Water Hyacinth (*Eichhornia crassipes*) – Biomass Production, Ensilability and Feeding Value to Growing Cattle

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Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2012

Acta Universitatis agriculturae Sueciae
2012:90

Cover: The development of water hyacinth along rivers and canals in the Mekong Delta of Vietnam
(photo: Hồ Thanh Thâm, 2010)

ISSN 1652-6880
ISBN 978-91-576-7737-2

Print: SLU Service/Repro, Uppsala 2012

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Abstract

Water hyacinth has now spread to all tropical and subtropical countries and is regarded as one of the world's most invasive aquatic plants. Water hyacinth (WH) is also known to have significant ecological and socio-economic effects. A potential of WH as feed for ruminants was evaluated through four studies with respect to: a) biomass yield and nutritive value of WH grown in two different habitats (pond and river), harvested in three cuts at four cutting intervals; b) fermentation quality of WH with and without additives; c) feeding value to growing cattle of ensiled; or d) fresh WH at four different levels of inclusion in a rice straw based diet.

Compositional changes as an effect of cut were generally small in the pond or negligible in the river habitat. Cutting interval had some minor effects on WH composition. The most obvious changes across habitats were an increase in neutral detergent fibre (NDFom) content from approximately 510 to 550 g/kg dry matter (DM) and a decrease in crude protein (CP) from approximately 210 to 170 g/kg DM when cutting interval was increased from 4 to 7 weeks. Water hyacinth has a potential as livestock feed. Results showed high CP contents (176 to 195 g/kg DM) and high DM yields for the two habitats of approximately 400 kg/ha/week. Application of sugars in the form of molasses or rice bran as a water absorbent resulted in a rapid decrease of pH to approximately 4.0. This level was maintained until at least day 14 and then gradually increased to approximately 4.8 at day 56. Ammonia nitrogen and fermentation end-product concentrations were within acceptable limits. The best fermentation quality was achieved in the silages with added molasses, absorbent or with a combination of the two and an inoculant. At the highest WH level, cattle consumed >50% ensiled WH which provided nearly three times as much metabolisable energy as when none was fed. These results were mainly due to an increasing digestibility with increasing level of ensiled WH. Cattle fed fresh WH showed abnormal rumen distension and a gradual increase of rice straw intakes over time. A long adaptation period to fresh WH is recommended and an inclusion level of not more than 30% of diet dry matter.

Keywords: additive, biomass yield, cut, cutting interval, digestibility, *Eichhornia crassipes*, habitat, intake, silage, water hyacinth.

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Dedication

To my families with my respectful gratitude.

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Tham, H.T., Man, N.V. and Udén, P. 2012. Biomass yield and nutritive value of water hyacinth (*Eichhornia crassipes*) grown in two habitats as affected by cut and cutting interval. *Grassland Science* (Accepted).

II Tham, H.T., Man, N.V. and Pauly, T. 2012. Fermentation quality of ensiled water hyacinth (*Eichhornia crassipes*) as affected by additives. *Asian-Australasian Journal of Animal Sciences* (In press).

III Tham, H.T. and Udén, P. 2012. Effect of fresh water hyacinth (*Eichhornia crassipes*) on intake and digestibility in cattle fed rice straw and molasses-urea cake (Manuscript).

IV Tham, H.T. and Udén, P. 2012. Effect of water hyacinth (*Eichhornia crassipes*) silage on intake and nutrient digestibility in cattle fed rice straw and cottonseed cake. *Asian-Australasian Journal of Animal Sciences* (Accepted).

Abbreviations

A	Absorbent
ADFom	Acid detergent fibre
BW	Body weight
C	Cut
CI	Cutting interval
CP	Crude protein
CSC	Cottonseed cake
DE	Digestible energy
DM	Dry matter
EWH	Ensiled water hyacinth
F	Fraction
FM	Fresh matter
I	Inoculant
IVOMD	*In vitro* organic matter digestibility
LAB	Lactic acid bacteria
LW	Live weight
M	Sugarcane molasses
ME	Metabolisable energy
MUC	Molasses-urea cake
NDFom	Neutral detergent fibre
OM	Organic matter
WH	Water hyacinth
WSC	Water soluble carbohydrates

1 Introduction

Vietnam is predominantly an agricultural economy based on paddy rice production (NIAH, 2003) and a population of 87 million (GSO, 2011). Of the total population, 68% has lived in rural areas (GSO, 2011) and an estimated 70% of the rural population relies almost exclusively on agriculture for their livelihood (Vu, 2007). The majority of farms in Vietnam are small with an average area of 0.77 ha in 2006 (Huy & Khoi, 2011) but production from these farms is an important component of rural agriculture (Chantalakhana, 1990). In these farms, ruminant production plays an important role (Trach, 1998). Rice straw is traditionally fed to the ruminants during periods with shortage of feed or labour for harvesting green forages, but does not provide adequate nutrients even for maintenance (Doyle *et al.*, 1986). Good quality grass is not readily available in Vietnam and becomes scarcer during the dry season. At the same time, starch and protein sources become more expensive during this period. A number of non-conventional feed resources such as cassava foliage, sugarcane tops, maize, including water hyacinth (*Eichhornia crassipes*) are available in Vietnam and neighbouring countries and have become more interesting for the improvement of ruminant production (Devendra, 1985).

Water hyacinth (WH) originates from Brazil and has now spread to all tropical and subtropical countries (Parsons & Cuthbertson, 2001) and is regarded as one of the world's most invasive aquatic plants. Water hyacinth is available all year round and is widespread on freshwater wetlands of the Mekong Delta, especially in standing water (MWBP/RSCP, 2006). It multiplies rapidly and forms dense mats (Gopal & Goel, 1993) which interfere with waterways, decimates aquatic wildlife and creates ideal conditions for diseases and its vectors, etc. (Kushwaha, 2012). Water hyacinth is also known to have significant ecological and socio-economic effects (Villamagna & Murphy, 2010). However, there are potential benefits from WH such as animal fodder, water purification, fibreboard, biogas, fertilizer and paper production (Lindsey & Hirt, 1999).

In countries like Vietnam, where poor quality rice straw is the major roughage source available, WH could offer a better alternative. A high protein content, especially in leaves (Virabalin *et al.*, 1993) and rapid growth (Gopal, 1987), has made WH interesting for use as fodder to cows (Rashid *et al.* 2001), goats (Dada, 2002), sheep (Abdalla *et al.*, 1987), pigs (Men *et al.*, 2006), ducks (Jianbo *et al.*, 2008) and tilapia fingerlings (El-Sayed, 2003). Its use as livestock feed is considered as an effective mechanical control method. Moreover, harvesting of WH can be conducted manually on a small scale and does not require new harvesting techniques to be introduced (Gunnarsson & Petersen, 2007).

2 Aims of the thesis

The overall objective of the thesis was to evaluate water hyacinth as a feed source to beef cattle in the Mekong Delta of Vietnam. Specific aims were to:

- Evaluate the effect of cutting interval and cut number on biomass yield and nutritive value of leaves and petioles from water hyacinth grown in two different habitats.
- Evaluate the influence of molasses, rice bran and fermented vegetable juice and their combinations on the fermentation quality of ensiled water hyacinth.
- Study the effect of feeding level on intake and *in vivo* digestibility of fresh water hyacinth in crossbred Sindhi cattle fed a molasses-urea cake and rice straw as a basal diet.
- Investigate the effect of feeding different combinations of rice straw and ensiled water hyacinth supplemented with a source of protein in the form of cottonseed cake on intake and digestibility of crossbred Sindhi cattle.

3 Background

3.1 Beef cattle production in the Mekong Delta of Vietnam

3.1.1 Cattle breeds and cattle production systems

The population of beef cattle in Vietnam increased rapidly in the period 2005 to 2007, from 5.5 to 6.7 million head. However, from 2008 the beef cattle population declined, to around 5.4 million head in 2011. The Mekong Delta has 666 thousand cattle, accounting for 12% of the country population (GSO, 2011). However, beef production is only 5% of total meat production of the country, and this gap will widen when national demand will continue to outstrip domestic supply (Department of Animal Husbandry, 2006). Beef consumption per capita was 0.9 kg/head/year for a period of 2004 to 2007 (USDA Foreign Agricultural Service, 2006). In 2011, Vietnam imported 9,000 tonnes of beef from four main markets, accounted for 97% of total imports of beef, including the United States of America, India, Australia and New Zealand (AgroMonitor, 2011). Other markets accounting for a relatively small proportion come from Laos, Cambodia, Thailand and China where favourable conditions near the national border to facilitate trade and competitiveness.

Local Yellow cattle and crossbred Sindhi cattle are the most common breeds of cattle in Vietnam. They are well adapted to the climate as well as to local feeding conditions. However, performance is poor with mature body weights ranging between 180 and 200 kg for females, around 300 kg for bulls and with a dressing percentage of 30 (Burns *et al.*, 2002; Su & Binh, 2002). Red Sindhi is often used by farmers as a first cross (F1) when attempting to increase body size of their animals. As a result of a cross-breeding program (with Red Sindhi × local Yellow cattle), body weight increased by 30 to 35% and dressing percentage increased 5 to 8% compared to local Yellow cattle. Many research projects have focused on the improvement of performance and quality of crossbred Sindhi cattle in Vietnam. Crosses between Sindhi cattle and either *Bos taurus* or *Bos indicus* breeds such as Simmental, Charolais, Limousine, Hereford, Sahiwal, Red Sindhi, Drought Master or Brahman have been introduced. These crosses have generally been well accepted by the farmers (Burns *et al.*, 2002; Su & Binh, 2002; Chowdhury *et al.*, 1995; Ly, 1995).

In the Northern part of Vietnam, the availability of feed resources for cattle was a major factor affecting herd size and cattle management on smallholder farms (Huyen *et al.*, 2010), and in the Mekong Delta this is also a dominant factor. Approximately 90% of all domestic cattle in Vietnam are kept in smallholder farms (Department of Animal Husbandry, 2006). These small farms kept an average of 2 to 4 cattle due to forage and labour shortages and had few options to further develop their cattle production. In general, ruminant production systems in Vietnam are divided into two categories:

The crop-based or crop-animal system

This is the prevailing ruminant production system in the Mekong Delta of Vietnam. It combines cattle and the production of annual crops using by-products of arable crops, and cut grasses for feeding the animals. Most crop residues are seasonally produced and only rice straw is available all year round. Small farms are often in this system using family labour and with low requirements for investments. The family labour is used for tending to the animals and for collecting forage. The integration of crops and animals has the potential for a more efficient use of the natural resource base than if the components are produced separately (Devendra, 2007). Although there is little market orientation for beef production, this mixed farming system will continue to be important and remain the dominant system in Vietnam also in the future.

The intensive system

As a result of limited land area and lack of high-quality forages, intensive systems have been developed to improve productivity. In 2011, there were 581 large-scale animal farms (GSO, 2011) in the Mekong Delta but number of cattle farms were unclear. This system includes large-scale farms, owned by state or private organisations. Feeds in the form of rice straw and by-products are collected from the surrounding region and stored for the dry season. In general, the major feed components in the rainy season are rice straw used as a basal diet, with additional concentrates and fresh grass. The latter is replaced by rice straw in the dry season. In this system, cultivated grasses are harvested instead of natural grasses leading to fewer grazing days and less grazing time for the cattle.

3.1.2 Available feeds for ruminants

Feed resources for ruminants in Vietnam consist of some natural pastures and of large quantities of agricultural by-products (Ly, 1995). There exist four categories of feeds:

Pastures

Natural pastures are generally poor in yield and quality and include species such as *Brachiaria mutica*, *Hymenachne acutigluma*, *Panicum repens*, etc. As there is no proper pasture management, over-grazing has become a serious problem often resulting in soil erosion (Ly, 1995). In a period marked by accelerated industrialization and modernization as well as increased population pressure, natural grasslands are converted to crop farming or used for buildings. With an expected growth of approximately 5% per year for beef cattle, feed shortage will soon become an acute problem for ruminant production in Vietnam.

Recently, grass cultivation has been studied and developed in research institutions and state farms in Vietnam with focus on species such as elephant grass (*Pennisetum purpureum*), *Panicum maximum*, *Paspalum atratum and* pangola grass (*Digitaria decumbens*). These grasses have reasonable productivity but variation depends much on season, soil type and management conditions. Elephant grass is a main fresh forage for cattle production in many farms due to its high yield and simple management technique while growing other species is not popular in smallholder farms. Legumes and multi-purpose trees such as *Stylosanthes guianensis*, *Sesbania sesban*, *Sesbania grandiflora*, *Gliricidia sepium*, *Flemingia macrophylla* and *Leucaena leucocephala* are less used as green fodders.

Crop residues

The Mekong Delta is considered the rice bowl of Vietnam (Xuan *et al.*, 1995). In 2011, rice production in this region was 23 million tons, accounting for 55% of the country's total rice production (GSO, 2011). Assuming a grain/straw ratio = 1/1.1 (Chowdhury *et al.*, 1995), approximately 25 million tons of rice straw is produced annually. Rice straw is therefore the most abundant crop residue for feeding of ruminants and it is available all year round (Chinh & Ly, 2001). However, it has low digestibility and protein content (Van Soest, 2006). Additional crop residues, suitable as feeds for cattle, include sugarcane tops, pineapple peel as well as maize and cassava (*Manihot esculenta*) foliage.

In developing countries like Vietnam, urea/ammonia treatment has also been applied to rice straw to increase its feeding value (Khang & Wiktorsson, 2004; Man & Wiktorsson, 2001). However, this technology has not been much adopted, particularly in small scale farms in the region due to technical and practical aspects of treating rice straw. A laborious treatment process, high costs of inputs, especially urea, and labour were highlighted in an electronic conference, summarised by Owen *et al.* (2012). In the future, the urea/ammonia technology may become economical as a result of increased scarcity of animal feed, and may also be promoted to reduce environmental pollution from burning rice straw in the fields (Owen *et al.*, 2012).

As an alternative to urea-treated rice straw, molasses-urea cake is recommended to supplement low quality diets with energy and digestible protein (Owen *et al.*, 2012). This alternative is attractive due to its low cost relative to protein supplements for improving intake and performance.

Sugarcane tops and maize stalks are also available in large quantities but are rarely used as animal feeds. Cassava is the third crop after rice and maize, and approximately 560,000 ha was planted in 2011 (GSO, 2011). Besides roots, cassava yields large amounts of leaves, approximately 4.5 tonnes dry matter (DM)/ha/crop (Ravindran & Rajaguru, 1988). Cassava leaves has been shown to be an excellent source of protein as a supplement in ruminant diets based on rice straw (Khang & Wiktorsson, 2004; Man & Wiktorsson, 2001).

Agro-industrial by-products

Rice bran, soya bean meal, coconut and ground nut cake belong to the group of agro-industrial by-products. Among these by-products, rice bran is the main by-product of the rice milling industry and is readily available in large quantities in the Mekong Delta of Vietnam. It is used for cattle as a supplement and is particularly during periods of intensive farm work due to its ease of use.

Non-conventional feed resources

Non-conventional feed resources category includes diverse feeds that are not traditionally used in Vietnam for ruminant feeding and include brewer's grains, cottonseed cake, and also water spinach. In a tropical region like Vietnam where WH is abundant, this plant may have a potential as feed for ruminants. A better utilization of crop residues and low quality roughages is an important strategy (Devendra *et al.*, 2001) because feed costs dominate animal production, even when household labour is valued at its full cost (Nin *et al.*, 2003).

