GROWTH AND PHYSIOLOGY OF HORTICULTURAL CROPS IRRIGATED WITH MUNICIPAL RECLAIMED WATER IN KING COUNTY, WASHINGTON

Final report prepared for King County

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Introduction

Humans used more than a half of earth's available fresh water in 1996 (Postel et al., 1996). By 2025, because of human population increase, that amount is expected to rise to more than 70% (Postel et al., 1996). Human use of this finite resource lessens or alters the timing of flows into natural systems affecting their sustainability. Further, water inputs that were first diverted for human use, often carry with them contaminants or are high in nutrients, such as nitrogen or phosphorous, which can lead to eutrophication, or the de-oxygenation of a body of water (Flemer and Champ, 2006). Water allocation among municipal, industrial, agricultural, or natural systems fuels conflicts globally (Getirana, Malta, and de Azevedo, 2008; Ghosh and Bandyopadhyay, 2009) and in the United States (Slaughter and Wiener, 2007). Where water is scarce, water-recycling programs have been adopted (for review of successful and unsuccessful projects see Po, Kaercher, and Nancarrow 2003). Use of recycled, or reclaimed water will likely become important globally as water availability continues to decline.

In Washington State the Washington Reclaimed Water Act was passed in 1992 and amended in 2007 to include recognition of the following values for reclaimed water: 1) reclaimed water is a consistent source of water in light of the predicted effects of climate change, 2) reclaimed water would lessen the water that is discharged directly into Puget Sound, 3) reclaimed water would increase the flows of streams and rivers, which is needed for salmon recovery, and 4) reclaimed water would enable better management of the Columbia River's water (DOE, 2009). The 2007 amendment also stipulated that state agencies are required to utilize reclaimed water where feasible, and so its use is expanding especially in government sectors. For example, Olympia, Washington's capital, will soon use reclaimed water to irrigate city-owned parks (Olympia, 2009).

While economics and infrastructure play roles in the limited adoption, public perception also figures strongly in the implementation and success of water reuse projects. The California Recycled Water Task Force gave 14 initial recommendations to improve or increase water reuse in that state. Of these, four pertained directly to public perception and education (Recycled Water Task Force, 2003). While communities often support the idea of recycled water, individuals are reluctant to use it themselves (Nancarrow et al., 2008). Reluctance becomes more pronounced as chances of contact or ingestion increase (Po, Kaercher, and Nancarrow, 2003). Public and target consumer acceptance is influenced by several factors, which can be generally summed into the following: perceived need, safety, and, if used for irrigation, impacts on soil and therefore plant quality (for reviews see Exall et al., 2004; Po et al., 2003). Po and colleagues (2003) note that where water is understood to be scarce (i.e. where there is a perception of need), the public and

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potential users are more accepting of reclaimed water. The same review demonstrates that the issue of safety is more complicated. There is the basic fear of pathogens or other contaminants in the water, but there are differences in perception of risk. In a survey of Australian environmental groups, households, industries, farmers, and sports clubs, added nutrients and salinity were cited as concerns along with issues of safety (Exall et al., 2004). Heavy metal accumulation is also a concern (Exall, 2004).

However, the added nutrients in reclaimed water can be beneficial when used for crop irrigation. That is, an additional benefit of using reclaimed water, beyond that of conservation, is that it does carry nutrients and can therefore fertilize when used for irrigation (Fasciolo et al., 2002). However, care is needed to adjust the amount of fertilizer applied to account for this. The nutritional value for irrigation may be specific to the treatment type, existing soil condition, crop species and varieties, as well as location of the treatment plant. In Puget Sound area, reclaimed water from the South Treatment Plant in Renton, King County, Washington can be a valuable source to supply irrigation water for landscape plants and urban farming in the area during the summer dry season. A portion of the water (1 million gallons per day) at the South Plant in Renton is treated to meet Class A reclaimed water standards by sand filtration and used for irrigation and other purposes (e.g., turf, wetland nurseries, and public works). The remaining wastewater is treated to secondary standards and is discharged into Puget Sound. As the class A reclaimed water is treated to the highest standard in Washington State, this water may be used for most non-potable purposes including irrigating food and ornamental crops as well as landscape plants. Potentially important users of reclaimed water in the Seattle area and King County are small-scale urban farms, commercial greenhouses, and nurseries for production of a range of ornamental and vegetable crops. Since irrigation water is limited in many areas in King County, reclaimed water may prove to be a key factor in maintaining the viability of these operations. Although the use of reclaimed water for irrigation is commonly practiced in many parts of the country as well as overseas, each area is likely to have unique concerns and management requirements that need to be addressed for efficient and safe use of this resource. In addition to public and environmental health concerns, there are horticultural questions that need to be addressed such as how to integrate the use of reclaimed water with existing fertilization practices and soil conditions, potential impacts of reclaimed water on plant growth and soil properties, and potential salinity issues. The overall goal of this two-year study was to evaluate plant growth and physiological responses of ornamental and vegetable crops to irrigation using reclaimed water from the South Plant, Renton, WA. We conducted a greenhouse experiment in year 1 and an outdoor plot study in year 2. The outdoor plot study in year 2 had an additional outreach objective to demonstrate the use of reclaimed water for growing crops. As a result, the study plots (gardens) were located at the South Plant facility and have been used as a means to educate the horticultural benefits and safety of the reclaimed water to stakeholders, potential customers, and the general public throughout the experiment; this outreach component has been successful. In this report, we focus on the experimental results to test the effects of reclaimed water from the South Plant on horticultural crops.

