Chapter IV Rose Hydroponics Supported by Industrial and Aquaculture Wastewater Re-use

Abstract

High-value floral hydroponics was investigated as an integrative technology for wastewater re-use. The goals of this investigation were to support hydroponic rose culture using (a) power station blow-down wastewater, (b) wetland integrated polyculture wastewater, and (c) power station blow-down wastewater (first used in integrated polyculture systems). Experimental dilution treatments of both wastewater and nutrient concentrations were trialed. The objectives of the trials were to determine whether differences resulted in measured rose flower attributes between treatments.

Roses were cultured successfully using SCL power station wastewater in all wastewater and nutrient dilution treatments. Product quality was high with flowers vibrantly colored, fragrant, and supported by long, straight stems. Shoot lengths of the flowers produced were comparable to those reported published data for hydroponic rose culture. However, there was one exception: in one hydroponic trial (Experiment C) losses of over half the floral product in the most concentrated wastewater dilution treatment occurred, and was attributed to the high ionic strength of the solution. Additionally, in another hydroponic trial (Experiment B), significantly shorter stem lengths were produced in the most dilute nutrient treatment, although flowers were still marketable. This investigation showed that the linkages between hydroponic rose production and re-use of multiple wastewater types could be successful if properly managed. However, investigations into the

logistics and economics of on-site production and regional distribution would be required before commercialization could be a reality.

1.0 Introduction and literature review

With respect to the integrated system approach of this study, high-value floral hydroponics was investigated as a technology that could be linked directly to the use of power station blow-down wastewater, to wetland integrated polyculture wastewater, and indirectly to power station blow-down wastewater but first used in integrated polyculture systems. Importantly, the research aimed to diversity the modular choices with demonstrated ability to extend a successful integrated system, while diversifying of the marketable product base.

Hydroponics is a well recognized and developed form of plant production. Commercial hydroponic production accounted for $ US 6-8 billion worldwide in 2001 and was dominated by tomatoes, cucumbers, lettuce, capsicums, and cut flowers (Hassal, 2001). Australia is recognized as the largest producer of hydroponic lettuce world-wide; as well as with greater strawberry production than, and near equivalent flower production of, the USA (Hassal, 2001). In Queensland, hydroponic production is dominated by lettuce, tomatoes and cut-flowers that utilize run-to-waste (non-circulating) systems.

Although there are many ways to grow plants hydroponically (e.g. nutrient film technique, aeroponics, flood and drain, trickle irrigation), the binding principal of all hydroponic methods is to grow plants without soil. Instead, the plants grow on media (e.g. gravel, expanded clay, perlite, rock wool, coco peat) irrigated with

nutrient fortified solutions.

Roses have been grown successfully using hydroponics (discussed later in this section). The description 'hybrid tea rose' was given to a French rose 'La France' in 1867. The progeny of this French rose branched into a long line of large-flowered roses that resulted from the hybridization of domesticated European roses with Chinese tea-scented roses, beginning in the 19th century (Cairns and Mattock, 1998). In this experiment, the German hybrid tea rose 'Royal William' (a.k.a. 'Fragrant Charm 84', 'Leonora Christine', 'Royal William') was selected for hydroponic experimentation, because this cultivar was characterized by robust repeat flowering, insect resistance, and good growth in local conditions; and because a consumer demand existed for its long-stemmed, highly fragrant, large red roses.

Hydroponic methodology is applied commonly in research (e.g. nutritional, physiological, morphological investigations) because specific advantages offered by the method to carrying out and monitoring the research. With respect to rose hydroponics research, specifically there are near 30 examples in the literature that are focused on highly technical, physiological aspects of plant growth. Of those publications, many are published in other languages (Japanese, and to lesser degrees Korean, Portuguese, German, and Hebrew). However, some abstracts of those studies are available for review in English print. Of the English language publications, two recent publications were comparable to aspects of the research of this experiment.

Lorenzo (2001) investigated the effects of salinity on eight month old *Rosa hybrida* (cv 'Lambada') rose plants grown in a 'simplified hydroponic system' under different nitrogen fertilization regimes. During the study growing temperature

ranged 18 - 35 ° C, and maximum photosynthetic flux density varied from 300 to 1000 μmol m^{-2} sec^{-1}. Shoot length was measured at 2-5 day intervals until the flower bud had developed and the petals became visible, at which time tissue nutrient concentrations were measured. Six groups of four plants were tested with salinity treatments of hydroponic solutions ranging in electrical conductivity (EC) from 1.2 to 3 dS m^{-1}. The volume of hydroponic systems was 3 L, and held one plant each, and the solution were renewed at 3 - 5 day intervals.

Lorenzo reported there were no observable differences in respect to shoot length or plant tissue concentration of NPK due to either salinity or fertilization regime. It was noted however that the visual symptoms of toxicity took a longer period of successive cultivation (not just one flowering cycle) in which to appear because of the accumulative nature of salinity toxicity. Despite fundamental similarities between Lorenzo's experiment, and this experiment (both examined the effect of ionic concentrations on rose growth indices such as shoot length) this experiment represents a significant advance in that it extends investigation to determine the maximum ion tolerances, and production and quality aspects including water usage, flower density, and vase life of the cut flowers for the rose plants. Although Lorenzo reported that the hydroponics solution was replaced often, little information regarding system design specifics was presented. It seems unlikely that water re-use was not a priority in Lorenzo's experiment.

Malorgio (2001) investigated a commercial run-to-waste *Rosa hybrida* (cv 'Susan') hydroponic system using nutrient concentrations that were lower than those use commonly by commercial growers using comparable systems. Run-to-waste refers to a common method of hydroponic production that irrigates plants growing in planters (containing substrate such as pumice), with the excess water (not absorbed by the plant) drains out the bottom of the planter as wastewater discharged to the local collection system or watershed (street sewers, ditches, fields, rivers, wetlands, etc). Malorgio's research was aimed at growing roses in less concentrated solutions in order to reduce the volume of nutrient-rich wastewater pollution.

One year old rose plants were grown under natural illumination in a greenhouse located at the University of Pisa over the period of June 1997 – July 1998. Hydroponic systems were of 33 cm diameter, plastic pots filled with pumice, and a plant density of two plants per pot, and six pots per square meter was observed. Each plant was fitted with an irrigation emitter, which gave 50, 60, or 70 cm^3 of water per plant per MJ m^{-2} (greater light exposure results in an increased photosynthetic rate, resulting in increased transpiration water use), it was not mentioned where the wastewater was terminally disposed of. Nutrient solution treatments trialed were 160 mg L^{-1} N, 35 mg L^{-1} P, and 220 K mg L^{-1} (full strength solution); and 80 mg L^{-1} N, 18 mg L^{-1} P, and 100 mg L^{-1} K (half strength solution). All treatments held the same concentrations of plant micronutrients. Stem length, flower production, leaf mineral content, and water and fertilizer use were measured over the one year of cultivation period.

Malorgio (2001) found that flower production was higher in full-strength nutrient application (mean of 132 flowers m^{-2}) in comparison to the half strength

nutrient application (mean of 116 flowers m^{-2}) under all water supply regimes, and that stem length showed a slight reduction in half strength nutrient treatments. It was also reported that increasing the water supply from 50 to 70 cm^3 of water per plant per MJ m^{-2} led to increases in drainage (wastewater production) from 23.5 to 32 %. Malorgio concluded that because (a) the use of high nutrient applications only slightly influenced plant growth, and (b) the higher production observed in the full strength nutrient application was associated with lower fertilizer use efficiency, use of half strength nutrient solution at 70 cm^3 of water per plant per MJ m^{-2} optimal for sensible reduction of nutrient leakage from the system without severely negative impacts on flower production.

