Purification of Anaerobic Digester Effluent through Intensive Production of Forage Crops in a Soilless Nutrient Film System

M.T. Alhattab, A.E. Ghaly

Department of Process Engineering and Applied Sciences, Dalhousie University, Halifax Nova Scotia, Canada

Abdel.ghaly@dal.ca

***Abstract*- Animal production is becoming more intensive and increases in efficiency have created a number of environmental and health problems. However, the efficiency of animal production and the quality of the environment must be tied together. A soilless nutrient film system was designed and constructed to purify the effluent from an anaerobic digester through the intensive production of forage crops. The system was composed of a growth chamber which consisted of three shelves each of which carried two hydroponic troughs. Each trough was divided into three compartments, each of which held a perforated tray used as a plant support medium. The lighting system was designed to provide an optimal level of illumination to the plants for growth. The effluent from the anaerobic digester was applied to the trays by means of fully automated wastewater application system. Tests showed that the system has the potential of producing 3.7 kg of forage per tray in 28 days and reducing the chemical oxygen demand from 23700 mg/L to less than 2220 mg/L (90.7%), the total solids form 23920 mg/L to less than 1900 mg/L (90.7%), the TKN form 3400 mg/L to less than 230 mg/L (93.8%) and NH_4-N from 520 mg/L to less than 110 mg/L (78.9%). Based on the results, an annual yield of 8 670 kg/ha of forage could be produced which is 35 times greater than the yield obtained from field production. The system also eliminates the need for land, fertilizer, harvesting and transport equipment and the storage facilities associated with field production of forage crops.**

Keywords*- *Purification; Wheat; Plant growth; Animal feed solids; COD; Nitrogen

I. INTRODUCTION

As with all types of agricultural production, animal production is becoming more intensive and increases in efficiency have created a number of environmental and health problems [1]. Thus, efficiency of animal production and the quality of the environment must be tied together. Techniques that will ensure adequate profit for the producer and an acceptable environment for the public are required.

Anaerobic digestion for energy recovery through methane production is used to minimize the pollution problem while producing gas which could be used for space and water heating of farm houses and animal barns, grain drying and heating greenhouses during the cold winter in Canada [2].

However, most farmers in Canada are reluctant to use the biogas technology due to the high capital investment required for the construction of large volume conventional anaerobic digesters and the high heating cost of the digestion system during the cold months of winter. Although, considerable technical improvements have been made by our research group ([2]-[7]) which resulted in appreciable cost reduction of the anaerobic digestion process, the process will only reduce (not eliminate) the solid content in the waste necessitating additional disposal and causing environmental problems [8]. Therefore, a system which would purify the waste and produce some usable by-products at the same time would be very valuable.

Several studies have been carried out to determine the feasibility of using the soilless technique to treat primary wastewater effluents while producing usable crops. Resh [9] reported that the growing of grains with a nutrient solution within an enclosed environmentally controlled chamber has become of commercial significance as a source of year round fresh grass feed for animals. Grains such as oats, barley, rye, wheat sorghum and corn were pre-soaked for twenty four hours prior to being placed in growing trays. The trays were manually watered with excess nutrient solution. After six days the grain had grown to 12-15 cm in height and was ready for harvesting and feeding to animals after 3 weeks.

Bouzoun and Palazzo [10] carried out an experiment in which reed canary grass was grown in the nutrient film technique treating primary sewage effluent during the winter months when the daily photoperiod was short and the temperature was low (10°C). The results showed that approximately 81% of the BOD, 75% of the total suspended solids, 30% of the total nitrogen and 21% of the total phosphorus were removed by the plants. The average daily uptake rates were 2.2 kg/ha of nitrogen and 0.3 kg/ha of phosphorus. The average nitrogen and phosphorus concentrations of the reed canary grass were 5.5% to 0.7%, respectively. The average concentrations of total digestible nutrients (TDN) and crude protein (CP) in the reed canary grass were 80.7% and 35.1%, respectively.

Ghaly et al. [11] examined the ability of alfalfa, white clover, oat, rye and barley to remove nutrients from aquaculture wastewater and their suitability as fish feed. They reported reduction in COD, NH4-N, NO3-N, NO2-N, phosphate and potassium of 54.7-91.0%, 56.0-91.5%, 82.9-98.1%, 95.9-99.5%, 54.5-93.6% and 99.6-99.8%, respectively. Oat, barley and rye grew well in this type of operation and can be used as fish feed.

Ghaly and Farag [8] tested cereal crops (wheat and barley) and two grasses (Trmothygrass and ochardgrass) for their ability to grow hydroponically and to remove pollution (nutrients) from dairy waste. The results indicated that wheat grew well and has a superior nutritional value as animal feed (higher digestible energy and higher contents of carbohydrates, fat, protein and minerals and less crude fibre compared to other crops).

