The National Center for Agricultural Research and Extension

Treatment and Reuse of Wastewater Using Surface and Subsurface Wetlands

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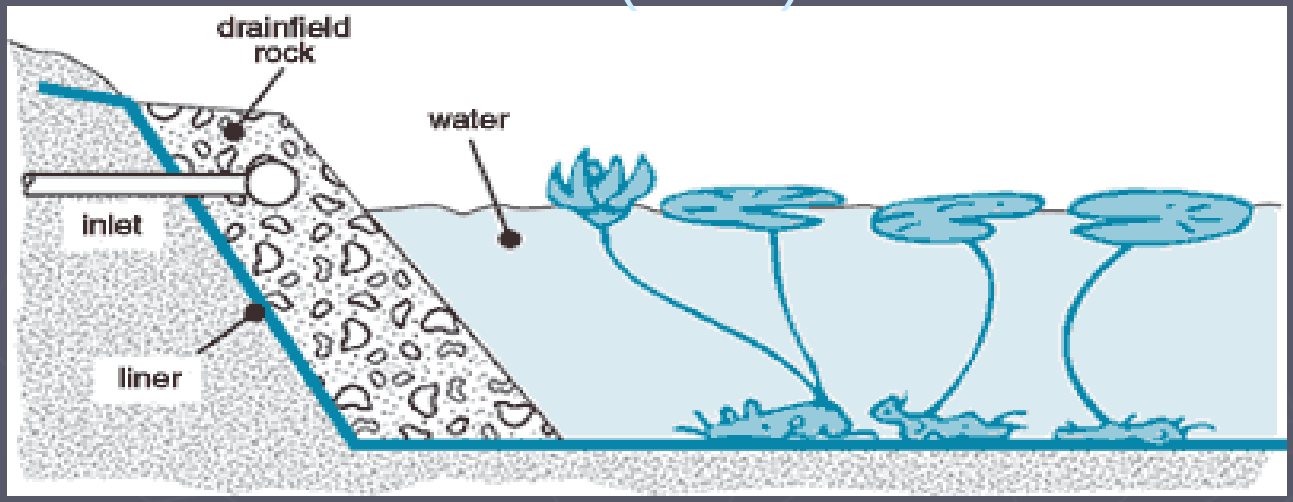
Background

- Jordan is a country with limited water resources.

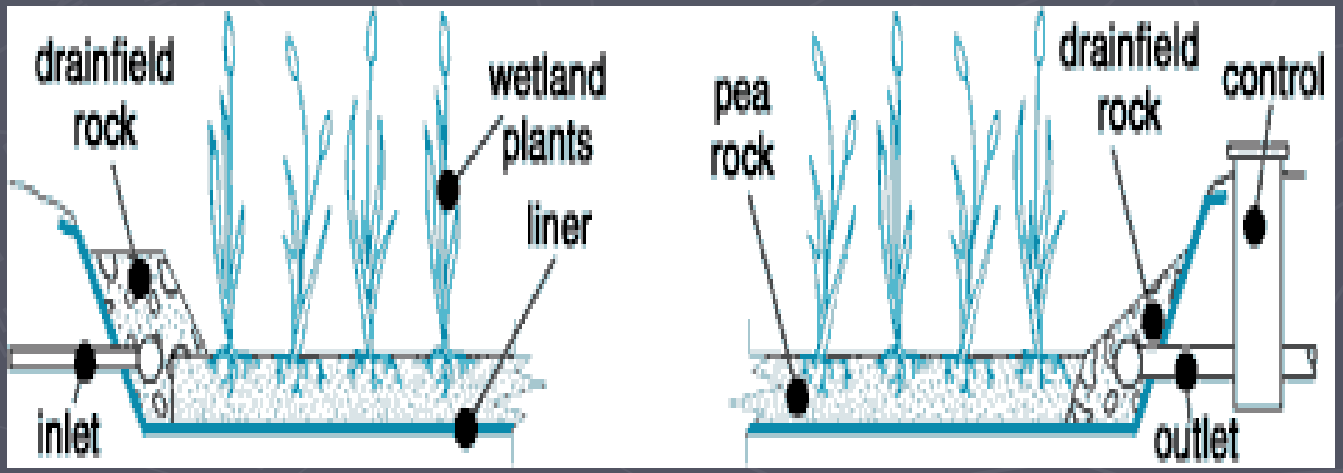
- The average amount of total available fresh per capita is currently 90 m^3/yr.

Types of constructed wetlands

1. Free water surface (FWS) constructed wetland.



2. Subsurface flow (SSF) or Vegetated submerged bed (VSB) constructed wetland.



Objectives

- Evaluate the use constructed wetlands to treat partially treated wastewater and improve the quality of treated wastewater effluent from wastewater treatment facility in Ramtha area, Jordan.

- Reuse of wetland - treated effluent for the irrigation of selected forage crops.

- Evaluate the potential uses of subsurface wetland for crop production to increase water use efficiency and reduce fresh water use.

Material and Methods

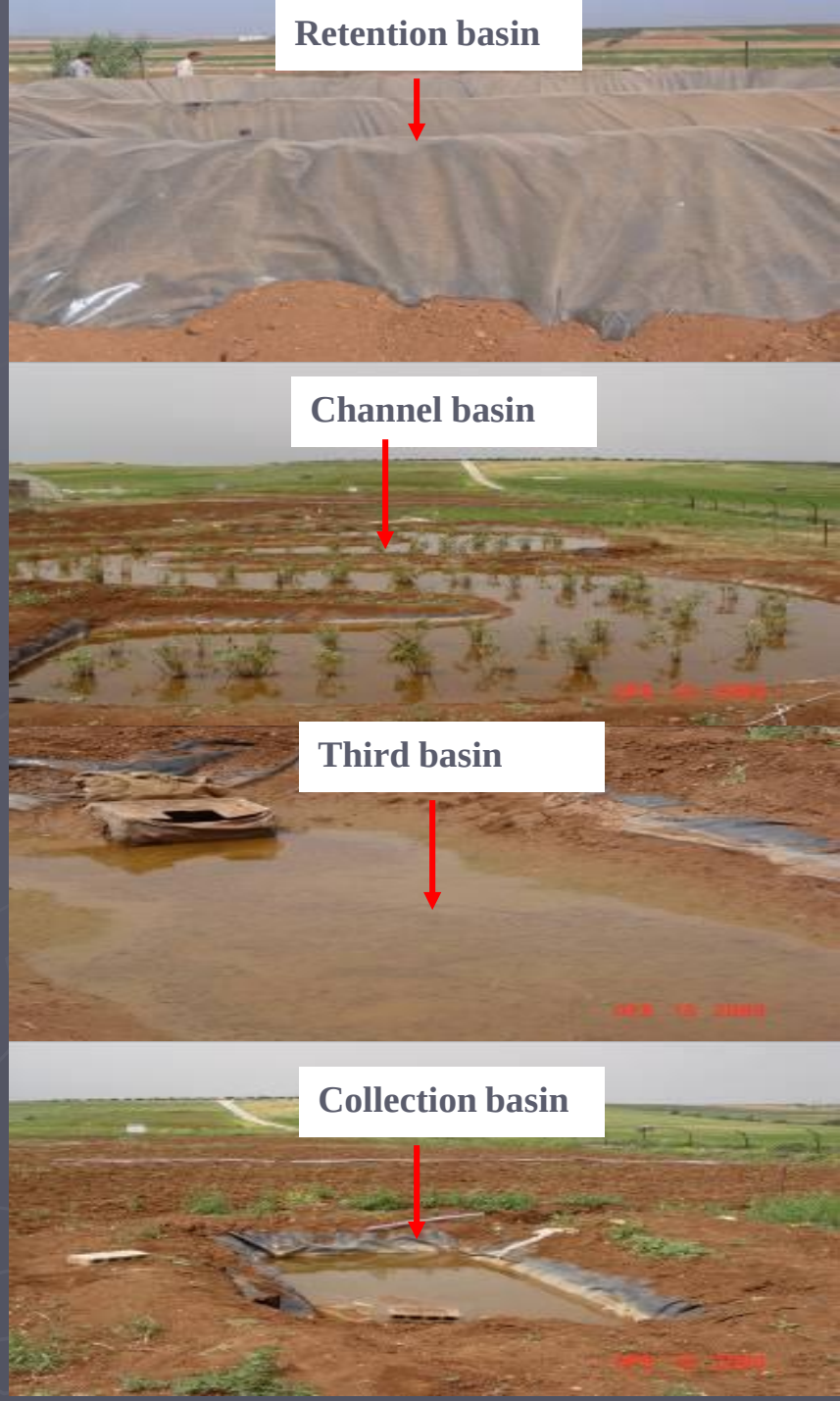
Site Description:

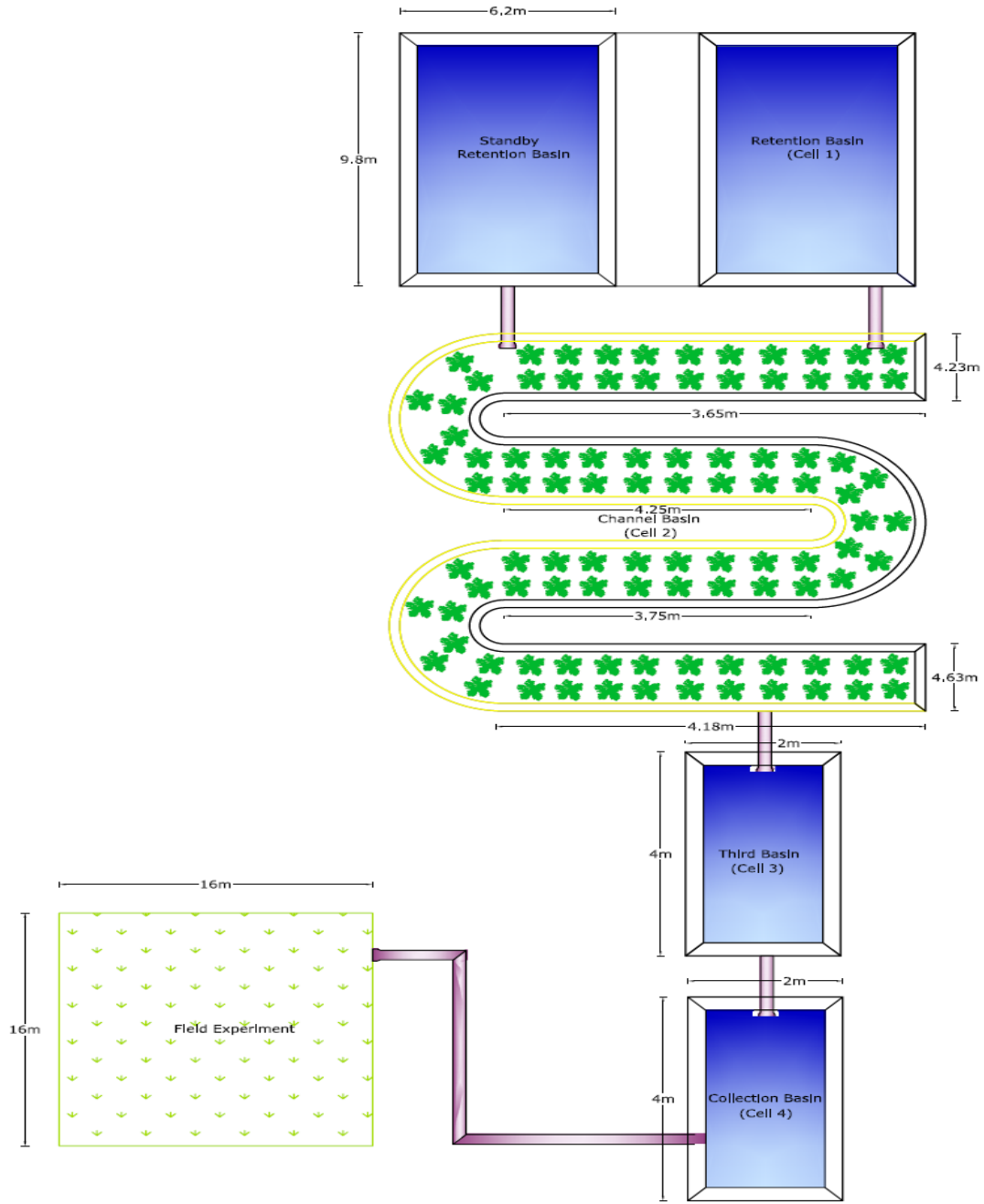
Field experiments were conducted at the National Center for Agricultural Research and Extension (NCARE) research station at Ramtha in the Northern part of Jordan. The experimental site is located near Ramtha wastewater treatment plant, where irrigation with treated wastewater is highly practiced.

Site Construction & Preparation Free Water Surface Wetland

- The free water surface (FWS) wetland was composed of three cells in series of which two are open water surface and one is a channel bed planted with Cyperus alternifolius.

- The FWS wetland was calibrated to estimate the volume of wastewater needed to fill the wetland.