3.2 The biology of water hyacinth

3.2.1 Description

The family Pontederiaceae has nine genera including *Eichhornia*, which has eight species of freshwater aquatics including water hyacinth (*Eichhornia crassipes*) (Barrett, 1988). Only *E. crassipes* is regarded as a pan-tropical aquatic weed (OEPP/EPPO, 2008). The name water hyacinth refers to its aquatic habitat and the similarity of the flower colour to that of the garden hyacinth (Parsons & Cuthbertson, 2001). Water hyacinth, a free-floating macrophyte, live at the air-water interface and form two distinct canopies: leaf canopies comprising above-water structures and root canopies comprising below water structures (Downing-Kunz & Stacey, 2012).

The English common names of the plant are waterhyacinth, water hyacinth, and water-hyacinth. Waterhyacinth is the standardized spelling adopted by the Weed Science Society of America to denote that it is not an aquatic relative of true “hyacinth” (*Hyacinthus* spp.) (Center *et al.*, 2002). Synonyms are *Eichhornia crassipes* (Mart. and Zucc.) Solms, *Pontederia crassipes* (Mart. and Zucc.), *Piaropus crassipes* (Mart. and Zucc.) Britton (Penfound & Earle, 1948).

Water hyacinth is an erect, free-floating, stoloniferous, perennial herb (Center *et al.*, 2002). The mature WH consist of roots, rhizomes, stolons, leaves, inflorescences and fruit clusters (Penfound & Earle, 1948) (Figure 1).

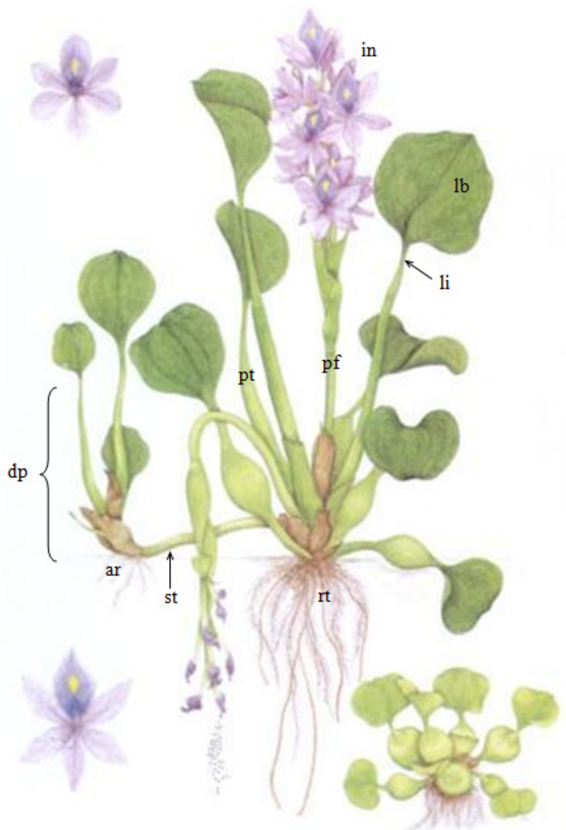

Figure 1. Morphology of water hyacinth plants with stolons.

ar: adventitious root; dp: daughter plant; in: inflorescence; lb: leaf blade; li: leaf isthmus; pf: peduncle of flower spike; pt: petiole; rt: root; st: stolon.

Source: Parsons and Cuthbertson (2001)

Petioles

Water hyacinth petioles are either erect (up to 60 cm long and bearing flowers) or horizontal (stolons), about 10 cm long and producing new plants from terminal buds (Parsons & Cuthbertson, 2001).

Leaves

There are two types of leaves. Some are up to 60 cm long, narrow and stand erect; others are almost round, up to 30 cm diameter and curved upwards with edges somewhat undulate. Both are smooth, glabrous, glossy and with semiparallel veins following the curvature of the leaf. Leaf stalks can be 50 cm long with bladder-like swellings, either bulbous or elongated, consisting of large air cells enabling the plant to float on water (Parsons & Cuthbertson, 2001).

Flowers

Water hyacinth flowers are attractive mauve with six lobes or petals. The uppermost petal has a yellow dot in the centre surrounded by darker purple. Each spike consists of about 8 (range from 3 to 35) flowers and individual flowers last only a few days. New plants flower when only 3 or 4 weeks old (Parsons & Cuthbertson, 2001). Under favourable conditions, WH may flower repeatedly throughout the year; although the intensity of flowering may vary with seasonal variation in growth rate (Malik, 2007).

Fruits and seeds

The fruit consists of a narrow 3-celled capsule about 1 to 1.5 cm long, containing up to 300 seeds. Seeds are about 1 to 1.5 mm long with many longitudinal ribs. The seeds can germinate in a few days. In cool temperature areas, they remain dormant for 15 to 20 years in dry mud, germinating when moistened. A temperature of 20 to 35^{o}C usually enhances germination. In other words, rapid growth occurs with increasing summer temperature (Malik, 2007; Parsons & Cuthbertson, 2001).

Roots

The root morphology is highly plastic, fibrous and has one single main root with many laterals, forming colossal root system. Because each lateral root has a root tip, WH may exploit nutrient in a low-nutrient water body (Xie & Yu, 2003). Lateral roots are generally longer and denser at low phosphorus levels than at high phosphorus levels (Xie & Yu, 2003). In shallow water, the roots may become attached to the bottom for several weeks when the water level drops (Parsons & Cuthbertson, 2001). The root-shoot ratio varies inversely with nutrient level, particularly with respect to nitrogen. Purple roots are characteristic of plants when nutrient levels are low in the water (Xie & Yu, 2003).

3.2.2 Distribution and impacts

Water hyacinth originates from the Amazon river basin of South America (Brazil) (Parsons & Cuthbertson, 2001). Water hyacinth has become the major floating water weed of tropical and subtropical regions worldwide because of its rapid growth (De Groote *et al.*, 2003). Plants were introduced into USA in

1884 (Penfound & Earle, 1948) and reached Europe (Portugal) in the 1930s (OEPP/EPPO, 2008).

In the Mekong Delta of Vietnam, the canal and river systems are diverse and interlaced, creating a favourable environment for WH growth. The ecological and socio-economic impacts of the invasive WH are currently well-understood (Villamagna & Murphy, 2010). Water hyacinth mats decrease dissolved oxygen concentrations, one of the most important water quality variables for aquatic fauna, by preventing the transfer of oxygen from the air to the water surface (Perna & Burrows, 2005). Although McVea and Boyd (1975) found a negative relationship between dissolved oxygen and WH coverage, a WH cover of to 25% of 400 m^2 experimental ponds did not decrease dissolved oxygen to dangerous concentrations for fish survival.

Water hyacinth is reported to limit the productivity of phytoplankton and submersed vegetation such as *Sagittaria kurziana* by shading of the mats (Villamagna & Murphy, 2010) preventing photosynthesis (McVea & Boyd, 1975). A reduced phytoplankton productivity can in its turn decrease zooplankton growth (Richard *et al.*, 1985). However, from a study in Lake Victoria in Uganda, it was shown that WH enhanced the abundance and diversity of aquatic macroinvertebrates at the interface with open water through the provision of a suitable habitat for their colonisation (Masifwa *et al.*, 2001).

Finally, the most direct impact of dense mats of WH is on boating access, navigability, water supply systems, drainage canals and on recreation (Villamagna & Murphy, 2010). It can be a serious matter in water-limited areas and small water bodies when water loss through evapotranspiration from WH is 3.7 times that from open water (Timmer & Weldon, 1967). Water hyacinth infestations are also known to exacerbate mosquito problems by hindering insecticide application (Seabrook, 1962). The socio-economic effects of WH are dependent on the extent of the invasion, the uses of the impacted water body, control methods and the response to control efforts (Villamagna & Murphy, 2010).

3.2.3 Habitat

Water hyacinth rapidly colonises still or slow moving water, resulting in thick extensive mats. It occurs in estuarine habitats, lakes, urban areas, water courses, and wetlands (Gopal, 1987). It prefers nutrient-enriched waters and can tolerate considerable variation in nutrients, temperature, pH levels and toxic substances (Gopal, 1987). Growth occurs in a wide range of temperature from 1 to 40°C, but is most favourable under warm condition with a maximum growth at 25 to 27.5°C (Wilson *et al.*, 2005). Plants tolerate acidity levels as low as pH 3 (DiTomaso & Healy, 2003) but optimum pH for growth is 6 to 8 (Wilson *et al.*, 2005). However, WH does not tolerate salinity above 1.6% (DiTomaso & Healy, 2003) and there is no evidence to indicate that this fresh water plant can adjust to saline water (Penfound & Earle, 1948).

3.2.4 Reproduction

Reproduction is rapid under favourable conditions from stolons (asexually) and by seeds (sexually) (DiTomaso & Healy, 2003). The major propagation is by means of stolons which form daughter plants at axillary buds (OEPP/EPPO, 2008). The spreading of the daughter plants is also thought to be enhanced by wind and wave action (OEPP/EPPO, 2009). Under suitable conditions, plant numbers can double between 1 to 3 weeks (Parsons & Cuthbertson, 2001; Gopal, 1987). The capacity for vegetative reproduction allows this aquatic plant to quickly occupy all available space (Gutiérrez *et al.*, 1996).

Growth is stimulated by inflow of nutrient rich water, such as from runoff of tropical rains, particularly in static water situations. In flowing water, fluctuations in nutrient levels are less important as nutrients are carried to the plants. In moving water, WH can achieve rapid growth by continually taking up nutrients, even at very low concentrations (Howard & Harley, 1998). However, growth is increased by high nutrient levels and temperature (Howard & Harley, 1998). Water hyacinth can double its population every seven days to yield 930 to 2900 tonnes fresh matter (FM)/ha/year (Lareo & Bressani, 1982), equivalent to approximately 75 to 230 tonnes DM/ha/year.

3.3 Chemical composition of water hyacinth

The composition of WH is characterized by low DM and high CP and ash contents (Table 1). Light green leaves and petioles of the immature plant are softer and contain a higher proportion of protein than those of the mature plant (Men *et al*, 2006). The leaf protein content is higher than sweet potato leaf (An *et al.*, 2003) while the protein content in whole plant is considerable higher than grasses such as elephant grass (Hong *et al.*, 2003) and can be used as a protein supplement of low quality diets (Khan *et al.*, 2002). Protein in leaves contains most essential amino acids and is particularly rich in glutamine, asparagine and leucine (Virabalin *et al.*, 1993) (Table 2).

Chemical composition of WH varies with season, habitat (Poddar *et al.*, 1991; Tucker & Debusk, 1981) as well as with harvesting frequency (Reddy & D'Angelo, 1990). Under warm weather conditions like in Vietnam, forages mature more rapidly (Buxton, 1996) and cell walls become highly lignified (Van Soest, 1988). Protein concentration is high in the immature forage but declines with advancing maturity (Buxton, 1996). Lignin, followed by silica and cutin, are the primary limiting factors of digestibility (Van Soest, 1981). Lignin content of WH in the range from 7 to 10% has been reported while silica has varied widely from 0.5 to 5% (Abdelhamid & Gabr, 1991; Biswas & Mandal, 1988). As nutrient composition of WH is generally related to nutrient availability in the habitat where the plants are growing, WH grown in sewage has high protein and mineral contents (Wolverton & McDonald, 1978).

Table 1. *Chemical composition (g/kg DM or as otherwise stated) of water hyacinth collected from different habitats.*

Items	Young leaf	Young petiole	Whole shoot	Whole shoot†
Dry matter (g/kg)	79	58	87	95
Crude protein	181	76	128	200
Ether extract	43	24	38	35
NDF	606	692	635	623
ADF	350	410	337	290
Hemicellulose/Cellulose	0.9	0.9	1.1	1.7
Lignin	75	94	76	-
Ash	142	134	131	257
Silica	10	19	4	52
IVOMD (%)	76	67	69	52
Metabolisable energy for ruminants (MJ/kg DM)	-	-	-	6.4
Oxalic acid‡	-	-	-	58
Tannin‡	-	-	-	27

Sources: Dung (2001) collected water hyacinth from the river in the Mekong Delta of Vietnam.
†Abdelhamid and Gabr (1991) collected from the ditch at Mansoura, Egypt.
‡ Biswas and Mandal (1988) collected from the pond at West Bengal, India.
ADF: Acid detergent fibre;
DM: Dry matter;
IVOMD: in vitro organic matter digestibility;
NDF: Neutral detergent fibre.

Table 2. *Amino acid content (g/kg crude protein) and mineral concentration (g/kg DM or as otherwise stated) of the water hyacinth.*

Amino acids	Leaf†	Petiole‡	Mineral*	Leaf	Whole shoot
Alanine	34	29	Ca	20	18
Arginine	36	11	P	8	7
Asparagine	51	34	Na	0.6	0.5
Cysteine	4	-	K	66	48
Cystine	8	-	Mg	6	5
Glutamine	59	30	Mn	0.4	0.3
Glycine	30	32	Fe	0.1	0.9
Histidine	11	6	Cu (mg/kg DM)	7	4
Isoleucine	23	14	Zn (mg/kg DM)	31	51
Leucine	51	27			
Lysine	27	16			
Methionine	13	-			
Phenylalanine	34	-			
Phenylalanine + Tyrosine	-	19			
Proline	27	17			
Serine	26	18			
Threonine	26	16			
Tyrosine	22	-			
Valine	28	20			

Sources: †Virabalin *et al.* (1993); ‡Wanapat *et al.* (1985); * Khan *et al.* (2002).

3.4 Utilisation of water hyacinth

Water hyacinth has received much attention in recent years due to its potential benefits as animal fodder, aquafeed, water purification, fertilizer, biogas production, even food for human and other products (Ogle *et al.*, 2001; Wolverton & McDonald, 1976) (Figure 2). Due to the extreme scarcity of forages in Vietnam, WH has become more interesting for the improvement of ruminant production. Therefore, attention has gradually shifted from control to the utilization of WH as a valuable resource (Gopal, 1998).

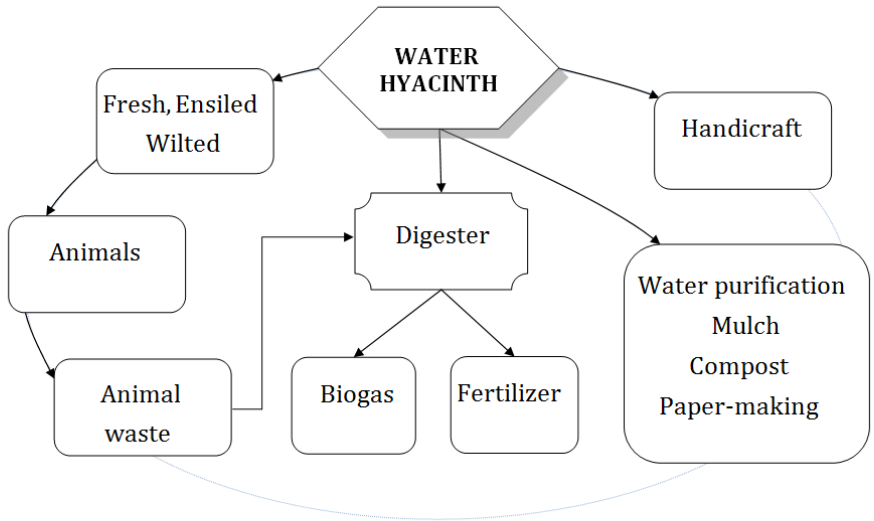

Figure 2. A diagram of possible uses of water hyacinth.

3.4.1 Animal feed

Water hyacinth can be used fresh, ensiled or wilted to animals. Whole plants, chopped or ground can used as feedstuffs for both ruminants and monogastrics.