Materials and Methods

In order to achieve our research goal, we conducted two independent studies to evaluate the produce safety, growth and physiology of horticultural crops: 1) A greenhouse study in 2008 and 2) outdoor garden study in 2009.

Experiment 1: The greenhouse study in 2008

We chose three ornamental species – amaranth (*Amaranthus hypochondriacus* cv. Burgundy), sunflower (*Helianthus annuus* cv. Sunspot), and delphinium (*Delphinium grandiflorum* cv. Blue Mirror); and three food crops – Romaine lettuce (*Lactuca sativa* cv. Paris island), carrot (*Daucus carota* cv. Danvers half long), and strawberry (*Fragaria ananassa* cv. everberry). All six species were used to determine the effects of reclaimed water on plant quality, and the food crops were also used to determine safety. Each species was chosen to address specific areas of concern. Lettuce is known to accumulate heavy metals, and has been used as an indicator of heavy metals in amended soils (Brown et al., 1996). Additionally, both lettuce and strawberries are primarily consumed raw, so pathogens that remain on the tissue after overhead irrigation are of concern. Carrots, as root crop, were used to determine whether heavy metals would accumulate in edible root tissue. Delphinium is a perennial ornamental that is increasing in demand in the Pacific Northwest. This species was chosen with the market and growers in mind. Sunflower is relatively salt tolerant, but its yield does decrease with increased soil salinity (Bhatt and Indiraku, 1973; Noreen and Asuipaf, 2008), and was used to assess the effects of salinity on plant growth. As delphinium and sunflower are C_3 species, the final species, amaranth, is an ornamental plant with NAD-ME type C_4 photosynthetic pathway and was grown to compare the response of the two photosynthetic pathways to reclaimed water.

The experiment was conducted in the Douglas Research Conservatory greenhouse, a facility of the University of Washington Botanic Gardens, Seattle, WA in 2008. Plants were planted as seeds except strawberries which were purchased as several-day-old starts in 4x4 inch pots. Each food crop was transplanted into 1-gal black, plastic molded nursery pots, while seeds of the ornamental species were planted into 2-gal pots. Soil from an urban agricultural field outside of Renton was used for the planting medium, and to account for variation across the field, the soil was collected from five randomly selected areas within the field. Three treatments were applied – tap water (TP), reclaimed water (RW), and half-strength Hoagland's solution (HG, Taiz and Zeiger, 1998). For each species there were 15 pots, with five pots for each of the three treatments, and one pot from each treatment representing soil from a different location in the field. The pots within a species were randomly assigned to locations on a greenhouse table, for a randomized complete block design, with the soil locations as the blocks, and a sample size of five for each treatment.

Plants were watered with the treatments as needed, beginning by watering all pots within a species with the same amount across all treatments. As plants developed, the amount and time of irrigation were adjusted for each species and treatment. For example, the Hoagland's-treated plants used water more quickly than those treated with tap water likely due to greater leaf area. Any differences in watering among treatments should not have affected our results. We ensured that the plants within a treatment all received equal amounts of their treatment solution (HG, RW, or TP), without causing them stress. To manage this, we adjusted the watering amounts by treatment, but made sure that all plants within a treatment were watered with the same amount.

At maturity, we harvested the aboveground portion from one plant per pot for amaranth and sunflower, respectively. We recorded stem height up to the base of the flower, separated leaves from stems, and recorded leaf area using a leaf area meter (Li-3100, Li-Cor Inc., Lincoln, NE, USA). The tissue was then dried at 70°C until the weight stopped decreasing and weighed.

The rate of photosynthetic CO_2 assimilation at saturated light (A_{max}) was used to approximate photosynthetic capacity. CO_2 assimilation measurements were taken for each species using a portable gas analysis system (LI-6400, Li-Cor Inc., Lincoln, NE, USA). On the ornamentals, relative chlorophyll content was measured using a chlorophyll meter (SPAD-502 meter, Minolta, Tokyo Japan) at the same time that photosynthesis was measured. Statistical analysis and regression were done using R version 2.8.1 (R Development Core Team (2008), Vienna, Austria). Significance was determined using ANOVA followed by Tukey's Honest Significant Difference. Results were deemed significant at $\alpha = 0.05$.

