Performance of a water hyacinth (*Eichhornia crassipes*) system in the treatment of wastewater from a duck farm and the effects of using water hyacinth as duck feed

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Received 3 July 2007; revised 15 September 2007; accepted 26 October 2007

Abstract

Nowadays, intensive breeding of poultry and livestock of large scale has made the treatment of its waste and wastewater an urgent environmental issue, which motivated this study. A wetland of 688 m² was constructed on an egg duck farm, and water hyacinth (*Eichhornia crassipes*) was chosen as an aquatic plant for the wetland and used as food for duck production. The objectives of this study were to test the role of water hyacinth in purifying nutrient-rich wastewater and its effects on the ducks’ feed intake, egg laying performance and egg quality. This paper shows that the constructed wetland removed as much as 64.44% of chemical oxygen demand (COD), 21.78% of total nitrogen (TN) and 23.02% of total phosphorus (TP). Both dissolved oxygen (DO) and the transparency of the wastewater were remarkably improved, with its transparency 2.5 times higher than that of the untreated wastewater. After the ducks were fed with water hyacinth, the average daily feed intake and the egg-laying ratio in the test group were 5.86% and 9.79% higher, respectively, than in the control group; the differences were both significant at the 0.01 probability level. The egg weight in the test group was 2.36% higher than in the control group (*P* < 0.05), but the feed conversion ratios were almost the same. The eggshell thickness and strength were among the egg qualities significantly increased in ducks fed with water hyacinth. We concluded that a water hyacinth system was effective for purifying wastewater from an intensive duck farm during the water hyacinth growing season, as harvested water hyacinth had an excellent performance as duck feed. We also discussed the limitations of the experiment.

Key words: water hyacinth (*Eichhornia crassipes*); duck farm; constructed wetland; chemical oxygen demand (COD); treatment effect; egg-laying ratio; egg quality

Introduction

In recent decades China’s livestock and poultry breeding developed rapidly, with its production pattern transformed from a traditional household sideline to the scale of a regional enterprise. It is no longer a self-sufficient and self-contained natural economy, but an important contributor to the whole rural economy. This is particularly true of duck-raising. Apart from this transformation of the production pattern to modern farming, an industrialized pattern is also developing that integrates farming, processing and selling. However, this rapid development has caused environmental pollution issues. Unlike the traditional method of household-raising, which is environmentally sound because its wastes could be used as organic fertilizer, modern livestock and poultry breeding farming produces far more wastes at a higher concentration. The situation is exacerbated by the disconnection between the livestock system and the cropping system. If left untreated, the wastes will damage the ecosystem and the environment, and hinder the sustainable development of the livestock industry. This is the reason that drives many scientists and research institutes in their pursuit of appropriate wastewater treatment techniques (Stone et al., 2004).

Constructed wetlands (CW) are a new wastewater treatment technology developed over the past three decades. At present, constructed wetlands are used to treat municipal effluent, industrial wastewater, acid mine drainage, agricultural wastewaters and other types of wastewater (Vymazal, 1998). Initially their main application was in the treatment of municipal effluent and industrial wastewater. More recently, several studies explored their role in treating wastewater discharged from poultry or livestock farms (Knight et al., 2000; Hunt and Poach, 2001). This technology is now applied in at least 26 States across the USA (Hunt and Poach, 2001).

Aquatic plants, essential components of the CW, play an important role in the treatment process (Greenway, 2004). Jing et al. (2001) pointed out that the plants in wetlands determine their treatment capacity because plants, apart from absorbing nutrients, promote physical, chemical and
microbial processes (Brix, 1997). The aquatic plants often seen in wetlands are herbaceous plants with rapid growth, a high biomass and strong absorptive abilities. Emergent plants, such as reed (Phragmites communis), bulrush (Typha latifolia), rush (Juncus effusus) and calamus (Acorus calamus), are also frequently chosen as research subjects in wetlands. However, with regard to the ability of removing nutrients by absorption, emergent plants are generally regarded as less capable than floating plants, such as water hyacinth (Eichhornia crassipes), because floating plants have an astonishing reproductive rate and their roots can directly absorb nutrients and elements from the wastewater and filtrate and absorb the suspended particles. Research over the past few decades has proved that some floating plants, such as water hyacinth (E. crassipes), water lettuce (Pistia stratiotes), pennywort (Hydrocotyle umbellata), duckweed (Lemna minor), water peanut (Alternanthera philoxeroides) and lidded cleistocalyx (Cleistocalyx operculatus), have the greatest effects on purifying eutrophic water (Yang et al., 2001; Vaillant et al., 2003; Sooknah and Wilkie, 2004). Therefore, water hyacinth and duckweed were applied in the treatment of pig and dairy manure-based wastewater (Busk et al., 1995; Costa et al., 2000).

