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Comparative values of various wastewater streams as a soil nutrient source

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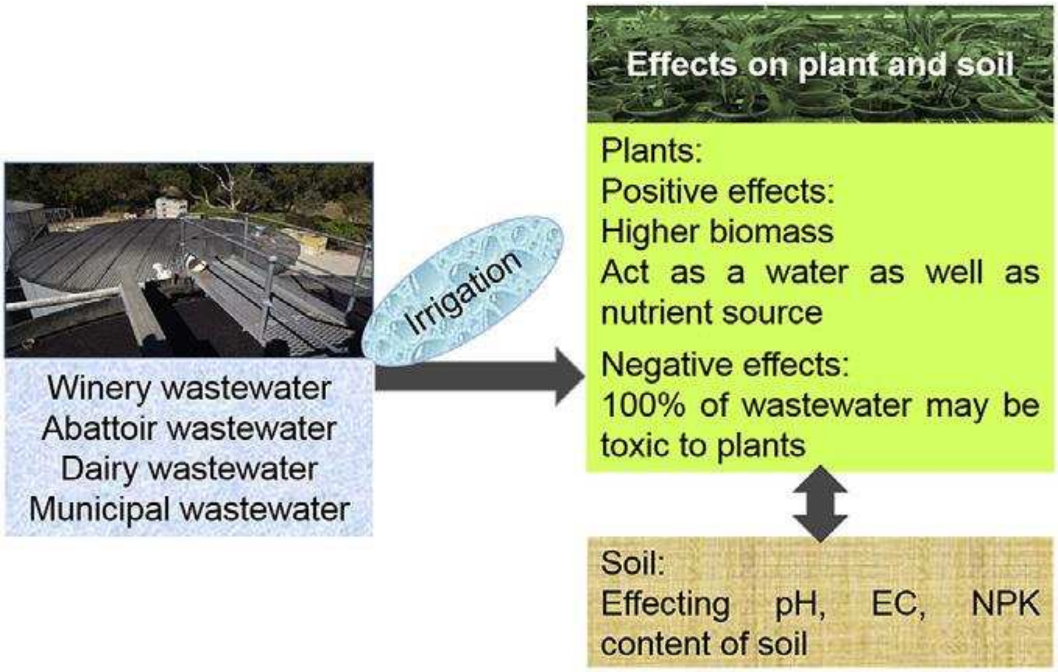
Highlights

- Abattoir wastewater showed best results even in 100% concentration.
- Winery wastewater was more toxic in 100%.
- Dairy wastewater was not good at full use, but 50–75% dilution showed higher yield.
- N, P and K content of plant and soil varied with different dilutions of wastewater.

Graphical abstract



Abstract

In order to assess whether wastewaters from different industries (winery, abattoir, dairy and municipal) could be used safely to irrigate agricultural crops, a pot experiment in glass house was conducted in a sandy clay loam soil (pH=6.12) from South Australia. Different concentrations (0, 0.05, 5, 25, 50, 75 and 100%) of the wastewaters diluted in an ordinary tap water were applied to soils sown with sunflower and maize seeds, and the effect of these irrigation treatments were evaluated at the early crop growth stages by recording the biomass yields, plant mineral nutrient contents, and also the soil chemical properties. Results showed that the winery effluent reduced the early growth of maize and sunflower when applied without any dilution, but increased yields of both plants when applied at 25% dilution with tap water. At this dilution of the winery wastewater, 80% more dry shoot yield (DSY) of sunflower and 58% more DSY of maize were obtained in comparison to the application of 100% concentration of the wastewater. Abattoir wastewater showed the highest yields at 100% concentration. Furthermore, municipal effluent did not show any inhibitory effect on both the crops. It was observed that metal contents in both the crops were different due to the application of different wastewaters, but did not exceed any toxic level. This study demonstrated that abattoir wastewater as such, and winery and dairy wastewaters at appropriate dilutions could be used for irrigation in agricultural fields to enhance crop productivity.

Keywords: Wastewater recycling; Soil and plant nutrients; Irrigation; Plant biomass yield; Metal contamination

1. Introduction

Wastewater irrigation has an extensive history that extents back to centuries ago (Keraita et al., 2008). Even the prehistoric civilizations practiced wastewater irrigation for crop production (e.g., the ancient Egyptians, the Mesopotamians, the Minoans, and Indus valley societies). According to extensive historical evidence, ancient Minoans likely used wastewater irrigation for agriculture from 3500 BC (Tzanakakis et al., 2007). Today freshwater shortage is a growing problem worldwide, and water resources are becoming insufficient to meet the global irrigation demand. In most cases, it is a regional problem linked to climate and occurs in various regions of the world, such as North Africa, the Middle East, southern Europe, Australia, southern USA, and the semi-arid region of Brazil (Norton-Brandão et al., 2013). Currently, about 70% of water consumption is committed to agricultural irrigation, and the growing use of bioenergy tends to aggravate water scarcity (Melo et al., 2010; Tsoutsos et al., 2013). In this context, the reuse of domestic and industrial effluents, as well as brackish and salty water, becomes a matter of high priority and attraction (Bixio and Wintgens, 2006; Porte et al., 2010; Chevremont et al., 2012). In recent years, wastewater reuse has experienced very rapid growth. Volumes of wastewater reuse have increased ~10–29% per year in Europe, the United States and China, and by up to 41% in Australia (Aziz and Farissi, 2014).

Most industries are unable to treat their waste waters adequately due to the high cost of chemicals conventionally. Wastewaters from different sources contain considerable amount of organic matter and plant nutrients (N, P, K, Ca, S, Cu, Mn and Zn), and have been reported to increase crop yields (Pathak et al., 1998; Pathak et al., 1999; Lubello et al., 2004). Wastewaters generated by industries are also one of the major sources of pollution (Huma, 2013). Use for irrigation purposes has emerged in the recent past as an important way of utilizing wastewaters, taking the advantage of the presence of considerable quantities of N, P, K and Ca along with other essential nutrients (Niroula, 2003). But there can be both beneficial and damaging effects of wastewater irrigation on crops including vegetables (Ramana et al., 2002).

The use of wastewaters would be of significant benefits to the agricultural industry, as it could be a cost-effective method for wastewater recycling as well as providing an important nutrient source. On the other hand, wastewater containing different toxic chemicals can be a cause of contaminating the water and soil. Water resources are most often affected by industrial pollution. Pollution caused by industrial and dairy effluents is a serious concern throughout the world (Dhanam, 2009). The elevated concentrations of heavy metals (in particular extractable Cu) and nutrients (especially N) present in spent litter were the main factors responsible for the toxicity to plants (Tam and Tiquia, 1994). For example, winery wastewater contains a significant amount of Na and K with a K:Na ratio of 3:1, and K concentrations up to 1000 mg L^{-1}. N and P contents in winery wastewater are usually low compared with other agricultural effluents, ranging from 8 to 35 mgL^{-1} and 2 to 20 mgL^{-1}, respectively (Bories et al., 2005). Dairy effluent has high organic loads as milk is its basic constituent with high levels of chemical oxygen demand, biological oxygen demand, oil and grease, and N and P contents (Brião and Tavares, 2007). To recycle nutrients through land application of dairy waste effluent requires the use of crops capable of utilising these nutrients (Macoon et al., 2002). Industrial effluents rich in organic matter and plant nutrients are finding agricultural use as cheaper way of their disposal (Nagda et al., 2006). Depending on the physiochemical properties of wastewaters, different chemical, physical and biological treatments can be applied to solve the problems associated with their toxic effects. From the available literature (Mosse et al., 2010; Kaur and Sharma, 2017), it was found that dilution of wastewater can be an effective tool to avoid the negative effect associated with wastewater irrigation. Therefore, it is important to measure the effective concentrations of wastewater as the safe limit for plant growth.