Experiment 2: Outdoor garden study in 2009

We conducted an outdoor garden experiment located at the South Plant facility using three ornamental crops: Sunflower (*Helianthus anuus* cv. Dwarf Incredible), Dephinium (*Delphinium grandiflorum* cv. Blue Mirror), and Amaranthus (*Amaranthus caudatus* cv. Love-Lies-Bleeding). These ornamental crops were planted in 9 raised beds (Fig. 1); this randomized complete block design allowed to have three replicates with three treatments: (1) tap water + fertilizer (control), (2) reclaimed water only, and (3) tap water + fertilizer. The raised beds were filled with screened loam topsoil (Pacific Topsoil, Inc., Bellevue, WA). The soil was tested for nutrient content before and after the experiment. Each raised bed was irrigated using soaker hoses delivering potable tap water or reclaimed water three times a week from June 1st 2009- August 12th. All garden beds received up to one hour irrigation to saturation; time to saturation varied depending on specific bed conditions. A complete fertilizer (Miracle-Gro, The Scotts Company, Marysville, OH) was applied as recommended by the manufacturer to the plots receiving fertilizer treatment. Briefly, the fertilizer was applied every two weeks; one teaspoon crystallized fertilizer dissolved in one gallon, one gallon of dilute fertilizer was applied to 10 ft^2. This fertilizer was made up of following chemical constituent percentages: Total Nitrogen: 15% (9.2% urea nitrogen and 5.8% ammonium nitrogen); Available phosphate: 30%; Boron: .02%; Soluble Potash: 15%; Copper: .07%; Iron: .15%; Manganese: .05%; Molybdenum: .00005%; and Zinc: .06%.

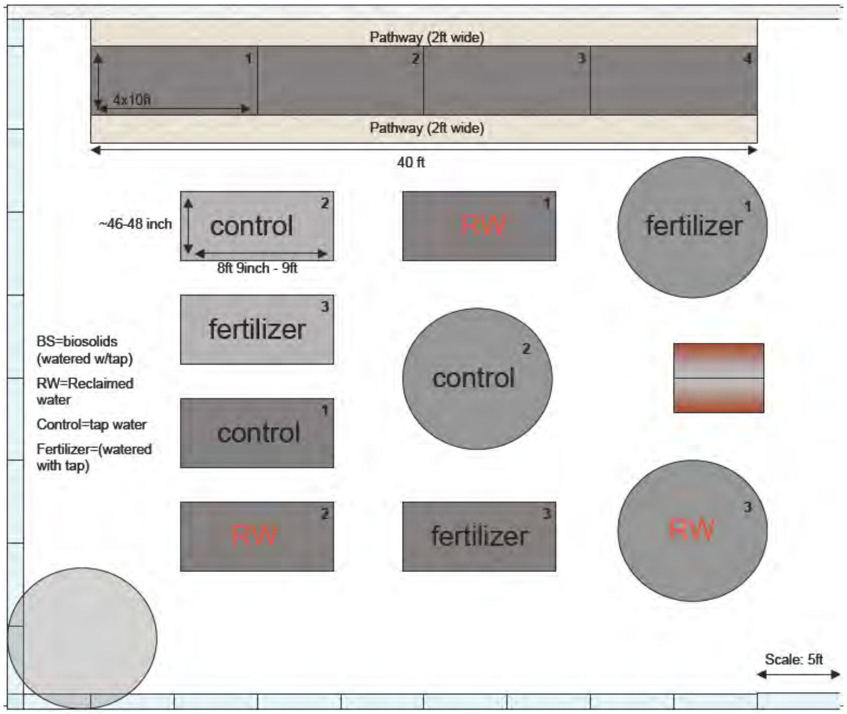


Figure 1. Layout of the outdoor garden experiment at the Renton South Plant facility

As in the experiment 1, we determined above-ground biomass, total leaf area per plant, photosynthesis, and leaf chlorophyll content using the SPAD meter as a measure of leaf N status. Total above-ground biomass accumulation and leaf area development were determined when these characteristics peaked in the summer by destructive sampling. At the beginning and end of the experiment, the soil was analyzed for soil pH, electrical conductivity (EC), cation exchange capacity (CEC), nitrate-N, micronutrients, and soil organic matter by the soil test laboratory at the University of Massachusetts.

Results

Growth and physiological characteristics

Experiment 1: Greenhouse study

Stem height is an important quality indicator for cut ornamentals. Stem height did not differ significantly among treatments for sunflower (data not shown). For amaranth, however, the plants that were watered with tap water were significantly shorter than plants watered with either half-strength Hoagland's solution or with reclaimed water (*P*=0.0111).

