Dynamic Soil, Dynamic Plant ©2010 Global Science Books

Feasibility of Vermicomposting Aquaculture Solid Waste on the Mekong Delta, Vietnam: A Pilot Study

Stephanie Birch[1*] • Richard Bell[1] • Jaya Nair[1] • Cao Van Phung[2]

[1] Department of Environmental Science, Murdoch University, 90 South Street, Murdoch, 6150, Western Australia
[2] Department of Soil Science, Cuu Long Rice Research Institute, Can Tho, Vietnam
(Viên Lúa VL ABSCL, Tân Thanh, Cần Thơ, Việt Nam)

Corresponding author: * skbirch@hotmail.com

ABSTRACT

The disposal of aquaculture waste from freshwater pond systems on the Mekong Delta, Vietnam, is causing serious pollution of waterways. Currently, there are few treatment options available for aquaculture wastes. This study investigates the use of vermicomposting to treat the solid component of the waste, aquaculture sludge (AS). *Perionyx excavatus* was used to vermicompost various proportions of AS, rice straw (RS) and water hyacinth (WH). Worm mortality rates ranged from 28 to 77% but there were no significant differences between treatments. Worm reproduction appeared to be increased where higher proportions (> 80%) of AS were used however the treatment with 100% AS had the lowest number of juvenile worms (1.3 ± 0.3 per 50 g substrate). Total N increased significantly with increasing bulking material and final values ranged from 0.4 to 0.9%. Total phosphorus (P), potassium (K), manganese (Mn), magnesium (Mg), calcium (Ca), and available P and K were significantly higher in treatments with WH than treatments with RS as a bulking material due to the initial composition of this material. It was concluded that AS from freshwater pond systems on the Mekong Delta can be effectively treated by vermicomposting and may have potential for subsequent use as an agricultural fertiliser.

Keywords: aquaculture sludge, *Perionyx excavatus*, rice straw, vermicomposting, water hyacinth
Abbreviations: AS, aquaculture sludge; **Cu**, copper; **EC**, electrical conductivity; **Fe**, iron; **K**, potassium; **Mg**, magnesium; **Mn**, manganese; **MD**, Mekong Delta; **N**, nitrogen; **P**, phosphorus; **RS**, rice straw; **TN**, total nitrogen; **TP**, total phosphorus; **TK**, total potassium; **VC**, vermicompost; **WH**, water hyacinth; **Zn**, zinc

INTRODUCTION

On the Mekong Delta (MD), in the south of Vietnam, aquaculture is a prominent industry with gross output increasing significantly in recent years (Son *et al.* 2001). However, large amounts of waste are also produced by aquaculture farms on the Delta (Phuong 1998). It is estimated that 450 million cubic metres of solid and liquid aquaculture waste is discharged annually directly to water sources without treatment. Such disposal results in localised water pollution in the form of increased suspended solids, higher nutrient levels and a fall in dissolved oxygen, all of which can lead to eutrophication of the receiving waterway (Cripps 1995).

Aquaculture in the MD includes a variety of different systems including freshwater pond culture, shrimp culture, mangrove farming, shrimp/mangrove farming, crab culture, crab/mangrove farming and integrated rice/fish farming (Estelles *et al.* 2002). Although saltwater aquaculture is a fast-growing industry in Vietnam (especially shrimp farming), freshwater aquaculture contributes more than half the total aquatic production of the region annually (Hao *et al.* 2001). Earth ponds are the most widely used system for freshwater aquaculture due to their relatively cheap construction and maintenance costs and low technology design (Midlen and Redding 1998). Earth ponds are typically 100-500 m² in area, 3-5 m in depth with a mean annual production of 4.8 tonnes of fish/ha (Phillips 2002).

Recently, investigations regarding alternative aquaculture waste disposal options have begun on the MD. Cao *et al.* (2009) report on the treatment and recycling of pond wastewater and solids onto agricultural crops, primarily rice (Kim *et al.* 2010). The present study is directed towards the treatment and recycling of solid aquaculture waste, or aquaculture sludge (AS) which is composed of fish waste and uneaten fish food that settles at the bottom of the fish pond (Cripps and Bergheim 2000). Although the direct application of this waste to crops is carried out in some circumstances, the production of odours and contamination of the crops with pathogens can be problematic and thus some form of treatment or processing of this waste is desirable.

Vermicomposting, an established organic waste treatment technology, was proposed as a possible treatment approach for AS. It is defined as the joint action of worms and microorganisms to stabilize and transform organic wastes into nutrient-rich end-products (Aira *et al.* 2002; Bajsa *et al.* 2003). On the MD, vermicomposting is practiced for the treatment and processing of cow manure and produces two potentially valuable outputs in the form of organic fertiliser (vermicompost, VC) and high protein animal feed (worms) (Cao, pers. comm.).

A considerable amount of research is available regarding the vermicomposting of other wastes, such as sewage sludge, paper mill pulp and textile mill sludge (e.g. Bajsa *et al.* 2003, Elvira *et al.* 1997, and Kaushik and Garg 2004, respectively). One of the key variables which affect the ability of worms to VC sludge is the type and amount of a bulking material mixed with it. The bulking material can affect the efficiency of vermicomposting, worm survival and reproduction rate (Domínguez *et al.* 2000), and the final nutrient composition of the waste material (Garg *et al.* 2006). The main functions of a bulking material are to: provide additional carbon; increase air voids within the waste; and reduce the bulk weight of the waste mixture (Haug 1993). A wide variety of materials have been used as bulking materials, some of which include:

- cardboard, dry leaves, woodchips (Maboeta and Rens-

Received: 21 April, 2010. Accepted: 15 November, 2010.

Original Research Paper

burg 2003);
- agricultural residues, oat straw (Contreras- Ramos *et al.* 2005);
- spent mycelia (Majumdar *et al.* 2006); and
- paper mulch (Ndegwa and Thompson 2000)

Although, research has found that straw-based materials take considerably longer for worms to fragment during vermicomposting (Edwards and Arancon 2004), two of the most widely-available and low cost organic materials on the MD are rice straw (RS) and aquatic weeds. Rice is harvested two-three times per year on the MD leaving large quantities of RS which is most commonly disposed of by burning. The free-floating aquatic weed, *Eichhornia crassipes*, commonly called water hyacinth (WH), is a severe environmental and economic problem in many tropical and subtropical parts of the world (Gupta *et al.* 2007) and is prolific in the waterways of the MD (Chomchalow and Pongpangan 1976).

The following experiment investigates the vermicomposting potential of AS by the worm *Perionyx excavatus*. Briefly refer to preliminary experiments that suggested *Perionyx excavatus* was the best worm to use.

The following research questions were examined:
1. Is a bulking material necessary for vermicomposting AS?
2. Is AS a suitable material for vermicomposting by *P. excavatus*?
3. Are RS and/or WH suitable bulking material/s for AS vermicomposting? and

What is the optimum ratio of AS to bulking material (RS and/or WH), in terms of worm production and final VC composition?

