An-Najah National University
Faculty of Graduate Studies

Treatment of Wastewater Using a Constructed Wetland System

(Four stages vertical flow sub-surface constructed wetland)

By
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Dedication

To our prophet Mohammad who is the first teacher, to the all humanity, to our earth planet, to my family, and to everyone helped me.

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Acknowledgments

First of all, praise be to Allah for helping me in making this thesis possible.

I would like to express my sincere gratitude to Prof. Dr. Marwan Haddad and Dr. Nu'man Mizyed for their supervision.

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Finally, I would like to thank all my friends whoencouragedme.

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الإقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

Treatment of Wastewater
Using a Constructed Wetland System
(Four stages vertical flow sub-surface constructed wetland)

معالجة المياه العادمة باستخدام طريقة

الـ(Constructed Wetland)

(Four stages vertical flow sub-surface constructed wetland)

أُقر بان ما اشتملت عليه هذه الرسالة إنما هي من نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Abstract

Constructed wetlands system is an innovative and inexpensive treatment approach that has thepotential to treat organic and inorganic compounds in wastewater. Constructed wetlands system, being simple in construction and maintenance and operation. Physical, chemical, and biological processes are combinedtogether in wetlands to remove Contaminants from wastewater.

A- Four-stages of constructed wetlands system (vertical flow beds) subsurface system connected on series was investigated in this research for treating wastewater.

Plastic barrels with a height of 90cm and a diameter of 45cm were placed above each others on steel stands with different elevations to achieve flow by gravity without pumping and it is received by storage barrels. In the four stages wastewater flow from the storage barrels to the first stage, then the effluent of the first stage is influent to the second stage, and the effluent of the second stage is influent to the third stage; the effluent of the third stage is also influent to the fourth stage which is the final stage in the experiment; the effluent of this stage is considered the treated wastewater.

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The system was replicated five times with different types of plants grown including (Corn Brooms, Barley, Alfalfa, Corn, and Sunflower). The period of the study was 6months so the plants were chosen as seasonal plants. the same media was used for all the stages in the experiment, it was three layers for total depth of 50cm. The first layer in the bottom of the bed was 13cm deep and filled with gravel size (10-15 cm). The second layer of the bed was 27cm deep filled with gravel size (1 -2cm); the third layer at the top was 10cm deep with gravel size (1-2cm) mixed with sand with percentage (3:1), (gravel: sand). The general porosity in the system was 45% which is high; thismeant more durable system, and these high voids are necessary for the aeration process of the wastewater in the system. Many tests were done during the operational period to check the efficiency of this system, tests were for BOD, COD, TSS, TDS, TKN, Cl, the removal of pollutants was high and the results are promising.

The removal of BOD efficiencies for the five crops (Corn Brooms, Parley, Alfalfa, Corn, Sunflower) were (96.5, 95.4, 94, 96.3, 96.9)% respectively with HLR=72.3Kg/ha.d, the removal rates of COD were (88.2, 86, 85.9, 80.8,78.9)% for the five crops with HLR=99.3 Kg/ha.d., the removal efficiency of TSS efficiencies increased to (90.5, 95.6, 91.4, 93.5, 91.8)% for the same crops with HLR=41.1Kg/ha.d. The removal efficiencies of TKN were (68.1, 66.2, 65.1, 64.9, 65.2)%for the same crops with HLR=41.8Kg/ha.d (High removal with high loading rate).The flow in each stage was 12ml/min (HLR).This flow achieved HRT = 6 days; The experimental results for the system investigated achieved high removal efficiencies for BOD,COD and TKN the system was capable of treating 22l/day.m^2 without energy (free energy). Thus, the system could be applied in Palestinian rural areas successfully. The system will provide efficient

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treatment of wastewater at low cost which will make it appropriate to these areas. The system allowed utilizing crops which will be planted in the constructed wetlands providing an economic return to the community when utilizing such treatment approach.

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Chapter One

Introduction

1.1. General:

Most of the Middle East countries are suffering from low availability of water resources due to aridity and an increasing water demand due to the increase of population. As aresult of that, water resources are over exploited. Due to the increase in water shortages in the last fewdecades, attention was paid to finding new resources of water in the area. One of these other resources is the treatment of wastewater. Treatment of wastewater also protects the environment and water resources from pollution.

In Palestine, wastewater collection and disposal is considered one of the most significant environmental problems. Wastewater collection systems are available in most cities in Gaza and the West Bank, but wastewater treatment plants had not been constructed for all the cities that have wastewater networks, so wastewater still flows in the Wadis from many cities.

Many of the wells have been contaminated and the percentage of pollution is high in the water pumped from the wells. In the West Bank also, there are many villages that do not have wastewater collection systems and depend on septic tanks for the disposal of wastewater and there are many environmental problems that result from using this inappropriate approach of wastewater disposal.

In order to build wastewater collection systems in these villages there is need to investigate treatment options for wastewater. Conventional systems for wastewater treatment are not suitable because of their high cost, so there is need to provide more cost-effective and suitable systems for the villages.

1.2 .Background:

During the past few years, a new technology for treating municipal and industrial wastewater has emerged. This technology involves the construction of "artificial wetlands," which use the physical, chemical and biological processes in nature to treat wastewater. These specially built wetlands are also referred to as "Constructed Wetlands" or "Created Wetlands" constructed wetlands can be designed for whole communities, subdivisions, private developments, and even for individual homes.

Interest has steadily increased because of their low cost (one-tenth to one-half that of conventional treatment), efficiency, and near nonexistent maintenance, Constructed wetlands have proven to be very effective methods for the treatment of wastewater for small communities with limited funds.[8],[12].

- **What Are the Advantages of Constructed Wetlands?**

1- Low construction, operation and maintenance costs with comparison to other methods.

2- Do not require chemical additions or other procedures used in conventional treatment systems.

3- Simple and effective .

- **What are the disadvantages of Constructed Wetlands?**

1- Constructed wetlands require relatively level landscapes and much larger areas.

2- It is more applicable for small areas and villages than big cities.

3- Delayed operational status because peak removal efficiencies of constructed wetlands depend on vegetation growth.

1.3. Water resources in West Bank:

The West Bank is composed of four main climatic regions: hyper-arid; arid, semi-arid and sub-humid. The main available water resources include: Groundwater, springs and harvested rainwater. There is little surface water available to the Palestinians and thus groundwater is the principal source of water in the West Bank.

1.3.1 Groundwater resources:

Three main aquifers characterize the groundwater resource in the West Bank.

Western Aquifer System, being the largest, has an annual safe yield of 362 mcm (of which 40mcm are brackish). 80% of the recharge area of this basin is located withinthe West Bank boundaries, whereas 80% of the storage area is located within Israeli borders. Groundwater flow is towards the coastal plain in the west, making this a shared basin between Israelis and Palestinians. This source is mainly used for municipal supply because its water is of good quality. Israelis exploit the aquifers of this basin by means of 300 deep groundwater wells to the west of the Green Line, as

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well as by means of Mekorot (the Israeli water company) deep wells within the West Bankboundary. Palestinians, on the other hand, consume only7.5% of the Palestinian Territories' safe yield. They extract their water from 138 groundwater wells tapping the country's 22 Western Aquifer System (120 for irrigation and 18 for domestic use) in Qalqilya, Tulkarm and West Nablus.

The Northeastern Aquifer System has an annual safe yield of 145 mcm (of which 70mcm are brackish). Almost 100% of the basin is recharged by precipitation falling on the West Bank area. But water then flows underground in a northern direction to the Bisan (Bet She'an) and Jezreel valley. Palestinians consume about 18% of the safe yield of the Aquifer by means of 86 agricultural and domestic wells in Jenin districtand East Nablus (Wadi Al Far'a, Wadi El Bathan, as well as Aqrabaniya and Nassariya) for both irrigation and domestic purposes.

The Eastern Aquifer System has an annual safe yield of 172 mcm (of which 70-80 mcmare brackish). It lies entirely within the West Bank territory. The Palestinian farmers tapped their water until 1967. Subsequently, Israel expanded its control over this Aquifer and began to tap its water to supply Israeli settlements implanted in the area. This Aquifer system has 122 Palestinian groundwater wells (109 for irrigation and 13 fordomestic use). In several parts of the basin, wells have been over-pumped, thus leading to a drop down in the water table and deterioration of its quality in the past few years.

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1.3.2 Surface water resources:

The only surface water available is the runoff in the wadis, which for most wadis is intermittent. An exception is the spring fed wadis - for instance Wadi Qilt and Wadi Far'ia, but these are already heavily utilized. To a large extent, the wadis are also overloaded by raw sewerage in the headwater areas. The yet un-exploited potential safe yield available to the Palestinians in the Eastern Aquifer has not been determined accurately but may be somewhere between 50 and 100 mcm /yr.[2],[3]

1.4 Problem definition:

In Palestine, domestic and industrial wastewater is collected mainly in cesspits or, toa much lesser extent, in sewerage networks. In some villages and refugee camps, black wastewater is collected in cesspits, while grey wastewater is discharged via open channels. The majority of the collected wastewater from the sewer localities is discharged into nearby wadis without any kind of treatment. About 65% of the West Bank population is not served with sewerage networks, and uses mainly cesspits and occasionally septic tanks. The other 35% is served with sewerage networks, but less than 6% of the total population is served with treatment plants.[4]

In recent years, a 'red line 'has been crossed, aspolluted water has begun to seep into these water sources, i.e. springs and groundwater aquifers. Alarming signals have been reported in some places about groundwater pollution with high concentrations of chloride (e.g. 400 mg/l), sodium (e.g. 200 mg/l), potassium (e.g. 35 mg/l) and nitrate (e.g up to 250 mg/l) in both the West Bank and Gaza Strip.

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Inadequate disposal of wastewater pollutes the neighborhoods and groundwater of the West Bank Aquifer and poses serious risks tothe health of the Palestinian communities and the surrounding environment. Current pressure on the environment will be worsening by the expected population growth[12],[13].

1.5. Objectives of the study:

1- Investigate an effective and low cost wastewater treatment method for treating wastewater in Palestine that is suitable for small communities (4 stages VF-Constructed Wetland).

2- Examine the effects of using different types of plants on treatment process.

1.6. Motivations:

1- Investigate an effective and low cost wastewater treatment method for treating wastewater in Palestine.

2- Improve the protection of the environment and the water resources from pollution.

3- Propose an alternative resource of water for agricultural uses (this treated wastewater can be used for agricultural uses).

4- Minimize the running cost for wastewater treatment plants by using this system.

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Chapter Two

Literature Review

2.1. What is a Constructed Wetland:

Constructed wetlands (CWs) are engineered systems (artificial wastewater treatment systems) that have been designed and constructed to utilize natural processes involving wetland vegetation, soils and the associated microbial assemblages to assist in treating wastewaters. They are designed to take advantage of many of the processes that occur in natural wetlands but do so within a more controlled environment.

Such systems rely on natural, biological, physical and chemical processes to treat wastewater.The basic classification of these systems is based on the type of macrophysics growth (emergent, submerged, free floating and rooted with floating leaves); further classification is usually based on the water flow regime (Surface flow, sub-surface vertical or horizontal flow).

Recently, the combinations of various types of CWs (called hybrid systems) have been used to enhance the treatment effect, especially for nitrogen constructed wetlands that have been used to treat a variety of wastewater including urban runoff, municipal, industrial, and agricultural types of wastewater.

2.2. Historical review:

The first attempts to use the wetland vegetation to remove various pollutants from water were conducted by K. Seidel in Germany in the early 1950s. The first full-scale free water surface (FWS, surface flow) CW was

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built in the Netherlands to treat wastewater from a camping site during the period 1967–1969.

Within several years, there were about 20 FWS CWs built in the Netherlands. However, FWS CWs did not spread throughout Europe, but constructed wetlands with horizontal sub-surface flow (HF CWs) became the dominant type of CWs in the continent.

The first full-scale HF CW was built in 1974 in Othfresen in Germany. The early HF CWs in Germany and Denmark used predominantly heavy soils, often with high content of clay. These systems had a very high treatment effect, but because of low hydraulic permeability, clogging occurred shortlyand the systems resembled more or less FSW systems.

In late 1980s in the United Kingdom, soil was replaced with coarse materials (washed gravel) and this set-up has been successfully used since then.

In the 1980s, treatment technology of constructed wetlands rapidly spread around the world. In the 1990s, increased demand for nitrogen removal from wastewater led to more frequent use of vertical flow (VF) CWs which provided higher degree of filtration bed oxygenation and consequent removal of ammonia via nitrification.In late 1990s, the inability to produce simultaneously nitrification and de-nitrification in a single HF or VF CWs and thus remove total nitrogen led to the use of hybrid systems which combined various types of CWs.

The concept of combination of various types of filtration beds was actually suggested by Seidel in Germany in the 1960s but only few full

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scale systems were built (e.g. Saint Bonaire in Franceor Oaklands Park in UK) in the 1980s and early 1990s. At present, hybrid CWs are commonly used throughout Europe as well as other parts of the world. VF–HF combination is the dominant set-up but HF–VF combination is also used and FWS CWs are commonly used in hybrid systems.[16]

2.3. Types of constructed wetland systems:

There are various types of constructed wetland systems for treating wastewater based on various parameters. The most important criteria are water flow regimes which include:

- Surface flow
- Sub-surface flow

The surface flow is also divided into various types based on types of plants and its situation in the system. [9],[10]

The sub-surface is also divided into two main types based on the movement of flow inside the media whether it is a vertical movement from the planted layer or horizontal one parallel to the surface as shown in figure (2-1).

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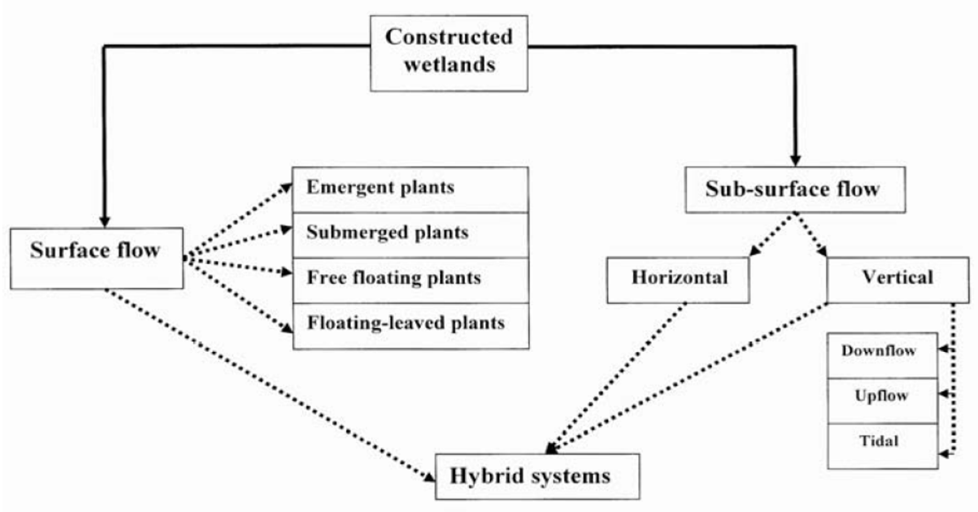

Figure (2-1): Classification of constructed wetlands for wastewater treatment (2008). [16]

2.3.1 Surface flow systems:

Constructed wetlands with surface flow, or the so called free water surface, have the water surface exposed to the atmosphere resembling natural wetlands. These systems consist of basins or channels with shallow wastewater; wastewater is usually on the top of the soil, or on top of any other medium to support the roots of the plants that are planted below it.

The surface flow systems can be classified according to the plants that are planted there into four types:

- **Systems with free-floating macrophytes.**
- **Systems with floating-leaved macrophytes.**
- **Systems with submerged macrophytes.**
- **Systems with emergent macrophytes.**

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2.3.1.1 Systems with free-floating macrophytes:

In this constructed wetland system plants float above the surface of wastewater as shown in figure 2-2.

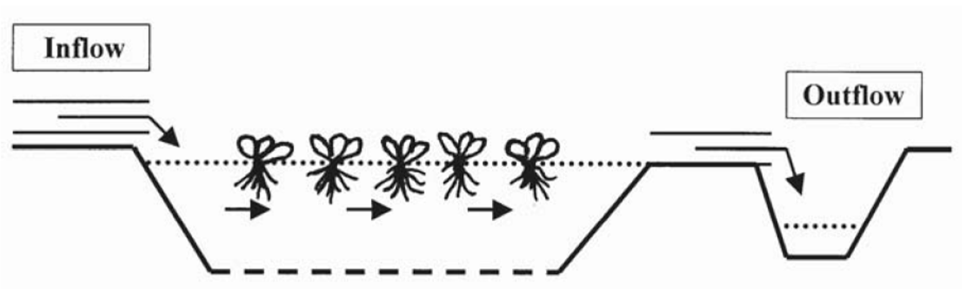

Figure (2-2): Schematic representation of the constructed wetland with free floating macrophytes(2001).[16]

2.3.1.2 Systems with floating-leaved macrophytes:

In this system, the leaves of the plants float on the surface of the wastewater and their roots are submerged inside the media or the soil as shown in figure 2-3

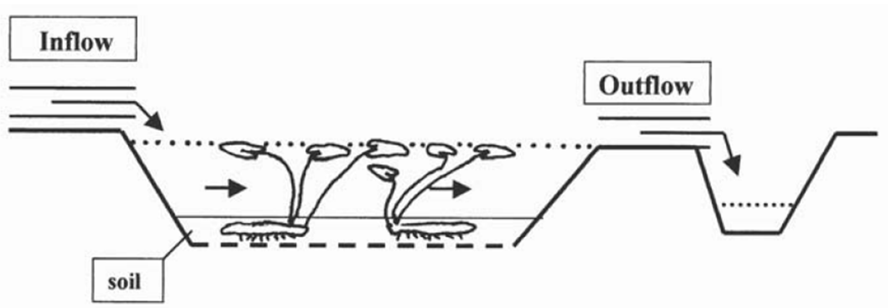

Figure (2-3): Schematic representation of a constructed wetland with floating-leaved Macrophytes(2001).[16]

2.3.1.3 Systems with submerged macrophytes:

In this system of FWS, the plants are submerged completely in the wastewater basins and can grow in the aerobic condition, but are absent in anaerobic wastewater as shown in figure 2-4.

