Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 13, Issue, 04, pp.16981-16992, April, 2021

DOI: https://doi.org/10.24941/ijcr.41180.04.2021

ISSN: 0975-833X

REVIEW ARTICLES

OPEN ACCESS

REVEGETATION IN REMEDIATED SOIL AT SOUTH EAST KUWAIT AND REVISION OF REMEDIATION STANDARD– A CASE STUDY FROM DESERT ENVIRONMENT

*Al-Baroud A., Vangala K, Al-Jumah K, Al-Rewaih K. and Potts M.

Soil Remediation Group, Kuwait Oil Company, Ahmadi, Kuwait

ARTICLE INFO

Article History:
Received 25th January, 2021
Received in revised form
20th February, 2021
Accepted 19th March, 2021
Published online 24th April, 2021

Key Words:
Ameloblastoma, Follicular, Mandible, Multilocular, Recurrence.

***Corresponding author:** Al-Baroud A.,*

ABSTRACT

The Sustainable Environmental and Economic Development (SEED) project was developed in Kuwait to undertake remediation and rehabilitation of abandoned upstream production areas within the Oil Fields of Kuwait. The aim of the rehabilitation component of the project was to leave previously contaminated areas of the oil fields, such as effluent pits, sludge pits and gatch pits, in a relative natural state in order that once remediated, they would not require ongoing management and would not pose a significant risk to sensitive environmental receptors. To this end, the rehabilitation component of the project included a native plant restoration and monitoring program with the purpose to evaluate the effectiveness of restoration methods, namely the use of irrigation and soil amendment, in facilitating the establishment of a native plant community. In addition, the remediated soil was returned to the various pits and if native plants could be established, that would provide an indication of the success of the soil remediation process. This study focuses on the remediation and rehabilitation undertaken in three pits (one sludge pit and two effluent pits). The contaminated soil was subjected to either bioremediation or thermal treatment, then reapplied to the pits. A reference area was planted in a location that represented a relatively undisturbed site in the oil field to establish an experimental control. If plant establishment was similar or better in rehabilitated features to the undisturbed reference areas, then rehabilitation could be considered on a similar trajectory as a natural ecosystem. Components of the rehabilitation program included eight native plant species, high-level and low-level irrigation and soil amendment (biogenic fertilizer). Plants were installed in the features using a block design whereby equal numbers of plants received the irrigation and soil amendment treatments, as applicable. The planting blocks were subdivided with half established with amended soil and half in unamended soil, these were then further divided into areas of high and low irrigation. In the reference area blocks, half of all plants received high-level irrigation and the other half received low-level irrigation. Plant survival and growth were measured over the monitoring period. Results of the monitoring showed that several factors can play a role in affecting establishment of native plant species. Overall, plant survival varied quite markedly depending on the site. It was hypothesized that plant survival would be best in the reference areas where soil disturbance was minimal. This hypothesis is consistent with the findings of this study. It was also hypothesized that high-level irrigation may result in better plant survival and growth by providing more available water at the root zones of plants. However, results showed that although irrigation events generally improved soil moisture levels, the difference in soil moisture between high and low irrigation rates was overall, not significant. This indicates that plants receiving high-level irrigation had similar moisture near their roots as plants receiving low-level irrigation. This could be the reason why in general, high irrigation resulted in only small improvements to plant survival and plant growth in some pits. In the sludge and effluent pits, the addition of an amendment to remediated soil was tested because of the potential to provide useful nutrients to plants and to improve soil texture and water holding capacity, thereby potentially improving plant survival and growth. There were significant differences in plant survival among the features; however, the addition of the soil amendment did not provide a clear or consistent improvement in plant survival, nor did it result in much greater plant growth (small improvements were realized). Rather, plant survival appeared to be more influenced by the size of plants at the time of installation. Because established criteria for planting the rehabilitated features was used, there was some control over certain variables that could affect plant establishment, such as species selection, site preparation, spacing of plants, and frequency and amount of irrigation. However, other variables not controlled could have also affected plant establishment and played a role in the results of this research. Differences in site conditions (i.e. location, aspect, wind, natural rainfall), soil texture and micronutrients, and the propagation and handling of plant material (in the plant nursery and during planting) could be confounding factors, together with irrigation rate and soil amendments. Several lessons learned were identified from this study and may be worth consideration in future restoration and rehabilitation of decommissioned facilities and/or disturbed landscapes across Kuwait oil fields. Adaptive management (i.e. the ability to direct change based on feedback from monitoring as one gains experience with local conditions) is very important, and it allows for the effective incorporation of lessons learned into the decision making process as the project evolves, and to positively affect the delivery of new projects as they are developed. The findings of this study lead to amendments to statutory remediation standard for future remediation projects within the oil fields of Kuwait.

Citation: Al-Baroud A., Vangala K, Al-Jumah K, Al-Rewaih K. and Potts M.. "Revegetation in Remediated Soil at South East Kuwait and Revision of Remediation Standard– A case study from desert environment*", 2021. International Journal of Current Research, 13, (04), 16981-16992.*

INTRODUCTION

The Sustainable Environmental and Economic Development (SEED) project was developed in Kuwait to undertake remediation and rehabilitation of abandoned upstream production features within the oil fields of Kuwait.

Rehabilitation Program: The rehabilitation program was designed to measure the ability of native plant species to become established in remediated soil, the success of which would provide a good indication of the success of the remediation processes engaged. In addition, this would leave the remediated features in a relative natural state minimizing the requirement for ongoing management and mitigating the risks to sensitive environmental receptors. Discussions about the advantages of planting established nursery grown plants versus seeding resulted in the conclusion that for the purposes of evaluation of the effectiveness of the remediation program, established plants grown in nurseries would be preferable as their success and growth rate could be better measured than the germination and survival of seedlings grown directly in-situ.

Some plants are capable of growing in heavily contaminated soils and during the field surveys shrubs and grasses growing directly adjacent to or on oil contaminated soils were examined. The ability of plants to grow in such conditions is also related to the degree of soil compaction, salinity and the hydrophobic nature of the soil. If the soil particles are not uniformly coated with oils, and the salinity levels are not too high, then there is the potential for water to penetrate the soil and plants to grow. A number of plants were proposed for the Rehabilitation Program and it was thought that in order to simplify the program, a maximum of five species (two shrubs, one grass, one sedge and one legume) would be used in the sludge and effluent pits. The species selected for the Rehabilitation Program are all native Kuwaiti species and were: *Rhanterium epapposum*, *Nitraria retusa*, *Panicum turgidum*, *Cyperus conglomeratus*, *Astragalus spinosus*, *Ziziphus spina-christi*, *Acacia gerrardii* and *Prosopis farcta* (See Figure 1)