This research by Malorgio (2001) was a good example of practical research that considered the environmental and commercial aspects of floral production together. It showed that it was possible for regional Italian 'run-to-waste' rose growers to produce a quality product, while exporting fewer nutrients (in the form of hydroponic nutrient solution leakage and discharge) into the environment. However, the system seemed to be designed for regions with ample fresh-water supply.

The Practical Hydroponics & Greenhouses Magazine covers a wide range of hydroponic developments, operations, and issues. This magazine published four feature articles in seven years describing commercial hydroponic production of roses in Australia. In issue number 65 (2002) an article entitled "A Rosey Future" described a commercial scale rose hydroponic operation run by Flora International located near Sydney (NSW, Australia). The system was essentially a run-to-waste scheme, in which 'some' of the wastewater was recirculated in the system after mixing with raw water and fresh nutrients. Thirty-five rose varieties were grown

under controlled greenhouse conditions (air temperature = 24 °C) in polystyrene boxes filled with coco peat substrate that was pH buffered with nitric or phosphoric acid to 5.8-6.5. The roses could receive up to thirty, 30 second duration watering periods each day, and annual rose production was 210 stems m^{-2}.

Issue number 31 (1996) featured an article entitled "The Tip and the Rose Farm" which described a commercial scale hydroponic rose operation run by Mayas Roses located in Casey (Victoria, Australia). This operation was unique because it is located on the site of the Narra Warren landfill methane-fuelled power station. The power station pipe of enough hot water (70 °C) to the flower farm to maintain temperatures of 18 - 30 °C within 8 greenhouses (16,000 rose bushes), although it was estimated that there is enough excess heat to support a further 24 greenhouses. The rose plants were grown in either Scoria or Growool substrates and were watered 7 - 16 times a day (dependent on season); and produced 400 'bunches' of roses per day.

In issue number 29 (1996) an article entitled "Hazelwood roses" described a commercial scale hydroponic rose operation located in the La Trobe Valley (Victoria, Australia). This operation was unique because it was located on the edge of the 30 km^2 (6 km long and 5 km wide) Hazelwood Power Station cooling water pond. The 32 °C cooling water, pumped through a network of root-zone pipes in the hydroponic growing beds, could supplement the primary greenhouse heating (briquette-fired boilers) and further increase greenhouse ambient temperatures by 2 °C. Rose cultivation took place within 66 poly tunnel greenhouses in raised bed planters on rockwool slabs. The irrigation system was drip lines run for a period of 1-4 minutes (depending on season) eight times per day at 8 L hr^{-1}. The system was

run initially as a recirculating design, but was changed to a run-to-waste system when unmentioned problems were encountered. Rose production was 10,000 'bunches' of fresh roses per week as well as dried rose petals as a secondary commodity.

Issue number 27 (1996) presented an article entitled "Thorton Roses" which described a commercial scale hydroponic rose operation run by Thorton Brother Roses located in Thielmere (NSW, Australia). Year-round hydroponic cultivation of 35 000 rose plants for cut flowers occurred in heated (16 – 28 °C) poly-tunnel greenhouse conditions. The hydroponic planters were fashioned using old mining conveyor belts lined with plastic and filled with 10 cm of local gravel. Plastic tubing perforated every 10 cm was positioned on top of the gravel through which hydroponic nutrient solution was delivered to plants at 45 minute periods, that occurred 5 - 6 per day. The solution returned to supply nutrient reservoirs via sub-stratum agricultural drainage pipes positioned at the bottom of the planters. The nutrient reservoirs are drained and refilled every two weeks, and the planters were purged with fresh water every 12 months to remove excess salts from the substrate.

The limited scientific coverage of rose hydroponics in the published literature, and the few industry reports of such practices, demonstrated the paucity of scientific knowledge regarding culture methods, such as water and nutrient deficiencies, and the use of wastewater as the hydroponic liquid medium. This study aimed to correct this.

Additionally, there are no studies to date within the published literature of hydroponics systems that are supported by power station wastewater, aquaculture wastewater, or by power station wastewater first used to culture fish and crayfish.

While examples of aqua-hydroponic systems that integrate recirculating vegetable hydroponics with fish culture (Quielleré et al., 1993, Quielleré et al., 1995, Lewis et al., 1978) are discussed in the published literature, these systems are too far removed from this study, in terms of cultivation methods and plant species included, to be relevant, and thus are not reviewed here.

2.0 Experiment A - Hydroponic Production of *Rosa hybrida* (cv 'Duftzauber 84') Roses in Power Station Wastewater

2.1 Experimental goals, objectives, and hypotheses

The goal of this experiment was to use SCL power station cooling wastewater to support rose hydroponics. The objective of the study was to determine whether differences in growth period, stem length, flower dry mass, flower diameter, vase life, plant flower number, and water quality and usage existed between 0%, 50%, and 100% wastewater treatments.

Null Hypothesis:

There will be no difference in growth period, stem length, flower dry mass, flower diameter, vase life, plant flower number, and water quality and usage results between rose plants propagated in 0 %, 50 %, and 100 % SCL power station cooling wastewater hydroponic solutions.

Alternate Hypothesis:

There will be reduced growth period, stem length, flower dry mass, flower diameter, vase life, plant flower number, and water quality and usage in roses propagated in 100 % SCL power station cooling wastewater hydroponic solutions.

2.2 System design and operating methods

Rose plants were obtained from St. Aubins nursery (Rockhampton, Queensland). The plants were held at the nursery in 10 L grow bags of sand substrate. Fertilizer was not applied over the 4 weeks the plants remained at the nursery before transport to CQU where the plants were pruned, their roots hose washed thoroughly with RO water to remove all bound sand prior to transfer into hydroponic units. Plants were transferred on September 12, 2001, and continuous flower harvesting concluded on Oct 22, 2001.

Fifteen hydroponic units were trialed using five replicates of three wastewater concentrations (0%, 50%, and 100%) positioned as five experimental blocks in the SW quadrant of the PSG green house (Figure 2.1).