MATERIALS AND METHODS

The following experimentation was carried out at the Cuu Long Rice Research Institute (CLRRI), O'Mon, Vietnam. Aquaculture sludge was collected locally from a freshwater earth-pond stocking the catfish *Pangasianodon hypophthalmus*. Following fish harvest, sludge was pumped onto adjacent land where dewatering occurred. Rice straw was collected locally two months prior to use and WH was collected from a waterway bordering the CLRRI one month prior to use and air-dried. Rice straw and WH were cut to lengths ≤10 cm and soaked in water for 24 hrs prior to mixing with AS. Materials were drained of excess water before mixing with AS. The characteristics of AS, RS and WH used in this experiment are given in **Table 1**.

Vermicomposting was carried out in 10 L plastic containers with perforated lids and bases to provide aeration and drainage (~1 mm diameter). Adult *P. excavatus*, raised on cow manure, were cleaned of excess dirt and weighed before being placed in vermicomposting containers. Each container was inoculated with 25 *P. excavatus* worms. Treatments were made in triplicate and containers were kept in complete darkness with ~70-75% moisture content at temperatures ranging from 25-30°C. Nine treatments (A through I), containing various mixtures of AS, RS and WH (**Table 2**), were constructed. Vermicomposting was conducted for 53 days, a period determined to be adequate by visual observation of the breakdown of materials.

At the completion of vermicomposting, three substrate samples were collected from each container, with each sample being a composite mixture of material throughout the container. Adult worms were hand sorted from each treatment container, counted and weighed. Adults were identified by the presence of a clitellum. Following removal of adults, a 50 g subsample of the material was weighed and juvenile worms and cocoons counted.

Vermicast analysis was conducted according to the methods used by the Soil Science Department of CLRRI. The Vietnamese reference methods (Nhà Xuất Bản Nông Nghiệp n.d.) have been translated from multiple sources, principally Jackson (1958) and Hesse (1971).

Data was analysed using one-way ANOVA at the 5% level of significance in Microsoft Excel. A test of least significant difference (LSD) was used to identify differences between means.

Table 1 Characteristics of aquaculture sludge, rice straw and water hyacinth.

Characteristic	AS	RS	WH
C:N ratio	21.9	48.1	57.4
TC [a]	10.7 ± 0.19	68.3 ± 5.48	71.7 ± 1.18
TN [a]	0.49 ± 0.01	1.42 ± 0.02	1.25 ± 0.04
TP [a]	0.44 ± 0.01	0.33 ± 0.00	0.47 ± 0.01
TK [a]	1.53 ± 0.23	1.11 ± 0.06	5.79 ± 0.27
Available N [b]	285 ± 4.67	-	-
Available P [b]	199 ± 38.1	-	-
Exchangeable K [b]	531 ± 155.6	-	-
Mg [a]	0.3 ± 0.01	0.24 ± 0.01	0.6 ± 0.02
Ca [a]	0.01 ± 0.00	0.23 ± 0.01	0.86 ± 0.13
Fe [a]	3.81 ± 0.3	0.08 ± 0.01	0.17 ± 0.01
Mn [a]	0.06 ± 0.01	0.05 ± 0.00	1.09 ± 0.13
Cu [b]	168 ± 15	5.33 ± 1.2	6.33 ± 1.45
Zn [b]	250 ± 43.3	178 ± 8.41	29.3 ± 1.2
pH (1:4)	6.8 ± 0.01	7.8 ± 0.04	7.4 ± 0.07
EC (1:4) [c]	0.54 ± 0.03	1.31 ± 0.24	4.6 ± 0.25

[a] percentage (%)
[b] mg kg^{-1}
[c] mS cm^{-1}
AS: aquaculture sludge, RS: rice straw, WH: water hyacinth, C:N: carbon to nitrogen ratio, TC: total carbon, TN: total nitrogen, TP: total phosphorus, TK: total potassium, Mg: magnesium, Ca: calcium, Fe: iron, Mn: manganese, Cu: copper, Zn: zinc, EC: electrical conductivity

Table 2 Treatments and the mixture ratios (by dry weight) of aquaculture sludge, rice straw and water hyacinth used for each treatment.

Treatment Name	Constituent (%) (dry weight)		
	AS	RS	WH
A	100	-	-
B	80	20	-
C	70	30	-
D	60	40	-
E	80	-	20
F	70	-	30
G	60	-	40
H	70	10	20
I	60	20	20

AS: aquaculture sludge, RS: rice straw, WH: water hyacinth

RESULTS

Worm mortality and reproduction

Worm mortality rates ranged from 28.0 ± 18.0% (treatment C) to 77.3 ± 13.1% (treatment F) but there were no significant difference among treatments ($P < 0.2$). There was also no significant difference in cocoon numbers among treatments ($P < 0.4$) with numbers ranging from 0.3 ± 0.3 cocoons per 50 g substrate (treatment G) to 4.3 ± 1.2 cocoons per 50 g substrate (treatment E). However, a significant difference in the average number of juveniles among treatments was observed ($P < 2.0 \times 10^{-4}$) (**Fig. 1**). Treatment A (100% AS) had the lowest number of juvenile worms (1.3 ± 0.3), significantly lower than all other treatments except F and G (4.0 ± 0.6 and 3.7 ± 2.2 juveniles, respectively). With the exception of treatment F, all treatments with 70-80% AS (B, C, E and H) were not significantly different but when comparing mixtures with 60 and 80% AS, there was a significant drop in juvenile numbers when the lower percentage of AS was used (i.e. B (80% AS) > D (60% AS) and E (80% AS) > G (60% AS). The H (70% AS) and I (60% AS) treatments containing both RS and WH also had a significantly higher number of juveniles where a higher proportion of AS was used (13.3 juveniles and 7.0 juveniles, respectively).