METHODS

Plant Species Selection: Plant selection for the rehabilitation of remediated sites was based on using a few perennial species that are native to Kuwait. It was essential to use perennials as otherwise the success of the plantings could not be evaluated. The majority (70%) of native Kuwait plants are annuals (Omar et al. 2007), limiting the choice of potentially suitable plant species. It was thought to be most practical to have two shrubs, two grasses and a legume. The choice of the *Rhanterium epapposum* was obvious, as it is the national flower of Kuwait. This species also forms the dominant plant community in Kuwait, is important in sand stabilization, and is the preferred species for grazers (Omar and Bhat 2008). The second shrub chosen was *Nitraria retusa* which is common in coastal and saline soils and should do better in some of the more saline soils found in and around oil field operations. The most common sedge species is undoubtedly *Cyperus conglomeratus*, which forms dominant plant communities in south east Kuwait and is widespread in sand formations in many phytogeographic regions of Arabia (Batanouny 1987, Omar et al. 2007). It is very resilient and it was thought to be a good choice for planting in potentially unstable disturbed areas, which was the expected condition of the remediated sites. A grass, *Panicum turgidum*, was chosen because it is one of the dominant grasses in Kuwait, forming distinct mounds of considerable size (Batanouny 1987). The choice of a legume was difficult as the majority of legumes are annuals. However, *Astragalus spinosus* was selected because it is a perennial species, it has large spines that would protect it from grazers and was thought to be suitable as a potential nitrogen fixer in conditions that are known to be nitrogen deficient. While there appears to be little information about the use of native legumes in Kuwait to improve soil conditions, many authors have found that various species are very effective at fixing atmospheric nitrogen and contributing to improved soils under desert conditions (Al-Fredan 2010, Weiwei 2002).

Irrigation Design: Water is a vital commodity in desert environments, and it is necessary to ensure that water penetrates the soil and does not evaporate. Much of the irrigation in Kuwait is done by means of drip or trickle irrigation or by overhead sprinkling. In many cases, trees are planted in depressions with a single emitter delivering water to the tree. Surface water evaporates rapidly and this often results in salts being brought to the surface by capillary action which is often seen as white encrustations. This salinization of soils occurs throughout arid zones where water percolation is slow and evaporation may be high resulting in decreased productivity (Al-Awadi et al. 2005).

Where water is a scarce commodity, porous irrigation tubes have been used very successfully to deliver water directly to the root zone of desert trees and shrubs (Bainbridge 2001, 2007). Common items such as clay pots, plastic or PVC pipes can be installedinto the ground to serve as efficient ways of delivering water to plant roots while minimizing loss from evaporation (Bainbridge 2001, 2007). For the scale of planting, PVC pipes of standard dimensions were recommended as they would be easy to obtain and have been used successfully in desert restoration projects elsewhere (Bainbridge 2007). Further, the pipes could be removed from the ground at project completion without disturbing established plants. In order to provide a measured amount of water to plants, a system using two different diameter PVC pipes (10 cm and 7.5 cm), each 50 cm long and capped with a PVC cap at the bottom end, was utilized. Five holes 3 millimeters (mm) in diameter were drilled at 7.5 centimeters (cm) intervals up one side of each pipe (See Figure 2). The pipes were installed45 cm into the ground and were removed at the conclusion of the irrigation phase. Larger diameter tubes provided 3.92 litres of irrigation water (i.e. high level irrigation) and smaller diameter tubes provided 2.2 litres of irrigation water (i.e. low level irrigation) during each irrigation event. The top of the PVC pipe was covered in a wire mesh screen to prevent animals falling in the pipes. A pair of larger holes was drilled near the top of each tube to allow a rod to be slipped through for extraction of the tube should maintenance be required. The normal precipitation in Kuwait falls irregularly in the winter months from October to May with most of the precipitation falling in December and January (Batanouny 1987, Brown 2002). During this period plants may grow, flower and reproduce. Once the late spring and summer temperatures occur, native plants either die or go into dormancy. It was therefore decided to limit the irrigation of plants to the winter and spring months to help them become established.

Irrigation was applied twice monthly from November to May regardless of natural rainfall patterns, and ceased during the hot summer months when the plants normally senesce or go into dormancy. Such an irrigation regime was also found to be effective by nursery growers in Kuwait (Kaitharath pers com).

Planting Time: The intent for specifying a definite window for planting was the necessity to give plants time to establish themselves prior to the hot summers when they would not have any water. Therefore, the earliest time in the winter is preferable and a recommended time from November to mid-December was thought to be optimal for plant establishment. This would give plants approximately four months to develop root mass and sufficient reserves to survive the summer dry period. However, in some instances the timing of plant installation was extended into subsequent months due to the delay in site preparation activities and availability of plant material.

Planting Layout

Reference Areas

Reference blocks were 24 m x 24 m with plants spaced at 2 m on centres (o.c.) resulting in a total of 144 plants (See Figure 3a). Plants were installed in a replicating pattern of shrub 1 (*R. epapposum*), legume (*A. spinosus*), grass 1 (*P. turgidum*), shrub 2 (*N. retusa*), legume (*A. spinosus*), grass 2 (*C. conglomeratus*).

Sludge and Effluent Pits: Upon completion of soil remediation, six planting blocks were laid out in each pit feature as given in Figure 3b. In the sludge pits, the blocks were a dimension of 24 m x 24 m and in the effluent pits, the blocks were a dimension of 48 m x 48 m. A soil amendment was applied in half of the planting blocks (Refer Figure 3). Planting occurred between December and early-March. Plants were installed in all pits in a replicating pattern of shrub 1 (*R. epapposum*), grass 2 (*C. conglomeratus*), legume (*P. farcta*), shrub 2 (*N. retusa*), grass 1 (*P. turgidum*), and legume (*P. farcta*). Prior to installation both in Reference Areas and Sludge & Effluent Pits, all plant material was inspected for general good health and as per quality assurance and control requirements. After the plants passed inspection, they were planted adjacent to the previously installed irrigation tubes. Half of the plants received low level irrigation and the other half received high level irrigation per each block. Plants were watered in-situ after they were installed and the irrigation tubes were also filled for the first watering.

Soil Remediation Processes and Standards: Soil remediation technologies utilized included thermal desorption and bioremediation. One sludge pit (SPC1) and two effluent pits (EPC3 and EPC4) were identified for testing these processes and their potential effects on restoration outcomes. Following the completion of treatment by the identified methods only material complying with the specific thresholds were backfilled into the pits in order to receive restoration plantings. Cleaned material met either Primary Ecotoxicity Remediation Standard (RS) of 5,580 ppmor Alternate Ecotoxicity RS of 10,000 ppm. One effluent pit was treated to the Alternate Ecotoxicity RS, all other features were treated to the Primary Ecotoxicity RS. A summary of the remediation methodologies and standards are provided in Table 1 below.

Soil Amendments: In order to establish the potential future requirement for the use of various amendments to help improve the structural, chemical and biological condition of treated soils,it was agreed that commercially available biogenic fertilizer amendment at a rate of approximately 2.5 kg/m^2 mixed into the top 50 cm of soil, which equates to a rate of approximately 5 kg/m^3 was used.