The influence of wastewater on soil-plant environment may therefore be both positive, due to the nutrient loading, and negative, due to the presence of toxic compounds, pH or Electrical conductivity (EC). With this in mind, the aims of the present study are: 1) to evaluate the impact of these wastewaters on the dry shoot and root weight, N, C, nutrient (P, K, S, Na, Ca, Mg, Al) and metal (Mn, Fe, Zn, Co, Cu, Cd, Cr, Ni, Pb and As) contents of sunflower (sunflower is also considered as a phytoremediation plant showing tolerance to irrigation with saline waters containing different cations and anions (Conceicao Silva et al., 2013)) and maize; 2) to recognise the impact that wastewaters (winery, abattoir, dairy and municipal) at different concentrations (0, 0.5, 5, 25, 50, 75 and 100%) may exert on the properties of soil, with particular regards to pH and EC; 3) to find irrigateable concentration of wastewaters for optimum production of the above crops.

2. Materials and methods

2.1 Sources and collection of wastewaters

All the wastewater samples were collected from different parts of South Australia (SA), Australia. The winery wastewater (W) was collected from Yalumba Winery, Angaston, SA. The dairy wastewater (D) was collected from Myponga dairy farm in SA. The Abattoir wastewater (A) was collected from the Primo Port Wakefield Abattoir in Port Wakefield, SA. The treated municipal wastewater (M), which was DAFF (dissolved air filtration flotation) treated, was collected from the Bolivar wastewater treatment plant, SA.

2. 2. Characterisation of wastewaters

Wastewaters were analysed for their different physiochemical characteristics as described below. Moreover, the physicochemical parameters of a tap water (TW) sample were also analysed since it was used as the control treatment. The pH, EC (electrical conductivity), DO (dissolved oxygen), TDS (total dissolved solid), SAL (salinity), TURB (turbidity) and ORP (oxidation reduction potential) of winery, abattoir, dairy, municipal wastewaters and tap water (as a control) were measured by an Aquaread™ multi-parameter water quality meter (Kiddee et al., 2013). The metre was calibrated in the laboratory before use in the field. To measure total organic carbon (TOC), samples were passed through 0.45 μm membrane filters, and analysed using a TOC analyser (Shimadzu TOC-LCSH) (Choi et al., 2009). Total metal contents were analysed using inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500c). In the American Society for Testing and Materials (ASTM) Standards (D1971-11) 'Standard practices for digestion of water samples for determination of metals by Flame Atomic Absorption Spectrometry (FAAS), Electrothermal Atomic Absorption (ETAAS), Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS)' for waste water samples, it is advised to put 100 volume of sample: 5 volume HCl: 1 volume HNO_3 together in microwave digestion vessels for 30 min at 121ºC and 15 psig.

2.3. Pot experiments

Effects of different concentrations of wastewaters on the plant growth were assessed by a glasshouse study. Different concentrations of wastewater diluted with tap water were used for irrigation throughout the crop growth period. Different treatments applied were: W100, A100, D100, M100 (100% wastewater only), W75, A75, D75, M75 (75% wastewater + 25% tap water), W50, A50, D50, M50 (50% wastewater + 50% tap water), W25, A25, D25, M25 (25% wastewater + 75% tap water), W5, A5, D5, M5 (5% wastewater + 95% tap water), W0.5, A0.5, D0.5, M0.5 (0.5% wastewater + 99.5% tap water), and W0, A0, D0, M0 (100% tap water only). Soil for planting sunflower and maize was collected from Kapunda, SA. The soil was characterised as a sandy clay loam soil with pH value of 6.12. The soil had an EC value of 111.7 µs cm^{-1} with cation exchange capacity (CEC) of 9.50 cmol (p^+) kg^{-1}, P content of 28.7 mg kg^{-1}, and K content of 212 mg kg^{-1}.

Seeds of maize and sunflower were sown into separate plastic pots containing 300g of soil, and watered every day (90 ml/day). The volume of the pot was 500 ml. The pots were arranged in a randomised complete block design. A total of 50 pots of each crops were established. Three replicate pots were watered with each concentration of wastewaters (0, 0.05, 5, 25, 50, 75 and 100%) to field capacity of the soil. Plants were grown in a glasshouse (University of South Australia, Mawson Lakes campus), where the temperature range was maintained between 20 and 25ºC. After 10 days, the seedlings were thinned to 6 plants per pot, and seedlings were irrigated with different concentrations of the wastewaters every day subsequently for another 35 days. Control plants were irrigated with tap water every day. Plants were destructively harvested 45 days after sowing. At the time of harvesting, plants were removed from the pots, and the soil was gently washed away from the roots and rinsed with deionised water. The roots and shoots were separated, and dry weights were determined. Plant samples were then taken and analysed for different parameters. The effect of different dilutions of effluents on dry shoot and root yields, nutrient contents of plants, pH, EC and N, P, K contents of post-harvest soil were measured. The root and shoot parts of each plant was separately weighted, and the root-shoot ratio was recorded (dry weight for roots/dry weight for shoot of plant). The root:shoot ratio can be used to assess the overall health of the plants.

2.4. Characterisation of plant and soil

The plant samples were dried to a constant weight at 60℃ by using a forced-air oven, and ground to a fine powder for metal analysis. The ground plant material (0.4 g) was weighed directly into a 75 ml digestion tube, 5 ml of concentrated nitric acid was added and left to cold digest in a fume cupboard overnight (Zarcinas et al., 1987). The tubes were heated using a temperature controlled digestion block (AI Scientific Block Digestion System, AIM 500, Australia) programmed to slowly increase the temperature to 140℃ until approxi mately 1 ml of digest remained in the tube. The digests were diluted with MQ-water and analysed for elemental contents using ICP-MS. N concentration of the plant samples were determined by combustion of 0.25 g of oven dried and ground samples at 1100℃ in a Leco TruMac CNS analyser (USCC, 2002).

After plant harvesting, soil samples were air dried, crushed to pass a 2-mm screen. Soil samples were analysed for texture, pH, EC and CEC values. Three soil sub-samples were taken from each pot to analyse the soil characteristics. Soil pH and EC were determined using end-over-end equilibration of soil with water at a ratio of 1:5 for an hour and measuring the suspension on a pH/conductivity meter (smartCHEM-LAB, TPS, Australia). N content of the soil samples were determined by combustion of oven dried and ground samples at 1100℃ in a Leco TruMac CNS analyser (USCC, 2002). For total P and K analysis, air-dried soil (0.5 g, <2 mm) was weighed directly into a Teflon digestion vessel, and 5 ml of aqua regia was added. The soil suspension was digested in a micro-wave digestion oven (MARS5, CEM, USA) in accordance with the Method 3051H (USEPA, 1997). Each microwave digestion batch included a standard reference material (Montana Soil SRM2711, certified by the National Institute of Standards and Technology, USA), and a blank to validate the digestion operation. The concentrations of P and K in the digest were measured using ICP-MS.

2.4. Statistical analysis

All data presented are expressed as the mean ± standard deviation (SD). Statistical analysis was performed using the SPSS statistical packages version 17.0. Comparisons of effects between different concentrations of wastewaters were made by one-way analysis of variance (ANOVA).

3. Results and discussion

3.1. Physiochemical studies of wastewaters and fresh water

Qualities of water containing industrial effluents and the tap water (which was used as control) were assessed with respect to various physicochemical properties (Table 1). Physicochemical analysis of all wastewater samples indicated a high conductivity, which is a clear reflection of the presence of large quantity of metals and salts. Dairy farm wastewater was highly turbid containing huge amounts of total solids. DO was very low in all wastewaters, which confirmed their highly polluted and deteriorating conditions. In case of winery wastewater, the pH value was lower than the usual range (6.50-8.50) for irrigation water recommended by FAO. On the other hand, the values of EC and TDS of dairy wastewaters exceeded than the usual range for irrigation water values recommended by FAO (Table 1). On average, the pH value of wastewaters ranged between 4.73 (winery) to 7.59 (abattoir) (Table 1). The wastewaters contained considerable amount of N and P, which are considered essential nutrients for improving plant growth. On the other hand, the concentrations of metals in the wastewaters were relatively low to meet the standards for wastewater reuse in irrigation. Given the fact that these metals could be accumulated in soils and plants with continuous use of wastewaters in irrigation, their periodic monitoring should be an important component of wastewater management. Certain physical and chemical properties of water up to an adequate level are good for plant and animal health, but become toxic at excessive level (Nawaz et al., 2006).