Ruminants

Water hyacinth contains high levels of cellulose and hemicellulose, which could serve as energy sources for ruminants (Mukherjee & Nandi, 2004). Fresh WH has been utilised as partial replacement of para grass (*Brachiaria mutica*) in diets to cattle (Thu, 2011; Biswas & Mandal, 1988), and has given better growth than after wilting when fed to goats (Aregheore & Cawa, 2000). Supplementation of wilted WH in a rice straw-based diet had positive effect on intake and growth of beef cattle (Islam *et al.*, 2009). Daily live weight gain was approximately 500 g when 30% dried WH has been included in the basal diet of wheat straw at a fixed amount of concentrates (Parashar *et al.*, 1999). As water hyacinth has a low dry matter content, wilting is generally preferred to reduce silage losses (McDonald *et al.*, 2011). Water hyacinth can be successfully ensiled with the addition of molasses, rice bran, cassava root as well as with organic acids, and the silages have been accepted by ruminants. An ensiled mixture of WH, rice straw, urea and molasses has been fed to dairy cattle resulting in an increase of milk yield (Chakraborty *et al.*, 1991). Utilisation of both wilted and ensiled WH as a feed for sheep has been reported (Abou-Raya *et al.*, 1980; Baldwin *et al.*, 1975). Although wilted WH has not been recommended as a sole feed for sheep, it can replace up to 50% of the concentrates in complete diets (Abdelhamid & Gabr, 1991).

Water hyacinth residues, after mechanical extraction of the juice, can be used in the diet of fattening buffalo calves (Borhami *et al.*, 1992). Water hyacinth accounted for 35% of diet, while the remaining was concentrates (61%), molasses (2%) and a mineral mixture (1%). Feed conversion efficiency was higher with the WH residues compared to a similar level of Egyptian clover (*Trifolium alexandrinum*).

Pigs

In Vietnam, a replacement of concentrates in pig diets by cooked or fresh WH reduced organic matter digestibility and digestible energy content without affecting feed intake and performance but the use of concentrates were reduced up to 6% in pig diets (Manh *et al.*, 2002b; Son & Trung, 2002). Manh *et al.* (2002a) also found that WH at a 15% DM content was successfully preserved by adding 4.5% of molasses on a FM basis. Due to its low cost, ensiled WH could be economically acceptable by small holder farms.

Rabbits

The University of Florida successfully fed pelleted WH to rabbits. Waste water grown WH completely or partially replaced alfalfa without effects on growth rate and reproductive parameters (Moreland *et al.*, 1991). The optimum inclusion level of WH will depend on the feedstuff substituted in a complete diet. The replacement of para grass with WH up to 60% in rabbit diets improved feed utilisation, growth performance and economic returns (Thu & Dong, 2009).

Ducks and geese

Using aquatic plants such as WH or duckweed is an alternative in duck production system in the Mekong Delta of Vietnam when the birds are confined and fed traditional diets such as unhulled rice, broken rice and rice bran (Sotolu, 2010; Men *et al.*, 2002). Men and Yamasaki (2005) found that a replacement of 5 to 25% of a commercial diet by fresh WH to growing ducks decreased performance but was economically profitable due to the lower feed cost. In China, WH has been harvested from wastewater treatment ponds and used as duck feed to evaluate egg-laying ratio and egg quality. Although feed conversion ratios were almost the same, the inclusion of WH in duck diets gave higher daily feed intake, egg laying ratio and egg quality compared to the unsupplemented control diet (Jianbo *et al.*, 2008).

Damron & Wilson (2008) reported that 20 Chinese goslings (9 weeks of age) fed concentrates with free access to a 185 m^2-pond in Florida covered by WH were able to clear approximately one-third of the WH after 8 weeks and also had a higher than goslings without access to WH.

Fish

Water hyacinth has been recommended as a feed source for herbivorous/omnivorous fresh water fish (Hertrampf & Piedad-Pascual, 2000). However, the relatively high fibre content may limit its use in tilapia feeds (Buddington, 1980). El-Sayed (2003) has evaluated on the effects of ensilaged WH for Nile tilapia fingerlings using 5% sugar cane molasses as an additive. The results indicate that the silage gave better performance than fresh WH as a replacement of wheat bran at a substitution level of 10 to 20%. The most suitable inclusion level will depend on the farming system. With a basal diets such as rice bran, broken rice as well as chicken manure, the supplementation of WH can be as high as 50% in the fish diet (Hertrampf & Piedad-Pascual, 2000). A maximum level of only 10% seems to be feasible as partial replacement of protein in a formulated feed based on fish meal and vegetable oil cake (Hertrampf & Piedad-Pascual, 2000).

3.4.2 Water purification

A beneficial aspect of WH is its capacity to remove contaminants from polluted bodies of water (Chen *et al.*, 1989). Various contaminants such as total suspended solids, dissolved solids, nitrogen, phosphorous, heavy metals, etc. as well as biochemical oxygen demand (BOD), have been minimised using WH (Gupta1 *et al.*, 2012). Nitrogen and phosphorus removal capacity from dairy waste water was found to be fastest in WH, followed by *Lemna minor* and *Azolla pinnata* (Tripathi & Upadhyay, 2003). Nitrogen removal by WH, *Lemna minor* and *Azolla pinnata* were 72, 63 and 60%, respectively, while 63, 59 and 56% of phosphorus were removed by these macrophytes. When WH growing in wetlands receiving domestic and industrial wastewaters, concentrations of Cu, Cd, Ni, Pb and Zn in the roots were 3 to 15 times higher than those in the shoots (Liao & Chang, 2004). This indicates that roots may act as a natural biosorbent (Low *et al.*, 1994).

3.4.3 Other uses

Water hyacinth has been used as mulch and compost and for paper-making (Nolan & Kirmse, 1974) and biogas generation (Kivaisi & Mtila, 1998). The fibres from the petioles can be used to make rope, baskets, carpet, etc. (Malik, 2007).

Water hyacinth seems to be a good source of organic carbon and has been used as an organic fertilizer (Oroka, 2012; Elserafy *et al.*, 1980). Positive responses of WH compost on growth and yield of *Brassica juncea* (Nuka & Dubey, 2011) and *Celosia argentea* L (Lagos Spinach) (Sanni & Adesina, 2012) have been reported. Water hyacinth, as a substrate for oyster mushroom (*Pleurotus sajor-caju*) cultivation at a proportion of 25% with rice straw, increased yield by 19% compared to pure rice straw (Nageswaran *et al.*, 2003). The possible use of WH pulp to produce greaseproof paper was reported by Goswami and Saikia (1994) and in the Khmer community in the Mekong Delta of Vietnam, one of the sources of income come has been the sale of WH flowers (Thuy, 2012).

Using WH to remove nutrients from water bodies and to produce biogas is technically feasible options for the control of WH (Wang & Calderon, 2012). With the rapid industrial development, there is a need for environmentally sustainable energy sources (Ganguly *et al.*, 2012). Utilisation of lingo-cellulosic material from WH biomass has been considered for production of ethanol in many tropical regions of the world (Aswathy *et al.*, 2010). Also, using combinations of WH and pig manure to produce biogas and generate electric power has been reported by Tran *et al.* (2011).

3.5 Control methods

Mechanical, chemical and biological control methods are commonly used to control WH (Julien *et al.*, 2001), but no one method is suitable for all situations (Gopal, 1998).

3.5.1 Mechanical

Mechanical control includes harvesting by hand or machine (Villamagna & Murphy, 2010). The use of machinery to remove WH from water bodies is the most effective non-polluting control method (Mara, 1976), especially in critical areas such as hydro-electric dams and ports. The main advantage to the use of mechanical harvesting is the simultaneous removal of nutrients and pollutants from the water body, and may therefore act as a means of slowing or even reversing eutrophication (Wittenberg & Cock, 2001). Mechanical harvesting of WH has also resulted in rapid increases in dissolved oxygen, and improved suitability of the habitat to support fish (Perna & Burrows, 2005). However it requires recurring efforts involving machine and labour inputs (Mara, 1976). Mechanical removal with harvesters is also slow and therefore not suitable for large mats. Studies have shown that costs of mechanical harvesting are on average US$ 600 to 1,200 per hectare, about six times more expensive than chemical treatment using glyphosate (Wittenberg & Cock, 2001).

3.5.2 Chemical

Chemical herbicides are the principal means of control when an immediate solution to a WH problem is needed (Charudattan, 1986). Glyphosate and 2,4-D [(2,4-dichlorophenoxy) acetic acid] have been the most widely used herbicides and considered as effective and safe herbicides to control WH (Chen *et al.*, 1989; Charudattan, 1986). They are relatively cheap, with costs per hectare for aerial application of US$ 25-200 (Wittenberg & Cock, 2001). Treated plants die and decompose in a few days to a few weeks. Despite such effectiveness of herbicides, the major disadvantages are that they are non-selective and could cause major environmental problems if incorrectly applied (Wittenberg & Cock, 2001). Chemical control needs to be carried out repeatedly as re-infestation of WH occurs from seeds or clonal multiplication of surviving plants (Chen *et al.*, 1989; Charudattan, 1986).

3.5.3 Biological

When chemical control is economically unfeasible or harmful to the environment, biological control is recognized as a cost effective, permanent and environmentally friendly control method (Charudattan, 1986). Using natural enemies from their original ecosystem is a prime target for biological control (De Groote *et al.*, 2003). Since 1971, two South American weevils, *Neochetina eichhorniae* and *Neochetina bruchi*, have been widely introduced in Australia, Asia and Africa (Wittenberg & Cock, 2001). In some areas, they have provided considerable control, but this is not consistent in all areas. The principal drawback with biological control of WH is the time required to achieve control. In tropical environments, this is usually 2 to 4 years and is influenced by the extent of the infestation, climate, water nutrient status, and other control options (Wittenberg & Cock, 2001).

4 Summary of materials and methods

A more detailed description of materials and methods can be found in Papers I-IV.

4.1 Study sites

The experiments (Papers I, III and IV) were conducted in the Vinh Long Province located 40 km east of Can Tho city (10°17’N and 105°56’E), in the Mekong Delta of Vietnam. The study in Paper II was carried out at the Department of Animal Sciences, College of Agriculture and Applied Biology, Can Tho University, Can Tho city, Vietnam.

4.2 Agronomy study (Paper I)

An agronomy study was carried out from February to July 2009 in one pond and one river habitat. The experimental design was a split-plot arrangement with three replicates. Main plots were the habitats and sub-plots were four cutting intervals (4, 5, 6, and 7 weeks). The experiment was set up in Tien River and in a pond of 1500 m^2 which was integrated with the farming of red tilapia (*Oreochromis* sp.). The selected pond had a water depth ranging from 1.5 to 2.6 m and exchanged its water with the adjacent river through variations of the tide.

There were 24 frames (length 4 m × width 3 m × height 4 m) with the vertical poles fixed in the mud at each corner and these were used as individual plots. Frames were made from Melaleuca (*Melaleuca quinquenervia*) poles surrounded by a wire mesh hanging down from the position of highest water level to prevent plants from escaping. To determine numbers of growing points, a 1-m^2 polyvinyl chloride (PVC) floating quadrate was placed at random within each frame. Plantlets having similar size and well-developed root systems were subsequently introduced into the frames at a level of 10 plantlets/m^2.

Number of growing points was measured weekly. All plants were harvested in three consecutive cuts after either: 4, 5, 6 or 7 weeks of growth. Final harvests were consequently done at 12, 15, 18 and 21 weeks after planting. Petioles were cut 4 to 5 cm from the base of the plant. Remainder of the plant, including some immature stolons, was left for re-growth.

Petioles and leaves were separated and weighed to determine the yield. Sub-samples were dried and ground for further analysis of plant composition. In the case of *in vitro* organic matter digestibility (IVOMD), cellulose, lignin, cutin, oxalic acid, Ca, P, Cu, Zn, Fe, K and Mg samples were pooled for economic reasons by habitat, cutting interval and plant part, resulting in a total of 16 samples. Both pond and river water was sampled on week 0, 7, 14 and 21 during the experiment for the determination of water quality.

4.3 Mini-silo ensiling study (Paper II)

A lab-scale ensiling study was carried out between March and May 2011. Water hyacinth, collected along Tien River in the Vinh Long province, was wilted for 7 hours to obtain a dry matter content of 240 to 250 g/kg. Additives included molasses, rice bran and an inoculant in the form of fermented vegetable juice and their combinations. A completely randomized experimental design was used, with eight treatments and three silo replicates for each treatment, giving a total of 24 silos. Treatments were: (1) Control (C), WH only; (2) WH and sugarcane molasses, at 40 g/kg wilted WH (CM); (3) WH inoculated with fermented vegetable juice at 10 ml/kg WH (CI); (4) CM and CI (CMI) combined; (5) WH and 150 g rice bran/kg WH (CA); (6) CA and CI combined (CAI); (7) CA and CM (CAM) combined; and (8) CA, CM and CI combined (CAMI). A total of 850 g material was filled into 1500-ml gastight polyethylene jars and stored indoors.

Before ensiling, all samples of the mixed material were collected for the analysis of pH and chemical composition. Concentration of lactic acid bacteria (LAB) in the fermented vegetable juice and the wilted WH was also determined. Weight losses during storage were recorded at 0, 3, 7 and 14 days and then at weekly intervals until opening and sampling after 56 days. To follow the pH changes over time, a second set of silos were made of the same plant material, two silos per treatment were opened after 3, 7, and 14 days of storage. After ensiling for 56 days, the silages were analysed for pH, chemical composition and fermentation end-products.

4.4 Experimental animals, feeds and management

In Papers III and IV, four crossbred Sindhi heifers (Red Sindhi × local Yellow cattle) were used for the experiment to determine voluntary intake and digestibility. The heifers were kept indoors in individual metabolism cages (1×2 m) and protected against mosquitoes by wire mesh screens covering the barn. Water and commercial mineral blocks were available at all times. The cattle were treated against internal and external parasites and vaccinated against Foot-and-mouth disease (*Aphtae epizooticae*). A summary of materials and methods in Papers III and IV is shown in Table 3.

Water hyacinth, used for both Papers III and IV, were collected along Tien River in Vinh Long province. In Paper III, WH was fed fresh. To make WH silage in Paper IV, the material was sun-dried to a DM content of 160 to 200 g/kg and sprayed with molasses at 40 g/kg wilted WH. Double plastic bags, filled with 25 to 30 kg WH per bag, were used for the ensiling. Each silage batch was fed after 2 to 4 weeks of ensiling.

Voluntary intake and digestibility were measured in both papers consecutively in the 4 experimental periods which each lasted 28 days. The intake measurements consisted of 5 days for adaptation to the diets and 14 days for feed intake measurements. Digestibility was finally measured in 7-d collections of faeces after 2 days of adaptation to the adjusted diets.

Animals were weighed prior to and after each 14-d feed intake measurement period in the morning before feeding. All feeds offered were weighed and recorded daily for each animal and refusals were collected and weighed daily in the morning before feeding. Faeces were immediately collected when voided and put into plastic bags for digestibility measurements. Total daily faecal output was weighed, mixed and 10% was sampled and stored in a freezer. After 7 days of faecal collection, individual samples were thawed, pooled and mixed and 10% was sampled and stored in a freezer awaiting analysis.