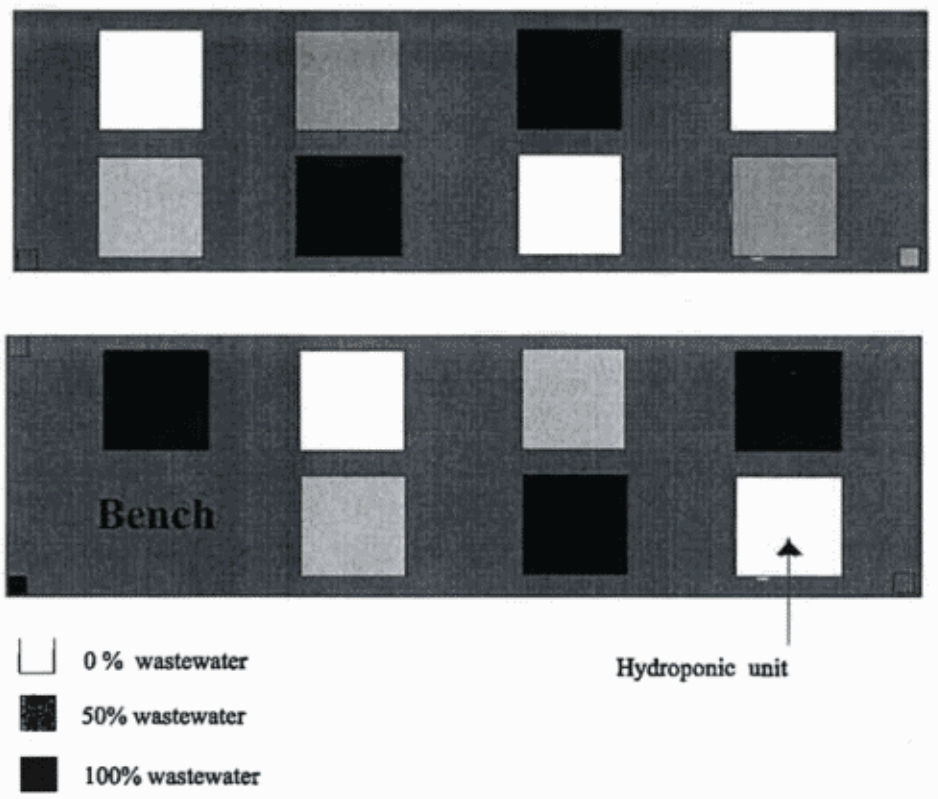


Figure 2.1. Experimental design of hydroponic rose units in the PSG green house.

The 25 L flood and drain planters (polystyrene with hard plastic outer shell) served to anchor rose roots in an expanded red-clay substrate, and provide root insulation from excess heat (Plate 2.1 A-C). Lifetech ® AP-2000 power heads flooded hydroponic vessels by pumping water from a 40 L polystyrene basin (triple wrapped in 5.0 mm industrial plastic bags) positioned below the hydroponic planters. Basins were kept firmly covered by placing bricks on fitted lids; introducing plastic grocery bags around the single hole in each lid, and tightly filling spaces around influent and effluent pipes entering and leaving the basin. Expanded clay substrate was washed thoroughly with reverse osmosis water prior to use in hydroponic units.

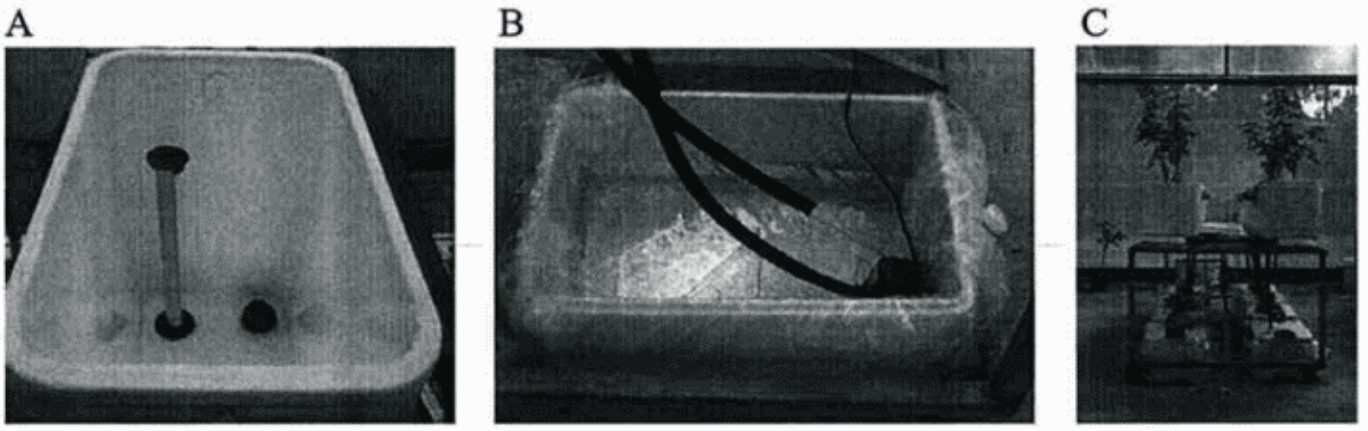


Plate 2.1. Hydroponic unit pipe stand and drain (A), wastewater basin (B), and (C) planted units employed in the rose hydroponic experiments.

Clipsal model L/B7 digital timers regulated four daily - 30 minute recirculation cycles at 7:30 am, 10:30 am, 1:00 pm, and 3:00 pm. Equal amounts of macro/micro nutrients (Section 2.3.6) were added to each of the units to support plant growth.

2.3 Methods

2.3.1 Stem length

A marketable flower was defined in this experiment as having a stem length ≥ 20.0 cm. When three sepals were fully contracted from the bud, flower stems were cut from the main plant with a manual seccateurs. Measurements of stem length were taken immediately from the base of the rose bud to the cut-end of the stem using a flexible measure tape.

2.3.2 Vase life

Each flower stem was re-cut underwater to a uniform height (20 cm) and placed in cleaned 375 ml Corona beer bottles filled with reverse osmosis water. If stems were ≤ 20.0 cm at the time of harvest, 1.0 cm was cut off underwater to exclude air pockets from forming in the stems and blocking transpiration (caused by the initial cut off the plant) . Vase life experiments were undertaken in a temperature and photoperiod controlled room, with conditions set at twelve hour light cycle and diurnal temperatures ranging from 22 ° C (dark) to 30 ° C (light). When all petals showed signs of desiccation (e.g. petal wilt and discoloration), the length of time the flower had spent in the control room was determined and recorded as vase life. In

instances where peduncles lost turgor before petal desiccation occurred, that time was noted as vase life instead.

2.3.3 Flower diameter

Flower diameter was determined at the time when the flower was at full bloom in the growth chamber, approximately 48 hours after introduction to the room. The measurement was determined by averaging diameter measurements taken from the widest and narrowest degrees of the flower transecting its central axis.

2.3.4 Flower dry weight

As vase life determinations concluded for each, rose flowers were cut from stem parts and dried for three days at 70 °C. Flowers then were weighed immediately upon oven removal using a Sartorius LG 12000s digital scale.

2.3.5 Water quality and usage

Temperature (TMP), pH, dissolved oxygen (DO), and total dissolved solids (TDS) water quality parameters were measured twice monthly using a TPS FL-90 water quality meter. The volume of water added to the hydroponic units was recorded.

2.3.6 Nutrient application

Each replicate received Manutec® hydroponic nutrient at 1.27 g L^{-1} part A and 0.68 g L^{-1} part B solute; reverse osmosis water was used in the systems. Nutrient composition can be found in appendix A.

2.4 Statistical analyses

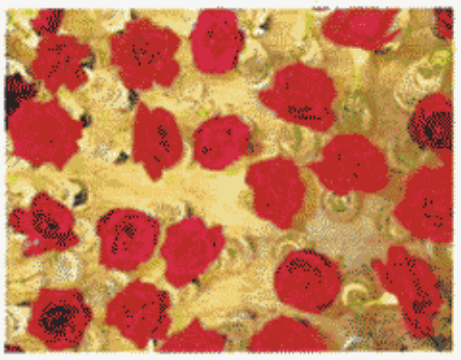
A one way analysis of variance was used to determine if differences in growth period, stem length, flower dry mass, flower diameter, vase life, plant flower number, and water usage occurred between treatments. Treatment was set as the factor and the aforementioned measures were set as dependent variables. A repeated measures general linear model was chosen for statistical analyses of hydroponic water electrochemistry over time. Time was set as the within subject variable, and wastewater treatment as the between subject factor within blocks.

