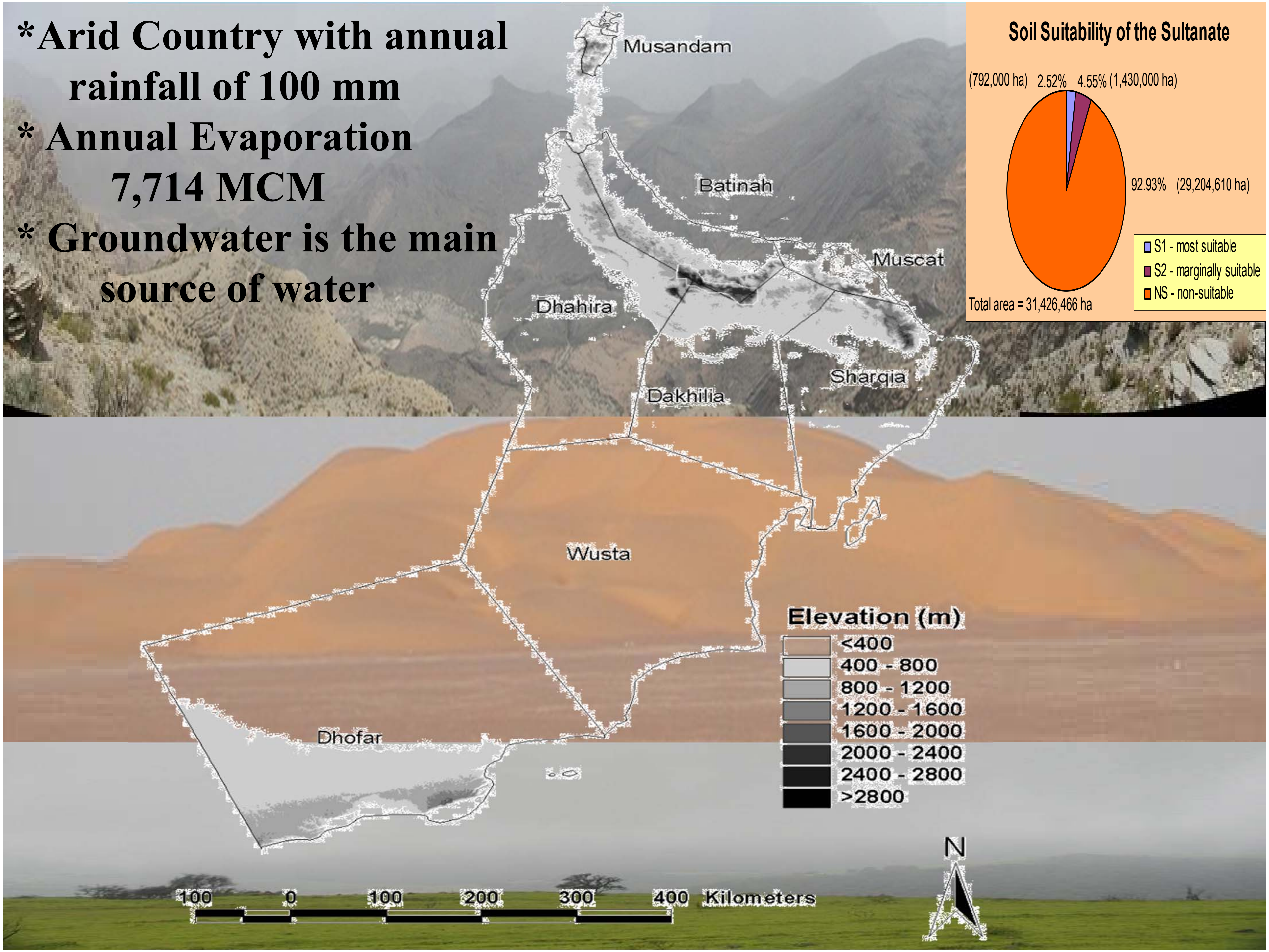
Integrated Approach to Grow Crops with Fish Using Treated Wastewater

Ahmed Al-Busaidi, Mushtaque Ahmed and Waad Al-Aghbari

Oman Water Society & Department of Soils, Water and Agricultural Engineering, College of Agricultural & Marine Sciences, Sultan Qaboos University, Muscat, Oman

ahmed99@squ.edu.om


*Arid Country with annual rainfall of 100 mm
* Annual Evaporation 7,714 MCM
* Groundwater is the main source of water
Musandam
Batinah
Muscat
Dhahira
Dakhilia
Sharqia
Wusta
Dhofar
Elevation (m)
<400
400 - 800
800 - 1200
1200 - 1600
1600 - 2000
2000 - 2400
2400 - 2800
>2800
100 0 100 200 300 400 Kilometers
N
Soil Suitability of the Sultanate
(792,000 ha) 2.52%
4.55% (1,430,000 ha)
92.93% (29,204,610 ha)
Total area = 31,426,466 ha
S1 - most suitable
S2 - marginally suitable
NS - non-suitable

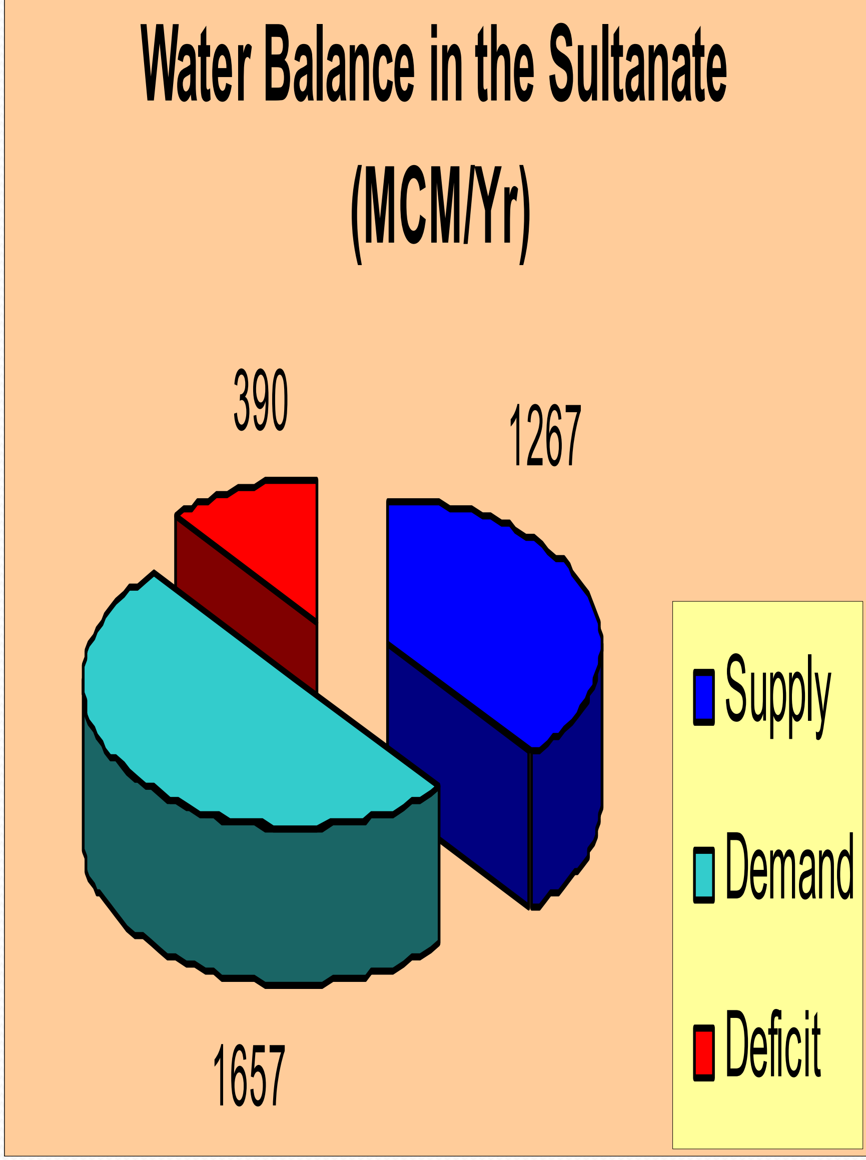
Challenges

1) **Water Shortage**

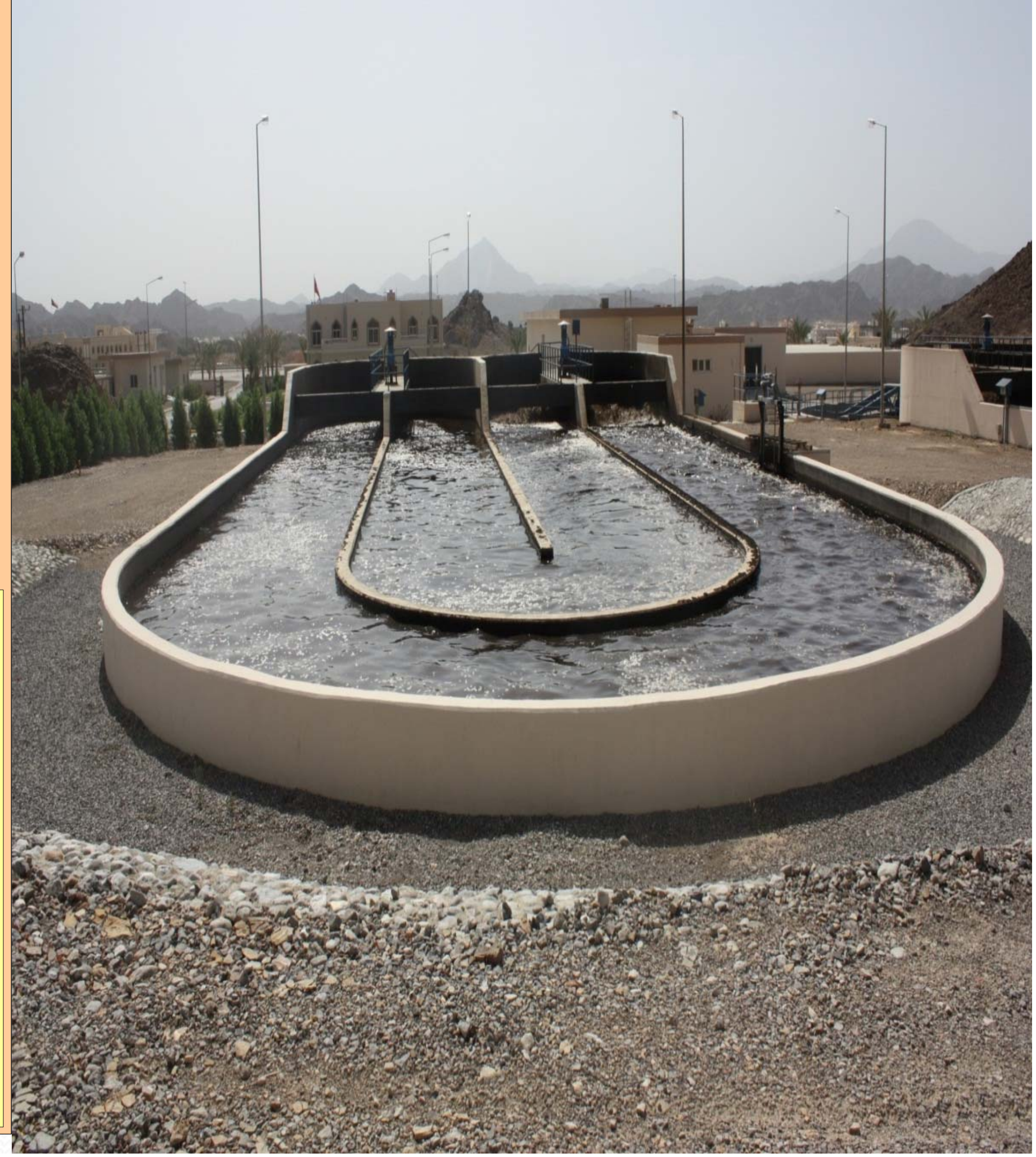
2) **Soil Suitability for Agriculture (salinity problem)**

Water Balance

Deficit



Excess



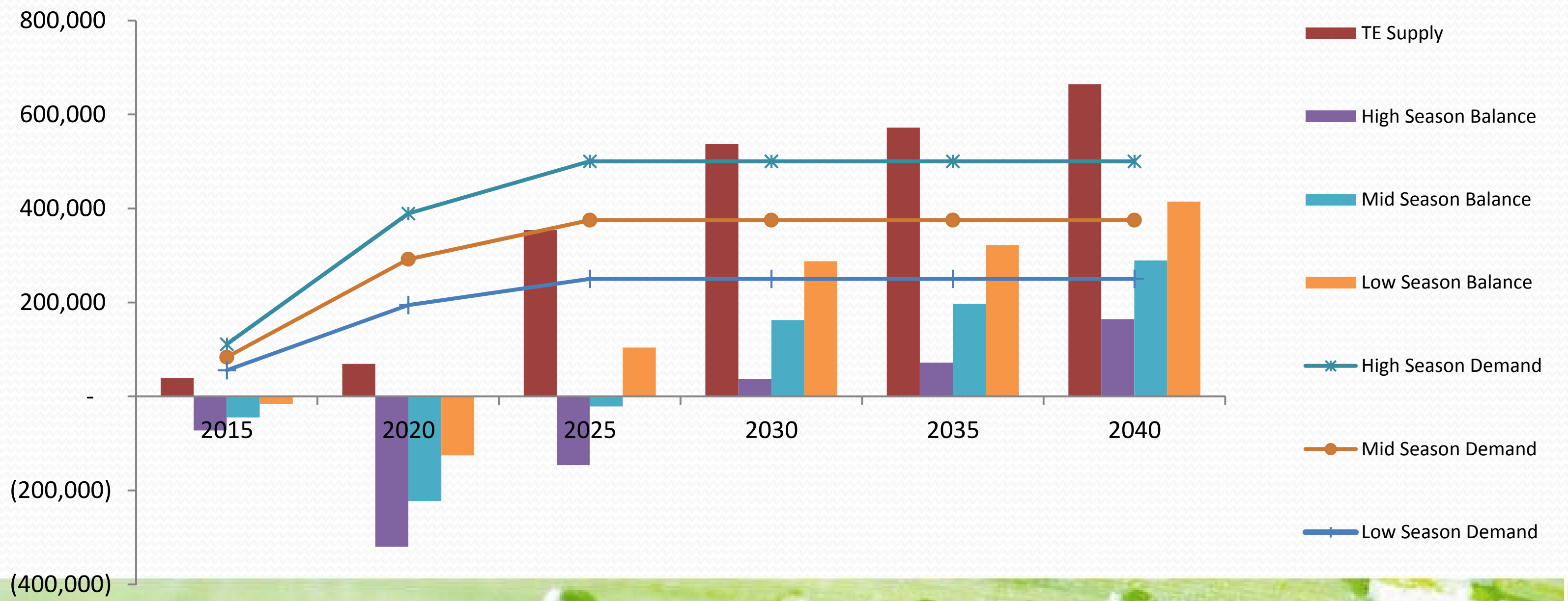
استراتيجية استغلال المياه المعالجة خارج محافظة مسقط – إجمالي الإنتاج السنوي حسب الموسم

Treated Wastewater outside Muscat

DID YOU KNOW?

You would have to flush your toilet around **six million** times to generate the same volume of wastewater that the city's two treatment plants receive every day.