Table 3. *Summary of materials and methods in Papers III and IV*

	Paper III	Paper IV
Experimental design	4×4 Latin square	4×4 Latin square
Animals	4 crossbred Sindhi heifers, average BW of 79 kg	4 crossbred Sindhi heifers, average BW of 135 kg
Diets	✓ *Measuring intake* - Rice straw: offered *ad libitum* - MUC: 3 g FM/kg BW/day - Different WH levels	✓ *Measuring intake* - Rice straw: offered *ad libitum* - CSC: 5 g DM/kg BW/day - Different EWH levels
	✓ *Measuring digestibility* - Rice straw: supplied at approximately 90% of the expected daily rice straw intake - MUC: 3 g FM/kg BW/day - Different WH levels	✓ *Measuring digestibility* - Rice straw and CSC: fixed at 10 and 5 g DM/kg BW/day, respectively - Different EWH levels
	✓ *Four diets* WH proportions were set as percentage of an expected total dietary DM intake of 30 g total DM per kg BW per day. • WH0: Rice straw + MUC + 0% WH • WH15: Rice straw + MUC + 15% WH • WH30: Rice straw + MUC + 30% WH • WH45: Rice straw + MUC + 45% WH	✓ *Four diets* EWH proportions were set as percentage of an expected total dietary DM intake of 30 g total DM per kg BW per day. • EWH0: Rice straw + CSC + 0% EWH • EWH15: Rice straw + CSC + 15% EWH • EWH30: Rice straw + CSC + 30% EWH • EWH45: Rice straw + CSC + 45% EWH
Measurements	Feed intake, nutrient intake, digestibility, energy content	Feed intake, nutrient intake, digestibility, energy content

BW: Body weight; CSC: Cottonseed cake; DM: Dry matter;
EWH: Ensiled water hyacinth; FM: Fresh matter;
MUC: Molasses-urea cake; WH: Fresh water hyacinth.

4.5 Measurements and analytical methods

The mean monthly air temperature and rainfall during the experimental periods in Papers I-IV were obtained from the meteorological station of Vinh Long province and Can Tho city.

In Paper I, analysis of pH, $NH4^+$–N, PO_4^{3-}, K, Ca, Mg, Fe, Cu, Zn, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and dissolved organic carbon (DOC) in water samples were determined according to APHA (1998). Procedures of the AOAC (1990) were used to determine the concentrations of Ca and P. Potassium was measured according to AOAC (2000). A one-stage *in vitro* method was used for determining of IVOMD according to Lindgren (1977). Cellulose, permanganate lignin (lignin (pm)) and cutin were analysed using the method of Robertson and Van Soest (1981). Copper, Fe, Mg and Zn were analysed by atomic absorption spectrometry according to AOAC (2000). Oxalic acid was determined by high performance liquid chromatography according to AFNOR (1989).

For Paper II, concentration of LAB in the fermented vegetable juice and the wilted WH was determined based on the technique described by International Organization for Standardization (1998) (ISO 15214:1998). Water soluble carbohydrates were analysed following the protocol of Udén (2006). Ethanol, acetic, propionic, butyric and lactic acids were measured by HPLC (Model 10A, Shimadzu Corp., Tokyo, Japan). After opening the mini-silos, pH of silages was determined using a pH meter (Mi150, Martini, Romania).

Water hyacinth samples (Papers I and II) as well as feeds, feed residues and faeces (Papers III and IV) were analysed for DM, CP, ADFom and ash according to AOAC (1990). Neutral detergent fibre (NDFom) was analysed according to Van Soest *et al.* (1991). In Papers III and IV, the contents of metabolisable energy (ME) and digestible energy (DE) in the diets (MJ/kg DM) were estimated according to McDonald *et al.* (2011) and Magalhães *et al.* (2010), respectively.

4.6 Statistical analyses

In Paper I, the results of yield and contents of DM, CP, ash, ADFom and NDFom were subjected to analysis of variance by Procedure Mixed, version 9.3 (SAS Institute Inc., 2011) by habitat and plant fraction according to a split-plot design with a repeated measurement statement (type=AR1) and for linear and quadratic effects of cutting interval. The remaining observations of minerals, cellulose, lignin (pm), cutin and IVOMD were analysed by analysis of variance and the general linear model (GLM) procedure of Minitab version 16.1 (Minitab Inc., 2010) by habitat with cutting interval as covariate.

For Paper II, the GLM procedure of Minitab software, version 16.1 (Minitab Inc., 2010) was used to evaluate the influence of additives on chemical composition, fermentation quality and weight loss of silage DM. Pearson correlation coefficients among all dependent variables were also calculated using the same software.

In Paper III, data from the intake period was subjected to analysis of variance using the same software. The data on diet composition, intake of rice straw, DM, OM, CP, ADFom, NDFom and ME were regressed against WH percentage in the consumed diets and tested for slope differences from zero. As WH and rice straw levels were not fixed during the digestibility periods, this data was only analysed by regressing digestibility on WH level in the diets.

For Paper IV, data on the digestibility, ME and DE intakes in the digestibility measurement were tested for linear effects of EWH proportion in the diets by including it as a covariate. Nutrient intakes were subjected to analysis of variance (ANOVA) using the GLM procedure of Minitab software, version 16.1 (Minitab Inc., 2010).

5 Summary of results

5.1 Biomass yield and chemical composition of water hyacinth grown in two different habitats (Paper I)

The effect of cut on WH biomass production in the two habitats is shown in Table 4. Average total DM yield for the two habitats was in the order of 400 kg/ha/week. Leaf constituted an average of 58, 78 and 56% of DM, CP and NDFom yields in the two habitats. In the pond, cut had an effect on DM and NDFom yields and leaf NDFom yield was also affected by cutting interval. In the river habitat, cut had a significant effect on all yield variables. However, only leaf CP yield was slightly affected by cutting interval.

Table 4. *Effect of cut on yield of water hyacinth (kg/ha/week) at two habitats.*

	Pond				River			
	Cut				Cut			
	1	2	3	Mean	1	2	3	Mean
Total DM yield	435	340	522	432	429	335	321	362
Leaf	236	221	308	255	224	201	201	209
Petiole	199	119	214	177	206	134	120	153
Total CP yield	82	61	83	75	81	66	63	70
Leaf	63	50	65	59	59	52	50	53
Petiole	20	10	18	16	23	14	13	17
Total NDFom yield	230	179	281	230	227	171	162	187
Leaf	121	109	158	129	110	96	98	101
Petiole	109	70	123	100	116	75	64	85

CP: Crude protein;
DM: Dry matter;
NDFom: Neutral detergent fibre.

The WH composition is summarised in Figure 3. Average DM content across habitats was 100 g/kg for leaf and 53 g/kg in petiole with a value of 81 g/kg in the whole plant. Crude protein, ash and NDFom in whole plants were on average 186, 179 and 523 g/kg, respectively. The levels of CP were 150% higher in leaf, for ash it was 30% lower and for NDFom 10% lower than in petiole.

Compositional changes were generally small in the pond or negligible in the river habitat as an effect of cut. The most obvious changes across habitats were a slight increase in NDFom content from approximately 510 to 550 g/kg DM and a decrease in CP from approximately 210 to 170 g/kg DM when cutting interval was increased from 4 to 7 weeks. In the pond habitat, cut had effects on most compositional variables, while mostly CP and NDFom in whole plant affected by cutting interval. Dry matter and NDFom in petiole had the lowest concentrations in the first cut but the highest contents of CP and ash. Crude protein content decreased with subsequent cuts in all fractions while ash and NDFom contents fluctuated. River grown WH was much less influenced by cut cutting interval had effects on leaf and whole plant DM contents. Crude protein and ADFom in whole plant were also affected by cutting interval.

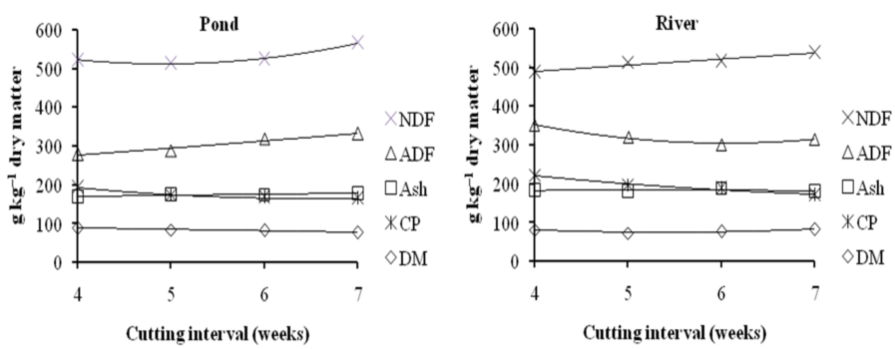

Figure 3. Composition of water hyacinth (total plant) as affected by cutting interval.

Cellulose, lignin (pm), cutin contents and IVOMD, pooled by cutting interval are shown in Table 5. Average IVOMD across habitats was highest in petiole (54%) and lowest in leaf (46%) while leaf contained 42% less lignin, 39% less cellulose and 8% less cutin. However, 'fraction' was only significant for cellulose and IVOMD in the pond habitat. Changes due to cutting interval were small or non-existent.

Table 5. *Cellulose, permanganate lignin and cutin (g/kg DM or as stated) and in vitro organic matter digestibility of water hyacinth pooled by cutting interval and fraction in two habitats.*

	Pond					River				
	Cutting interval (weeks)				Mean	Cutting interval (weeks)				Mean
	4	5	6	7		4	5	6	7	
Cellulose										
Leaf	163	175	186	188	178	165	189	176	190	180
Petiole	281	289	298	313	295	267	290	289	307	288
Lignin (pm)										
Leaf	34.3	34.0	40.6	29.7	34.7	45.1	44.9	38.4	32.3	40.2
Petiole	62.6	58.6	69.1	64.0	63.6	65.8	69.2	64.1	61.7	65.2
Cutin										
Leaf	3.3	3.5	3.3	3.5	3.4	2.3	3.6	3.3	6.5	3.9
Petiole	4.7	2.8	5.7	5.2	4.6	2.6	3.8	3.3	3.9	3.4
IVOMD (%)										
Leaf	47.3	46.5	43.8	38.8	44.1	51.1	44.0	47.1	47.6	47.5
Petiole	42.4	44.3	50.2	50.7	46.9	64.8	65.2	59.5	57.8	61.8

IVOMD: *in vitro* organic matter digestibility;
Lignin (pm): Lignin determined by oxidation of lignin with permanganate.

5.2 Effect of additives on the fermentation quality of ensiled water hyacinth (Paper II)

Fermentation quality of the silages is shown in Table 6. No free liquid or effluent was found in any of the mini-silos. On visual inspection (day 56), spoilage moulds were found on the top of the silos of the control (C) and C with added rice bran treatments. Mould development was virtually absent in silage with added rice bran and molasses, while the remaining silages had little or no mould growth. Silage colour was greenish yellow and changed to a brownish yellow colour after 56 days of storage. After 56 days, pH had increased to approximately 4.8. Ammonia nitrogen levels in silages were significantly decreased by the addition of molasses and rice bran but not by inoculants, while weight losses were decreased only by rice bran. Lactic acid formation was higher in silage added inoculant than in all other treatments. Butyric acid contents, which indicate badly fermented silages, were low in all silages (<2 g/kg DM).

Table 6. *Fermentation end-product concentrations, pH and weight losses in water hyacinth (WH) silages after 56 days of ensiling (g/kg DM or as otherwise stated) after addition of additives.*

	Treatments							
Item	C	CM	CI	CMI	CA	CAI	CAM	CAMI
pH	5.4	4.9	5.2	4.6	4.9	4.7	4.8	4.8
NH_3-N (g/kg N)	15.2	8.4	14.4	15.6	11.2	13.4	14.7	10.9
Weight loss	39.8	35.0	42.0	45.2	26.1	22.4	18.2	21.0
Lactic acid	10.9	21.1	95.4	11.7	60.4	69.2	44.9	40.2
Acetic acid	1.5	2.0	1.0	1.6	1.0	0.7	1.0	0.9
Propionic acid	0.4	1.5	0.2	1.0	0.7	0.5	1.3	1.0
Butyric acid	0.3	1.4	1.6	1.7	1.5	0.4	1.9	0.9
Ethanol	0.5	0.2	0.3	0.2	0.2	0.1	0.2	0.2

M: Molasses; A: Absorbent (Rice bran); I: Inoculants (in the form of fermented vegetable juice).
C = WH only (control);
CM = C + 40 g sugarcane molasses/kg WH;
CI = C + 10 ml inoculant/kg WH;
CMI = CM + CI;
CA = C + 150 g rice bran/kg WH;
CAI = CA+ CI;
CAM = CA + CM;
CAMI = CA + CM + CI.

5.3 Intake and digestibility in cattle fed different levels of fresh/ensiled water hyacinth (Papers III and IV)

The chemical composition of the experimental feeds is shown in Table 7. The fresh WH was low in DM even after wilting for 8 hours, but had a high CP content of approximately 183 g/kg DM in average. Rice straw had a higher NDFom content, had less CP but with a similar ash content compared to WH. No silica was found in WH but rice straw had a level of 60 g silica/kg DM. Molasses-urea cake and cottonseed cake were very high in CP (380 and 370 g/kg DM, respectively).

Table 7. *Dry matter and chemical composition (g/kg DM) of feeds used in the experiments.*

	DM (g/kg)	Ash	CP	ADFom	NDFom	Lignin	Remarks
Fresh WH	80	164	191	307	521	-	Paper III
Ensiled WH	166	169	174	319	503	-	Paper IV
Rice straw	928	142	58	398	663	76	Paper III
Rice straw	916	142	53	389	666	76	Paper IV
Molasses-urea cake	786	218	380	109	157	31	Paper III
Cottonseed cake	881	56	370	300	418	-	Paper IV

ADFom: Acid detergent fibre;
CP: Crude protein;
DM: Dry matter;
NDFom: Neutral detergent fibre;
WH: Water hyacinth.

In Papers III and IV, rice straw intake decreased with increasing levels of EWH and fresh WH which resulted in similar total DM intakes across diets. Results also showed that increasing level of EWH and fresh WH in the diet resulted in an increasing CP content and a decreasing NDFom content (Table 8). In both experiments, there was a trend for a decrease in ADFom and NDFom intakes with increasing inclusive level in the diets. Crude protein digestibility increased as expected in both experiments with increasing level of WH. There were no effects of fresh WH levels on ADFom and NDFom digestibility but for EWH, digestibility of NDFom and ADFom increased with increasing level of EWH offered.

Table 8. *Intake and digestibility of the diets from the digestibility measurements.*

	Paper III (Fresh water hyacinth)					Paper IV (Ensiled water hyacinth)				
	WH0	WH15	WH30	WH45	P	EWH0	EWH15	EWH30	EWH45	P†
Intake (g/day)										
Concentrates‡	226	246	245	239	-	723	723	724	702	-
Rice straw	2488	1931	1336	886	<0.001	3049	2454	1772	1014	<0.001
Water hyacinth	0	392	784	1141	-	0	637	1186	1853	-
DM	2714	2568	2365	2266	0.183	3772	3814	3682	3569	0.831
DM (% BW)	3.2	2.9	2.6	2.6	0.045	2.6	2.7	2.6	2.5	0.773
OM	2312	2177	1994	1899	0.162	3299	3318	3190	3073	0.742
CP	228	279	318	354	0.144	428	508	568	636	<0.001
ADFom	1014	916	803	731	0.065	1403	1372	1280	1195	0.311
NDFom	1683	1522	1335	1219	0.066	2335	2255	2072	1891	0.18
Digestibility (%)										
OM	53	58.2	62	64.2	0.075	47.4	56.3	60.8	72.2	<0.001
CP	49.3	57.6	66.7	65.2	0.005	57.3	66.8	71.7	75.1	<0.001
ADFom	52.4	55.9	59.2	63.1	0.17	31.1	43.6	44	49.1	0.005
NDFom	59.7	63.4	66	67.6	0.18	37	47	53.8	61.8	<0.001
ME (MJ/day)	19.5	21.6	22.7	24	0.29	15.3	23.2	29.7	41.3	<0.001

†Probability for treatment differences on intake or linear effect of water hyacinth level on diet digestibility; ‡Molasses-urea cake (Paper III) or cottonseed cake (Paper IV).
ADFom: Acid detergent fibre; BW: Body weight; CP: Crude protein; DM: Dry matter; ME: metabolisable energy; NDFom: Neutral detergent fibre; OM: Organic matter.