3.2 Effect of wastewater concentration on dry shoot and root yields of sunflower and maize

The effect of different concentrations of wastewater irrigation on dry root and shoot weights are shown in Table 2. It was observed that higher concentration (100%) of wastewater inhibited the seedling growth of sunflower and maize. In contrast, the lower concentration stimulated growth of both the crops. The effect of wastewater at a higher concentration on seedling growth was inhibitory in all cases except the abattoir wastewater.

The dry weight was found to be reduced significantly ($p<0.05$) with increase in concentration of combined effluents except abattoir wastewater. For winery wastewater, the dry shoot weight (DSW) and dry root weight (DRW) of sunflower and maize were very small at 100% effluent concentration (3.30 and 10.5 g/pot), which were 90% and 82% less than A100 for sunflower and maize, respectively. The maximum DSW was found from 25% concentration (W25) treatment, which was 16.8 g/pot. For abattoir wastewater, A100 gave the best result for DSW for both sunflower and maize. This may be due to the presence of not only the readily available N, P and K, but also organic matter that improves the soil properties related to availability of nutrients and water. In case of dairy wastewater, D25 provided the best dry weight result for sunflower, which was around 41% higher than D100 treatment. D50 gave the best results for maize, which was 44% higher than D100 treatment. D100 did not give the best result, and this might be due to the presence of elevated amounts of total dissolved solids. These solids may inhibit the uptake of necessary elements like P, Mg etc. by plants (Thabaraj et al., 1964). The best effects of wastewater on early growth of maize was found in M50, and of sunflower was found in M75 treatment. But comparative to all wastewaters with all dilutions, A100 treatment provided the highest shoot (sunflower: 34.9 g/pot; maize: 58.1 g/pot) and root (sunflower: 19.9 g/pot; maize: 33.7 g/pot) weights. Effects of 10% concentration of different wastewaters are shown in Table 4.

Nighat et al. (1991) reported that the healthy growth of mustard plants were obtained following treating the soils with various diluted effluents. For example, overall growth of plants was maximum in wheat seedlings irrigated with dairy effluent of 50% concentration after a month of sowing. Kaur and Sharma (2017) reported that dairy industry effluents led to healthy growth of wheat at 50% of dilution and thus, the effluents had potential to be utilised as liquid fertilisers at dilution of 50%. Both added wastewaters and nutrients that are provided with their applications can be attributed to such increase in plant biomass production (Mohammad and Ayadi, 2004). Similar results were reported by Day et al. (1979) who observed that wheat irrigated with wastewater produced higher yield than wheat grown with pump water alone. They attributed this increase to the N and P in the added wastewater. Increased yield of sunflower by the wastewater application in the current study could be attributed to the presence of the readily available adequate amounts of N, P and K (Khan et al., 2009).

3.3 Nutrient contents of sunflower and maize plants

3.3.1 Total N, P and K contents

N, P and K concentrations of sunflower and maize plants were different in all treatments (Figure 1). The N concentration of sunflower treated with 50% of concentration of abattoir wastewater was the highest, and in control was the lowest. In case of maize, N concentration increased from control to 100 % concentration for most of the wastewaters. The N concentration of maize treated with 100% of concentration of dairy wastewater was the highest, and in control was the lowest. This might be due to the higher concentration of N in dairy wastewater than other wastewaters. The results are in agreement to the findings that the effluents of sugar mill wastewater diluted to a particular dilution improved the plant growth of green grams (Nath et al., 2007). Singh et al. (2006) also reported the same during assessing the effects of fertiliser factory effluents on the growth of gram plants. Enhancement of plant N content with wastewater application indicated that wastewater application provided the soil with these nutrients, which enhanced the availability of the nutrient required for plant growth and soil fertility. N concentration in plant shoots was reported to be higher when grown with wastewater (Day et al., 1979), and was found that N recovery in plants with wastewater was higher than the N recovery in plant material grown with well water. These results were attributed to significant increase in soil N with wastewater irrigation compared with the control.

P concentration in sunflower increased significantly as concentrations of wastewater irrigation increased for abattoir wastewater, and was the highest in 100% concentration of abattoir wastewater. And P concentration in maize was the highest in 75% concentration of abattoir wastewater. The efficacy of P uptake by plants could be controlled predominantly by the concentration of HPO_4^{2-} and H_2PO4^-, and K in the soil solution, which could in turn be affected by the addition of wastewater to soils.

K concentration in sunflower was the highest in 75% concentration of dairy wastewater. And for maize, the highest plant K concentration was observed in 75% concentration of winery wastewater. This might be due to the higher K content in winery wastewater than other wastewaters. Since K concentrations in wastewater have been reported to be an environmental issue due to its potential negative effect on soil structure (Arienzo et al., 2009a), this high uptake can be a useful feature of these plants in preventing soil aggregate dispersion. Other researchers also reported an increase in P and K uptake by the plants irrigated with treated wastewaters (Papadopoulos and Stylianou, 1988; Mohammad and Mazahreh, 2003).

It is probably the organic constituents in the wastewater that accounted for the increased levels of N, P and K compared to the control treatment (Arienzo et al., 2009b).

In this study, sunflower and maize plants were yellowing from the apical to the medium part of the older leaves, characterising N deficiency symptoms when irrigated with municipal wastewater and tap water. This might be due to the low N content present in these water samples. Similar result was found by (da Fonseca et al., 2005) during irrigating maize crop with treated sewage effluents.

3.3.2 Other macro and micronutrient (Na, Ca, Mg, Al and S) contents

Wastewater irrigation significantly increased Na, Ca, Mg, Al and S contents in the soil (Figure 2). Plants had high Na, Ca, Mg, and K contents (Khan et al., 2009) after irrigating with wastewater. Earlier studies also reported an increase in these nutrient uptake by plants with an increased concentration of the elements in leaves of plants irrigated with sewage water than that irrigated with ground water (Brar et al., 2002; Mohammad and Mazahreh, 2003). The relatively higher micronutrient contents in the control plants in the current study could be explained by the "concentration/dilution effect" induced with relatively lower biomass. Such phenomenon was observed in earlier research also (Rusan et al., 2007). High sodicity levels in soils are known to result in inhibited plant growth (Bernstein, 1975), and this is likely to be consistent with the increased Na levels observed in sunflower and maize plants tested here. However, the highest Na concentrations in sunflower and maize shoots was determined to be approximately 10 and 30 mg/g (100% DWW). Sodicity impacts on plant growth are complex, and elevated soil Na levels can limit plant growth by affecting soil structure and plant water and oxygen uptake (Sparks, 2003). Although the concentrations of inorganic elements observed are unlikely to be causes of immediate plant toxicity, the long term effects of DWW application on Na accumulation in soils, and the resultant impacts on soil health and potential groundwater quality are important areas to consider in future research. Longer term studies are required to identify and quantify any such changes.