العام / الإنتاج اليومي (متر مكعب/ اليوم)	2015	2020	2025	2030	2035	2040
Total production الإنتاج السنوي(m3/day)	38,861	69,129	353,998	537,773	572,137	664,706



حيا
Haya water

Water Parameters for Tertiary Treated Wastewater

Parameter	Units	Standards of Haya Concession Agreement	Effluent expected values from Haya STPs	Class A (agricultural irrigation permissible limits) (115/2001)
BOD	mg/l	<15	<5	15
TSS	mg/l	<15	<5	15
Total N as N	mg/l	<15	<15	-
NO_3 as N	mg/l	-	<11.3	11.3
Total P as P	mg/l	30	< 30	30
Faecal Coliforms	MPN/100 ml	< 200	< 200	200
Viable Helminth Ova	Number /L	< 1	< 1	< 1
Residual Chlorine at customer point	mg/l	0.3 < **x** < 1		-

Water from Samail STP

Parameters	Value	EPA Standard	FAO Standard	Omani Standard	Jordanian Standard	Saudi Standard
BOD (mg/l)	<MDL	١٥	١٥	15	15	10
pH	7.60	٩ - ٦	٨ – ٦,٥	٩ - ٦	٩ - ٦	٨,٤ – ٦
EC (dS/m)	1.37	٢,٣	٣ - ٠,٧	2 - 2.7	٢,٥ – ٢	3 – 3.5
N-NH4 (mg/l)	0.22	٥	٥	5	٥	5
TSS (mg/l)	7.00	15	١٥	15	٥٠	10
N-NO3 (mg/l)	0.00	٥٠	٣٠ - ٥	50	٣٠	10
Oil & Grease (mg/l)	0.90	٥	٠,٥٠	0.50	8	0.0
Coli forms (cell/100 ml)	0	٢٠٠	١٠٠	200	100	2.2
E-Coli (cell/100 ml)	0	٢٠٠	١٠٠	200	100	2.2

Water from Nizwa STP

Parameters ml/l	Sample 1	Sample 2	EPA Standard	FAO Standard	Omani Standard	Jordanian Standard	Saudi Standard
Cd	< 0.001	< 0.001	0.01	0.01	0.01	0.01	0.01
Co	0.001	0.002	0.05	0.05	0.05	0.05	0.05
Cu	0.009	0.018	0.50	0.20	1.00	0.20	0.40
Cr	0.002	0.003	0.10	0.10	0.05	0.10	0.10
Fe	0.014	0.017	5.00	5.00	5.00	5.00	5.00
Pb	0.005	0.009	0.10	5.00	0.20	0.20	0.10
Mn	0.002	0.002	0.20	0.20	0.50	0.20	0.20
Mo	0.002	0.006	0.01	0.01	0.05	0.01	0.01
Ni	0.039	0.031	0.10	0.20	0.10	0.20	0.20
V	0.004	0.002	0.10	0.10	0.10	0.10	0.10
Zn	0.016	0.036	5.00	2.00	5.00	5.00	4.00

Network for Treated Wastewater

Treated Wastewater Application

Inorganics Standards for Wastewater Reuse (mg/l)

Limitations:

Contains some Heavy Metals

Monitoring is Required

PARAMETER	STANDARDS	
	Class A	Class B
Aluminum (as Al)	5	5
Arsenic (as As)	0.100	0.100
Barium (as Ba)	1	2
Beryllium (as Be)	0.100	0.300
Boron (as B)	0.500	1
Cadmium (as Cd)	0.01	0.010
Chloride (as Cl)	650	650
Chromium (total as Cr)	0.050	0.050
Cobalt (as Co)	0.050	0.050
Copper (as Cu)	0.500	1
Cyanide (total as CN)	0.050	0.100
Fluoride (as F)	1	2
Iron (total as Fe)	1	5
Lead (as Pb)	0.100	0.200
Lithium (as Li)	0.070	0.070
Magnesium (as Mg)	150	150
Manganese (as Mn)	0.100	0.500
Mercury (as Hg)	.001	0.001
Molybdenum	0.010	0.050
Nickel (as Ni)	0.100	0.100
Ammonical (as N)	5	10
Nitrate (as NO_3)	50	50
Phenol (total)	0.001	0.002
Phosphorus (total P)	30	30
Selenium (as Se)	0.020	0.020
Silver (as Ag)	0.010	0.010
Sodium (as Na)	200	300
Sulphate (as SO_4)	400	400
Sulphide (total as S)	0.100	0.100
Vanadium (as V)	0.100	0.100
Zinc (as Zn)	5	5

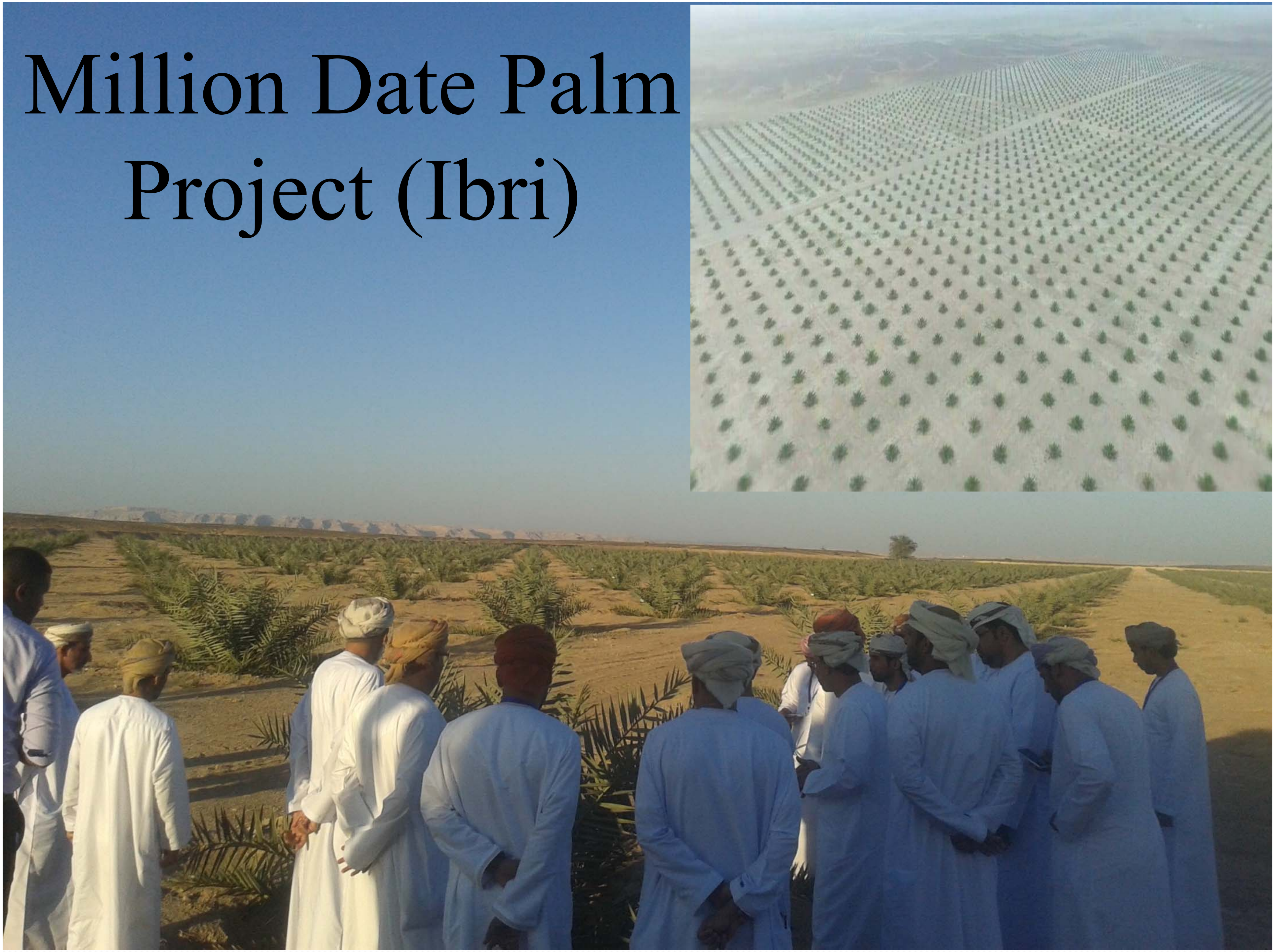
Heavy Metals in Date Palms Irrigated by Groundwater and Treated Wastewater

Date palms in Oman

واقع زراعة النخيل في السلطنة

النسبة المئوية للانتاج %	كمية انتاج التمر (طن) Pro. (Ton)	متوسط انتاج النخلة (كجم) X (Kg)	عدد النخيل * No. of Date palms	المحافظة/المنطقة Area	الترتيب
4.42	338674	34.17	11573.92	محافظة مسقط A	1
42.55	2817190	39.55	111407.06	منطقة الباطنة B	2
1.73	144381	31.31	4521.00	محافظة مسندمC	3
10.36	550545	49.29	27136.37	منطقة الظاهرة D	4
20.81	952428	57.22	54497.28	المنطقة الداخلية E	5
16.76	1397010	31.41	43878.51	المنطقة الشرقيةF	6
0.05	21388	6.19	132.43	محافظة ظفارG	8
3.32	265012	32.84	8704.10	محافظة البريمي H	7
100.00	261850	40.37	**6486628**	المجموع Total	

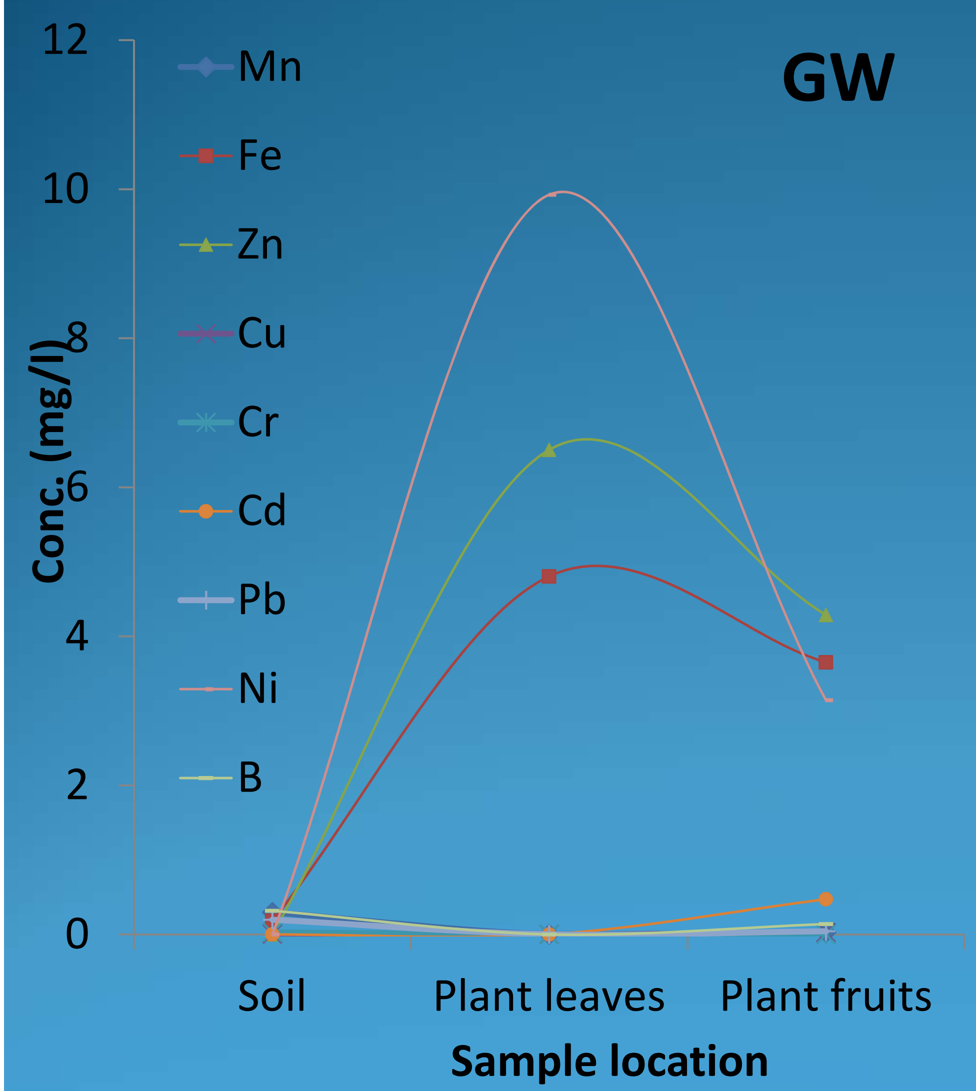
Million Date Palm Project (Ibri)

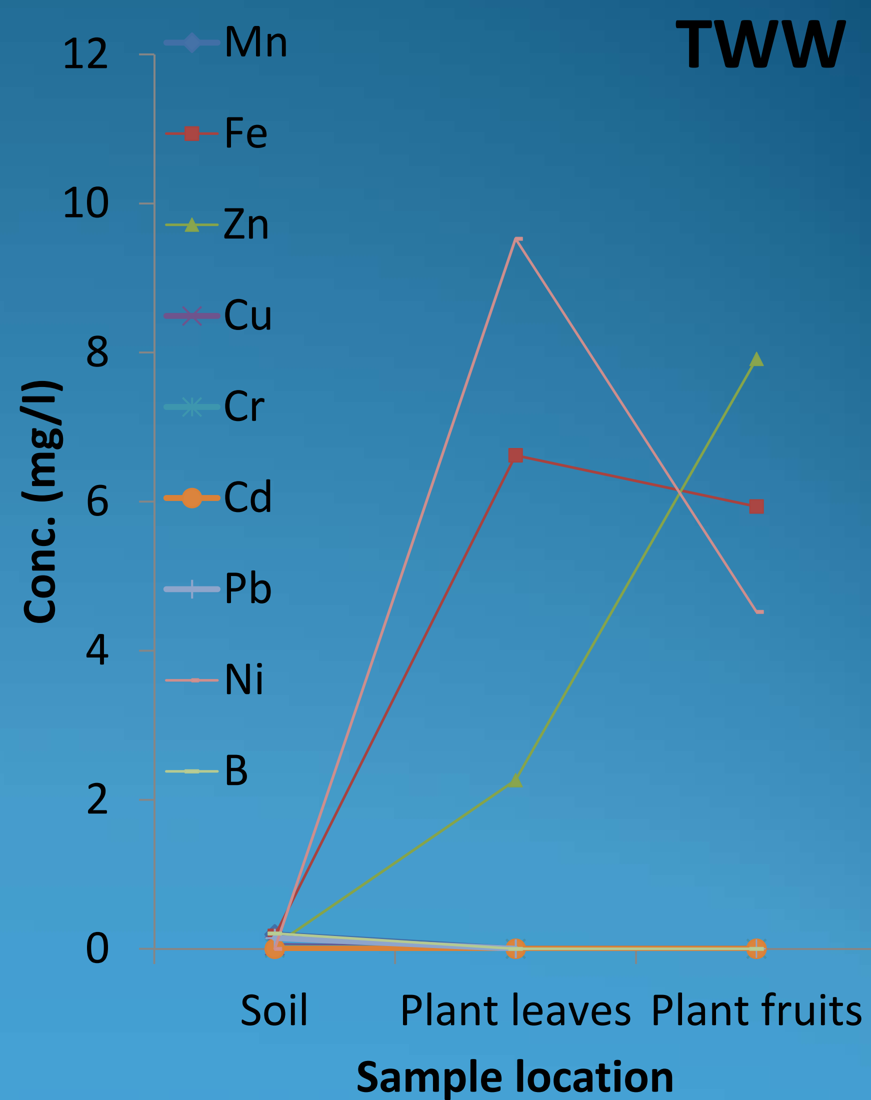



2006 10 8

Result and discussion

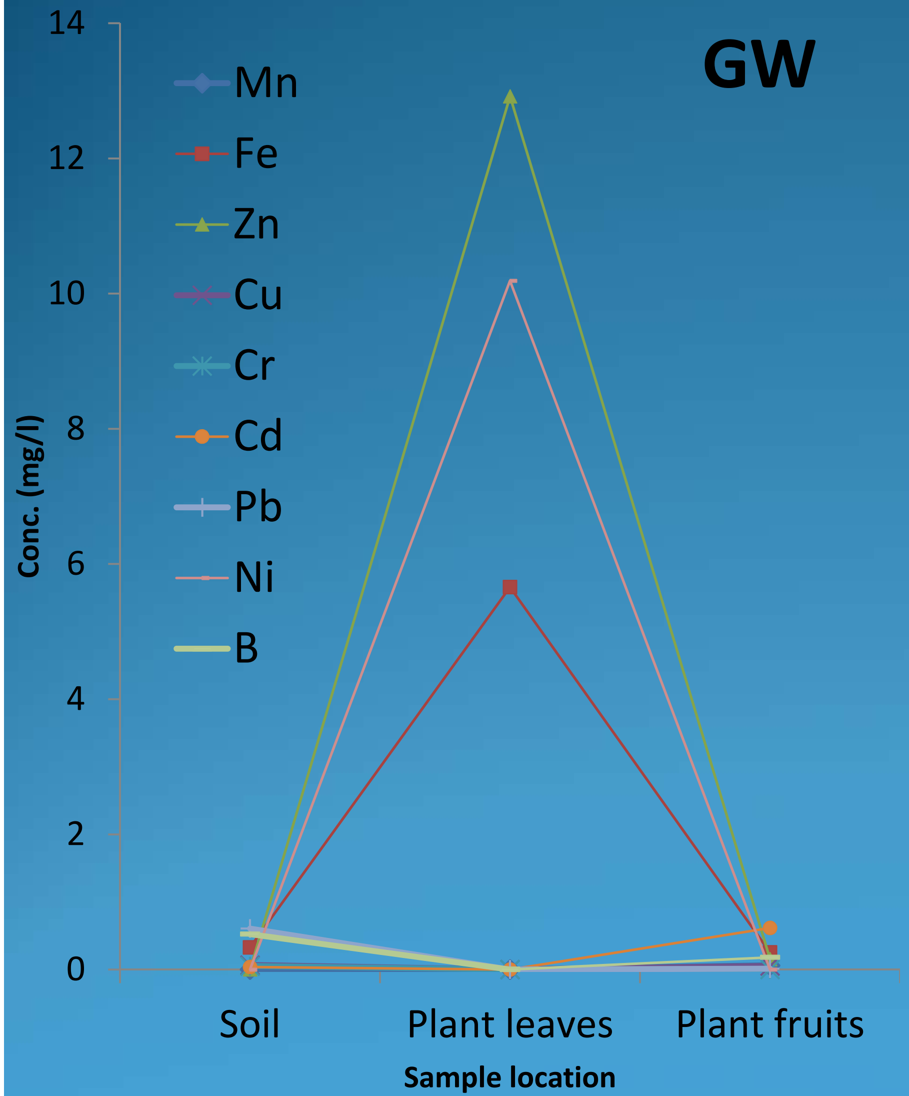
Heavy metals translocations in location 1