Snow and Ghaly [12] examined the ability of hydroponically grown microphytes (water hyacinth, water lettuce and parrot's feather) for their ability to remove nutrients from aquaculture wastewater and their suitability as fish feed. The reduction in TS, COD, NH_4-N, NO_3-N, NO_2-N and PO_4-P were 21.8-48.04%, 71.1-89.5%, 55.9-76.0%, 49.6-90.6%, 34.5-54.4% and 64.5-76.8%, respectively. The effluent leaving the hydroponic system was suitable for reuse in aquaculture production system. However, the plants did not contain a sufficient amount of protein and fat to meet the dietary requirements of fish.

The aim of this study was to design, construct and evaluate a nutrient film system for purification of the effluent from anaerobic digester through production of a forage crop (animal feed) from wheat seeds.

II. Experimental Apparatus

The hydroponic system consisted of a frame and growth chamber, a hydroponic unit, a waste feeding unit, a cooling unit, a lighting unit, a supernatant collection unit and control unit.

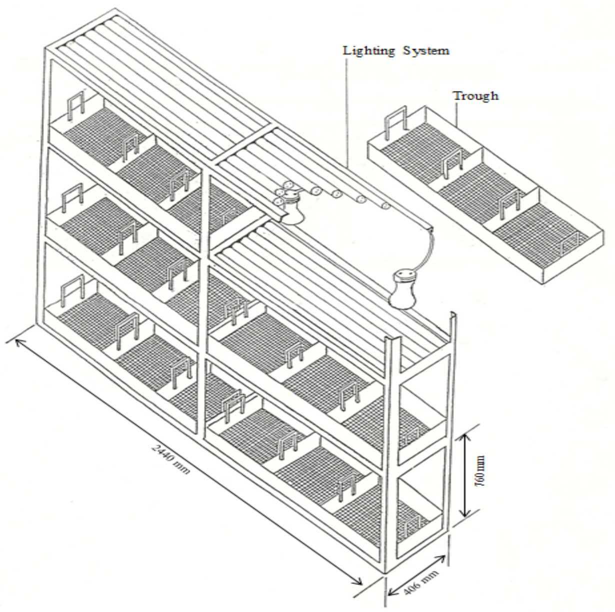

Fig. 1 The nutrient film system

A. Frame and Growth Chamber

The growth chamber was used to house the hydroponic and light units. The frame of the growth chamber was constructed of angle iron and measured approximately 244 cm (width) x 41 cm (depth) x 283 cm (height). It consisted of three shelves, 76 cm apart (Fig. 1). Each shelf was divided vertically into two cells by a 1.2 cm thick plywood sheet to provide a better control of light and feed. The two sides, back and top were covered with 0.6 cm thick plywood sheets. The front was covered with a plastic sheet to control the humidity inside the growth chamber and to provide visual observation of the growing plants.

B. Hydroponic Unit

The hydroponic unit consists of six growth troughs. Each trough was made of galvanized steel and was divided into three compartments (Fig. 2). Each compartment had a separate aeration system to provide oxygen to the immersed roots of the growing plants. It consisted of an "E" shaped perforated stainless steel tube of 0.6 cm outside diameter. Each lateral was 10 cm long and the main was 26.5 cm long. The tube was connected to a manifold which supplied air to 6 compartments. The air flow from the main supply to the manifold was controlled by a pressure regulator (Model 129121-510, Aro, Brayn, OH). Small screw valves mounted on each manifold were used to control the air flow to each compartment. Each compartment held a perforated germination tray which was used as a plant support medium. The supernatant from each compartment was collected separately through an outlet. The trays were positioned in the troughs so as to keep the plant roots in contact with the liquid portion of the waste. This was done by means of supports welded into the corners of each compartment, 5 cm below the edge of the trough.

C. Lighting Unit

The lighting unit (Fig. 1) was designed to provide approximately 430 hectolux of illumination per shelf. This was achieved by a mixture of fluorescent and incandescent lamps. Six 40 W cool white fluorescent lamps 122 cm in length were fastened above each trough. Four 100W incandescent bulbs were also mounted amongst the fluorescent tubes on each shelf. This gives a total of twelve fluorescent lamps per shelf and four incandescent ones.

D. Cooling Unit

A cooling unit was designed to continuously remove the heat produced by the lamps to avoid heating of the wastewater on the upper and middle shelves. For each of these two shelves, a 5 cm diameter PVC pipe (having 6 mm diameter holes spaced 6 cm apart and facing out) was placed under the backside of the troughs. Two metal blocks placed under each trough provided a 5 cm space between the trough and the lighting system of the shelf below it. A 5 cm diameter PVC pipe was attached vertically to the left side of the frame and acted as a manifold through which air was blown by means of a motor driven fan (Model AK4L143A type 821, Franklin Electric, Bluffton, IN).