Soil Analysis: Soil samples were taken from reference areas, sludge pits and effluents pits. The intention of the sampling design was to evaluate any changes in remediated soil chemistry over time due to irrigation and weathering. Each composite sample consisted of 10 subsamples taken from randomized locations in planting blocks. Samples were taken from two depths respectively, surface (0-25 cms) and deep (25-60 cms). Physical, chemical and biological (i.e. microbial biomass) analyses were completed for composite samples in reference areas and sludge and effluent pits. The analytical data was reviewed to determine that conditions were favourable for planting and to support technical decisions related to the need for and quantity of soil amendments.

Monitoring Program: The monitoring program was instigated to determine the success of the rehabilitation element of the project. This looked at a number of parameters including, plant growth and survival, which are the focus of this research. In addition natural plant colonization, soil moisture and salinity were also monitored, however, these are not considered within this research study.

Plant Growth and Survival: It is essential to have a method of comparing the growth and establishment of plants in the rehabilitation blocks to establish the success of the remediation of the contaminated soils. In this case, it was assumed that plants would grow better in soils that were less contaminated than in soils that were more contaminated. The results from the many different planting blocks, irrigation treatments and soil amendments provide enough information to determine trends in growth and survival that may be worth consideration when planning future restoration work.

Plant Survival

Survival was measured by visual observation of the condition and general health of the plant. A plant was categorized as one or more of the following:

- Stable (no obvious growth)
- Growing (new shoot and/or leaves)
- Dead (plant dead or >50% dead)
- Flowers (flower buds or open flowers)
- Herbivore impact (evidence of loss of plant tissue from grazing)
- Salt burn
- Sand engulfment
- Presence of pests
- Disease incidences
- Nutrient deficiency
- Wilting

The condition of plants was measured once monthly during the growing season from November to May. This is the time period when seeds germinate, plants produce new shoots and leaves, and flowering occurs. From June through October, plants enter a dormant state whereby growth stops and metabolic activity either ceases or is drastically reduced, allowing plants to withstand the intense heat and drought conditions of the summer months. Although plants may appear to be dead at this time, they are indeed alive and will initiate active growth again when environmental conditions are favorable to do so.

Height and Width of Plants: Plant growth was measured by determining the height and width of plants from each planting block. These measurements were done at the time of plant installation, the beginning of the growing season in (November-December) and towards the end of the growing season (April-May). Plants that died during the monitoring period were not included in the calculations of average plant width. The weighted average width was calculated to account for the different number of plants used in averaging plant width in each planting block. For the purposes of results summaries, only average plant width is presented. The reason for this is that plant width is common measurement in plant community evaluations and is related to an estimate of "cover" or the horizontal projection of the plant biomass on the ground. It can be used as an evaluation of abundance, which is often expressed as a percent. Therefore, the growth of plants measured as a change in the average width of plants gives an indication of plant health, as well as how much plant cover exists in the rehabilitated features.

Data Synthesis and Analysis: The data collated during the 18 month monitoring period has been utilized to better understand those factors that might affect restoration success in remediated areas, particularly plant survival and growth, data on percent survival and total average growth (i.e. plant width at the post monitoring minus plant width at the prior to monitoring period) were summarized according to influencing factors such as site, species, irrigation level and soil amendment (i.e. amended versus unamended soil), where applicable. In order to determine whether irrigation was improving moisture availability to plants, soil moisture measurements were analyzed before and after irrigation events. In addition, the difference in soil moisture levels in high versus low irrigation blocks after events were compared to determine whether high-level irrigation resulted in more water present in the rooting zones of plants. Comparisons of means were analyzed using student t-tests and/or paired student t-test for data collected before/after irrigation events (Zar, 2010).

RESULTS

The results presented below are arranged for each feature i.e. one Reference Area, one Sludge pit & two Effluent Pits). Enclosed provides locational information within the Burgan Oil Field for all rehabilitated features included in this report.

Reference Area: The Reference Area is located in the central portion of the Burgan Oil Field.

Plant Survival: A summary of average plant survival over the first and second growing seasons in the reference area is provided in Table 2 below. Overall, the survival rate for the first year of plant establishment was 100% under both irrigation regimes. It was also observed that the majority of all plants were flowering and growing, especially *R. epapposum* and *A. spinosus.* At the start of the second growing season (in Dec month), plant survival remained generally high across both irrigation blocks, the one exception being *N. retusa* in the high irrigation block (8% survival). A majority of all other plants appeared to have survived the summer dormancy period relatively well, and plant survival remained consistent over the second growing season. There was only additional mortality observed in *P. turgidum* (2 plants). Results demonstrated good survival rates for all species under the respective irrigation regimes (79% under high irrigation and 90% under low irrigation).

Plant Growth: A summary of plant width over the first and second growing seasons in the reference area is provided in Figure 4. For all plant species, the average width under both high and low irrigation levels increased over each monitoring period (i.e. growing season). It appears that some species exhibited slightly better growth under high irrigation (*R. epapposum, C. conglomeratus* and *A. spinosus*) by the end of the monitoring period, whereas others performed better under low irrigation (*N. retusa* and *P. turgidum*). In light of the variability in plant width measurements, these trends are not likely to be significant.

Sludge and Effluent Pits: Sludge and effluent pits are located in the southern portion of the Burgan Oil Field (Figure1). The pits subject to rehabilitation and subsequent monitoring include sludge pit C1 (SPC1), effluent pit C3 (EPC3) and effluent pit C4 (EPC4). The hydrocarbon contaminated soil in the pits and the earthen berm walls surrounding the pits was subject to either thermal desorption treatment or bioremediation. The bioremediation process used a consortium of microbes to biodegrade the petroleum hydrocarbon in the soil. The process involved a specially designed nutrient formulation and water to maintain the growth of microbe populations without any harmful secondary pollutants created. Soil was monitored and tilled regularly until the required ecotoxicity standard was met.

In SPC1, cleaned soil was almost entirely thermally treated (approximately 95%) and a small amount (approximately 5%) was bioremediated. In EPC3, the cleaned soil comprised approximately equal amounts of thermally treated and bioremediated soil. In EPC4, the soil was entirely bioremediated in-situ. It is also important to note that in EPC4, low microbe counts were identified during monitoring due to high salinity levels. As a consequence, low-saline thermally treated soils (such as those from SPC1 and EPC3) were mixed at a 1:1 ratio with the bioremediated soil, and then gypsum was added to further reduce the Sodium Absorption Ration (SAR). The thermally treated and bioremediated soil met either the Primary Ecotoxicity RS (SPC1 and EPC3) or the Alternate Ecotoxicity RS (EPC4). Lastly, a biogenic soil amendment was applied in half of the planting area of the pits at a rate of approximately 2.5 kg/m^2 and was mixed into the top 50 cm of cleaned soil. In SPC1, six planting blocks were laid out, each with a dimension of 24 m x 24 m. Planting blocks #1, #2, and #3 were placed in amended soil and blocks #4, #5 and #6 were placed in unamended soil. A total of 144 plants were installed in each block, at a distance of 2 m o.c., in a replicating pattern of shrub 1 (*R. epapposum*), grass 2 (*C. conglomeratus*), legume (*P. farcta*), shrub 2 (*N. retusa*), grass 1 (*P. turgidum*), and legume (*P. farcta*). Half of the plants received low level irrigation and the other half received high level irrigation per each block. A grand total of 864 plants were installed in SPC1. In EPC3 and EPC4, six planting blocks were also laid out respectively, but each with a dimension of 48m x 48m. Planting blocks #1, #2, and #3 were placed in amended soil and blocks #4, #5 and #6 were placed in unamended soil. A total of 576 plants were installed in each block, at a distance of 2 m o.c., in a replicating pattern of shrub 1 (*R. epapposum*), grass 2 (*C. conglomeratus*), legume (*P. farcta*), shrub 2 (*N. retusa*), grass 1 (*P. turgidum*), and legume (*P. farcta*).