6 General discussion

6.1 Biomass production and chemical composition of water hyacinth (Paper I)

During first three weeks, the number of growing points increased rapidly, but this was followed by a sharp decrease in the following weeks. Growth rate of WH can be affected by water nutrient level, plant density, solar radiation and season (Reddy & Sutton, 1984). Water hyacinth multiplies vegetatively very rapidly and forms dense mats (Gopal, 1987). Crowded conditions began to occur in the third week of growth due to the growth of new plants, extending from the parent plant. Water hyacinth tends to grow vertically at high plant densities (Reddy & DeBusk, 1984). Increasing plant density results in an increase of self-shading (Gopal, 1987) causing senescence of lower leaves (Luu & Getsinger, 1990) and is likely to have been responsible for death of growing points, especially after harvest. Shading stimulates the elongation of petioles and the enlargement of leaf surface area to capture available light (Heard & Winterton, 2000). Specific growth rate is expressed as percent increase in biomass per day and was maximal at low plant density and decreased as the plant density increased (Reddy & DeBusk, 1984). Water hyacinth is an example of an exotic plant that competes effectively for space (Gutiérrez *et al.*, 2001) and has the ability to expand into new growing areas, if available (Boyd, 1976). However, this was not possible under the present conditions. Both WH and water lettuce growing in monoculture are very productive (Moorhead *et al.*, 1988) but when these species were grown together, WH grew above the water lettuce to compete for space, resulting in shading and stressing of both plants (Agami & Reddy, 1990). Water hyacinth growing in flowing water has shown higher productivity than in a pond because of higher plant nutrient turnover (Boyd, 1976) and a warmer river water (Fitzsimons & Vallejos, 1986). Wilson *et al.* (2005) developed mathematical models to evaluate the growth rate of WH in which temperature and water nutrient concentration were found to be the most important factors. Seasonal growth of WH in California has been reported. The higher plants and most biomass were found in late summer while the number of dead leaves was greatest in winter (Spencer & Ksander, 2005). Water hyacinth can take up large quantities of nitrogen, resulting in rapid growth and multiplication (Ueki, 1978). Influence of nutrient supply on growth and nutrient storage by WH plants has been widely reported. Increases in water nitrogen increases WH growth rate (Carignan *et al.*, 1994). Biomass yield increased with an increase of phosphorus up to 1.06 mg P/L of culture medium, but higher concentrations had no effects (Reddy *et al.*, 1990). Biomass accumulation is also affected by the potassium supply with a maximum accumulation of 9.3 kg DM/m^2/year was reached at a K concentration of 52 mg/L (Reddy *et al.*, 1991). Center and Spencer (1981) reported a biomass yield of 92 to 100 tonnes DM/ha/year in a eutrophic lake in Florida with a peak occurring in late summer. Based on weekly growth measurement over one year, annual biomass yield of WH cultured in nutrient medium, ranged between 47 and 106 tonnes DM/ha/year (Reddy & Sutton, 1984). Annual yields from 14 to 95 tonnes/ha were also summarised by Gopal (1987). The difference are likely to be a result of differences in habitat, method of harvesting or initial biomass densities (Fitzsimons & Vallejos, 1986). About 35 to 50% of the total biomass was roots when plants were cultured in nutrient poor waters, while only 14 to 25% when plants were grown in nutrient rich waters (Reddy & Sutton, 1984). In the presence of insect such as *Neochetina bruchi*, WH biomass was lower than compared to the treatment without insects (Heard & Winterton, 2000).

Chemical composition of WH varies with regard to habitat, density as well as season (Poddar *et al.*, 1991; Tucker & Debusk, 1981). Highest CP and lowest ADFom occurred in the winter at the time of lowest growth rates. As DM productivity increased in warmer weather, CP levels decreased and ADFom content increased (Tucker & Debusk, 1981). A trend was observed for P storage that the plant tissue P increased with increasing P supply (Reddy *et al.*, 1990). However, storage of P by WH is short-term because of rapid turnover. If plants are not harvested, dead tissue will decompose and release P into its habitat (Reddy *et al.*, 1990). At high density of 40 kg fresh weight WH/m^2, the cell wall fraction of WH increased and CP content decreased compared with a density of 5 kg fresh weight/m^2 (Tucker, 1981). Compared to water lettuce, nitrogen use efficiency of WH is higher due to a higher photosynthetic rate (Reddy & DeBusk, 1984). Higher concentrations of nitrogen were accumulated in the shoots of WH than in its roots, whereas nitrogen accumulation was similar in the roots and shoots of water lettuce

(Agami & Reddy, 1990). Roots are found to hold Zn more than other parts of WH (Rupainwar *et al.*, 2004). Insect damage also reduced the concentrations of nitrogen and P in plants growing in high nutrient water (Heard & Winterton, 2000).

6.2 Fermentation quality of ensiled water hyacinth (Paper II)

In a tropical region like Vietnam where WH is abundant, it would be of interest to produce silage. Silage making has an advantage in periods when drying is not possible and for later use in a season when fresh forage is not available (Driehuis & Elferink, 2000; Church, 1991).

The main principles of ensiling include a rapid lowering of pH by lactic acid fermentation and the maintenance of anaerobic conditions (Driehuis & Elferink, 2000). To improve silage quality, application of silage additives has played an important role (Knický, 2005). A wide variety of additives have been used including nutrients, fermentation acids and bacterial inoculants (Kellems & Church, 2003). Water hyacinth can be successfully ensiled with the addition of sugarcane molasses, rice bran, cassava root meal as well as with organic acids. Aboud *et al.* (2005) reported that addition of 10 or 20% molasses to WH silage improved *in vitro* organic matter digestibility. Byron *et al.* (1975) showed that WH treated with a high level of formic acid (0.5%) was more acceptable to cattle than with a low formic acid level (0.25%), high acetic acid (0.5%) or low acetic (0.25%). Aerobic spoilage of silage is associated with penetration of oxygen into the silage during storage or feeding (Driehuis & Elferink, 2000). Therefore, focus should be put on the maintenance of anaerobic conditions in silos by compression to remove as much air as possible during silo filling. Water hyacinth also need to be chopped to improve compaction (Gunnarsson & Petersen, 2007).

The characteristics of an ideal crop for preservation as silage include sufficient levels of water soluble carbohydrates (WSC), low buffering capacity and a DM content above 200 g/kg (McDonald *et al.*, 1991). As WH has a low DM content, wilting is necessary to reduce silage losses but prolonged wilting of crops has been shown to result in lower WSC of temperate grasses (Pettersson & Lindgren, 1990; Uchida *et al.*, 1989). However, weather conditions are not always favourable for adequate wilting, and the use of a suitable absorbent can be considered as an alternative to reduce effluents (McDonald *et al.*, 1991). Rice bran, readily available in large quantities in the Mekong Delta of Vietnam, could be a candidate. In Paper II, wilted WH had a low WSC content of 4.3 g/kg DM. To improve this, the addition of sugar-rich sugarcane molasses seems necessary to improve lactic acid production.

Fermentation characteristics such as pH, ammonia nitrogen and fermentation end-products are normally used to evaluate silage fermentation (Weissbach, 1996). Other factors include fungal counts and the presence of *Aspergillus fumigates* and mycotoxins (Amigot *et al.*, 2006).

Silage pH is a standard indicator for the course of fermentation. However, it is heavily influenced by the DM content which means that it is only applicable as an indicator at lower DM contents (Weissbach, 1996). At higher DM contents, silages stabilise at a higher pH values (Leibeinsperger & Pitt, 1988). If the pH fall is insufficient to prevent development of coliform and clostridial bacteria, it may also rise again (Wilkinson, 2005). Although the pH values of the silages in Paper II were not as low as expected even for the best treatments, the silages were well preserved as illustrated by low acetic and butyric acid as well as NH_3-N concentrations. An acceptable level of NH_3-N in silage should be below 110 g/kg N (Church, 1991). This was achieved both in the molasses silage and in the silage with added absorbent, molasses and inoculant.

6.3 Effect of different forms of water hyacinth on intake and digestibility in cattle (Papers III and IV)

6.3.1 Fresh water hyacinth

In Paper III, rice straw intake for the WH30 treatment increased from Period 1 to 4 which indicate a requirement for a considerably longer adaptation period to fresh WH on the order of at least 12 weeks. To obtain maximum level of intake and ensure a stable population of rumen microflora, Forbes (2007) suggested that an adaptation period of 10 to 14 days is required. In Paper III, abnormal rumen distension had appeared when cattle were fed fresh WH. In legume species, soluble proteins, saponins, absence of condensed tannins, and rapid breakdown of plant cell walls in the rumen are factors presumed to cause bloat (Coulman *et al.*, 2000). However, the factors in WH have not been identified. Fresh WH has been reported to be easily accepted by pigs (Men *et al.*, 2006) while the National Academy of Sciences (1976) claimed that the major constraints for its use as a ruminant feed is the high water and ash contents. This may have caused the low feed intake when animals were fed high level of fresh WH in the study of Aregheore and Cawa (2000). Forbes (2007) indicated that there was little evidence that the frequency of feeding affected the digestibility of the feed, although it might improve feed intake.

Polyphenols and nitrate have been found in WH at concentrations of 42 and 8 g/kg DM, respectively, but these levels are considered safe in diets for animals (Mishra, 2006). Water hyacinth had an oxalic acid content of 24 g/kg DM as reported by Ha and Kim (2004) but in Paper I, no oxalic acid was found. Ingestion of forage containing a large quantity of soluble oxalate can result in calcium (Ca) deficiency in animals due to formation of calcium oxalate in the intestines and the blood (Rahman *et al.*, 2010). However, WH contains considerable amount of Ca, approximately 32 g/kg DM (Paper I) which may compensate for losses caused by oxalate. Monogastrics are usually more susceptible to oxalate toxicity than ruminants (Rahman *et al.*, 2010) whereas sheep may consume oxalate-rich forages without effects on intake or live weight gain (Rahman *et al.*, 2011).

Fresh WH was utilised to replace 50% Guinea grass (*Panicum maximum*) in a goat diet (Aregheore & Cawa, 2000). The CP content was 9% compared to 7% in the diet with only Guinea grass and live weight gains were 162 and 58 g/day, respectively. An inclusion of 60% fresh WH leaf in a diet of rice straw and concentrates for growing cattle, resulted in a live weight gain of 115 g/day compared to 152 g/day when fresh WH leaf was replaced by corn silage (Begum *et al.*, 2000).

6.3.2 Ensiled water hyacinth

In small-holder cattle farms in developing countries such as Vietnam, most work is done manually by the family (Ashbell *et al.*, 2001). Under such condition, plastic bags could serve as 'silos' for WH ensiling (Paper IV), due to their flexibility and proven ability to produce an acceptable silage quality (Ashbell *et al.*, 2001).

Feeding EWH (Paper IV) seemed to reduce both the risk of distended rumen and problems of a long adaption time seen with fresh WH (Paper III). Productivity depends largely on intake. Factors affecting intake of grass silage by cattle are extent of digestion, feed passage rate, and fibre concentration (Steen *et al.*, 1998). Silage dry matter intake is also negatively correlated with concentrations of ammonia N, lactic acid and total fermentation acids, and positively correlated to the concentration of residual water soluble carbohydrates, as summarised by Huhtanen *et al.* (2002). Linn *et al.* (1975) reported that higher butyric acid contents of aquatic plant silages may have a depressing effect on DM intake. In Paper II, the WH silage with added molasses had a butyric acid level of 1.4 g/kg DM, which is below the upper limit of 2 g/kg DM silage stated by Castle and Watson (1985). Besides NH_3-N, other nitrogenous compounds are also formed during ensiling including biogenic amines which could reduce intake (Van Os *et al.*, 1996).

7 Conclusions and future research

7.1 Conclusions

Based on the results in Papers I-IV and from the literature, the following conclusions were drawn:

- In both pond and river habitats, highest biomass yield was found in the first cut. Cut had only an effect on NDFom yield in the pond, while it had a significant effect on all yield variables in the river habitat. There was an increase in NDFom content and a decrease in CP when cutting interval was increased from 4 to 7 weeks in the pond habitat, though not significant for NDFom content in the river plants. Water hyacinth has a potential as feed for livestock due to high crude protein content and high dry matter yield for the two habitats of approximately 400 kg/ha/week.
- Conserving water hyacinth as silage for cattle may be improved by the addition of molasses or rice bran. Water hyacinth was successfully ensiled with either sugarcane molasses, rice bran or with a combination of the two additives.
- The improvement of crude protein intake and digestibility has been seen when increasing level of fresh water hyacinth in cattle diets. To exclude problems of bloat and low intake of rice straw, an inclusion level of fresh water hyacinth in the diet should not exceed 30% for growing cattle.
- Nutrient digestibility increased with increasing level of ensiled water hyacinth offered. It seems likely that ensiled water hyacinth at levels of at least 50% of the diet has the potential to supply enough metabolisable energy for reasonable live weight gains of >300 g/day in cattle.

7.2 Future research

- With 762.000 ha area of water surface for aquaculture in the Mekong Delta of Vietnam, a greater availability of water hyacinth should be beneficial in establishing wastewater treatment systems and biomass production, with the emphasis on water quality and the relationship between fish production and water hyacinth coverage in an integrated water hyacinth-fish farming system.

- Depending on household conditions and animal species, either daily harvest or harvest at certain times of the year are interesting alternatives. However, to both ensure an acceptable intake of WH and to increase labour efficiency, it seems that ensiling may offer a better alternative for ruminants. Both these aspects require further studies.
- Wilting is not always feasible in the rainy season in order to ensure acceptable dry matter content for ensiling. In practice, a combination of suitable absorbents and additives are therefore needed to shorten or omit the wilting process without reducing silage quality. This should be investigated further.
- Long-term effects on animal productivity of feeding fresh or ensiled water hyacinth to ruminants should be investigated in the future with respect to growth rate as well as feed conversion efficiency.

Tóm tắt (Abstract in Vietnamese)

Lục bình (*Eichhornia crassipes*) còn gọi là bèo Tây hay bèo Nhật Bản, thuộc chi Eichhornia của họ Pontederiaceae, có nguồn gốc từ Brazil. Lục bình đã du nhập vào Mỹ năm 1884, vào Việt Nam khoảng năm 1902 và Châu Âu những năm 1930. Hiện nay, lục bình lan toả khắp các quốc gia nhiệt đới và cận nhiệt đới. Ở vùng Đồng bằng sông Cửu Long, hệ thống sông ngòi chằng chịt đã tạo điều kiện cho lục bình phát triển rộng khắp. Chúng còn được xem là một trong những loài thực vật thuỷ sinh xâm hại nhất thế giới bởi tốc độ phát triển rất nhanh của nó.

Lục bình có tác động đáng kể liên quan đến các vấn đề kinh tế, xã hội và sinh thái. Chúng cản trở sự thông suốt của giao thông đường thuỷ cũng như ảnh hưởng đến hệ thống cung cấp nước, cản trở dòng chảy,… và phải tốn nhiều công sức cũng như chi phí để giúp khơi thông dòng chảy. Nhiều loài cá khó tồn tại ở ao, hồ dày đặc lục bình do hàm lượng ôxy hoà tan bị giảm nghiêm trọng. Sự suy giảm các loài thực vật thuỷ sinh do quá trình quang hợp bị hạn chế, điều này cũng tác động đến sự phát triển của động thuỷ sinh, gây mất cân bằng hệ sinh thái. Bên cạnh những bất lợi hiện hữu, cũng có những thuận lợi mà lục bình mang lại. Chính đặc điểm hấp thụ kim loại nặng cũng như các chất dinh dưỡng trong nước nên lục bình góp phần làm sạch nguồn nước. Như một loài rau dân dã, hoa, đọt non và ngó lục bình được chế biến thành các món ăn không kém phần hấp dẫn. Lục bình còn được sử dụng làm thức ăn cho gia súc, gia cầm và cá; là nguồn nguyên liệu tiềm năng cho sản xuất hàng thủ công mỹ nghệ và biogas; dùng làm cơ chất cho quá trình sản xuất nấm, làm phân hữu cơ.