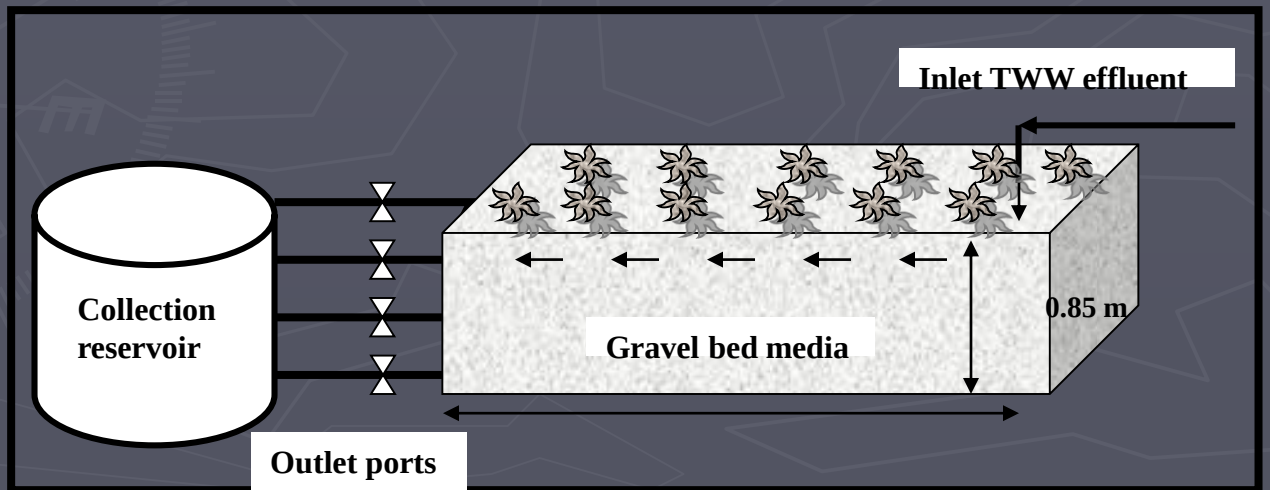
Free Water Surface Constructed Wetland Layout

Sub-Surface Flow Wetland

- The sub-surface flow (SSF) wetland has a dimension of 2m*4m (W: L) with a 0.85 m media depth. The soil was compacted and lined using a 600 micron polyethylene layer.

- Four different gravel size layers were used as treatment media in the construction. The diameter of the first, second, third and fourth media layer was ranging from 18-20mm, 10-12mm, 6-8mm and 2-3mm respectively.

- The SSF wetland was calibrated to estimate the volume and the porosity of the system.



Measurements & Treatments

1. Surface Wetland

- Different hydraulic retention times (HRT) were tested.
- Different flow rates were used within each HRT

HRT (days)	Flow rate (m^3/day)
3	26.67
6	13.33
9	8.89
12	6.67

- Primary treated wastewater effluent was used.
- Different mixtures were tested.

Mixture Treatment	Primary treated wastewater	Treated wastewater effluent
1.	0	100
2.	25	75
3.	50	50
4.	75	25

Measurements (Continued…)

2. Subsurface Wetland

- The use of subsurface wetland was also to evaluate its potential for crop production. According to this, the wetland was planted with barley crop (*Hordium vulgare*) in the first season and with corn crop (*Zea mays* L.) in the second season. The treated wastewater effluent was used within this wetland with a HRT of 1 day.

- Water quality parameters (turbidity, EC, PO_4, TKN and pathogens; fecal coliform and total coliform) were monitored for both wetlands for inflow and outflow on a regular basis.

Measurements (Continued…)

3. Field experiment

- The treated effluent out of both wetlands was directed to irrigate a forage crop field run in 4*4 m^2 plots in 4 replicates in a randomized complete block design.

- The three types of treated effluents that were used: a) treated wastewater from the surface wetland, b) treated wastewater from the sub-surface wetland and c) control treatment with the treated wastewater effluent of Ramtha wastewater plant. At the first season, the field experiment was planted with barley crop (*Hordium vulgare*). In the second season, the field was planted with corn crop (*Zea mays* L.).

- Irrigation scheduling was based on crop water requirements using FAO reference evapotranspiration and crop coefficients.

- Yield data was collected and standard statistical analysis (ANOVA) was used to evaluate the differences between treatments.

Field Experiment Layout

Legend:
T1= TW: Treated wastewater effluent
T2= SW: Surface wetland effluent
T3= SSW: Sub-surface wetland effluent

Results & Discussion
1. Free water surface wetland

- The quality of wastewater and / or HRT in FWS constructed wetland significantly affected the pH, EC, TSS, E.coli, PO_4 and turbidity to greater levels and insignificantly affected the concentrations of BOD_5, COD, TKN, and NO_3.

Changes of EC

- Results showed a significant difference due to mixture and time effect. Mixture 2 showed the lowest salinity change.

Obs	Mixture	Time	Estimate	Standard Error	Letter Group
1	1	_	-10.2083	2.3374	AB
2	2	_	-4.0833	1.8802	A
3	3	_	-13.0000	1.9638	B
4	4	_	-7.6250	1.8370	AB

- According to the effect of time, results indicated that salinity change under HRT=3 days was the lowest with significant difference from HRT = 9 and 12 days.

Obs	Mixture	Time	Estimate	Standard Error	Letter Group
5	_	3	-3.7500	2.1956	A
6	_	6	-7.1250	2.1956	AB
7	_	9	-13.0000	1.9638	B
8	_	12	-11.0417	1.6528	B

Changes of TSS

- The surface wetland significantly reduced the TSS and results showed a significant effect due to the interaction effect of mixture and time.

Obs	Mixture	Time (Days)	Change (%)	Standard Error	Letter Group
9	1	3	0	31.2671	ABCD
10	1	6	0	31.2671	ABCD
11	1	9	36.0000	22.1092	ABC
12	1	12	59.6667	18.0521	A
13	2	3	-10.5000	22.1092	BCD
14	2	6	77.5000	22.1092	A
15	2	9	-9.0000	22.1092	BCD
16	2	12	-59.6667	18.0521	D
17	3	3	-30.0000	22.1092	CD
18	3	6	17.0000	31.2671	ABCD
19	3	9	43.0000	22.1092	AB
20	3	12	-1.0000	31.2671	ABCD
21	4	3	69.0000	22.1092	A
22	4	6	72.5000	22.1092	A
23	4	9	53.0000	22.1092	AB
24	4	12	60.0000	22.1092	A