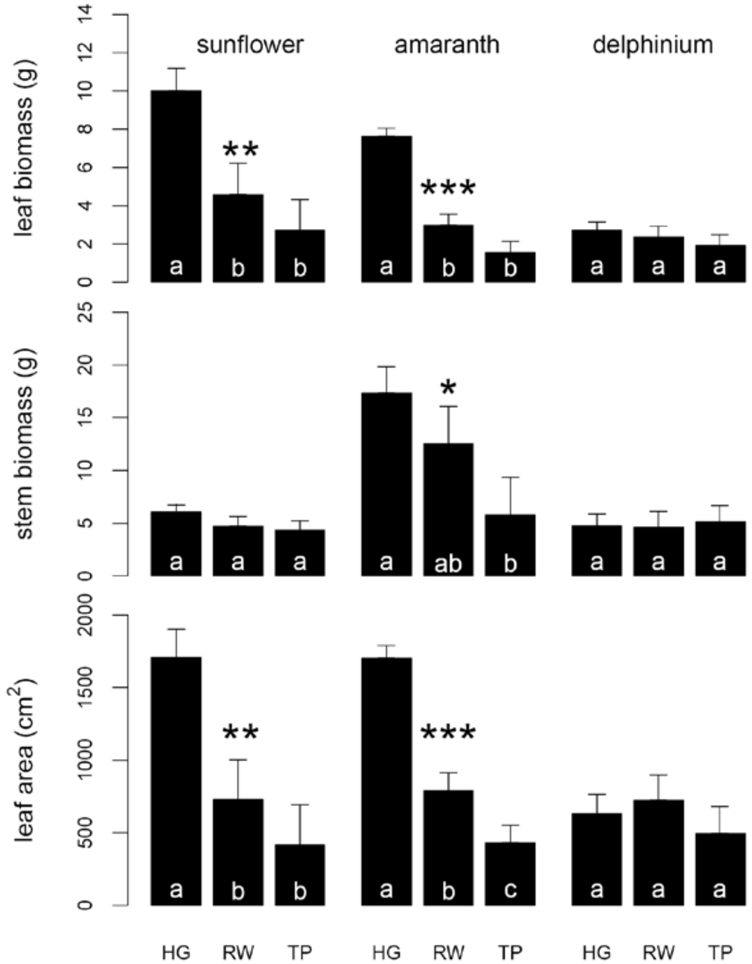


Fig. 2. Leaf biomass, stem biomass, and leaf area of three ornamentals: Sunflower, amaranth, and delphinium in response to half-strength Hoagland solution (HG), reclaimed water (RW), and tap water (TP) irrigation. The same letters within each species indicate that results are not significantly different at 5% while different letters denote significant difference at 5% (*), 1% (**), or 0.1% (***) significance level.

Amaranth height increased 24% from plants grown in TP to plants grown in RW and HG. There was no significant difference in height between amaranth plants watered with HG and RW.

Biomass and leaf area are indicators of overall growth and productivity. Sunflower leaf area and leaf biomass were significantly different among treatments (*P*=0.0080 and 0.0062, respectively); however, the plants watered with half-strength Hoagland's solution drove this difference (Fig. 2), with both leaf area and leaf biomass being higher than those from the other treatments. For leaf biomass, HG plants had a 119% and 271% increase over RW and TP plants, respectively. The increase in leaf area was 135% and 308%, respectively. There was no significant difference between plants watered with reclaimed or tap water, and stem biomass was not significant. Amaranth responded significantly in leaf area, leaf biomass, and stem biomass ($P<0.0001$ for leaf area and biomass, $P=0.0161$ for stem biomass). As with sunflower, those plants grown with Hoagland's solution had significantly larger biomass than the other two treatments ($P=0.0191$), with HG plants having a 156% and 389% increase in biomass over RW and TP plants, respectively. Leaf area exhibited a similar pattern; however, RW and TP plants also differed significantly ($P=0.0721$). Leaf area from HG plants was 115% greater than TP plants, and leaf area from RW plants was 84% higher. The significance in stem biomass for amaranth was driven by an increase of 116% from the TP to HG plants (*P*=0.0132). RW plants did not differ significantly from either of the other two treatments. Delphinium did not differ in stem or leaf biomass or in leaf area among treatments.

For these growth parameters, as well as biomass of the berries, strawberry did not differ significantly among the treatments (data not shown). Carrot, however, did differ in leaf area and in root biomass ($P=0.0055$ and 0.0035, respectively). For leaf area, the difference was driven by the plants grown with half-strength Hoagland's solution, with the HG plants being 371% and 1223% larger than the RW and TP plants, respectively. There was no significant difference between the RW and TP treatments. Root biomass exhibited a positive effect of reclaimed water and half-strength Hoagland's solution. While the RW and HG plants did not differ significantly in root biomass, there was an 826% increase in biomass from TP plants to the RW and HG plants (*P*=0.0057 and 0.0066).