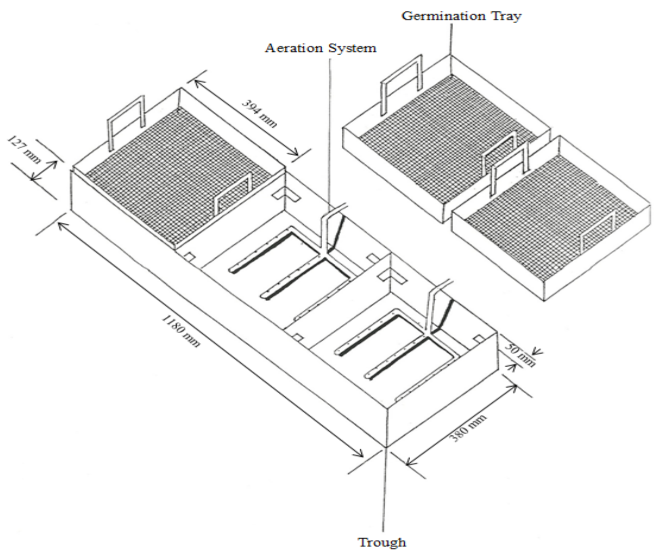

Fig. 2 The hydroponic unit

E. Wastewater Feeding Unit

The waste feeding unit consisted of a feed tank for storing the digester effluent, a pump to transfer the wastewater from the feed tank to the hydroponic systems, 6 solenoid valves for controlling and distributing the wastewater to the various troughs and 6 irrigation units for applying the wastewater onto the trays in the hydroponic unit. The feed tank (Fig. 3) had a capacity of 100 L and was constructed of Plexiglas cylinder (45 cm in diameter and 65 cm in height). Four 2.5 cm baffles were installed vertically along the inside wall of the tank to promote complete mixing. A mixing system was used to agitate the waste material in the tank. The mixing system consists of a motor (Model NSI-10RS3, Bodine Electric, Chicago, IL) mounted on the tank cover, a shaft and a 40 cm diameter impeller. The waste application system consisted of a pump, applicators and a control system. A variable speeds pump (Model 110-23E, TAT Pumps, Logan, OH) with a capacity of 138 cm^3/ revolution was used to transfer the wastewater from the feeding tank to the applicators through a manifold (PVC pipe of 2.5 cm outside diameter) connecting a system of feeding tubes to six wastewater applicators through six solenoid valves. The solenoid valves controlled the amount of wastewater fed to each compartment. Each wastewater applicator was fabricated from stainless steel pipe with holes punched along the lower edge to allow the wastewater to flow out. The wastewater entered the applicator at the center of the top edge to ensure a uniform distribution. To overcome the problem of clogging, a water line with six solenoid valves attached to the applicator was used to flush out the applicator after feeding periods.

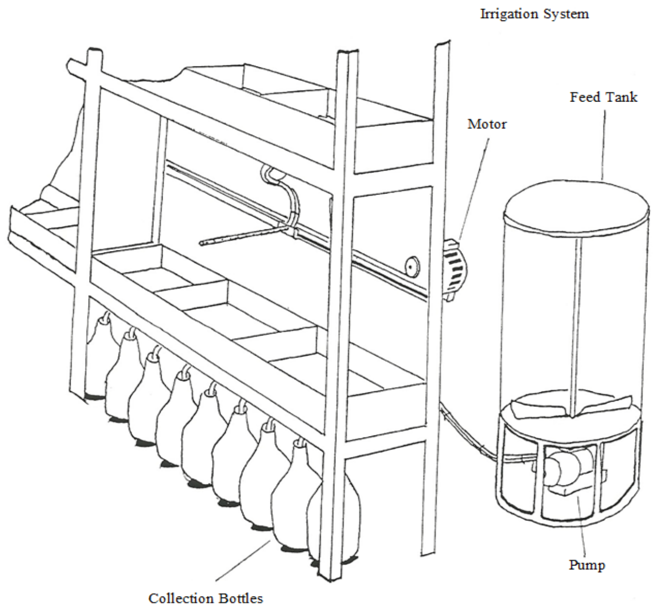

Fig. 3 The wastewater application unit

F. *Waste Collection System*

The supernatant from each tray was collected in a separate container (2.7 L each) located at the bottom of the system. The outlets were connected to plastic tubes of 1 cm outside diameter, which passed through a solenoid valve. Prior to feeding, the outlet tubes were closed using solenoid valves so that the fresh wastewater was retained in the compartments to allow time for the plants to assimilate the nutrients.