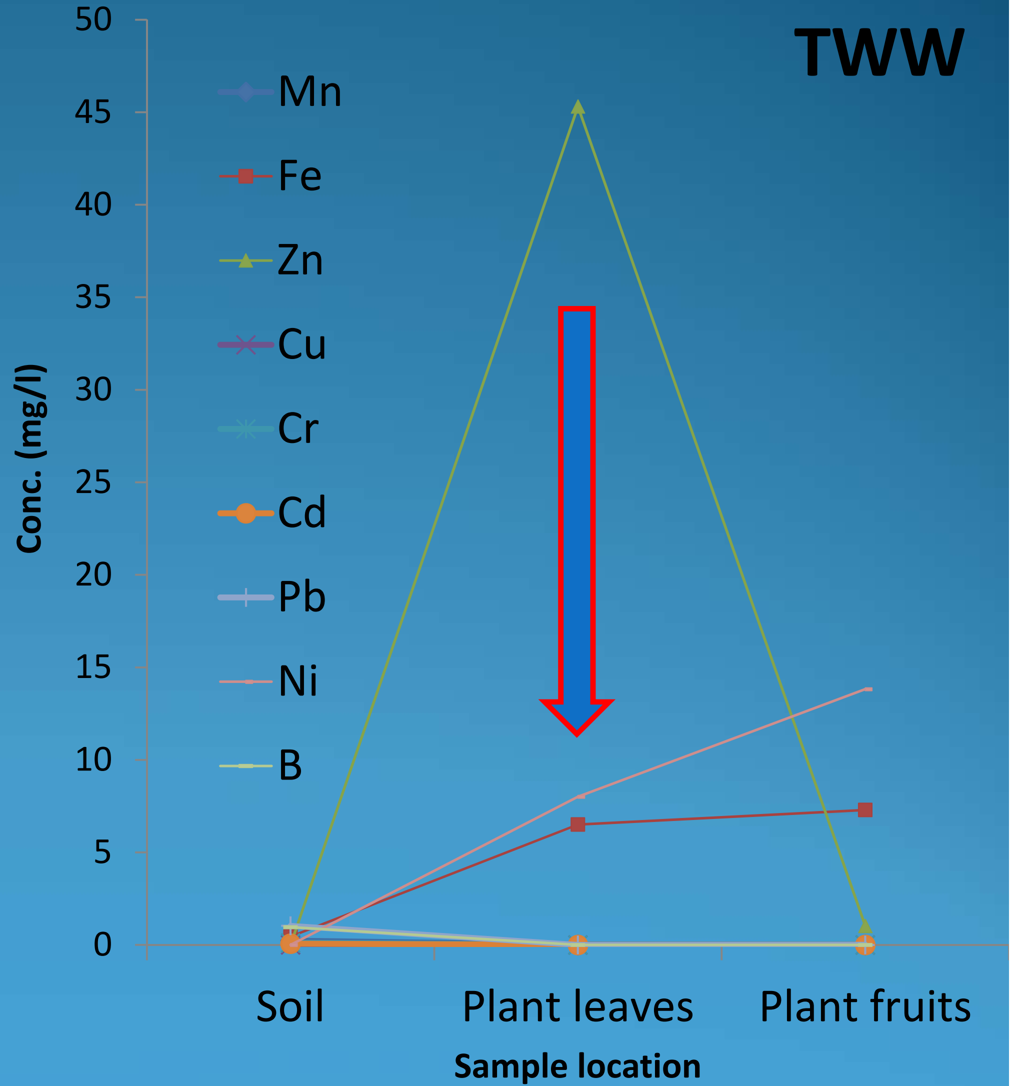




Result and discussion

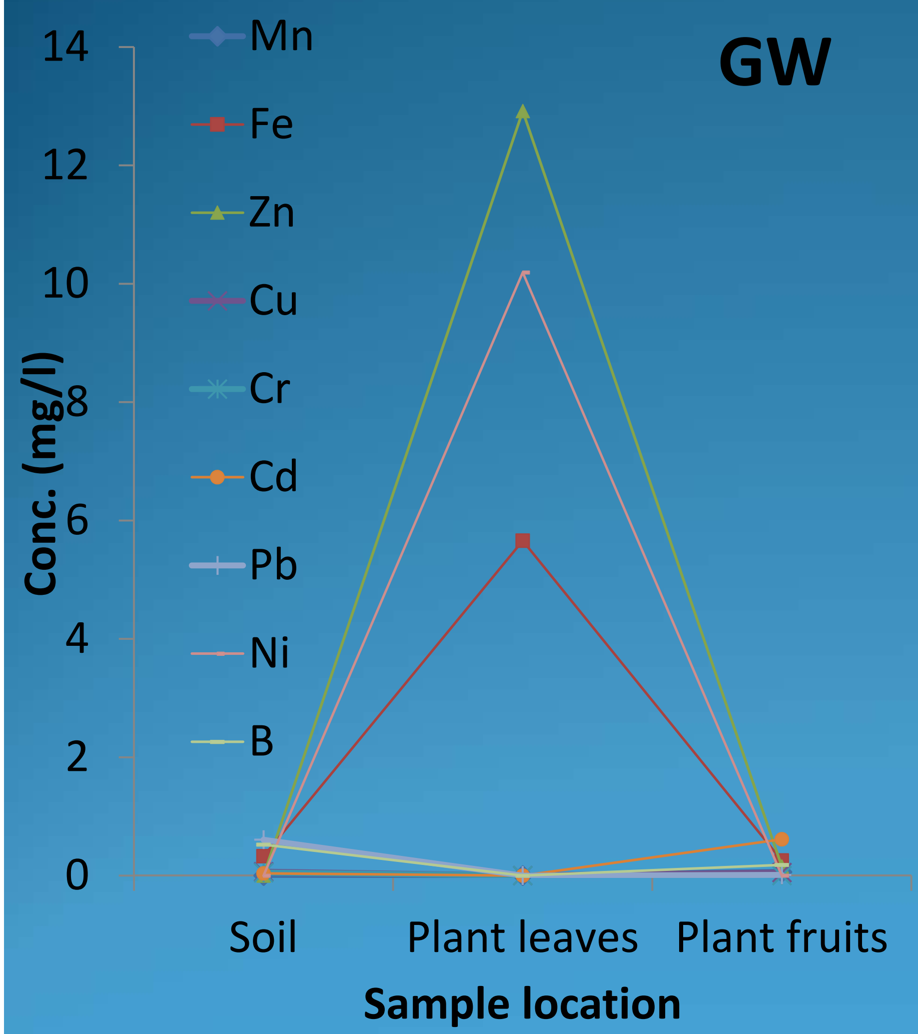
Heavy metals translocations in location 2

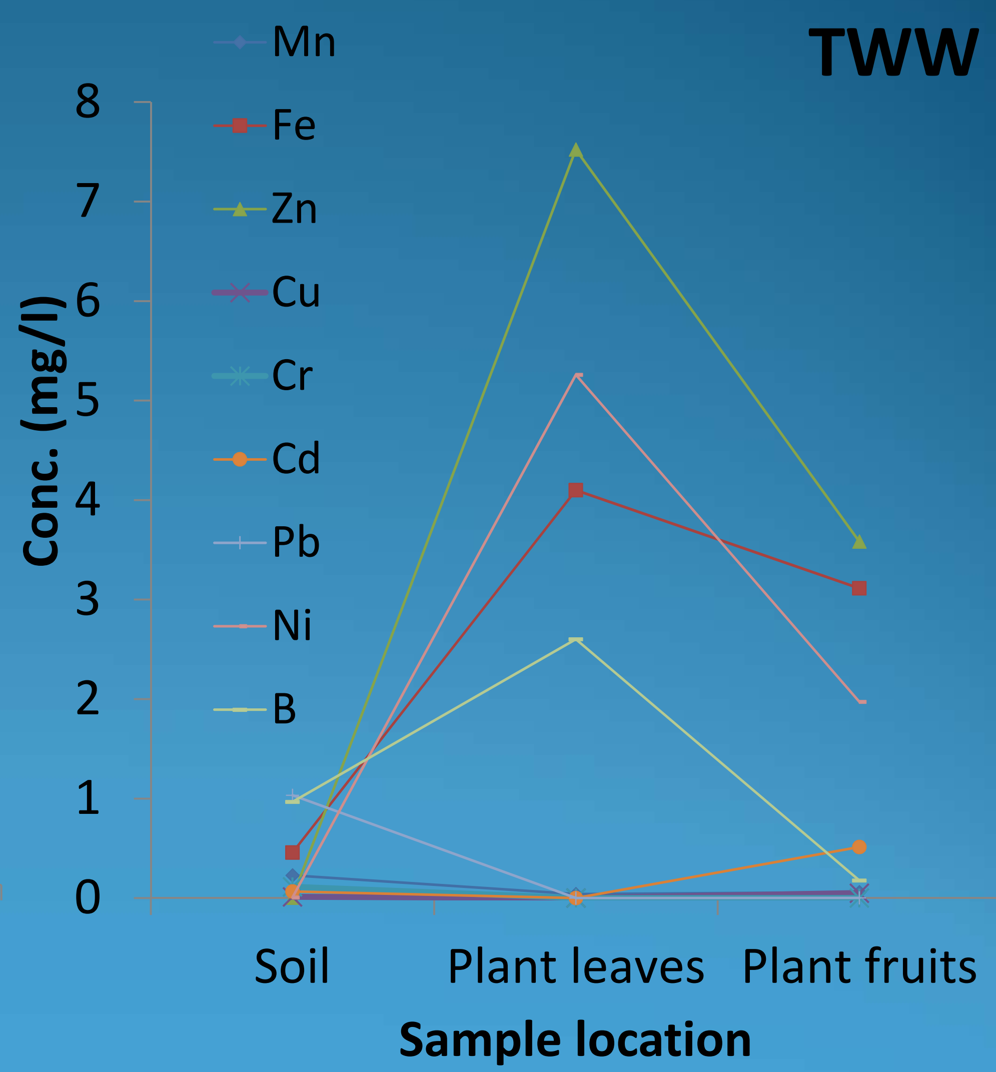




Result and discussion

Heavy metals translocations in location 3





Guideline for safe limits of heavy metals

Samples	Standards	Fe	Zn	Cu	Pb	Cd	Mn	Cr	Ni	As
Water ($mg\ L^{-1}$)	Indian Standard (Awashthi 2000)	0.03	5.0	0.05	0.10	0.01	0.1	0.05	-	0.05
	WHO/FAO (2007)	NA	2.0	0.20	5.0	0.01	0.2	0.10	-	-
	European Union Standards (EU2002)	-	-	-	-	-	-	-	-	-
	USEPA (2010)	NA	2.00	1.00	.015	.005	.05	0.10	-	-
	Kabata-Pendias (2010)	0.8	NA	NA	NA	NA	NA	NA	-	-
Soil ($mgkg^{-1}$)	Indian Standard (Awashthi 2000)	NA	300-600	135-270	250-500	3-6	NA	NA	75-150	-
	WHO/FAO (2007)	-	-	-	-	-	-	-	-	-
	European Union Standards (EU2002)	NA	300	140	300	3.0	NA	150	75	-
	USEPA (2010)	NL	200	50	300	3.0	80	NA	-	-
	Kabata-Pendias (2010)	1000	NA	NA	NA	NA	NA	NA	-	-
Plant ($mgkg^{-1}$)	Indian Standard (Awashthi 2000)	NL	50.0	30.0	2.5	1.5	NL	20	5	1.1
	WHO/FAO (2007)	450	60.0	40.0	5.0	0.2	500	5.0	10	-
	European Union Standards (EU2002)	NL	60	40	0.30	0.20	NL	NA	-	-
	USEPA (2010)	-	-	-	-	-	-	-	-	-


Help Me

Conclusion:

* Date Palm can be irrigated by treated wastewater
* Monitoring is needed

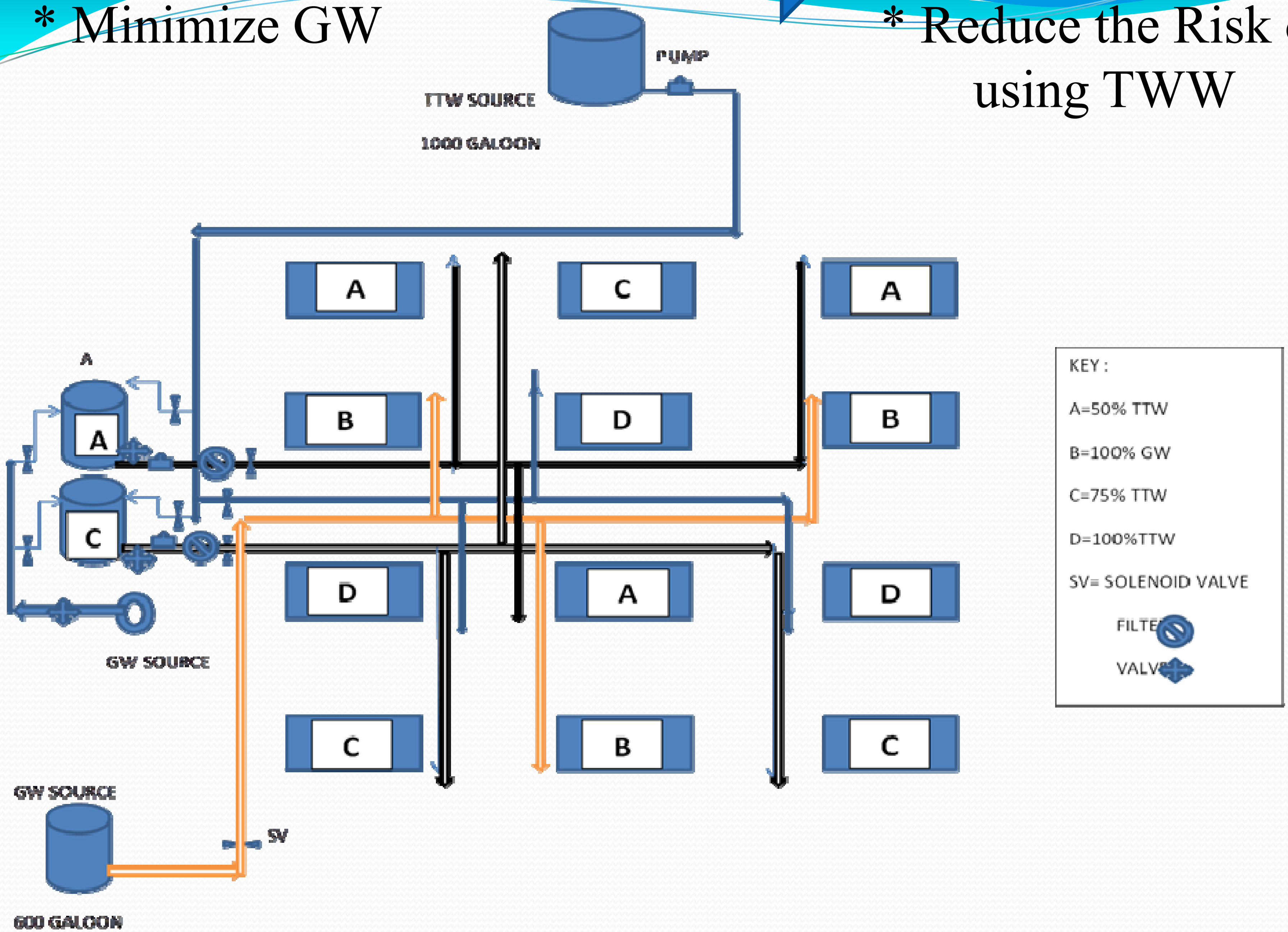

Wheat Irrigated by Treated Wastewater

Vegetables Irrigated by Treated Wastewater, Groundwater and Mix of both Waters

* Maximize TWW
* Minimize GW

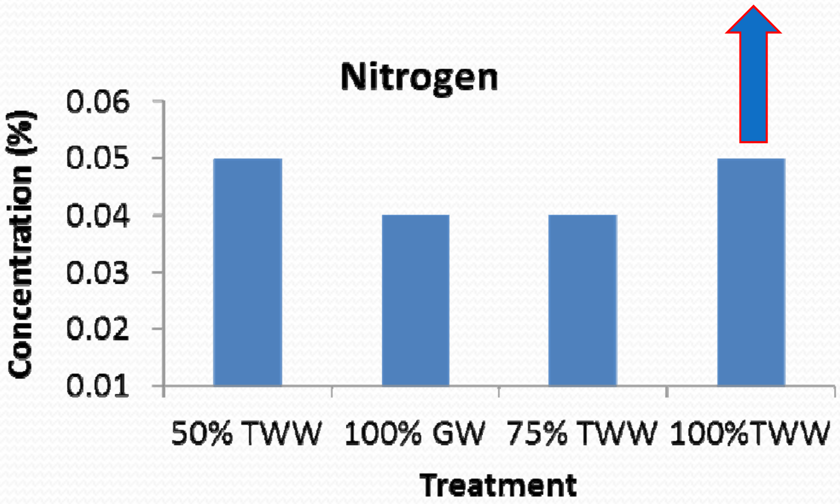
Mixing

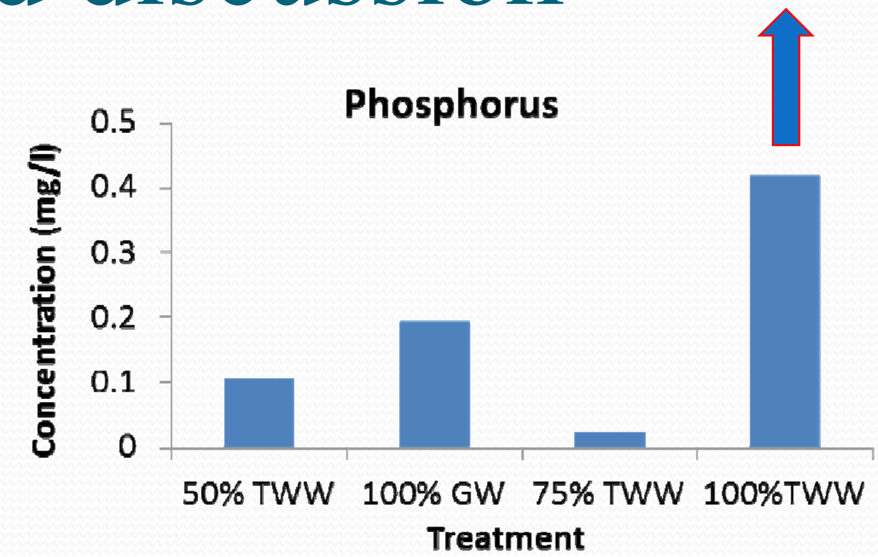
* Save GW
* Reduce the Risk of using TWW

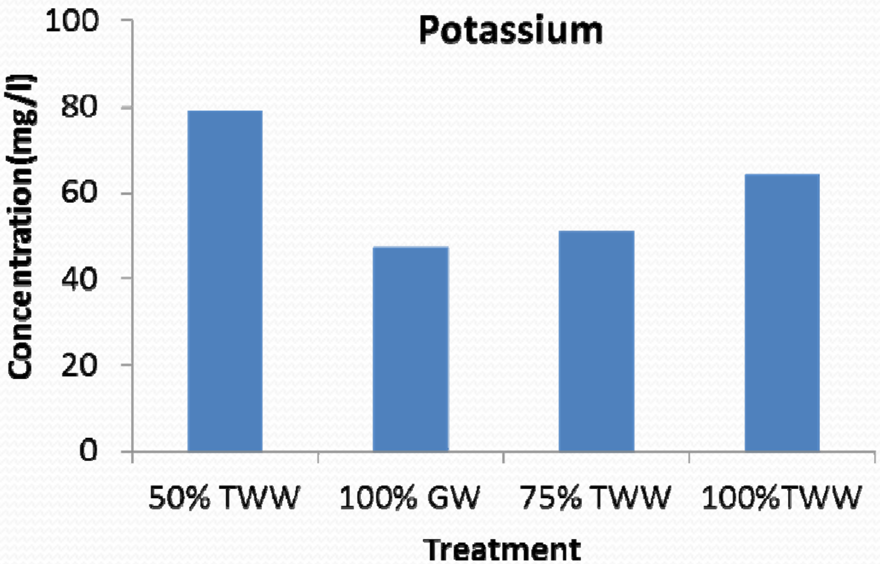


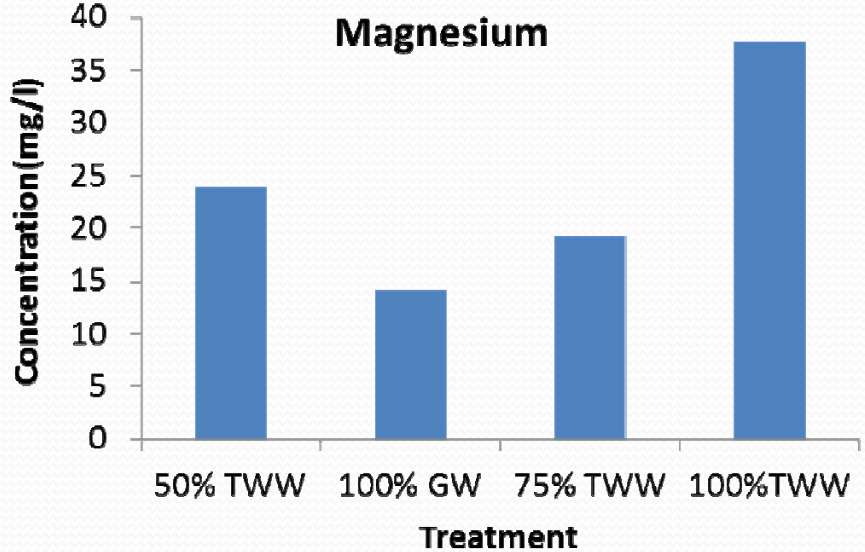
Result and discussion

- 1st Season





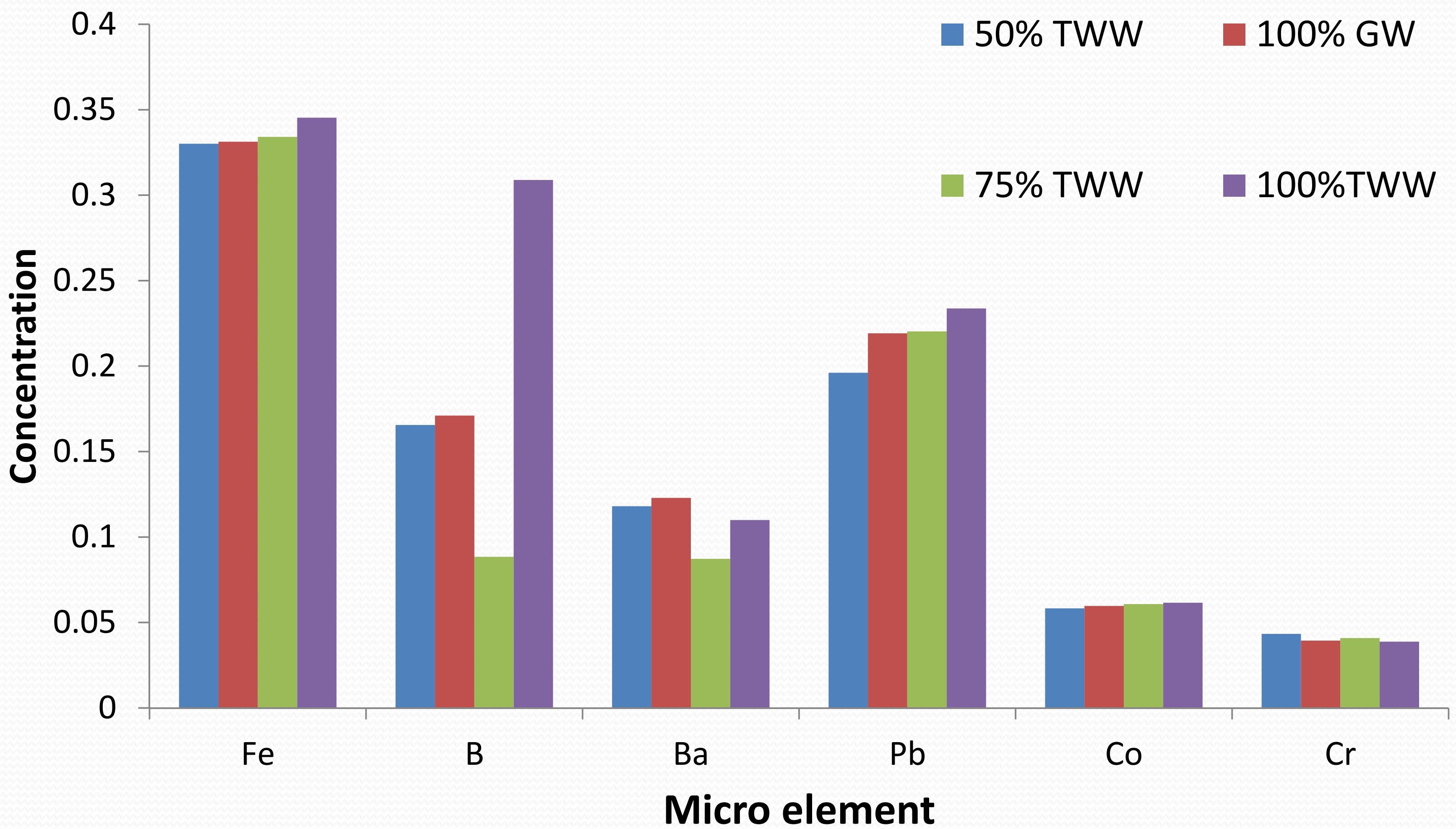




1st Season

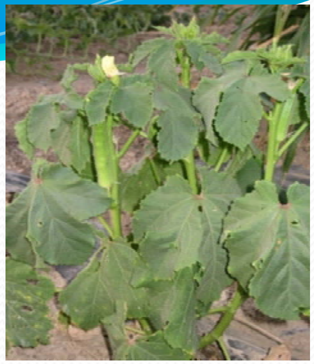
Result and discussion

- Soil chemical properties (mg/l)