Table 1. Remediation Treatments and Standards in Rehabilitated Features

Features	Remediation Treatment(s)Applied		Remediation Standard Applied	
	Thermal Desorption	Bio-remediation	Primary RS	Alternate RS
SPC1	X	X	X	
EPC3	X	X	X	
EPC4		X		X

Table 2. Average Survival Of Plants over Time in Reference Area

Species	% Survival High Irrigation				% Survival Low Irrigation			
	Monitoring Period		Monitoring Period		Monitoring Period		Monitoring Period	
	Start	End	Start	End	Start	End	Start	End
R. epapposum	100	100	100	100	100	100	100	100
N. retusa	100	100	8	8	100	100	75	75
P. turgidum	100	100	100	100	100	100	92	75
C. conglomeratus	100	100	92	92	100	100	100	100
A. spinosus	100	100	96	96	100	100	100	100
Average	100	100	79	79	100	100	93	90

Table 3. Plant Species and Number of Plants in SPC1

Species	Amended Soil						Unamended Soil					
	Planting Block #1		Planting Block #2		Planting Block #3		Planting Block #4		Planting Block #5		Planting Block #6	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
R. epapposum	12	12	12	12	12	12	12	12	12	12	12	12
N. retusa	12	12	12	12	12	12	12	12	12	12	12	12
P. turgidum	12	12	12	12	12	12	12	12	12	12	12	12
C. conglomeratus	12	12	12	12	12	12	12	12	12	12	12	12
P. farcta	24	24	24	24	24	24	24	24	24	24	24	24
Plants per Sub-block	72	72	72	72	72	72	72	72	72	72	72	72
Plants per Block	144		144		144		144		144		144	

Table 4. Plant Species and Number of Plants in EPC3 and EPC4

Species	Amended Soil						Unamended Soil					
	Planting Block #1		Planting Block #2		Planting Block #3		Planting Block #4		Planting Block #5		Planting Block #6	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
R. epapposum	48	48	48	48	48	48	48	48	48	48	48	48
N. retusa	48	48	48	48	48	48	48	48	48	48	48	48
P. turgidum	48	48	48	48	48	48	48	48	48	48	48	48
C. conglomeratus	48	48	48	48	48	48	48	48	48	48	48	48
P. farcta	96	96	96	96	96	96	96	96	96	96	96	96
Plants per Sub-block	288	288	288	288	288	288	288	288	288	288	288	288
Plants per Block	576		576		576		576		576		576	

Table 5. Average Survival of Plants in SPC1 Over Time

Species	% Survival							
	End of 1st Monitoring Period				End of 2nd Monitoring Period			
	Amended Soil		Unamended Soil		Amended Soil		Unamended Soil	
	High	Low	High	Low	High	Low	High	Low
R. epapposum	63.89	27.78	38.89	27.78	50.00	25.00	33.33	19.44
N. retusa	50.00	27.78	13.89	13.89	0.00	0.00	0.00	0.00
P. turgidum	100.00	100.00	100.00	100.00	55.56	38.89	30.56	33.33
C. conglomeratus	100.00	100.00	100.00	100.00	55.56	11.11	25.00	16.67
P. farcta	83.33	59.72	51.39	37.50	34.72	38.89	30.56	31.94
Average	79.44	63.06	60.83	55.83	39.17	22.78	23.89	20.28