2.5 Results

2.5.1 Flower growth

Successful hydroponic production of roses took place in all treatments (Plate 2.2). Differences in variables between treatments were not significant. Table 2.1 shows flower density,

A



B

Plate 2.2. Flowers in vase life chamber (A); flower bloom (B).

growth period, stem length, flower dry weight, flower diameter, vase life, and water usage of marketable flowers. On average, the experiment produced 7 marketable flowers per unit (0.45 m^2) after 49 days hydroponic culture, with an average diameter of 8 cm on 45 cm stems that lasted 6 days in the control room. Mean ambient air temperature from the day of transplantation to harvest was 22.3 ° C.

	marketable flowers per 0.45 m^2	growth period	stem length (cm)	flower dry weight (g)	flower diameter (cm)	vase life (d)	water use per marketable flower (L)	water use per flower (L)*
0 %								
mean	6.8	49.3	42.04	1.04	7.76	5.8	10.1	6.4
Stdv	1.9	1.8	5.24	0.06	0.62	0.1	2.7	0.7
50 %								
mean	7.0	48.3	45.00	1.01	7.60	6.0	10.2	6.4
Stdv	1.4	1.9	3.95	0.07	0.41	0.3	2.0	0.5
100 %								
mean	8.2	48.5	47.58	0.98	7.26	5.9	9.8	6.7
stdv	2.6	2.6	1.85	0.07	0.61	0.1	2.4	0.3

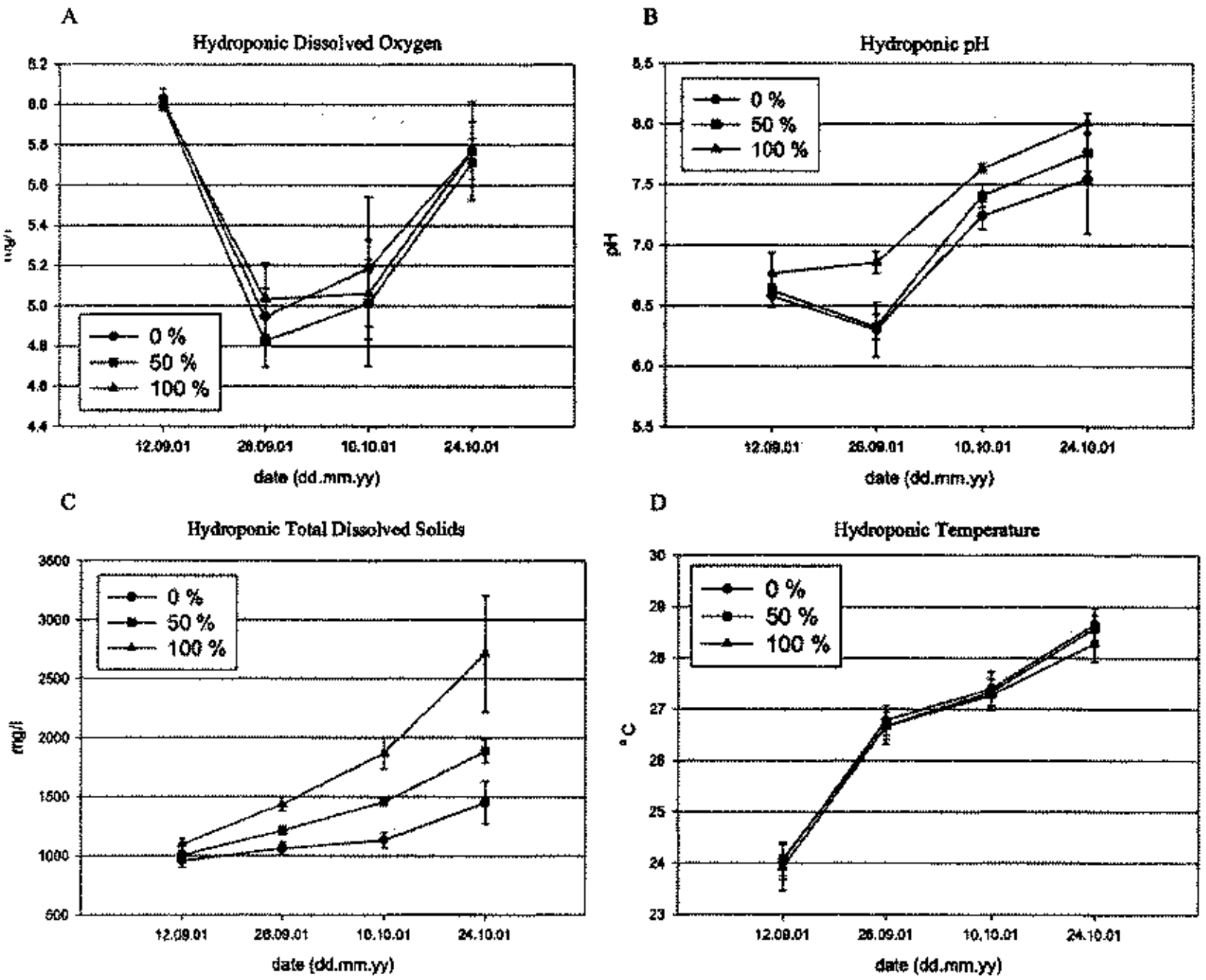
Table 2.1. Experiment A: number of marketable flowers produced, growth period, stem length, flower dry weight, flower diameter, vase life, and water usage of marketable roses, delineated by wastewater treatment. (* includes transpiration of all non-marketable flowers and marketable flowers produced.

2.5.2 Water quality

Figure 2.2 (A-D) shows hydroponic electrochemical data. TDS concentrations in the 100 % treatment were significantly greater ($p \leq .01$) than the 0 % treatment on the last three sampling occasions, and significantly greater ($p \leq .01$) than the 50 % treatment on the last two sampling dates. TDS within the 50 % treatment was greater than that of the 0 % treatment on the last two sampling dates. *In-situ* pH within in the 100 % treatment was significantly greater ($p \leq .01$) than the 0 % treatment for the last three sampling occasions, and significantly greater ($p \leq .01$)

than the 50 % treatment on the second and last sampling dates.

Time had a significant effect on DO ($p \leq .0.01$), pH ($p \leq .01$), TDS ($p \leq .01$), and temperature ($p \leq .01$). All factors increased except DO, which dropped by 1.0 mg L^{-1} before returning to near initial levels.



Figures 2.2. (A) dissolved oxygen, (B) pH, (C) total dissolved solids, and (D) temperature of rose culture hydroponic solution over the course of the experiment.

2.6 Discussion

The experimental goal was met: roses were cultured successfully using SCL power station wastewater. The experimental objective also was met, and the experimental hypothesis was accepted across variables among marketable flowers. Product quality was high with flowers vibrantly colored, fragrant, and supported by long, straight stems.