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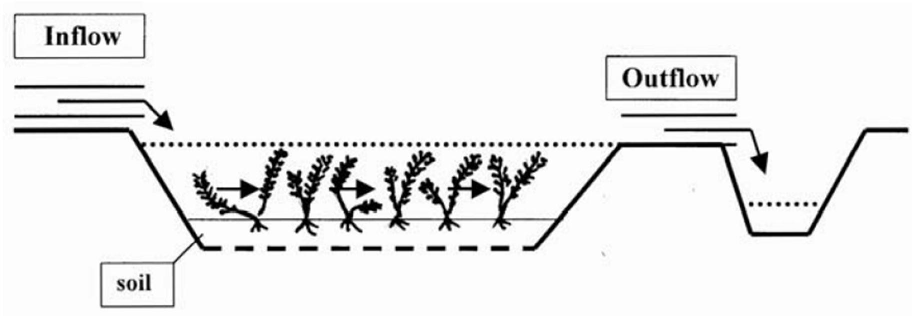

Figure (2-4): Schematic representation of a constructed wetland with submerged macrophytes(2001).[16]

2.3.1.4 Systems with emergent macrophytes:

In this constructed wetland, the plant is above and below the surface of the wastewater and consists of shallow basins containing 20-30 cm of rooting soil with water depth of 20-40cm ,this type is mostly commonly used in Europe. Figure 2-5 shows a profile for this type.

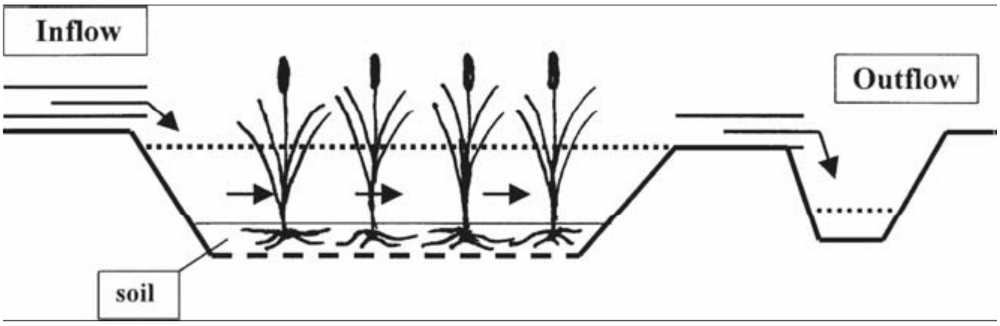

Figure (2-5): Schematic representation of the free water surface constructed wetland withEmergent macrophytes (2001).[16]

2.3.2.Sub-surface systems:

In this type of constructed wetlands, wastewater flows through porous medium under the surface of the bed planted with emergent vegetation, and this has many benefits as it controls mosquitoes and makes less contact between wastewater and humans.

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The sub-surface constructed wetland also makes a good control over the spread of odors, and media in this type provides a greater area for treatment than FWS do, so the treatment will be faster .[11]

Sub-surface constructed wetland can be divided into two main types with respect to the direction of flow inside the media of the system as shown below:

- Horizontal- Flow (HF or HSF) CWs.
- Vertical - Flow (VF) CWs.

2.3.2.1 Horizontal flow (HFCWs):

In horizontal subsurface flow (constructed wetlands (HF CWs)) wastewater flows slowly and horizontally through the medium (that is parallel to the surface of the cell) (figure 2-6).

This type of constructed wetland was developed in the 1950s in Germany by Käthe Seidel who designed the HF CWs using coarse materials as the rooting medium. This type is used commonly in secondary treatment for wastewater and is considered effective in the removal of organics, suspended solids, microbial pollution and heavy metals. Concentration of dissolved oxygen in the filtration beds is very limited so the removal of ammonia is limited.[16]

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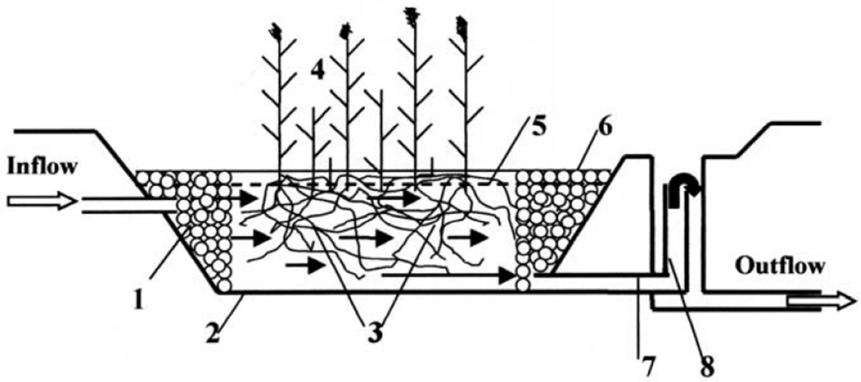

Figure (2-6): Schematic representation of a constructed wetland with horizontal sub-surface flow (2001).[16]

2.3.2.2 Vertical flow:

In vertical subsurface flow (constructed wetlands (VF CWs)) wastewater flows slowly and vertically through the medium (that is perpendicular to the Surface of the cell) (figure2-7).

Proven advantages of vertical flow technology include its ability to maintain high dissolved oxygen concentrations in treated liquid as it travels through the system. This results in very high reductions of BOD and significant nitrification. On the other hand, VF CWs do not provide de-nitrification as compared to HF CWs. And vertical flow systems require less land

The removal of organics and suspended solids in this type is also high and is divided into three types:

- Down flow.
- Up flow.
- Tidal flow.

`

- **Down flow:**

VF CWs are fed intermittently with large batches, thus flooding the surface. Wastewater then percolates down through the bed and is collectedby a drainage network at the bottom. Typical arrangement of down flow VF system is shown in (Fig.2-7).

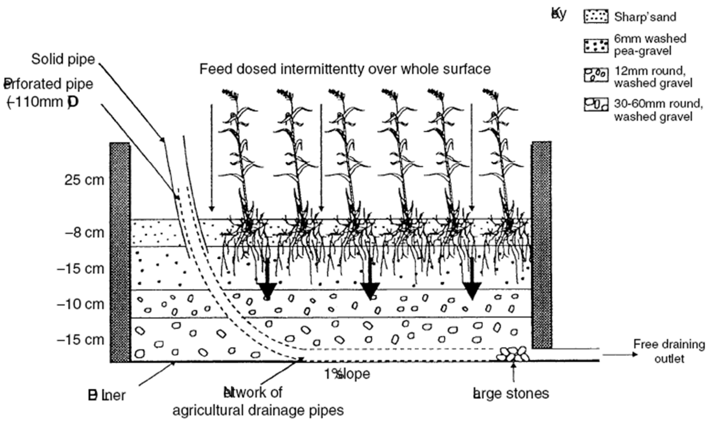

Figure (2-7):Typical arrangement of a down flow vertical-flow constructed wetland (fromCooper et al., 1996).[16]

- **Up flow:**

In up flow vertical CWs, wastewater is fed on the bottom of the wetland. Water percolates upward (opposite to the direction of gravity) and is then collected either near the surface or on the surface of the wetland bed. These systems are commonly used in Brazil. Typical arrangement of up flow VF System is shown infigure 2-8.

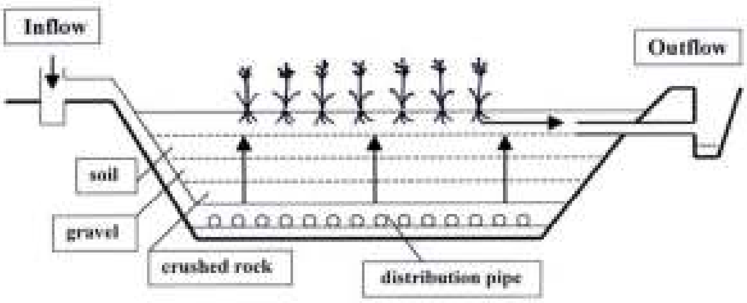

Figure (2-8): Schematic representation of a constructed wetland with vertical up-flow(2001).[16]

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- **Tidal flow:**

Tidal flow systems are a new form of VF systems which is created to overcome the problems that happened in the previous forms of VF; these problems are mainly clogging problems. In tidal flow systems, wastewater percolates upwards until the surface is flooded. When the surface is completely flooded, the feeding is stopped, wastewater is then heldin the bed and, later on, wastewater is drained downwards. After water has drained from the filtration bed, the treatment cycle is complete and air can diffuse into the voids in the filtration material(Cooper, 2005).

2.3.2.3 Vertical flow (two stages):

Recently, there has been a research that investigated, a two-stage constructed wetland (CW) system consisting of two vertical flow (VF) beds for N treatment,the first stage uses sand with a grain size of 2–3.2mm for the main layer and has a drainage layer that is impounded; the second stage uses sand with a grain size of 0.06–4mm and a conventional drainage layer.

The temperature of treated wastewater during the experiment surrounding between (4-21).

The average nitrogen removal efficiencies were 53% and average nitrogen elimination rates of 2.7 gN/m^2.dand 986 gN/m^2.Yr, respectively, could be achieved.[17]

2.3.2.4 Hybrid systems:

In these systems, various types of constructed wetlands are combined to achieve higher treatment especially for nitrogen VF systems that have much greater dissolved oxygen in the wastewater, thus, providing better

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conditions for nitrification. On the other hand, limited de-nitrification occurs in VF systems, the system was originally designed by Seidel as early as in the late 1950s and the early1960s.

Most hybrid constructed wetlands combine VF and HF stages and all types of constructed wetlands could be combined, The stages can be from 2-4 for treatment and the arrangement of the Hydride systems can be(VF-HF) where the VF placed before or can be (HF-VF) where the HF placed before ,Figure (2-9) shows the two-stage hybrid system H-V. [16]

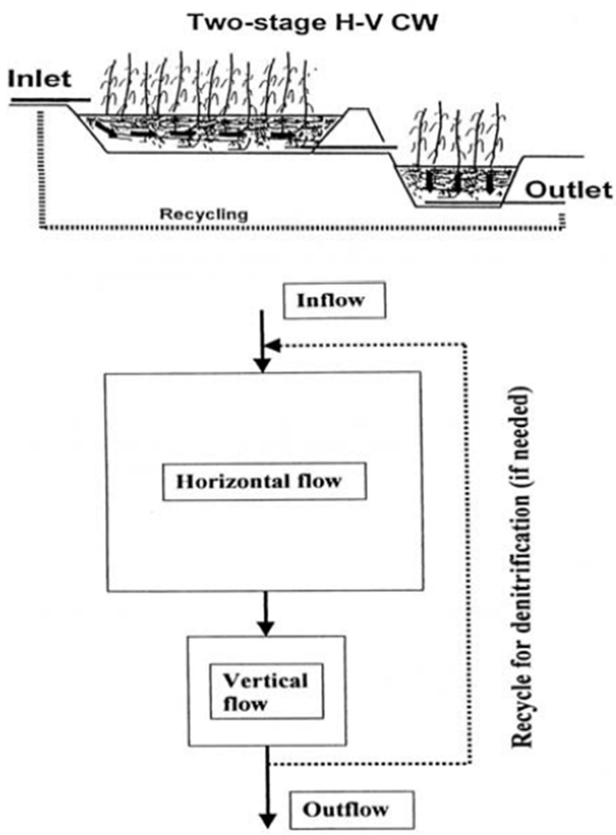

Figure (2-9): Schematic arrangement of the HF-VF hybrid system according to Brix andJohansen. From Vymazal (2001a).[16]

The results of treatment using this system indicate very good removal for organics (BOD5 and COD) and TSS while removal of nitrogen is enhanced with nonitrate increase at the outflow.

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2.3. Constructed wetland in Palestine:

In Palestine, the use of constructed wetland systems for treatment of wastewater has been recently used successfully in few small villages. However, there are some problems which are mainly operational ones.

These systems were done as experiments in three villages to show if the system is applicable. These villages are Bidya, Kharas and BaniZaid. All of these systems were implemented in the period between (2000-2004). The Bidya experiment was done as a pilot constructed wetland to serve 298 persons in 42 houses. The objective of the project was to solve the problem of wastewater disposal in the village. Wastewater was disposed in percolation pits next to the houses, these pits were emptied periodically by vacuum tankers and the wastes were discharged randomly.The system was horizontal sub surface flow, the media used in the system included aggregates and sand.

In Kharas, the design capacity of this treatment plant was 120 $m^{3/}d$ that is equivalent to 200-300 house service with future extension options being feasible to cover the entire village. It achieved high removal efficiency for COD, BODand TSS but there was a problem after 7 years as the gravel media in the system got clogged and the system stopped. The third system was done in BaniZaid village for 100 houses connected to the system. The objective behind the construction of the system was to provide alternative resources other than fresh water for irrigation purposes and protecting the environment through replacing the cesspits by sewage networks and also protecting the aquifers from pollution.

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All the systems that were implemented were sub-surface constructed wetlands and they were applied as a pilot system, to be expanded to the entire villages if they proved successful.

The main problems occurred in these systems were clogging as mentioned above and overloaded problems which the researcher tried to overcome in this research. The level of the treatment was acceptable, but the researcher wanted to also enhance the treatment level more, especially for N. [4],[5]

2.4. Summary:

2.4.1 What was done and what are the benefitsof the research:

The previous discussion showed nearly all the types of constructed wetlands that were done before. In this experiment, vertical flow sub-surface constructed wetland system for four stages connected in series for treatment of wastewater will be investigated, it is the first time that this type of system (4-stages VF subsurface constructed wetland) done.

In this research the researcher will examine the effectiveness of using this system in removing pollutants. The proposed design is aimed to achieving high removal of pollutants and this system will be done without any recirculation and free of energy because everything will be done by gravity, and this can be achieved easily on reality in slopes areas.

In hybrid systems, there are combined various types of constructed wetland with recycle, but in this experiment 4-stagesVF CW will be without any recycling.

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The vertical flow systems do not spread very much because of higher operation and maintenance requirements due to the necessity to pump the wastewater intermittently on the wetland surface, and this what the researcher want to solve it by applying flow by gravity.

In this system, there was no need to use any pumps since all the flow occurred by gravity without any problems and without any energy.

It is the first time that this system done, which is using 4-stageVF subsurface system to examine the efficiency of this way in removing pollutants by gravity, and the researcher achieve high removal efficiency with minimum cost, and this system can be applied successfully in slope grounds without any energy.

2.4.2 What is lacking and what does the research need to cover:

In the previous systems that were done before, there were problems that occurred in these systems that researcher tried to overcome in this research.

- Overcoming the clogging problem, which is a serious problem in this system the porosity is 45% which means more durable system, and also a high porosity makes a good aeration for the wastewater in the system This means a high and fast removal of pollutants especially (BOD, TKN)
- In this system, the researcher do not need to use any pumps since all flows occurred by gravity without any problems and without any energy and this minimizes running cost. This way can be applied easily in the areas that have little natural slopes.
- Achieve high removal for pollutants by using several stages (4-stages) with sub-surface VF connected in series.

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Chapter Three

Methodology

3.1. Experiment Set-up:

3.1.1 Study Site:

The Constructed wetland that is done was implemented at An-Najah National University which is located in the city of Nablusin Palestine. The system was built inside a project for the university which was done also for wastewater treatment researches using constructed wetland systems.

There was a septic tank that collected wastewater from all the university'scolleges, and then the wastewater was pumped to the storage tank which supplied wastewater to the system. The system consisted of several barrels connected inseries; the out flow in the previous barrel was inflow in the second barrel, and so on until it reached to the forth stage which was the final stage and the flow of wastewater will get out of this stage treated.

The flow in all the 4-stages was a vertical flow and sub surface flow because the wastewater remains beneath of the surface of media in the 4-stages. The researcher replicated the system five times with five different types of plants; the plants selected were seasonal ones because the experimental period was 6-months.

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3.1.2 Wetland Construction:

- **System construction and media of the system:**

The system that the researcher did consisted of plastic barrels 45cm in diameter, larger barrels of 60 cm in diameter were used as storage tanks which contained raw wastewater.

Steel stands were built with different heights to put the barrels on them so that the system can be run by gravity (free energy) without any pumping to minimize the cost as maximum as possible. The outflow from the first barrels will be inflow in the second barrels and so on until we reach to the forth barrels (4- stages) which are the final stage.

The system was replicated five times with different types of plants, and the flow entered toeach barrel by means of gravity without any pumping, this was achieved by placing the barrels at different heights.

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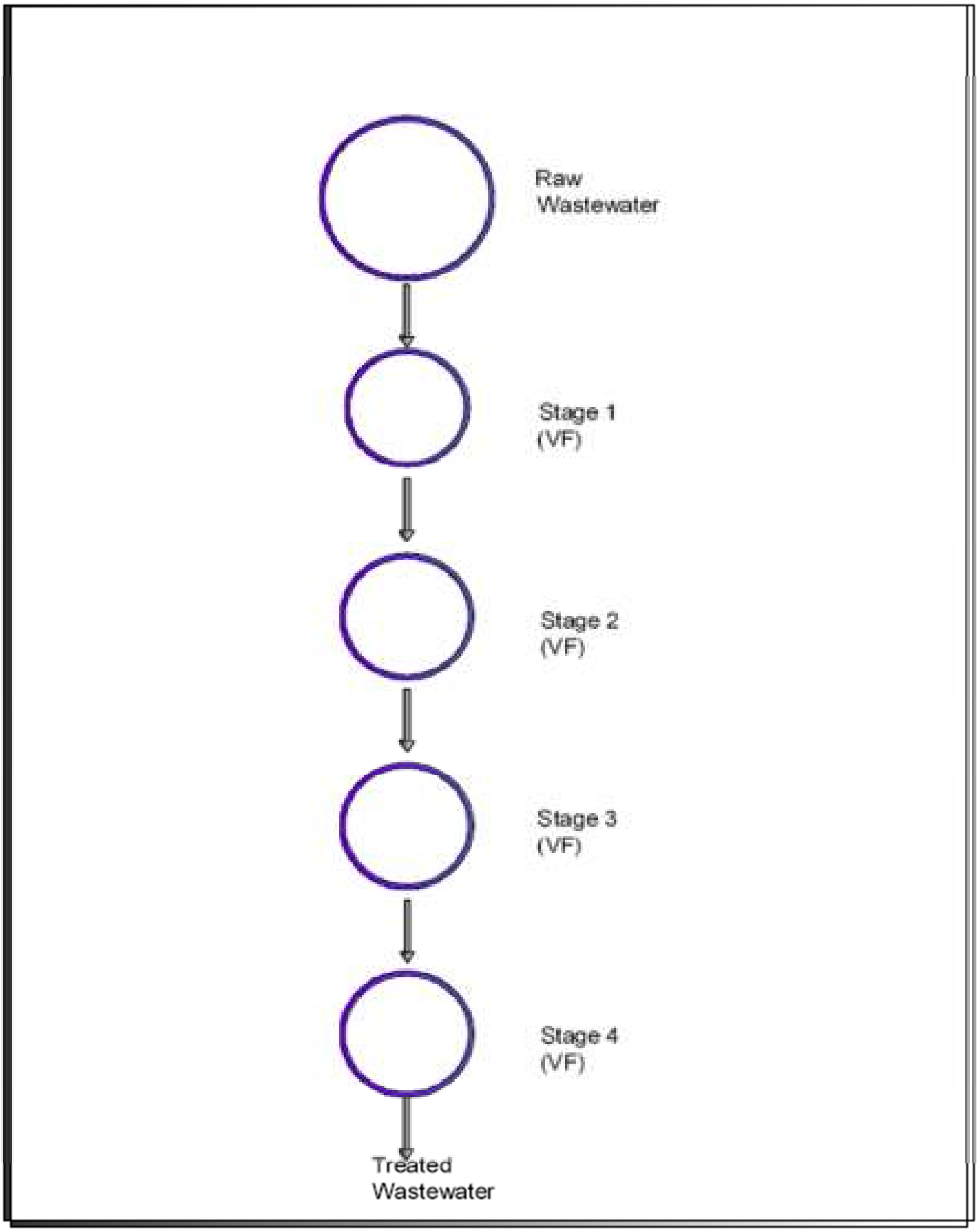

Figure (3-1): The system done (4-stages) VF - sub-surface constructed wetland.