Changes of E.coli

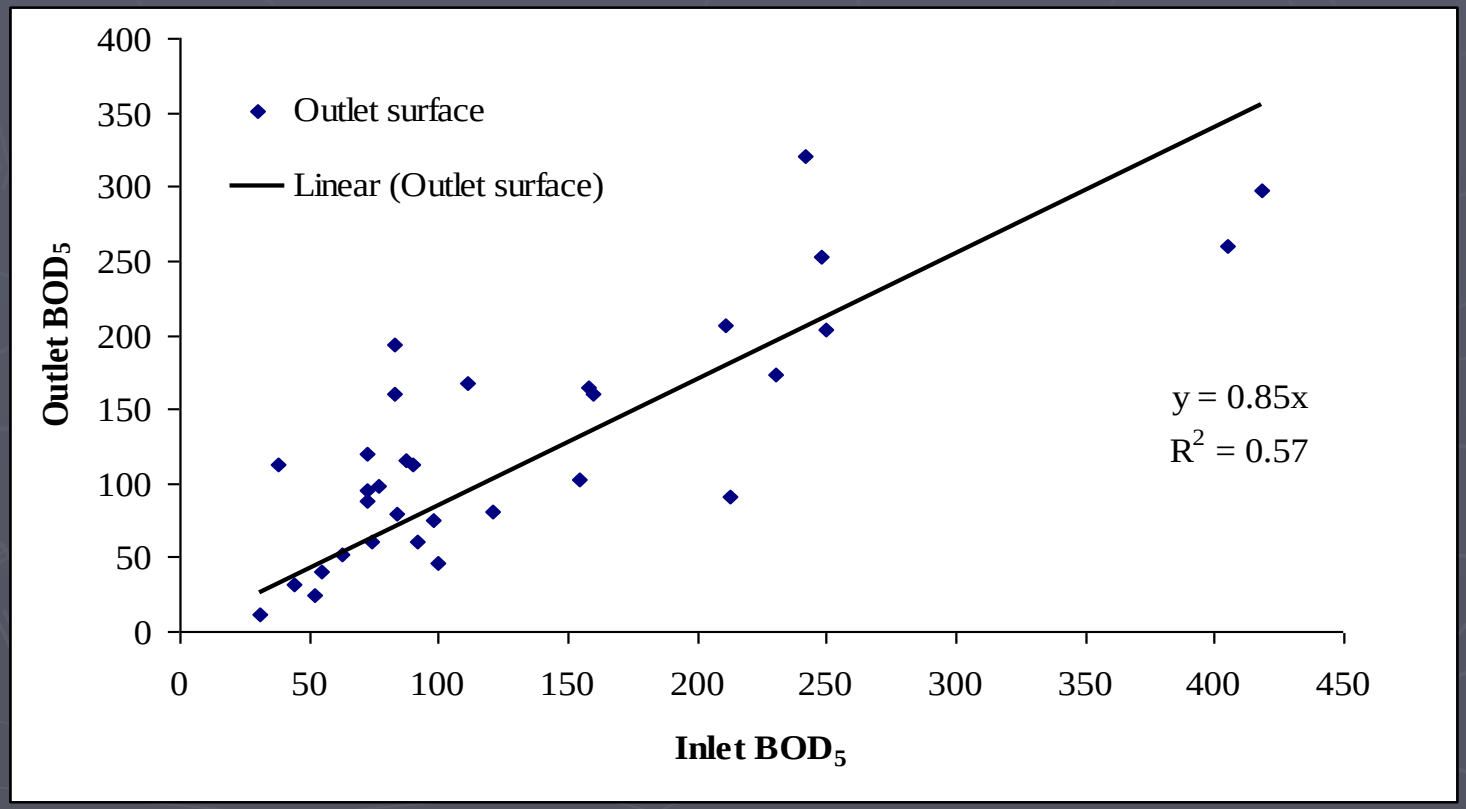
- The surface wetland significantly reduced the numbers of E.coli and results showed a significant difference due to interaction between mixture and time.

- It is believed that the longer HRT the longer the bacteria are exposed to unfavorable conditions.

Obs	Mixture	Time (Days)	Change (%)	Standard Error	Letter Group
9	1	3	99.0000	16.5353	ABC
10	1	6	26.0000	16.5353	DE
11	1	9	75.0000	16.5353	ABCD
12	1	12	79.3333	9.5467	ABC
13	2	3	-142E-16	11.6922	E
14	2	6	79.5000	11.6922	ABC
15	2	9	63.0000	11.6922	BCD
16	2	12	93.3333	9.5467	AB
17	3	3	-142E-16	11.6922	E
18	3	6	95.5000	11.6922	AB
19	3	9	-62.0000	11.6922	F
20	3	12	92.0000	11.6922	ABC
21	4	3	97.5000	11.6922	AB
22	4	6	81.0000	11.6922	ABC
23	4	9	99.5000	11.6922	A
24	4	12	62.2500	8.2677	CD

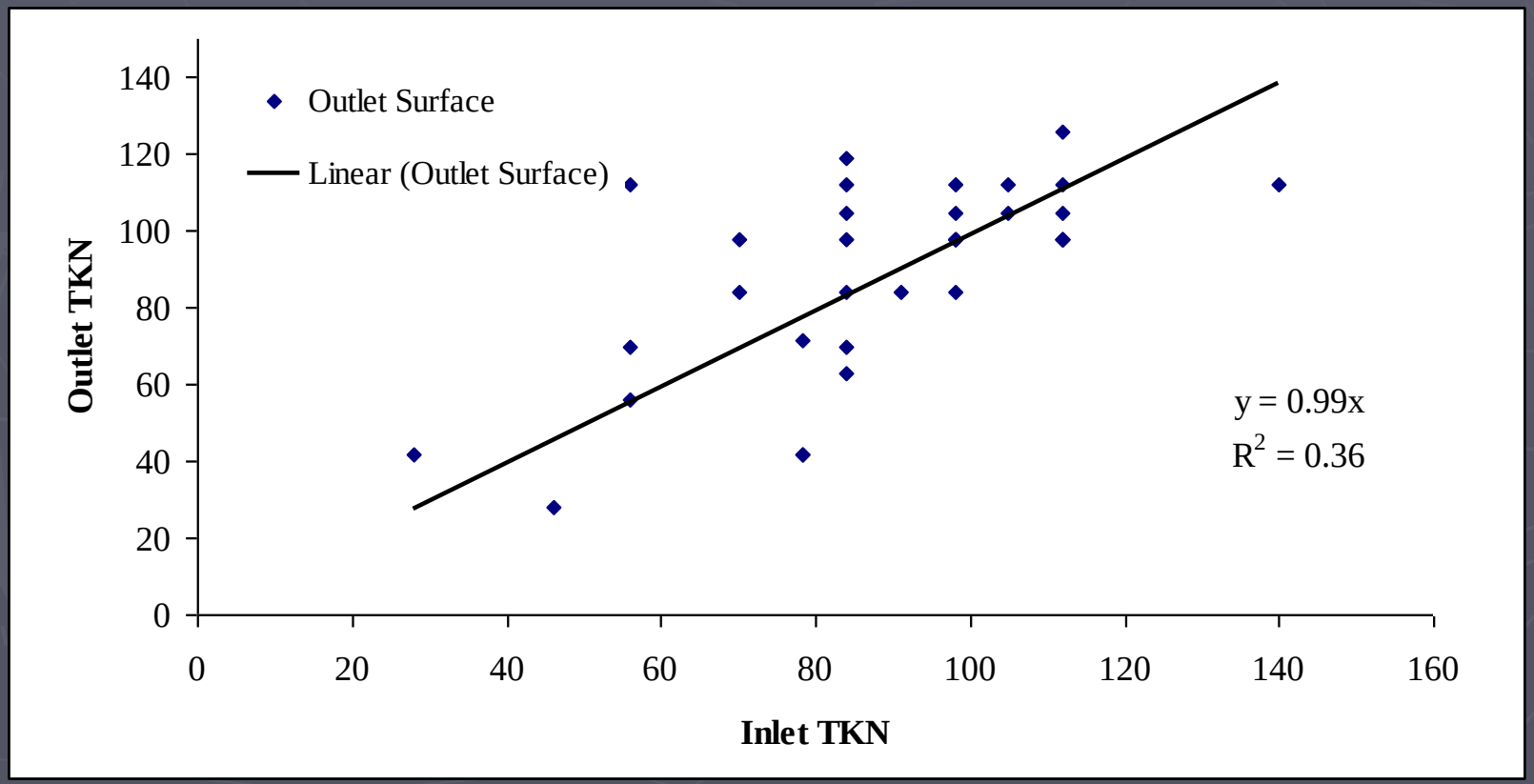
Changes of Biochemical Oxygen Demand

- Wetlands tend to be natural exporters of organic C as a result of decomposition of organic matter into fine particulate matter and dissolved compounds. This may explain why the system was sometimes inefficient in achieving high BOD_5 removal.