Among floating aquatic plants, water hyacinth has been extensively studied at the laboratory and pilot levels and evaluated on a large scale for removing organic matter from wastewater (Casabianca et al., 1995). Although water hyacinth is an invasive plant in most countries all over the world, it is also used as a resource in agricultural production and waste management (Gunnarsson and Petersen, 2007). Moreover, water hyacinth propagates and grows very rapidly. The plant reproduces itself in five days under favorable conditions and can also capable of generative propagation through producing seeds (Wu et al., 2001). What’s more, water hyacinth can survive extremely eutrophic water, according to Sooknah and Wilkie (2004) who evaluated the potential of water hyacinth, pennywort and water lettuce for improving the water quality of anaerobically digested flushed dairy manure wastewater. They found that, in untreated dairy manure wastewater (total chemical oxygen demand 2,010 mg/L), growth of water hyacinth was inhibited and both pennywort (H. umbellata) and water lettuce (P. stratiotes) failed to grow. In a 1:1 dilution of dairy manure wastewater, all three plants grew successfully. However, growth of pennywort and water lettuce was limited while the growth of water hyacinth was robust. Accordingly, in this study we used the CW technology to explore the treatment effects of the plant water hyacinth on the duck manure-based wastewater. The water hyacinth was chosen because it is well-known for its adaptability, alkaline resistance, fertilizer resistance and tolerance to diseases. Water hyacinths sustain a natural growth in waters with a pH of 9. Apart from improving water quality and lessening water pollution, they also serve as a high quality aquatic feed and green mature.

Chemical analysis has shown that water hyacinth is rich in nutrition, with organic matter accounting for 80.1% of the dry matter, and in particular, the crude protein content is 12.4% and includes many amino acids such as lysine and methionine that animals need. The ash and crude fat content are 19.9% and 4.72%, respectively, it is a source of many kinds of vitamins, conforms to completely to feed requirement, and is a good green fodder for animals (Lindsey and Hirt, 1999). Abdelhamid and Gabr (1991) evaluated the use of water hyacinth as a feed for ruminants and also studied its nutritional effects. In the study, we used water hyacinth harvested from the wastewater treatment pond as duck feed to explore the effects on the egg-laying ratio and egg quality.

1 Materials and methods

1.1 Experimental site and design

The egg-duck farm of Lihong Poultry Ltd. in Deqing County, Zhejiang Province, China, is among the largest in Zhejiang Province, China. Its total area is 53,360 m², of which 13,340 m² is covered by water. Its annual holding of egg ducks and breeder ducks reaches 100,000 and their manure is directly discharged into the pond where they live, making the water high in nutrients and poor in quality (Fig.1). This practice undermines the ducks’ health and their egg production rate as well as the quality of the eggs. Moreover, nutrient-rich wastewater is discharged from the pond to the nearby rural river systems, causing environmental pollution in the local ecosystems.

A constructed wetland of 688 m² was built on the farm (Fig.2) to test the role of water hyacinth in treating the nutrient-rich duck pond water.

To develop the duck farm in a sustainable way, an integrated approach was used in our experimental design: the wetland plant, water hyacinth, was reused as duck feed. The process of wastewater treatment with water hyacinth and its recycling utilization in our study is illustrated in Fig.3.

1.2 Materials

The water hyacinths in the CW were transplanted from nearby waterways and initially covered 393 m², about 59% of the total CW water surface area.

Two thousand 200-d-old commodity Shao ducks were
randomly divided into two groups: the experimental group and the control group (CK). Each group included 4 replications, each with 250 Shao ducks. The control group was fed the basic date grain, while the experimental group was fed the basic date grain, at the same time as added fresh water hyacinth from the constructed wetland. The roots of the fresh water hyacinth were removed so that only the leaves and stems of water hyacinth were used as duck feed, and mixed with the basic date grain.

1.3 Methods

The experiment started on 20 September 2005, and ran for a 40-d period. Water samples from the duck pond and the CW were collected and analyzed every 4 d. The analyzed indicators included chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), dissolved oxygen (DO) and transparency. COD was measured by the dichromate method, transparency by a Secchi disc and DO by an electrochemical probe. In measuring TP and TN, the water samples were first diluted, and then TP was determined by the ammonium molybdate spectrophotometric method and TN by the alkaline potassium persiflange digestion-UV spectrophotometric method.