Amaranth, lettuce, and carrot all showed differences in rate of photosynthesis among treatments; however, the patterns among species were not the same (data not shown). The photosynthetic rate of amaranth grown with half-strength Hoagland's solution was significantly higher than that of plants treated with reclaimed and tap water ($P<0.0001$), with the HG plants having a 50% and 56% higher rate than the RW and TP plants, respectively. The significance in the photosynthetic rate of lettuce was also driven by plants grown with half-strength Hoagland's solution, which had a 133% higher rate than the TP plants (*P*=0.0484). RW lettuce plants were not significantly different from either the HG or TP plants. Carrots grown with tap water, on the other hand, had a lower rate of photosynthesis than either those grown with reclaimed or half-strength Hoagland's solution (*P*=0.0004), showing a positive effect of the HG and RW treatments. The HG and RW plants had a 134% and 90% greater photosynthetic rate than the TP plants, respectively. The HG and RW plants were not significantly different. Sunflower, strawberry, and delphinium did not differ significantly in the photosynthetic capacity ($A_{\max}$) per unit leaf area.

Sunflower and amaranth had similar patterns of chlorophyll content as based on the SPAD chlorophyll meter (Fig. 3). In both cases, plants treated with half-strength Hoagland's solution were significantly higher than either of the other two treatments ($P=0.0019$ and

$P<0.0001$, respectively), with the increase from the TP and RW plants to the HG plants being 28% for sunflower and 42% for amaranth. RW and TP plants were not significantly different for either species. Lettuce had the opposite pattern. Plants treated with tap water had significantly lower chlorophyll content than those treated with either half-strength Hoagland's solution and reclaimed water ($P<0.0001$), showing a positive effect of both the HG and RW treatments. The increase in chlorophyll content was 69% from the TP plants to the HG and RW plants combined. The HG and RW plants were not significantly different. Delphinium and strawberry did not differ significantly across treatments, and as mentioned in above, it was not possible to use the chlorophyll meter on the carrot leaves.

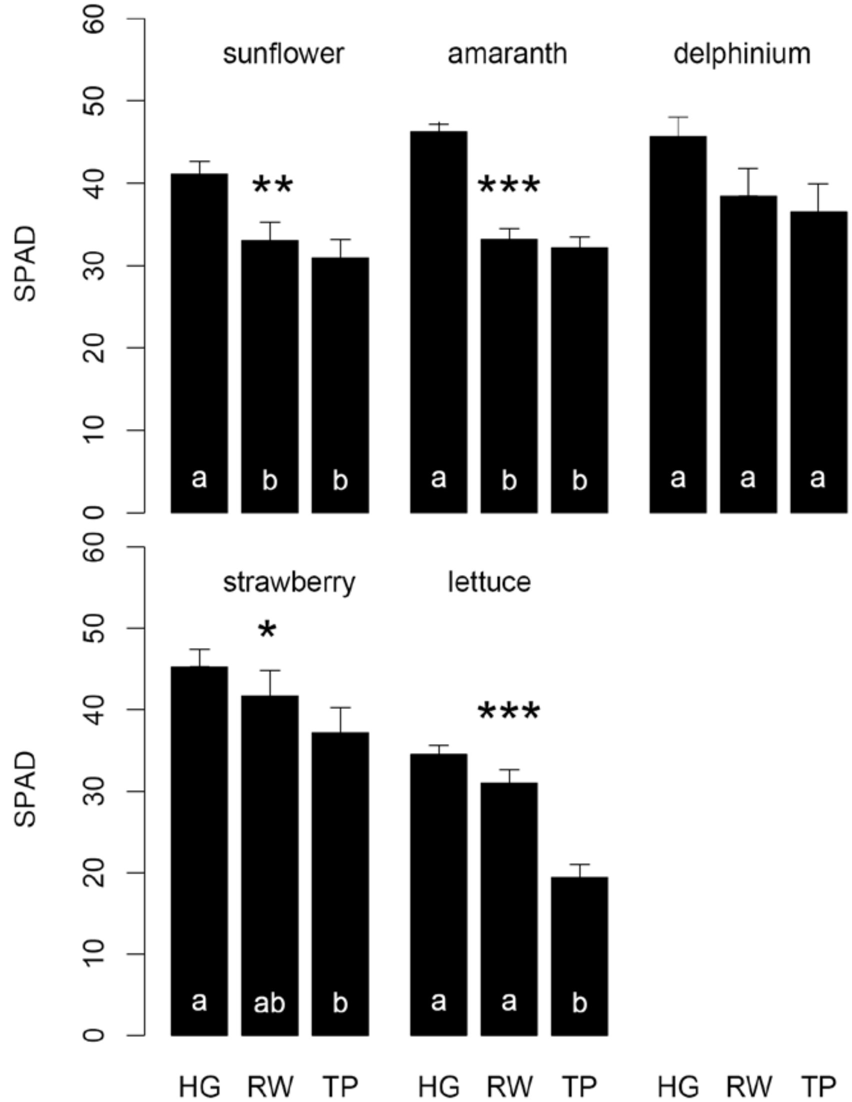


Fig. 3. Chlorophyll content estimates using SPAD meter of all species except carrot in response to half-strength Hoagland solution (HG), reclaimed water (RW), and tap water (TP) irrigation. The same letters within each species indicate that results are not significantly different at 5% while different letters denote significant difference at 5% (*), 1% (**), or 0.1% (***) significance level.