G. *Control System*

The wastewater application system was fully automated and consisted of a motor-driven pulley arrangement on each shelf to which the applicator tubes were attached. The motors (Sigma Model 20-3424SG-24007, Faber Industrial Technologies, Clifton, NJ) ran at 6 rpm and were controlled by an electronic circuit. The system was set up so that each applicator travelled 122 cm (three tray length). When a guide on an applicator hit a micro switch located at each end of the shelf, the motor stopped, waited a few seconds and then reversed and the applicator travelled in the opposite direction. This process continued for the designated feeding time, which was controlled by computer. A computer was used to operate and control the various components of the hydroponic system. A basic computer program allowed the user to configure the operating frequency and duration of the lighting, wastewater application and supernatant collection systems. The computer was connected to a data coordinator which had 24 digital output ports and 24 digital input ports. The digital output ports were connected to electronic circuits which were responsible for the lighting, cooling, wastewater application and supernatant collection systems.

III. EXPERIMENTAL PROCEDURE

A. *Selection of Crop*

Wheat was found to be a potential crop that can be grown hydroponically for wastewater purification and production of animal feed [8]. Wheat is an annual plant with flat blades and terminal spike. Its height may vary from 60 to 150 cm. The plant passes through a vegetative phase followed by a reproductive or fruiting period. Vegetative development stages include germination, root growth, tillering, joining, culm elongation and heading. When the wheat grain is exposed to moisture, water is absorbed and the grain swells. The embryo begins to push out both the coleorhiza and the coleoptile. The coleoptile turns upward to form the stem while the coleorhiza turns downward to form the primary root. Wheat will germinate between 4°C and 37°C, with 20-25°C being the optimum. The minimum moisture content for germination is 35-40% of the grain dry weight and germination is more rapid as moisture increases above this level which makes it suitable for hydroponic growth. Light is not of great importance in controlling wheat germination. Young wheat plants consist mainly of crown, roots and basal leaves. The wheat seeds were purchased from Walkers Livestock, Dartmouth, Nova Scotia.

TABLE I

SOME CHARACTERISTICS OF THE DIGESTER EFFLUENT USED IN THE STUDY

Item	Measured Value (mg/L)
Total solids	23 920
Volatile solids	17 820
Ash	6 100
Chemical oxygen demand	
Total chemical oxygen demand	23 700
Soluble chemical oxygen demand	9 060
Nitrogen	
Total kjeldahl nitrogen	1 400
Ammonium nitrogen	520
Nitrite nitrogen	0
Nitrate nitrogen	0
Other nutrients	
Phosphorous	206
Potassium	9 100

N:P:K ration 2.52:1:4.42

TABLE II
NUTRIENT REQUIREMENT AND AVAILABILITY

Nutrient	Required	Amount of waste applied	Available
	(mg/tray/day)	(ml/tray/day)	(mg/tray/day)
Nitrogen	52	150	75
		300	150
		450	225
Phosphorous	26	150	31
		300	62
		450	93
Potassium	17	300	137
		600	273
		900	410

TABLE III
PLANT HEIGHT RECORDS (CM)

Seed Rate (g)	Day	Manure Application Rate (mL/tray/day)		
		150	300	450
300	7	4.0	4.0	4.0
	28	37.5	37.5	37.5
	Increase (cm)	33.5	33.5	33.5
400	7	4.0	3.5	4.0
	28	39.0	38.0	39.0
	Increase (cm)	35.0	34.5	35.0
500	7	3.5	4.0	4.0
	28	40.0	39.0	39.0
	Increase (cm)	36.5	35.0	35.0

Day 7 = end of germination period.
Day 28= end of experiment.

TABLE IV
WEIGHT OF HARVESTED WHEAT PLANTS (KG)

Seed Rate (g)	Day	Manure Application Rate (mL/tray/day)		
		150	300	450
300	7	1.8000	2.0000	2.4000
	28	0.1836	0.2100	0.2400
	Increase (cm)	10.20	10.50	10.00
400	7	2.5000	2.7000	3.4000
	28	0.2500	0.2808	0.3604
	Increase (cm)	10.00	10.40	10.60
500	7	2.7000	2.9000	3.7000
	28	0.2808	0.3045	0.3604
	Increase (cm)	10.40	10.50	10.00

B. *Experimental Design*

Two factors were investigated in this study: (a) manure feeding rate at 3 levels (150, 300 and 450 ml/ tray/ day) and (b) seeding rate at 3 levels (300, 400 and 500 g/cell). The nitrogen, phosphorous and potassium required for wheat are 56, 28, 17 kg/ha ([13]-[15]), respectively. This gives a fertilizer N:P:K ratio of 10:5:3. The chemical analysis performed on the digester effluent is shown in Table I. The N:N:K ratio of the effluent was 12.6:5.0:22.1 (on Ammonium nitrogen basis). The wastewater is deficient in phosphorous but very rich in potassium. No attempt was made to add phosphorous as the application rates were chosen on the basis of phosphorous availability in wastewater. The amount of nutrient required and applied per tray per day was calculated as shown in Table II.