Chemical analysis

There was a significant difference in total N (TN) and available N (AN) among treatments ($P < 2.33 \times 10^{-8}$ and 0.02, respectively) (**Fig. 2**). Treatment A (0.48 ± 0.34% N) produced the VC with the lowest total N and treatments G and

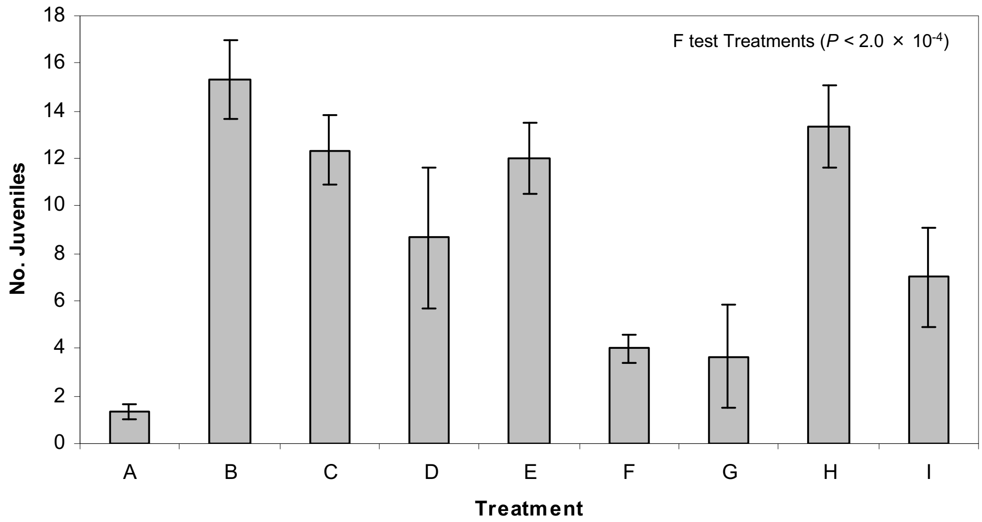

Fig. 1 Number of juvenile worms in a 50 g subsample after 53 days vermicomposting. See **Table 2** for details of Treatments. Vertical bars indicate standard errors for the mean of three replicates.

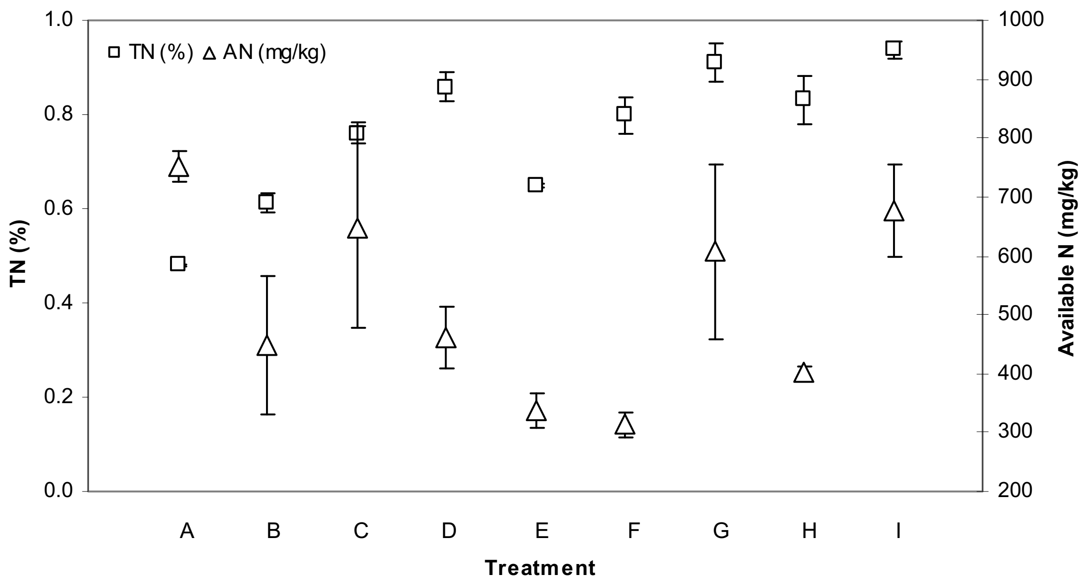

Fig. 2 Total nitrogen (TN) (%) and available nitrogen (AN) (mg kg^{-1}) after 53 days vermicomposting. Values represent mean ± standard error (SE).

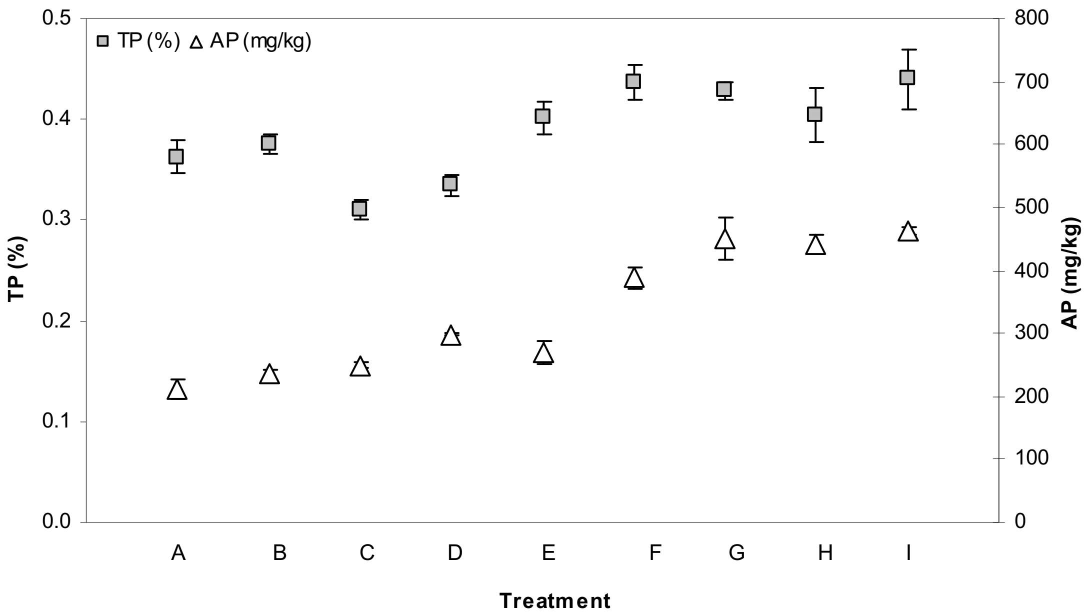

Fig. 3 Total phosphorus (TP) (%) and available phosphorus (AP) (mg kg^{-1}) after 53 days vermicomposting. Values represent mean ± standard error (SE).