<u>Experiment 2: Outdoor garden study</u>

The results from the outdoor garden study were largely similar to the greenhouse study results; fully fertilized plants exhibited highest biomass and physiological traits and tap watered plants without fertilizer ranked lowest in all parameters measured. Unlike the greenhouse study, the reclaimed water treatment produced above-ground biomass and leaf area that are similar to fully fertilized plants in all three crops. Physiological characteristics were also similar between fully fertilized and reclaimed water treated plants while tap water only plants appeared to suffer from serious nutrient deficiencies (nitrogen in particular) (Table 1).

Table 1. Above ground biomass, total leaf area, net photosynthetic rate, and SPAD readings of three ornamental crops in response to reclaimed water irrigation in experiment 2 (garden study). Photosynthesis was determined under saturating light condition (PAR=1500 mol m^{-2} s^{-1}).

Crop	Treatment	Biomass* ($g\ plant^{-1}$)	Leaf area ($cm\ plant^{-1}$)	Photosynthesis ($\mu mol\ m^{-2}\ s^{-1}$)	Chl. content (SPAD unit)
Sunflower	Fertilized	179.9a	3809.0a	34.4a	46.0a
	Reclaimed water	135.8a	3392.7a	30.4a	44.3a
	Tap water	24.2b	644.9b	16.9b	35.2b
Amaranthus	Fertilized	54.1a	3791.9a	22.8a	31.8a
	Reclaimed water	64.4a	2482.2a	17.2ab	29.7a
	Tap water	3.8b	219.9b	11.1b	16.5b
Delphinium	Fertilized	9.9a	515.1a	15.2a	40.8a
	Reclaimed water	9.3a	278.9a	13.1a	41.8a
	Tap water	4.0b	50.1b	15.7a	20.9b

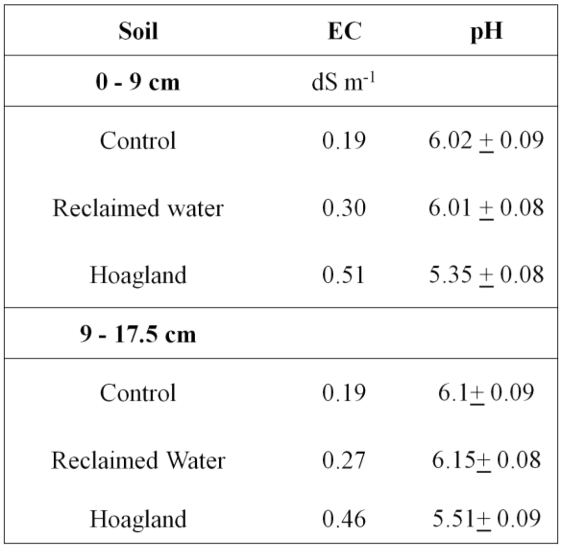
* All values represent least square means (LSM) of three replicates. LSMs with the same letter within a column for each species are not significantly different by Tukey-Kramer method of multiple comparison at *P*= 0.05. The comparisons were made with log transformed data for biomass and leaf area to achieve homogeneity of variances.

Soil chemical properties

In experiment 1, Soil pH and electrical conductivity from all treatments were within acceptable range with relatively low values after the experiment was completed (Table 2). There was virtually no difference between the two depths (0-9 and 9-17.5 cm) from which the soils were sampled and tested. Soil pH was lower in Hoagland solution treatment but similar between tap water and reclaimed water treatments.

Similar patterns were found in the soil analysis of the outdoor garden study (Table 3). Compared to the initial condition, fully fertilized beds were slightly acidic (pH 5.27) while reclaimed water (pH 5.97) stayed similar to the initial condition (pH 6.07). The electrical conductivity in all treatments was sufficiently lower than the level that is known to cause salinity problems (EC > 2.0) in plants. The cation exchange capacity (CEC) was at the adequate level (> 10 meg/100g) in all treatments. Organic matter was also adequate in the initial as well as the final samples from all treatment. However, nitrate (NO_3^-) concentration was significantly lower in tap water treatment after the experiment was completed; soil nitrate level was excessive in full fertilizer treatment and sufficient in reclaimed water treatment. The initial nitrate nitrogen concentration was variable between blocks ranging from 1ppm to 38ppm between blocks. This initial difference in N availability between blocks is likely to be responsible for the variability between blocks.

Table 2. Soil pH and electrical conductivity (EC) of soils collected from the upper (0-9 cm) and lower portion (9-17.5 cm) of the treatment pots at the termination of greenhouse study (experiment 1).