3.3.3 Metal contents (Mn, Fe, Zn, Co, Cu, Cd, Cr, Ni, Pb and As) in plants

Metal accumulation in plants depends upon availability and species of metals, solubility, their translocation potential and the type of plant species (Sinha et al., 2006). The accumulation of metals in plants showed heterogeneous trend and varied with respect to metal as well as species of plants. Metal contents of sunflower and maize as affected by different concentrations of wastewaters are shown in Table 3a and 3b. The concentrations of Zn, Cu and Pb in sunflower were the highest in 75% concentration of dairy wastewater. The results indicated that Mn, Zn, Cu, Cd, Pb and As concentrations were the highest in maize grown in the soil receiving dairy wastewater of 100% concentration. The highest concentration of Fe and Co were in maize plant irrigated with 75% dilution of dairy wastewater, and those values were 274 and 0.33 mg Kg^{-1}, respectively. Out of all the metals studied, the maximum accumulation of Fe and minimum accumulation of As were recorded in all the plants. Excessive contents of heavy metals in the crops irrigated with different dilutions of wastewaters were not observed in the current experiment, and was not reported in earlier literature (Al-Jaloud et al., 1995). Barman et al. (2000) studied the accumulation of metals in the economically important crops and vegetables irrigated with tannery wastewater. They reported that the accumulation of metals from soil to plant parts did not follow any particular pattern and varied with respect to metals, their species and plant parts.

3.4 Effect of wastewater concentration on post-harvest soil properties

3. 4. 1. pH and electrical conductivity (EC)

Soil pH and EC as affected by wastewater applications of different concentrations are shown in Figure 3. The treatment effects on soil pH were not consistent. The pH values of the soil after the crop harvest ranged from 6.2 to 8.1. The lowest value of soil pH was observed in 5% concentration of municipal wastewater treatment for maize. The inconsistency in wastewater irrigation effect on soil pH was reported earlier also. For example, Schipper et al. (1996) found that soil pH increased following long term wastewater irrigation, and they attributed this increase to the chemistry and high content of basic cations such as Na, Ca and Mg in the wastewater applied for a long period. Other researchers found that soil pH decreased with wastewater irrigation due to the oxidation of organic compounds and nitrification of ammonium (Hayes et al., 1990; Vazquez-Montiel et al., 1996; Mohammad and Mazahreh, 2003).

Soil salinity, measured as EC, was significantly higher with wastewater irrigation (ranged 195 to 1682 µs cm^{-1}) than tap water irrigation (Figure 3). Dairy wastewater irrigated soil showed higher EC values compared to other wastewaters. Mohammad and Mazahreh (2003) reported that the increase in EC for soil irrigated with wastewater compared with that irrigated with potable water could be attributed to the original high level of TDS of the wastewater.

3.4.2 N, P, K contents of soil

Soil N, P and K concentrations affected by different concentrations of wastewaters are shown in Figure 4. Higher N concentrations were observed in 100% dairy wastewater for sunflower and maize. This might be due to a higher content of N in dairy wastewater than other wastewaters. Soil P concentration was higher in abattoir wastewater irrigated soil than other treatments. The highest soil P was found in 100% concentration of abattoir wastewater for sunflower, and at 75% concentration of the wastewater for maize. Soil K concentration was also affected by the concentration of wastewaters. The highest K concentration was found in 75% dilution of abattoir wastewater for sunflower, and at 100% concentration of dairy wastewater for maize.

Several researchers reported accumulation of N, P and K in the soil with wastewater application, which was attributed to the original contents of these nutrients in the wastewater applied (Monnett et al., 1996). Wastewater could provide N, P and K in amounts equal to 4, 10 and 8 times of the fertiliser requirements of forage crops (Burns et al., 1985). Results of the current study also agree with those reported by (Day et al., 1974; Mohammad and Mazahreh, 2003) who found that P was higher in soils irrigated with wastewater than in soil irrigated with fresh water or rainfall water.

For municipal wastewater, N, P and K concentrations of soil was lower than other wastewaters for both the crops. This was due to the utilisation of treated Class A type municipal wastewater which contains less amount of all nutrients.

4. Conclusions

This study demonstrated that soil and crop parameters were significantly affected by different concentrations of wastewater irrigation. The nutrient contents of sunflower and maize plants were also affected by the application of wastewaters. The presence of macronutrients and micronutrients in wastewaters helped to boost up the growth of sunflower and maize. The growth parameters (dry biomass weight) showed that the abattoir and dairy wastewaters led to a healthy growth at 100% concentration and 25% of concentration for sunflower, and 100% concentration and 50% concentration for maize, and the biomass yield was higher in wastewater than control. These wastewaters had the potential to be utilised as liquid fertilisers at 100% concentration and 25% concentration for sunflower, and 100% concentration and 50% concentration for maize. For the winery wastewater, 25% of concentration was good for early growth of sunflower and maize. Sunflower and maize were very sensitive to winery wastewater application with a sharp decrease in dry shoot and root biomasses between 0% and 100% winery wastewater treatments. The municipal wastewater did not show any significant difference in dry weight of sunflower and maize at different concentrations. It could be commended from the present study that abattoir wastewater as such, and appropriate dilutions of wastewaters from winery and dairy industries, could be used for irrigation in agricultural fields to enhance the productivity of different crops. Field experimentation is needed in future that considers various soil types and agro-climatic conditions in order to study the influence of wastewater irrigation on probable soil-plant interactions.

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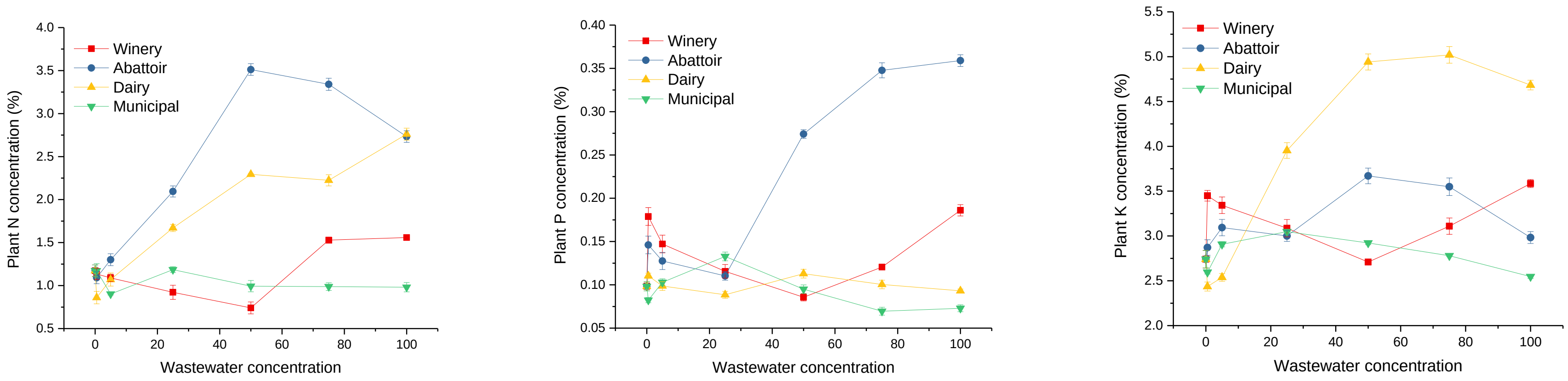
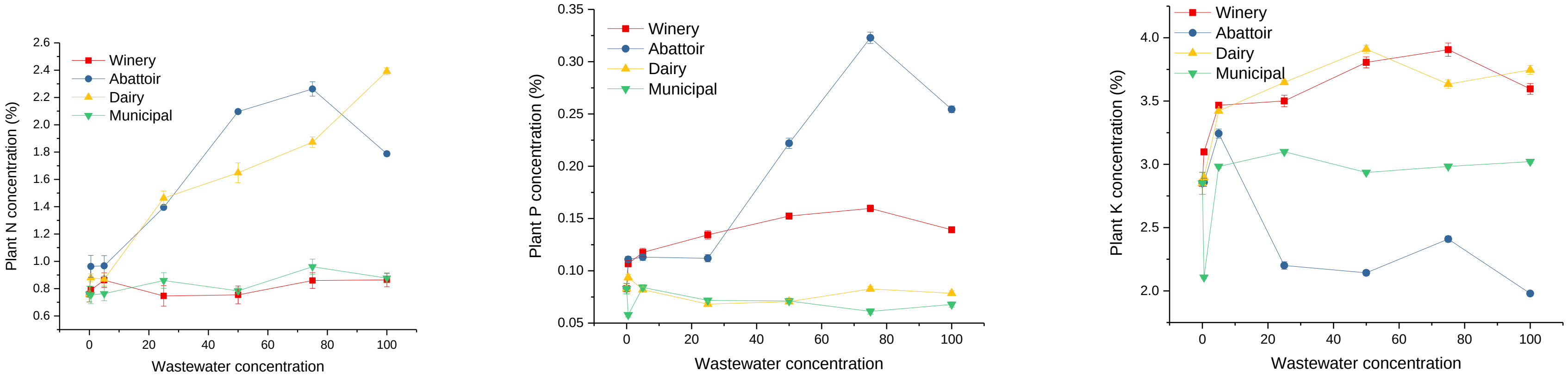
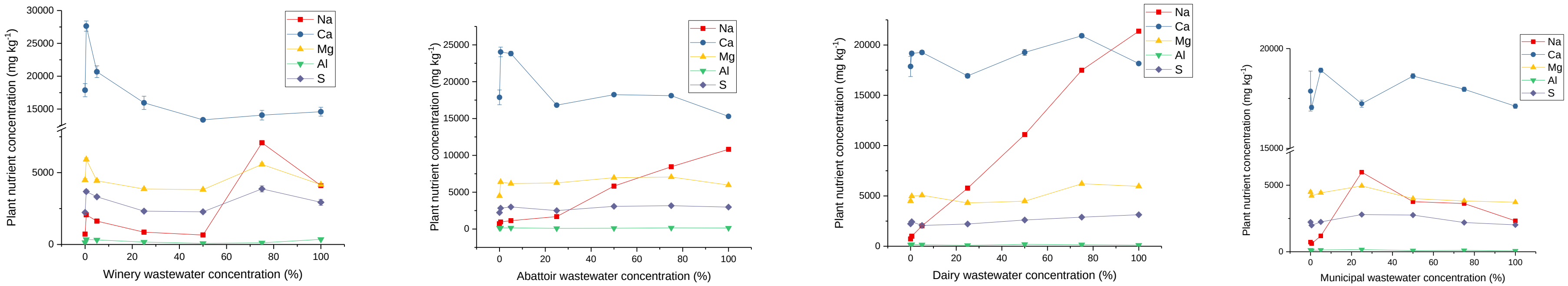