Luận án này là tập hợp kết quả của 4 nghiên cứu được thực hiện từ năm 2009 đến năm 2011 tại cù lao An Bình thuộc xã An Bình, huyện Long Hồ, tỉnh Vĩnh Long và phòng thí nghiệm thuộc Bộ môn Chăn nuôi, Khoa Nông nghiệp & Sinh học ứng dụng, Trường Đại học Cần Thơ nhằm đánh đánh giá tiềm năng của lục bình để sử dụng làm thức ăn cho bò.

Một số mục tiêu cụ thể bao gồm:

- Đánh giá ảnh hưởng của khoảng cách thu hoạch và lứa thu hoạch đến năng suất và giá trị dinh dưỡng của lục bình được trồng ở 2 môi trường (sông và ao).
- Nghiên cứu ảnh hưởng của các chất bổ sung như: mật đường, cám và nguồn vi khuẩn acid lactic (dung dịch thu được từ quá trình lên men dưa cải) đến chất lượng lục bình ủ chua.
- Đánh giá ảnh hưởng của các mức độ lục bình tươi trong khẩu phần bò lai Sind đến lượng ăn vào và tiêu hoá dưỡng chất được bổ sung bánh đa dưỡng chất với khẩu phần cơ bản là rơm.
- Nghiên cứu lượng ăn vào và tiêu hoá của bò lai Sind khi khẩu phần kết hợp mức độ khác nhau của lục bình ủ chua được bổ sung bánh dầu bông vải.

Dựa vào các kết quả nghiên cứu, các kết luận sau đây đã được rút ra:

- Trong môi trường sống ở ao, lứa thu hoạch ảnh hưởng đến năng suất chất khô (DM) và năng suất xơ trung tính (NDF) của lục bình, trong khi năng suất NDF ở lá chịu ảnh hưởng bởi khoảng cách thu hoạch. Khi lục bình phát triển trên sông, lứa thu hoạch ảnh hưởng đến tất cả các năng suất khảo sát, nhưng chỉ năng suất đạm thô ở lá bị ảnh hưởng bởi khoảng cách thu hoạch. Tiềm năng sử dụng của lục bình cho gia súc là đáng kể vì thành phần đạm thô cao (từ 176 đến 195 g/kg vật chất khô) và năng suất chất khô cao (khoảng 400 kg/ha/tuần, tương đương 21 tấn/ha/năm) cho cả 2 môi trường phát triển.
- Lục bình được ủ chua thành công với các chất bổ sung như mật đường, cám hoặc sự kết hợp của 2 chất bổ sung đó. Giá trị pH của mẻ ủ giảm nhanh chóng và duy trì ở mức 4.0 ít nhất 2 tuần ủ đầu tiên, sau đó tăng dần đến 4.8 ở tuần thứ 8. Hàm lượng NH_3-N và các sản phẩm cuối của quá trình lên men đều nằm trong giới hạn cho phép.
- Đạm thô ăn vào và tỉ lệ tiêu hoá dưỡng chất được cải thiện khi gia tăng tỉ lệ lục bình tươi trong khẩu phần của bò. Để hạn chế tình trạng trướng hơi và sự ăn vào hạn chế của rơm, thời gian thích nghi của bò đối với lục bình nên được kéo dài và tỉ lệ lục bình tươi không nên vượt quá 30% trong khẩu phần bò tăng trưởng.
- Tỉ lệ tiêu hoá dưỡng chất gia tăng khi tăng mức độ lục bình ủ chua trong khẩu phần của bò. Ở tỉ lệ ít nhất 50% của khẩu phần, lục bình ủ chua có khả năng cung cấp đủ năng lượng tiêu hoá để bò có mức tăng trọng từ 300 g/ngày.

References

Abdalla, A.L., Ambrosano, E.J., Vitti, D.M.S.S. & J C Silva F (1987). Water-hyacinth (*Eichhornia crassipes*) in ruminant nutrition. *Water Science and Technology* 19(10), 109-112.

Abou-Raya, A.K., Hathout, M.K., El-Talty, Y.L. & Abdel-Khabir, A.M. (1980). Utilization of water hyacinth as animal feed: II. Evaluation of wilted shoots in metabolism trials with sheep with reference to N, Ca, Na and K balances. *Agricultural Research Review* 58(6), 49-60.

Aboud, A.A.O., Kidunda, R.S. & Osarya, J. (2005). Potential of water hyacinth (*Eichhornia crassipes*) in ruminant nutrition in Tanzania. *Livestock Research for Rural Development* 17 (8), http://www.lrrd.org/lrrd17/8/abou17096.htm.

AFNOR (1989). *Contrôle de la qualité des produits alimentaires: Méthodes d'analyse officielles*. Paris, France: Association Française de Normalisation Tour Europe Cedex 7, pp. 373.

Agami, M. & Reddy, K.R. (1990). Competition for space between *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. cultured in nutrient-enriched water. *Aquatic Botany* 38(2-3), 195-208.

AgroMonitor (2011). *AgroMonitor releases Vietnam meat and foodstuff annual report 2011 and outlook for 2012*: Vietnam Market Analysis and Forecast Joint Stock Company, Ha Noi, Vietnam.

Amigot, S.L., Fulgueira, C.L., Bottai, H. & Basílico, J.C. (2006). New parameters to evaluate forage quality. *Postharvest Biology and Technology* 41(2), 215-224.

An, L.V., Frankow-Lindberg, B.E. & Lindberg, J.E. (2003). Effect of harvesting interval and defoliation on yield and chemical composition of leaves, stems and tubers of sweet potato (*Ipomoea batatas* L. (Lam.)) plant parts. *Field Crops Research* 82(1), 49-58.

AOAC (1990). *Official Methods of Analysis (15th ed.)*. Virginia, USA: Association of Official Analytical Chemists Inc.

AOAC (2000). *Official Methods of Analysis (17th ed.)*. Washington DC, USA: Association of Official Analytical Chemists.

APHA (1998). Standard methods for the examination of water and wastewater, 20th ed. In: Clescerl, L.S., *et al.* (Eds.). Washington DC, USA: American Public Health Association.

Aregheore, E.M. & Cawa, K. (2000). Voluntary intake by crossbred Anglo-Nubian goats of water hyacinth (*Eichhornia crassipes*) fed in two states plus Guinea grass (*Panicum maximum*) in confinement. *Scientia Agriculturae Bohemica* 31(4), 261-271.

Ashbell, G., Kipnis, T., Titterton, M., Hen, Y., Azrieli, A. & Weinberg, Z.G. (2001). Examination of a technology for silage making in plastic bags. *Animal Feed Science and Technology* 91(3-4), 213-222.

Aswathy, U.S., Sukumaran, R.K., Devi, G.L., Rajasree, K.P., Singhania, R.R. & Pandey, A. (2010). Bio-ethanol from water hyacinth biomass: An evaluation of enzymatic saccharification strategy. *Bioresource Technology* 101(3), 925-930.

Baldwin, J.A., Hentges, J.F., Bagnall, L.O. & Shirley, R.L. (1975). Comparison of pangolagrass and water hyacinth silages as diets for sheep. *Journal of Animal Science* 40(5), 968-971.

Barrett, S.C.H. (1988). Evolution of breeding systems in *Eichhornia* (Pontederiaceae): A review. *Annals of Missouri Botanical Garden* 75(3), 741-760.

Begum, N., Khan, M.J. & Islam, K.M.S. (2000). Feeding rations containing road side grass, maize silage or water hyacinth in bull calves. *Pakistan Journal of Biological Sciences* 3(10), 1730-1732.

Biswas, P. & Mandal, L. (1988). Use of fresh water hyacinth (*Eichhornia crassipes*) in the ration of growing calves. *Indian Veterinary Journal* 65, 496-500.

Borhami, B.E., S. M, Z., Fahmy, W.G. & Somaa, A. (1992). The utilization of protein extraction residues from berseem and water hyacinth for fattening buffalo calves. *Buffalo Bulletin* 11(2), 40-43.

Boyd, C.E. (1976). Accumulation of dry matter, nitrogen and phosphorus by cultivated water hyacinths. *Economic Botany* 30(1), 51-56.

Buddington, R.K. (1980). Hydrolysis-resistant organic matter as a reference for measurement of fish digestion efficiency. *Transactions of the American Fisheries Society* 109(6), 653-656.

Burns, B.M., Binh, D.V. & Su, V.V. (2002). Beef cattle genetic and breeding projects in Vietnam and the future direction. In: Allen, J*., et al.* (Eds.) *Development Strategies for Genetic Evaluation for Beef Production in Developing Countries*. pp. 148-153. ACIAR Proceedings 108: Australian Centre for International Agricultural Research, Canberra, Australia.

Buxton, D.R. (1996). Quality-related characteristics of forages as influenced by plant environment and agronomic factors. *Animal Feed Science and Technology* 59(1-3), 37-49.

Byron, H.T., James F Hentges, J.R., O'Connell, J.D. & Bagnall, L.O. (1975). Organic acid preservation of waterhyacinth silage. *Hyacinth Control Journal* 13, 64-66.

Carignan, R., Neiff, J.J. & Planas, D. (1994). Limitation of water hyacinth by nitrogen in subtropical lakes of the Paraná floodplain (Argentina). *Limnology and Oceanography* 39, 439-443.

Castle, M.E. & Watson, J.N. (1985). Silage and milk production: studies with molasses and formic acid as additives for grass silage. *Grass and Forage Science* 40(1), 85-92.

Center, T.D., Hill, M.P., Cordo, H. & Julien, M.H. (2002). Waterhyacinth. In: Driesche, R.V*., et al.* (Eds.) *Biological Control of Invasive Plants in the Eastern United States*. pp. 41-64 USDA Forest Service.

Center, T.D. & Spencer, N.R. (1981). The phenology and growth of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) in a eutrophic north-central Florida lake. *Aquatic Botany* 10(0), 1-32.

Chakraborty, B., Biswas, P., Mandal, L. & Banerjee, G.C. (1991). Effect of feeding fresh water hyacinth *(Eichhorinia crassipes)* or its silage on the milk production in crossbred cows. *Indian Journal of Animal Nutrition* 8(2), 115-118.

Chantalakhana, C. (1990). Small farm animal production and sustainable agriculture. In, The 5 th AAAP Animal Science Congress, Vol. 2, May 27-June 1, 1990, Taipei, Taiwan. pp. 39-58.

Charudattan, R. (1986). Integrated control of waterhyacinth (*Eichhornia crassipes*) with a pathogen, insects, and herbicides. *Weed Science* 34(Suppl. 1), 26-30.

Chen, Y.-L., Chiang, H.-C., Wu, L.-Q. & Wang, Y.-S. (1989). Residues of glyphosate in an aquatic environment after control of water hyacinth (*Eichhornia crassipes*). *Journal of Weed Science and Technology* 34(2), 117-122.

Chinh, B.V. & Ly, L.V. (2001). Identification of some levels of urea applied for treatment of rice straw using as feed for dairy and growing cattle. In: *Proceeding on improved utilization of by-products for animal feeding in Vietnam, 28-30 March, 2001.* Agricultural Publishing House, Hanoi, Vietnam. pp. 20-26.

Chowdhury, A., Majid, M.A., Huque, K.S., Islam, M. & Rahman, M.M. (1995). Effect of variety on yield and nutritive value of rice straw. *Asian-Australasian Journal of Animal Sciences* 8(4), 329-335.

Church, D.C. (1991). *Livestock Feeds and Feeding, 3rd ed.* Prentice Hall, Englewood Cliffs, New Jersey, USA.

Coulman, B., Goplen, B., Majak, W., McAllister, T., Cheng, K.J., Berg, B., Hall, J., McCartney, D. & Acharya, S. (2000). A review of the development of a bloat-reduced alfalfa cultivar. *Canadian Journal of Plant Science* 80(3), 487-491.

Dada, S.A. (2002). The utilization of water hyacinth (*Eichhornia crassipes*) by West African dwarf (wad) growing goats. *African Journal of Biomedical Research* 4, 147-149.

Damron, B.L. & Wilson, H.R. (2008). Geese for water hyacinth control. *American Small Farm*, 22-23.

De Groote, H., Ajuonu, O., Attignon, S., Djessou, R. & Neuenschwander, P. (2003). Economic impact of biological control of water hyacinth in Southern Benin. *Ecological Economics* 45(1), 105-117.

Department of Animal Husbandry (2006). *The report of the animal husbandry sector in the period from 2001 to 2005 and the direction for the development in the period from 2006 to 2015 (in Vietnamese)*. Hanoi, Vietnam: Department of Animal Husbandry, Ministry of Agriculture and Rural Development of Vietnam.

Devendra, C. (1985). *Non-conventional feed resources in Asia and the Pacific, 2nd edn.* FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Devendra, C. (2007). Perspectives on animal production systems in Asia. *Livestock Science* 106(1), 1-18.

Devendra, C., Sevilla, C. & Pezo, D. (2001). Food-feed systems in Asia - Review. *Asian-Australasian Journal of Animal Sciences* 14(5), 733-745.

DiTomaso, J.M. & Healy, E.A. (Eds.) (2003). *Aquatic and riparian weeds of the West*. University of California. Division of Agriculture and Natural Resources, California Weed Science Society: ANR Publications, pp. 52-55.

Downing-Kunz, M.A. & Stacey, M.T. (2012). Observations of mean and turbulent flow structure in a free-floating macrophyte root canopy. *Limnology and Oceanography: Fluids and Environments* 2, 67-79.

Doyle, P.T., Devendra, C. & Pearce, G.R. (1986). *Rice straw as a feed for ruminants*. International Development Program of Australian Universities and Colleges Limited (IDP), Canberra, Australia.

Driehuis, F. & Elferink, S.J.W.H.O. (2000). The impact of the quality of silage on animal health and food safety: A review. *Veterinary Quarterly* 22(4), 212-216.

Dung, N.N.X. (2001). *Evaluation of green plants and by-products from the Mekong delta with emphasis on fibre utilisation by pig.* Diss. Uppsala:Swedish University of Agricultural Sciences, Agraria 285.

El-Sayed, A.-F.M. (2003). Effects of fermentation methods on the nutritive value of water hyacinth for Nile tilapia *Oreochromis niloticus* (L.) fingerlings. *Aquaculture* 218(1-4), 471-478.

Elserafy, Z.M., Sonbol, H.A. & Eltantawy, I.M. (1980). The problem of water hyacinth in rivers and canals I. Production of compost from plant. *Soil Science and Plant Nutrition* 26(1), 135-138.

Fitzsimons, R. & Vallejos, R. (1986). Growth of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) in the middle Paraná River (Argentina). *Hydrobiologia* 131(3), 257-260.

Forbes, J.M. (2007). *Voluntary Food Intake and Diet Selection in Farm Animals, 2nd ed.* Wallingford, Oxfordshire, UK: CABI Publishing.

Ganguly, A., Chatterjee, P.K. & Dey, A. (2012). Studies on ethanol production from water hyacinth-A review. *Renewable and Sustainable Energy Reviews* 16(1), 966-972.