Soil	**EC**	**pH**
0 - 9 cm	dS m^{-1}	
Control	0.19	6.02 ± 0.09
Reclaimed water	0.30	6.01 ± 0.08
Hoagland	0.51	5.35 ± 0.08
9 - 17.5 cm		
Control	0.19	6.1± 0.09
Reclaimed Water	0.27	6.15± 0.08
Hoagland	0.46	5.51± 0.09

Table 3. Soil chemical properties at the beginning (initial) and end of the garden study (experiment 2).

Treatment	pH	EC (dS m^{-1})	CEC (meq/100g)	NO_3^- (ppm)	Organic matter (%)
Initial	6.07a	0.19bc	11.5ab	17.0bc	8.8a
Fertilized	5.27b	0.55a	13.2a	91.7a	7.7a
Reclaimed water	5.97ab	0.21b	11.1b	36.7b	7.5a
Tap water	6.46a	0.12c	11.4b	3.7c	8.1a

* All values represent least square means (LSM) of three replicates. LSMs with the same letter within a column are not significantly different by Tukey-Kramer method of multiple comparison at *P*= 0.05.

Discussion

The primary objective of this study was to assess growth and physiological responses of horticultural crops irrigated with reclaimed water in comparison with complete fertilization or no fertilization regime. We focused on biomass, leaf area, stem height, photosynthetic rate, and chlorophyll content. These parameters are measures of plant productivity and quality, and therefore are likely to be of interest to existing and potential customers who are considering the reclaimed water from the South Plant for irrigation of horticultural crops in the region.

Overall, any treatment effect on both photosynthesis and chlorophyll content was more pronounced in the fully fertilized plants in both greenhouse and outdoor plot studies, as typified by sunflower, amaranth, strawberry, and lettuce. However, both carrot and lettuce responded positively to the reclaimed water treatment in the greenhouse study; carrots showed an increase in photosynthetic rate and strawberry an increase in chlorophyll content in comparison with tap water plants. All three species tested in the experiment 2 with outdoor plots responded positively to reclaimed water. Increases in photosynthetic rate and chlorophyll are also correlated with leaf nitrogen content, so it is likely that nitrogen availability played a key role in the results observed here. Although nitrogen was not measured in the tap water, the much higher concentration of phosphorous in the reclaimed water compared with the tap water suggests that there was an overall increase in nutrient availability.

In all physical parameters measured, sunflower exhibited only an effect due to full fertilizer treatment in the greenhouse study while significant increase in biomass and leaf area were observed in the outdoor plot study. Amaranth did demonstrate a positive response to reclaimed water in both experiments. In the greenhouse study, stem height did not differ in the fully fertilized (HG) and reclaimed water (RW) treatments. This result suggests that the reclaimed water may contain adequate nutrients to produce ornamental plants of the comparable quality and marketability as fully fertilized plants without additional fertilization. In horticultural markets, ornamental quality is often not directly linked to plant vigor or productivity but determined by other aesthetic indicators like stem length. For example, in cut-flower roses the quality and marketability are primarily graded and classified by stem length (Kim and Lieth, 2004).

Carrot also responded positively to reclaimed water with an increase in root biomass. Increases in growth after application of reclaimed water have been observed in several studies. A positive fertilization effect was noted when reclaimed water mixed with potable water was applied to turf, although the effect decreased over time likely due to dilution after rain events (Murakami and Ray, 2000). Several tree species also responded favorably (Adrover et al., 2008). In some cases the effect of reclaimed water on growth depended on the parameters measured. Wheat (*Triticum aestivum* L.), for example, demonstrated no effect in height, tiller production, or weight of 1000 seeds, but did increase in grain yield (Day et al., 1979).

In some cases, the nutrients available in reclaimed water were not sufficient to supply all of the needs of the plant. Maize (*Zea mays* L.), for example, was found to decrease its nitrogen use efficiency when treated with reclaimed water (Feigin et al., 1981). While this pattern was observed in the greenhouse study, plants irrigated with reclaimed water performed equally well with the fully fertilized plants in the outdoor garden study (Table 1). In the outdoor garden experiment, the difference in plant performance between fully fertilized and reclaimed water treatments was minimal in block 1 where initial soil nutrient was adequate; the different was largest in block 3 where initial soil condition was poor (data not shown). This suggest that reclaimed water may provide adequate nutrients for crop growth in fertile soils without additional fertilizers. It should be noted that some species (e.g., Amaranth) demonstrated a more positive response to reclaimed water than other species. This species specific response may be related to the ability of each species to allocate limited resources into different functions. Amaranth is a C4 species that is in general more efficient in nitrogen and water use than most C3 species. These results are not surprising when comparing the amounts of nitrogen and phosphorous available in the two treatments; Reclaimed water did contain some levels of nitrogen and phosphorous, but less than those in the half-strength Hoagland's solution.