C. *Experimental Protocol*

The trays were filled with water and allowed to stand until the 7th day when most of the seeds had germinated. The wastewater was then applied on a daily basis and a 12-hour photo period was maintained throughout the experiment. The total volume of the effluent from each compartment was recorded at 3-day intervals and the trays were toped up as required with water. The height of the seedlings was recorded at 3 day intervals. Samples of the effluent form each compartment were taken every 3 days starting from the 7th day before the application of wastewater. The COD, solids and nitrogen analyses were performed on the samples. At the end of the experiment (28 days) all plants were harvested and the total weight was determined. The yield was calculated and plants were dried in an air forced drying oven (Isotemp oven, Model No. 655F, Fisher Scientific, Toronto, Ontario). The dry weight of the plants was determined. The solids, chemical oxygen demand (COD), ammonium, nitrate, phosphorous and potassium analyses were performed on the samples taken from the effluent to determine the reduction in pollution potential of the waste materials. The COD, solid, NO_3, NO_2, P and K analyses were carried out according to the procedures described in the Standard Methods for Examination of Water and Wastewater [16]. The nitrogen analyses were performed using Kjeltec Auto Analyzer (Model 1030, Toronto, Hoganas, Sweden).

IV. RESULTS

A. *Seed Germination and Plant Growth*

The results of the plant heights and weights are presented in Tables III and IV. Within 24 hours of placing the seeds onto the trays, they started swollen and began to germinate. By day 3, the radical and plumu broke through the seed coat and were visible in most seeds (60%). By day 5, the root mate started to develop. By the end of the germination period (7 days), the wheat plants grew to a height of 3-5 cm regardless of the seeding rate. The plant continued to grow and showed no sign of nutrient deficiency. They reached a height of about 35-40 cm by the end of the experiment (28 days).

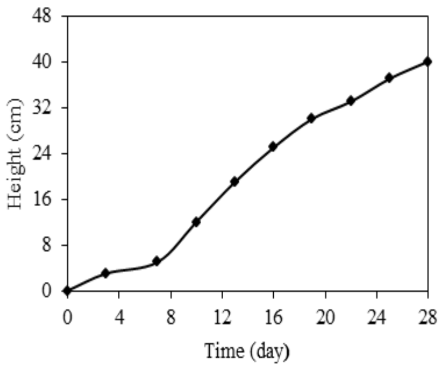

Fig. 4 Average crop height

(a) Above ground biomass

(b) Root mat

Fig. 5 Growth after 28 days

The increase in plant height is shown in Fig. 4. Fig. 5 shows the above ground and the root mat of the plants at the end of the experiment. The final weight (wet) of plants ranged from 1.8 kg/tray to 3.7 kg/tray. The dry weight was in the range of 8.9-10.5% (moisture content of 89.5-91.1%).

B. Effluent Quality

1) Total Solids

The results of the solid analysis are presented in Table V. At the end of the germination period, the total solids in the growing chambers were in the range of 150-200 mg/L, mostly in soluble form (products of enzymatic activities of plants and microbes). The solid concentration increased with time during the growth period due to the continuous addition of manure and reached 1940-4880 mg/L at the end of the growth period, depending on the manure application rate.

TABLE V
EFFLUENT TOTAL SOLIDS (MG/L)

Seed Rate (g)	Day	Manure Application Rate (mL/tray/day)		
		150	300	450
300	7	180	195	205
	28	1 940	2 860	4 000
	Increase (cm)	91.9	88.0	83.3
400	7	160	180	190
	28	2 120	3 140	4 550
	Increase (cm)	91.1	86.9	80.9
500	7	150	160	180
	28	2 220	3 720	4 740
	Increase (cm)	90.7	84.5	80.1

Digester effluent total solid = 23 920 mg/L

TABLE VI
EFFLUENT CHEMICAL OXYGEN DEMAND

Seed Rate (g)	Day	Manure Application Rate (mL/tray/L)		
		150	300	450
300	7	98	130	150
	28	1 120	1 630	2 030
	Increase (cm)	95.3	93.1	91.4
400	7	135	180	200
	28	1 630	1 800	2 290
	Increase (cm)	93.1	92.2	90.3
500	7	170	230	260
	28	1 900	1 900	2 380
	Increase (cm)	92.4	91.8	90.0