Name Of Species: Cyperus conglomeratus
Local Name Of Species: Thanda

Name Of Species: Panicum turgidum
Local Name Of Species: Thamam

Name Of Species: Acacia gerrardii
Local Name Of Species: Talh

Name Of Species: Astragalus spinosus
Local Name Of Species: Qatad

Name Of Species: Rhanterium epapposum
Local Name Of Species: Arfaj

Name Of Species: Ziziphus spina-christi
Local Name Of Species: Sidr

Name Of Species: Prosopis farcta
Local Name Of Species: Yanbout

Name Of Species: Nitraria retusa
Local Name Of Species: Gharqad

Figure 1. Native Plant Species used in Study

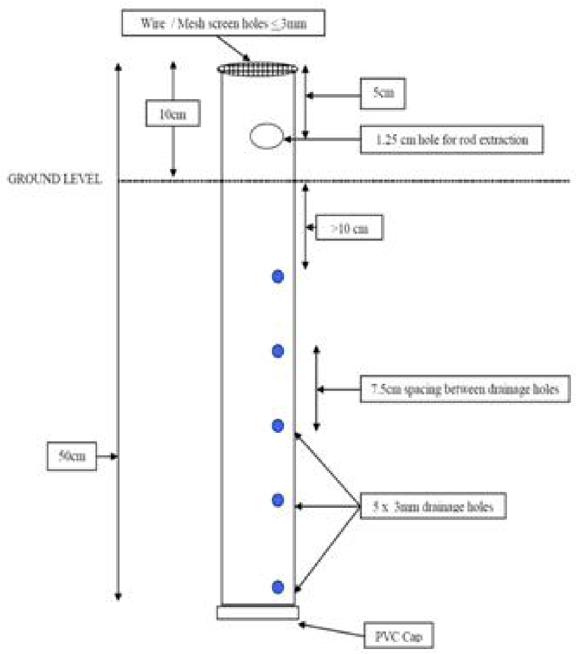


Figure 2. Irrigation Tube Design

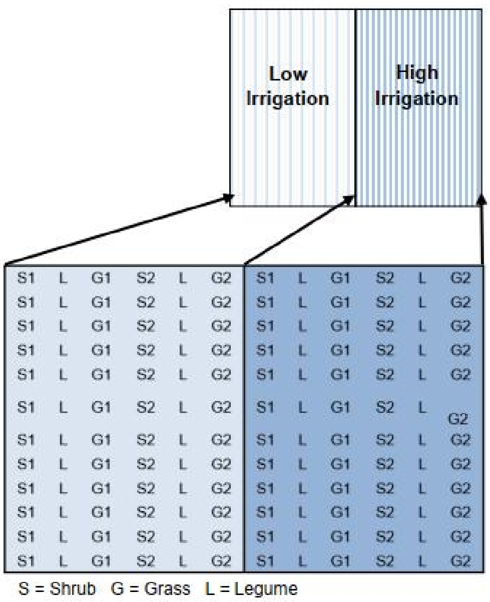


Figure 3a. Reference Area Planting Block Layout

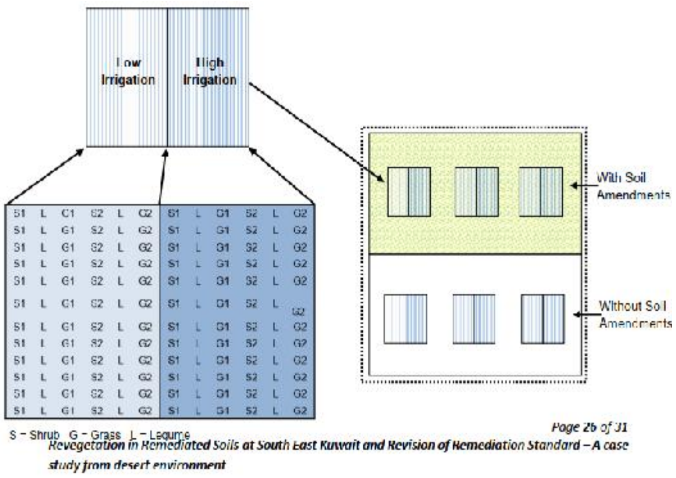


Figure 3b. Feature Planting Block Layout

Half of the plants received low level irrigation and the other half received high level irrigation per each block. A grand total of 3,456 plants were installed in EPC3 and EPC4, respectively. Prior to planting, soil across all planting blocks was decompacted by ripping to a depth of 40 cm without inverting the soil layers. Prior to their installation, all plant material for each pit was inspected for general good health and as per QA/QC requirements. After the plants passed inspection, they were planted adjacent to the previously installed irrigation tubes. Plants were watered in-situ after they were installed and the irrigation tubes were also filled for the first watering.

Plant Survival

Sludge Pit C1: In SPC1, overall, the survival rate for the first year of plant establishment ranged from approximately 56% in unamended, low irrigation soils to 79% in amended, high irrigation soils. There was an improvement in survival in amended soils (by approximately 13%) and under high irrigation levels (by approximately 11%). Differences in survival were also species specific. For example, all *P. turgidum* and *C. conglomeratus* plants appeared to survive, whereas *N. retusa* and *R. epapposum* appeared to struggle, especially in unamended soil.

At the end of the second growing season, plant survival declined for all species across all treatments. Plant survival fell below an average of 25% in unamended soil (high and low irrigation) and in amended soil with a low irrigation rate. All of the *N. retusa* died and *R. epapposum* and *C. conglomeratus* also did not survive well. Overall, average plant survival ranged from approximately 20% to 39%, with those plants in amended soil under high irrigation surviving the best. Soil amendment improved average survival by approximately 9%, as did high irrigation levels (an improvement most importantly realized in amended soil).

Effluent Pit C3: In EPC3, overall, the survival rate for the first year of plant establishment ranged from approximately 29% in unamended, low irrigation soils to 64% in amended, high irrigation soils. There was an improvement in survival in amended soils (by approximately 14%) and perhaps more importantly, under high irrigation levels (by approximately 21%). Differences in survival were also species specific. *R. epapposum* did not survive well, regardless of the treatment.

At the end of the second growing season, plant survival declined for all species across all treatments. Plant survival fell below an average of 25% in unamended soil (high and low irrigation) and in amended soil with a low irrigation rate. All of the *N. retusa* in unamended soil died, and *R. epapposum* and *P. farcta* survival also fell below 25% across all treatments. Overall, average plant survival ranged from approximately 10% to 33%, with those plants in amended soil under high irrigation surviving the best. Soil amendment improved average survival by approximately 6%; however, perhaps more importantly, high irrigation improved average survival by approximately 16% (especially if soil was amended).

Effluent Pit C4: In EPC4, overall, the survival rate for the first year of plant establishment ranged from approximately 34% in amended, low irrigation soils to 68% in unamended, high irrigation soils. There was an improvement in survival in unamended soils (by approximately 26%) and under high irrigation levels (by approximately 8%).

Figure 4: Average Width of Plants under High / Low Irrigation over Time (Mean ± Stdev)

all widths in cm	*Rhanterium epapposum*		*Nitraria retusa*		*Panicum turgidum*		*Cyperus conglomeratus*		*Astragalus spinosus*	
	High	Low	High	Low	High	Low	High	Low	High	Low
At Planting	31.25 (±11.89)	31.67 (±14.20)	5.50 (±5.30)	5.25 (±5.61)	55.42 (±18.02)	37.67 (±10.53)	30.42 (±6.89)	29.33 (±10.38)	5.29 (±1.33)	5.46 (±0.83)
End of 1st Monitoring Period	54.33 (±13.56)	51.50 (±8.83)	5.50 (±3.63)	10.67 (±8.87)	60.50 (±23.20)	46.50 (±21.92)	36.92 (±15.68)	37.92 (±12.60)	17.21 (±5.87)	18.25 (±5.21)
End of 2nd Monitoring Period	95.67 (±15.38)	91.00 (±12.05)	12.00 (±0.00)	37.67 (±34.33)	86.42 (±18.71)	83.00 (±32.60)	73.27 (±21.80)	68.25 (±23.38)	34.13 (±11.08)	32.33 (±9.38)
Total Average Growth (cm)	64.42	59.33	6.50	32.42	31.00	45.33	42.85	38.92	28.84	26.87

Average Width of Plants under High / Low Irrigation in Lot C over Time (Mean ± Stdev)