Gopal, B. (1987). *Water hyacinth*. Elsevier, Amsterdam, The Netherlands, 471 pp.

Gopal, B. (1998). Aquatic weeds: from weed control to plant management. In: Monteiro, A.*, et al.* (Eds.) *Management and ecology of aquatic plants. Proceedings of the 10th EWRS International Symposium on Aquatic Weeds, Lisbon, Portugal, 21-25 September 1998.* Doorwerth: European Weed Research Society. pp. 357-360.

Gopal, B. & Goel, U. (1993). Competition and allelopathy in aquatic plant communities. *Bot. Rev.* 59(3), 155-210.

Goswami, T. & Saikia, C.N. (1994). Water hyacinth - A potential source of raw material for greaseproof paper. *Bioresource Technology* 50(3), 235-238.

GSO (2011). *Statistical data on agriculture, forestry and fishery*. General Statistics Office of Vietnam: http://www.gso.gov.vn/default_en.aspx?tabid=469&idmid=3.

Gunnarsson, C.C. & Petersen, C.M. (2007). Water hyacinths as a resource in agriculture and energy production: A literature review. *Waste Management* 27(1), 117-129.

Gupta1, P., Roy, S. & Mahindrakar, A.B. (2012). Treatment of water using water hyacinth, water lettuce and vetiver grass - A review. *Resources and Environment* 2(5), 202-215.

Gutiérrez, E., Huerto, R., Saldaña, P. & Arreguín, F. (1996). Strategies for waterhyacinth (*Eichhornia crassipes*) control in Mexico. *Hydrobiologia* 340(1), 181-185.

Gutiérrez, E.L., Ruiz, E.F., Uribe, E.G. & Martínez, J.M. (2001). Biomass and productivity of water hyacinth and their application in control programs. In: Julien, M.H.*, et al.* (Eds.) *ACIAR Proceedings 102, Australian Centre for International Agricultural Research, Australia*. pp. 109-119.

Ha, J.K. & Kim, H.J. (2004). Management of dairy-animal feeding for better productivity and food safety. In: *Seminar on Sustainable Dairy-sector Development for Poverty Reduction, 22-27 November 2004.* Faisalabad, Pakistan. pp. 25-35.

Heard, T.A. & Winterton, S.L. (2000). Interactions between nutrient status and weevil herbivory in the biological control of water hyacinth. *Journal of Applied Ecology* 37(1), 117-127.

Hertrampf, J.W. & Piedad-Pascual, F. (2000). *Handbook on Ingredients for Aquaculture Feeds*: Kluwer Academic Publishers, The Netherlands.

Hong, N.T.T., Wanapat, M., Wachirapakorn, C., Pakdee1, P. & Rowlinson, P. (2003). Effects of timing of initial cutting and subsequent cutting on yields and chemical compositions of cassava hay and its supplementation on lactating dairy cows. *Asian-Australasian Journal of Animal Sciences* 16(12), 1763-1769.

Howard, G.W. & Harley, K.L.S. (1998). How do floating aquatic weeds affect wetland conservation and development? How can these effects be minimised? *Wetlands Ecology and Management* 5, 215-225.

Huhtanen, P., Khalili, H., Nousiainen, J.I., Rinne, M., Jaakkola, S., Heikkilä, T. & Nousiainen, J. (2002). Prediction of the relative intake potential of grass silage by dairy cows. *Livestock Production Science* 73(2-3), 111-130.

Huy, H.T. & Khoi, L.N.D. (2011). Analysis of labour migration flows in the Mekong Delta of Vietnam. In: Stewart, M.A., *et al.* (Eds.) *Environmental Change and Agricultural Sustainability in the Mekong Delta, Advances in Global Change Research 45*. pp. 115-140 Springer.

Huyen, L.T.T., Herold, P. & Valle Zárate, A. (2010). Farm types for beef production and their economic success in a mountainous province of northern Vietnam. *Agricultural Systems* 103(3), 137-145.

International Organization for Standardization (1998). *Microbiology of food and animal feeding stuffs - Horizontal method for the enumeration of mesophilic lactic acid bacteria-colony-count technique at 30 degrees C (ISO 15214:1998)*. Switzerland.

Islam, S., Khan, M.J. & Islam, M.N. (2009). Effect of feeding wilted water hyacinth (*Eichhornia crassipes*) on the performance of growing bull cattle. *Indian Journal of Animal Sciences* 79(5), 494-497.

Jianbo, L., Zhihui, F. & Zhaozheng, Y. (2008). 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. *Journal of Environmental Sciences* 20, 513-519.

Julien, M.H., Griffiths, M.W. & Stanley, J.N. (2001). *Biological control of water hyacinth 2. The moths Niphograpta albiguttalis and Xubida infusellus: biologies, host ranges, and rearing, releasing and monitoring techniques*. Canberra, Australia.

Kellems, R.O. & Church, D.C. (2003). *Livestock Feeds and Feeding, 5th ed.* Prentice Hall, Upper Saddle River, New Jersey, USA.

Khan, M.J., Steingass, H. & Drochner, W. (2002). Evaluation of some aquatic plants from Bangladesh through mineral composition, *in vitro* gas production and *in situ* degradation measurements. *Asian-Australasian Journal of Animal Sciences* 15(4), 537-542.

Khang, D.N. & Wiktorsson, H. (2004). Effects of fresh cassava tops on rumen environment parameters, thyroid gland hormones and liver enzymes of local yellow cattle fed urea-treated fresh rice straw. *Tropical Animal Health and Production* 36(8), 751-762.

Kivaisi, A.K. & Mtila, M. (1998). Production of biogas from water hyacinth (*Eichhornia crassipes*) (Mart) (Solms) in a two-stage bioreactor. *World Journal of Microbiology & Biotechnology* 14, 125-131.

Knický, M. (2005). *Possibilities to improve silage conservation - Effects of crop, ensiling technology and additives*. Diss. Uppsala, Sweden:Swedish University of Agricultural Sciences.

Kushwaha, S.P.S. (2012). Remote sensing of invasive alien plant species. In: Bhatt, J.R.*, et al.* (Eds.) *Invasive Alien Plants: An Ecological Appraisal for the Indian Subcontinent*. pp. 131-138. United Kingdom: CABI International.

Lareo, L. & Bressani, R. (1982). Possible utilization of the water hyacinth in nutrition and industry. *Food & Nutrition Bulletin* 4(4), 60-64.

Leibeinsperger, R.Y. & Pitt, R.E. (1988). Modeling the effects of formic acid and molasses on ensilage. *Journal of Dairy Science* 71(5), 1220-1231.

Liao, S.-W. & Chang, W.-L. (2004). Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan. *Journal of Aquatic Plant Management* 42, 60-68.

Lindgren, E. (1977). Results from a modified one-stage *in vitro* technique. In: Knutsson, P.-G. (Ed.) *Quality of forage: Proceedings of a seminar organized by the NJF, Uppsala 20-22 April, 1977*. Department of Animal Nutrition and Management, Swedish University of Agricultural Science, Uppsala, Report no. 54. pp. 119-126.

Lindsey, K. & Hirt, H.-M. (1999). *Use water hyacinth. A practical handbook of uses for the water hyacinth from across the world*: Marianum Press, Kisubi, Uganda.

Linn, J.G., Goodrich, R.D., Otterby, D.E., Meiske, J.C. & Staba, E.J. (1975). Nutritive value of dried or ensiled aquatic plants. II. Digestibility by sheep. *Journal of Animal Science* 41(2), 610-615.

Low, K.S., Lee, C.K. & Tai, C.H. (1994). Biosorption of copper by water hyacinth roots. *Journal of Environmental Science and Health. Part A, Environmental Science and Engineering* 29(1), 178-188.

Luu, K.T. & Getsinger, K.D. (1990). Seasonal biomass and carbohydrate allocation in waterhyacinth. *Journal of Aquatic Plant Management* 28, 3-10.

Ly, L.V. (1995). Ruminant production in Vietnam and development of forage in smallholder farm. In: *Enhancing Sustainable Livestock-crop Production in Smallholder Farming Systems. Proceedings of the Fourth Meeting of Forage Regional Working Group on Grazing and Feed Resources of Southeast Asia.* Nha Trang, Vietnam, 20-24 March 1995: Food and Agriculture Organization of the United Nations. pp. 57-62.

Magalhães, K.A., Valadares Filho, S.C., Detmann, E., Diniz, L.L., Pina, D.S., Azevedo, J.A.G., Araújo, F.L., Marcondes, M.I., Fonseca, M.A. & Tedeschi, L.O. (2010). Evaluation of indirect methods to estimate the nutritional value of tropical feeds for ruminants. *Animal Feed Science and Technology* 155(1), 44-54.

Malik, A. (2007). Environmental challenge vis a vis opportunity: The case of water hyacinth. *Environment International* 33(1), 122-138.

Man, N.V. & Wiktorsson, H. (2001). The effect of replacing grass with urea treated fresh rice straw in dairy cow diet. *Asian-Australasian Journal of Animal Sciences* 14(8), 1090-1097.

Manh, L.H., Dung, N.N.X. & Yamasaki, S. (2002a). Water hyacinth (*Eichhornia crassipes*): Ensiling techniques, its composition and intake of pigs. In: *Proceedings of the 2002 annual workshop of JIRCAS Mekong Delta Project - Development of new technologies and their practice for sustainable farming systems in the Mekong Delta.* November 26-28, 2002, Can Tho University, Can Tho city, Vietnam. pp. 168-175.

Manh, L.H., Dung, N.N.X., Yamasaki, S. & Takada, R. (2002b). Replacement of concentrate by water hyacinth (*Eichhroria crassipes*): Effects on digestibility, feed intake and live weight gain in pig production. In: Yamasaki, S*., et al.* (Eds.) *Proceedings of the 2002 annual workshop of JIRCAS Mekong Delta Project - Development of new technologies and their practice for sustainable farming systems in the Mekong Delta.* November 26-28, 2002, Can Tho University, Can Tho city, Vietnam. pp. 152-158.

Mara, M.J. (1976). Estimated costs of mechanical control of water hyacinths. *Journal of Environmental Economics and Management* 2(4), 273-294.

Masifwa, W.F., Twongo, T. & Denny, P. (2001). The impact of water hyacinth, *Eichhornia crassipes* (Mart) Solms on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria, Uganda. *Hydrobiologia* 452(1), 79-88.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. & Wilkinson, R.G. (2011). *Animal Nutrition. 7th edn*. Harlow, England: Pearson.

McDonald, P., Henderson, N. & Heron, S. (1991). *The Biochemistry of Silage. 2nd edn*. Marlow, Bucks, England: Chalcombe Publications.

McVea, C. & Boyd, C.E. (1975). Effects of water hyacinth cover on water chemistry, phytoplankton, and fish in ponds. *Journal of Environmental Quality* 4(3), 375-378.

Men, B.X., Ogle, B. & Lindberg, J.E. (2002). Effect of diet and management system on growing duck performance in the Mekong Delta of Vietnam. *Journal of Sustainable Agriculture* 20(3), 21-32.

Men, B.X. & Yamasaki, S. (2005). Use of water hyacinth as partial supplements in diets of growing crossbred common ducks. In: *Proceedings of the Workshop on the Technology Development for Livestock Production, JIRCAS - CTU.* Can Tho University, Vietnam. pp. 83-90.

Men, L.T., Yamasaki, S., Caldwell, J.S., Yamada, R., Takada, R. & Taniguchi, T. (2006). Effect of farm household income levels and rice-based diet or water hyacinth (*Eichhornia crassipes*) supplementation on growth/cost performances and meat indexes of growing and finishing pigs in the Mekong Delta of Vietnam. *Animal Science Journal* 77(3), 320-329.

Minitab Inc. (2010). *Minitab Statistical Software, version 16.1.0*: State College, Pennsylvania, USA.

Mishra, S.P. (2006). Mineral content and antinutritional constituents in fibrous residue from water hyacinth harvested at different maturity stages. *Indian Journal of Agricultural Biochemistry* 19(2), 85-87.

Moorhead, K.K., Reddy, K.R. & Graetz, D.A. (1988). Water hyacinth productivity and detritus accumulation. *Hydrobiologia* 157(2), 179-185.

Moreland, A.F., Collins, B.R., Hansen, C.A. & Obrien, R. (1991). Wastewater grown waterhyacinth as an ingredient in rabbit food. *Journal of Aquatic Plant Management* 29, 32-39.

Mukherjee, R. & Nandi, B. (2004). Improvement of in vitro digestibility through biological treatment of water hyacinth biomass by two *Pleurotus* species. *International Biodeterioration & Biodegradation* 53 7-12.

MWBP/RSCP (2006). *Invasive Alien Species in the Lower Mekong Basin: Current State of Play. Mekong Wetland Biodiversity Programme and Regional Species Conservation Programme, The World Conservation Union (IUCN), Asia, Sri Lanka*; 22pp.

Nageswaran, M., Gopalakrishnan, A., Ganesan, M., Vedhamurthy, A. & Selvaganapathy, E. (2003). Evaluation of waterhyacinth and paddy straw waste for culture of oyster mushrooms. *Journal of Aquatic Plant Management* 41, 122-123.

National Academy of Sciences (1976). *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries*. Washington DC., USA.

NIAH (2003). *The Vietnam National Country Report on Animal Genetic Resources*. National Institute of Animal Husbandry, Ha Noi, Vietnam.

Nin, A., Lapar, M.L. & Ehui, S. (2003). Globalization, trade liberalization and poverty alleviation in Southeast Asia: the case of the livestock sector in Vietnam. In: *Proceedings of The 6th annual conference on global economic analysis, June 12-14, 2003*, Scheveningen, The Hague, The Netherlands. pp. 1-38.

Nolan, W.J. & Kirmse, D.W. (1974). The paper making properties of waterhyacinth. *Hyacinth Control Journal* 12, 90-97.

Nuka, L. & Dubey, V. (2011). Response of water hyacinth manure on growth attributes and yield in *Brassica juncea*. *Journal of Central European Agriculture* 12(2), 336-343.

OEPP/EPPO (2008). Data sheets on quarantine pests *Eichhornia crassipes*. *Bulletin OEPP/EPPO Bulletin* 38(3), 441-449.

OEPP/EPPO (2009). National regulatory control systems *Eichhornia crassipes*. *Bulletin OEPP/EPPO Bulletin* 39(3), 460-464.

Ogle, B.M., Dao, H.T.A., Mulokozi, G. & Hambraeus, L. (2001). Micronutrient composition and nutritional importance of gathered vegetables in Vietnam. *International Journal of Food Sciences and Nutrition* 52(6), 485-499.

Oroka, F.O. (2012). Water hyacinth-based vermicompost on yield, yield components, and yield advantage of cassava+groundnut intercropping system. *Journal of Tropical Agriculture* 50(1-2), 49-52.

Owen, E., Smith, T. & Makkar, H. (2012). Successes and failures with animal nutrition practices and technologies in developing countries: A synthesis of an FAO e-conference. *Animal Feed Science and Technology* 174(3-4), 211-226.

Parashar, S.K., Rajora, N.K. & Jain, L.S. (1999). Utilization of water hyacinth (*Eichhornia crassipes*) by growing crossbred calves. *Indian Journal of Dairy Science* 52(5), 320-323.

Parsons, W.T. & Cuthbertson, E.G. (Eds.) (2001). *Noxious Weeds of Australia (2nd edition)*. Collingwood, Victoria, Australia, pp. 139-144: CSIRO Publishing.

Penfound, W.T. & Earle, T.T. (1948). The biology of the water hyacinth. *Ecological Monographs* 18(4), 447-472.