a) Sunflower

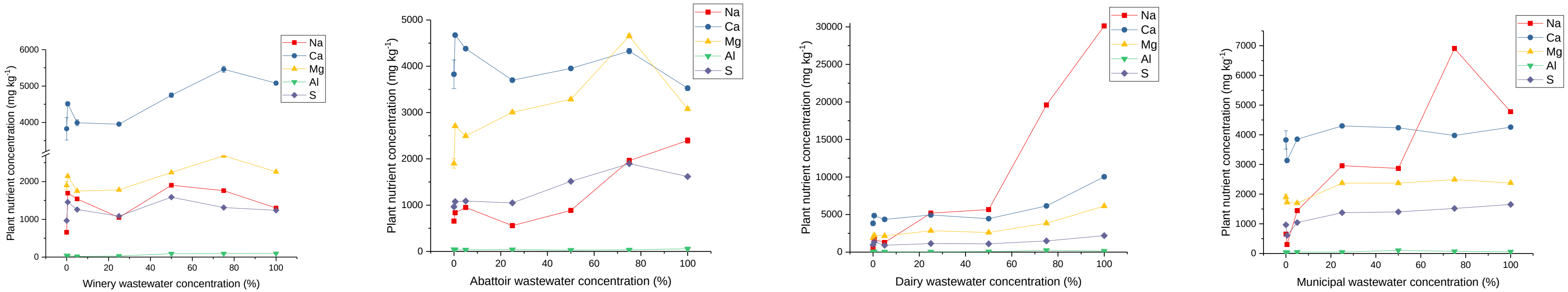


b) Maize

Fig. 1. Nitrogen, phosphorus and potassium concentrations in (a) sunflower and (b) maize plants following irrigation with different wastewater sources

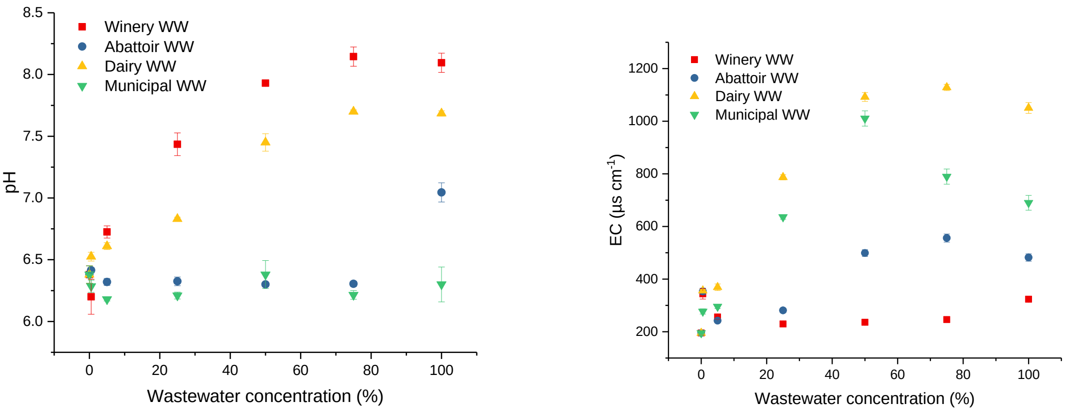


a) Sunflower

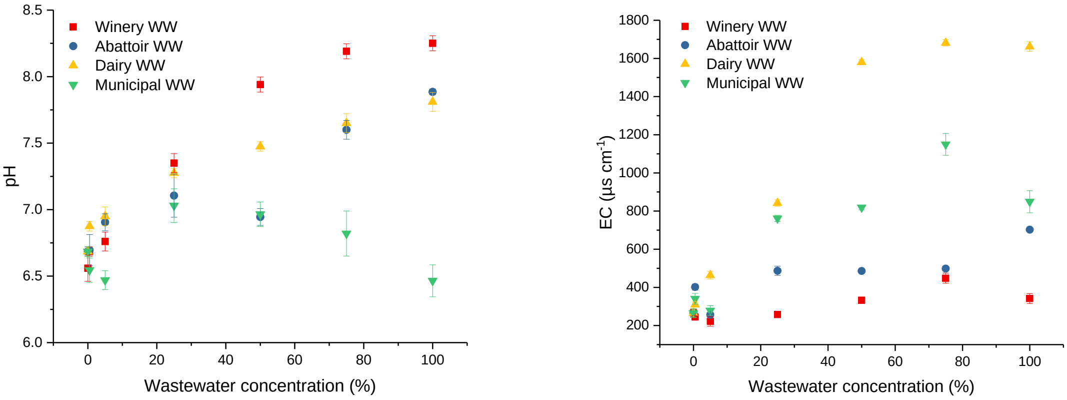


b) Maize

Fig. 2. Na, Ca, Mg, Al, S concentrations as affected by different concentrations of wastewaters

