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Waste-Water Use in Energy Crops Production

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1. Introduction

1.1 Waste water use in irrigation

Water supply and water quality degradation are global concerns that will intensify with increasing water demand; for this reason, worldwide, marginal-quality water will become an increasingly important component of agricultural water supplies, particularly in water-scarce regions. The status of severe water resource shortage determines that new water source must be developed to cope with the deficiency of water sources for agriculture irrigation. One of the major types of marginal-quality water is the wastewater from urban and peri-urban areas (Pedrero *et al.*, 2010). The municipal wastewater is a potential water resource with stability of water quantity and reliable supply. Irrigation with reclaimed municipal wastewater that is properly treated and satisfied with the agricultural recycling standards has huge benefits and profound social effects (Shi *et al.*, 2008).

In recent years wastewater use has gained importance in water-scarce regions. In Pakistan 26% of national vegetable production is irrigated with wastewater (Ensink *et al.*, 2004). In Ghana, informal irrigation involving diluted wastewater from rivers and streams occurs on an estimated 11,500 hectares, an area larger than the reported extent of formal irrigation in the country (Keraita and Drechsel, 2004). In Mexico about 260,000 hectares are irrigated with wastewater, mostly untreated (Mexico CAN, 2004).

Wastewater reuse in agriculture is an ancient practice that has been generally implemented worldwide. Agricultural deployment of wastewater for irrigation is based on the value of its constituents, which are used as fertilizers. However, crop irrigation with insufficiently treated wastewater may result in health risks. The use of sewage effluent for irrigation exposes the public to the dangers of infection with a variety of pathogens such as bacteria, viruses, protozoa and helminths. Thus the benefit of wastewater reuse is limited by its potential health hazards associated with the transmission of pathogenic organisms from the irrigated soil to crops, to grazing animals and humans (Gupta *et al.*, 2009). Human health risks from wastewater irrigation include firstly farmers' and consumers' exposure to pathogens including helminth infections, and secondly, organic and inorganic trace elements. Protective measures such as wearing boots and gloves, and changing irrigation methods can reduce farmer exposure (Qadir *et al.*, 2010).

1.2 Energy crops and biofuels

Energy crops, also called "bioenergy crops", are grown for the specific purpose of producing energy (electricity or liquid fuels). As these crops are not grown for the purpose of producing food, there are no health risks implicated for the consumers.

The possibility of using biomass as a source of energy in reducing green-house gas emissions is a matter of great interest. In particular, biomass from agriculture represent one of the largest and most diversified sources to be exploited and more specifically, ethanol and diesel deriving from biomass have the potential to be a sustainable means of replacing fossil fuels for transportation (Singh *et al.*, 2008; Dalla Marta *et al.*, 2010).

These liquid biofuels are bioethanol (gasoline-equivalent) and biodiesel (diesel-equivalent). Bioethanol is used as an additive or substitute for gasoline, and biodiesel, alone or combined with diesel for diesel engines. The first is obtained from fermentation of grains such as maize starch-, sugar cane or reserve organs rich in carbohydrates (Jerusalem artichoke, sugar beet, among others). Biodiesel comes from vegetable oils through a chemical process called "transesterification" (Huergo, 2001).

Bioethanol is by far the most common biofuel in use worldwide. Global bioethanol production increased from 4.4 billion litres in 1980 to 46.2 billion litres in 2005 (Fig. 1). The largest producers of ethanol are United States, Brazil and China. Bioethanol is produced from the fermentation of starch or sugar-rich crops. Bioethanol can also be produced from cellulosic materials, such as trees, grasses, and agriculture residues. However, cellulosic ethanol is not yet commercially viable due to high production costs (Fulton *et al.*, 2004; de Vries *et al.*, 2010).

Global biodiesel production increased from 11.4 million litres in 1991 to 3.9 billion litres in 2005. Germany, France, United States, and Italy are the leading producers of biodiesel. This biofuel can be produced from vegetable oil, used frying oil, or animal fat through a transesterification process in which oil molecules react with an alcohol and a catalyst to form fatty acid- methyl esters (FAME or biodiesel) and glycerol (Pin Koh and Ghazoul, 2008).