Digester effluent COD = 23 700 mg/L

TABLE VII
EFFLUENT TOTAL KJELDHAL NITROGEN (MG/L)

Seed Rate (g)	Day	Manure Application Rate (mL/tray/L)		
		150	300	450
300	7	12	12	12
	28	180	250	300
	Increase (cm)	94.7	92.6	91.2
400	7	13	13	13
	28	190	280	320
	Increase (cm)	94.4	91.8	90.6
500	7	14	14	14
	28	230	300	370
	Increase (cm)	93.8	91.2	89.1

Digester effluent NH4-N = 520 mg/L

2) COD

COD: The results of the COD analysis are presented in Table VI. The COD concentration of the effluent obtained at the end of the germination period was in the range of 92-350 mg/L. This continued to increase during the growth period due to the continuous addition of manure and reached 1120-2860 mg/L at the end of the experiment, depending on the manure application rate.

3) TKN

The results of the TKN analysis are presented in Table VII. The TKN of the effluent ranged from 12 to 16 mg/L at the end of the germination period. It continued to increase during the growth period reaching 180-340 mg/L at the end of the experiment, depending on the manure application rate.

TABLE VIII
EFFLUENT AMMONIUM NITROGEN

Seed Rate (g)	Day	Manure Application Rate (mL/tray/L)		
		150	300	450
300	7	2	2	2
	28	95	180	220
	Increase (cm)	81.8	65.4	57.7
400	7	3	3	3
	28	100	190	230
	Increase (cm)	80.8	63.5	55.8
500	7	3	3	3
	28	110	200	240
	Increase (cm)	78.9	61.5	53.8

Digester effluent NH4-N = 520 mg/L

TABLE IX
NITRATE NITROGEN CONCENTRATION (MG/L) AT THE END OF GERMINATION AND GROWTH PERIOD

Seed Rate (g)	Day	Manure Application Rate (mL/tray/day)		
		150	300	450
300	7	1.5	1.5	1.5
	28	5.5	5.6	10.1
400	7	1.6	1.6	1.6
	28	7.2	8.4	6.7
500	7	1.7	1.7	1.7
	28	7.1	4.4	10.1

Values are the average of three measurements
Initial nitrate concentration = 0 mg/L

4) NH4+-N

The results of the NH_4^+-N analysis are presented in Table VIII. The concentration of NH_4-N in the effluent at the end of the germination period was very low (2-3 mg/L). It continued to increase during the growth period till it reached 95-230 mg/L at the end of the experiment.

5) NO3-N

The results of NO_3-N analysis are presented in Table IX. The concentration of NO_3-N in the effluent at the end of the germination period was low (1.5-1.7 mg/L). It continued to increase during the growth period till it reached 5.5-10.1 mg/L at the end of the experiment, depending on the manure application rate.

V. DISCUSSION

A. Plant Growth and Yield

By the end of the germination period, most of the seedlings were 3-5 cm in height regardless of the seeding rate. A germination percentage of 89% was achieved in the hydroponic system. The manure application rate and seeding rate did not seem to have any significant effect on the height of the plants measured at the end of the experiment.

On the other hand, the weight of the harvested plants was significantly affected by the manure application rate and seeding rate, the higher the manure application rate and/or the seeding rate, the higher was the weight of the harvested crop. A treatment combination of a wastewater application rate of 450 mL/tray/day and a seeding rate of 500 g/tray gave the highest crop yield (3.7 kg of wheat forage per tray).

B. Nutritional Quality of the Plants

The composition of the hydroponically produced wheat forage was compared to that of several field forage crop (Table X). Not only the hydroponically produced wheat as a forage crop could be 35 fold of field production of forage crops, but it also had a superior nutritional value compared to the other forage crops. It had higher digestible energy, higher carbohydrates, fat, protein and mineral contents and less crude fibre. It provides some of the macro and micro nutrients (Sodium, Magnesium, Manganese, Iron, Copper, Boron, Selenium, Iodine and Cobalt) that are below the detection limits in the field forage crops. It also had much less sulfur content compared to those found in the forage crops. According to Barney [17] materials with total digestible energy (TDE) greater than 150 MJ/kg and crude protein (CP) greater than 15% is considered to be an excellent quality animal feed.