Changes of Total Kjeldahl Nitrogen (TKN)

- Results from the graph indicated that many values are at or above the regression line, indicating that there is a net production of TKN from the anaerobic decomposition of the organic nitrogen.



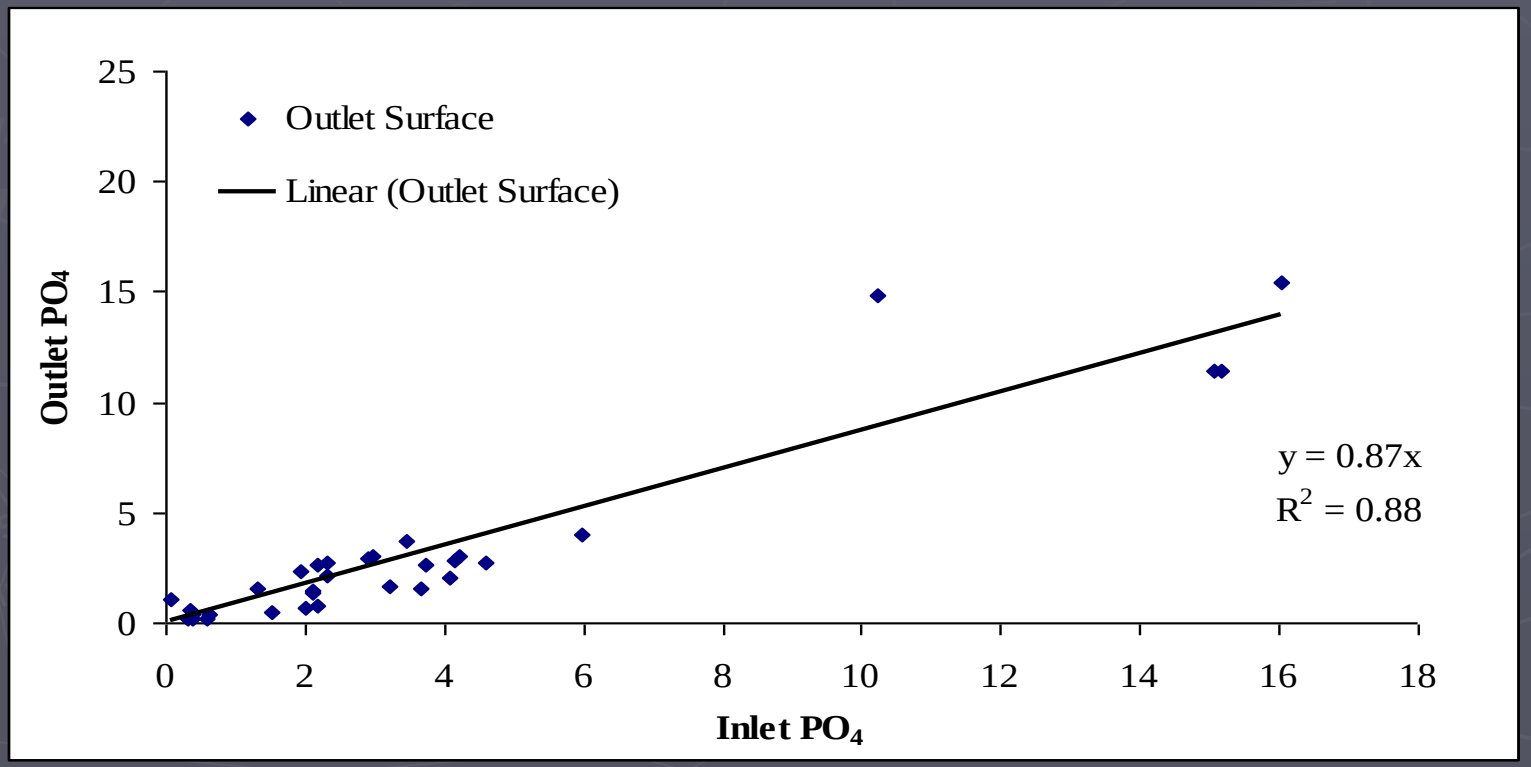
Changes of Phosphorus

- Phosphorus removal in most constructed wetland systems is not very effective because of the limited contact opportunities between the wastewater and the soil (media). Phosphorus removal in FWS is a result of bacteria removal, plant uptake, adsorption and precipitation.

- Results showed a significant difference with due respect to time. P removal was the highest under HRT of 12 days due to the longer contact between the effluent and the soil.

Phosphorus (Continued…)

- The relationship of inlet vs. outlet concentration was significant with respect to linear model with high R^2 of 0.88.