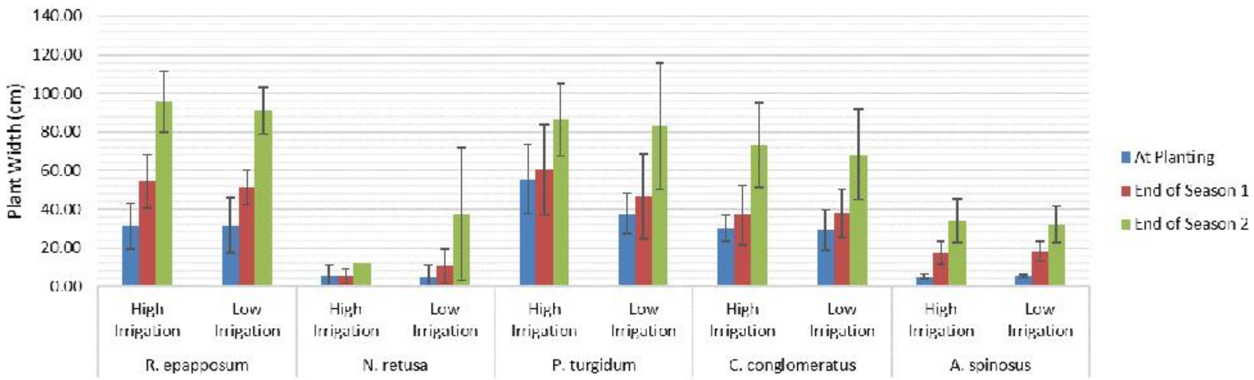


Figure 5: Weighted Average Plant Width by Species Over Time in SPC1

Species	Plant Width (cm)								Percent Growth				Average Growth (cm)			
	At Planting				End of 2nd Monitoring Period											
	Amended Soil		Unamended Soil		Amended Soil		Unamended Soil		Amended Soil		Unamended Soil		Amended Soil		Unamended Soil	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
R. epapposum	17.31	17.72	16.06	17.11	27.50	28.34	34.58	37.14	58.87	59.93	115.32	117.07	10.19	10.62	18.52	20.03
N. retusa	5.08	4.97	5.28	5.11	0.00	0.00	0.00	0.00	----	----	----	----				
P. turgidum	27.47	27.36	28.22	28.33	98.00	97.50	100.00	98.05	256.75	256.36	254.36	246.10	70.53	70.14	71.78	69.72
C. conglomeratus	27.31	25.78	25.06	25.17	62.05	62.00	51.33	56.25	127.21	140.50	104.83	123.48	34.74	36.22	26.27	31.08
P. farcta	6.98	7.26	7.47	7.03	83.75	74.82	95.00	93.85	1099.86	930.58	1171.75	1234.99	76.77	67.56	87.53	86.82

Average Growth of Plant Species Across Soil Treatments in SPC1

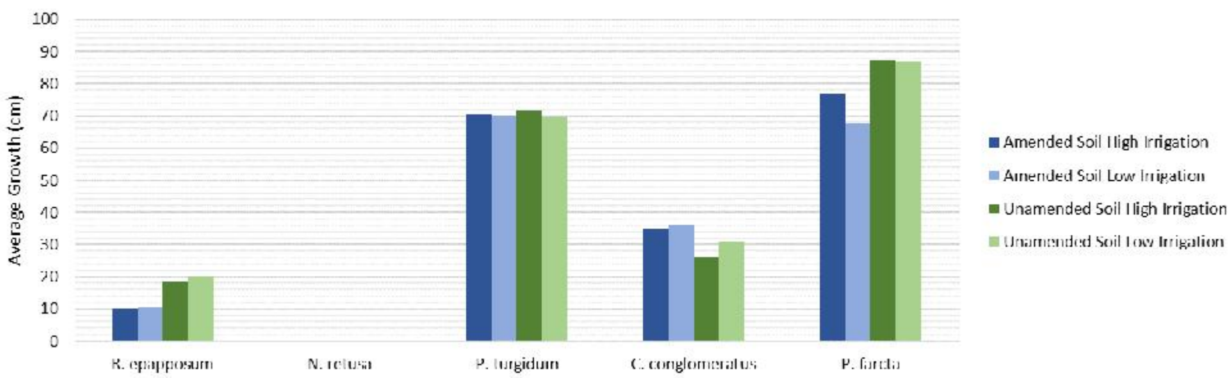


Figure 6. Weighted Average Plant Width by Species Over Time in EPC3

Species	Plant Width (cm)								Percent Growth				Average Growth (cm)			
	At Planting				End of 2nd Monitoring Period											
	Amended Soil		Unamended Soil		Amended Soil		Unamended Soil		Amended Soil		Unamended Soil		Amended Soil		Unamended Soil	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
R. epapposum	22.90	26.32	22.36	22.03	33.68	27.86	37.14	21.43	47.07	5.85	66.10	-2.72	10.78	1.54	14.78	-0.60
N. retusa	9.97	10.17	8.61	9.64	0.00	0.00	26.25	40.00	----	----	204.88	314.94	----	----	17.64	30.36
P. turgidum	29.94	31.39	29.93	28.26	54.92	52.08	65.63	48.85	83.43	65.91	119.28	72.86	24.98	20.69	35.70	20.59
C. conglomeratus	24.82	23.75	21.01	21.80	32.91	28.89	37.72	27.69	32.59	21.64	79.53	27.02	8.09	5.14	16.71	5.89
P. farcta	11.51	10.85	9.64	9.14	59.04	31.58	54.08	42.50	412.95	191.06	461.00	364.99	47.53	20.73	44.44	33.36

Average Growth of Plant Species Across Soil Treatments in EPC3

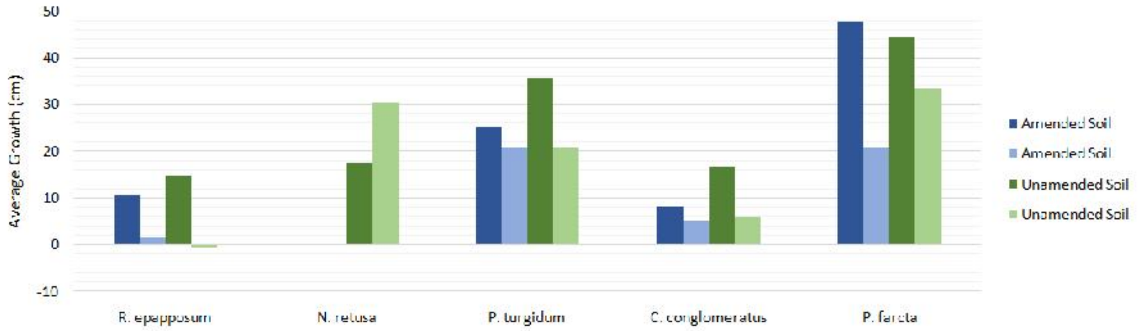
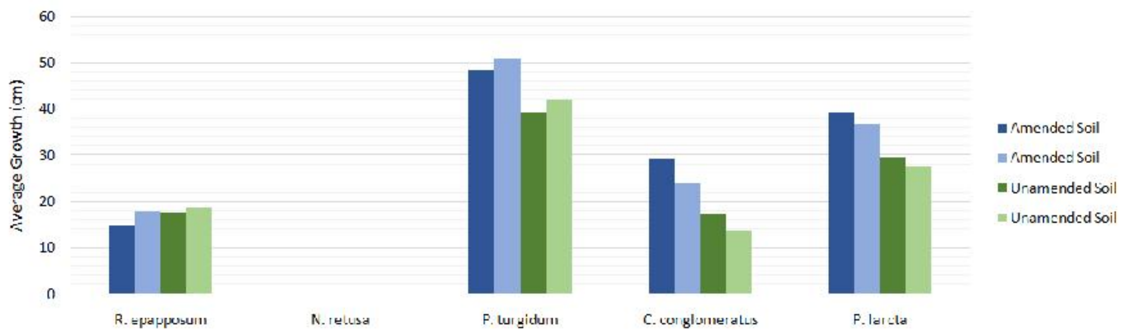