C. Effluent Quality

The solid and COD concentrations in the feed manure were 23920 and 23700 mg/L, respectively. The effluent TS and COD concentrations were affected by the manure application and the seeding rates, the higher the manure application rate and/or the seeding rate, the higher were the effluent TS and COD concentrations. The solid removal efficiency of the nutrient film system was in the range of 80.1-91.9% while the COD removal efficiency was in the range of 90.0-95.3%. Most of the solids and COD found in the effluent were in the soluble form because of the effective removal of the suspended solids by the root mat. It also appears that a good portion of the soluble solids may have consisted of some end products of the biological/enzymatic activities of the plants and microbes. Wheat seeds contain protein (13%), fat (7%), carbohydrate (70%) and elements (10%). The protein includes albumins, globulins, stutlins and prolamins of which albumins are water soluble. The fats include phospholipids, glycolipids and sterols all of which are water soluble. Starch is the carbohydrate most commonly found in wheat seeds, although hemicellulose, cellulose, raffinose, mucilage, pectins and a series of oligosaccharides may be present. Starch is found in the form of sugars which are important source of respiration during the germination period [19].

$$\text{Amylose} \xrightarrow{\alpha\ \text{amylase}} \text{Glucose} + \text{Maltose} \tag{1}$$

$$\text{Maltose} \xrightarrow{\alpha\ \text{glucosidase}} \text{Glucose} \tag{2}$$

Bewley and Black [20] showed that as seeds start to take up water during germination, there is a rapid leakage of ion, sugars, organic acids, amino acids, proteins and growth enzymes (such as gibberellins and cytokinins) into the medium, all of which affect the quality of the growth medium. However, little is known about the effects of these compounds on the processes of seed germination. Therefore, none of these compounds was measured in this study.

Both, the manure application rate and the seeding rate affected the concentrations of TKN, NH_4-N and NO_3-N in the effluent. The nutrient film system achieved TKN and NH_4-N reductions of 89.1-94.7% and 53.8-81.8%, respectively. The NO_3-N concentration in the influent was zero which increased in the effluent to 5.5-10.5 mg/L by the end of the experiment due to the process of nitrification. The low reduction of NH_4-N could be due to the production of NH_4-N in the nutrient film system through a series of biological transformation of organically bound nitrogen to inorganic nitrogen in the form of ammonium by heterotrophic microorganisms in a process called ammonification.

$$\text{Organic Nitrogen} \xrightarrow[\text{Microorganisms}]{\text{Heterotrophic}} NH_4\text{-N} \tag{3}$$

The heterotrophic microorganism responsible for ammonification belongs to the genera *Pseudomonas*, *Vibrio*, *Proteus*, *Serratia*, *Bacillus* and *Clostridium* [12]. The ammonia is then converted to nitrite (NO_2) and nitrate (NO_3) by bacteria from the genera *Microsomonas* and *Nitrobocter* in an aerobic process called nitrification [21].

$$NH_4^+ + 3/2\ O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + H_2O + 2H^+ \tag{4}$$

$$NO_2^- + 1/2\ O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \tag{5}$$

The continuous aeration and the pH of 7.2 facilitated the nitrification process in the nutrient film system. The pH was within the optimum range of 5.8-8.5 reported for the nitrification process [22].

Sooknah and Wilkie [23] showed that remediation of wastewater occurs by various physical, chemical and biological mechanisms including settling of suspended solids, ion exchange, chemical precipitation, chemical fixation and the uptake and transformation by microorganisms and plants. In this study, plants enhance the treatment of wastewater by filtering and adsorbing of suspended particulate matter by the root mat, uptake inorganic nutrient from water and acting as a medium for bacterial growth.

TABLE X
COMPARISON OF HYDROPONICALLY PRODUCED WHEAT FORAGE TO COMMONLY USED FIELD FORAGES IN FEEDING OF CATTLE IN CANADA

Item	Hydroponic Wheat	Field Forage Crop*				
		Alfalfa	Timothy grass	Blue grass	Orchard grass	Wheat pasture
Dry matter (%)	22	24	26	36	24	21
Carbohydrates (g Kg^{-1})	330	340	360	400	340	380
Crude fibre (g Kg^{-1})	65	270	310	270	300	180
Crude fat (g Kg^{-1})	93	30	38	39	40	40
Total digestible energy (MJ Kg^{-1})	187	157	167	180	170	187
Crude protein (g Kg^{-1})	288	190	110	150	140	200
Macroelements (g Kg^{-1})						
Phosphorus	9	2.7	2.8	3.0	3.0	3.6
Potassium	3 500	26	19	19.0	26	31
Calcium	2.9	13.5	4	3.7	3.3	3.5
Sodium	3.2					
Chloride	1 900	4	5.7	4.2	4.1	6.7
Microelements (mg Kg^{-1})						
Magnesium	3 040					
Manganese	98					
Iron	205					
Copper	6					
Zinc	299	18	28	25	21	21
Boron	0.8					
Selenium	0.1					
Iodine	0.5					
Cobalt	0.1	2 800	1 500	1 900	2 000	2 200
Sulphur	0.2					