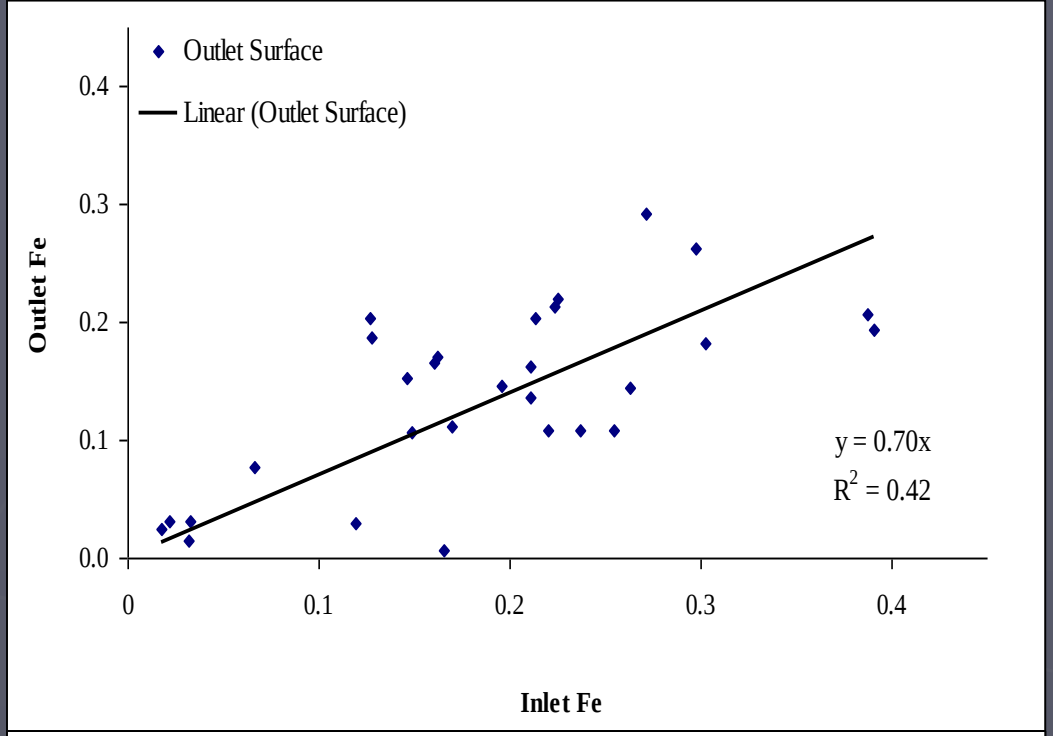


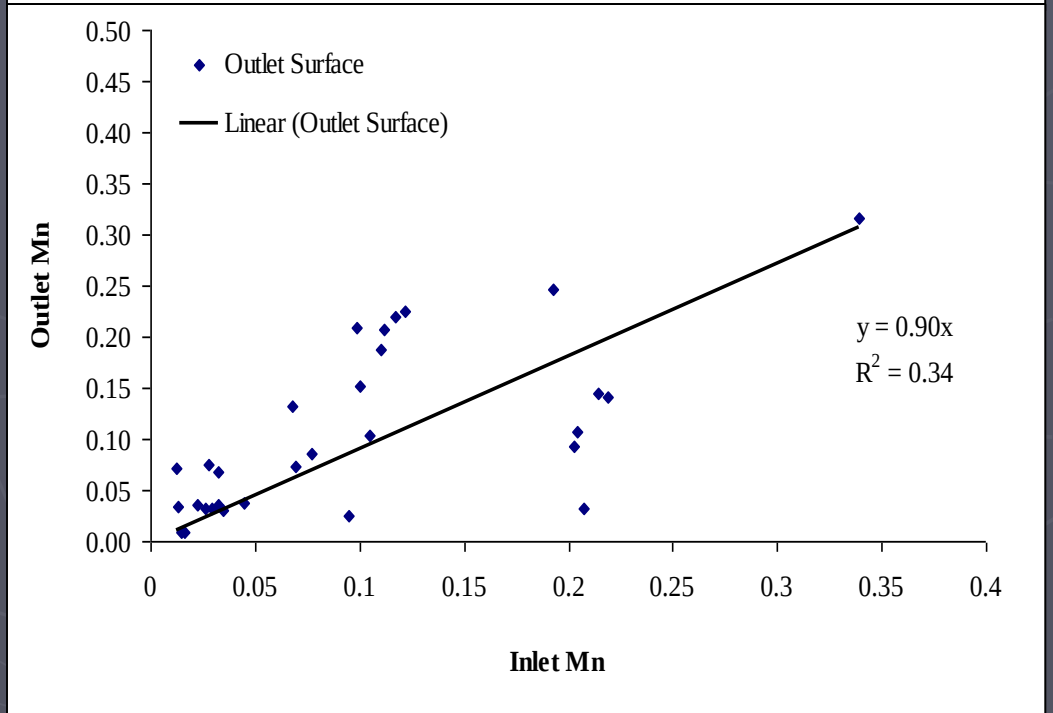
Changes of Trace Elements

- **The three main wetland processes that remove heavy metals are binding to soils, sedimentation and particulate matter, precipitation as insoluble salts, and uptake by bacteria, algae and plants.**

- The quality of influent mixture and/or HRT in FWS wetland affected significantly the removal of Fe and Mn and insignificantly affected the removal of Cu and Zn. Cadmium and lead were below the detection limit.

Results indicated the tendency of the system to remove 30% and 10% of the inlet Fe and Mn, respectively.





Changes of Turbidity

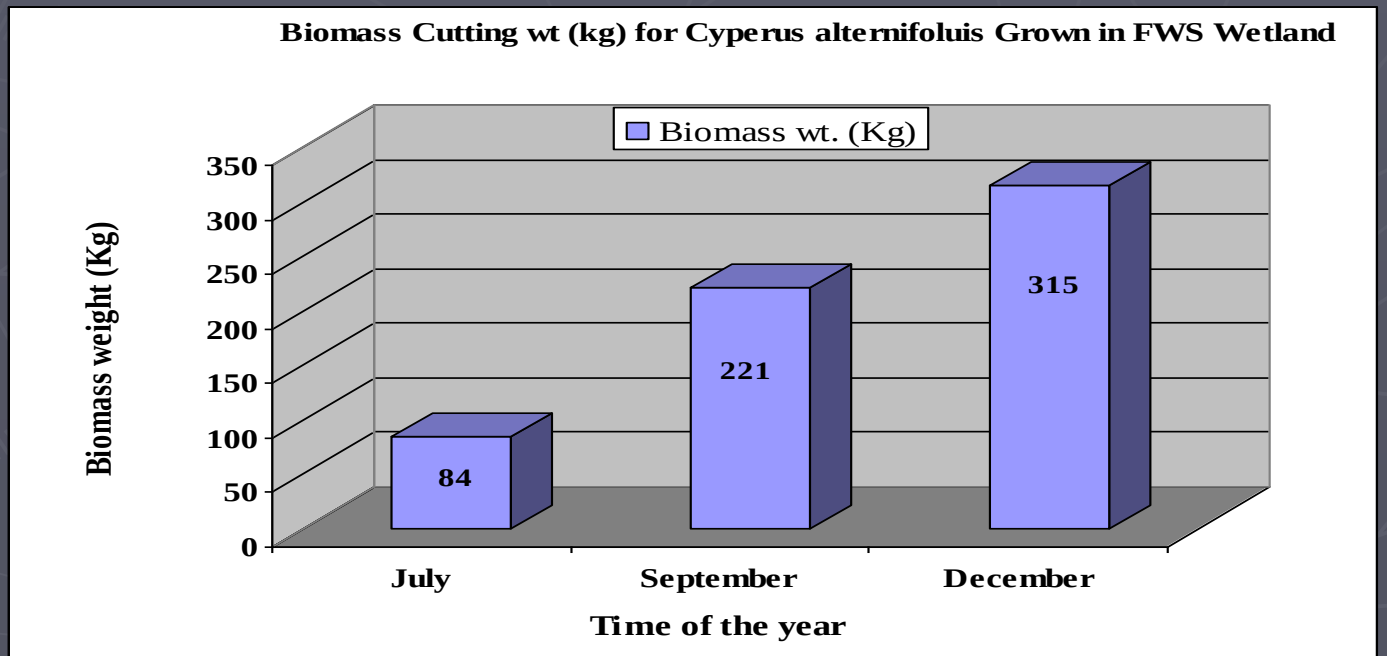
- Turbidity measurement is important as a guide to quality as well as an essential parameter for proper control and operation of treatment plants.