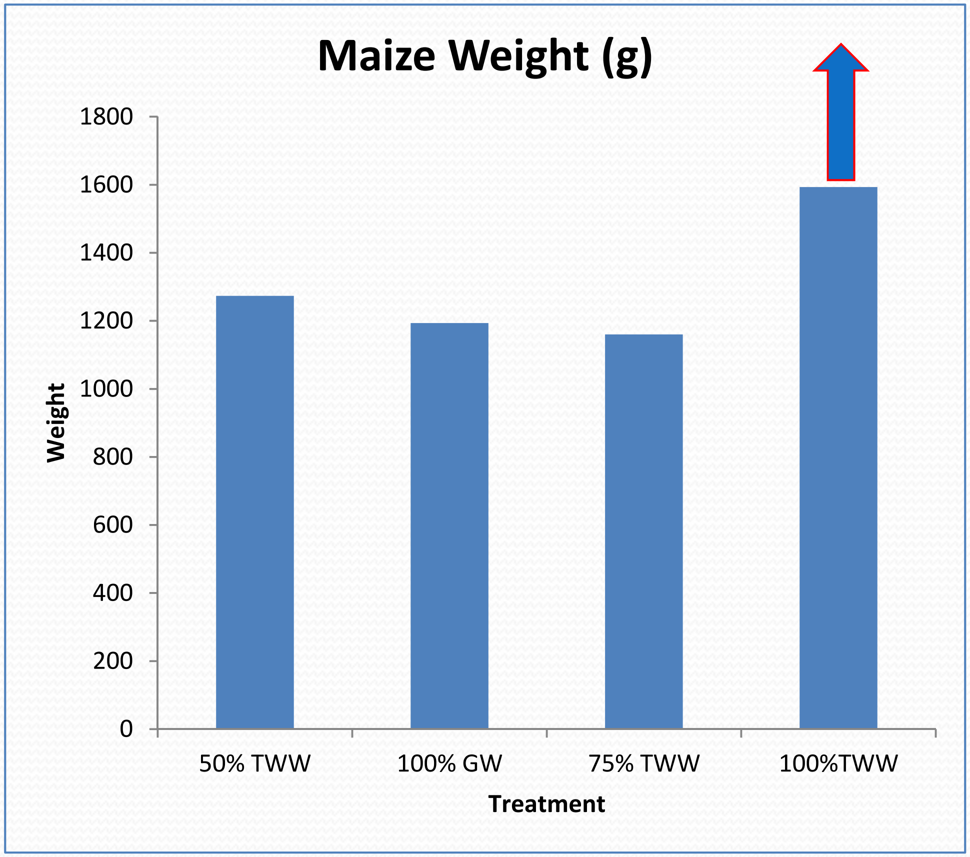


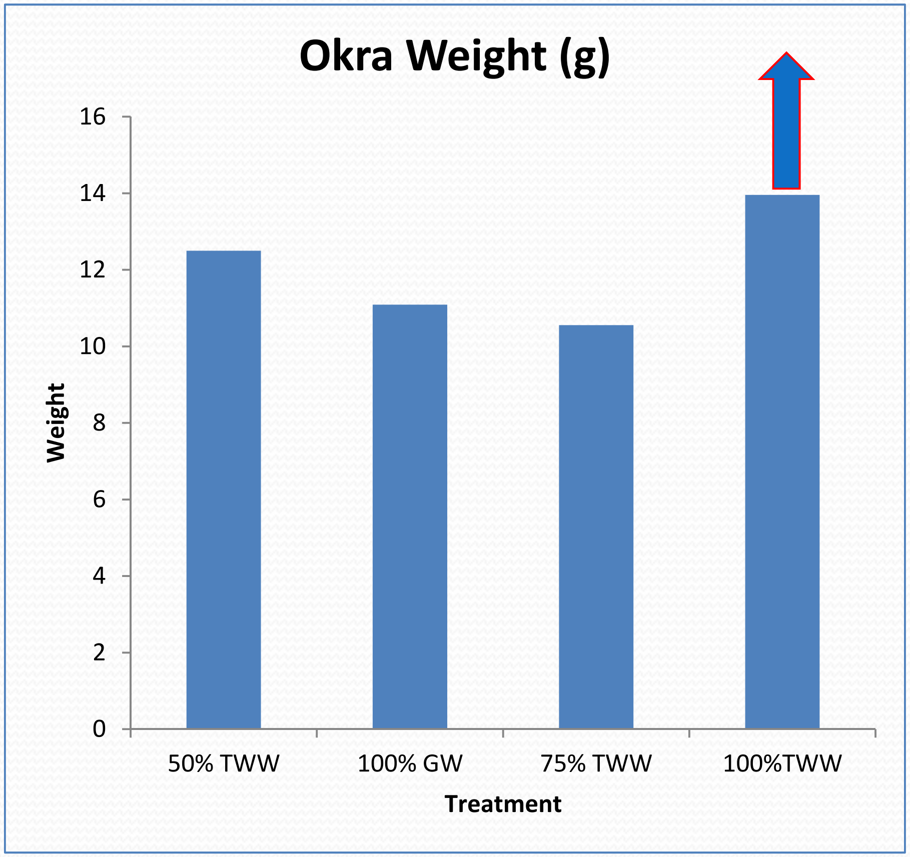
- 1st Season

Result and discussion



- Crop physical properties

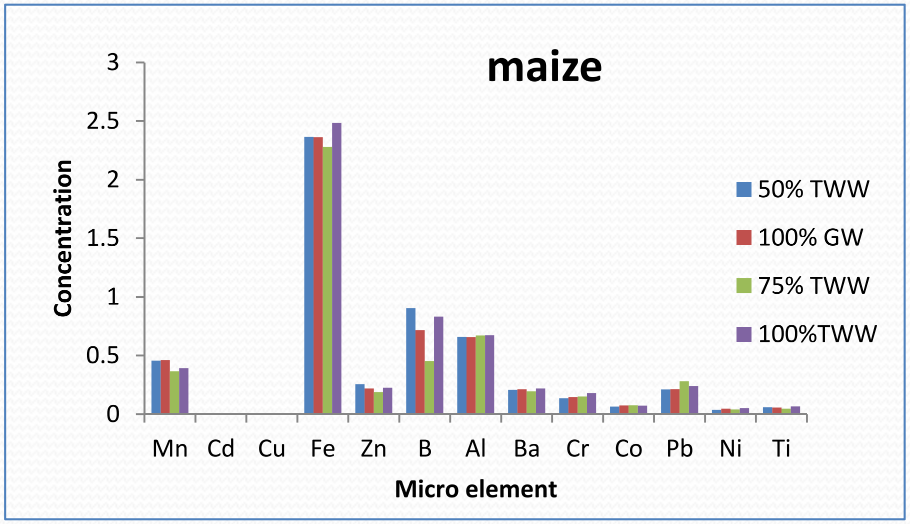


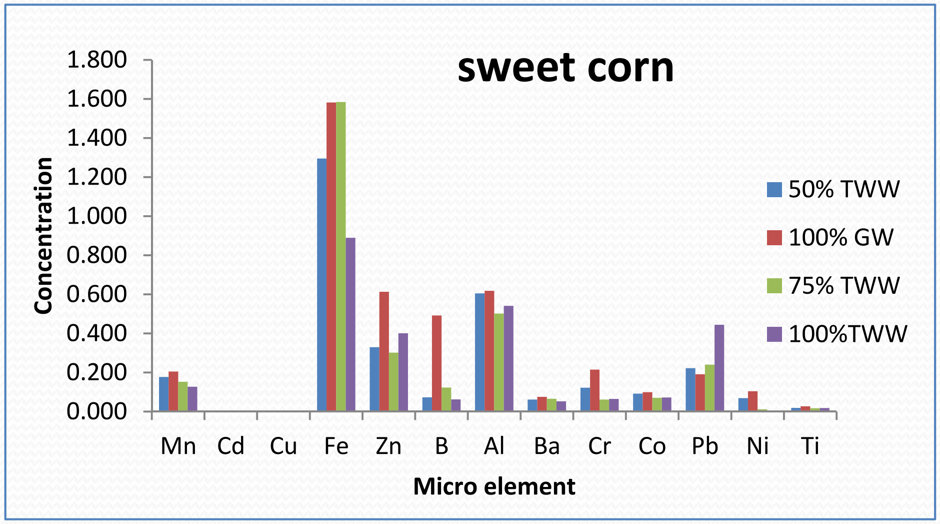


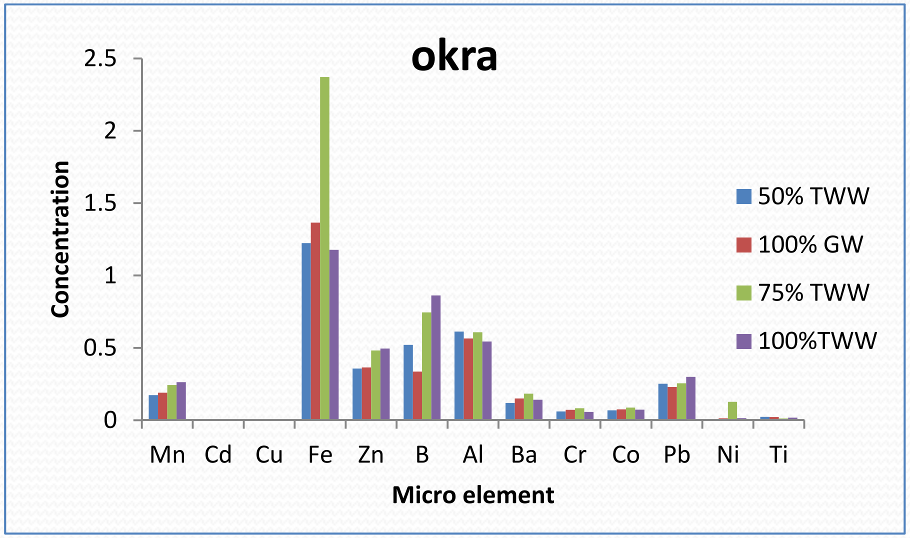
1st Season

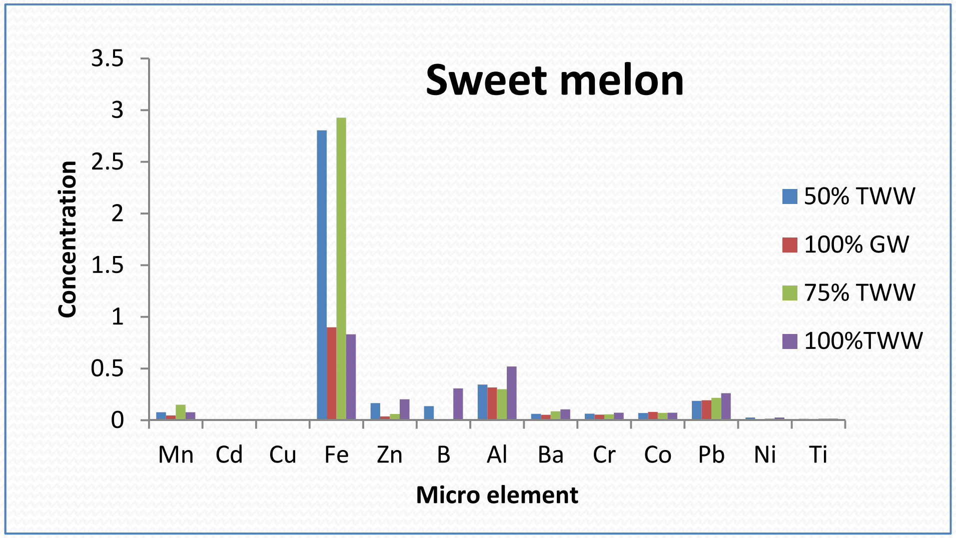
Result and discussion

- Crop chemical properties (mg/l)