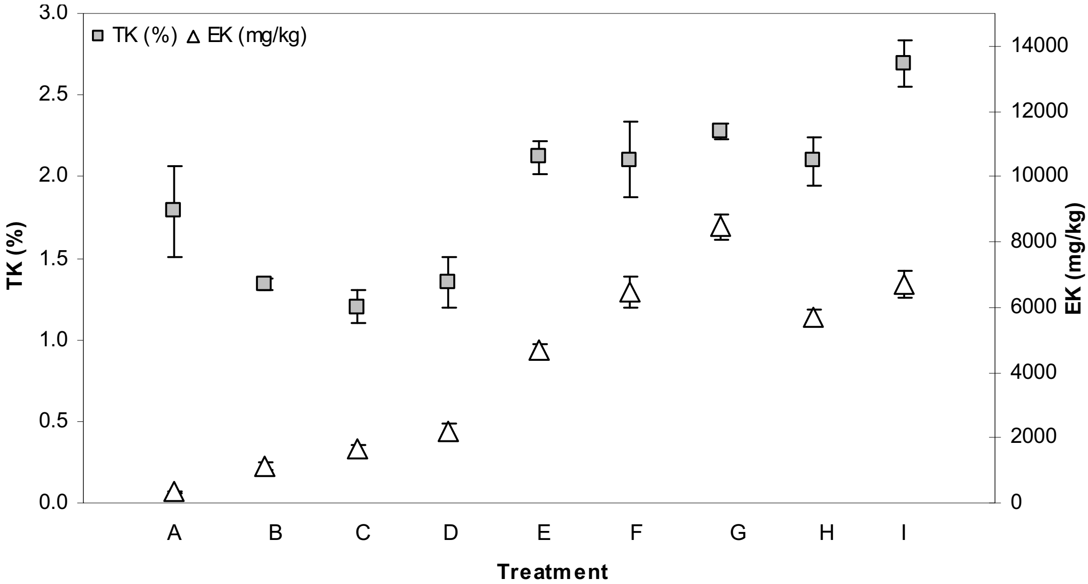

Fig. 4 Total potassium (TK) (%) and exchangeable potassium (EK) (mg kg^{-1}) after 53 days vermicomposting. Values represent mean ± standard error (SE).

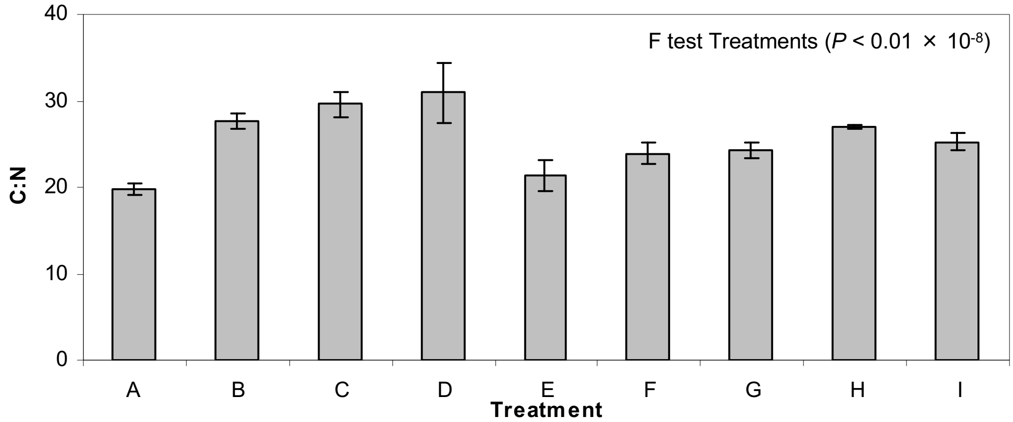

Fig. 5 Carbon to nitrogen (C:N) ratios in treatments A-I after 53 days vermicomposting. Values represent mean ± standard error (SE).

I resulted in the highest (0.91 ± 0.04% N; 0.94 ± 0.02% N), which was significantly higher than all treatments. Total N increased significantly with increasing bulking material for RS (D > C > B), WH (E > F > G) and RS + WH (H > I). However, available N did not follow the same pattern and no trend was apparent.

The results also show a significant difference in total P (TP) and available P (AP) among treatments ($P < 3.63 \times 10^{-4}$ and 9.25×10^{-10}, respectively) (**Fig. 3**). In treatments C, D and F, G, where bulking material proportions were higher (i.e. 30-40%), TP was significantly higher in treatments with WH than treatments with RS. Available P was also significantly higher in treatments containing WH (E-I) compared to those without (A-D). Available P was also significantly higher where more AS was present with D (80% AS) > B (60% AS) and G (80% AS) > F (70% AS) > E (60% AS).

There was a significant difference in total K (TK) and exchangeable K (EK) among treatments ($P < 2.59 \times 10^{-5}$ and 1.65×10^{-13}, respectively) (**Fig. 4**). Treatments containing WH (E-I) had significantly higher TK and EK than those with only RS (B-D). Treatment A had significantly higher TK than treatments with AS+RS (B-D) but had the lowest EK. Treatment I had significantly higher TK (2.69 ± 0.14%) than all treatments but G. Treatment G had the highest EK (8457 ± 366 mg kg^{-1}).

Treatment A had significantly lower ($P < 0.01 \times 10^{-8}$) C:N than most treatments (19.7 ± 0.62), with the exceptions of treatments E and F (**Fig. 5**). The WH treatments had a significantly lower C: N than the RS treatment of the same mixture ratio (i.e. E (20% RS) < B (20% WH), C (30% RS) < F (30% WH), D (40% RS) < G (40% WH)). There was no significant difference between treatments H and I.

The pH of treatments containing WH (7.20–7.78) was significantly higher than those treatments without WH (6.04–6.57) ($P < 8.27 \times 10^{-10}$). Electrical conductivity (EC) was also significantly higher in treatments containing WH (2.07–3.07 mS cm^{-1}) compared to those without (1.03–1.49 mS cm^{-1}) ($P < 1.06 \times 10^{-8}$).

Treatments with WH also contained significantly higher Mn, Mg and Ca than treatments without WH (**Fig. 6**). Treatments with higher AS tended to have higher Zn, Cu and Fe (**Table 3**), though this difference was only significant when comparing treatments with 80% AS to those with 60%.

DISCUSSION

Aquaculture sludge and rice straw characteristics

When comparing the AS used in this study to that described in Buyuksonmez *et al.* (2005) and Marsh *et al.* (2005), large differences in characteristics of the waste are evident (**Table 4**). Total C of AS found in the present study was less than half of that used by Buyuksonmez *et al.* (2005) and together Buyuksonmez *et al.* (2005) and Marsh *et al.* (2005) reported total N and P levels 7-11 fold higher than that found on the MD. The micronutrients of the AS in Vietnam were also generally lower with the notable exception of Fe, which was much higher. However, the AS characteristics of the present study were comparable to the average of 12 farms

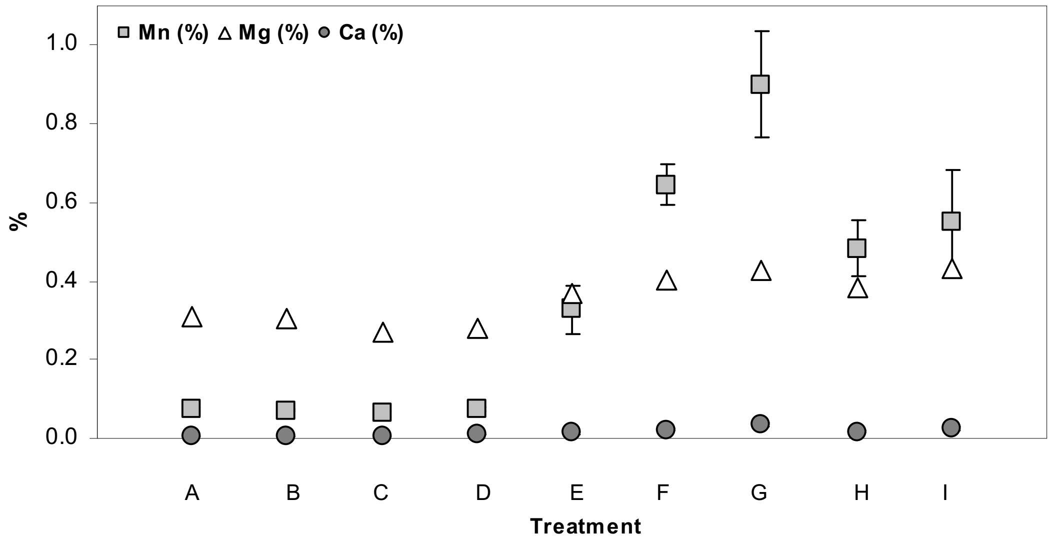

Fig. 6 Manganese (Mn), magnesium (Mg) and calcium (Ca) concentrations after 53 days vermicomposting. Values represent mean ± standard error (SE).