*Perston [18]

TABLE XI
COMPARATIVE ANALYSIS OF SOILLESS AND SOIL CULTURES (RESH, [9])

Practice	Soil	Soilless
Sterilization of growing medium	Chemical fumigants Labour intensive Time required is lengthy	Steam, chemical fumigants, bleach and HCl Time needed is short Reduced labour cost
Plant nutrition	Highly variable Localized deficiencies Difficult to sample, test and adjust	Relatively stable Homogenous to all plants Easy to sample and test
Plant spacing	Limited by soil nutrition and available light	Limited only by available light Closer spacing is possible More efficient use of space results in greater yields per unit area
Weed control	Weeds require regular cultivation	No weeds
Disease	Soil-borne diseases and insects Animals can attach crop Crop rotation is used to overcome build-up of infestation	No diseases and insects in medium No attach by animals No need for crop rotation
Water	Plants are subjected to water stress due to poor soil-water relations, soil structure and low water-holding capacity Saline waters cannot be used Water is lost by percolation past the plant root zone and by evaporation from the soil surface	No water stress due to automation Reduced labour costs High saline water can be used Efficient water use No loss of water if managed properly
Fruit quality	Fruits are soft due to K and Ca deficiencies	Fruits are firm with a long shelf life
Sanitation	Organic wastes used as fertilizers onto edible portions of plants cause human diseases	No human disease causing organisms present on plants.
Transplanting	Need to prepare soil, uproot and transplant plants which leads to transplanting shock Difficult to control soil temperatures, disease organisms which retard or kill transplants	No preparation of medium is required Transplanting shock is minimized Medium temperature can be controlled No diseases present.
Plant maturity	Normal maturity	Plants can mature faster

Several aquatic field crops and macrophytes have demonstrated considerable potential for nutrient removal from various wastewaters and production of value added products such as animal feed and fish feed ([12], [24], [25]). Ghaly and Farag [8] used two cereals (wheat and barley) and two grasses (orchard grass and timothygrass) to purify dairy wastewater and reported removal efficiencies of 72.4, 88.6 and 60.8% for TS, COD and NH_4-N, respectively. Snow and Ghaly [26] used a hydroponic system to treat aquaculture wastewater with barley plants and reported reduction in TS, COD, NH_4-N, NO_2-N, NO_3-N and PO_4-P of 52.9, 72.3, 82.3, 97.9, 78.9 and 6.3%, respectively. Snow and Ghaly [12] used water hyacinth, water Lettuce and Parrot's feather to treat aquaculture wastewater and achieved reduction in TS, COD, NH_4-N, NO_2-N, NO_3-N and PO_4-P of 21.4-48.0%, 71.1-89.5%, 55.9-76.0%, 49.6-90.6%, 34.5-54.4% and 64.5-76.8%, respectively. The removal efficiencies achieved in this study was comparable to those reported in the literature.

D. Advantage of Soilless Production System

The soilless hydroponic system will eliminate the need for land, fertilizer, harvesting and transport equipment and storage facilities associated with field production of forage crops. The other advantages of the soilless production system are presented in Table XI [9].

The average dairy cow (590 kg) will eat about 2.5% of its weight grass [27]. This amounts to approximately 15 kg of grass/cow/day (450 kg/cow/month). At a monthly production rate of 3.7 kg/tray, about 75 kg wheat forage/ m^2 of floor area will be produced per month using the hydroponic system. Thus, 6 m^2 will be required to produce feed for each cow, which could be divided into 30 compartments (0.2 m^2) with one compartment planted every day to provide continuous production of the forage crop on a daily basis. Based on the results obtained from this study, a yield of 8670 tonnes per hector per year is possible. This is 35 times greater than the obtainable yield form field production of conventional forage of 245 tonnes per hector per year.

Using forage will have a positive impact on milk production. Coureur et al. [28] tested milk production with diets of grass, grain, hay, silage and found that the group of cows fed on the grass diet increased their milk production by +0.21 kg/day for every 10% of grass added into the diet. The grass diet was also reported to have increased the nutritional value of butter.

VI. CONCLUSION

The nutrient film system which developed in this study produced a kind of wheat forage in 28 days (from germination to harvest). The productivity of the system is 35 times higher than the conventional felid production method. The system was capable of purifying partially treated animal waste. The seeding rate and manure application rate affected the concentration of total solids, COD, TKN, NH_4-N and NO_3-N in the effluent. The solid, COD, TKN, and NH_4 removal efficiencies were 90.7, 92.4, 93.8, and 78.9%, respectively.

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