In addition to the nutritive effects of reclaimed water, any potentially negative effects may be of concern especially for commercial customers. In particular, increased soil salinity has been the primary consideration when discussing the effects of reclaimed water on plant growth and quality. In arid and semi-arid environments, salinity has been observed to increase in soil and plant tissue treated with reclaimed water (da Fonseca et al. 2007; Barhi, 1998; Stevens et al., 2003). The effects of salinity, like the fertilization effect, vary with species (Adrover et al. 2008). In the arid regions such as Central Valley California and Arizona, selection of plants that are tolerant to salinity could be an effective solution for irrigation of turfs and landscape plants with reclaimed water (Hunter and Wu, 2005; Niu and Rodriguez, 2006). Although salinity can be a concern for irrigation with reclaimed water in the arid regions, it may not directly comparable with our region because the degree of salinity issues due to irrigation with reclaimed water depends on many factors: salinity of ground water, salinity of reclaimed water, quantity and patterns of precipitation among others. In the coastal Pacific Northwest, both ground water and reclaimed water have low salinity compared to more arid regions. In addition, copious precipitation throughout the long rainy season is likely to minimize accumulation of salts in the arable layer of the soil. Likewise, the growing season requiring supplemental irrigation is limited to three to four months during the summer. Therefore, salinity due to irrigation with reclaimed water is less likely to be a concern in our region in contrast to more arid regions in the country. It is also important to stress that the nutritional quality and salinity level can vary greatly among different reclaimed water processing facilities depending on treatment methods and quality standards. In the South Plant, Renton, WA, the class A reclaimed water had no measurable impacts on salinity and pH of the sports field and landscaped areas at Fort Dent Park, WA in a long-term (10 years) study (King County, 2006). In the present study, the soil salinity of reclaimed water treatment was lower than that of fully fertilized soils and sufficiently lower than the level to be concerned for salinity issues in both experiments (Table 2 and 3).

With the growth and physiological parameters tested in these experiments, we did not detect any negative symptoms or effects due to salinity or toxicity in reclaimed water treated plants. Here, the effect of reclaimed water on physical parameters was either less than the effect of half-strength Hoagland’s solution or not significantly different. Furthermore, in no case were the reclaimed water plants inhibited in growth compared to the tap water plants (control) in both experiments. Some researchers theorize that the additional nutrients in reclaimed water may help to negate the negative effects of salinity (AlJaloud et al. 1996). At least on the short term, it is highly unlikely that salinity will be a problem with the species tested in this study when they are irrigated with the Class A reclaimed water from the Renton South Plant.

Two species, strawberry and delphinium, did not respond to either the half-strength Hoagland’s solution or the reclaimed water treatments in the greenhouse study. As there is considerable variability in plant response to reclaimed water fertilization, the variability observed in this experiment is not atypical. The size of the strawberry and delphinium plants used for this experiment may have contributed to the variability, and therefore, inability to detect a response statistically.

As discussed earlier, it might be possible to achieve relatively high, marketable plant quality – judged by stem length and/or aesthetic value –without intensive additional fertilization when using reclaimed water for irrigating ornamental crops. In fact, consumers may prefer moderately sized healthy looking plants to overly grown plants with extensive vegetative growth (Fig. 4).

Fig 4. Sunflowers and amaranth plants grown with HG (blue), RW (red), and TP (white) in the greenhouse study (experiment1).

Fig 5. Outdoor garden plots for experiment 2 set up at the Renton South Plant in 2009.

The findings of the present study provide needed information about the effects of reclaimed water on horticultural crops for public, stakeholders, and current and potential users including small-scale urban farmers and commercial nurseries of the reclaimed water from the South Plant, Renton, and therefore help diversify the use of reclaimed water use in the region.

Conclusions

The results of the greenhouse experiment support that the sand filtered reclaimed water from the South Treatment Plant in Renton, WA provide considerable nutrient benefits (e.g., nitrogen) while additional fertilization would be needed to maximize plant growth and productivity in low fertility soils. It is recommended to adjust the fertilization rates to account for the nutritive effects of reclaimed water considering soil fertility, and doing so has the potential to lower associated costs both economically and environmentally. AlJaloud and colleagues (1996) found that using reclaimed water saved 150 kg N ha^{-1}. The greenhouse study as well as the outdoor plot study did not detect any detrimental effects due to reclaimed water on plant growth and physiology. Salinity is unlikely to be an inhibitor to growth for the horticultural crops irrigated with reclaimed water in this study in our region. A longer-term study (King County, 2006) supports this assessment as salt accumulation has not occurred for 10 year period and did not inhibit plant growth and production in association with the extended use of reclaimed water. In summary, both greenhouse and outdoor experiments in our study demonstrated similar results: 1) considerable nutritional benefits for plant growth and physiology from reclaimed water, 2) no symptoms of salinity issue in plants and soils due to reclaimed water from the Renton South Plant.

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