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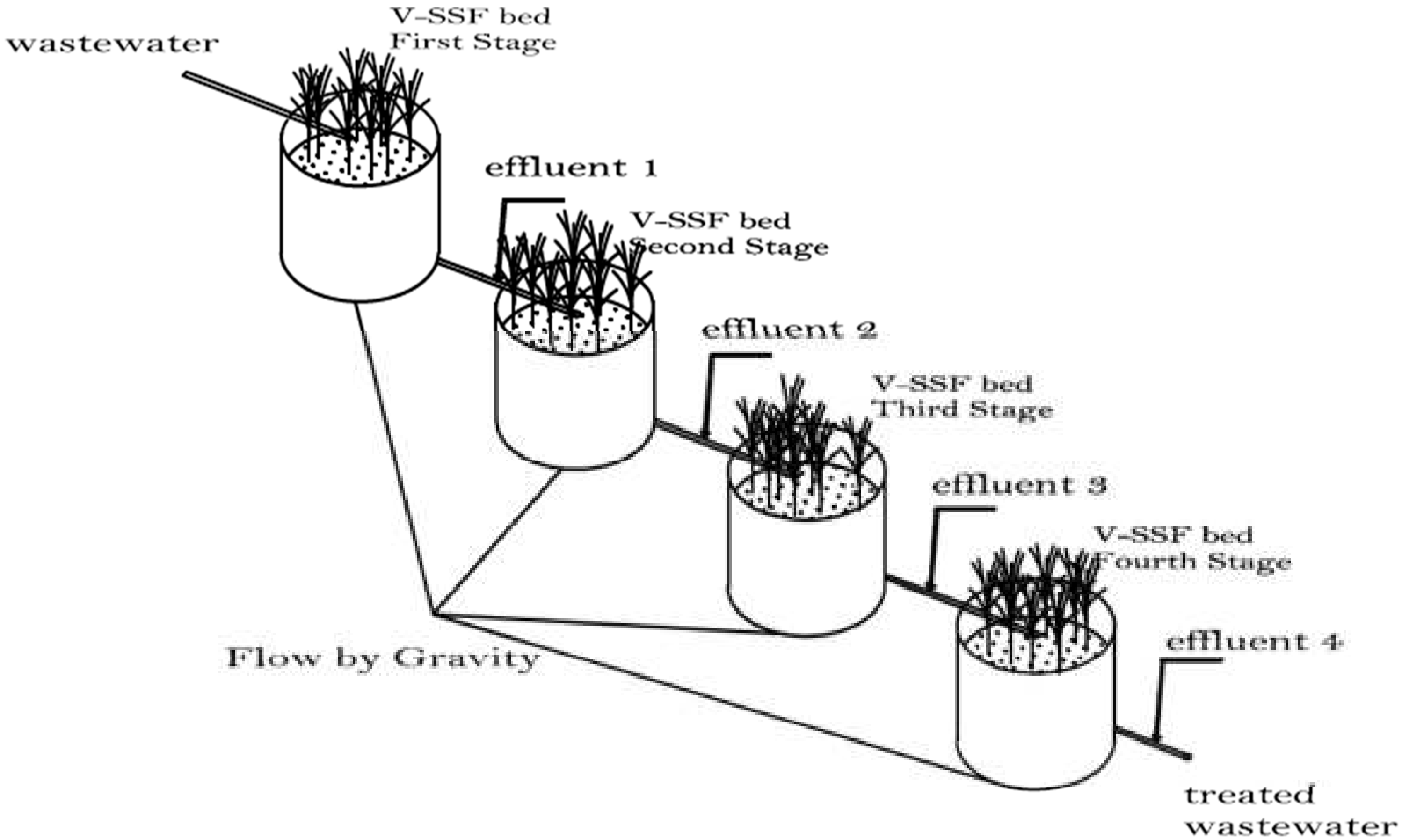

Figure (3-2): (4-stages)VF sub-surface constructed wetland was repeated five times each one with different plant.

Figure (3-3):(4-stages)VF sub-surface constructed wetland An-Najah National University 2010.

Each barrel in all stages and the replicated ones was filled with the same media on layers. The first layer consisted of gravels whose size was between (10-15) cm at 13cm high as shown in figure (3-4).

This size was chosen because there was a valve in the bottom of each barrel (stage) which was used for controlling the flow in the system, so it was chosen larger than the entrance of valve (which was ½ inch) so the valve would not be clogged by small aggregates.

Figure (3-4): The first layer in the constructed wetland consisted of gravel for a 13cm-depth.

The second layer was filled with aggregates with sizes between (1-2) cm for a 27cm-depth. The third layer had the same characteristics as those of the second layer but it wasmixed with siltsand with (3:1) ratio (aggregates: sand) and it was 10cm thick as shown in figure (3-3).

This layer was mixed with sand to provide fine media suitable for plants roots.

Figure (3-5):Constructed wetland with total height for media equal to 50 cm.

The total thickness (depth) of the media inside each barrel was 50 cm, and the general porosity in the media was 45% which is high porosity. Figure (3-6) shows longitudinal section for the treatment cell.

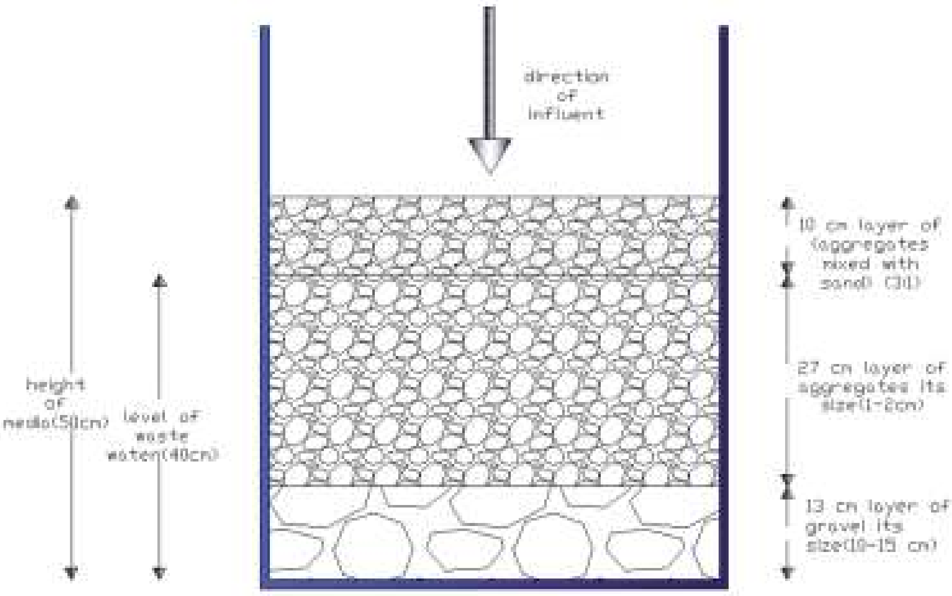

Figure (3-6): Profile of the treatment cell.

The constant level of wastewater inside the system was 40 cm; 10 cm were left to allow aeration for the system and the roots of the plants. The flow in each barrel was 12ml/min for all stages and for all replicated systems that grown with different types of plants, HLR was (22 l/m^2per-day) and HRTin the system was 6 days.

The level of water in each barrel can be maintained stable through two methods:

- Raising the outlet valve for each barrel to the height of 40cm.
- Or filling the barrels with wastewater and the flow in each barrel is the same so the level of water will be stable, because Qin = Q out which is the method the researcher used.

There was a perforated 1.5 inch diameter steel pipe placed inside each barrel with a length of 60 cm. The researcher put it to measure the level of wastewater inside the system, and to provide aeration for the system.

The porosity in the system was (45%); the high porosity in constructed wetlands has many benefits:

- prevents the clogging in the system especially in the future which meansa more durable constructed wetland system.
- Increases the quantity of wastewater in the system leading to increased quantity of treated wastewater because the quantity inside the system will increase and the HRT also will increase so we can increase the HLR , and treat more wastewater quantity, which means less area is needed .

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- Maintains very good aeration for the wastewater in the system from the atmosphere which means fast removal of BOD and TN because DO will be more.

  The flow in the system was a vertical one from top to the bottom in all four stages.

3.2. Experiment process:

3.2.1. Flow and Loading rates in the system:

The flow of the wastewater in the system is fed at the inlet and flows through the porous media under the surface of the beds in a vertical path (down flow) until it reaches the outlet zone (4th-stage outlet), where it is collected. The table below shows the hydraulic loading rates for the different parameters in system. The HLR were calculated for all stages of the system (4-stages) which treat the wastewater gradually and shown in table 3.1.

Samples were taken from the inlet (raw wastewater before it inters to the first stage) and from the treated wastewater (the outlet of the 4th-stage) for all replicated five systems which were planted with different types of plants.

The loading rates of the different parameters were calculated and shown in table (3.1) the area is based on the surface area of all the four stages of the system.

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Table (3.1): Loading rates for the different parameters in the experiment for the all system (four stages VF- CWs):

Parameter	Loading rate
BOD	72.3Kg/ha.d.
COD	99.3 Kg/ha.d.
TSS	41.1Kg/ha.d
TKN	41.8Kg/ ha.d

3.2.2. Plants that grown in the system:

There were five plants that were planted in the system because the researcher replicated the system five times with five different types of plants.

These plants were chosen to be seasonal crops because the experiment extended for a 6-month period.

The five crops were Corn Broomsfigure (3-4), Alfalfa figure (3-5), Corn Figure (3-6), Barley Figure (3-7), and sunflower figure (3-8).

Each crop was planted four times in four barrels (4-stages); each barrel represented as a stage of treatment. The highest was the first stage and the lowest was the final one.

We have four barrels in the system, and in all of experiment the total numbers of barrels were 20. As shown in the figure (3-3).

Table (3-2): Time table for the experiment implementation:

Time	Action
(1-30)/4/2010	Building up the system
(1-30)/5/2010	Running off the system
(1-6)/6/2010	Growing of the plants
(7-6/20-7)2010	Growth of the plants
(21-7/10-10)2010	Sampling and testing

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Figure (3-7): Constructed wetland planted with Corn Brooms.

Figure (3-8): Constructed wetland planted with Alfalfa.

Figure (3-9): Constructed wetland planted with Corn.

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Figure (3-10):Constructed wetland planted with Barley.

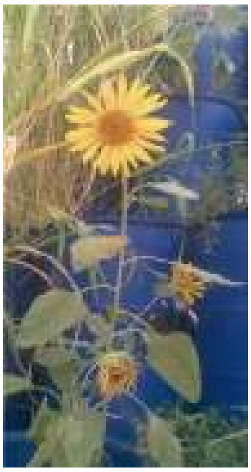

Figure (3-11): Constructed wetland planted with Sunflower.

3.2.3. Wetland operation:

After the system was built, and the seeds of the plants were planted,we ran the system and wastewater flew through the Barrels continuously by means of gravity.

The flow was 12ml/min and each barrel contained 25.6 liter of wastewater which was kept at a level of 40 cm, (10 cm beneath) the surface of constructed wetland.The HRT in each barrel was 1.5days, which means 6 days for all four stages. The researcher controlled the flow by using valves and the flow is measured several times weekly by using graduated cylinders and a timer toinsure that the flow rate is maintained at 12ml/min.

Many tests were performed to examine the quality of the water before and after treatment. TSS, TDS, BOD, COD, N, Cl tests were conducted throughout the period of the experiment. These tests were applied to all types of plants planted in the system.

3.2.4. Sampling and testing:

The samples were taken in glass bottles from the inlet (raw wastewater) and the outlet (the 4th- stage outlet) for the all replicated systems which grown with different types of plants (treated wastewater) of the system. Sampling was usually performed at around 10 a.m. and the tests were done immediately after half an hour following the collection of samples.

Maximum temperature of the atmosphere during the study was (32±4) C^o while the temperature of the wastewater in the treatment plant was (24±2) C^o.

3.2.5. TestingMethodology:

The testing methodology was done according to the standard methods stated in the Examination of Water and Wastewater book edited by ANDREW D. EATON, LENORE S. CLESCERI, ARNOLD E. GREENBERG, 1995

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Chapter Four

Results and Discussion

4.1. General results:

The experiment was done in certain circumstances, and many tests were done for BOD, COD, TSS, TDS, TKN, and Cl. These tests lasted for4 months (July, August, September and October of 2010). The temperature of the treated wastewater was (24±2)C^{o} during the study. The removal efficiency of BOD wasbetween (94% to 96.9%), for COD, (79.4% to 88.5%), for TSS, (90.5% to 95.6%) and for TN (62.5% to 65.4%).

4.2. (TSS) removal performance:

TSS concentration percent removal attained (90.5_95.6) %, the HLR = 41.1Kg/ha.d this loading rate is the average of all loading rates during the operational period of the system. It was the same for all the replicated trials of the system . Because the inflow of the wastewater is the same in the five systems that grown with different types of plants.

The removal of SS was a physical treatment process, Gravity sedimentation (discrete and flocculants).[7]

Table 4-1 shows the measured influent and effluent concentrations for TSS during the operational period for the different types of plants that were planted in the system which was replicated five times.

Figure 4-1 shows the removal efficiency for TSS, the effluent values on the chart represents the average effluent values of the five systems, and the influent values are the average of the Influents values through the operational period.

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Table (4-1): Measured influent and effluent concentrations and removal efficiencies of TSS through the operational period for the system (4stages VF- CWs) which was replicated 5 times using different types of plants.

	Waste water	Corn Brooms (S_1)		Barley (S_2)		Alfalfa (S_3)		Corn (S_4)		Sunflowers (S_5)	
Time	**In**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**
July	123	20.0	83.7	12.0	90.2	20.0	83.7	19.0	84.6	21.0	82.9
August	167.5	12.5	92.5	2.5	98.5	17.5	89.6	12.5	92.5	10.0	94.0
September	165	12.5	92.4	5.0	97.0	7.5	95.5	2.5	98.5	5.0	97.0
October	150	10.0	93.3	5.0	96.7	5.0	96.7	2.5	98.3	10.0	93.3
Average	**151.4**	**13.8**	**90.5**	**6.1**	**95.6**	**12.5**	**91.4**	**9.1**	**93.5**	**11.5**	**91.8**
Standard deviation	20.4	4.3		4.1		7.4		8.1		6.8	

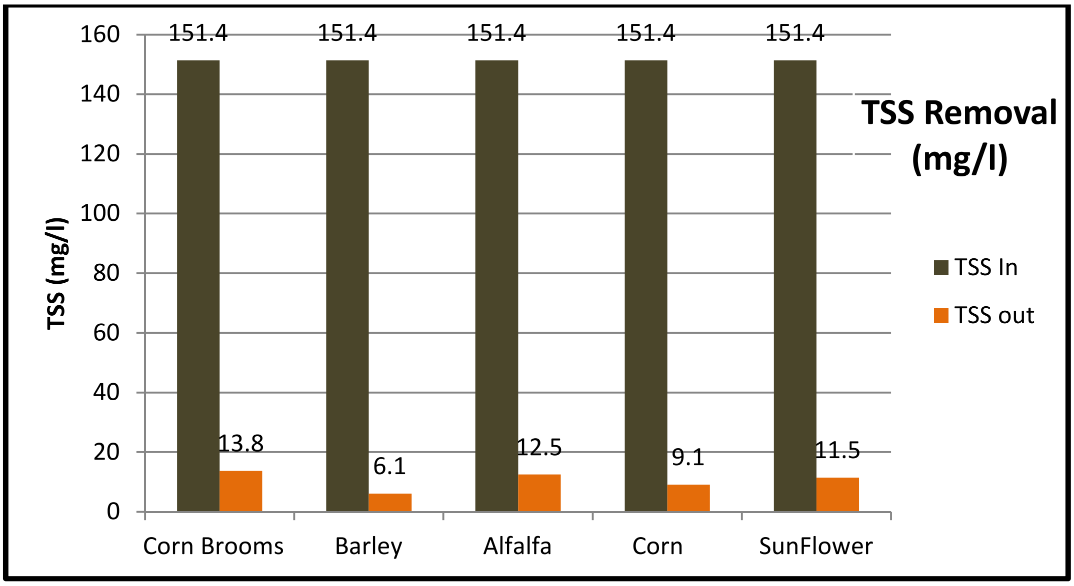

Figure (4-1): Removal efficiency of TSS.