Table 3 Iron, zinc and copper concentrations after 53 days vermicomposting.

Treatment	Fe[a]	Zn[b]	Cu[b]
A	4.43 ± 0.41	260 ± 40	20.7 ± 2.6
B	3.85 ± 0.12	237 ± 9.0	19.0 ± 1.5
C	2.74 ± 0.20	180 ± 12	15.0 ± 1.0
D	2.67 ± 0.19	183 ± 35	15.3 ± 1.9
E	4.29 ± 0.16	240 ± 17	21.7 ± 1.7
F	3.75 ± 0.37	230 ± 35	17.0 ± 2.1
G	3.00 ± 0.46	170 ± 21	14.3 ± 1.5
H	3.56 ± 0.30	230 ± 25	18.7 ± 0.3
I	3.64 ± 0.11	260 ± 15	19.0 ± 1.2

[a] Percentage (%)
[b] mg kg^{-1}
Fe: iron, Zn: zinc, Cu: copper

Table 4 Characteristics of aquaculture sludge reported in four separate studies. The results shown in CARD (n.d.) are averaged from the characteristics of 12 fresh water pond farming systems in An Giang province, Vietnam.

Characteristic	Data source			
	Buyuksonmez *et al.* (2005)	**Marsh *et al.* (2005)**	**CARD (n.d.)**	**Present study**
C:N ratio	7.1	-	15.6	21.9
TC[a]	24	-	5	10.7 ± 0.19
TN[a]	3.4	3.8	0.32	0.49 ± 0.01
TP[a]	-	3.3	0.28	0.44 ± 0.01
TK[a]	-	0.2	1.1	1.53 ± 0.23
Available N[b]	453	-	-	285 ± 4.67
Mg[a]	-	0.4	-	0.6 ± 0.02
Ca[a]	-	6.58	0.01	0.86 ± 0.13
Fe[a]	-	0.2	3.9	0.17 ± 0.01
Mn[a]	-	0.03	0.05	1.09 ± 0.13
Cu[b]	-	77	35	6.33 ± 1.45
Zn[b]	-	1070	111	29.3 ± 1.2

[a] percentage (%)
[b] mg kg^{-1}
C:N: carbon to nitrogen ratio, TC: total carbon, TN: total nitrogen, TP: total phosphorus, TK: total potassium, N: nitrogen, Mg: magnesium, Ca: calcium, Fe: iron, Mn: manganese, Cu: copper, Zn: zinc

in the neighbouring Vietnamese province of An Giang (Cao *et al*. 2009).

These differences are likely attributed to the differing aquaculture systems from which the AS was taken. Marsh *et al.* (2005) collected AS from a highly intensive recirculating aquaculture system and Buyuksonmez *et al.* (2005) collected AS from a flow-through system, both of which filter water and create smaller volumes of concentrated waste. In comparison, the extraction of AS in Vietnam by pumping sediment from pond beds is likely to result in a mixture of AS and soil which would act to dilute some nutrients in the AS, but add others such as Fe from the soil.

The low nutrient concentrations of AS used in the present study have implications for worm growth, survival, reproduction, vermicomposting rate and quality of VC produced. Suthar (2007) found that waste decomposition and worm production was associated strongly with the quality of the substrate. Low nutrients in the MD AS are likely to result in reduced decomposition and worm production. Also, low levels may restrict the increase of microbial populations, the main mechanism of waste decomposition during vermicomposting (Edwards and Bohlen 1996). Low AS nutrient content has implications for the nutrient content of VCs produced from it although final nutrient values depend also on the bulking material used.

VCs often require inorganic supplements for use as a fertiliser (e.g. Arancon *et al.* 2003). Arancon *et al.* (2003) supplemented cow manure VC with inorganic N fertiliser even though the VC contained 1.9% N, almost 4-fold more than total N of AS found in present experiment. Hence, nutrient supplementation may ultimately be necessary to enhance the quality of VC made from AS in the MD so that it can be used as a complete organic fertiliser.

The RS used in the present experiment is relatively high in N and P (**Table 1**). Rice straw usually contains approximately 0.5-0.8% N, 0.07-0.12% P and 1.2-1.7% K (Dobermann and Fairhurst 2000). Therefore the total N and P values recorded in **Table 1** may not be representative of RS on the MD and may affect the calculated nutrient supplements required when using the VC as an organic fertiliser (as discussed below). Nevertheless findings of the present experiment illustrate comparative differences among treatments that should not be affected by higher than usual nutrient levels in the RS.

AS vermicomposting for worm production

The results indicate that a bulking material may be required to improve worm reproduction in AS. Treatment A, with no bulking material, contained very low juvenile numbers at the termination of vermicomposting compared to other treatments, particularly those with 20% bulking material. Vigueros and Camperos (2002) found that 70% sewage sludge with 30% WH resulted in higher cocoon production than 98% sewage sludge and 2% WH and Bhattacharjee and Chaudhuri (2002) observed a higher reproduction rate of *P. excavatus* in mixtures of cow dung with straw compared to cow dung alone. Together with the present results, these findings suggest sludge proportions close or equal to 100% are not optimal for worm reproduction. A lower oxygen level in the sludge without a bulking material is a possible cause of the lower numbers, however, no measured data are available to either confirm or dismiss this hypothesis (although no sign of anaerobic conditions were detected).

Though *P. excavatus* does not appear to reproduce well without a bulking material present, juvenile numbers indicated that *P. excavatus* reproduced better in the higher proportions of AS. When comparing the number of juveniles in 80% AS (with 20% bulking material) to 60% AS (with 40% bulking material), the number of juvenile worms were significantly higher in the former. These results are supported by Marsh *et al.* (2005) who found that substrates with higher aquaculture sludge contents improved worm growth. Therefore, it is possible that *P. excavatus* prefers a small amount of bulking material in the AS for reproduction as opposed to none or too much.