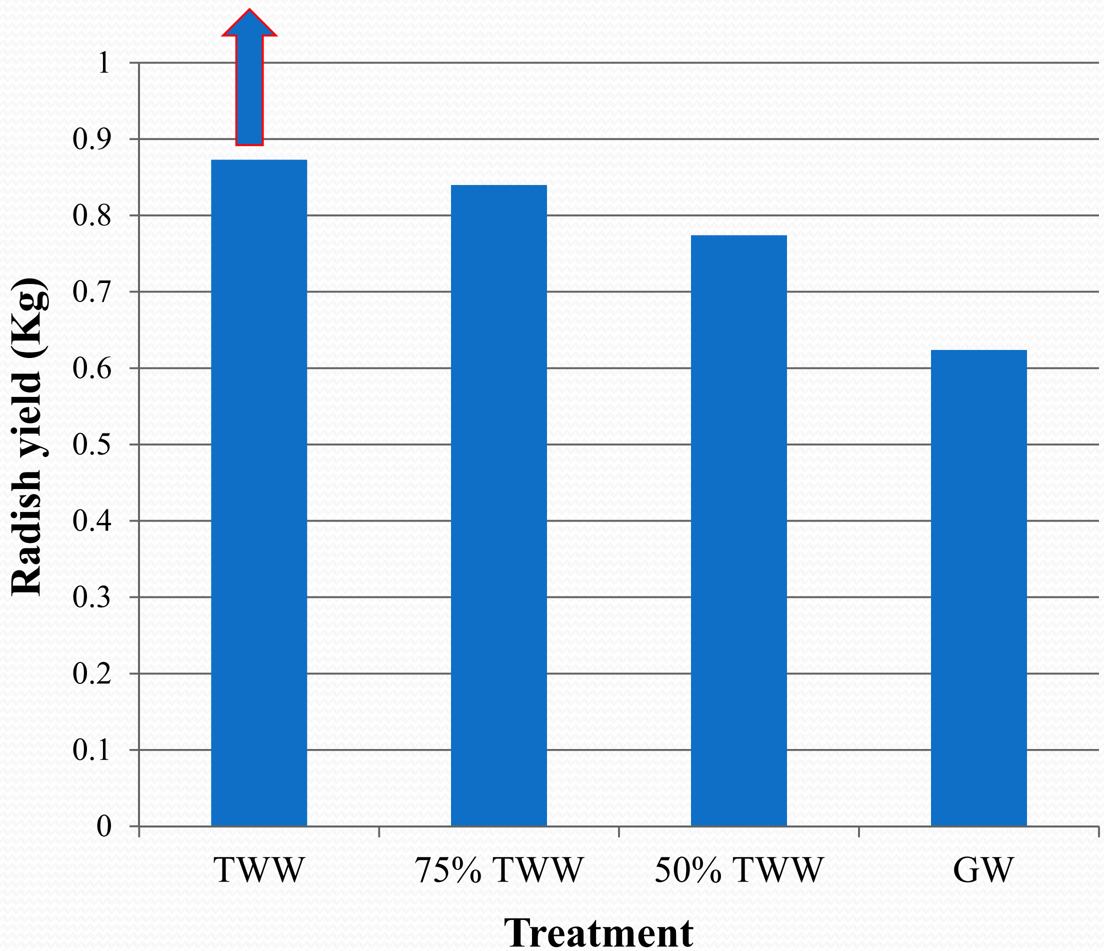


- 2nd Season

2^{nd} Season

Result and discussion

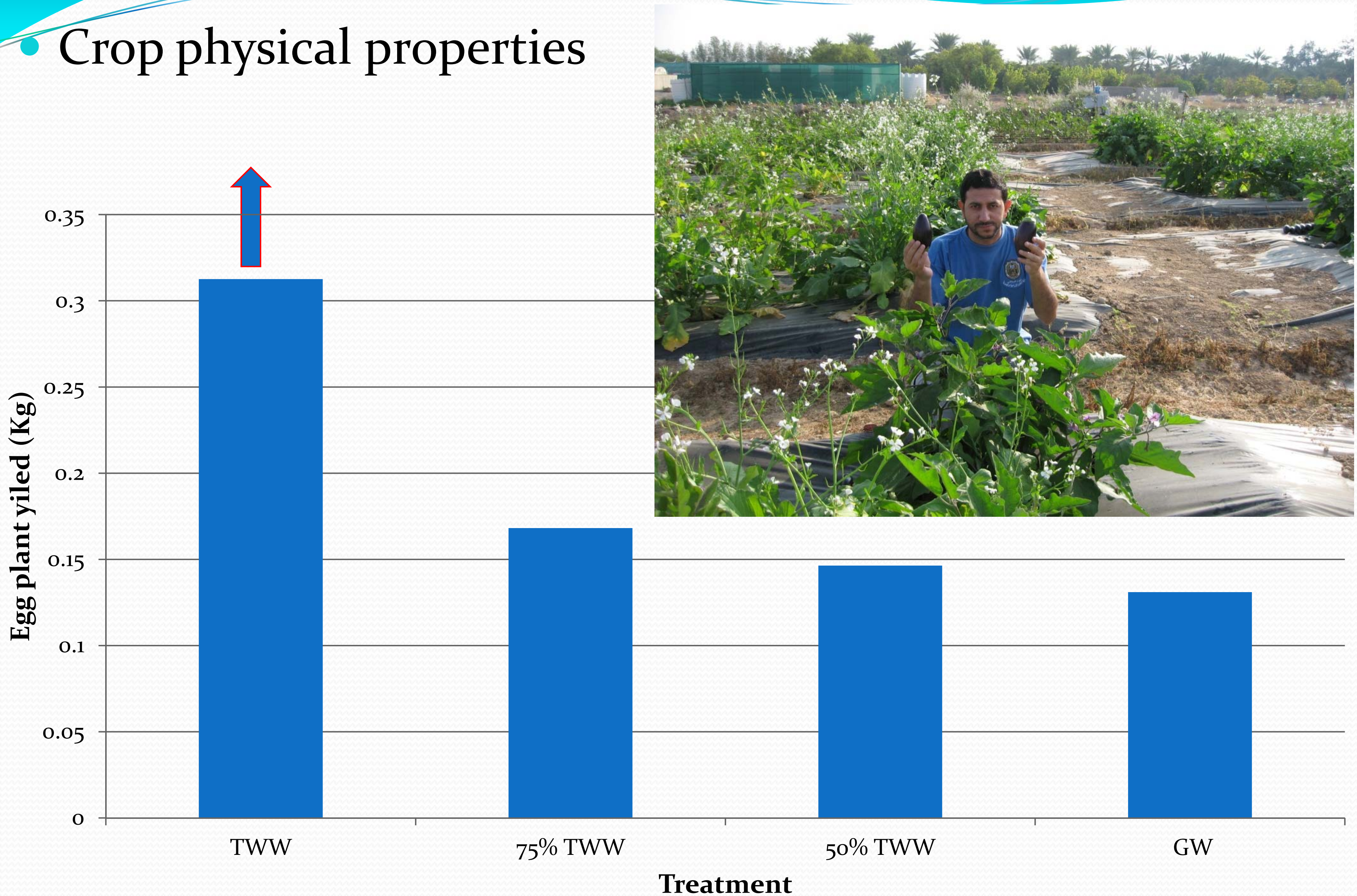
- Crop physical properties



- 2nd Season

Result and discussion

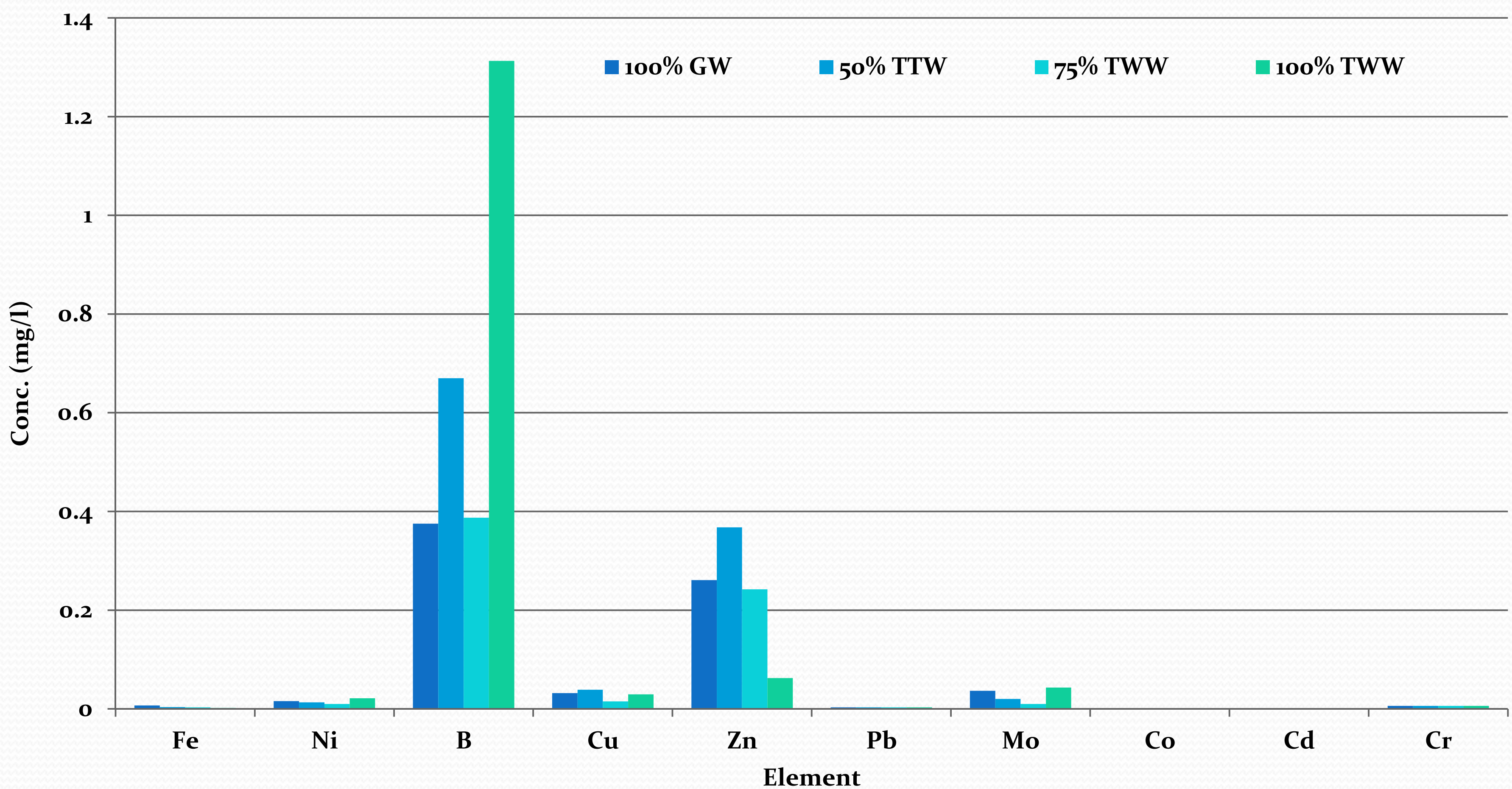
- Crop physical properties



- 2nd Season

Result and discussion

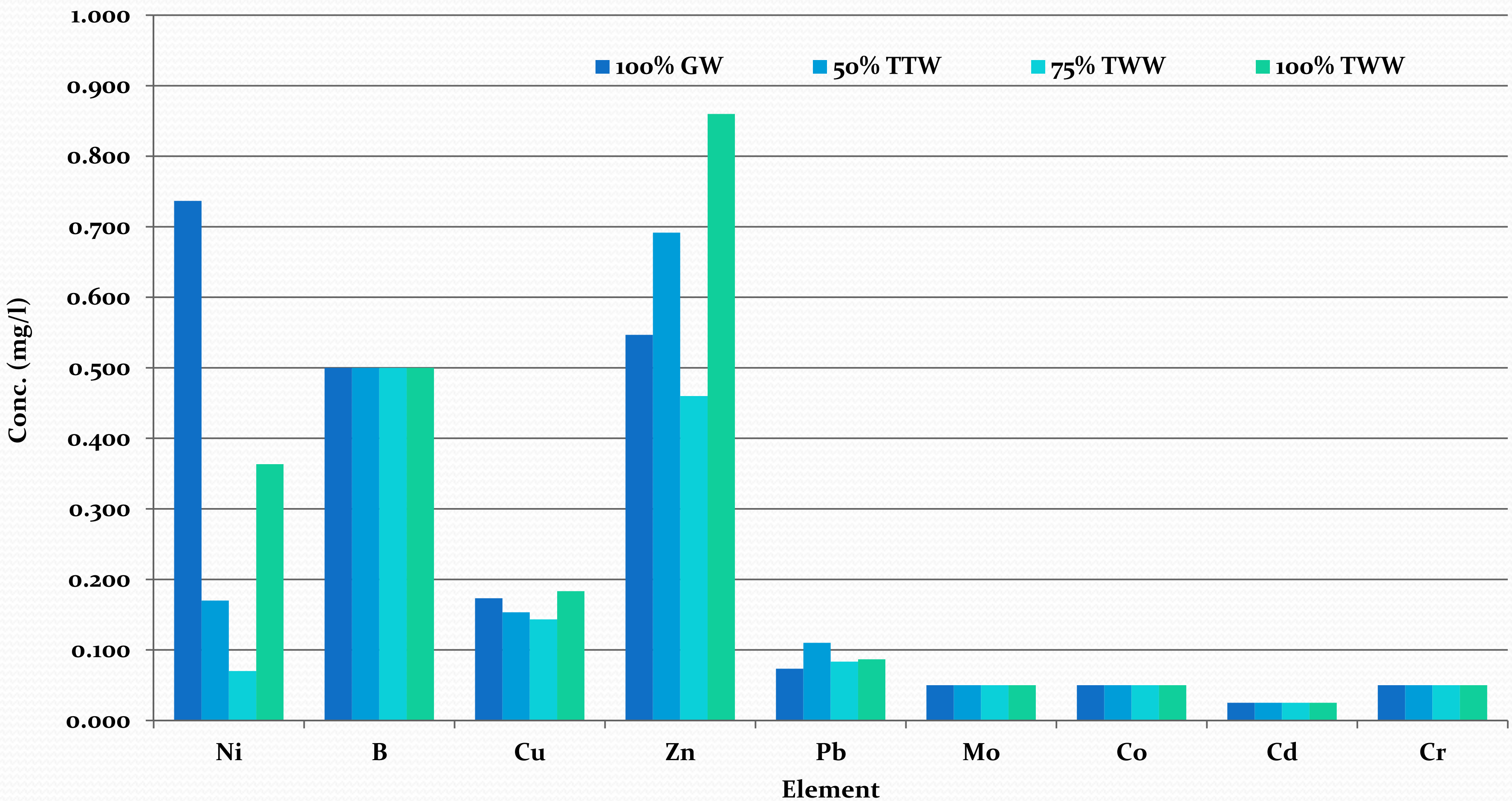
- Soil chemical properties (mg/l)



2nd Season

Result and discussion

- Crop (Eggplant) chemical properties (mg/l)



Guideline for safe limits of heavy metals

Samples	Standards	Fe	Zn	Cu	Pb	Cd	Mn	Cr	Ni	As
Water (mg L^{-1})	Indian Standard (Awashthi 2000)	0.03	5.0	0.05	0.10	0.01	0.1	0.05	-	0.05
	WHO/FAO (2007)	NA	2.0	0.20	5.0	0.01	0.2	0.10	-	-
	European Union Standards (EU2002)	-	-	-	-	-	-	-	-	-
	USEPA (2010)	NA	2.00	1.00	.015	.005	.05	0.10	-	-
	Kabata-Pendias (2010)	0.8	NA	NA	NA	NA	NA	NA	-	-
Soil ($mgkg^{-1}$)	Indian Standard (Awashthi 2000)	NA	300-600	135-270	250-500	3-6	NA	NA	75-150	-
	WHO/FAO (2007)	-	-	-	-	-	-	-	-	-
	European Union Standards (EU2002)	NA	300	140	300	3.0	NA	150	75	-
	USEPA (2010)	NL	200	50	300	3.0	80	NA	-	-
	Kabata-Pendias (2010)	1000	NA	NA	NA	NA	NA	NA	-	-
Plant ($mgkg^{-1}$)	Indian Standard (Awashthi 2000)	NL	50.0	30.0	2.5	1.5	NL	20	5	1.1
	WHO/FAO (2007)	450	60.0	40.0	5.0	0.2	500	5.0	10	-
	European Union Standards (EU2002)	NL	60	40	0.30	0.20	NL	NA	-	-
	USEPA (2010)	-	-	-	-	-	-	-	-	-

Biological Test

Sultanate of Oman
Diwan of Royal Court
Muscat Municipality
Microbiological Laboratory

سلطنة عمان
ديوان البلاط السلطاني
بلدية مسقط
المختبر الميكروبيولوجي

Microbial Analysis Report

Reference no:
Submitted by:
Date received:
Type of sample: Sweet Melon
Trade mark:
Country of manuf.
Date of manuf.: Expir:
Number of samples:
Date of report:
Remarks:

TYPE OF TEST	RESULTS
Total aerobic plate count	-
Colifom bacteria	-
E. coli	Nil
Staphylococcus aureus	-
Salmonella spp.	Nil
Yeast & mould	-
Others (*Bacillus cereus*)	-

HK

Maximizing Water Productivity by Integrated Approach of Aquaculture System

+

=

Hydroponics system **Aquaculture system** **Aquaponics system**

Farm-based project

Started in 2001 in response to requests from farmers.

Tilapia previously introduced throughout Oman for malaria control

Mixed sex Nile tilapia-Egypt

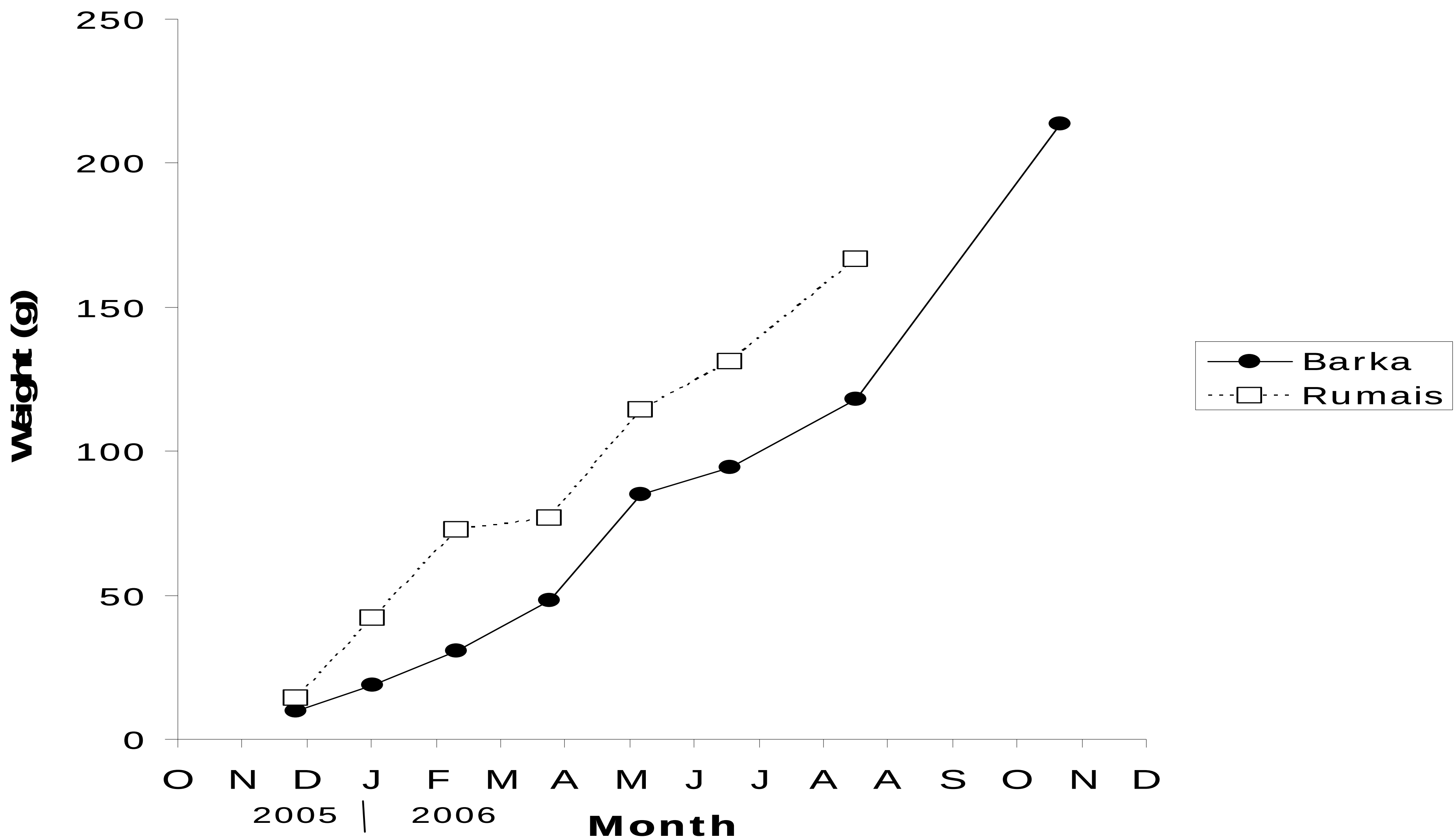
A village falaj

Tilapia culture

Brackish water - **Barka**

Fresh water tilapia farm, **Sinaw**, Oman

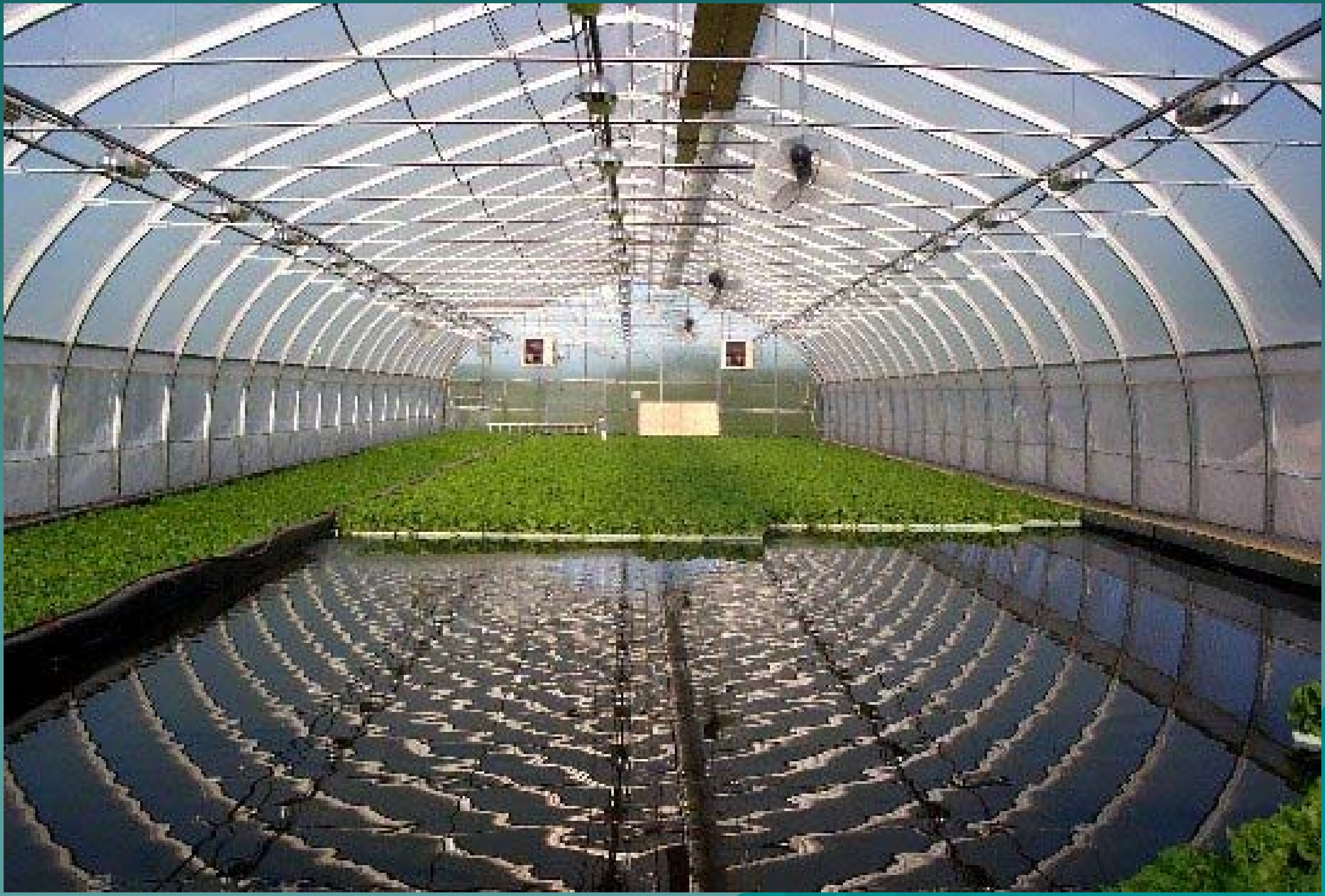
Comparative growth of Nile tilapia in freshwater (Barka) and at 10ppt salinity (Rumais)