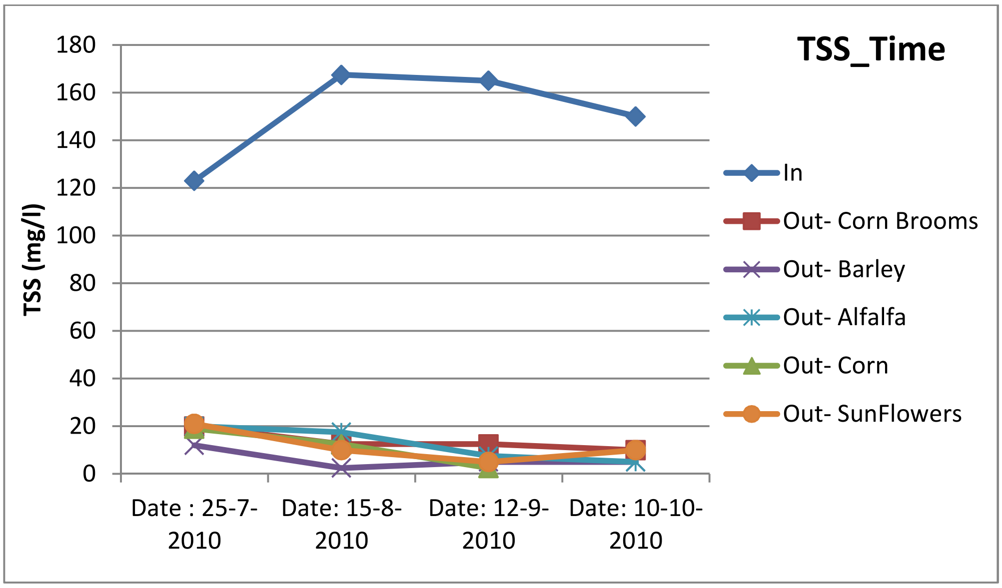

Figure (4-2): Measured TSS influent and effluent concentrations during the operationalperiod.

Figure (4-2) shows the influent values through the operational period and shows the effluent values forfive systems grown with different types ofplants during the operational period, the difference between the inlet and outlet values was very significant and it represents the removal values of TSS, which means that the system is effective in removing TSS.

Table (4-2) shows the loading rates values and the eliminated values of TSS in the five replicated systems, the loading rate was the same for the five systems because the inflow was the same .

The loading rates were calculated for the whole the system (the area for the four stages)and also the eliminated values were calculated for all system (for the four stages), these eliminated values of TSS had been eliminated in the all 4-stages.

Table (4-2): TSS load and eliminated values ($gm^{-2}d^{-1}$) for the (4 stages VF- CWs) system that replicated five times using different types of plants.

TSS		Corn Brooms	Barley	Alfalfa	Corn	Sun-flowers
	Load	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated
July	3.3	2.8	3.0	2.8	2.8	2.8
August	4.6	4.2	4.5	4.0	4.2	4.3
September	4.5	4.1	4.4	4.3	4.4	4.4
October	4.1	3.8	3.9	3.9	4.0	3.8
Average	**4.1**	**3.7**	**4.0**	**3.8**	**3.9**	**3.8**

Figure (4-3) shows the eliminated values of TSS for each system during the operational period while figure (4-4) shows the eliminated values of TSS with time - for example the first five points shows the eliminated values for all the systems that replicated with different types of plants in June month.

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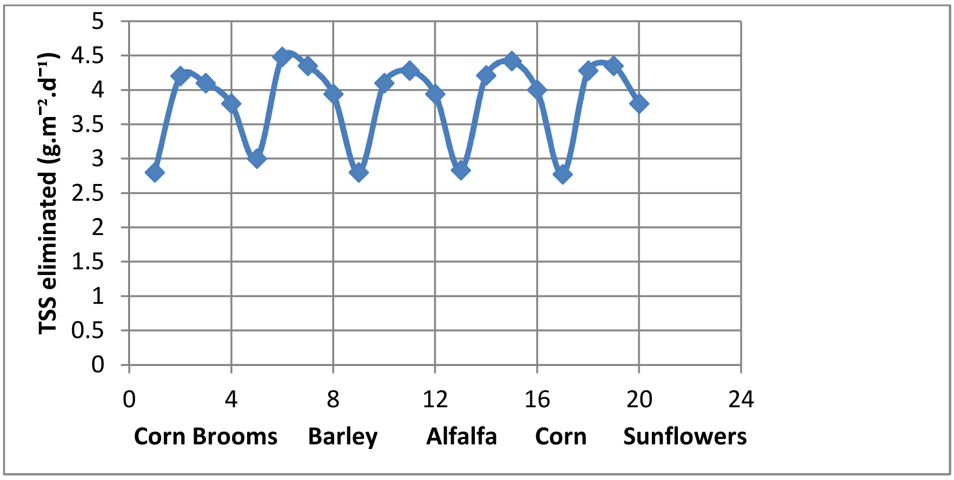

Figure (4-3): The eliminated values of TSS through the operational period of the system which replicated five times.

The eliminated values of TSS for the system were good, the behavior of different types of plants nearly the same through the operational period of study, the curve initially increasing and then concaved down during the operational period of the system for the all five replicated systems.

The inflow for the system was the same for all replicated ones, it noticed from the graph that the elimination values were more in the system grown with Barley.

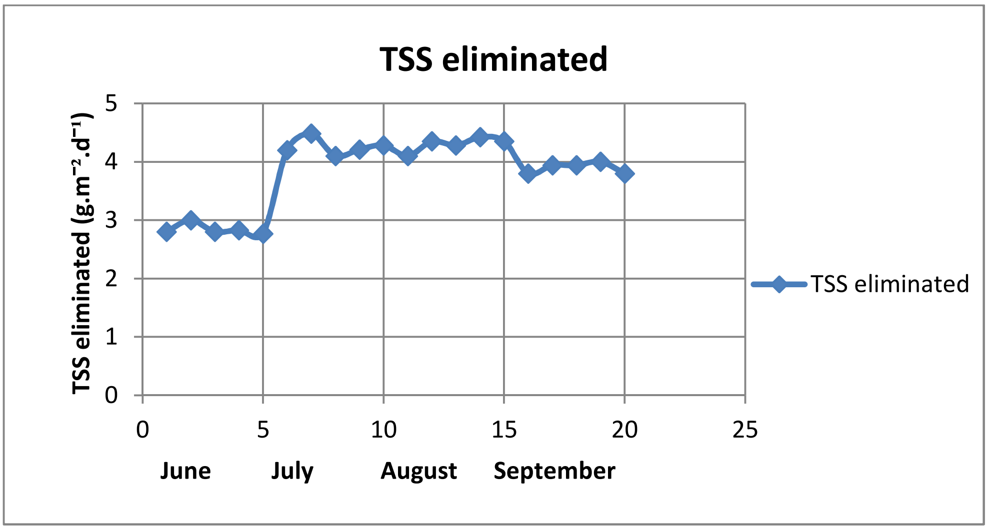

Figure (4-4):The eliminated values of TSS through the operational period of the system which replicated five times.

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Figure (4-4) shows that the elimination in the first month of operational period was the lowest for all the replicated systems, because the growth of plants in all five systems were not completed.

Figure (4-5) shows the effluent values of TSS concentrations for each system during the operational period.

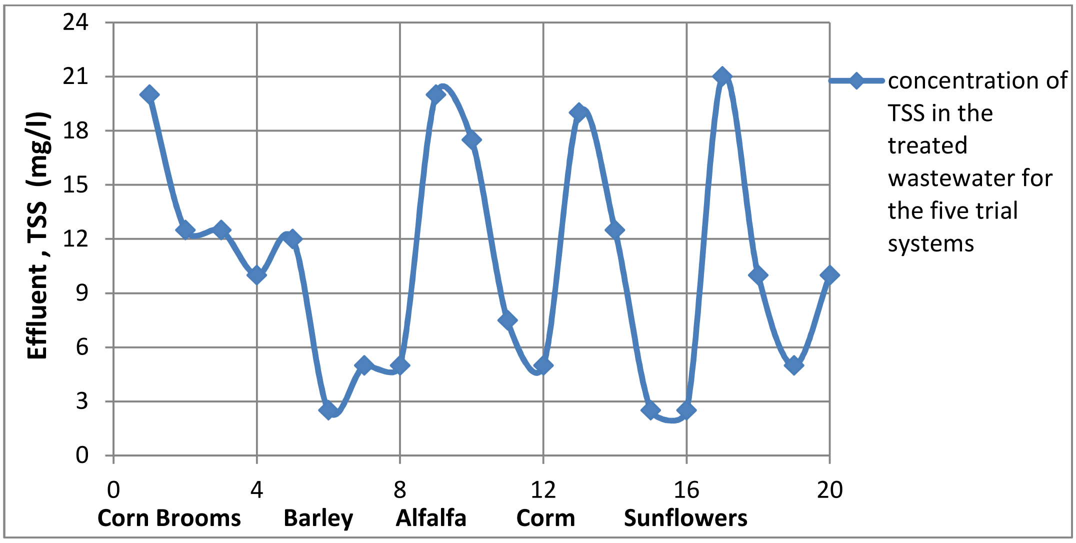

Figure (4-5) The effluent values of TSS through the operational period of the system which replicated five times using different types of plants.

The behavior of the curves for the five replicated system is nearly the same, the effluent of TSS initially starts higher and then it starts decreasing with time through the operational period.

It noticed that the TSS effluent of the system that replicated with growing Barley was the lowest effluent value through the operational period, this was related to the type of the roots for the plants grown in the systems, it was noticed that the roots of Barley were more spread and thinner and it perform as an effective a filter for SS.

Shows the effects of roots type on the performance of TSS removing in the figures (4-6,4-7,4-,4-8,4-9).

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Figure (4-6): Roots are strong but are not dense and their spread in the media is less (Corn Brooms).

Figure (4-7): Roots are denser and their spread in the media is more (Barley).

The roll of roots in increasing the removal of TSS is explained in figures (4-8and 4-9), it depends on the nature and the types of roots for the plants grown in the system.

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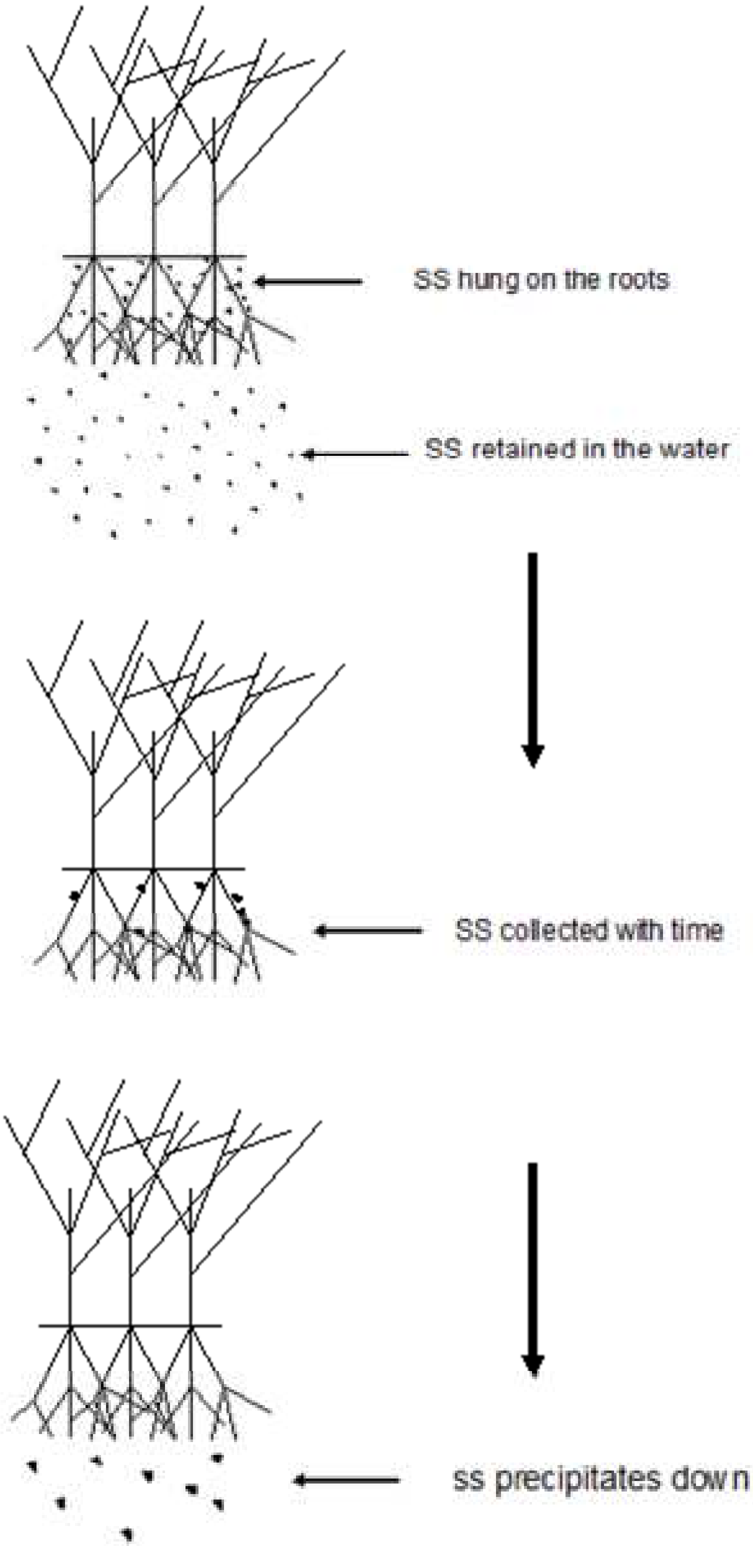

Figure (4-8):Mechanism of roots rolls in TSS removal (less dense roots like Corn Brooms less removal for TSS).

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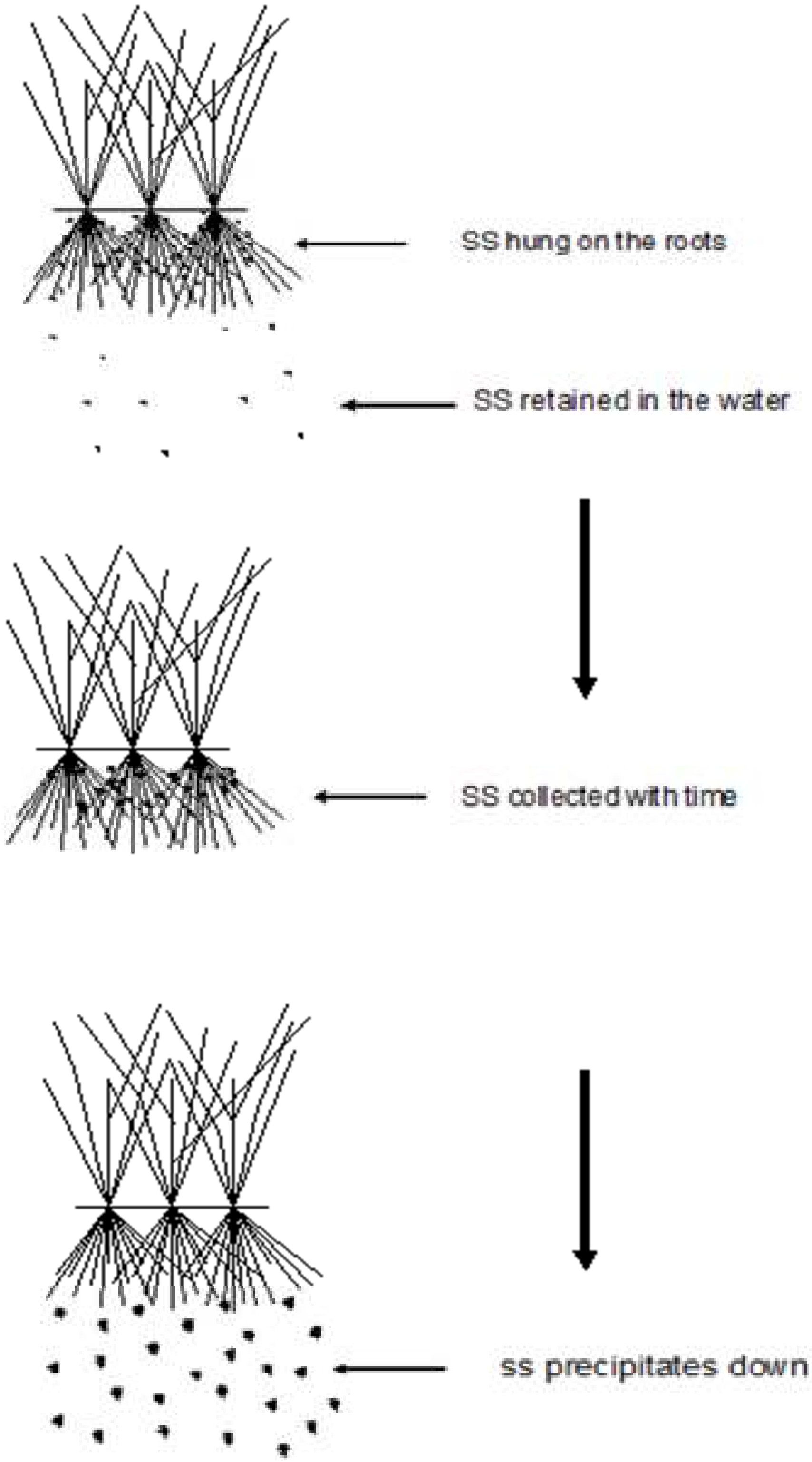

Figure (4-9): Mechanism of roots roll in TSS removal (more dense roots like Barley_ more removal for TSS).