Perna, C. & Burrows, D. (2005). Improved dissolved oxygen status following removal of exotic weed mats in important fish habitat lagoons of the tropical Burdekin River floodplain, Australia. *Marine Pollution Bulletin* 51(1-4), 138-148.

Pettersson, K.L. & Lindgren, S. (1990). The influence of the carbohydrate fraction and additives on silage quality. *Grass and Forage Science* 45(2), 223-233.

Poddar, K., Mandal, L. & Banerjee, G.C. (1991). Studies on water hyacinth (*Eichhornia crassipes*) – Chemical composition of the plant and water from different habitats. *Indian Veterinary Journal* 68, 833-837.

Rahman, M.M., Ishii, Y., Niimi, M. & Kawamura, O. (2010). Interactive effects of nitrogen and potassium fertilization on oxalate content in napiergrass (*Pennisetum purpureum*). *Asian-Australasian Journal of Animal Sciences* 23(6), 719-723.

Rahman, M.M., Nakagawa, T., Niimi, M., Fukuyama, K. & Kawamura, O. (2011). Effects of feeding oxalate containing grass on intake and the concentrations of some minerals and parathyroid hormone in blood of sheep. *Asian-Australasian Journal of Animal Sciences* 24(7), 940-945.

Ravindran, V. & Rajaguru, A.S.B. (1988). Effect of stem pruning on cassava root yield and leaf growth. *Sri Lankan Journal of Agricultural Science* 25(2), 32-37.

Reddy, K.R., Agami, M., D'Angelo, E.M. & Tucker, J.C. (1991). Influence of potassium supply on growth and nutrient storage by water hyacinth. *Bioresource Technology* 37(1), 79-84.

Reddy, K.R., Agami, M. & Tucker, J.C. (1990). Influence of phosphorus on growth and nutrient storage by water hyacinth (*Eichhornia crassipes* (Mart.) Solms) plants. *Aquatic Botany* 37(4), 355-365.

Reddy, K.R. & D'Angelo, E.M. (1990). Biomass yield and nutrient removal by water hyacinth (*Eichhornia crassipes*) as influenced by harvesting frequency. *Biomass* 21(1), 27-42.

Reddy, K.R. & DeBusk, W.F. (1984). Growth characteristics of aquatic macrophytes cultured in nutrient-enriched water: I. Water hyacinth, water lettuce, and pennywort. *Economic Botany* 38(2), 229-239.

Reddy, K.R. & Sutton, D.L. (1984). Waterhyacinths for water quality improvement and biomass production. *Journal of Environmental Quality* 13(1), 1-8.

Richard, D.I., Small, J.W. & Osborne, J.A. (1985). Response of zooplankton to the reduction and elimination of submerged vegetation by grass carp and herbicide in four Florida lakes. *Hydrobiologia* 123(2), 97-108.

Robertson, J.B. & Van Soest, P.J. (1981). The detergent system of analysis and its application to human foods. In: James, W.P.T.*, et al.* (Eds.) *The Analysis of Dietary Fibre in Food*. pp. 123-158. New York, USA: Marcel Dekker Inc.

Rupainwar, D.C., Rai, S., Swami, M.S.N. & Sharma, Y.C. (2004). Uptake of zinc from water and wastewater by a commonly available macrophyte. *International Journal of Environmental Studies* 61(4), 395-401.

Sanni, K.O. & Adesina, J.M. (2012). Response of water hyacinth manure on growth attributes and yield of *Celosia argentea* L (Lagos Spinach). *Journal of Agricultural Technology* 8(3), 1109-1118.

SAS Institute Inc. (2011). *Base SAS® 9.3 Procedures Guide: Statistical procedures*. Cary, North Carolina, USA: SAS Institute Inc.

Seabrook, E.L. (1962). The correlation of mosquito breeding to hyacinth plants. *Hyacinth Control Journal* 1, 18-19.

Son, V.V. & Trung, N.B. (2002). Utilization of water hyacinth (*Eichhornia crassipes*) as a supplement in diets of fattening pig. In: Yamasaki, S., *et al.* (Eds.) *Proceedings of the 2002 annual workshop of JIRCAS Mekong Delta Project - Development of new technologies and their practice for sustainable farming systems in the Mekong Delta.* November 26-28, 2002, Can Tho University, Can Tho city, Vietnam. pp. 146-151.

Sotolu, A.O. (2010). Digestibility value and nutrient utilization of water hyacinth (*Eichhornia crassipes*) meal as plant protein supplement in the diet of *Clarias gariepinus* (Burchell, 1822) juveniles. *American-Eurasian Journal of Agricultural & Environmental Sciences* 9(5), 539-544.

Spencer, D.F. & Ksander, G.G. (2005). Seasonal growth of waterhyacinth in the Sacramento/San Joaquin Delta, California. *Journal of Aquatic Plant Management* 43, 91-94.

Steen, R.W.J., Gordon, F.J., Dawson, L.E.R., Park, R.S., Mayne, C.S., Agnew, R.E., Kilpatrick, D.J. & Porter, M.G. (1998). Factors affecting the intake of grass silage by cattle and prediction of silage intake. *Animal Science* 66(01), 115-127.

Su, V.V. & Binh, D.V. (2002). Cattle breeding in Vietnam. In: Allen, J., *et al.* (Eds.) *Development Strategies for Genetic Evaluation for Beef Production in Developing Countries*. pp. 98-101. ACIAR Proceedings 108: Australian Centre for International Agricultural Research, Canberra, Australia.

Thu, N.V. (2011). Effects of water hyacinth (*Eichhornia crassipes*) in local cattle diets on nutrient utilization, rumen parameters and microbial protein synthesis. In: *Proceedings of SAADC 2011 strategies and challenges for sustainable animal agriculture-crop systems, Volume III: full papers. Proceedings of the 3rd International Conference on sustainable animal agriculture for developing countries, Nakhon Ratchasima, Thailand, 26-29 July, 2011*. pp. 422-426.

Thu, N.V. & Dong, N.T.K. (2009). A study of water hyacinth (*Eichhornia crassipes*) as a feed resource for feeding growing rabbits. In: Preston, R., *et al.* (Eds.) *International Conference on Livestock, Climate Change and the Environment.* 16-18 October 2009, An Giang University, Vietnam.

Thuy, T.N. (2012). Poverty reduction strategies in an ethnic minority community: Multiple definitions of poverty among Khmer villagers in the Mekong Delta, Vietnam. *Asian Social Science* 8(6), 196-208.

Timmer, C.E. & Weldon, L.W. (1967). Evapotranspiration and pollution of water by water hyacinth. *Hyacinth Control Journal* 6, 34-37.

Trach, N.X. (1998). The need for improved utilisation of rice straw as feed for ruminants in Vietnam: An overview. *Livestock Research for Rural Development* 10(2), http://www.lrrd.org/lrrd10/2/trach102.htm.

Tran, T.T., Nguyen, V.D., Do, D.N., Nguyen, H.P. & Choi, J. (2011). Assessment of electric power generation via water hyacinths and agricultural waste. *Journal of Energy and Power Engineering* 5, 627-631.

Tripathi, B.D. & Upadhyay, A.R. (2003). Dairy effluent polishing by aquatic macrophytes. *Water, Air, & Soil Pollution* 143(1), 377-385.

Tucker, C. (1981). Relationships between culture density and the composition of three floating aquatic macrophytes. *Hydrobiologia* 85(1), 73-76.

Tucker, C.S. & Debusk, T.A. (1981). Seasonal growth of *Eichhornia crassipes* (Mart.) solms: Relationship to protein, fiber, and available carbohydrate content. *Aquatic Botany* 11(0), 137-141.

Uchida, S., Kim, K.H. & Yun, I.S. (1989). The effect of wilting on silage making from the viewpoint in connection with monsoon Asia (A review). *Asian-Australasian Journal of Animal Sciences* 12(1), 43-49.

Udén, P. (2006). *In vitro* studies on microbial efficiency from two cuts of ryegrass (*Lolium perenne*, *cv.* Aberdart) with different proportions of sugars and protein. *Animal Feed Science and Technology* 126(1-2), 145-156.

Ueki, K. (1978). Habitat and nutrition of water hyacinth. *Japan Agricultural Research Quarterly* 12(3), 121-127.

USDA Foreign Agricultural Service (2006). *Vietnam livestock and products annual 2006*. Hanoi, Vietnam: USDA Foreign Agricultural Service, Hanoi, Vietnam.

Van Os, M., Jailler, M. & Dulphy, J.P. (1996). The influence of ammonia, biogenic amines and γ-aminobutyric acid on grass silage intake in sheep. *British Journal of Nutrition* 76, 347-358.

Van Soest, P.J. (1981). Limiting factors in plant residues of low biodegradability. *Agriculture and Environment* 6(2-3), 135-143.

Van Soest, P.J. (1988). Effect of environment and quality of fibre on the nutritive value of crop residues. In: Reed, J.D*., et al.* (Eds.) *Plant breeding and the nutritive value of crop residues. Proceedings of a workshop held at ILCA, Addis Ababa, Ethiopia, 7-10 December 1987.* ILCA, Addis Ababa.

Van Soest, P.J. (2006). Rice straw, the role of silica and treatments to improve quality. *Animal Feed Science and Technology* 130(3-4), 137-171.

Van Soest, P.J., Robertson, J.B. & Lewis, B.A. (1991). Methods for dietary fibre, neutral detergent fibre and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74, 3583-3597.

Van Soest, P.J. & Wine, R.H. (1968). Determination of lignin and cellulose in acid-detergent fiber with permanganate. *Journal of AOAC International* 51, 780-785.

Villamagna, A.M. & Murphy, B.R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology* 55(2), 282-298.

Virabalin, R., Kositsup, B. & Punnapayak, H. (1993). Leaf protein concentrate from water hyacinth. *Journal of Aquatic Plant Management* 31, 207-209.

Vu, D.D. (2007). Use of urea molasses multinutrient blocks for improving cattle productivity in Viet Nam. In: Makkar, H.P.S*., et al.* (Eds.) *Feed supplementation blocks: Urea-molasses multinutrient blocks: Simple and effective feed supplement technology for ruminant agriculture*. pp. pp. 137-148. Food and Agriculture Organization of the United Nations: Rome.

Wanapat, M., Sriwattanasombat, S. & Chantai, S. (1985). The utilization of diets containing untreated rice straw, urea-ammonia treated rice straw and water hyacinth (*Eichhornia crassipes*, Mart). *Tropical Animal Production* 10, 50-57.

Wang, Z. & Calderon, M.M. (2012). Environmental and economic analysis of application of water hyacinth for eutrophic water treatment coupled with biogas production. *Journal of Environmental Management* 110, 246-253.

Weissbach, F. (1996). New developments in crop conservation. In: Jones, D.I.H., *et al.* (Eds.) *Proceedings of Proceedings of the XIth International Silage Conference*, University of Wales, Aberystwyth, 8-11th September, 1996. pp. 11-25.

Wilkinson, J.M. (2005). *Silage*. Lincoln, United Kingdom: Chalcombe Publications.

Wilson, J.R., Holst, N. & Rees, M. (2005). Determinants and patterns of population growth in water hyacinth. *Aquatic Botany* 81, 51-67.

Wittenberg, R. & Cock, M.J.W. (2001). *Invasive Alien Species: A Toolkit of Best Prevention and Management Practices*. Wallingford, Oxon, UK: CAB International.

Wolverton, B. & McDonald, R.C. (1976). Don't waste waterweeds. *New Scientist*, 318-320.

Wolverton, B.C. & McDonald, R.C. (1978). Nutritional composition of water hyacinths grown on domestic sewage. *Economic Botany* 32(4), 363-370.

Xie, Y. & Yu, D. (2003). The significance of lateral roots in phosphorus (P) acquisition of water hyacinth (*Eichhornia crassipes*). *Aquatic Botany* 75(4), 311-321.

Xuan, V.T., Hai, L.T. & Loc, C.B. (1995). Research priorities for improving animal production by agro-ecological zone in Vietnam. In: Devendra, C., *et al.* (Eds.) *Proceedings of Global Agenda for Livestock Research - Proceedings of the Consultation for the South-East Asia Region*, 10-13 May, 1995, Los Baños, Philippines. Paper 13: International Livestock Research Institute.

Acknowledgements

I gratefully acknowledge the Swedish International Development Agency, Department for Research Cooperation (SIDA-SAREC) for the financial support through the Mekong Basin Animal Research Network (MEKARN) project. I am thankful to the Department of Animal Nutrition and Management, SLU, for providing an intellectual environment and academic facilities during my study; and to Can Tho University (CTU) for their permission to take part in this PhD program.

This thesis was completed under the guidance and contributions of my supervisors:

I would like to express the most special thanks to my main supervisor, Assoc. Prof. Peter Udén, for providing the great opportunity to work with him. The beginning of scientific research is difficult, but to transfer research results into the language of science is even more difficult. However, Peter helped me master the process but not really as expected and I found the success in the most difficult times. I have comprehended not only his skills in processing data and writing scientific paper but also in communication skills. I always wondered why I did not move to Kungsängen earlier?!!!. His negative questions in some cases always made me confused, but I know that in my heart I always say "yes, I have the greatest respect for you".

The flow of work has covered up homesickness, and perhaps Sweden is the second loving house that I have gone through because it has the warmth of the people, especially to Prof. Inger Ledin. I would therefore like to express my gratitude to her great efforts in helping me and giving valuable comments for this thesis. She gave me the motivation to overcome the most difficult phase which I may not have overcome otherwise.

Sincere thanks to Dr. Ngo Van Man, my co-supervisor in Vietnam, who understood my situation, the advantages as well as the difficulties that I have faced to achieve the most reasonable solution.

I would like to acknowledge Dr. Thomas Pauly for his valuable comments about silage. Although there were few opportunities to work together, I have experienced him as a very serious, enthusiastic and friendly researcher.

I also would like to express my sincere gratitude to:

All staff at the Department of Animal Nutrition and Management, SLU, who provided me with useful knowledge and sincere encouragement. The daily lunchtime chats with Peter, Thomas, Rolf, Torsten, Bengt-Ove and Kamyar are really memorable.

Börje Ericson and Jorge André for their help of chemical analyses, to Dr. Margareta Emanuelson and Dr. Ewa Wredle for their encouragement in my studies, and to Prof. Brian Ogle for his help to correct English.

Prof. Ulf Olsson for his help with the statistical analyses.

Assoc. Prof. Duong Nguyen Khang, Mr. Nguyen Van Cong and Mr. Nguyen Kien Cuong of the MEKARN project in Nong Lam University, Vietnam, for their timely distribution of funds.

Dr. Vo Lam and Mrs. Tran Nhut Phuong Diem (An Giang University, Vietnam) who gave me an opportunity to meet farmers for the exchange of research ideas.

Ms. Pham My Ngoan, Mr. Pham Truong Giang and Mr. Nguyen Thanh Luan for their assistance in taking care of the experimental animals and chemical analyses.

My friends from Vietnam, Laos, Cambodia, Sweden, Iran, China and Brazil for their friendship. The warm dinners and humorous stories helped me somewhat to forget my homesickness. You are wonderful people!!

My teachers but also colleagues at Department of Animal Sciences, Can Tho University for sharing experiences and knowledge.

Dr. Nguyen Minh Thong, who introduced me to the scientific research environment. I am very grateful for his help and encouragement.

Dr. Nguyen Thi Hong Nhan and Assoc. Prof. Nguyen Nhut Xuan Dung for creating the most favourable conditions for chemical analyses; to Prof. Nguyen Van Thu for his distribution of molasses-urea cake.

To my parents, older sisters and brothers for their tireless support, encouragement and having a belief in me. To my wife for all her love, unfailing supply and patience over the last years.

I also would like to express my gratitude to all those not mentioned here who helped me to complete this thesis.