The success of cultivation of a quality product across all treatments occured despite significant differences in water quality (TDS and pH) between full-strength SCL wastewater and reverse osmosis water treatments. Disparities between treatments in TDS and pH occurred at the initiation of the experiment probably due to buffering by nutrient additions and the impact of clay, however variations became more evident as time progressed. The 100 % wastewater treatment maintained higher pH from the initiation of the experiment due to initial ionic differences between reverse osmosis water and full-strength wastewater. The pH increase in all treatments over time was most likely due to the effect of expanded clay, which adsorbs hydrogen ions effectively making the hydroponic solutions more alkaline (Clapham, 1983). The water quality in the 100 % system was nearing values that could have resulted in reduced productivity or product quality: total dissolved solids values of 5 000 mg L^{-1} and pH values over 8.0 are the upper limits of tolerance for non-halophytic plants. Initial dissolved oxygen levels fell modestly probably in response to temperature rise (*c.* 3°C over the same period), and possibly in response

to concomitant logarithmic increase in aerobic microbes in the water and substrate expected in response to the nutrient applications and increased temperature. The system then exhibited what appeared to be a natural attenuation recovery period for oxygen (enhanced by the regular aeration through oxic substrates) as concentrations slowly rose back to near initial values irrespective of temperature.

When rose production rates in Experiment A were extrapolated to annual figures (17.7 to 136.5 flowers m^{-2} $year^{-1}$), the value was very similar to that reported for an Italian commercial hydroponic greenhouse by Malorgio (2001), and flower stem lengths were comparable to other published data (Lorenzo et al., 2001, Malorgio et al., 2001). Water use was efficient but, comparison of rose production efficiency with hydroponic systems reported in the literature is not possible or appropriate since other systems reported were not managed for water use efficiency (mostly run-to-waste design) and because water use is often not measured.

2.7 Conclusion

This experiment showed that the linkages between SCL industrial wastewater and hydroponic floral production could be successful. However, investigations into the logistics and economics of on-site production and regional distribution would be required before commercialization could be a reality. Additional research utilizing semi-commercial scale systems trialed over repeated harvests of several floral species is necessary to ensure year round production at the SCL Stanwell power station.

3.0 Experiment B - Hydroponic Production *Rosa hybrida* (cv 'Duftzauber 84') in Polyculture - Wetland System Wastewater

3.1 Experimental goals, objectives , and hypothesis

The goal of this experiment was to use wastewater drawn from the recirculating wetlands section of the integrated polyculture - wetland system to support rose hydroponics and thus to successfully link with integrated polyculture - wetlands to floral hydroponics. It was assumed that the roses would be able to grow well in the aquaculture wastewater if it was fortified with a hydroponic complete nutrient supplement, and therefore the objective of this experiment was to trial three concentrations of hydroponic nutrient applications in order to identify a point at which growth efficiency and/or quality of roses was affected by malnutrition.

Null Hypothesis:

There will be no difference in flower growth period, stem length, flower diameter, vase life, and water use between roses propagated in individual nutrient concentrations.

Alternate Hypothesis:

There will be reduced stem length, flower diameter, vase life, and water use in roses propagated in the lower concentration nutrient solutions.

3.2 System design and operating methods

Immediately after the conclusion of Experiment A, then hydroponic units were purged with RO water for 5 minutes in preparation for the initiation of experiment B. The purging was accomplished by flushing units with a hose and letting the wash-water drain out of the bottom into the greenhouse drainage. The planter reservoirs then were filled with RO water and re-dosed with the same level of hydroponic nutrient trialed in Experiment A (see section 2.3.6). Rose plants were maintained by periodic RO water replacement. On March 15 2002, the basins were drained and refilled with RO water containing a second nutrient dose of equal concentration to the previous application, and rose plants were pruned back to 5 - 8 branches on this date. On June 15 the basins were drained and refilled again with RO water containing a third nutrient dose of but half the concentration of the previous application, and rose plants were pruned again on this date. On August 20, the units again were purged with RO hose water in the same way as described above and the basins were then filled with RO water. They were drained and refilled successively once each week for three weeks thereafter, followed by occasional topping up to sustain the plants' water needs (weekly or bi-monthly) from August 20th until the initiation of this experiment on December 1, 2002, when roses were hand-pruned, hydroponic units were flushed with RO water, and basins refilled with the experimental wastewater and nutrients. Three nutrient concentrations were trialed in 4 replicates of 100 % polyculture wastewater randomly positioned in the SW quadrant of the PSG green house: three replicates acted as quality growth

controls and consisted of reverse osmosis water with nutrient concentrations matching the treatment containing the highest nutrient concentration (Figure 3.1, Table 3.1) .