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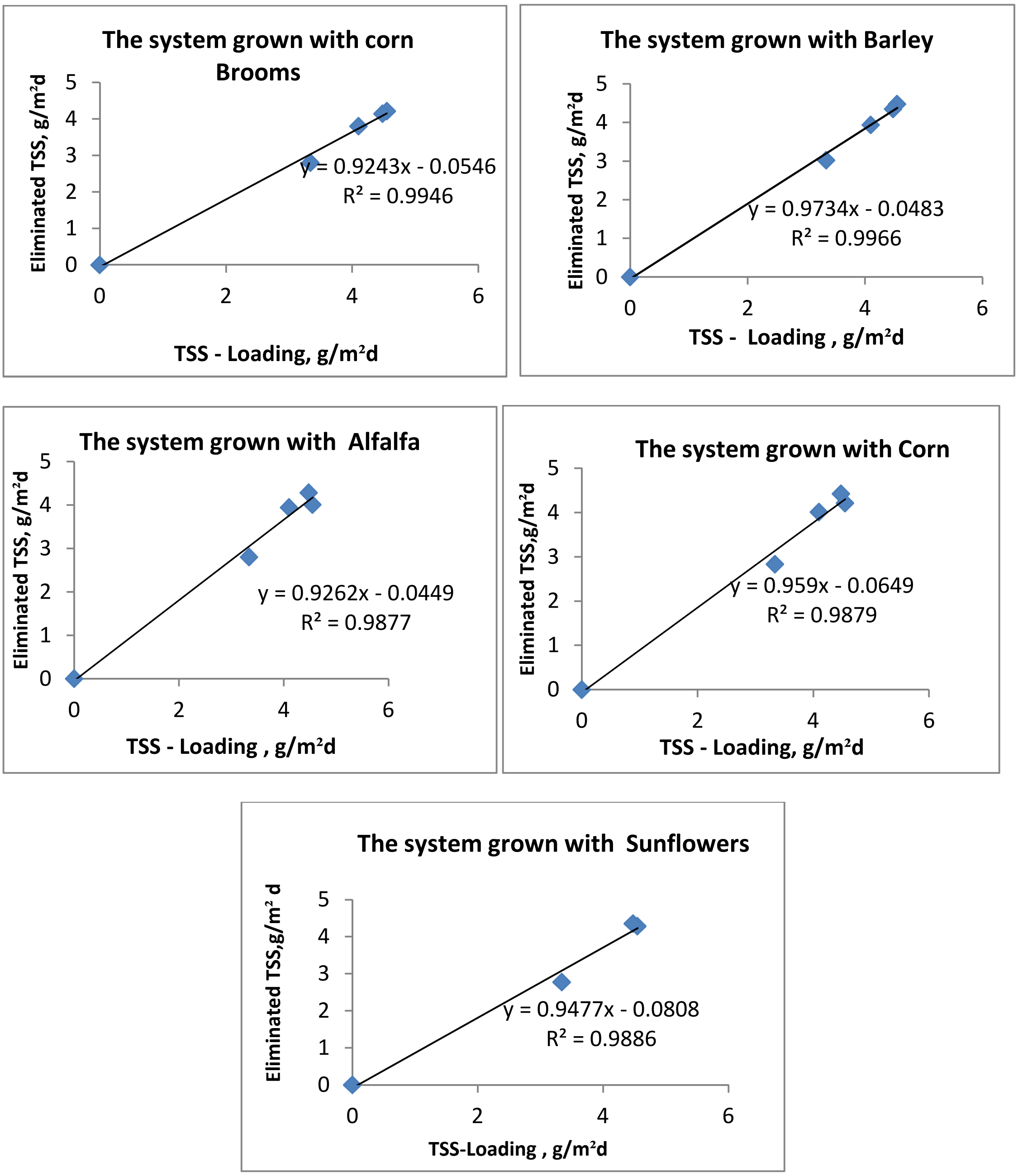
The eliminated values of TSS (g/m^{2}d) are correlated to loading rates(g/m^{2}d) these relationships are shown in figures (4-10).

These figures show that the eliminated values of TSS increase linearly with loading rates. With high coefficient of determination (R^2=0.987-0.996) are observed.



Figures (4-10): Eliminated TSS as a function of loading rate.

4.2.1 Removal Mechanism of TSS:

One of the primary intermediate mechanisms in the removalof suspended solids in this systems is the flocculation and settling of colloidal and supra colloidal particulates.

This systems is relatively effective inTSS removal because of the relatively low velocity and high surface areain the media provides opportunities for TSS separations bygravity sedimentation (discrete and flocculent), Straining and physical capture, and adsorption on biomass film attachedto gravel and root systems. The roots of the plants can also help in removal of SS.

4.3. (BOD) Removal performance:

BOD concentration percent removal attained (94_96.9) %, with HLR of = 72.3Kg/ha.d and it differed from one plant to another. The highest outflow concentration was 16mg/l which was the average of effluent values in the system planted with Alfalfa.

BOD removal depends on the DO concentration in the system which was good in all systems (above 3.5 ppm) but in the Alfalfa system it was the lowest (2.5ppm) as shown in table 4-5. This could explain the lower removal rates for the system with Alfalfa. The removal of BOD is a biological, chemical, and physical treatment process.[7]

Table 4-3 shows the measured influent and effluent concentrations for BOD during the operational period for the different types of plants in the system which were replicated five times.

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Figure 4-11 shows the removal efficiency for BOD, the effluent values on the chart represents the average effluent values during the operational period of the five systems, and the influent value is the average of the influents values to the systems through the operational period.

Table (4-3): Measured influent and effluent concentrations and removal efficiency of BOD through the operational period for the system (4 stages VF- CWs) which was replicated 5 times using different types of plants.

BOD	Waste water	Corn Brooms (S_1)		Barley (S_2)		Alfalfa (S_3)		Corn (S_4)		Sunflowers (S_5)	
Time	**In**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**
July	330.0	10.0	97.0	15.0	95.5	19.0	94.2	11.0	96.7	10.0	97.0
August	250.0	10.0	96.0	10.0	96.0	15.0	94.0	9.0	96.4	8.0	96.8
September	240.0	10.0	95.8	13.0	94.6	15.0	93.8	11.0	95.4	5.0	97.9
October	250.0	8.0	96.8	11.0	95.6	15.0	94.0	8.0	96.8	10.0	96.0
Average	**268.0**	**9.5**	**96.5**	**12.3**	**95.4**	**16.0**	**94.0**	**9.8**	**96.3**	**8.3**	**96.9**
Standard Deviation	41.9	1.0		2.2		2.0		1.5		2.4	

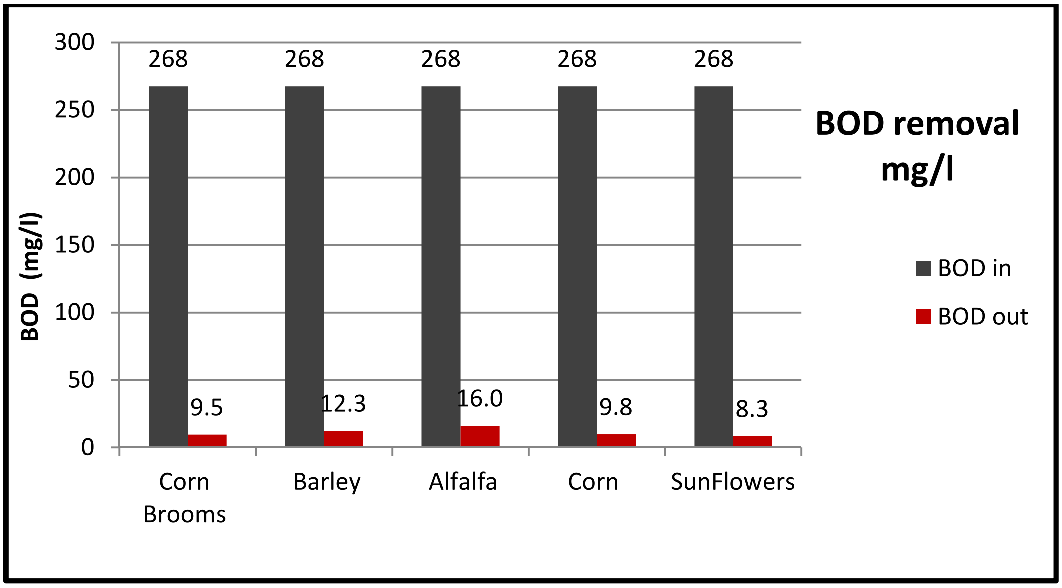

Figure (4-11): Removal efficiency of BOD.

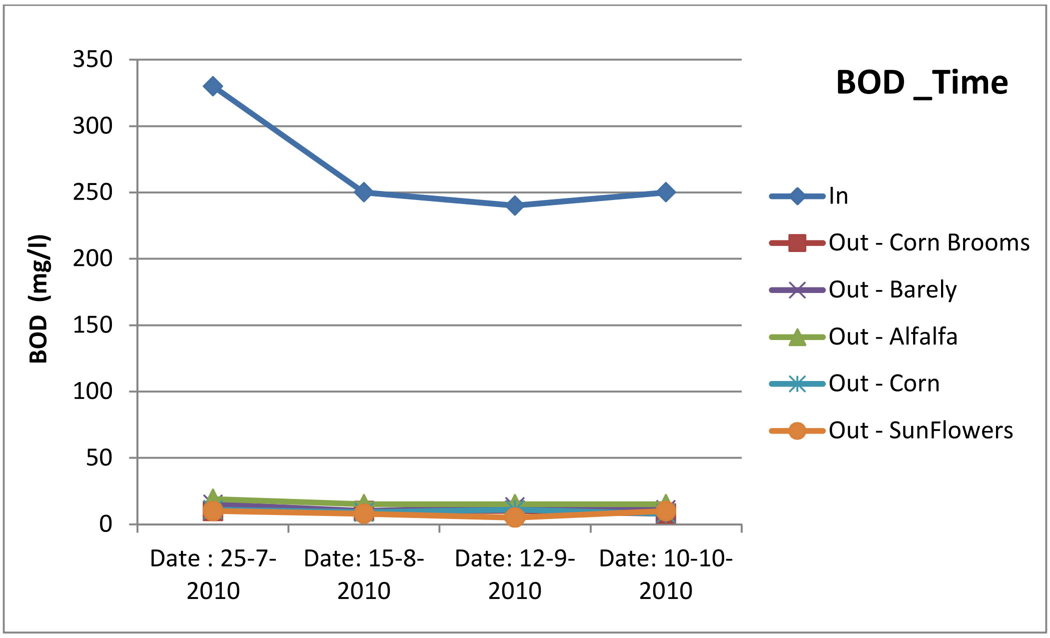

Figure (4-12): Measured BODinfluent and effluent concentrations during the operational period.

Figure (4-12) shows the influent and effluent BOD values through the operational period for the five systems grown with different types of plants. The difference between the inlet and outlet values represent the removal rates of BOD, which shows that the system is effective in removing BOD.

Table (4-4) shows the loading rates values of BOD for the five replicated systems which were the same for all systems because the inflow was the same. Table 4-4 also shows the eliminated values of BOD for the all five systems.

Table (4-4): BOD loading and eliminated values (g $m^{-2}d^{-1}$) for the (4stages VF- CWs) that replicated five times using different types of plants.

BOD		Corn Brooms	Barley	Alfalfa	Corn	Sun-flowers
	Load	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated
July	9.0	8.7	8.6	8.5	8.7	8.7
August	6.8	6.5	6.5	6.4	6.6	6.6
September	6.5	6.3	6.2	6.1	6.2	6.4
October	6.8	6.6	6.5	6.4	6.6	6.5
Average	7.3	7.0	7.0	6.9	7.0	7.1

Figure (4-13) shows the eliminated values of BOD for each system during the operational period while figure (4-14) shows the eliminated values of BOD with time.

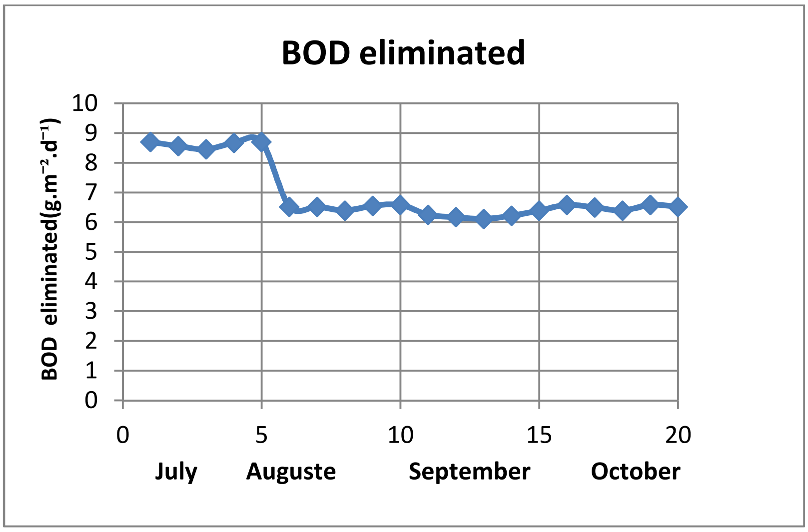

Figure (4-13:) The eliminated values of BOD through the operational period of the system which replicated five times.

It is noticed in figure 4-13 that the eliminated values of BOD in the systems through the operational period were more in July, and this is

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related to inflow values which was the highest in July as it was 330 mg/l, so the elimination will be more when the inflow is more.

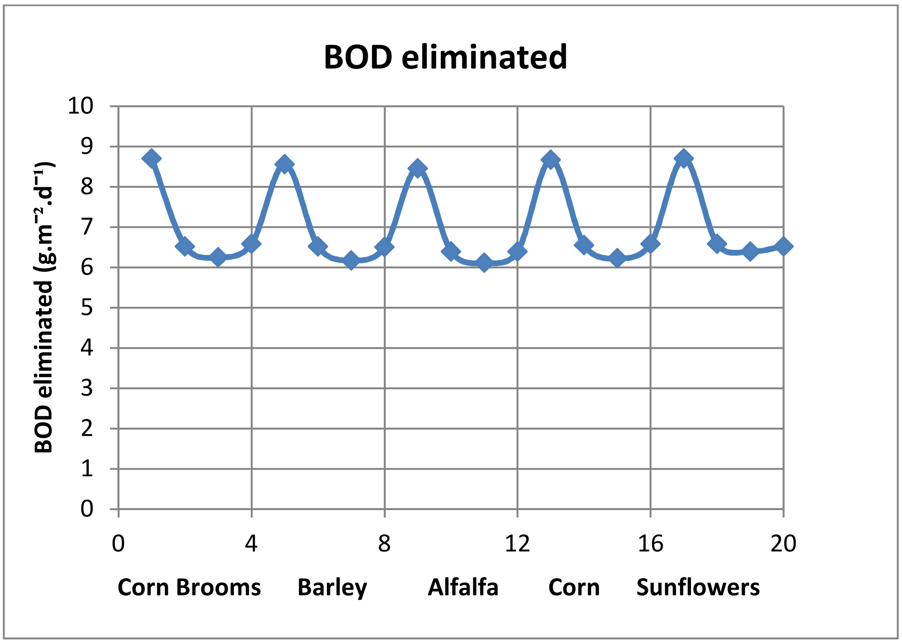

Figure (4-14):The eliminated values of BOD through the operational period of the system which replicated five times using different types of plants.

The behavior and the shape of the curves forthe five replicated trials planted with different types of plants were nearly the same, the elimination of BOD starts higher and then it decreases with time.

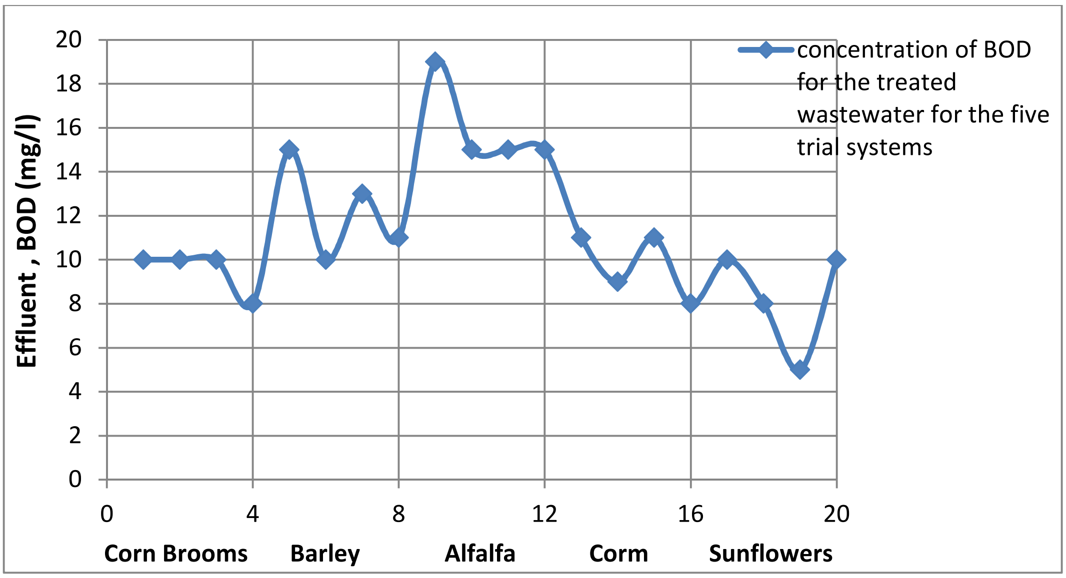

Figure (4-15):The effluent values of BOD through the operational period of the system which replicated five times using different types of plants.

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Figure (4-15) shows the effluents of BOD concentrations for the five trials of the system was more in the system grown with Alfalfa plant, this occurred because of the way of Alfalfa growing. It grows in the two directions horizontally and vertically while the other plants grow vertically.

So this spread in growing of the Alfalfa plant decreases the aeration of the system from the atmosphere and thiswas confirmed from the DO measurements in the five trials . It was the lowest in the system grown with Alfalfa plant, it equal to 2.5mg/l while in the other systems it was above 3.5mg/l as shown in table (4-5).

In this system the aeration from the atmosphere is very effective and important factor in aeration process because the porosity in the system reached 45% so the aeration can occurs easily.