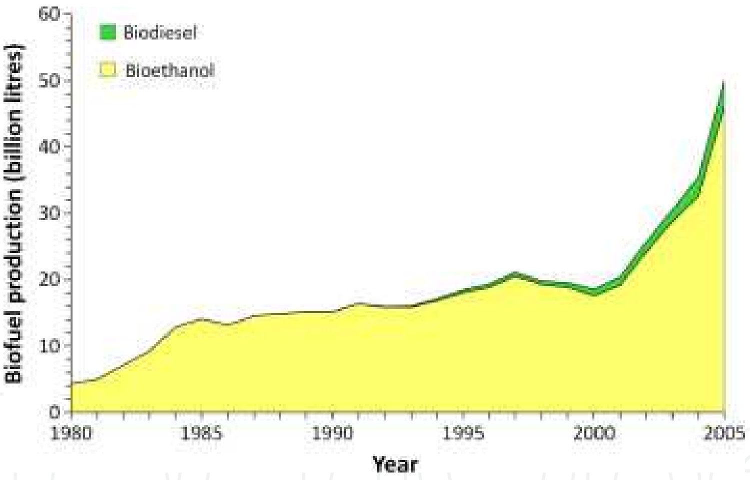

Fig. 1. Increase in global production of bioethanol and biodiesel between 1980 and 2005. Taken from Pin Koh and Ghazoul, 2008.

Argentina is today the fourth largest producer of biodiesel after the European Union, United States and Brazil. Most of Argentina's biodiesel is already destined to foreign markets. The Argentine biodiesel industry is mainly based on the use of soybean as feedstock. The ethanol production complex in Argentina is mainly comprised by sugar mills in the northwestern part of the country. However, the ethanol produced by these firms is not exclusively meant for fuel usage. In 2006, a large ethanol distillery was inaugurated in the Tucumán province, aimed at producing ethanol fuel for the domestic and export markets[1].

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[1] http://www.argentina.gov.ar/argentina/portal/papups/biofuels-opportunities.pdf

2. Waste water use in energy crops production in Mendoza, Argentina: research experience

In Argentina we have no available data of wastewater use for irrigation; but information from Mendoza province is the following: 3.2 m^3/s of domestic efluents are generated; it is estimated that 10,300 hectares are irrigated with urban waste water with different treatment level (G. Fasciolo, personal communication, 2010).

Mendoza weather conditions may be labeled 'warm-arid'. Annual rainfall ranges from 100 mm in the north, up to 400 mm in the south, with a mean annual temperature varying from 13°C in the south to 20°C in the north (Guevara, 1997). Irrigation is essential for crops production. The main species grown in Mendoza province are wine-grape, some fruit trees, and vegetables such as garlic, onion, potato and tomato.

In order not to compete for water with these traditional species, we studied energy crops production using waste water irrigation. Jerusalem artichoke (*Helianthus tuberosus* L.) and rape (*Brassica napus* L.) were selected for this study.

Photo 1. Horacio Lelio (one of the authors of this chapter) between the two energy crops tryed in our research, "rape" in the left and "Jerusalem artichoke" in the right, december 2008.

Jerusalem artichoke is a potentially useful crop for bioetanol production (Kays and Nottingham, 2008). Some studies indicate that 4,500 l of ethanol can be produced from 50 tons of tubers. Rape oil can be used as raw material to produce biodiesel (de Vries, 2010).

2.1 Brief characterization of the energy crops studied

Brassica napus L. ("rape" or "canola") is a cultivated plant of the Brassica family. It is an annual plant that reaches 0.3 to 1 m tall, leaves are 5 to 40 cm long, flowering occurs in early spring with yellow flowers, the fruit is a siliqua from 5 to 7 cm with several seeds 1.5 mm in diameter.

Canola is the name given to certain varieties of oilseed rape. This name is a trademark for a hybrid variety of rape initially bred in Canada.

Photo 2. Rape in flower, spring 2008.

Photo 3. Jerusalem artichoke in flower, March 2008.

Rape is cultivated worldwide for forage, vegetable oil for human consumption and biodiesel. The major producers are the European Union, Canada, United States, Australia, China and India.

According to the United States Agriculture Department, rapeseed was the third largest source of vegetable oil in 2009, after soybean and palm[2].

The main use of rapeseed oil is biodiesel production. This biofuel may be used in pure form in newer engines without damage, and is frequently combined with fossil-fuel diesel in ratios varying from 2% to 20% biodiesel. Rapeseed oil is the preferred oil stock for biodiesel

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[2] http://es.wikipedia.org/wiki/Brassica_napus

production in most of Europe, partly because rapeseed produces more oil per unit of land area compared to other oil sources, such as soy beans[3].

Helianthus tuberosus L. ("Jerusalem artichoke", "sunroot", "sunchoke" or "topinambur") is a species of sunflower native to North America, and long used by the American Indian for food. It has been introduced and became naturalized in all temperate regions in the Northern and Southern Hemispheres. It is also cultivated widely across the temperate zone for its tubers, which are used as root vegetable (Duke J., 1983).