The death of some *P. excavatus* adults was apparent in the present experiment however, no significant difference was found in worm mortality among treatments (data not shown). The results do not support those of Suthar (2009) who found that worm mortality was higher in higher proportions of sewage sludge. A number of possible factors may have contributed to worm mortality including substrate water content, temperature during vermicomposting and feed constituents (i.e. heavy metals).

The moisture and temperature preferences of *P. excavatus* are relatively well researched. Hallatt (1992) found that *P. excavatus* grew and reproduced best when substrate water levels were between 75.2 and 83.2% (w/w). The water content of the VC in the present experiment ranged between 70 and 80% and so is an unlikely cause of *P. excavatus* mortality. The temperature conditions within vermicomposting containers may have hindered *P. excavatus* survival. Edwards *et al.* (1998) found that survival of *P. excavatus* at 30°C in digested sewage was low compared to those kept at 25°C. The temperatures within containers during this experiment (averaging 30.3 ± 0.16°C) may have negatively affected worm survival.

Heavy metal content within the feed materials can also affect worm survival if levels are toxic. Kuperman *et al.* (2004) found that 0.12% available Mn was toxic to worms. Although available Mn was not tested in the present experiment, total Mn was 0.18-0.32%. Manganese becomes available at a pH of < 6 and at low oxygen saturation (Porter *et al.* 2004). Although pH of VCs in the present experiment was > 6, oxygen levels may have been sufficiently low to increase the availability of Mn and thus cause toxicity to worms. However, oxygen levels were not recorded and this hypothesis cannot be substantiated without further investigation. Apart from Mn, levels of total Cu and Zn within VCs are well below the highest levels tested by Malley *et al.* (2006) (1642 mg Cu kg^{-1} and 2492 mg Zn kg^{-1}) which caused no death of *Eisenia fetida* worms. Amounts of available Fe and Mg are also likely to exist at low levels of availability due to near neutral pH in the VC. Overall, there is little evidence that worm mortality was caused by heavy metals within the feed.

AS vermicomposting for organic fertiliser production

VC produced from a variety of wastes has been found by many (including Edwards and Burrows (1988), Atiyeh *et al.* (2000), Manna *et al.* (2003), Marinari *et al.* (2000) and Domínguez (2004)) to improve growth of a wide variety of plant species. A desirable organic fertiliser is rich in N, P and K, which are released into the soil over time. The results of the present study indicate that final quality of VC nutrient content is very dependent on the initial materials. Total N of the final VC increased with increasing bulking material content, which is expected as the total N of RS and WH was higher than AS. Total P and K of the final VC increased when WH was present, which is expected because

Table 5 Characteristics of vermicompost produced from 60:20:20 (AS: RS: WH).

Characteristic	Mean
C:N ratio	25.3 ± 1.0
TC [a]	23.7 ± 14
TN [a]	0.94 ± 0.0
TP [a]	0.44 ± 0.0
TK [a]	2.69 ± 0.1
Available N [b]	677 ± 79
Available P [b]	463 ± 6.4
Exchangeable K [b]	6707 ± 393
Mg [a]	0.43 ± 0.0
Ca [a]	0.02 ± 0.0
Fe [a]	3.64 ± 0.1
Mn [a]	0.55 ± 0.1
Cu [b]	19.0 ± 1.2
Zn [b]	266 ± 15.3
pH (1:4)	7.37 ± 0.1
EC (1:4) [c]	2.37 ± 0.2
H_2O [a]	75 ± 0.7

[a] percentage (%)
[b] mg kg^{-1}
[c] mS cm^{-1}
C:N: carbon to nitrogen ratio, TC: total carbon, TN: total nitrogen, TP: total phosphorus, TK: total potassium, N: nitrogen, P: phosphorus, Mg: magnesium, Ca: calcium, Fe: iron, Mn: manganese, Cu: copper, Zn: zinc, EC: electrical conductivity, H_2O: moisture content

WH had higher total P and total K than AS or RS. The final micronutrients, pH and EC of the VCs can also be explained by initial AS, RS and WH characteristics. Thus the characteristics of the initial materials seem to be a good indication of the quality of the VC produced.

Water hyacinth is, perhaps, preferable for use as a bulking material over RS. As previously discussed, there was no significant difference in worm mortality or reproduction when WH was used in comparison to RS. However, in terms of the final nutrient content of the waste, VCs with WH had more P and K than those with only RS. As noted previously, the RS used in the present study had higher than usual total N and P, hence RS may be even less favourable if poorer quality RS was used. Therefore, for the production of an organic fertiliser, the inclusion of WH appears desirable.

Before use as an organic fertiliser, it is desirable that the VC is fully mature. In recent years, researchers have attempted to establish reliable parameters to determine compost maturity. Although a general maturity index is impractical due to the wide variety of materials used in various composting processes, Bernal *et al.* (1998) determined a compost maturity index for a sewage sludge and maize straw mixture (79:21 dry weight basis), two materials similar to the AS and RS used in the present study. Maturity was calculated to be reached when C:N was 8.6, total N 3.2% and total carbon 27%. According to this maturity index, C:N of all present VCs was too high, total N too low and total carbon too high for full maturity to have been reached. It is suggested that vermicomposting of AS using RS and WH take place over a longer time period which would allow more complete processing of materials by worms.

The amount of VC required to fertilise various crops can be calculated using recommended inorganic fertiliser quantities. The following example shows the required VC to fertilise a rice crop on the Mekong Delta during the dry season, although comparisons to other food crop requirements could also be made. Cuu Long Rice Research Institute rice fertiliser recommendations were used for calculations; 100 kg of N ha^{-1}, 26 kg P ha^{-1} and 53 kg K ha^{-1} applied 7, 21 and 45 days after sowing seed (CARD 2009). The 60:20:20 (AS: RS: WH) VC was used for the following example due to its high total N, total P and total K (**Table 5**).

Table 6 shows the calculated amount of VC required to provide nutrients equivalent to that recommended by CLRRI. If however, the massive 738,880 kg ha^{-1} of VC is applied to the crop in order to supply sufficient N, there will

Table 6 Total inorganic fertiliser applications (kg ha^{-1}) for dry season rice crop and amount of vermicompost required (kg ha^{-1}) to provide equivalent N, P and K (assuming 20% of nutrients within the vermicompost are mineralised under the first crop).

	N	P	K
Inorganic fertiliser [a]	100	26	53
Vermicompost [a]	738 880	280 778	39 517

[a] mg kg^{-1}
N: nitrogen, P: phosphorus, K: potassium

be excessive amounts of P and K. Overtime the excess nutrients are likely to make their way into ground and surface water causing pollution and eutrophication. Conversely, if 39,517 kg ha^{-1} is applied, the crop is likely to be N and P deficient and inorganic supplements of approximately 73.3 kg ha^{-1} of N and 7.7 kg ha^{-1} of inorganic P would be required. However, the application of such large quantities of VC is highly impractical. This supports the notion that supplementing VC with inorganic nutrients to achieve the optimal concentration of nutrients and nutrient balance for crop production is desirable.