Table (4-5): DO concentration for the wastewater in the 5-systems (4stages VF CWs) that were replicated 5 times with different types of plants:

VF constructed wetlands with different types of plants	DO Concentration in each system
Corn Brooms	3.5
Barley	4.5
Alfalfa	2.5
Corn	4.7
Sunflower	4.9

`

Figure(4-16):The plant grows in vertical direction the aeration from the atmosphere to the system was more, DO= 4.7mg/l

Figure(4-17): The plant grows and spreads in both directionsVertical and Horizontal so the aeration from the atmosphere to the system was less, DO =2.5 mg/l

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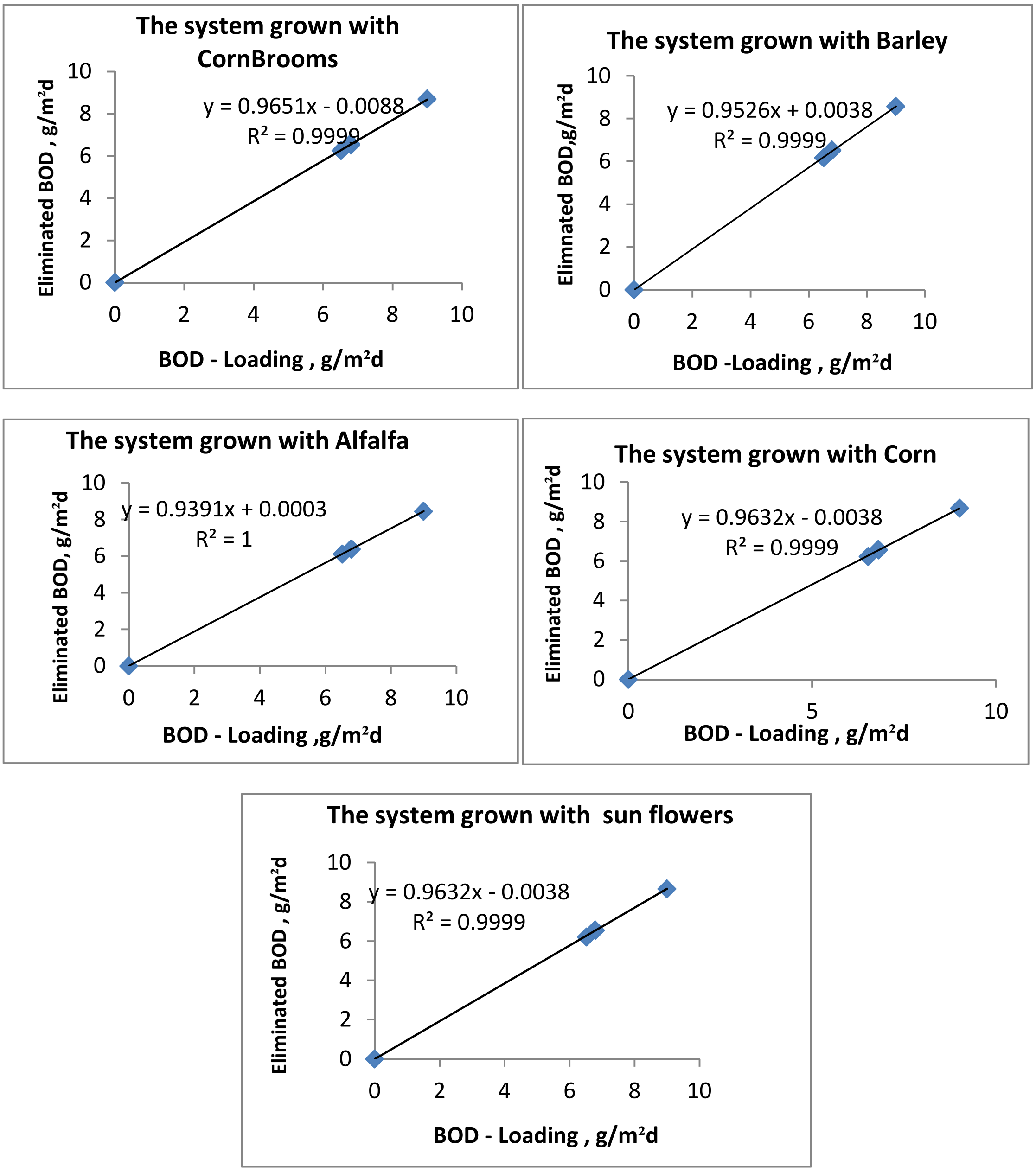
The eliminated values of BOD (g /m^2d)are correlated to loading rates (g /m^2d) these relationships are shown in figures 4-18.

These figures show that the eliminated values of BOD increase linearly with loading rates. with high coefficient of determination (R^2=0.999-1).



Figures (4-18): Eliminated BOD as a function of loading rate.

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4.3.1 Removal Mechanism of BOD:

Simple bacteria (cells) decompose the organic material present in the wastewater. Through their metabolism, the organic material is transformed into cellular mass, which is no longer insolution but can be precipitated at the bottom of a settling tank or retained as slime onsolid surfaces or vegetation in the system. The water exiting the system is then muchclearer than it was when it entered it.

A key factor in the operation of any biological system is the adequate supply of oxygen.Indeed, cells need not only organic material as food but also oxygen to breathe just like humans. Without an adequate supply of oxygen, the biological degradation of the wasteis slowed down, thereby requiring a longer residency time of the water in the system. For a given flow rate of water to be treated, this translates into a system with a larger volumeand thus taking more space.

The presence of a root structure would provide additional surface for Biofilm attachment. Plants may also contribute some oxygen to the granular bed.

Oxygen sources to the system which is important for biological treatment would be from surface aeration (which is the main source in this system because of the high percentage of voids which reach 45%) and plant-mediatedtransport.

The main reaction occurred in this system is:

Organic maters + O_2 +NH_3 +PO_4 $\rightarrow$ CO_2 + H_2O + New Cells (biomass)[7].

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4.4. (COD) Removal Performance:

COD concentration percent removal attained (79.4_88.5)%, the HLR = 99.3 Kg/ha.d and it differed from one plant to another; the highest outflow was in the two systems planted with Corn and Sunflower and was (76.3, 77.3) mg/l respectively. Although the removal efficiency of BOD in these two systems was high we expect that depending on the type of the plant, if it is denser per area unit, the removal of COD will be more.

The removal of COD is a biological, chemical, and physical treatment process.[7].

Table 4-6 COD measured concentrations before and after treatment process, the lower value in the effluent concentration was in the system grown with Corn Brooms while the highest value was in the system grown with Sun Flowers in July.

Figure 4-11 shows the removal efficiency for BOD, the effluent values on the chart represents the average effluent values of the five systems planted with different types of plants during the operational period, and the influent valuesare the average of the values through the operational period.

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Table (4-6): Measured influent and effluent concentrations and removal efficiency of COD through the operational period for the system (4 stages VF- CWs) which was replicated 5 times using different types of plants.

COD	Waste water	Corn Brooms (S_1)		Barley (S_2)		Alfalfa (S_3)		Corn (S_4)		Sunflowers (S_5)	
Time	**In**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**
July	408.0	40.0	90.2	56.0	86.3	64.0	84.3	75.0	81.6	85.0	79.2
August	352.0	48.0	86.4	48.0	86.4	48.0	86.4	70.0	80.1	73.0	79.3
September	352.0	45.0	87.2	45.0	87.2	54.0	84.7	72.0	79.5	81.0	77.0
October	350.0	40.0	88.6	56.0	84.0	40.0	88.6	64.0	81.7	70.0	80.0
Average	**365.5**	**43.3**	**88.2**	**51.3**	**86.0**	**51.5**	**85.9**	**70.3**	**80.8**	**77.3**	**78.9**
Standard Deviation	28.4	3.9		5.7		10.1		4.7		6.5	

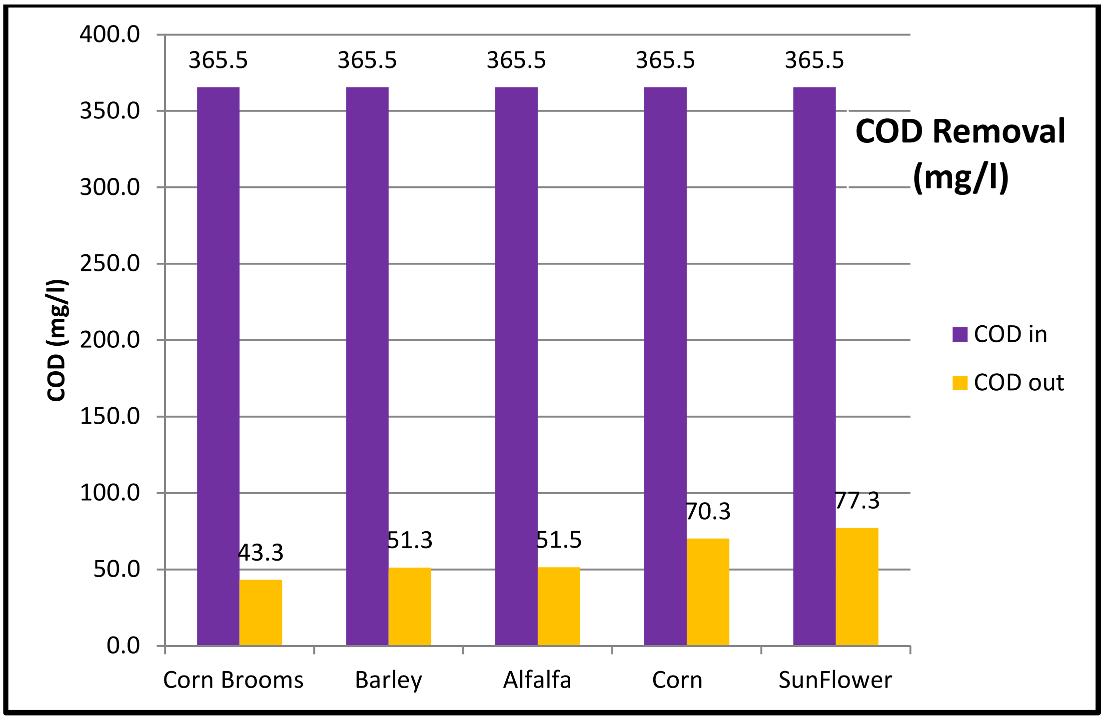

Figure (4-19): Removal efficiency of COD.

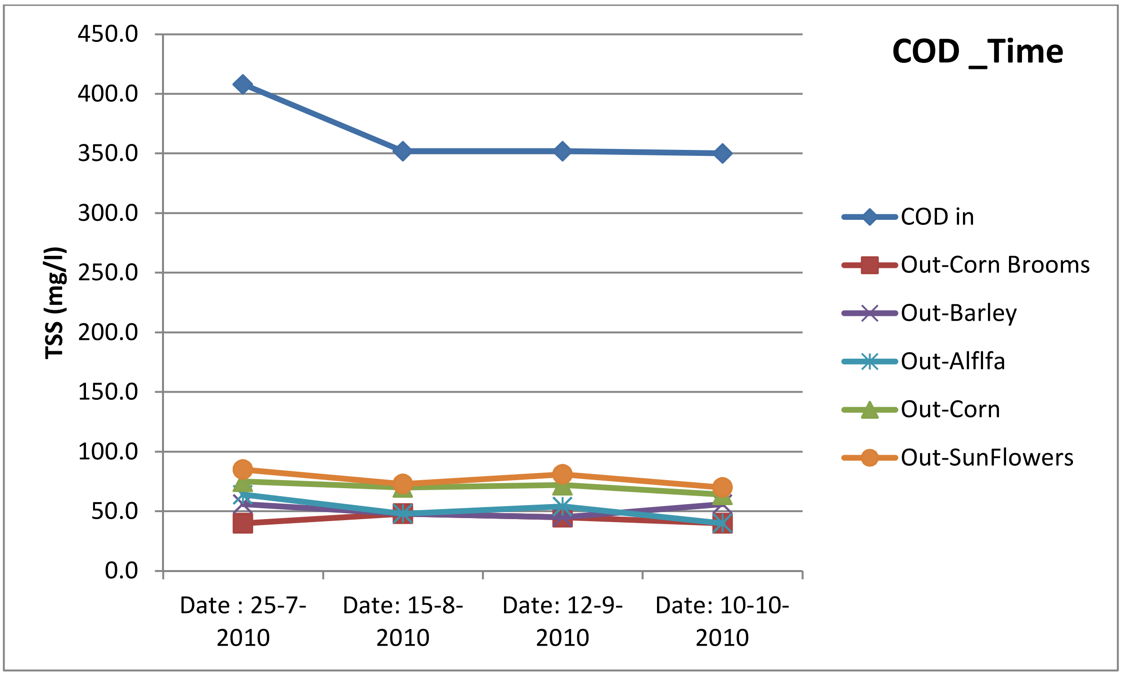

Figure (4-20): Measured COD influent and effluent concentrations during the operational period.

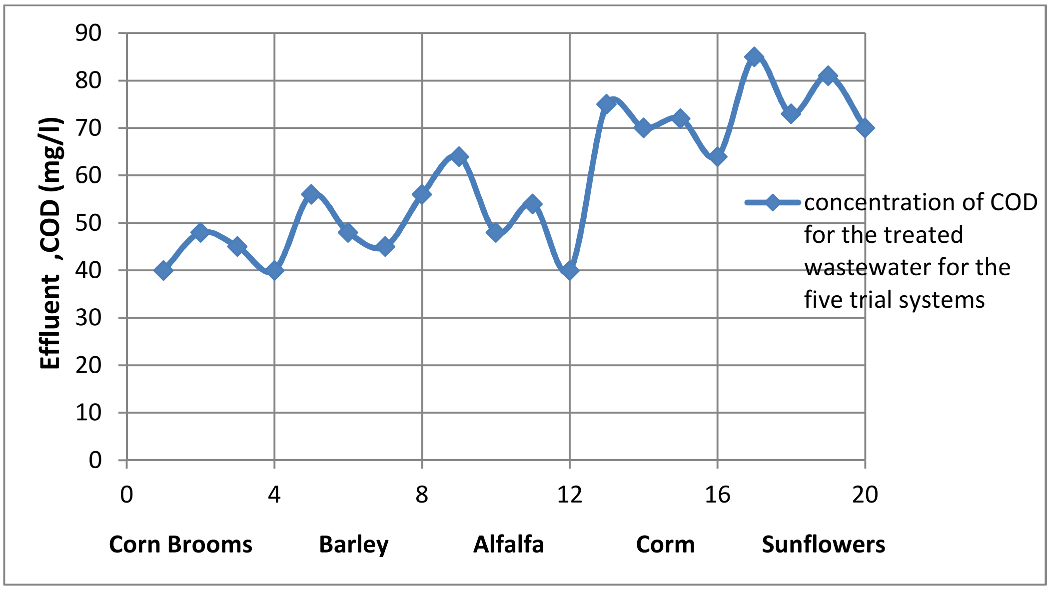

Figure (4-21): The effluent values of COD through the operational period of the system which replicated five times using different types of plants.

Figure (4-21) shows the effluent concentrations values (mg/l) for the five systems grown with different types of plants during the operational period of the system, the highest value was in the system grown with Sunflowers while the lowest one was in the system grown with Corn Brooms.

It is noticed that this is related to the density of the plants in the system (number of plant per area in the each bed) when it is more the removal of COD will be more.

Table (4-7): COD loading and eliminated values (g $m^{-2}d^{-1}$) for the (4stages VF- CWs) that replicated five times using different types of plants.

COD	Waste Water	Corn Brooms	Barley	Alfalfa	Corn	Sun-flowers
	Load	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated
July	11.09	10	9.57	9.35	9.05	8.78
August	9.57	8.26	8.26	8.26	7.66	7.58
September	9.57	8.34	8.34	8.1	7.61	7.36
October	9.51	8.42	7.99	8.42	7.77	7.61
Average	**9.93**	**8.76**	**8.52**	**8.53**	**8.02**	**7.83**

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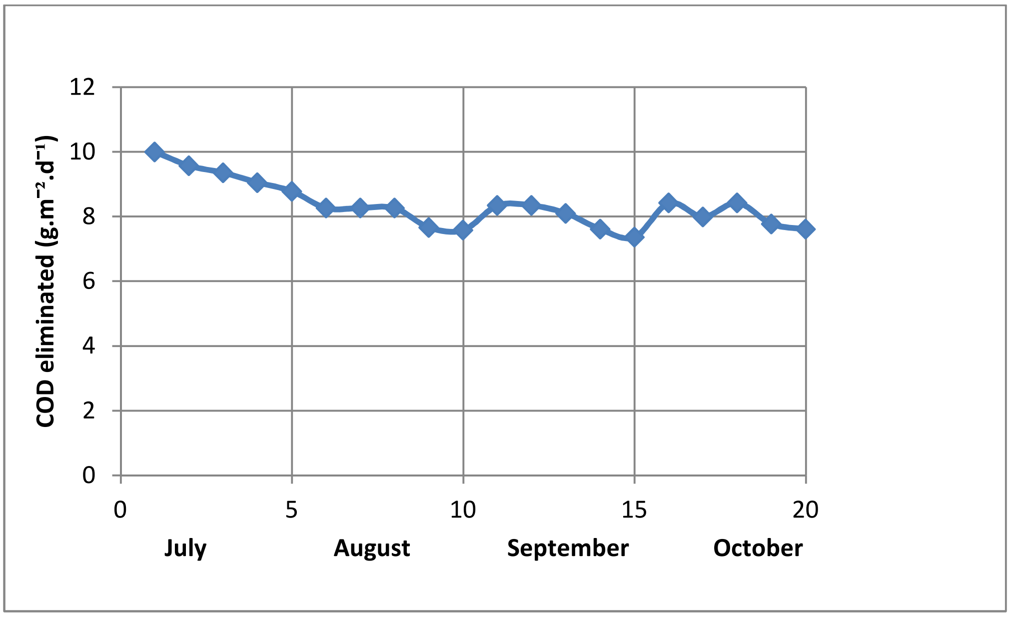

Figure (4-22):The eliminated values of COD through the operational period of the system which replicated five times

Table (4-7) shows the loading rates and the eliminated values for COD through the operational period of the system, and Figure (4-22) shows the eliminated values of COD with time. It were more in July month and this occurred because the inflow concentration of COD in this month was the highest through the operational period, and when the inflow concentration of COD be more the eliminated values will be more .

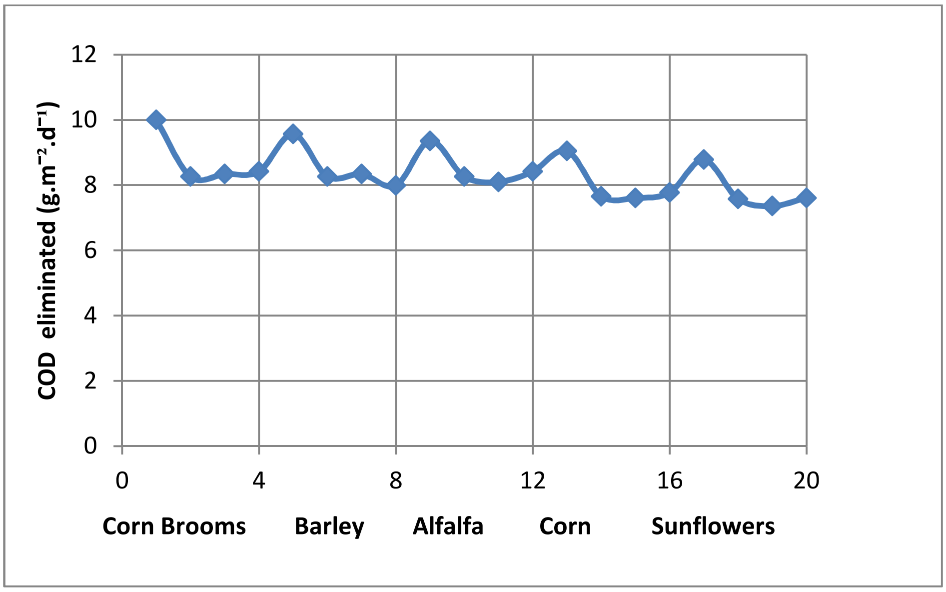

Figure (4-23):The eliminated values of COD through the operational period of the system which replicated five times using different types of plants.