It is an herbaceous perennial plant growing to 1.5–3 m tall. The flowers are yellow, produced in capitate flowerheads which are 5–10 cm in diameter. The tubers are elongated and uneven, typically 7.5–10 cm long and 3–5 cm thick, and vaguely resembling ginger root, with a crisp texture when raw. They vary in color from pale brown to white, red or purple (Huxley, *et al.*, 1992).

The main uses of Jerusalem artichoke are: horticulture, forage and industry (inulin extraction and ethanol production).

2.2 Waste-water use in energy crops production: our experiences

We conducted a trial in which yield and potential to produce ethanol of Jerusalem artichoke and yield and potential to produce biodiesel of a winter rape cultivar were compared. Two types of irrigation: urban waste water (UWW) and ground water (GW) were used (Table 1).

Both researches were conducted in the Urban Waste Water Treatment Plant of Obras Sanitarias Mendoza in Tunuyán (33°32′89′′ S and 69°00′80′′ W). The characteristics of the soil of the trial are shown in table 2.

Photo 4. Urban Waste Water Treatment Plant of Obras Sanitarias Mendoza in Tunuyán; the treatment pools are behind the trees.

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[3] http://www.openmarket.org/2007/11/12/biofuel-mandates-cause-global-warming-scientists-say/

Parameter	GW	UWW
Electrical conductivity (dS/M)	0.42	1.10
Total nitrogen (mg/l)	5.6	28.7
Mineral nitrogen, $NH_4 + NO_3$ (mg/l)	1.05	14.7
Phosphorus, P (mg/l)	0.13	11.51
Phosphorus, PO_4^{-3} (mg/l)	0.39	35.3
Potassium, K (mg/l)	11	20
Potassium, K_2O(mg/l)	13.2	24
Organic matter (mg/l)	73.4	236

Table 1. Characterization of irrigation waters, ground water (GW) and urban waste water (UWW)

Photo 5. Appearance of the waste water used for irrigation.

Variable	Soil Condition	
Depht (cm)	0-10	10-30
pH	6.63	6.76
Electrical conductivity (dS/M)	19.80	12.20
Saturation percentage (g%g)	35	49.8
sedimentation volume (ml%g)	116	124
Total nitrogen (mg/kg)	5570	3780
Phosphorus (1:10) (mg/kg)	26.2	13.3
Exchangeable Potassium (mg/kg)	1149	740
Organic matter (g%g)	9.2	6.2
C/N Relationship	9.6	9.5

Table 2. Soil characterization

2.3 Jerusalem artichoke trial

2.3.1 Materials y methods

Two cultivars of Jerusalem artichoke were tryed (red tubers, **R**, and white tubers, **W**), and two kinds of waters were used for irrigation (urban waste water, **UWW**, an ground water, **GW**).

Photo 6. Tubers of the two Jerusalem artichoke cultivars tryed in this experience. R, with red tubers, in the left; and W, with white tubers, in the right.

The experimental test had a random plot design, with 3 repetitions per treatment (each combination of cultivar and kind of water). The planting density was 25,000 plantas/hectares; 0.8 m between rows and 0.5 m between plants in the row. The tubers seed weight was around 50 g, and planting depth was 10 cm. It was carried out manual weed control and we did weekly irrigations with 22 mm of water (35 applications in total = 767 mm). We harvested individual crop plants and in each one, the following parameters were determined:

- Performance of tubers per plant (kg)
- Number of tubers per plant
- Height (m)
- Number of main stems
- Performance of dry biomass (kg). On a sample of biomass combustion heat was determined, with a calorimeter bomb.

In laboratory, we estimated the potential to produce bioethanol from tubers, taking into account the following relationship: for each kg of fermentable carbohydrates, 0.5563 l of ethanol is obtained[4].

2.3.2 Results

Jerusalem artichoke tuber yield showed differences between type of water treatment, being 177,750 kg/hectares in UWW and 144,000 kg/hectares in GW.

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[4] http://journeytoforever.org/biofuel_library/ethanol_motherearth/meCh2.html

Varieties	UWW	GW
R	206,250	154,000
W	149,500	134,250
Average	177,750	144,000

Table 3. Tuber yield per hectare (kg) for each irrigation treatment (ground water GW and urban waste water UWW) and for two varieties (R and W).

In both varieties yield was higher when UWW was used for irrigation. R had higher yield than W variety. Yields in this trial were bigger than those got in Australia when Jerusalem artichoke was irrigated using UWW; Parameswaran (1999) in that country had 120,000 kg tubers/ hectare.

