load of microorganisms and to remove some of the nitrogen and mineral and organic phosphorus.
- Tertiary treatments that are the ultimate in a processing phase. They are often designed to refine the treatment of secondary effluents by targeting a particular type of pollutant.

The mineral nitrogen content of municipal wastewater after secondary treatment is generally between 20 and 60 mg. l^{-1} (FAO, 2003). Larger values can however be observed in for pond in treatment lagoon systems and up to 85 mg. l^{-1} (Bahri, 2002); in this case, ammonia nitrogen, which is less leachable than nitrates, is usually predominant, making it a nitrogenous reserves available for plants (Gaye & Niang, 2002; Vazquez-Montiel *et al,* 1996.).

The content of inorganic phosphorus (PO_4^{3-}) in wastewater after secondary treatment varies from 6 to 15 mg. l^{-1}; 15 to 35 mg. l^{-1} of P_2O_5 (FAO, 2003). A recent estimate of da Fonseca *et al.* (2007) showed a smaller range of variation (4.2 - 9.7 mg. l^{-1} PO_4^{3-}). Various studies mentioned the N/P/K concentrations of 12/0.6/16 (Kalavrouziotis *et al.,* 2008), 42/4/52 (Bahri, 2002) and 30.09.37 (Vazquez-Montiel *et al.,* 1996).

For potassium, the concentration in effluents from secondary treatment varies from 10 to 40 mg.l^{-1} (da Fonseca *et al*., 2007). The biological treatment systems such as lagoons have very little influence on the elimination of this element.

Observed effects on growth and yield of crops

Because of their nutrient content and wealth of trace elements, wastewaters when reused for irrigation, provoke higher yields of crops. In most cases, the studies on the influence of wastewater on crops attest to accelerate plant growth and a significant increase in yield, clearly associated with the intake of nutrients by wastewater. In this context, Mohammad Rusan *et al.* (2007) found an increase in the biomass of forage plant when irrigated by raw or treated wastwater. Yadav *et al*, 2002 reported a significant enrichment of trace elements in tissue cultured plants under wastewater irrigation.

At the plant growth, Manios *et al.* (2006) conducted a study on tomato and cucumber, testing three treatments: (i) wastewater with decreasing concentrations of nitrogen, (ii) optimal nutrient solution and (iii) control treatment with tap water. The growth parameters measured were stem height, number of leaves, biomass of leaves and stems, and root dry biomass. The results show that the agronomic parameters studied were more improved under irrigation with wastewater containing the higher nitrogen and irrigation with optimum nutrient solution comparatively to control conditions. An increase in yield was observed both on cereal crops such as sorghum (do Monte & e Sousa, 1992) and maize (Adekula & Okunade, 2002). However, Khuda and Sarfraz (2005) reported that vegetables such as spinach, cabbage and cauliflower, are better suited to irrigation with wastewater than root vegetables such as carrots, turnips and radishes.

CONCLUSIONS

Morocco is a country where agriculture is a top priority being the most important natural resource of the country. Unfortunately, the annual rainfall is very irregular both in space and in time and almost all of the Moroccan territory belongs to the arid storey, semi-arid and Saharan. This climate is responsible for a negative water balance since evaporation outweighs precipitation (water deficit of around 1000 mm). Taking into account all these factors, the recourse to irrigation is more than necessary to ensure the best crop yields. Given the scarcity of these water resources and the pressure of demand, the option is to reuse TWW. This abundant and regular resource is the most appropriate strategy.

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