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Figure (4-23) shows the eliminated values of COD related to the type of plants grown in the systems, the eliminated values of COD where more in the system that grown with Corn Brooms.

It was noticed from the figure that the shape and the behavior of the graphs for the 5-systems that grown with different types of plants during the operational period nearly the same.

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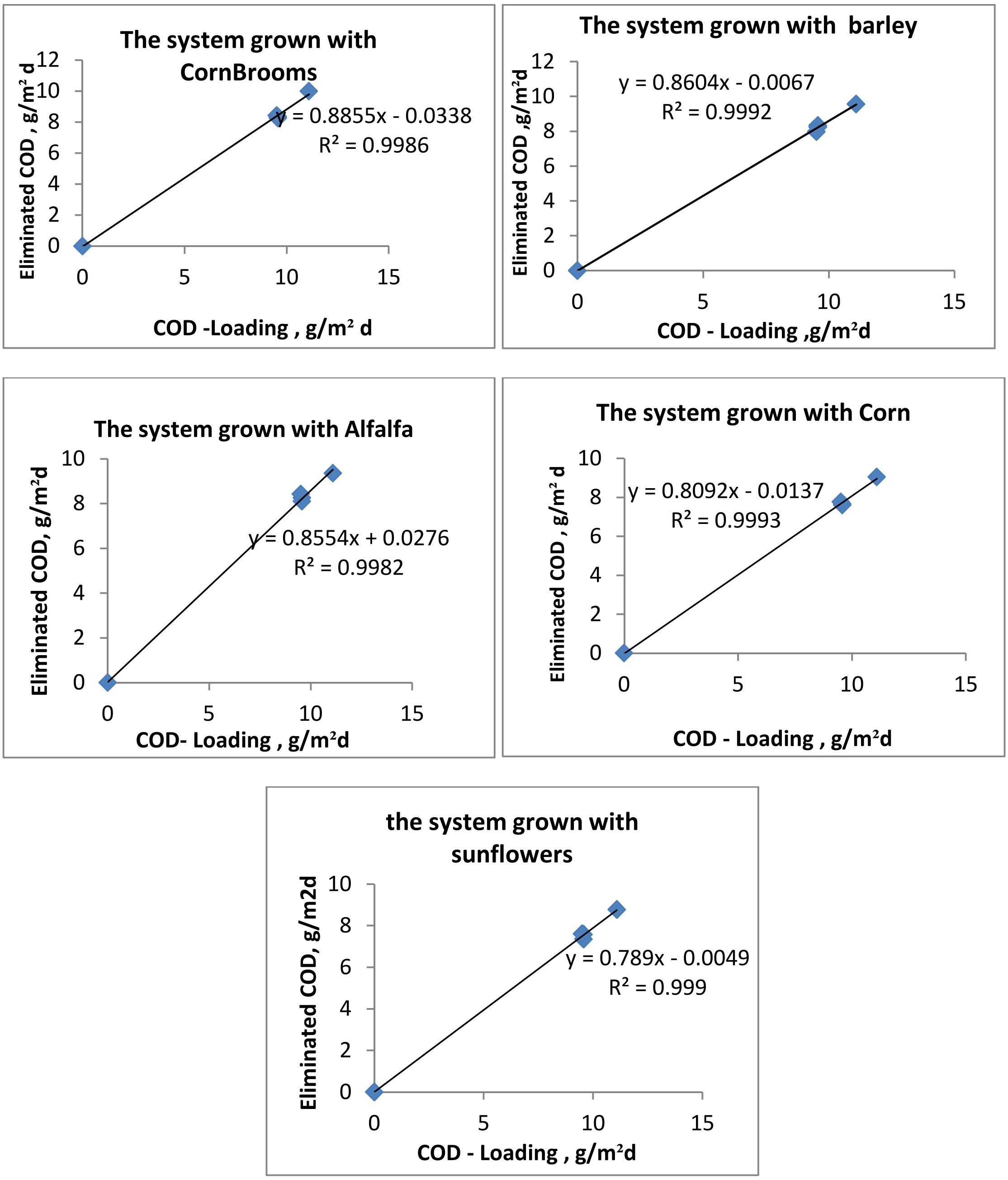
The figures (4-24) shows the relationships between the eliminated values of COD(g/ m^2d)are correlated to loading rates (g/ m^2d) for each system.

These figures show that the eliminated values of COD increase linearly with loading rates. High coefficient of determination (R^2=0.998-0.998) are observed.



Figures (4-24):Eliminated COD as a function of loading rate.

4.5. (TKN) Removal Performance:

TKN is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+) in the chemical analysis of wastewater. TKN concentration percent removal in experiment attained (64.9_68.1)%, with HLR = 4.18 g/m^2.d (41.8 Kg/ ha.d), (1526 g/m^2.yr).

There was no significant difference between the five systems that were planted with different types of plants.

Table 4-8 and figure 4-25 show the removal efficiency of TKN. The system achieved high removal efficiency with high HLR for TN with respect to the researches that were done before using constructed wetland systems.

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Table (4-8): Measured influent and effluent concentrations and removal efficiency of TKN through the operational period for the system (4 stagesVF- CWs) which was replicated 5 times using different types of plants.

TKN	Waste water	Corn Brooms (S_1)		Barley (S_2)		Alfalfa (S_3)		Corn (S_4)		Sunflowers (S_5)	
Time	**In**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal %**	**Out**	**Removal%**	**Out**	**Removal %**
July	165.8	57	65.6	59.6	64.1	62.2	62.5	62.2	62.5	62.2	62.5
August	150	44	70.7	47	68.7	47	68.7	47.5	68.3	47.5	68.3
September	160	50.8	68.3	54	66.3	57	64.4	57	64.4	56	65.0
Average	**158.6**	**50.6**	**68.1**	**53.5**	**66.2**	**55.4**	**65.1**	**55.6**	**64.9**	**55.2**	**65.2**
Standard deviation	8	6.5		6.3		7.7		7.5		7.4	

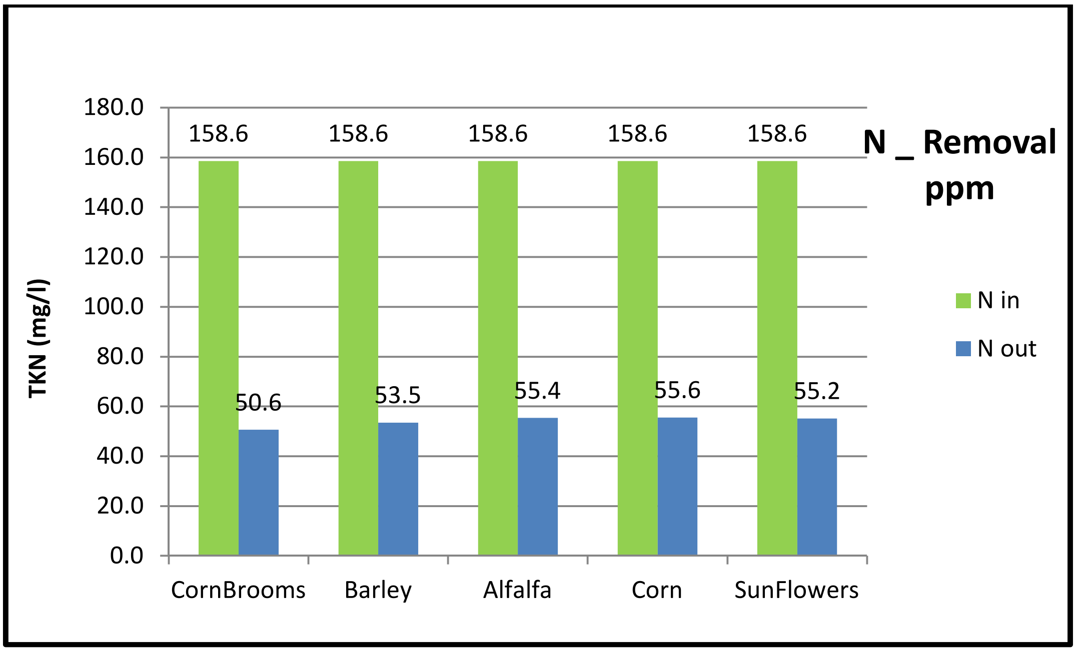

Figure (4-25): Removal efficiency of TKN.

Figure 4-26 shows the inflow concentration values of TKN and shows the outflow concentrations of TKN for the five systems grown with different types of plants during the operational period of the system, there was a little difference between the five systems.

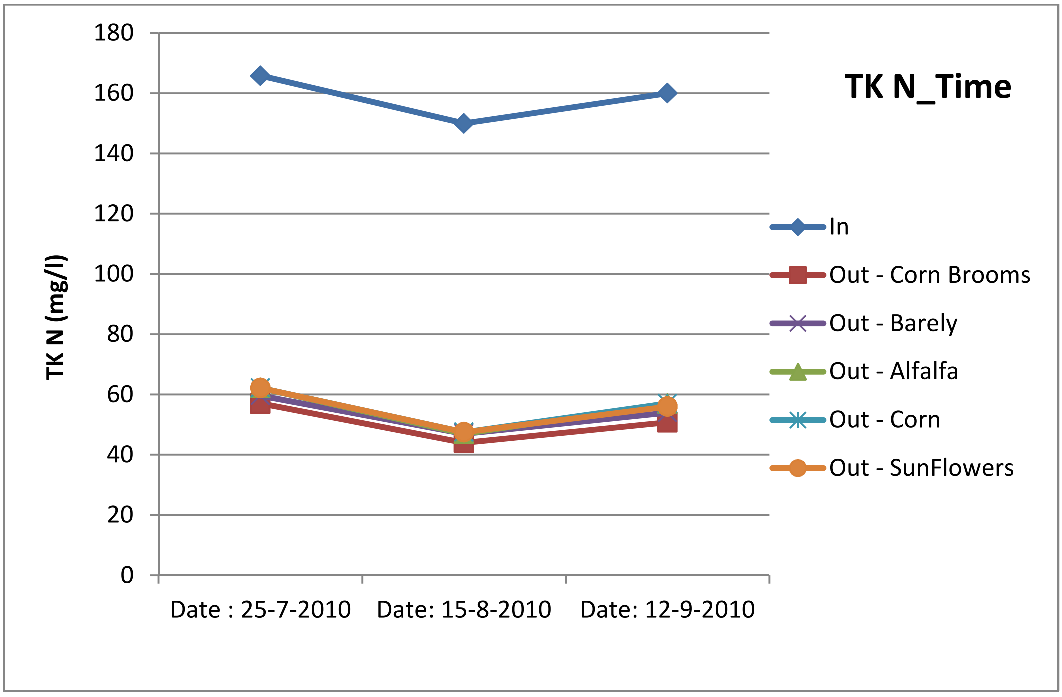

Figure (4-26): Removal efficiency of TKN during the operational period.

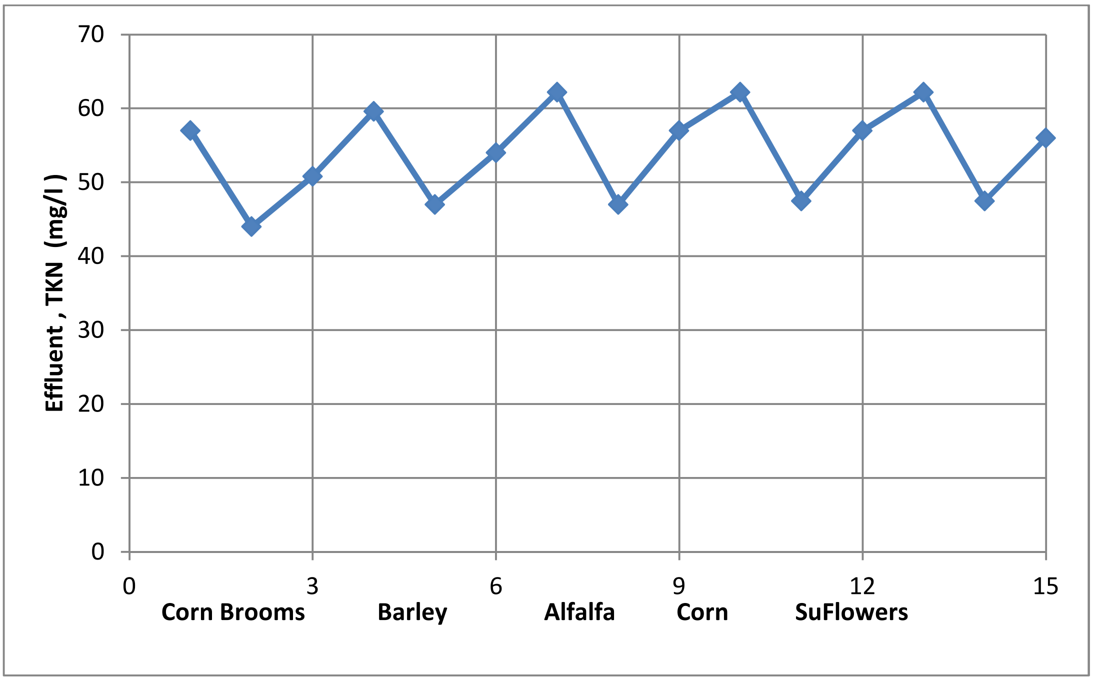

Figure (4-27): The effluent values of TKN through the operational period of the system which replicated five times using different types of plants

Figure (4-27) shows the effluent concentrations of TKN in the five systems which was nearly the same, the behavior of the five curves was nearly the same through the operational period of the system.

Table (4-9): TKN loading and eliminated values (g $m^{-2}d^{-1}$) for the (4stages VF-CWs) that replicated five times using different types of plants.

TKN		Corn Brooms	Barley	Alfalfa	Corn	Sun-flowers
	Load	Eliminated	Eliminated	Eliminated	Eliminated	Eliminated
July	4.51	2.96	2.89	2.82	2.82	2.82
August	4.08	2.88	2.8	2.8	2.79	2.79
September	4.35	2.97	2.88	2.8	2.8	2.83
Average	**4.31**	**2.94**	**2.86**	**2.8**	**2.8**	**2.81**

TKN loading rates in the system were high, it was 4.18g /m^2 d with comparison to the researches done before, and the eliminated values were high.

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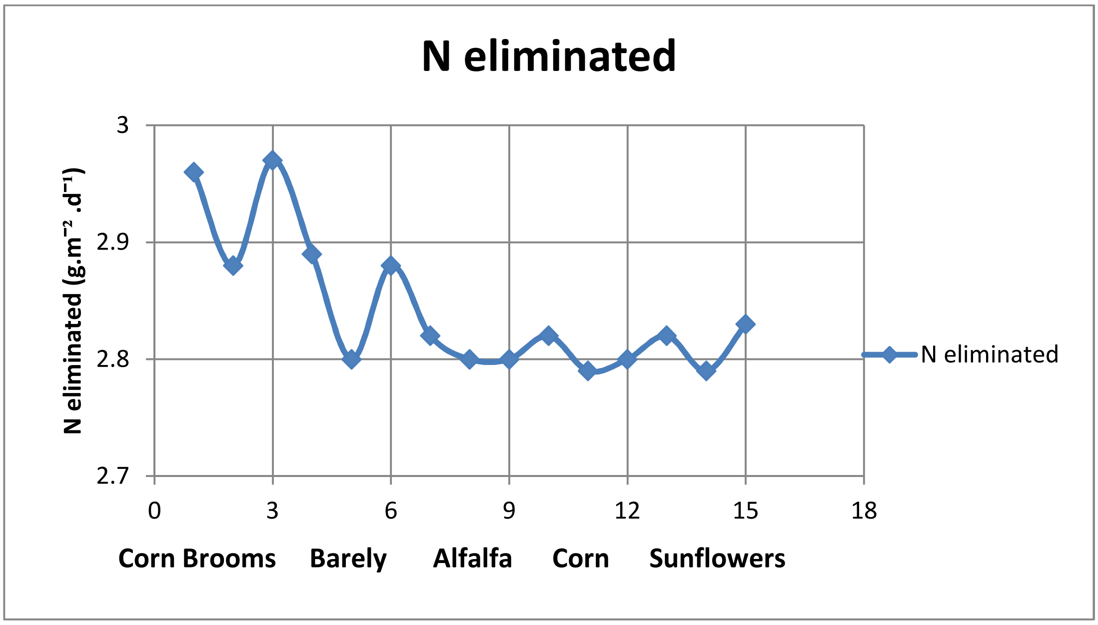

Figure (4-28):The eliminated values of TKN through the operational period of the system which replicated five times

Figure (4-28) shows the eliminated values for the five systems grown with different types of plants which was nearly the same, the difference was not significantit was little more in the system grown with Corn Brooms because the density of plant was more and the growth of plant also was more. The length of Corn Brooms reach (2.5-2.8) m, the length of Barley reach (.5-.7)m, the length of Alfalfa reach (.9-1.2)m, the length of Sunflowers reach (.9-1.3)m, the length of Corn reach (.9-1.5)m.

In the system replicated with Corn Brooms the growth of the plant was more and the density was more, so the effect of plant up take was more, but the deference was not significant it surrounding between (0.8-1.4)$gm^{-2}d^{-1}$.