- Turbidity reduction showed a significant response with respect to mixture, time and interaction of both mixture and time. Significant removal was achieved under mixture 2 and 3 and under hydraulic residence times of 3, 6, and 9 days.

Biomass Cuttings for the Macrophyte

- For effective removal of nutrients from wetland systems and to avoid nutrient recycling when plants die, periodic harvesting from systems with high biomass productivity is not only desirable but a requirement.

- Biomass cuttings for Cyperus alternifoluis were 84, 221, and 315 kg for the first, second and the third cutting, respectively.



Hydrology
Water Balance & Actual HRT

Water balance

- Some treatments showed a reduction in percentage effluent. This was mainly at the beginning of the research due to losses and technical errors or limitation within the system with regards to flow meters failure and clogging of the outlet system. Others showed high increase in percentage effluent which may be attributed to overloading of the system.

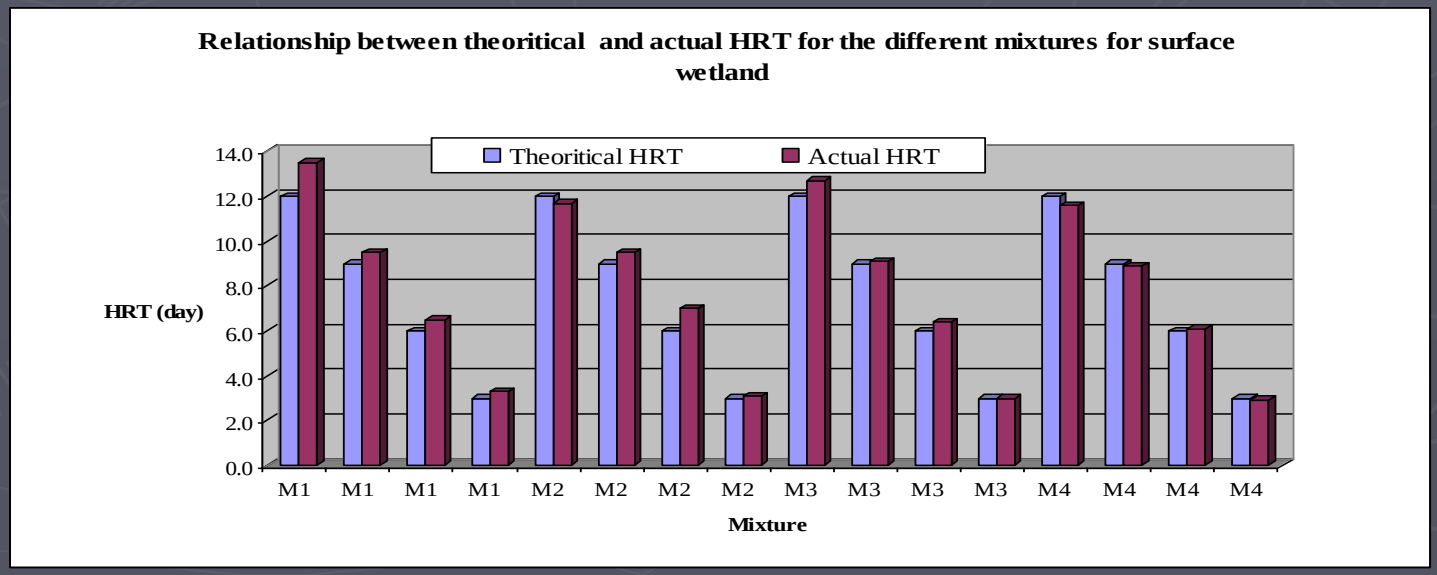
Treatment	% Effluent from influent
100% TWW , HRT = 12	97.08
100% TWW , HRT = 9	87.83
100% TWW , HRT = 6	87.04
100% TWW , HRT = 3	83.28
75% TWW, 25% P , HRT = 12	103.45
75% TWW, 25% P , HRT = 9	98.10
75% TWW, 25% P , HRT = 6	85.65
75% TWW, 25% P , HRT = 3	91.46
50% TWW, 50% P , HRT = 12	85.04
50% TWW, 50% P , HRT = 9	95.89
50% TWW, 50% P , HRT = 6	89.07
50% TWW, 50% P , HRT = 3	95.65
25% TWW, 75% P , HRT = 12	102.81
25% TWW, 75% P , HRT = 9	100.29
25% TWW, 75% P , HRT = 6	96.66
25% TWW, 75% P , HRT = 3	102.13

Actual HRT

- New HRTs were recalculated based on average flow rate:

$$Q_{av} = \frac{(Q_{inlet} + Q_{outlet})}{2}$$

- Evapotranspiration and seepage from the FWS wetland has the effects of increasing HRT and increasing constituent concentrations. When actual HRT were found less than the theoretical HRT, this may be attributed to either short circuiting effects or overloading of the wetland. Consequently, this lowers the removal efficiency of the system.



Suitability of Wastewater for Irrigation Field Experiment

- Barley season: results indicated a significant response with due to treatment effect. Treatment 3 (sub-surface wetland effluent) had resulted in the highest biological and straw yield and with a significant difference from T1 and T2.

Obs	TRT	Biological yield (Ton/du)	Standard Error	Letter Group
1	1	0.3300	0.02062	B
2	2	0.2850	0.02062	B
3	3	0.5900	0.02062	A

Obs	TRT	Straw yield (Ton/du)	Standard Error	Letter Group
1	1	0.1975	0.03853	B
2	2	0.1750	0.03853	B
3	3	0.3775	0.03853	A

- No significant difference was found between the three treatments with respect to seed yield.

Suitability of Wastewater for Irrigation (continued…)

- Corn season: ANOVA analysis was carried out for the data of biological yield. Treatments 2 and 3 (FWS and SSF wetland effluents) resulted in the highest biological yield and with a significant difference from T1 (TWW effluent).