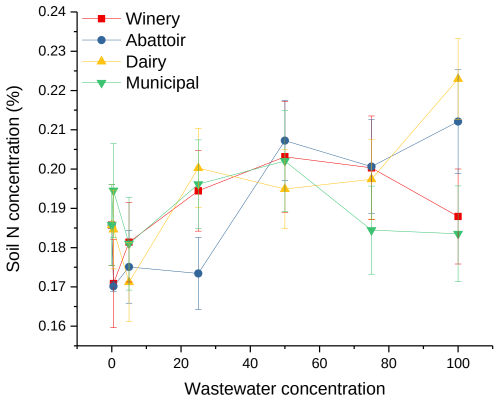


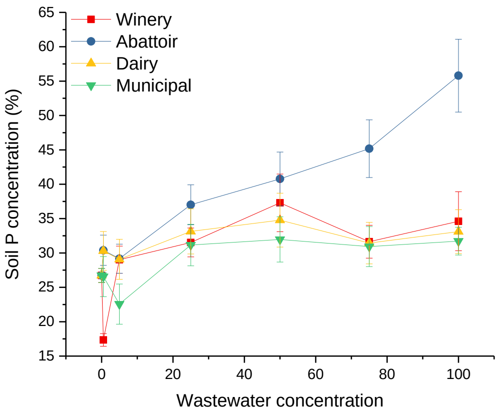
a) Sunflower

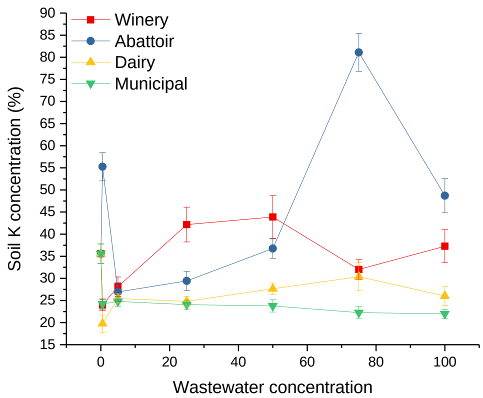


b) Maize

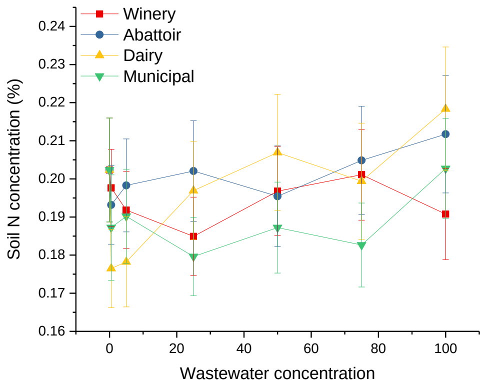
Fig. 3. Soil pH and EC as affected by different concentrations of wastewaters applied for short period (35 days)

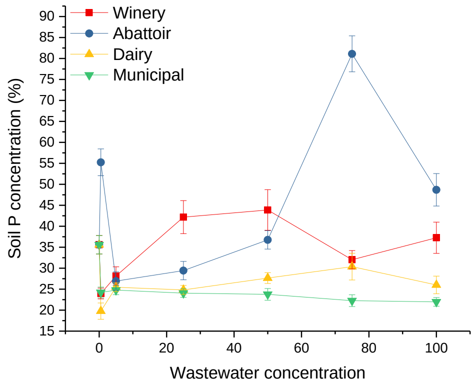

Winery
Abattoir
Dairy
Municipal
Soil N concentration (%)
Wastewater concentration

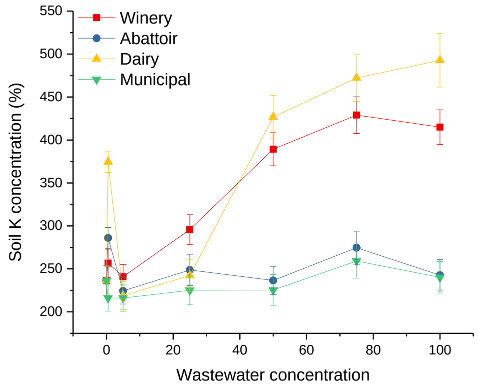

Winery
Abattoir
Dairy
Municipal
Soil P concentration (%)
Wastewater concentration


Winery
Abattoir
Dairy
Municipal
Soil K concentration (%)
Wastewater concentration

a) Sunflower







b) Maize

Fig. 4. Soil N, P and K concentrations as affected by different concentrations of wastewaters applied for short period (35 days)

Table 1. Physio-chemical characteristics of winery (W), abattoir (A), dairy (D), municipal (M) wastewaters, and tap water (TW).

Parameters	WWW	AWW	DWW	MWW	TW	Standard value[b]
pH	4.73±0.04	7.59±0.04	6.93±0.04	6.44±0.27	6.06±0.04	-
EC (dS m^{-1})	1.75±0.01	2.69±0.02	6.84±0.00	1.61±0.02	0.66±0.01	1.3-2.9
DO (%)	2.00±0.26	0.40±0.10	0	52.9±2.21	16.1±0.49	-
TDS (mg L^{-1})	1135±5.031	1750±8.892	7916±3.792	944.0±9.071	429.0±0.581	-
TS (mg L^{-1})	2873±237.1	1877±287.1	9280±475.1	980.0±26.46	436.7±20.80	-
SAL (ppt)	0.87±0.01	1.34±0.01	5.30±0.01	0.80±0.01	0.37±0.06	-
TURB (NTU)	251±1.01	185±1.01	280±26.6	0	0	-
ORP (mV)	-119.6±2.951	-279.3±2.531	-321.2±5.272	96.90±11.73	215.7±1.621	-
COD (mg L^{-1})	320±7.16	365±20.1	370.33±4.58	91±6.94	3.09±0.01	-
BOD_5 (mg L^{-1})	122±10.2	125±12.1	120.5 ± 1.87	35±3.20	2.39±0.29	-
TKN (mg L^{-1})	3.20±.71	180±15.2	280.34±21.2	5.3±0.97	0.18±0.00	-
TN (mg L^{-1})	7.80±0.15	359±9.69	422±4.20	9.72±1.00	0.34±0.06	25-125
TC (mg L^{-1})	1785±2.52	223.4±0.57	571.6±4.91	38.33±0.10	21.70±0.29	-
TOC (mg L^{-1})	1793±4.16	1.21±1.68	120.9±8.85	8.80±0.12	3.23±0.13	-
IC (mg L^{-1})	10.05±2.02	222.2±2.15	450.7±4.30	29.53±0.22	18.47±0.36	-
Op(atmospheres)[a]	0.628±0.002	0.967±0.006	2.463±0.043	0.578±0.006	0.238±0.001	-
Chloride (mg L^{-1})	66.85±4.291	232.6±29.10	5870±231.3	367.7±10.21	73.27±9.093	-
P (mg L^{-1})	28.2±1.41	52.9±1.27	27.8±1.82	0.07±0.00	0	0.8-12
K (mg L^{-1})	271±7.12	67.2±0.54	112± 0.60	44.2 ± 0.24	7.21±0.20	-
Na (mg L^{-1})	60.1±1.53	112±0.95	137± 0.50	244±2.08	65.8±1.66	-
Ca (mg L^{-1})	123±3.67	48.7±1.45	235± 8.41	45.1±1.69	26.8±0.13	-
Mg(mg L^{-1})	17.8±0.36	17.9±0.16	144± 5.45	30.0±1.01	14.8± 0.09	-
S (mg L^{-1})	13.8±4.72	8.75±0.34	13.8±2.32	72.0±8.02	17.4±0.32	-
Al(µg L^{-1})	364±22.7	4.37± 0.47	20.37±3.56	0.97±0.42	13.7±0.74	20
Mn (µg L^{-1})	138±10.5	260±10.21	182±12.1	20.9±1.32	1.03±0.12	10000
Fe (µg L^{-1})	258±16.5	275±9.64	597±37.7	74.3±7.23	54.7±1.53	10000
Zn (µg L^{-1})	2.09±0.02	4.77±0.55	21.9±4.78	49.7±2.84	111±7.65	5000
Co(µg L^{-1})	0.64±0.02	2.52±0.10	11.2±1.37	1.20±0.08	0.13±0.01	100
Cu(µg L^{-1})	0.27±0.12	5.21±0.32	4.99±1.86	12.1±0.38	99.6±10.9	5000