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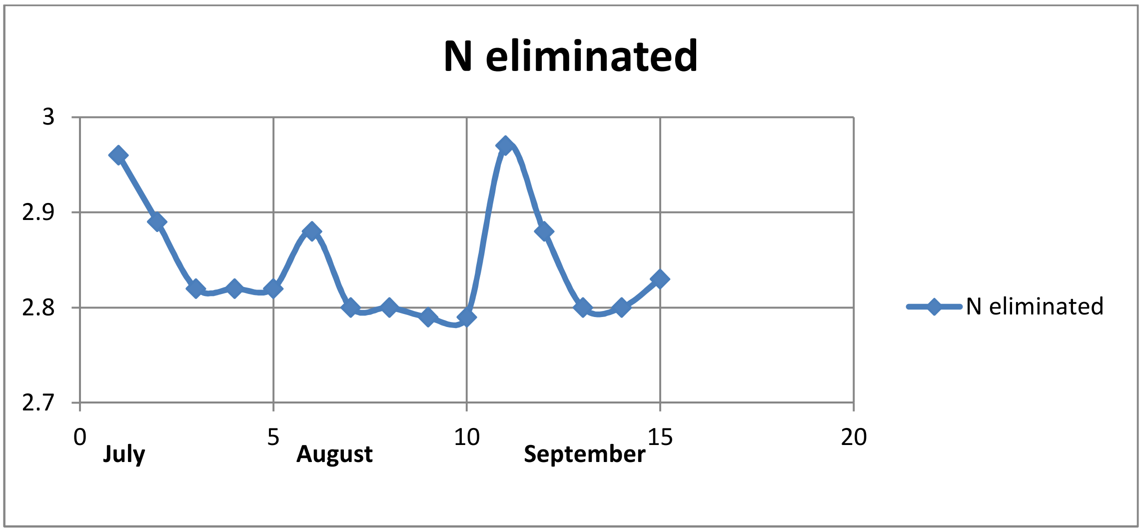

Figure (4-29):The eliminated values of TKN-TIME through the operational period of the system which replicated five times.

Figure (4-29) shows the eliminated values for the five systems that grown with different plants with time.

4.5.1 Removal Mechanism of TKN:

N removal process occurred through the nitrification process and little by plant uptake.[7]

Nitrification is the biological conversion of ammonium to nitrate nitrogen and it is a two-step process. Bacteria known as *Nitrosomonas* convert ammonia and ammonium to nitrite. Next, a bacteria called *Nitrobacter* finish the conversion of nitrite to nitrate.

The reactions are generally coupled and proceed rapidly to the nitrate form; therefore, nitrite levels at any given time are usually low.These bacteria known as “nitrifiers” are strict “aerobes,” meaning they must have free dissolved oxygen to perform their work. So nitrification occurs only under aerobic conditions at dissolved oxygen levels of 1.0 mg/L or more. At dissolved oxygen (DO) concentrations less than 0.5mg/L, water

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temperature affects the rate of nitrification. Nitrification reaches a maximum rate attemperatures between 30 and 35 C^{o}.

The temperature of the wastewater in this experiment was moderate between (22-26)C^{o}.[6]

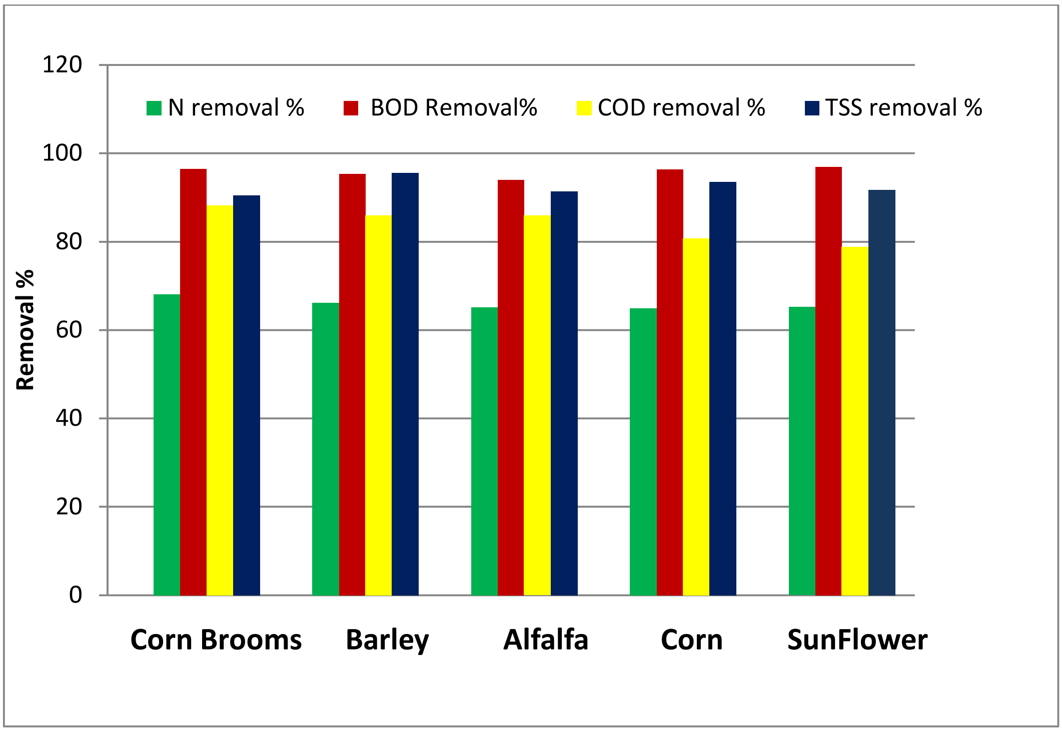

Figure (4-30): Comparison between the treated wastewater in 5 systems(4-stages VF constructed wetlands) that were planted with different types of plants.

Table (4-10):Average removal efficiency for the system that replicated five times using different types of plants.

The system replicated five times	Removal Performance Efficiency%				
	TSS	BOD	COD	TKN	TDS
Corn Brooms	90.5	96.5	88.2	68.1	158.2
Barley	95.6	95.4	86	66.2	134.1
Alfalfa	91.4	94	85.9	65.1	145
Corn	93.5	96.3	80.8	64.9	148.7
Sunflowers	91.8	96.9	78.9	65.2	149
Average removal for the pollutants	**92.6**	**95.8**	**84**	**65.9**	**147**

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Figure (4-31): Photo showing the wastewater before (right) and after (left) treatment process.

4.6. TDS & Cl performance:

There were other tests done for wastewater before and after treatment and the effect of treatment on these parametersare shown through the TDS, Cl and the tables (4-6 / 4-7).

There is an increase in concentration and this happened due to the evapotrasperation process; water evaporates so the concentration of TDS for the outlet increases.

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Table (4-11): Changes of TDS concentrations for the (4- stages VF CWs) which was replicated 5 times using different types of plants.

TDS	Waste water	Corn Brooms (S_1)		Barley (S_2)		Alfalfa (S_3)		Corn (S_4)		Sunflowers (S_5)	
Time	**In**	**Out**	**Increase %**	**Out**	**Increase%**	**Out**	**Increase%**	**Out**	**Increase%**	**Out**	**Increase %**
July	408.0	752.5	184.4	975.0	239.0	977.5	239.6	950.0	232.8	820.0	201.0
August	735.0	850.0	115.6	880.0	119.7	1010.0	137.4	830.0	112.9	950.0	129.3
September	710.0	1425.0	200.7	785.0	110.6	885.0	124.6	1047.5	147.5	1090.0	153.5
October	725.0	1050.0	144.8	817.5	112.8	865.0	119.3	1005.0	138.6	982.5	135.5
Average	**644.5**	**1019.4**	**158.2**	**864.4**	**134.1**	**934.4**	**145.0**	**958.1**	**148.7**	**960.6**	**149.1**
Standard deviation	158.0	297.4		83.6		70.3		94.3		111.2	

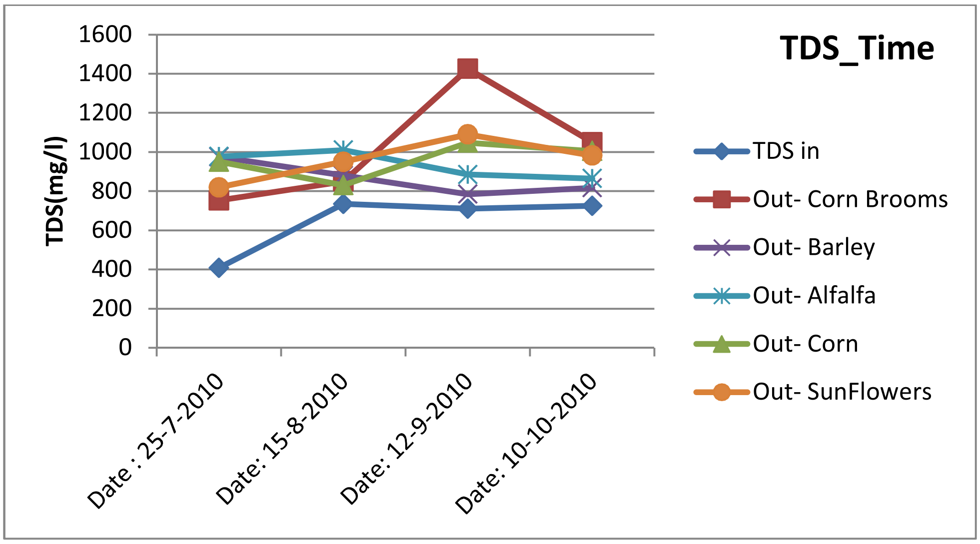

Figure (4-32): The behavior of TDS during the operation's period of the system.

Table (4-12): Changes of Cl concentrations for the(4- stages VF CWs) which was replicated 5 times using different types of plants.

Parameter	Type of plant	Outflow(ppm)	Increase (%)
CL Inflow = 113.4 (mg/l)	Corn Brooms	195	171.9
	Barley	173.7	153.1
	Alfalfa	195	171.9
	Corn	195	171.9
	Sunflower	187.9	165.6

Table (4-13): Summary of the results for the system replicated with different types of plants.

	Removal efficiency				
Parameter	**Expt. 1 Corn Brooms**	**Expt. 2 Alfalfa**	**Expt. 3 Corn**	**Expt. 4 Barley**	**Expt. 5 Sunflower**
TSS	90.8	91.7	97.1	95.9	92.3
BOD	96.4	94	96.2	95.4	96.9
COD	88.5	86.3	79.7	86.3	79.4
TN	65.6	62.5	62.5	64.1	62.5
TDS	163.9	150.2	115.9	139	121.5
CL	171.9	171.9	171.9	153.1	165.6

The removal performance for all pollutants was very good and promising , TKN still little high because its concentrations was high in the influent.

Chapter Five

Conclusions and Recommendations

In this thesis, the study concentrated on the treatment of wastewater using VF-Sub surface constructed wetland for 4-stages with high porosity in the media of the system that reached 45% and showed the effect of using this method on the treatment process. The researcher did tests for BOD, COD, N, TSS, TDS, and CL and showed the effect of the system in removing these pollutants by taking samples before and after the treatment process. The researcher got very good and promising results by using this treatment technique. The results obtained from this study point out a number of important conclusions.

5.1. The main conclusion of the study is summarized in:

1- High removal efficiency for all pollutants that were tested, BOD(94-96.9)%, COD (79.4-88.5) %, TSS (90.8-97.1) %, N (62.5-65.4)%.

2- We can apply this system for treatment of the wastewater in Palestinian Territories successfully in the areas where the effluent of wastewater does not exceed 3500 m3/day. This is a simple and cheep technology for the treatment of wastewater.

3- High removal with high porosity to prevent clogging in the future which means a more durable system

4- High removal of TN (62.5-65.5 %) with high HLR that reaches (4.18g.d/m2g/m2.d, 1525.7g/m2.yr).

5- There is no high or difference between the results among the five systems replicated with different types of plants.

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6- In the BOD values of treated wastewater there was a value higher than the other values which was the value of the system planted with alfalfa, and the researcher enucleated this by the lower concentration of DO for the wastewater in this system which was the lowest among the five systems. Whenever DO ismore in the system the removal process of BOD will be more. This lower value for DO occurred because the Alfalfa plant was planted and spread in a vertical and horizontal direction which laminated the aeration for the system from the atmosphere, so the BOD removal process was lowerThe other plants were planted vertically so that the aeration for the system from the atmosphere would be more, So when we choose the plants for constructed wetland systems we must take this point in our consideration.

7- COD removal is less in the systems that are planted with Sun Flower and Corn and the researcher enucleated this by the difference of intensity of the plant per area. When the density of the plant is more per area the removal of COD will be more and in these two typesthe number of plants per area is less than the rest of plants in the other systems.

8- In the TSS tests the system planted with Barley had the highest removal of TSS and the researcher enucleated this by the intensity of the roots for the plants, that is when it is spread more it would serve as a filter for the SS. The SS accumulates with time on it and then precipitate and falls down, thus, the removal process will be more.

9- In TDS and Cl tests of the outlet values in the treated wastewater are more, meaning that there was an increase in the concentration of

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these two parameters; this happened because of the evapotranspiration process which increased the concentration of these two parameters. However, these values of the outlet are still less than the specifications of the WHO for the reuse of the treated wastewater in the irrigation process.

10- We can use the treated wastewater irrigation purposes.

11- It is better to leave the first stage of this type of system(4-stage VF-constructed wetland) without growing any plant in it, because it may die from the high concentration of pollutants.

12- The advantage of using systems that contain several stages is that we can do maintenance works without the need to shut down the whole system.If we want to do maintenance in each stage we can operate the other three stages and the system still work until we finish our maintenance,this leads to a more practical and durable system.

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جامعة النجاح الوطنية
كلية الدراسات العليا

معالجة المياه العادمة باستخدام طريقة ال(Constructed Wetland)

(Four stages vertical flow sub-surface constructed wetland)

إعداد
مجد محمود مسعود

إشراف
أ. د. مروان حداد
د. نعمان مزيد

قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2011

معالجة المياه العادمة باستخدام طريقة

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إشراف

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د. نعمان مزيد

الملخص

نظام الأراضي الرطبة (Constructed Wetland) هو نظام مبتكر وغير مكلف كطريقة لمعالجة المياه العادمة لديه الامكانية لمعالجة المواد العضوية وغير العضوية في المياه العادمة.

نظام الأراضي الرطبة نظام بسيط في الانشاء وفي الصيانة وفي التشغيل، تحدثعمليات فيزيائية وكيميائية وبيولوجية في النظام لتعالج الملوثات الموجودة.

في هذه التجرية تم انشاء نظام أراضي رطبة مكون من أربع مراحل للمعالجة وهو من نوع التدفق تحت السطحي العمودي، هذه المراحل متصلة على التوالي لمعالجة المياه العادمة وللمرة الاولى يتم عمل مثل هذا النموذج لفحص فعاليته في معالجة المياه الملوثة .

تم وضع براميل بلاستيكية بارتفاع 90 سم وقطر 45 سم فوق بعضها البعض على دعائم حديدية تم عملها بارتفاعات مختلفة لكي يكون التدفق بواسطة الجاذبية الأرضية بدون ضخ.

في المراحل الأربعة للمعالجة يتدفق الماء غير المعالج من براميل بلاستيكية (استخدمت كخزان) إلى المرحلة الأولى في النظام والمياه التي تخرج من هذه المرحلة الاولى تدخل إلى المرحلة الثانية والمياه التي تخرج من المرحلة الثانية تدخل إلى المرحلة الثالثة والمياه التي

تخرج من المرحلة الثالثة تتدفق إلى المرحلة الرابعة والتي هي المرحلة النهائية في نظام المعالجة والتي تخرج منها المياه معالجة بصورتها النهائية .

هذا النظام تم تكراره خمس مرات بزراعة نباتات مختلفة وهي (ذرة مكانس، شعير، برسيم، ذرة، وعباد الشمس) على التوالي.

فترة الدراسة كانت عبارة عن ستة أشهر لذلك تم اختيار نباتات فصلية. نفس الوسط تم استخدامه في كل مراحل التجربة وكان عبارة عن ثلاث طبقات بعمق كلي يصل الى 50سم.

الطبقة الأولى من الأسفل كانت عبارة عن حصى كبير بعمق 13سم وحجمه ما بين (10–15) سم، الطبقة الثانية كانت عبارة عن طبقة بعمق 27 سم مكونة من حصى حجمه ما بين (1–2) سم، الطبقة الثالثة والأخيرة من فوق كانت بعمق 10 سم بنفس خصائص الطبقة الثانية لكنها ممزوجة مع رمل زراعي بنسبة (1:3) (حصى : رمل).

معدل النفاذية في هذا النظام يصل إلى 45% وهو مرتفع مما يعني نظام أكثر ديمومة وهذه الفراغات الكثيرة تساهم في تهوية النظام بصورة جيدة، تم عمل فحوصات كثيرة أثناء الفترة التشغيلية لفحص كفاءة النظام .

تم عمل فحوصات للـــ(BOD, COD, TSS, TDS, TKN, CL) وكانت النتائج في التجارب الخمسة لـــ (ذرة المكانس، شعير، برسيم، ذرة، عباد الشمس) كالتالي:

نسبة المعالجة للـــ (BOD) كانت على التوالي (96.5, 95.4, 94, 96.3, 96.9) % بمعدل تحميل على النظام 72.3 كغم/هكتاريوم.

وكانت نسبة المعالجة للـــ(COD) على التوالي (88.2، 86، 85.9، 80.8، 78.9)% بمعدل تحميل 99.3 كغم /هكتاريوم

نسبة المعالجة للـــ (TSS) على التوالي (90.5،95.6، 91.4، 93.5، 91.8)% بمعدل تحميل 41.1 كغم /هكتار يوم.

نسبة المعالجة للــ (TKN) على التوالي (68.1،66.2،65.1،64.9، 65.2)% بمعدل تحميل 41.8 كغم/هكتار يوم (معدل معالجة عالي مع معدل تحميل عالي).

التدفق في كل مرحلة كان 12 ملل/الدقيقة ومعدل زمن مكوث المياه في النظام يصل إلى 6 أيام و يستطيع معالجة 22 لتر/ اليوم م^2، وقد أثبت النظام كفاءة عالية جدا في معالجة المياه الملوثة بتكلفة قليلة كما أن هذا النظام يعمل بدون استخدام أي نوع من المضخات حيث انه يعتمد على الجاذبية (بدون أي ضخ.. طاقة مجانية) ويمكن تطبيقه في الأراضي قليلة الانحدار لتحقيق ذلك ويمكن تطبيقه في فلسطين بكل نجاح، كما أن تكلفة التشغيل والصيانة لا تذكر بالنسبة للأنظمة الأخرى، والنظام يتيح زراعة نباتات والتي من الممكن ان يكون لها عائد مادي على التجمع المطبق فيها النظام.