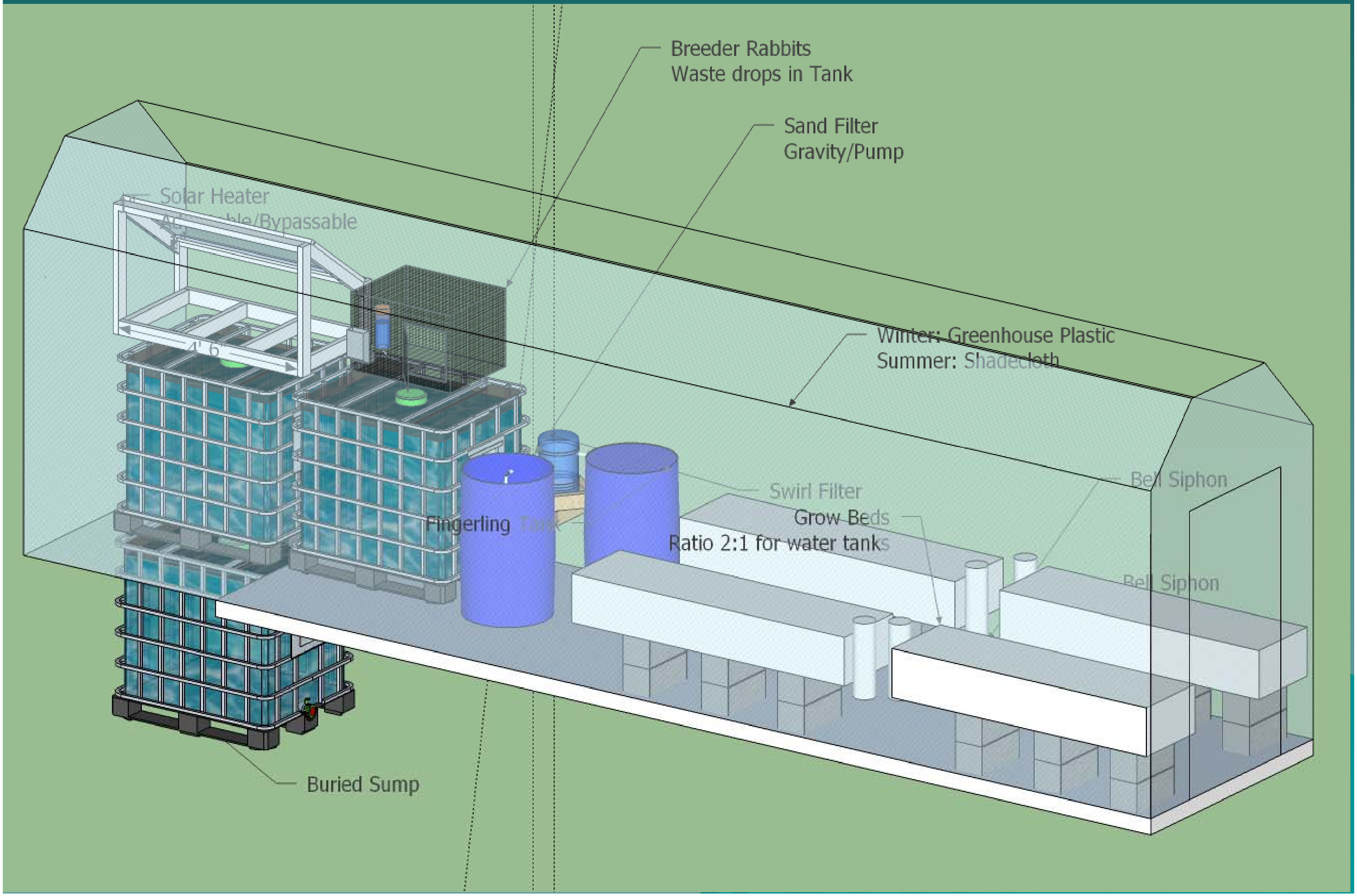
Integrating Fish Culture with Freshwater Agriculture

Trial farm - Barka

Aquaponics for Smart Cities



Greenhouse Aquaponics



Greenhouse Aquaponics

The combined growing of fish and greenhouse crops has been tested successfully in Oman. In 2010 a report was published by a group of scientists from Sultan Qaboos University and the Ministry of Agriculture and Fisheries for the combined production of tomatoes and red hybrid tilapia

Aquaponics: a promising method for growing fish and crops in Oman

By Dr Stephen Goddard

AQUAPONICS is the combination of fish production (aquaculture) with the soil-less production of plants (hydroponics). It operates within a closed-loop system and utilises minimal resources. Fish feed provides most of the nutrients required for healthy plant growth. These nutrients, excreted directly by the fish, or generated by the microbial breakdown of organic wastes, are absorbed by growing plants. Nutrient removal by the plants in turn treats the water by removing nitrogenous compounds, such as dissolved ammonia, which are harmful to fish. Water is then re-oxygenated and returned to the fish tanks. Fresh, potable water is added to the system, as necessary to replace evaporative loss.

Aquaponics Research in Oman

The combined growing of fish and greenhouse crops has been tested successfully in Oman. In 2010 a report was published by a group of scientists from Sultan Qaboos University and the Ministry of Agriculture and Fisheries for the combined production of tomatoes and red hybrid tilapia. The trials were conducted at the Rumais Agricultural Station. This research is now being extended with support from the Agricultural and Fisheries Development Fund, which is operated by the Ministry of Agriculture and Fisheries. New varieties of salad crops and various fish species will be grown in a climate-controlled greenhouse and the results will be made available to growers. The unit in Rumais will also function as a demonstration facility. The main research objectives are to examine the production and uptake of minerals and their effects on the growth of plant crops, fish and plant crop productivity, the potential costs/benefits for farmers and quality and safety issues.

Commercial Development

The commercial development of large-scale aquaponics is being pioneered in Oman by Water Farmers Canada in collaboration with the Al-Raid Business Corporation. Their initial project, developed on a site at Manuma, is now in its third phase of expansion and has the seen the production of commercial quantities of fruits, salads and vegetables in systems integrated with the production of tilapia.

Production systems

Two main systems are used in aquaponics. The first involves growing crops in shallow grow-beds, using media to provide support for root systems. Expanded clay balls are commonly used to provide the physical support necessary for the roots of tall or trellised plants. The system operates on a flood and ebb system, where each tank is filled with mineral-rich water and drained 2-3 times each hour. A second method, used for smaller plants such as herbs and salads, involves floating the plants in a styrofoam raft. The plants are grown in small coir pots and receive their necessary minerals from the fish tank via the water which circulates around their exposed roots beneath the floating rafts.

Aquaponic systems need to be run intensively for maximum benefit with carefully managed planting and harvesting cycles. This necessitates maintaining the necessary balance between the culture of fish and the growing of plants. This ensures adequate circulating minerals and maintenance of water quality. Whilst most benefits of aquaponics are normally derived from the sale of plants there is considerable interest in growing fish of high value.

Tilapia are hardy fish. They are able to survive high water temperatures and are a suitable species for aquaponics production in Oman. Other, more highly valued species, include the Asian sea-bass and koi carp, which are sold for aquaria and ornamental fish ponds.

Sustainability

The benefits of using soil-less culture techniques and water re-cycling provide considerable benefits for long-term sustainability. Water consumption is less than 10 per cent of normal levels for horticultural production and can be provided from potable supplies. This eliminates the risk of contamination with pathogens which may occur in ground-water supplies. Reduced water demand is clearly useful in a hot arid environment. There are no direct mineral or fertilizer costs since the primary mineral source is the fish feed, which is contributing also to fish production. Some small additions of alkaline salts, to maintain a stable, neutral pH and ferrous salts, to maintain the necessary iron content, are the only mineral additives used in aquaponics. The intensive nature of aquaponic production reduces the amount of land necessary for commercial production units. Additionally, aquaponic systems operate with a low energy footprint, by maximising the use of gravity for water flow.

Safety

Neither chemicals nor pesticides are used in aquaponic systems, which have a high level of environmental compatibility as they do not discharge effluents. Being the ideal closed loop system, all chemical and biological by-products of the system are naturally used and neutralised within the system itself. The systems can be initiated with potable water and there are no direct risks of contamination with coliform bacteria or salmonella, since these pathogens do not survive in cold-blooded animals, such as fish. As in all crop production systems cross-contamination is possible, but the risk is greatly reduced when compared with field crops or greenhouse production systems using soil. Major testing programmes on aquaponic produce in Canada and Hawaii have recommended normal washing procedures following harvest for raw salad crops and herbs. Farmers using aquaponic techniques also have opportunity to seek organic certification since no pesticides or chemicals are used during production and crops should remain free of any unwanted residues.

(Dr Stephen Goddard is the Director of the Centre for Marine Biotechnology at Sultan Qaboos University. All pictures were taken at the Al Raid Farm in Manuma, near Rumais).

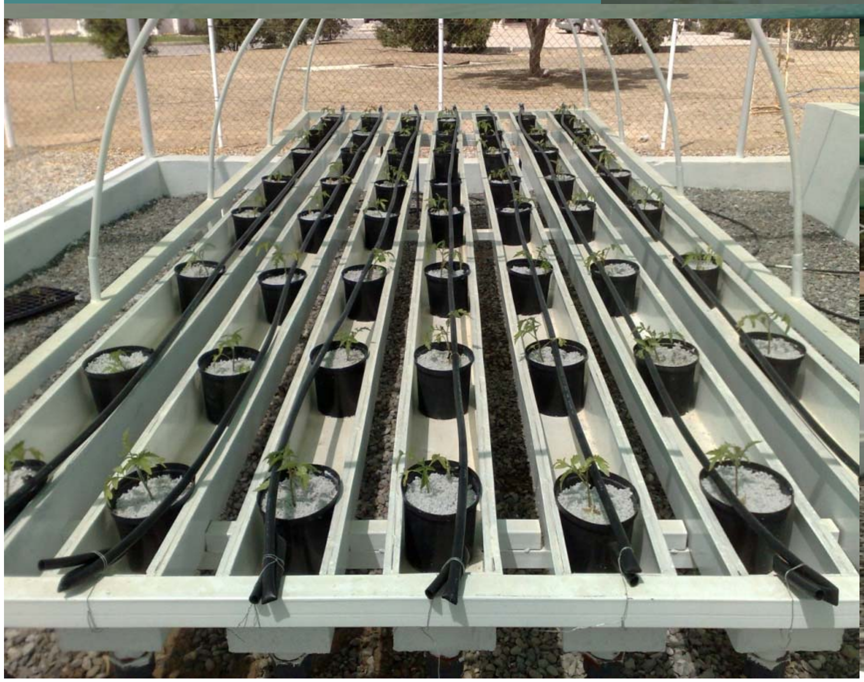
Integrating Fish Culture with Saline Agriculture

Salinity tolerance of hybrid Tilapia

Strain evaluations for red hybrid *Tilapia (O.mossambicus x O.niloticus).* Evaluate for salinity tolerance and growth rate

Consumer preference

Integrating Fish Culture with Saline Agriculture



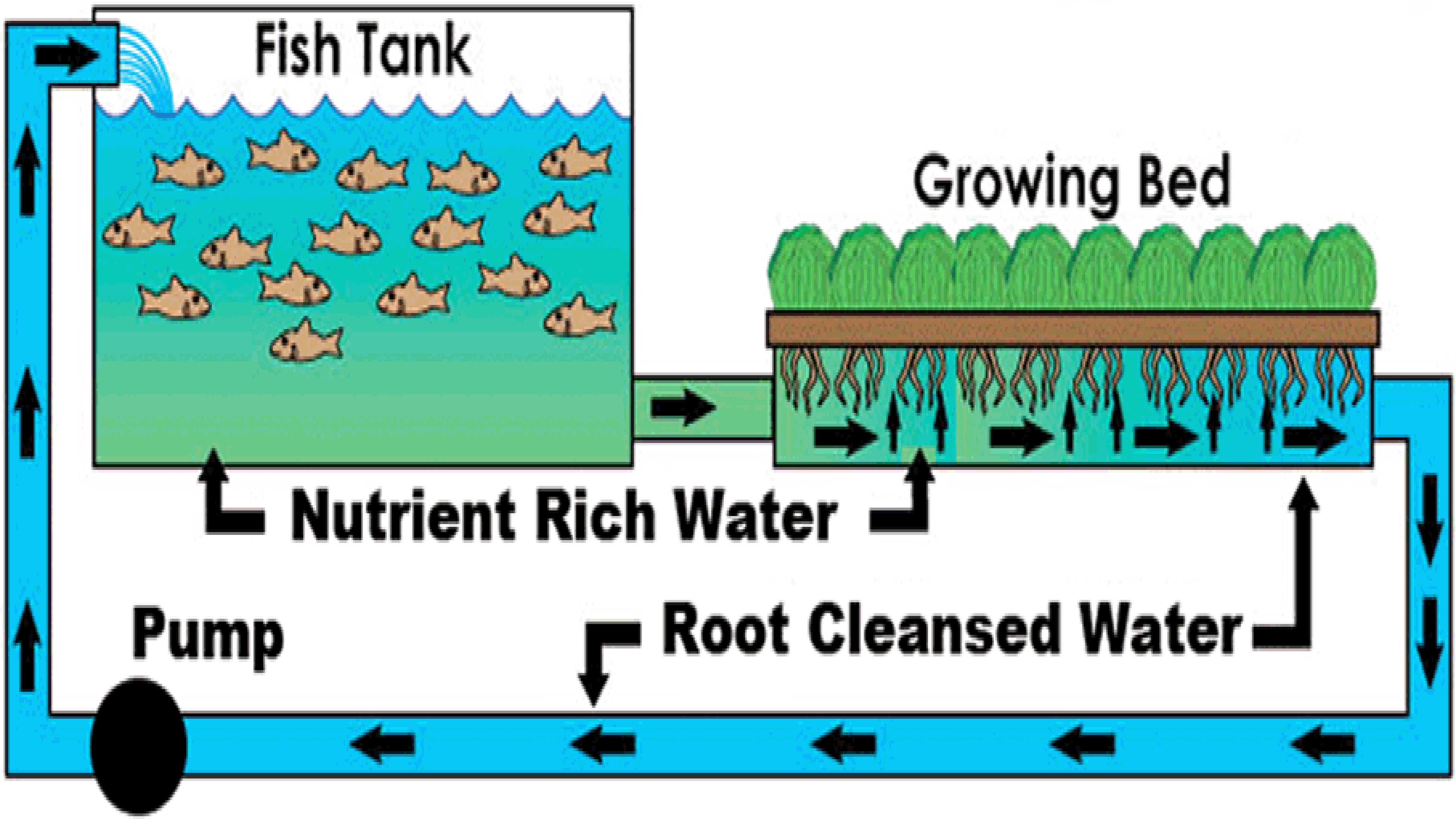
Result and discussion

Tomato plant growth at different irrigation water treatments, low saline fish effluent (3E), higher saline fish effluent (6E), low saline (S3), high saline (S6) and freshwater (FW).

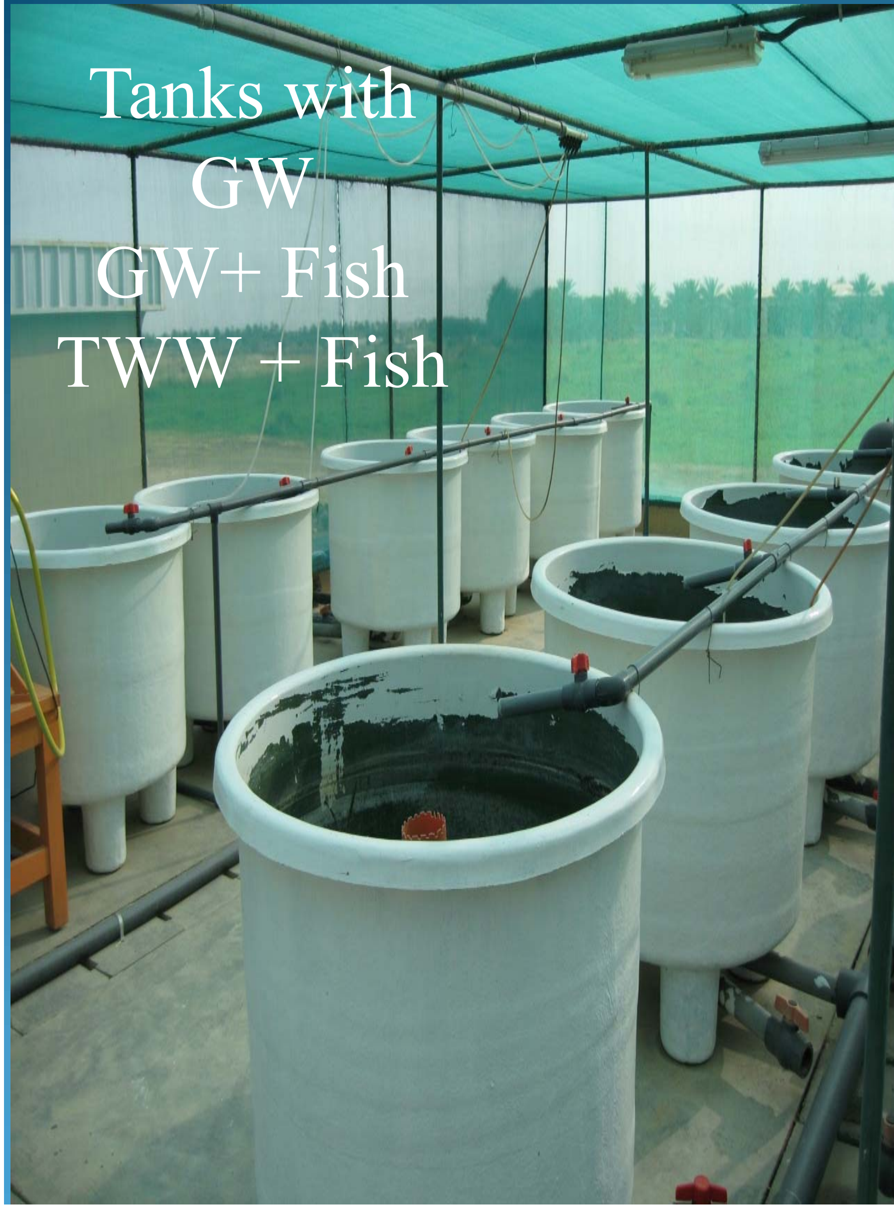
Treatment	Height (cm)	Fresh weight (g)	Leaf area (cm^2)	Root weight (g)
3E	39.80^{a}	25.40^{a}	9.33^{a}	11.20^{a}
6E	30.83^{b}	7.33^{b}	4.37^{bc}	6.67^{b}
S3	23.50^{d}	4.00^{c}	4.40^{bd}	3.75^{d}
S6	20.75^{e}	4.25^{c}	2.88^{e}	5.00^{c}
FW	28.25^{c}	6.00^{b}	3.75^{cde}	6.75^{b}