Over time and with subsequent crops, mineralisation of vermicomposted material will continue. The release of nutrients from composts and processed organic manures are generally slower than nutrient release from mineral fertilizer (Adegbidi *et al.* 2003). Atiyeh *et al.* (2000) found that, over an extended time period, as nutrients became more and more limiting, plants in VC outgrew plants in commercial fertiliser. Thus further research should investigate the value of VC to crops compared to inorganic fertilisers over a number of successive crops and extended time period.

Macronutrients are also important when considering VC for use as an organic fertiliser. According to Dobermann and Fairhurst (2000), Fe and Mn become toxic to rice in soils above 300-500 mg kg^{-1} (0.03-0.05%) and 800-2500 mg kg^{-1} (0.08-0.25%), respectively. The levels found in the VC (3.64 ± 0.01% Fe and 0.55 ± 0.01% Mn), are considerably higher than these levels, thus monitoring would be required to ensure a toxic build-up does not occur under the crop. Limiting Mn in the VC is possible by reducing the amount of WH in the mixture whereas limiting of Fe, found naturally in soil of the MD, would be difficult. Copper and Zn are also high in the VC (19.0 ± 1.2 mg Cu kg^{-1} and 266 ± 15.3 mg Zn kg^{-1}). Soil toxicity levels for rice occur >20 mg Cu kg^{-1} and >600 mg Zn kg^{-1} (Dobermann and Fairhurst 2000) so monitoring of these nutrients would also be required to prevent a build up of toxic levels. As high levels of Cu and Zn result from the AS, inputs into the fish pond in the form of fish feed, should be investigated and attempts made to restrict the source if vermicomposted AS is to be used as an organic fertiliser.

CONCLUDING REMARKS

Aquaculture sludge appears to be a suitable material for vermicomposting with *P. excavatus*. However, the bulking material and mixture ratio selected for AS vermicomposting may depend on the desired product output: worms or VC. If a high worm biomass is desired, a mixture with a higher proportion of AS is recommended (e.g. 80%). If the VC is desired as an organic fertiliser, a mixture with a lower proportion of AS (60%) appears to more desirable due to the higher nutrient contents within the bulking materials, especially WH which contained higher P and K, compared to AS. However the long time period required to fully breakdown RS and WH would need to be taken into consideration. If VC is used as an organic fertiliser, it is likely that inorganic nutrient supplements would be required to supply the full requirements of the crop.

It is recommended that further research investigates the value of vermicomposted AS as a fertiliser for a variety of food crops over a number of seasons. Long-term benefits of its use should be quantified in comparison to the use of inorganic fertilisers. Further research could also be conducted to optimise the output of the desired product; VC or worms. The nutritional value and economical value of feeding worms to fish should be investigated in order to promote further sustainable cycling of nutrients. A cost-benefit analysis should be undertaken to weigh the labour and time costs necessary to manage and apply the VC waste/fertiliser against financial savings of reduced inorganic fertiliser use and any increased crop production. Despite the potential environmental benefits of implementing an AS vermicomposting recycling system, implementation on a large scale needs to be driven by a clear financial benefit to farmers on the MD.

ACKNOWLEDGEMENTS

Dr. Cao Van Phung and the staff at Cuu Long Rice Research Institute are gratefully acknowledged for their support of the present research. Acknowledgment and thanks also goes to the Australian Youth Ambassador Program and staff at Murdoch University who also assisted this research project.

REFERENCES

Adegbidi HG, Briggs RD, Volk TA, White EH, Abrahamson LP (2003) Effect of organic amendments and slow-release nitrogen fertiliser on willow biomass production and soil chemical characteristics. *Biomass and Bioenergy* **25**, 389-398

Aira M, Monroy F, Domínguez J, Mato S (2002) How earthworm density affects microbial biomass and activity in pig manure. *European Journal of Soil Biology* **38**, 7-10

Arancon NQ, Edwards CA, Bierman P, Metzger JD, Lee S, Welch C (2003) Effects of vermicomposts on growth and marketable fruits of field-grown tomatoes, peppers and strawberries. *Pedobiologia* **47**, 731-735

Atiyeh RM, Domínguez J, Subler S, Edwards CA (2000) Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei*, Bouché) and the effects on seedling growth. *Pedobiologia* **44**, 709-724

Bajsa O, Nair J, Mathew K, Ho GE (2003) Vermiculture as a tool for domestic wastewater management. *Water Science and Technology* **48 (11/12)**, 125-132

Bernal MP, Paredes C, Sánchez-Monedero MA, Cegarra J (1998) Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bioresource Technology* **63**, 91-99

Bhattacharjee G, Chaudhuri PS (2002) Cocoon production, morphology, hatching pattern and fecundity in seven tropical earthworm species – a laboratory-based investigation. *Journal of Biosciences* **27 (3)**, 283-294

Buyuksonmez F, Rynk R, Hess TF, Fornshell G (2005) Composting characteristics of trout manure. *Journal of Residuals Science and Technology* **2 (3)**, 149-157

Cao VP, Nguyen BP, Tran KH, Bell RW (2009) Recycling of fishpond waste for rice cultivation in the Cuu Long delta, Vietnam. In: Nair J, Furedy C, Hoysala C, Doelle H (Eds) *Technologies and Management for Sustainable Biosystems*, Nova Science Publishers, New York, USA, pp 87-95

Chomchalow N, Pongpangan S (1976) Aquatic weeds in Thailand: Occurrence, problems, and existing and proposed control measures. In: Varshney CK (Ed) *Aquatic Weeds in South East Asia: Proceedings of a Regional Seminar on Noxious Aquatic Vegetation*, New Delhi, 12-17 December, 1973, Dr. W Junk B.V. Publishers, The Hague, pp 43-50

Collaboration for Agricultural and Rural Development (CARD) (2009) International Newsletter Program No. 05, January, 2009. Available online: www.card.com.vn/news/index.aspx

Contreras-Ramos SM, Escamilla-Silva EM, Dendooven L (2005) vermicomposting of biosolids with cow manure and oat straw. *Biology and Fertility of Soils* **41**, 190-198

Cripps SJ (1995) Serial particle size fractionation and characterisation of an aquacultural effluent. *Aquaculture* **133**, 323-339

Cripps S, Bergheim A (2000) Solids management and removal for intensive land-based aquaculture production systems. *Aquacultural Engineering* **22**, 33-56

Dobermann A, Fairhurst T (2000) *Rice: Nutrient Disorders and Nutrient Management, Handbook Series*, Potash and Phosphate Institute (PPI), Potash and Phosphate Institute of Canada (PPIC) and International Rice Research Institute (IRRI), 193 pp