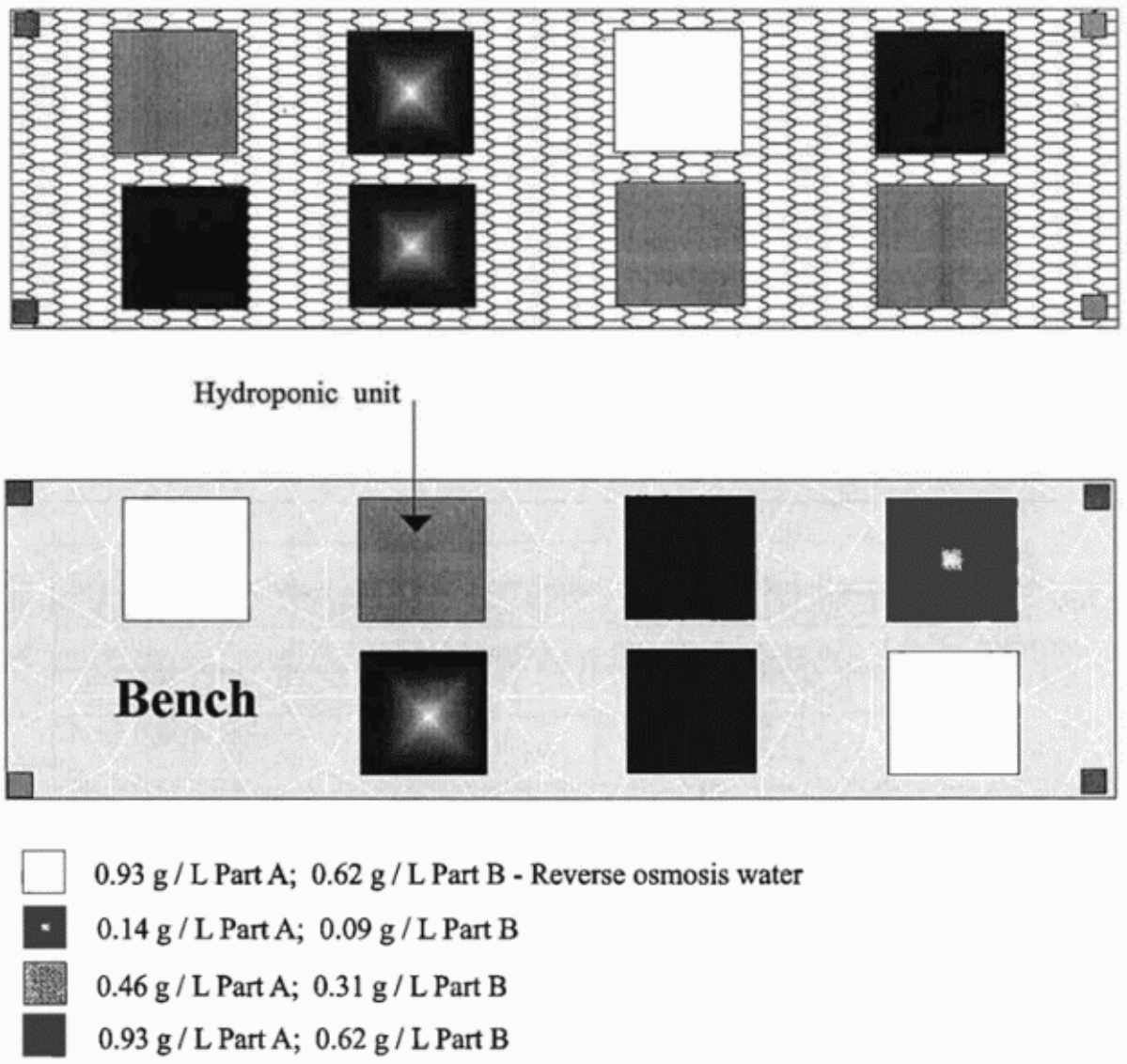


Figure 3.1. Experimental design of hydroponic units in the PSG green house.

	part A nutrient ($g\ L^{-1}$)	part B nutrient ($g\ L^{-1}$)
treatment		
1	0.93	0.62
2	0.46	0.31
3	0.14	0.09
RO water	0.93	0.62

Table 3.1. Amount of part A and part B Manutec nutrients applied to replicates in treatment and RO water replicates. The composition of Manutec can be found in Appendix D.

Table 3.2 shows the concentration of total nitrogen and total phosphorus of polyculture wastewater used in the experiment. Water was pumped to hydroponic units using an *Ogna* submersible pump and collapsible hoses (10 cm diameter) obtained from the CQU School of Biological and Environmental Sciences.

Polyculture - Wetland Wastewater Nutrient Concentration				
	sample 1	sample 2	mean	stdv
total phosphorus ($\mu g\ L^{-1}$)	130	122	126.3	5.7
total nitrogen ($\mu g\ L^{-1}$)	1170	1189	1179.2	13.6

Table 3.2. Total nitrogen and total phosphorus concentrations entering the units in polyculture wastewater (samples taken 01/12/02)-.

The same Lifetech AP-2000 power heads as used in hydroponic Experiment A (see Section 2.0) were used in 41.1 liter Rubbermaid plastic storage bins that were non-insulated but painted white exteriorly. Reservoirs were positioned below the hydroponic rose planters and lids were fitted using bricks and plastic bags as outlined in section 2.0. A *Clipsal* model LB/4 digital timer regulated four daily, 30 minute

recirculation cycles (7:30 am, 10:30 am, 1:00 pm, and 3:00 pm).

In this experiment only three flowers (the first three to have peduncles that reached 5 cm after pruning) were allowed to grow on each plant (similar to the methodology of Lorenzo, 2001) to minimize water loss via evapotranspiration because top up water was not available. Plants were pruned on December 1, 2002 and recording of stem length measurements began when stems reached 5 cm in length; and harvesting was concluded on January 19, 2003. Other stems (not chosen for measurement) on each plant were allowed to lengthen (instead of cutting back) to discourage new stems from initiating, however, all leaves were pruned off those stems every second day to limit transpiration. If flower buds began to form on the leaf-less stems before all three experimental flowers could be harvested, they were excised from the stem at their bases the first sign of bud development.

3.3 Measurement methods and statistical analyses

Stem length, flower diameter, and vase life measurements were completed following methods attained previously in section 2.0.

A one-way analysis of variance was used to determine differences in stem length, flower diameter, vase life, and water or usage between treatments. Treatment was set as factors and the aforementioned measures were set as dependent variables.

3.4 Results

Successful hydroponic production of roses occurred in all treatments. Stem lengths of flowers grown in the most dilute treatment were significantly shorter than flowers grown in all other treatments by an average of 9 cm ($p \leq 0.05$). Stem lengths of flowers grown in the remaining treatments (including the nutrient fortified RO water control) were not significantly different from one another. Table 3.3 presents the flower growth period, stem length, diameter, vase life and water usage data collected. On average, experimental plants produced flowers, after 36 days of hydroponic culture and 11 L of water use per flower produced; that were 8 cm diameter with 44 cm stems, and which lasted 5 days in the control room. Mean ambient temperature from the time of the latest pruning to harvest was 26.5° C.

	growth period (days)	stem length (cm)	flower diameter (cm)	vase life (d)	water use per flower (L)
Treatment 1					
mean	35.8	46.3	8.0	5.5	10.8
stdv	1.9	8.9	0.7	0	0.3
Treatment 2					
mean	35.8	46.1	8.1	5.0	10.7
Stdv	4.0	2.2	0.2	0	0.2
Treatment 3					
mean	38.8	37.2	7.6	5.7	10.4
Stdv	6.4	3.4	0.3	0	0.0
RO H2O					
mean	35.1	46.7	8.1	5.3	10.3
Stdv	2.2	4.2	0.2	0	0.5

Table 3.3 Experiment B: flower growth period, stem length, flower diameter, vase life, and water usage delineated by treatment.

3.5 Discussion

The experimental goal was met: roses were cultured successfully using polyculture wetland wastewater, and thus completing the linkage of integrated polyculture - wetlands to floral hydroponics.

The experimental objective: to determine whether differences in flower characteristics resulted between wastewater treatments, also was met. The null hypothesis was rejected in the case of stem length but accepted across the remaining parameters of growth period, flower diameter, vase life, and water use. A quality product was cultivated successfully across treatments, even though significantly shorter stem lengths were produced in the most dilute wastewater replicates.

Product quality was high: flowers were vibrantly colored, fragrant, and supported by straight stems. Warmer ambient temperatures resulted in a flower growth period that was markedly faster than in Experiment A however water use and flower quality were comparable. Shoot lengths of the flowers produced were comparable to published data (Lorenzo et al., 2001, Malorgio et al., 2001). Additionally, the reduced concentration of *Manutec* nutrients used in treatment 2 (in combination with the wastewater nutrients) is recommended as sufficient to support the growth of three flowers.

3.6 Conclusion

This experiment illustrated that wastewater re-use linkages between integrated polyculture - wetlands and floral hydroponics could be successful. Additionally, a rough guideline to fertilization requirements of the German rose using *Manutec* hydroponic nutrient mix under similar cultivation conditions is presented.

4.0 Experiment C - Hydroponic Production of *Rosa hybrida* (cv 'Duftzauber 84') in Power Station / Polyculture - Wetland System Wastewater

4.1 Experimental goals, objectives, and hypotheses

The goals of this experiment were to re-use the residual wastewater generated in the experiment run in Chapter II (Metal Accumulation within *Lates calcarifer, Cherax quadricarinatus*, and *Baumea articulata* cultured in Integrated Polyculture - Constructed Wetland Mesocosms Irrigated with Industrial Wastewater) to support rose hydroponics and to successfully link the power station wastewater, integrated polyculture wetlands, floral hydroponics triad. The objective was to determine whether there were differences in flower growth period, stem length, flower diameter, vase life, bloom percentage, and water quality and water usage between 0%, 50%, and 100% wastewater treatments.