Figure 7. Weighted Average Plant Width by Species Over Time in EPC4

Species	Plant Width (cm)								Percent Growth				Average Growth (cm)			
	At Planting				End of Monitoring Period 2											
	Amended Soil		Unamended Soil		Amended Soil		Unamended Soil		Amended Soil		Unamended Soil		Amended Soil		Unamended Soil	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
R. epapposum	16.77	15.97	9.59	9.51	31.64	33.75	27.28	28.27	88.67	111.33	184.46	197.27	14.87	17.78	17.69	18.76
N. retusa	2.07	2.03	5.37	4.57	0.00	0.00	0.00	0.00	----	----	----	----	----	----	----	----
P. turgidum	22.76	21.70	21.48	21.20	71.08	72.61	60.73	63.21	212.30	234.61	182.73	198.16	48.32	50.91	39.25	42.01
C. conglomeratus	7.78	7.24	14.10	14.02	36.79	31.36	31.25	27.63	372.88	333.15	121.63	97.08	29.01	24.12	17.15	13.61
P. farcta	6.39	6.74	6.38	6.34	45.76	43.53	36.04	33.81	616.12	545.85	464.89	433.28	39.37	36.79	29.66	27.47

Average Growth of Plant Species Across Soil Treatments in EPC4



Differences in survival were also species specific. At the end of the second growing season, plant survival declined for all species across all treatments. Plant survival fell below an average of 25% for every species, depending on the treatment. For *N. retusa* and *R. epapposum* specifically, these plants performed the worst. All *N. retusa* died and *R. epapposum* survival was below 25% in all treatments. Overall, average plant survival ranged from approximately 6% to 29%. The EPC4 feature is the only site where bio-remediated soils have been used for planting. Plants in unamended soil survived approximately 11% better than plants in amended soil; as did plants growing in high irrigation compared to low irrigation.

Plant Growth

Sludge Pit C1: A summary of plant width from the time of plant installation to the end of the second growing season in SPC1 is provided in Figure 5. Results indicate that all species exhibited overall positive growth by the end of the monitoring period, with the exception of *N. retusa* (for which all plants died). *P. farcta* averaged approximately 80 cm of new growth; *P. turgidum* averaged approximately 71 cm of new growth; *C. conglomeratus* averaged approximately 32 cm of new growth; and *R. epapposum* averaged approximately 15 cm of new growth.

In SPC1, there did appear to be a difference in the average growth of certain plant species depending on the soil type. *P. farcta* and *R. epapposum* grew an average of 15 cm and 9 cm greater, respectively, in unamended soil. There was a smaller improvement in growth for *C. conglomeratus* (7 cm) in amended soil, and *P. turgidum* grew similarly in both soil types. Growth according to irrigation level also appeared to be species specific, with *P. farcta* growing slightly better under high irrigation (by 5 cm). Otherwise, the average growth by species only varied by ± 3 cm between high and low irrigation levels.

Effluent Pit C3: A summary of plant width from the time of plant installation to the end of the second growing season in EPC3 is provided in Figure 7. Results indicate that all species exhibited overall positive growth by the end of the monitoring period, with the exception of *N. retusa* in amended soil(for which all plants died). *P. farcta* averaged approximately 37 cm of new growth; *P. turgidum* averaged approximately 25 cm of new growth; *N. retusa* averaged approximately 24 cm of new growth (in unamended soil only); *C. conglomeratus* averaged approximately 9 cm of new growth; and *R. epapposum* averaged approximately 7 cm of new growth.

In EPC3, there did appear to be small differences in the average growth of certain plant species as a result of soil type. *C. conglomeratus*, *P. turgidum* and *P. farcta* all grew an average of 5 cm greater in unamended soil. For *N. retusa*, only plants in unamended soil survived and they appeared to grow quite well under the soil conditions. Perhaps more important than soil type was the effect of irrigation level on plant growth. All plant species grew better under high irrigation (with the exception of *N. retusa*). *P. farcta* grew by an average of 19 cm greater under high irrigation; *R. epapposum* grew by an average of 12 cm greater under high irrigation; *P. turgidum* grew by an average of 10 cm greater under high irrigation; and *C. conglomeratus* grew by an average of 7 cm greater under high irrigation.

Effluent Pit C4: A summary of plant width from the time of plant installation to the end of the second growing season in EPC4 is provided inFigure 8. Results indicate that all species exhibited overall positive growth by the end of the monitoring period, with the exception of *N. retusa* in amended soil(for which all plants died). *P. turgidum* averaged approximately 45 cm of new growth; *P. farcta* averaged approximately 33 cm of new growth; *C. conglomeratus* averaged approximately 21 cm of new growth; and *R. epapposum* averaged approximately 17 cm of new growth. In EPC4, there did appear to be differences in the average growth of certain plant species as a result of the soil amendment. *C. conglomeratus*, *P. farcta*, and *P. turgidum* grew an average of 11 cm, 10 cm and 9 cm greater, respectively, in amended soil. For *R. epapposum*, plants grew only slightly better (by 2 cm) in unamended soil. Growth according to irrigation level also appeared to be species specific, with *C. conglomeratus* growing slightly better under high irrigation (by 4 cm). Otherwise, the average growth by species only varied by ± 2 cm between high and low irrigation levels.

CONCLUSION

The successful establishment of the Kuwait desert species installed across the various lot features differed markedly. A summary of survivorship is presented in Table 8 below. The reference areaexhibited survival rates of 79% and 90% under High / Low Irrigation rates, respectively after two growing seasons. High versus low irrigation rates were tested to determine if plant survival and growth were improved by a greater amount of water available during the growing season. Results appear to indicate that although irrigation events improved soil moisture levels, the difference in soil moisture between high and low irrigation rates was overall. This indicates that plants receiving high-level irrigation had similar moisture near their roots as plants receiving low-level irrigation. This could be the reason why high irrigation did not appear to provide a greater benefit to plant survival, nor did it provide a marked increase in plant growth in reference areas (Table 9).

One important factor when considering the use of irrigation (and the amount) is soil texture. Coarse-textured, sandy soil with low amounts of clay, silt and organic matter result in poor soil aggregation. These soils tend to reach their saturation point much sooner than fine-textured soil, with the excess water draining downward and out of the available reach of plants (i.e. limited water holding capacity). In the reference areas, soil texture was characterized as silty fine to coarse sands. This soil texture may have resulted in better water holding capacity, and prolonged water availability as a result of slower drainage, leading to greaterplant survival rates and average plant growth. The scope of works for the rehabilitation part of the project allowed for control over certain variables that could affect plant establishment, such as species selection, site preparation, spacing of plants, and frequency and amount of irrigation. However, other variables not controlled could have affected plant establishment, including differences in the local Lot site conditions (i.e. location, natural rainfall, soil texture and micronutrients), the propagation and handling of plant material (in the plant nursery and during planting), and potentially the size and condition of the plants installed. The general intent of the reference areas was to provide a “control” measure to compare the results of plant establishment in other features undergoing rehabilitation.