Cd(µg L^{-1})	0.20±0.05	0.24±0.05	0.43±0.05	0.32±0.02	0.01±0.00	50
Cr(µg L^{-1})	11.6±1.25	5.44±0.23	5.48±0.12	2.08±0.12	0.92±0.07	1000
Ni(µg L^{-1})	6.32±0.47	1.76±0.17	2.25±0.30	11.8±0.61	5.07±0.96	2000
Pb(µg L^{-1})	0.01±0.00	5.37±0.24	0.16±0.04	2.76±0.17	0.89±0.13	5000
As(µg L^{-1})	4.54±0.83	3.77±0.23	10.9±0.73	2.54±0.12	1.17±0.25	2000

Note: ± Standard deviation

All values are the mean of three replicates

[a]Op = E.Ce. x 10^3 x 0.36 (USDA, Agric. Hand Book, No. 60) (Ramana et al., 2002)

[b]Standard value = Standard value for short term use (Anzecc, 2000)

Table 2. Dry shoot and root yields of sunflower and maize following irrigation with different concentrations of winery, abattoir, dairy and municipal wastewaters

Wastewater concentration	Sunflower			Maize		
	DSW (g/pot)	DRW(g/pot)	Root: Shoot	DSW (g/pot)	DRW(g/pot)	Root: Shoot
WW0/TW	7.20±0.30	5.64±0.21	0.85	12.2±0.25	7.04±1.93	0.58
W0.5	6.20±0.20	4.86±0.20	0.86	12.0±0.40	6.94±1.07	0.72
W5	6.60±0.15	5.06±0.63	0.84	12.7±0.25	7.73±0.51	0.70
W25	16.8±0.30	5.26±0.90	0.34	24.8±0.30	8.32±0.67	0.35
W50	5.40±0.20	4.62±0.03	0.95	16.5±0.20	5.42±0.82	0.74
W75	5.70±0.20	4.72±0.25	0.92	10.8±0.20	6.94±1.07	0.73
W100	3.30±0.10	3.19±0.29	1.20	10.5±0.20	6.04±0.52	0.76
A0.5	8.00±0.30	6.51±1.71	0.81	11.9±0.40	9.20±0.99	0.98
A5	9.10±0.31	7.06±0.93	0.78	17.0±0.31	11.7±0.92	1.01
A25	16.8±0.32	13.2±0.95	0.64	24.8±0.31	14.7±1.63	0.99
A50	18.2±0.23	11.5±1.25	0.63	40.3±0.32	19.2±1.20	1.00
A75	22.5±0.21	13.7±1.43	0.61	54.0±0.32	25.7±2.33	1.00
A100	34.9±0.24	19.9±0.16	0.57	58.1±0.33	33.7±2.33	1.00
D0.5	7.70±0.22	7.60±0.14	0.99	13.1±0.25	10.3±0.21	1.01
D5	10.8±0.15	7.76±1.50	0.72	15.2±0.31	11.9±0.49	1.01
D25	14.1±0.21	9.46±1.19	0.67	18.1±0.20	13.7±1.98	1.01
D50	13.5±0.21	9.16±2.17	0.68	21.6±0.30	19.0±0.57	1.00
D75	12.3±0.23	8.45±0.91	0.69	15.5±0.25	12.9±0.49	0.99
D100	8.30±0.31	6.25±1.77	0.75	12.2±0.30	9.85±0.92	1.01
M0.5	7.10±0.25	5.78±1.44	0.82	12.3±0.20	8.80±0.99	1.00
M5	7.40±0.33	6.12±0.82	0.83	12.6±0.20	9.00±0.85	0.99
M25	7.30±0.13	5.93±1.80	0.81	13.3±0.32	9.65±0.49	0.99
M50	7.40±0.21	6.16±0.62	0.83	14.9±0.41	11.2±0.42	0.99
M75	8.30±0.31	6.38±0.54	0.77	13.9±0.25	10.3±0.49	0.99
M100	6.40±0.12	5.08±0.60	0.87	14.7±0.20	11.3±0.85	1.01

Table 3a. Metal intake of sunflower from different concentrations of winery, abattoir, dairy and municipal wastewaters

Sunflower	Metal content (mg Kg^{-1})→									
Concentration↓	Mn	Fe	Zn	Co	Cu	Cd	Cr	Ni	Pb	As
WW0	60.3±2.39	140±12.9	19.7±2.19	0.18±0.01	10.2±1.39	0.22±0.01	0.62±0.01	1.29±0.43	0.52±0.09	0.05±0.02
W0.5	68.6±3.28	241±10.3	26.6±2.19	0.25±0.02	17.7±1.28	0.20±0.09	0.76±0.09	1.77±0.10	1.22±0.29	0.09±0.02
W5	51.4±5.40	233±8.73	21.3±4.30	0.19±0.08	13.9±2.19	0.20±0.09	0.71±0.19	1.57±0.26	1.07±0.18	0.07±0.02
W25	34.2±3.20	139±20.1	21.0±2.11	0.12±0.02	16.3±2.19	0.14±0.02	0.56±0.09	1.13±0.37	1.14±0.48	0.04±0.02
W50	49.7±2.38	99.1±7.64	16.8±1.47	0.24±0.02	11.5±1.70	0.14±0.02	0.50±0.10	0.92±0.18	0.78±0.11	0.03±0.02
W75	55.4±2.19	154±13.2	22.2±2.19	0.82±0.19	16.3±2.17	0.14±0.02	0.82±0.19	1.38±0.22	1.34±0.13	0.09±0.03
W100	46.1±5.84	324±20.2	23.0±2.10	0.47±0.19	16.7±2.19	0.12±0.02	0.79±0.19	1.69±0.28	1.59±0.92	0.12±0.02
A0.5	108±11.0	132±10.3	22.1±1.93	0.20±0.02	10.8±1.30	0.22±0.03	0.62±0.10	1.46±0.20	0.90±0.09	0.06±0.02
A5	87.1±6.30	136±10.3	22.4±2.11	0.20±0.02	12.6±1.21	0.22±0.02	0.87±0.19	1.19±0.30	0.85±0.20	0.05±0.02
A25	56.9±3.20	99.1±10.9	16.5±1.30	0.15±0.02	10.5±1.03	0.20±0.02	0.81±0.19	1.08±0.39	0.71±0.09	0.04±0.01
A50	44.4±2.10	134±20.1	18.8±1.29	0.31±0.04	11.4±2.10	0.23±0.04	1.02±0.20	1.16±0.32	0.87±0.19	0.05±0.02
A75	56.5±3.19	171±9.19	17.9±2.19	0.34±0.09	13.4±1.93	0.21±0.09	1.12±0.28	1.05±0.19	0.99±0.19	0.06±0.02
A100	52.4±5.29	147±7.19	18.9±1.28	0.50±0.09	13.2±1.28	0.16±0.03	1.21±0.28	0.86±0.19	1.11±0.36	0.06±0.02
D0.5	67.8±8.19	138±9.19	18.5±2.10	0.15±0.10	8.54±1.28	0.18±0.02	0.59±0.19	1.08±0.28	0.39±0.10	0.05±0.02
D5	75.1±6.20	99.9±10.3	26.2±4.19	0.16±0.09	16.3±2.19	0.11±0.09	0.73±0.19	1.11±0.29	0.51±0.10	0.06±0.02
D25	40.7±2.19	94.8±10.3	19.3±1.29	0.14±0.02	12.3±1.93	0.24±0.07	0.69±0.08	0.91±0.09	0.69±0.08	0.03±0.01
D50	54.0±4.29	186±10.3	26.9±3.20	0.28±0.02	20.4±2.20	0.27±0.03	1.23±0.10	1.05±0.10	1.54±0.39	0.06±0.02
D75	66.7±8.19	177±10.3	28.3±1.30	0.31±0.02	23.7±4.19	0.29±0.02	0.84±0.14	1.28±0.29	1.87±0.49	0.07±0.02
D100	67.8±8.10	135±9.19	26.6±2.19	0.31±0.02	22.7±3.10	0.35±0.01	0.73±0.18	1.34±0.20	1.51±0.47	0.06±0.01
M0.5	72.7±5.29	93.5±8.19	17.6±1.29	0.16±0.01	7.09±1.20	0.23±0.02	0.58±0.02	1.24±0.29	0.51±0.11	0.03±0.02
M5	54.4±8.19	125±10.3	18.1±1.29	0.17±0.02	8.57±0.92	0.17±0.01	0.63±0.19	1.38±0.39	0.65±0.09	0.07±0.02
M25	38.2±4.19	92.9±9.10	17.6±1.30	0.15±0.01	6.96±0.72	0.19±0.01	0.53±0.09	0.81±0.09	0.53±0.09	0.04±0.01
M50	49.4±3.10	93.1±9.19	19.4±1.09	0.17±0.01	12.1±1.21	0.18±0.01	0.63±0.09	0.96±0.09	0.77±0.08	0.04±0.01
M75	80.5±2.02	127±9.20	23.0±1.29	0.18±0.01	15.2±2.10	0.31±0.01	0.64±0.09	1.14±0.30	1.19±0.40	0.03±0.01
M100	76.9±9.29	110±6.30	22.4±1.38	0.16±0.02	15.0±1.21	0.29±0.01	0.53±0.02	1.06±0.20	0.97±0.09	0.04±0.01