Null Hypothesis:

There will be no difference in flower growth period, stem length, flower diameter, vase life, water quality and water usage resulting between rose plants cultivated in 0 %, 50 %, and 100 % wastewater solutions.

Alternate Hypothesis:

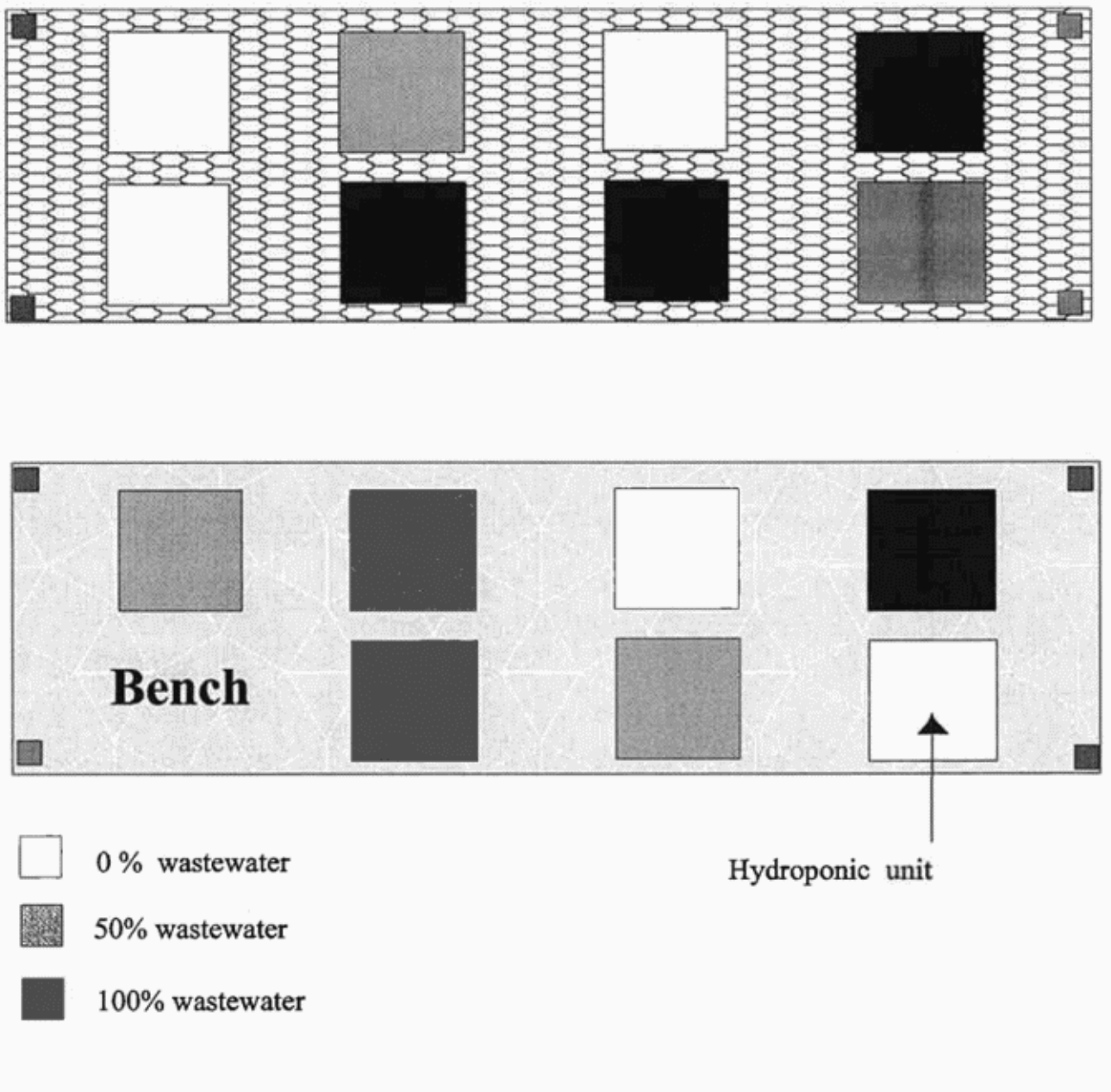
There will be reduced flower growth period, stem length, flower diameter, vase life, water quality, and water usage resulting between rose plants cultivated in 100 % wastewater solutions.

4.2 System design and operating methods

Directly following experiment B, hydroponic units were purged with RO with water for 5 minutes each by flushing units with a hose and letting the wash-water drain out the bottom into the greenhouse drainage. The reservoirs then were filled with RO water and re-dosed with the same level of hydroponic nutrient trialed in Experiment A (see Section 2.3.6). Rose plants were maintained by periodic water and nutrient replacement, and one pruning on March 1 2003. On April 12, 2003 the units again were purged with RO water in the same fashion, and basins were refilled. The hydroponic planter reservoirs were drained and refilled once each week for three weeks, as well as topped up occasionally with RO water on a needs basis to sustain the plants until the initiation of this experiment (Experiment C). Hydroponic planter reservoirs were not supplemented with nutrients over the period.

Replicates were set randomly in the SW quadrant of the PSG green house (Figure 4.1). On June 27 wastewater was transferred manually (from the experiment

outlined in Chapter III, Section 2) to the hydroponic units using 25 L buckets, and mixed with RO water to make up 0 %, 50 %, and 100 % wastewater concentrations within appropriate treatments. Nutrients were added to the replicates in the same concentration used in treatment 2 of Experiment B (see Section 3, Table 3.1). On July 10, 2003, three ml of 32 % HCL was added to the basins to bring initially high pH levels in the reservoirs to *c.* 4.0. Although low, it was predicted that pH would rise slowly in the hydroponic water over the growth period (as in Experiment A), and to remain within in the pH range in which roses are known to grow: moderately acidic to moderately alkaline conditions, with a pH of 6.0 to 6.5 being optimal (Beales et al., 1998).



Rose plants were pruned to two branches on July 1, 2003, and harvesting was concluded on August 27, 2003. Two flowers were allowed to grow, one per branch, on each plant (similar to the methodology of Lorenzo, 2001), consisting of the individuals that reached 5 cm first after pruning. Additional stems were managed in the same fashion as in experiment B (see Section 3.2).

4.3 Measurement methods and statistical analysis

Stem length, flower diameter, vase life, and water quality measurements were completed following methods in Experiment B (Section 3.0).

A one-way analysis of variance was used to determine if differences in stem length, flower diameter, vase life, and water usage between treatments occurred. Treatment was set as factors, and the aforementioned measures were set as dependent variables.

4.4 Results

4.4.1 Flower growth

Successful hydroponic production of roses took place in all treatments. Significantly fewer flowers were brought to bloom in the 100 % treatment ($p \leq 0.05$):

only 40 % of the flower buds opened at maturity as sepals failed to loosen and contract. Differences in remaining flower characteristics were not significant among treatments. Table 3.3 shows flower growth period, stem length, flower diameter, vase life, and water usage for 5 plants in each treatment. On average, experimental plants produced flowers after 51 days of hydroponic culture and 17 L of water use per flower, 8 cm in diameter on 66 cm stems, and which lasted 6 days in a vase. Mean ambient temperature from the time of pruning to time of harvest (i.e. July 1, 2003 to August 27, 2003) was 17.5 ° C.