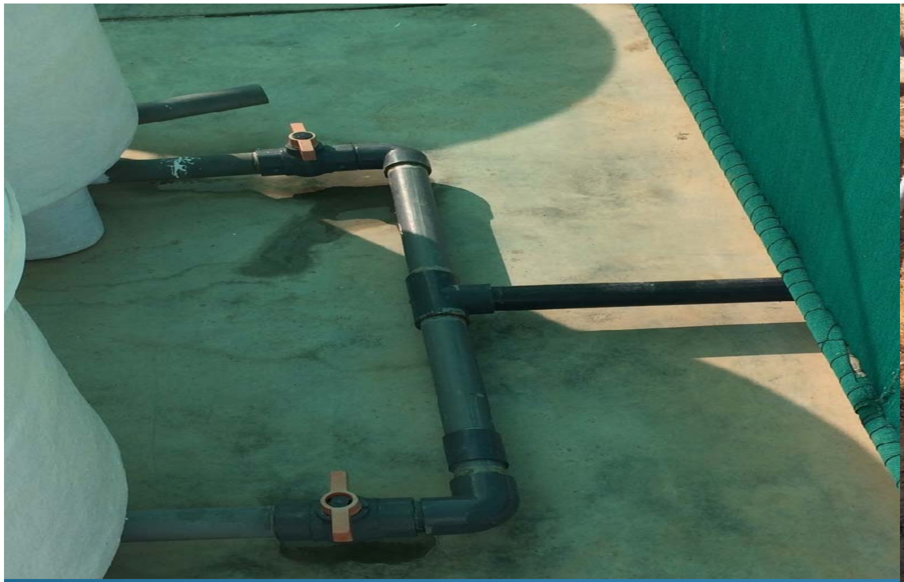
Mean values in each column followed by the same superscript are not significantly different (*P* > 0.05).

Maximizing Water Productivity by Integrated Approach of Aquaculture System using Treated Wastewater



Integrated Aquaculture with TWW





Fish tanks connected to field crops

Irrigated crops: Radish, Bean & Hot pepper

Integrated Aquaculture with TWW

Ground water

Ground water with fish waste

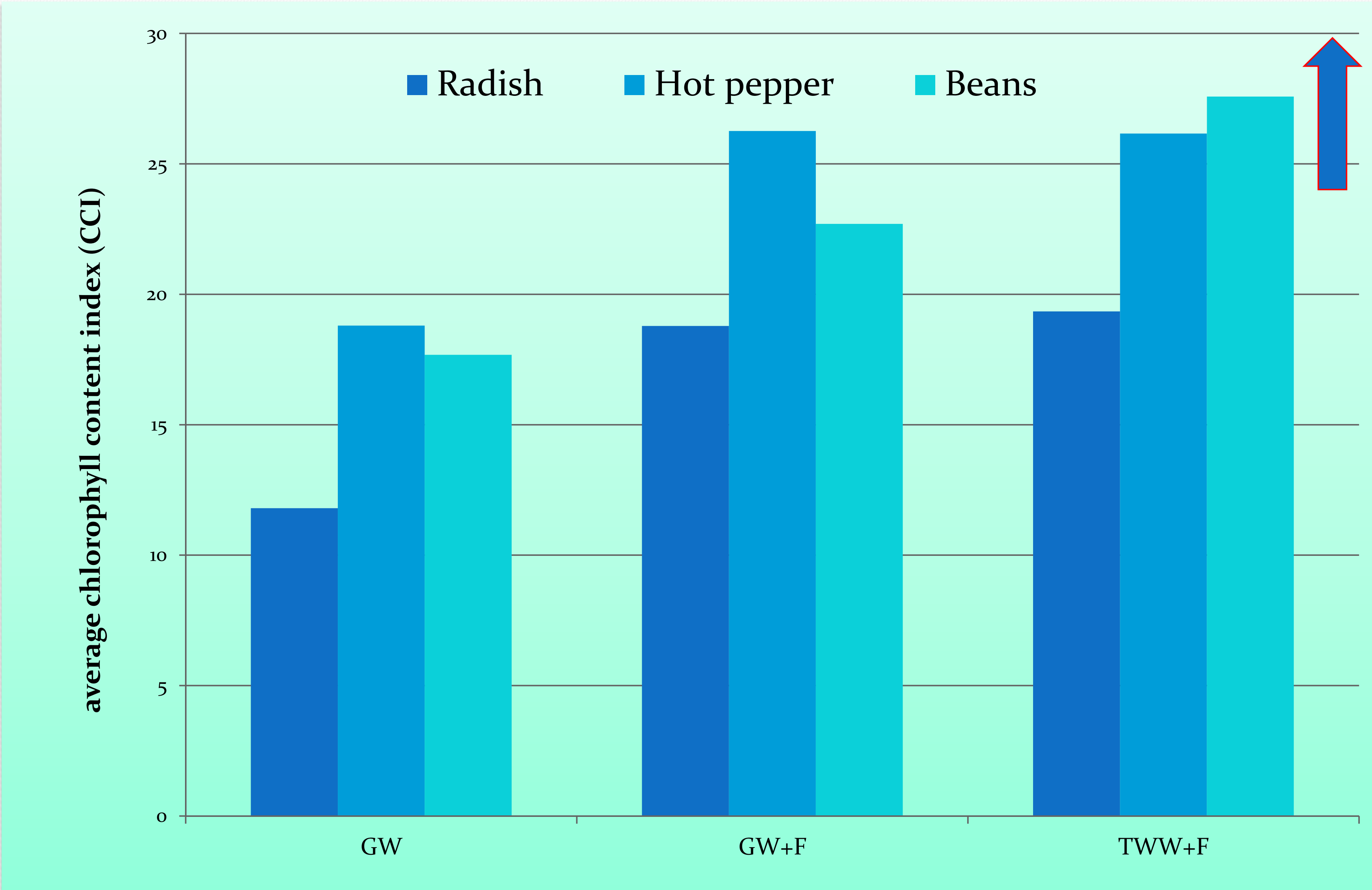
Treated waste water with fish waste

Water and Plant analysis's

	TWW	GW	TWW + FISH	GW +FISH
EC (mS/cm)	1.78	1.20	2.16	2.03

Sample	Na ppm	K ppm	Ca ppm
GW+Fish (Water)	700	43	28
TWW + Fish (Water)	650	52	41
TWW (Water)	520	81	55
GW (Water)	630	29	36
GW + Fish (Plant)	350	440	210
TWW + Fish (Plant)	570	825	280
GW (Plant)	225	195	60

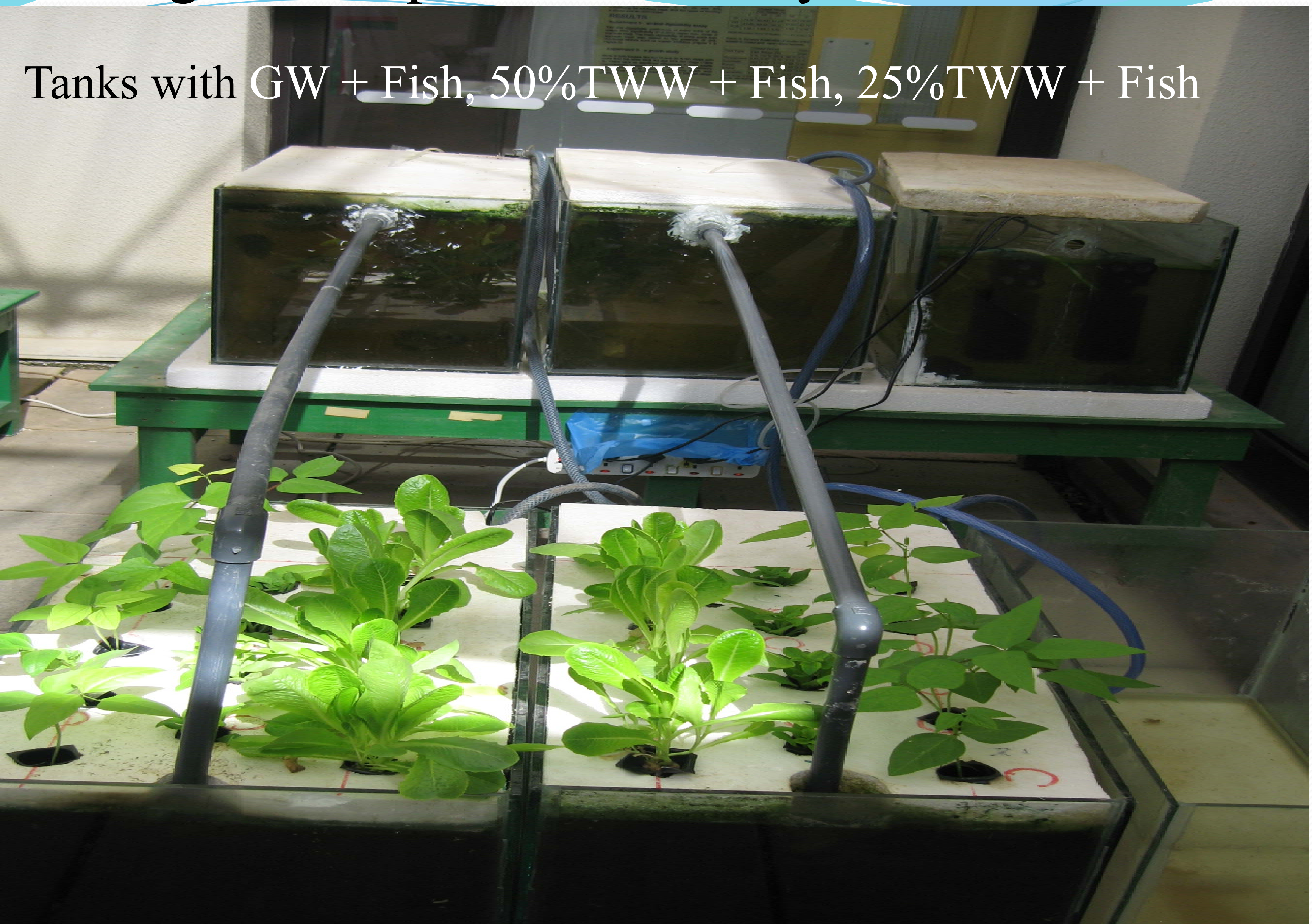
Chlorophyll content index (CCI) for the three crops



High Ammonia & **Nitrate**: affect fish life

2: Integrated Aquaculture Study in Shade House

Tanks with GW + Fish, 50%TWW + Fish, 25%TWW + Fish



Integrated Aquaculture with TWW

Water analysis				
rameter	25% TWW	50% TWW	Fresh water	
nperature (cº)	25.49	25.21	25.31	
alinity ms/cm)	0.341	0.503	0.424	
) (mg/L)	4.32	3.11	4.69	
pH	6.72	6.81	6.27	

grated Aquaculture study in Shade House

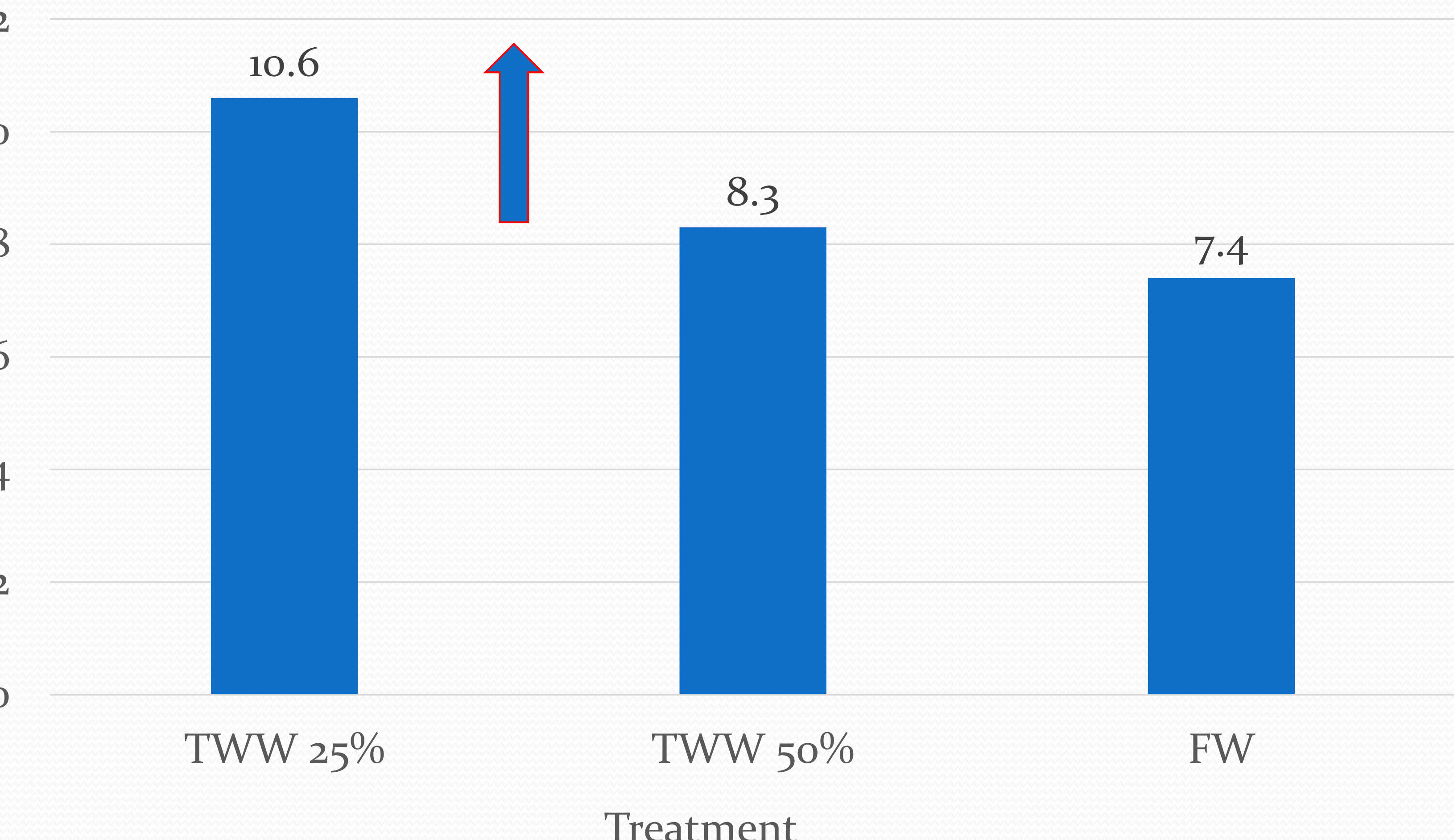
Plant analysis (Lettuce)

tment	CCM-200 (CCI)
n water	8.4
V 25%	12.5
V 50%	14.8

Treatment	Nitrogen analysis	
	samples	Nitrogen %
25% TWW	Lettuce shoot / A	2.54
	Lettuce shoot / B	3.64
50% TWW	Lettuce shoot /A	3.52
	Lettuce shoot / B	4.23
Fresh	Lettuce shoot	3.56

Integrated Aquaculture with TWW

Lettuce growth as affected by different treatments



Average elements concentrations of all treatments