Domínguez J, Edwards CA, Webster M (2000) vermicomposting of sewage sludge: Effect of bulking materials on the growth and reproduction of the earthworm *Eisenia andrei*. *Pedobiologia* **44**, 24-32

Domínguez J (2004) State-of-the-art and new perspectives on vermicomposting research. In: Edwards CA (Ed) *Earthworm Ecology* (2nd Edn), CRC Press LLC, Florida, pp 401-425

Edwards CA, Arancon NQ (2004) The use of earthworms in the breakdown of

organic wastes to produce vermicomposts and animal feed protein. In: Edwards CA (Ed) *Earthworm Ecology* (2nd Edn), CRC Press LLC, Florida, pp 345-380
Edwards CA, Bohlen PJ (1996) *Biology and Ecology of Earthworms* (3rd Edn), Chapman and Hall, London, 426 pp
Edwards CA, Burrows I (1988) The potential of earthworm compost as plant growth media. In: Edwards CA and Neuhauser EF (Eds) *Earthworms in Waste and Environmental Management*, SPB Academic Publishing, The Netherlands, pp 211-220
Edwards CA, Domínguez J, Neuhauser EF (1998) Growth and reproduction of *Perionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management. *Biology and Fertility of Soils* **27**, 155-161
Elvira C, Sampedro L, Domínguez J, Mato S (1997) vermicomposting of wastewater sludge from paper-pulp industry with nitrogen rich materials. *Soil Biology and Biochemistry* **29 (3/4)**, 759-762
Estelles P, Jensen H, Sánchez L, Vechiu G (2002) *Sustainable Development in the Mekong Delta*, Afdeling, Denmark, 111 pp
Garg P, Gupta A, Satya S (2006) Vermicomposting of different types of waste using *Eisenia foetida*: A comparative study. *Bioresource Technology* **97**, 391-395
Gupta R, Mutiyar PK, Rawat NK, Saini MS, Garg VK (2007) Development of a water hyacinth based vermireactor using an epigeic earthworm *Eisenia foetida. Bioresource Technology* **98**, 2605-2610
Hallatt L, Viljoen SA, Reinecke AJ (1992) Moisture requirements in the life cycle of *Perionyx excavatus* (Oligochaeta). *Soil Biology and Biochemistry* **24 (12)**, 1333-1340
Hao VN, Tinh TNN, Sang VN, Hai VN, Hien TN, Khoi DP, Sinh XL, Van VM (2001) Report at the Final Workshop, June 12-13, 2001: Final report of the deepwater rice fish project in Mekong River Delta, Vietnam, no pages
Haug RT (1993) *The Practical Handbook of Compost Engineering*, CRC Press LLC, Florida, 719 pp
Hesse PR (1971) *A Textbook of Soil Chemical Analysis*, John Murray Publishers Ltd., London, 520 pp
Jackson ML (1958) *Soil Chemical Analysis*, Prentice Hall, Inc., Englewood Cliffs, New Jersey, 498 pp
Kaushik P, Garg VK (2004) Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues. *Bioresource Technology* **94**, 203-209
Kim JK, Dao VT, Kong IS, Lee HH (2010) Identification and characterization of microorganisms from earthworm viscera for the conversion of fish wastes into liquid fertilizer. *Bioresource Technology* **101**, 5131-5136
Kuperman RG, Checkai RT, Simini M, Phillips CT (2004) Manganese toxicity in soil for *Eisenia fetida*, *Enchytraeus crypticus* (Oligochaeta), and *Folsomia candida* (Collembola). *Ecotoxicology and Environmental Safety* **57**, 48-53
Maboeta MS, Rensburg LV (2003) Vermicomposting of industrially produced woodchips and sewage sludge utilising *Eisenia fetida. Ecotoxicology and Environmental Safety* **56**, 265-270
Majumdar D, Patel J, Bhatt N, Desai P (2006) Emission of methane and carbon dioxide and earthworm survival during composting of pharmaceutical sludge and spent mycelia. *Bioresource Technology* **97**, 648-658
Malley C, Nair J, Ho G (2006) Impact of heavy metals on enzymatic activity of substrate and on composting worms *Eisenia fetida. Bioresource Technology* **97**, 1498-1502
Manna MC, Jha S, Ghosh PK, Acharya CL (2003) Comparative efficacy of three epigeic earthworms under different deciduous forest litters decomposition. *Bioresource Technology* **88**, 197-206
Marinari S, Masciandaro G, Ceccanti B, Grego S (2000) Influence of organic and mineral fertilisers on soil biological and physical properties. *Bioresource Technology* **72**, 9-17
Marsh L, Subler S, Mishra S, Marini M (2005) Suitability of aquaculture effluent solids mixed with cardboard as feedstock for vermicomposting. *Bioresource Technology* **96**, 413-418
Midlen R, Redding T (1998) Aquaculture systems. In: Midlen R, Redding T (Eds) *Environmental Management for Aquaculture*, Chapman and Hall Aquaculture Series **2**, London, pp 1-20
Ndegwa PM, Thompson SA (2000) Effects of C-to-N ratio on vermicomposting of biosolids. *Bioresource Technology* **75**, 7-12
Nhà Xuất Bản Nông Nghiệp (Publisher) (no date) Viện Thổ Nhưỡng Nông Hóa (Institute), Sổ Tay Phân Tích: Đất, Nước, Phân Bón, Cây Trồng (Book title) (in Vietnamese)
Phillips MJ (2002) *Fresh water aquaculture in the Lower Mekong Basin: MRC Technical Paper No. 7*, Mekong River Commission, Phnom Penh, 65 pp
Phuong NT (1998) Cage culture of *Pangasius* catfish in Mekong Delta, Vietnam: Current situation analysis and studies for feed improvement. PhD dissertation, National Institute Polytechnique of Toulouse, France
Porter GS, Bajita-Locke JB, Hue NV, Strand D (2004) Manganese solubility and phytotoxicity affected by soil moisture, oxygen levels, and green manure additions. *Communications in Soil Science and Plant Analysis* **35 (1-2)**, 99-116
Son PN, Thach VN, Chi TCN, Hung TP, Loc DN, Chau MN, Hai MT, Yamada RR (2001) Specification of fish market in the Mekong Delta. In: *Development of new technologies and their practice for sustainable farming systems in the Mekong Delta. Proceedings of the 2001 annual workshop of JIRCAS Mekong Delta Project*, Cuu Long Delta Rice Research Institute, Can Tho, Vietnam, pp 28-45
Suthar S (2007) Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agriculture wastes. *Bioresource Technology* **98**, 1608-1614
Suthar S (2009) Vermistabilization of municipal sewage sludge amended with sugarcane trash using epigeic *Eisenia fetida* (Oligochaeta). *Journal of Hazardous Materials* **163**, 199-206
Vigueros LC, Camperos ER (2002) vermicomposting of sewage sludge: A new technology for Mexico. *Water Science and Technology* **46 (1)**, 153-158