If plant establishment was similar in rehabilitated features to the undisturbed reference areas, then restoration could be considered on the right track or on a similar trajectory as a more natural ecosystem. Based on the summary results for rehabilitated features presented below, the features typically performed worse than the reference area. In the sludge and effluent pits, high and low irrigation rates were tested, as well as amended and unamended soil treatments. However, prior to receiving the amendment, soil from the pits was treated to remove hydrocarbons and other contaminants to meet Primary or Alternate RS (see Section 2.6 for details). A summary comparison of the average plant survival and growth in Primary RS and Alternate RS soils revealed some interesting trends (Table 10). Plant growth and survival was highly variable and therefore, significant differences in plant response to soil treatments were not observed. This is likely due to the very different way the soil was treated during the remediation process, although in the end, the remediation standards were met. Averages for plant survival, growth and increases in soil moisture after irrigation for each pit respectively are provided in Tables 8-9 above.

The survival rate ranged from between 6% and 39%, a range lower than that observed in the reference area. The addition of a soil amendment alone was not responsible for affecting plant survival in SPC1 and EPC3. High level irrigation, in addition to the soil amendment, resulted in the highest survival rates observed in these features. In EPC4, although plant survival was generally better in unamended soil, high level irrigation also improved the survival of plants. Nonetheless, an average of over 80% of plants died across the pit features. The addition of a soil amendment also did not consistently improve plant growth (Table 9). In SPC1 and EPC3, plants grew slightly better in unamended soil. In EPC4, there was a small improvement in plant growth in amended soil, but overall average growth was still slightly below that of the reference area. Irrigation did significantly increase soil moisture after it was applied. However, there was no significant difference in the amount of additional soil moisture between high and low irrigation levels, except in unamended EPC4 soil. Therefore, in general, most plants had similar soil moisture at their root zones under both high and low irrigation levels. Although high level irrigation did notably improve overall plant survival (Table 8), it provided only small improvements in plant growth (Table 8).

The reasons for the differences in plant establishment (i.e. survival and growth) among the rehabilitated pit features is likely the result of confounding factors, including the soil remediation process, soil amendment and irrigation, and potentially the site specific micro-climate conditions in the pits. Although the control of some variables was attempted through the creation of technical specifications for remediation standards, planting and site preparation, it is difficult to control all aspects when restoring natural ecosystems. Results of this study have shown that there are only marginal differences in overall plant survival and growth between Primary RS and Alternate RS soils. These results appear to indicate that plants have a similar ability to survive under both remediation standards (i.e. can tolerate PHCs up to 10,000 mg/kg as indicated in Alternate RS), although better growth may be expected if Primary RS soils are used for planting. Whilst this study primarily focuses on environmental impacts, further studies from within oil environments have also indicated that the Alternate RS (10,000mg/kg) remediation standard is suitable for the protection of Human Health (Washington, 2001). Importantly, it is worth noting the differing treatment technologies used and the potential impact this has had on the results. Because each remediation methodology, results in differences in soil texture, microbiology and organic matter content, it is difficult to conclude the importance of the PHC level (i.e. remediation standard) over other aspects such as soil quality. Results from other studies, including those in Kuwait, indicate a tolerance of native plants to hydrocarbon contaminated soil, even their use in phytoremediation technologies. Although not included in this research, it would be important to understand whether the plants in the sludge and effluent pits successfully formed the endophytic relationships with bacteria and fungi that are known to be beneficial to survival and growth in impacted soil.

The addition of a soil amendment to remediated soil was tested because of the potential to provide useful nutrients to plants and to improve soil texture and water holding capacity. After thermal treatment, soil would be considered inert, having no organic matter or living microbes and poor physical structure. Soil testing indicated that cleaned material was suitable for planting (i.e. not expected to be harmful to plants); therefore, only a biogenic fertilizer amendment was added. The amount of amendment added (at a rate of 5 kg/m^3). Although the addition of a soil amendment could have improved the physical and biological condition of the soil, this was not evident through a clear benefit to plant survival and/or growth within amended planting blocks, or at any of the rates applied. EPC4, also tested a patented bioremediation process by which a consortium of microbes was used to treat, through biodegradation petroleum hydrocarbon in the soil. The process was conducted in-situ and was intended to generate carbon dioxide, water, and microbial biomass without any harmful secondary pollutants created. A specially designed nutrient formulation and water were periodically applied in the pit over the remediation period to maintain the growth of microbe populations. Through monthly monitoring, low microbe counts were identified due to high salinity levels. As a consequence, low-saline thermally treated soils (such as those from EPC3) were mixed at a 1:1 ratio with the bioremediated soil from EPC4, and then gypsum was added to further reduce the SAR. Upon completion of the bioremediation process and salinity reduction, additional nutrients in the form of the biogenic fertilizer were also added to EPC4. It appears, based on the results from this pit, that bioremediation was not a successful method to achieve a suitable planting medium for the purposes of restoration. EPC4 soil exhibited some of the lowest plant survival rates of all rehabilitated features. The results of this study indicated that there was no significant difference between the remediation standards that had been adopted and their impact on potentially sensitive environmental and human health receptors encountered within the Oil Fields of Kuwait. The findings led to a revision of remediation standard of 10,000mg/kgby the environment regulator in Kuwait for future remediation projects.

REFERENCES

Al-Awadhi, J.M., S.A. Omar and R.F. Misak. 2005. Land degradation indicators in Kuwait. Land Degradation & development. 16: 163-176.

Al-Fredan, M.A.A. 2010. Nitrogen fixing legumes in the plant communities. Amer. J. Environ. Sci. 7:166-172.

Bainbridge, D. 2001. Buried clay-pot irrigation: A little known but very efficient traditional method of irrigation. Agricultural Water Management. 48: 79-88.

Bainbridge, D. 2007. A Guide for Desert and Dryland Restoration. Island Press. Washington.391 pp.

Batanouny, K.H. 1987. Current knowledge of plant ecology in the Arab Gulf countries. Catena. 14:291-316.

Brown, G. 2002. Species richness, diversity and biomass production of desert annuals in an ungrazed *Rhanterium epapposum* community over three growth seasons in Kuwait. Plant Ecology 165:53-68.

Brown, G. 2002. Community composition and population dynamics in response to artificial rainfall in an undisturbed desert annual community in Kuwait. Basic Appl. Ecol. 3:145-156.

Omar, S.A.S. 2007. Vegetation of Kuwait: a Comprehensive Illustrative Guide to the flora and Ecology of the Desert of Kuwait. Kuwait Institute for Scientific Research. Kuwait. 161 pp.

Omar, S., N.R. Bhat. 2008. Alteration of the *Rhanterium epapposum* plant community in Kuwait and restoration measures. Int. J. Environ. Studies. 65: 139-155.

Weiwei, W. H. Zhenghai, G. Guilan and Y. Yusuo. 2002. Studies on the Characteristics Related to symbiotic Nitrogen Fixation of Legumes in Xinjiang Region. 12th ISCO Conference. Beijing. 428-434.

Washington. 2001. API Publication Number 4709: Risk-Based Methodologies for Evaluating Petroleum Hydrocarbon Impacts at Oil and Natural Gas E&P Sites.

Zar, Jerrold H. 2010. Biostatistical Analysis. 5th Edition. Pearson Prentice-Hall, Upper Saddle River, NJ. 944 pp.

****