The experiment on feeding egg ducks with water hyacinth ran from November 1 to November 30, 2005 for 30 d. Each duck of the experimental group was fed only 50 g per day of fresh water hyacinth. For each group, we recorded the feed intake quantity, the egg-laying quantity and the total egg weight. Every 10 d, we randomly selected 40 eggs from each of two groups, a total of 3 times, and measured the egg weight, egg shape index, egg shell thickness, the egg shell strength, Haugh units, relative weight of the egg shell and egg-yolk color. Egg shell strength was measured by an INSTRON materials testing machine produced in the USA; and the egg-yolk color was measured by comparison with a Roche color fan produced in Switzerland.

1.4 Analysis of experimental data

The data were analyzed by SPSS software with one-way variance analysis (ANOVA).

2 Results and discussion

The overall effects of the CW treatment on the wastewater are shown in Table 1. Through comparing indicators before and after treatment, we concluded that the water quality was improved to a safe level. The ANOVA results are shown in Table 2 with COD, TP, TN and transparency as indicators.

### 2.1 Removal rate of COD

The COD was reduced from 270 to 96 mg/L with a removal rate of 64.44% (Table 1).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Before treatment (mg/L)</th>
<th>After treatment (mg/L)</th>
<th>Removal rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>270</td>
<td>96</td>
<td>64.44</td>
</tr>
<tr>
<td>TP</td>
<td>8.86</td>
<td>6.82</td>
<td>23.02</td>
</tr>
<tr>
<td>TN</td>
<td>12.72</td>
<td>9.95</td>
<td>21.78</td>
</tr>
<tr>
<td>DO</td>
<td>&lt; d.l.</td>
<td>2.14</td>
<td>–</td>
</tr>
<tr>
<td>Transparency</td>
<td>9</td>
<td>22.25</td>
<td>–</td>
</tr>
</tbody>
</table>

–: It is too low to be detected, d.l.: below detection limits.
Table 2  One-way variance analysis (ANOVA) results

<table>
<thead>
<tr>
<th>Item</th>
<th>COD</th>
<th>TP</th>
<th>TN</th>
<th>Clarity</th>
<th>F-value</th>
<th>$F_{0.01}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40.77*</td>
<td>19.16*</td>
<td>18.38*</td>
<td>41.16*</td>
<td>8.10</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at 0.01 level; $F_{0.01}(1, 20) = 8.10$.

there was a sharp drop of the COD during the first 12 d of the experiment due to the comparatively high temperature, which guarantees a rapid growth of water hyacinths (Fig.5). As demonstrated in Fig.6, the coverage of water hyacinths on day 16 was 1.5 times higher than the initial coverage. After that, the growth of water hyacinths slowed, along with the decline of COD, which even rose slightly at one time. The explanation for this is that plants transport oxygen, thereby increasing the removal of organic matter by micro-organisms in sediments or on the surfaces of the plant rootstocks (Reddy and D’Angelo, 1997). However, if plants die, their decomposition consumes oxygen, which counteracts the reduction of COD, so the water hyacinths should be harvested regularly. In this experiment, the harvested water hyacinths were used to feed ducks, thus completing a recycling process. Fig.4 also shows the COD in the duck pond. There is no significant change of COD during the experimental period, with its value remaining near 250 mg/L. The statistical analysis found that the $F$-value was 40.77, which meant a significant COD difference (at the 0.01 level) between the water in the CW and the pond (CK).

2.2 Removal of TP and TN

Table 1 shows that the CW removal rates of TP and TN were 23.02% and 21.78%, respectively, far lower than that of the COD. However, when compared with the TP and TN in the duck pond water (Fig.7), the difference was significant (Table 2). The TP and TN of the duck pond rose to 11.67 and 14.94 mg/L, while those of the CW were 6.62 and 9.95 mg/L, respectively. Although this was a sharp decline, these TP and TN levels were still high. This was related to the treatment capacity of the CW. With the temperature falling, water hyacinths as well as other biological organisms, especially microbes, slowed their activities and growth, resulting in less effective removal of TP and TN.