Table 3b. Metal intake of maize from different concentrations of winery, abattoir, dairy and municipal wastewaters

Maize	Metal content (mg Kg^{-1}) →									
Concentration ↓	Mn	Fe	Zn	Co	Cu	Cd	Cr	Ni	Pb	As
WW0	38.7±2.19	56.5±3.19	8.43±1.29	0.04±0.02	5.52±0.92	0.02±0.01	1.44±0.19	0.62±0.19	0.18±0.02	0.03±0.02
W0.5	36.5±3.10	45.8±2.19	11.9±1.09	0.05±0.01	8.16±1.93	0.02±0.01	1.50±0.20	0.66±0.10	0.35±0.01	0.05±0.01
W5	34.4±1.20	27.0±2.10	12.3±0.92	0.04±0.01	6.95±1.30	0.04±0.01	1.28±0.19	0.60±0.09	0.37±0.02	0.03±0.01
W25	28.2±2.10	38.3±1.08	8.75±0.92	0.04±0.01	6.52±0.92	0.01±0.00	1.22±0.30	0.54±0.10	0.34±0.08	0.03±0.00
W50	31.5±1.20	79.3±9.11	9.94±1.03	0.08±0.01	6.50±0.40	0.02±0.01	2.87±0.41	1.22±0.29	0.41±0.02	0.06±0.02
W75	42.4±3.11	81.3±8.20	10.5±1.03	0.13±0.02	7.03±0.92	0.02±0.01	1.82±0.38	0.84±0.09	0.49±0.09	0.07±0.01
W100	41.2±1.03	90.1±2.10	10.9±1.10	0.10±0.01	8.06±0.24	0.03±0.01	2.46±0.29	1.12±0.39	0.65±0.02	0.08±0.01
A0.5	31.0±1.20	40.7±2.10	10.4±0.99	0.04±0.01	4.95±0.11	0.02±0.01	0.88±0.02	0.80±0.04	0.58±0.04	0.03±0.01
A5	32.9±2.10	42.6±2.94	9.95±0.93	0.04±0.01	5.54±0.29	0.02±0.01	1.46±0.10	0.60±0.09	0.61±0.09	0.02±0.01
A25	21.7±1.20	67.2±3.20	9.24±0.99	0.05±0.01	7.48±0.40	0.02±0.00	2.86±0.19	1.05±0.02	0.55±0.08	0.04±0.01
A50	20.5±2.10	76.6±4.11	10.7±1.09	0.04±0.00	8.88±0.59	0.03±0.01	2.37±0.30	0.96±0.11	0.76±0.10	0.04±0.01
A75	25.4±3.10	73.8±4.21	12.0±1.91	0.05±0.01	9.63±0.69	0.03±0.01	2.51±0.49	1.08±0.20	0.65±0.08	0.05±0.01
A100	25.9±3.21	93.5±6.30	11.5±1.03	0.08±0.01	8.71±0.50	0.03±0.01	4.38±0.60	1.67±0.20	0.44±0.03	0.06±0.00
D0.5	35.2±3.20	70.2±4.30	9.61±1.90	0.05±0.01	4.74±0.94	0.02±0.01	2.23±0.29	0.76±0.11	0.54±0.08	0.04±0.01
D5	36.0±4.39	54.5±2.94	9.11±1.09	0.04±0.01	5.16±0.98	0.02±0.01	2.26±0.31	0.67±0.29	0.53±0.10	0.03±0.01
D25	32.6±3.29	85.7±4.21	12.4±1.93	0.07±0.01	6.75±0.98	0.04±0.01	2.91±0.49	0.90±0.29	0.51±0.11	0.04±0.01
D50	28.0±3.11	98.1±4.21	12.1±1.91	0.07±0.02	9.11±1.09	0.05±0.02	3.54±0.51	1.61±0.31	0.73±0.21	0.04±0.01
D75	41.2±5.11	274±5.20	18.1±2.11	0.33±0.02	13.4±1.93	0.14±0.03	3.43±0.60	1.58±0.31	0.78±0.21	0.09±0.01
D100	44.1±5.93	193±4.30	23.3±3.20	0.30±0.02	17.6±1.99	0.20±0.03	2.54±0.50	1.21±0.20	1.10±0.20	0.10±0.01
M0.5	35.0±2.11	51.7±3.10	6.99±0.98	0.03±0.01	3.53±0.30	0.02±0.00	1.85±0.49	0.58±0.09	0.46±0.10	0.02±0.01
M5	38.4±4.20	65.2±6.91	9.11±0.90	0.05±0.01	4.76±0.98	0.02±0.00	2.09±0.40	0.69±0.09	0.71±0.11	0.03±0.01
M25	32.9±8.30	74.9±6.93	9.02±0.90	0.05±0.01	4.33±0.98	0.02±0.00	2.63±0.40	0.87±0.09	0.26±0.11	0.03±0.01
M50	37.0±5.20	123±7.91	9.38±0.91	0.07±0.01	4.98±0.97	0.03±0.00	3.79±0.50	1.18±0.08	0.37±0.11	0.04±0.01
M75	34.3±4.80	92.6±6.90	9.71±0.90	0.08±0.01	4.59±0.98	0.03±0.00	2.06±0.40	0.78±0.09	0.42±0.11	0.03±0.01
M100	35.2±4.20	79.4±6.91	11.5±0.90	0.06±0.01	5.67±0.98	0.03±0.00	2.54±0.40	0.92±0.09	0.58±0.11	0.02±0.01

Table 4. Effect of 10% concentration of winery, abattoir, dairy and municipal wastewater on dry shoot, dry root weight, and plant nutrient concentrations

Plant Type	Waste Water type	DSW		DRW		Plant N		Plant P		Plant K		Plant Na		Plant Mg	
Sunflower	Winery	-0.29	**	-0.16	**	0.04		0.00		0.02		402.3		-31.61	
	Abattoir	2.43	**	1.20	**	0.21	**	0.03	**	0.04		1032	**	88.93	**
	Dairy	1.22	**	0.49		0.17	**	0.00		0.26	**	2103	**	-86.04	
	Municipal	-0.01		-0.04		-0.01		0.00		-0.01		193.9		-78.34	**
Maize	Winery	-0.20	**	-0.05		0.01		0.01	**	0.07	**	32.21		58.34	**
	Abattoir	4.89	**	2.43	**	0.13	**	0.02	**	-0.09	**	157.9	**	146.9	
	Dairy	1.75	**	1.95	**	0.35	**	0.00		0.19	**	1009	**	130.8	
	Municipal	0.25	**	0.31	**	0.02		0.00		0.04		522.3	**	70.55	

* significant at .05, ** significant at <.001