Number of tubers produced per plant was significantly higher in those urban waste water irrigated. Besides, plants belonging to W variety had significantly more tubers than R plants. Results can be seen in the following table.

Varieties	UWW	GW
R	94.27 b	66.08 b
W	122.53 a	113.08 a
Average	108.4 a	89.58 b

Table 4. Number of tubers per plant for each irrigation treatment (ground water GW and urban waste water UWW) and for two varieties (R and W).
Different letters indicate significant differences at P = 0.05

Plant height significantly differed between irrigation treatments (P= 0,00001), but did not between varieties (P= 0.1257). Results are shown in table 5.

Varieties	UWW	GW
R	3.07 a	2.56 a
W	2.87 a	2.86 a
Average	2.97 a	2.71 b

Table 5. Plant height (m) for each irrigation treatment (ground water GW and urban waste water UWW) and for two varieties (R and W).
Different letters indicate significant differences at P = 0.05

The number of main stems per plant differed significantly betwen kind of irrigation water (p= 0.0013), but did not differ between varieties (p= 0.5207). Plants irrigated with urban waste water had more stems than those ground water irrigated (table 6).

Varieties	UWW	GW
R	1.47 a	1.39 a
W	1.62 a	1.32 a
Average	1.54 a	1.35 b

Table 6. Number of main stems per plant for each irrigation treatment (ground water GW and urban waste water UWW) and for two varieties (R and W).
Different letters indicate significant differences at P = 0.05

Dry aerial biomass per plant differed between irrigation treatments (P= 0.00001) and between varieties (P= 0.0125). It was higher in plots irrigated with UWW and in R variety, as can be seen in table 7.

Varieties	UWW	GW
R	0.87 a	0.58 a
W	0.71 b	0.62 a
Average	0.79 a	0.60 b

Table 7. Aerial dry biomass per plant (kg) for each irrigation treatment (ground water GW and urban waste water UWW) and for two varieties (R and W).
Different letters indicate significant differences at P = 0.05

The remanent dry aerial biomass of the crop per ha was 23,250 kg in UWW and 17,750 kg in GW. The combustion heat of it was 3,668 kcal/kg, representing an important energy contribution that can be usefull in the industrial process for obtaining ethanol.

The potential to produce ethanol was 15,000 l/ha in plots irrigated with UWW and 13,000 l/ha in the GW irrigated. Ethanol potential production was estimated from the amount of fermentable carbohydrates in the tubers. To produce 1 l of ethanol from tubers, 11 kg were needed, considering that soluble solids in tubers were about 16% (Lelio *et al.*, 2009).

Tuber yield of both varieties of Jerusalem artichoke urban wastewater irrigated is higher of that found when the crop is ground water irrigated. This high yield is related to more tubers per plant, higher plants, more stems per plant, and higher aerial biomass per plant.

2.4 Rape trial

In this work yield and potential to produce biodiesel of a winter rape cultivar under two irrigation treatments (urban waste water (UWW) and ground water (GW)) were compared.

2.4.1 Materials and methods

The experimental test had a random plot design, with 3 repetitions per treatment (each kind of irrigation water, UWW and GW). "Gospel" winter rape cultivar was grown. Sowing date was February 28th, 2008, and a density of 8 kg/ hectare was sown, with a distance of 0.4 m between rows. Each plot had 7 rows of 5 m long. It was carried out manual weed control and we did weekly irrigations (32 applications in total = 700 mm). At the end of November, 2008, the plots were harvested and the following parameters were determined:

- Number of plants per square meter.
- Number of siliqua per plant, on 30 plants randomly taken in each plot.
- Number of seed per siliqua, on 150 siliqua randomly taken in each plot.
- One thousand seeds weight, on five groups of 1000 seeds per experimental plot.
- Seed yield per unit surface. Cut in farm and laboratory threshing.
- Oil in seeds, Soxlhet methodology.

Variance tests were performed to compare the previous parameters.

2.4.2 Results

In the following table results of yield components for each irrigation system (UWW and GW) are shown.

Yield component	Kind of irrigation water		Significant differences at 5 % level
	UWW	GW	
Nº plants/ m²	27.5 ± 4.33	33.32± 8.77	No, p=0.3603
Nº siliqua/ plant	692.3± 16.80	533.7± 16.62	Yes, p= 0.0003
Nº seeds/ siliqua	23.07± 0.83	20.48 ± 0.38	Yes, p= 0.0048
1000 seeds weight	3.60± 0.10	2.43 ± 0.35	Yes, p=0.0050
% oil in seeds	36.7	36.2	-

Table 8. Number of plants/m², number of siliqua/plant, number of seeds/siliqua, 1.000 seeds weight, oil percentage in seeds in each irrigation treatment (UWW y GW) of rape grown in Tunuyán, 2008.