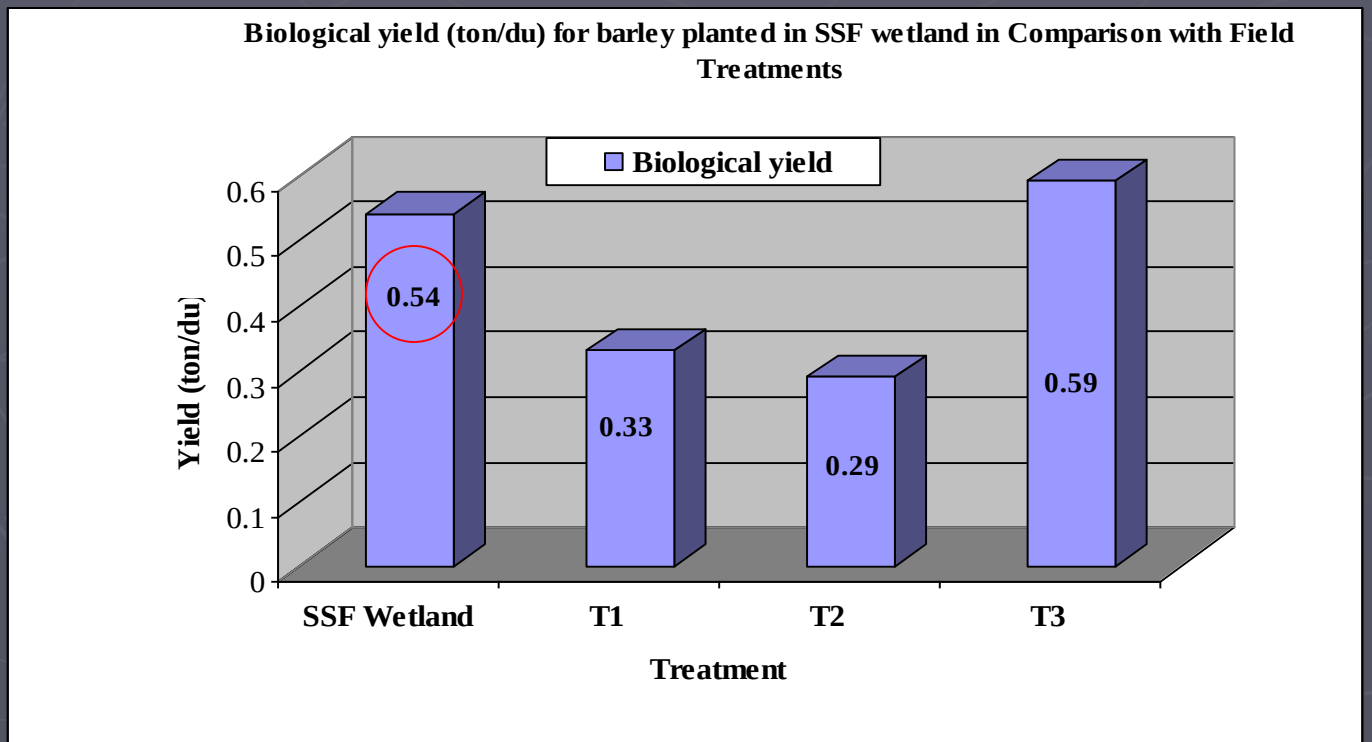
Obs	TRT	Biological Yield (Ton/du)	Standard Error	Letter Group
1	1	2.6765	0.09107	B
2	2	3.0582	0.09107	A
3	3	3.0092	0.09107	A

Sub-surface Wetland Processes

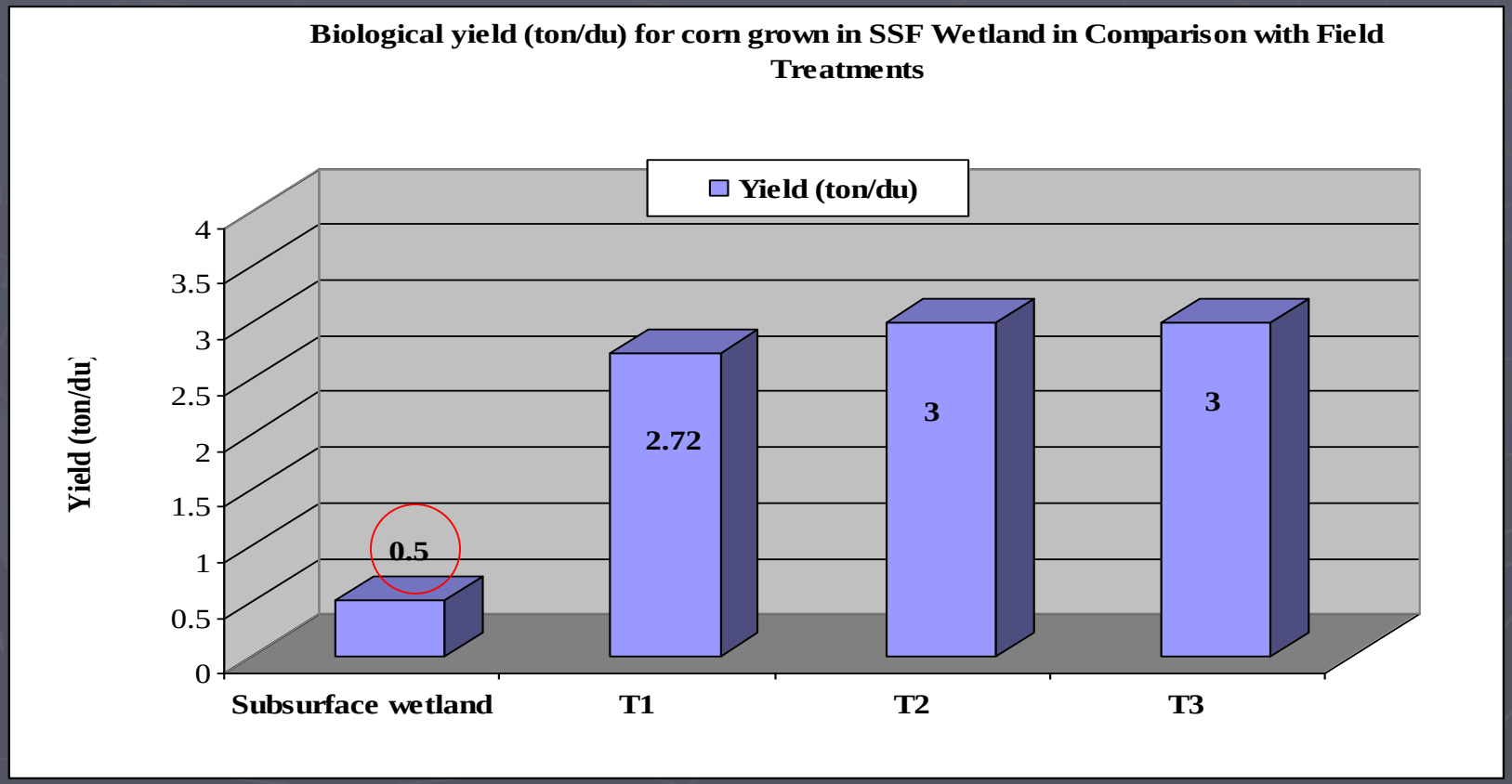
- The SSF wetland affects the concentration of pH, EC, TSS, NO_3, E.coli, PO_4, turbidity, Fe, Cu, Zn and Mn to greater levels.

Potential Uses of Subsurface Wetland for Crop Production

- Results for the first season indicated the possibility of using the SSF wetlands for the production of specific fodder crops.



- During the second season, corn crop did not perform well within the SSF wetland. Visual observation indicated that corn crop was affected by the salinity of the wastewater as the plants were stunted with small leaves and with little coverage inside the SSF bed.




Thank you