Other researchers reported similar findings: while the CW is very efficient in removing pollutants from wastewater, especially in terms of COD, BOD (biological oxygen demand), SS (suspended solids) and bacteria, they were not reliable in removing N and P (Mitsch et al., 2000; Guo et al., 2003). Liao and Lou (2002a, 2002b), in their research on the treatment effects of Vetiveria zizanioides and Cyperus alternifolius on pig manure, reported that the removal rates of TN and TP by the CW were related to the seasons, with a higher removal rate in spring than in autumn, bearing out the findings of this experiment, which was implemented in autumn.

2.3 Changes in DO and transparency

The DO index indicates the amount of oxygen dissolved in water. It approximates zero in heavily polluted water, an adverse environment for aquatic biology. Table 1 shows that the inflow of the CW was severely polluted, with the DO near zero. However the treatment water, which reached a maximum DO of 2.14 mg/L, met the Chinese standard for the V level of surface water environmental quality (Chinese National Environmental Protection General Bureau, 2002), which is $DO \geq 2$ mg/L.

Figure 8 shows the dynamic changes in the DO. Like the COD, the DO rose sharply in the first 12 days of the experiment, which can also be accounted for by the growth of the plants because the level of DO is correlated with the photosynthesis of aquatic plants and with the respiration of aquatic organisms. In wastewater treatment systems, oxygen plays an important role owing to its direct involvement in the treatment of a number of pollutants (Hiley, 1995).

Transparency means the amount of light permeating...
water. The Secchi disc has long been used to determine the water transparency, which is an important indicator describing the optical characteristics of water and reflects the water’s clearness or turbidity. The transparency also serves as a significant index to assess the nutrient status of water; the higher the value, the less nutrient-rich is the water and the fewer phytoplankton, and vice versa. The normal range of transparency is from 25 to 40 cm; lower than 25 cm being deemed as excessive and higher than 40 as deficient.

As shown in Fig. 9, there is a big difference between the transparency of wastewater before and after treatment, from 9 to 22.25 cm (even peaking once at 26.25 cm). In the duck pond (CK), the maximum transparency value of the pond water was 9 cm and then it fell continuously. These differences could be attributed to the aquatic plants in the CW, which filter particles, trap sediments and provide a surface area for microbe growth (Greenway, 2004).

2.4 Effects on egg ducks with water hyacinth as duck feed

2.4.1 Effects on egg production performance with water hyacinth as feed

The effects on egg production performance with water hyacinth as duck feed are shown in Table 3. The feed intake of the experimental group was 5.86%, significantly greater \((P < 0.01)\) than the control group (CK). The egg laying rate of the experimental group was 9.79%, also significantly greater \((P < 0.01)\) than the control group (CK). The egg weights of the experimental and control groups were significantly different \((P < 0.05)\) at 65.59 and 64.08 g, respectively. The feed conversion ratios of the two groups were not significantly different.

Because feeding egg ducks with water hyacinth enhanced the daily feed intake, it increased the level of feed digestion and utilization, thus increasing their egg production performance. Water hyacinth is a rich source of protein, vitamins and minerals and, in particular, it contains unknown nutrition factors, which may stimulate the duck’s reproductive function. If the ducks are fed with water hyacinth every day, it not only promotes the egg laying rate, but also increases the feed utilization rate (Fan, 2003). In this experiment, the egg laying rate and egg weight were significantly increased after the egg ducks were fed with a quota of water hyacinth. Many reports indicated that, along with enhancing the daily grain crude protein level, egg production performance also increased a certain amount (Nardone and Valfre, 1999). In our

<table>
<thead>
<tr>
<th>Index</th>
<th>Average value</th>
<th>Increase ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed intake (g)</td>
<td>176.63±3.82A</td>
<td>166.85±2.18B</td>
</tr>
<tr>
<td>Egg laying rate (%)</td>
<td>89.75±3.22A</td>
<td>81.75±2.24B</td>
</tr>
<tr>
<td>Egg weight (g)</td>
<td>65.59±0.52A</td>
<td>64.08±0.93B</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>2.87±0.14A</td>
<td>2.97±0.09A</td>
</tr>
</tbody>
</table>

* The different capital letters in the same row mean significant at the 0.01 probability level. The different small letters in the same row mean significant at the 0.05 probability level. The same letters in the same row means no significant difference.
experiment, the experimental group had a greater feed intake than the control group. Moreover, the water hyacinth had a higher crude protein content than the general diet, so the ducks received more crude protein to promote their egg production performance than the control group.