Photo 7. Rape crop before harvest.

As it can be seen in table 8, number of plants per unit surface did not show significant differences, average was 30.41 plants/m²; that is between the range recommended for winter cultivars, from 20 to 60 plants/m² (Iriarte and Apella, 2007).

The number of siliqua per plant significantly differed between irrigation treatments. We found 692.3 siliqua per plant in UWW plots and 533.7 in GW plots; both higher than values indicated by other authors (Iriarte y Valetti, 2008, Tamagno *et al.*, 1999).

The number of seeds per siliqua differed between UWW and GW irrigation treatments. Siliqua from UWW plots had 23.07 seeds average, while GW siliqua had 20.48 seeds.

One thousand seeds weight presented significant differences. Bigger seeds were produced in UWW compared with GW.

Rape yield can be estimated from yield componentes: number of plants per unit surface, number of siliqua per plant, number of seeds per siliqua, and seeds weight (Gómez and Miralles, 2006). In our trial, yield estimations were 15,811 kg/ hectare in UWW and 8,851 kg/ hectare in GW treatment.

Harvest plots yield results

In UWW plots yield was higher (7,690 kg/ hectare) than in GW plots (3,886 kg/ hectare). These values of yield are very high; probably associated to the high level of nutrients in the irrigation UWW (Rebora *et al.*, 2010).

Photo 8. Rape harvest, december 2008.

Photo 9. Final dry of siliqua in laboratory.

Oil

Oil percentage found in seeds of both treatments was lower than that indicated for Gospel cultivar (47%). It was 36.7 in UWW and 36.2% in GW seeds. Usually, seed yields are associated with low oil percentage in seeds. Besides, high levels of nitrogen fertilization tend to reduce oil content in seeds.

Variable	Kind of irrigation water	
	UWW	GW
Seed yield (kg/ha)	7,690	3,886
Oil (%)	36.7	36.2
Oil yield (kg/ha)	**2,822**	**1,406**

Table 9. Oil yield of rape grown under two irrigation treatments (UWW, urban waste water, and GW, ground water) in Tunuyán, Mendoza, 2008.

Biodiesel production

Every 100 litres oil, 100 litres biodiesel can be obtained (Muñoz, 2005). According to the previous relation, the oil that could be obtained represents the ammount of biodiesel that could be produced per unit surface; this is 2,822 l biodiesel/hectare when rape is irrigated with urban waste-water and 1,406 litres biodiesel/ha when it is irrigated with ground water. From our results we are able to say that the use of urban waste water in rape irrigation allows to reach very high yields, both of seeds and biodiesel per unit surface.

3. Conclusions

In recent years waste-water use has gained importance in water-scarce regions. Waste-water reuse in agriculture is an old practice that has been generally implemented worldwide. Agricultural deployment of wastewater for irrigation is based on the value of its water content and its constituents, which are used as fertilizers. However, crop irrigation with insufficiently treated wastewater may result in health risks. Energy crops, not grown for the purpose of producing food, have no health risks implicated for the consumers. Many crops can be used as energy crops for biofuels (bioethanol and biodiesel) production.

Mendoza province generates 3.2 m^3/s of domestic efluents. It is estimated that 10,300 hectare are irrigated today with urban waste water with different treatment level. There are still many ha that could be used for energy crops using remanent urban waste-water.

Both “rape” and “Jerusalem artichoke” have shown to be interesting energy crops under urban waste-water irrigation in Mendoza, Argentina, For biodiesel and bioethanol production, respectively.

To conclude, urban waste-water could be used to enlarge oasis in Mendoza, and energy crops such us rape and Jerusalem artichoke present higher yields when they are irrigated with this type of water compared to the yields of those crops using ground water irrigation.

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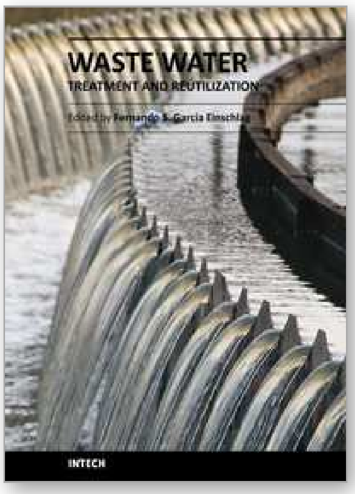

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