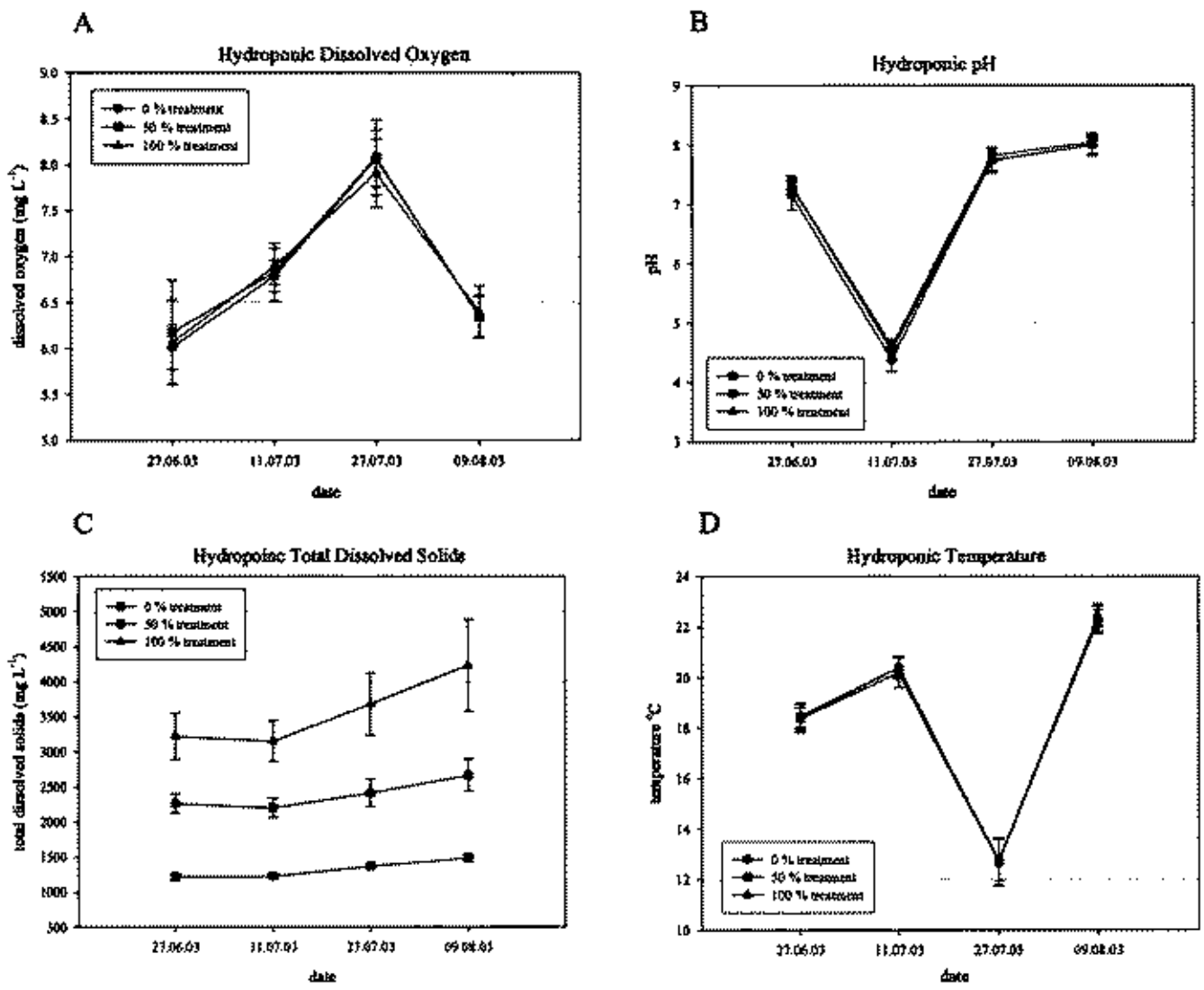
	days growth	stem length (cm)	flower dia (cm)	Vase life (d)	Liters (l)	% bloom
0 %						
mean	53.6	68.1	8	6	16.7	100
stdv	1.0	12.9	1	0	0.7	0
50 %						
mean	51.3	66.8	8.0	5.7	16.2	100.0
Stdv	5.4	10.5	0.4	0.3	1.2	0.0
100 %						
mean	46.5	62.7	7.2	5.8	16.7	40.0
Stdv	6.9	20.2	0.2	0.4	1.3	54.8

Table 4.1. Experiment C: flower growth period, stem length, flower diameter, vase life, water usage, and bloom percentage of flowers delineated by wastewater treatment.

4.4.2 Water quality

Mean electrochemical hydroponic DO, pH, TDS, and temperature over the experiment were 6.8 mg L^{-1}, 6.9, 2.4 g L^{-1}, and 18.5 °C, respectively (Figure 4.2 A-D). Mean TDS concentration in the 100 % treatment was significantly greater than in the 50 % treatment ($p \leq .05$) while the latter were significantly greater than in the

0 % treatment ($p \leq .01$). Total dissolved solids concentrations increased over time in all cases; and an interaction of main effects occurred when TDS concentration in the 0 % treatment did not decrease over the first 2 week period. Differences in other electrochemical characteristics between treatments were not significant. Time had a significant effect on DO ($p \leq .0.05$), pH ($p \leq .05$), and temperature ($p \leq .05$): values increased over the experiment although they fluctuated markedly.



Figures 4.2. Dissolved oxygen (A), pH (B), total dissolved solids (C) and (D) temperature of hydroponic water during Experiment C

4.5 Discussion

The experimental goal was met: roses were cultured successfully using wastewater from the experiment run in Chapter II (despite significantly lower production in the 100 % wastewater treatment), thus completing the power station wastewater, integrated polyculture wetlands, floral hydroponics triad linkage.

The experimental objective also was met, and the null hypothesis was rejected in the case of the number of flowers that bloomed in the 100 % wastewater treatment, but accepted across treatments for flower growth period, flower diameter, vase life, and water use variables.

Clearly successful cultivation was achieved in the 0 % and 50 % wastewater treatments and product quality was high: blooms were vibrantly colored, fragrant, and supported by straight stems. Losses of over half the floral product in the 100 % wastewater treatment was attributed to high TDS concentration in all replicates, as flowers did not bloom if final TDS concentrations measured ≥ 4000 mg L^{-1}. Although Lorenzo (2001) did not observer any impacts of high solution conductivity on rose production, the hydroponic solution ionic concentration used in his experiment was half that of the concentration of wastewater that affected flower production in this experiment (data were converted using the relationship: dS m^{-1} x 640 = TDS mg L^{-1}). Over all floral production and water use was calculated to be less efficient than in previous trials A and B. This was attributed to the winter growing conditions with cooler temperatures and lower relative humidity compounded by high dissolved solids in the most concentrated treatment. However, flower stem lengths were longer than in previous trials in this study, possibly a response to the reduction of flowers allowed to grow on each plant, and were

comparable to other published data (Lorenzo et al., 2001, Malorgio et al., 2001).

4.6 Conclusion

This study illustrated that triad linkages of power station wastewater, integrated polyculture wetlands, and floral hydroponics were possible. However, when using 100 % strength wastewater, TDS values could reach levels where rose blooming would fail to occur, thus requiring manipulation of hydrology to overcome that limiting factor of tertiary re-use in recirculating rose hydroponics.