2.4.2 Effects on egg quality with water hyacinth as feed

The effects on egg quality with water hyacinth as duck feed are shown in Table 4. Eggshell thickness and intensity were significantly different (P < 0.05) between the experimental and control groups, increasing by 9.43% and 16.66%, respectively, compared to the control group. The egg shape index, Haugh units, eggshell relative weight and egg-yolk color of the two groups were not significantly different, and the eggshell relative weight was the same (0.11).

Eggshell strength is an important indicator for the egg damage rate, as it is linked with the eggshell’s thickness, porosity, membrane thickness, mineral content and protein matrix (Dai, 2001). As well as promoting digestion and absorption in the ducks, water hyacinth is rich in protein and minerals, especially calcium, which reached 2.03% (of dry matter), and therefore it could increase the eggshell strength. Because the experimental and control groups had the same eggshell relative weights, this indicated that adding water hyacinth to the diet increased egg weight, and correspondingly increased the eggshell weight, so it was also the reason that eggshell thickness was greater in the experimental group. High Haugh units indicate good egg crude protein and a better protein quality (Dai, 2001). Egg-yolk color does not affect the egg’s nutritional value, but it is important for increasing egg sales.

3 Conclusions

We concluded that a water hyacinth system was effective in treating wastewater from an intensive duck farm during the water hyacinth growing season and that, after harvesting, the water hyacinth was an excellent duck feed. This study observed the treatment capacity of the CW with water hyacinth during a 40-d period in autumn. Its long-term capacity has not yet been studied. In future, water hyacinth will be replaced by Potamogeton crispus L. and grassleaf sweetflag rhizome (Rhizoma Acori Graminei) as the CW aquatic plants during spring and winter because the growth of water hyacinth stops if the temperature remains under 0°C for a period of 24 h. Another point is that the study planted only one type of wetland plant in the CW. Other studies, however, have reported that the integration of various plants enhances the CW treatment capacity (Martin et al., 1996).

Periodical harvests of the plants in the CW are essential to maintain its treatment capacity. Otherwise, the decomposing plants would re-pollute the water because the plants themselves contain high levels of nutrients and minerals. The Fe, Ca and K contents of aquatic plants are much higher than those of terrestrial plants (Sahu et al., 2002).

Although the CW is widely applied to wastewater treatment, it has a limited capacity to remove organic matter completely. A CW is generally able to remove as high as 90% of the COD, BOD, SS and bacteriological pollutants from the wastewater, but the removal rates of N and P are only around 50% in most cases (Verhoeven and Meuleman, 1999). Our study also found that the water still contained high levels of N and P after treatment.

Considering all of the above points, we suggested the CW as the first phase of wastewater treatment. In future research, the outflow of the CW will be further treated by diverting it into fishponds, because at this stage the water has a high DO content and its transparency and other indices make it favorable for fish production. The water discharged from the fishponds will then be used to irrigate a paddy field, thus finishing its third treatment. After this, the water, through river ways, will flow back to the duck farm to finish the whole recycling process. Thus, the CW is only one part of the whole ecological engineering system and this experiment is only a first exploratory step. A study of the whole system calls for longer observations, more experiments and more discussion.

Acknowledgements

This work was supported by the Food and Agriculture Organization (FAO) of United Nations Project (No. TCP/CPR/2904A) “Integrated Control and Comprehensive Utilization of Water Hyacinth (Eichhornia crassipes)”, the Interdisciplinary Seed Research Fund of Zhejiang University (No. 308102-812651).

References


Table 4 The effect on the egg quality of adding water hyacinth to the diet*

<table>
<thead>
<tr>
<th>Group</th>
<th>Egg shape index</th>
<th>Eggshell thickness (mm)</th>
<th>Eggshell strength (N)</th>
<th>Haugh unit</th>
<th>Eggshell relative weight</th>
<th>Egg-yolk color level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test group</td>
<td>1.32±0.02a</td>
<td>0.58±0.02a</td>
<td>36.55±1.44a</td>
<td>76.60±9.10a</td>
<td>0.11±0.01a</td>
<td>11.13±0.42a</td>
</tr>
<tr>
<td>Control group</td>
<td>1.30±0.03a</td>
<td>0.53±0.03b</td>
<td>31.33±1.91b</td>
<td>80.98±7.26a</td>
<td>0.11±0.01a</td>
<td>11.21±0.03a</td>
</tr>
</tbody>
</table>

* The different letters in the same list mean significant at the 0.05 probability level. The same letters in the same list mean no significant difference.
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