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Decomposition of Organic Substrates and their Effect on Mungbean Growth in Two Soils of the Mekong Delta

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Abstract
Agricultural land use in the Mekong Delta of Vietnam is dominated by intensive irrigated rice cropping systems on both alluvial and acid sulfate soils. A stagnating and occasionally declining productivity may be linked on the alluvial soils to low N use efficiency and low soil organic matter content while on acid sulfate soils to acidity, Al toxicity and P deficiency. For economic reasons, farmers increasingly diversify their cropping system by replacing the dry season rice by high-value horticultural crops grown under upland conditions. However, upland cropping is likely to further exacerbate the soil-related problems. Organic substrates from decentralized waste and waste water management are widely available and may help to alleviate the reported soil problems. During the dry season of 2003/2004, the effect of the application of various types and rates of locally available waste products on crop performance was evaluated at both an alluvial and an acid sulfate soil site. The C and N mineralization dynamics of nine organic substrates from waste and waste water treatment were determined by anaerobic (N) and aerobic (C) incubation in the laboratory. The response of 12 week-old mungbean (dry matter accumulation) to substrate application (1.5 – 6.0 Mg ha^{-1}) was evaluated on a degraded alluvial and on an acid sulfate soil. In the alluvial soil, largest mineralization rates were observed from anaerobic sludge. Biomass increases in 12 week-old mungbean ranged from 25-98% above the unfertilized control. In the acid sulfate soil, highest net-N release rates were observed from aerobic composts with high P content. Mungbean biomass was related to soil pH and exchangeable Al^{3+} and was highest with the application of aerobic composts. We conclude that the use of organic substrates in the rice-based systems of the Mekong Delta needs to be soil specific.

Keywords: acid sulfate soil, Al toxicity, N mineralization, Vietnam, *Vigna radiata*

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1 Introduction

In Vietnam, the area planted to rice increased from 5.6 Mha in 1980 to 7.7 Mha in 2000, with >90% of the production occurring in lowland ecosystems (MACLEAN *et al.*, 2002; CAN, 2003). Nearly half of this lowland rice is produced in the Mekong Delta, where the area cultivated with rice has been substantially increasing as a result of infrastructure development and recent demographic growth (CHIEM, 1994). Being the key component of agricultural land use, rice is used in diverse production systems and cropping patterns. This diversity is largely determined by soil type with acid sulfate soils and alluvial soils covering each about 40% of the land area (VAN BO *et al.*, 2002).

Rice triple cropping systems are mainly found in areas with alluvial soils with a limited influence of the late season flood (nearly 0.9 Mha). Fields are fully irrigated, rice is direct wet-seeded, and production is based on high external input use. Main problems in this production system are associated with pollution of the environment by agrochemicals and a relatively low productivity, probably linked to near-permanent soil flooding, increased incidence of soil-born diseases, a low N use efficiency and, in some instances, a low soil nutrient supply and declining soil organic matter content (DOBERMANN *et al.*, 2002). With the rapid economic development in the Mekong Delta, farmers tend to diversify their cropping system. The most prominent strategy is the replacement of the dry season rice by high-value horticultural crops grown under upland conditions (e.g.; the rice - rice - field vegetable rotation). While short-term economic benefits are obvious, upland cropping is likely to further accelerate the mineralization of soil organic matter and hence to exacerbate the problems of low soil nutrient supply and the physical degradation of the soil structure, related to low soil organic matter content.

The rice double cropping system dominates on the acid sulfate soils and is concentrated in areas where seasonal floods occur (about 0.7 Mha). During the period of intense flooding in October-November, a 2-3 months fallow period follows a crop of transplanted wet season rice. Another irrigated rice crop is grown after flood recession during the dry season (NI, 2000). Rice production is constraint by soil-related nutrient imbalances such as iron toxicity and P and Zn deficiencies (TINH *et al.*, 2001). During intermittent soil aeration phases, the acidification of the aerobic soil can result in severe Al toxicity and further exacerbate the problem of P deficiency (HUSSON *et al.*, 2000). The geochemistry of the acid sulfate soils tends to limit the choice of crops to be grown during the aerobic soil phase to the relatively acidity-tolerant species and cultivars (MINH, 1996). However, as in the triple cropping system, mixed production of wet season rice with diverse dry season upland crops on raised beds are emerging, particularly in the peri-urban areas.

Organic substrates from decentralized waste or wastewater treatment are widely available in South Vietnam (WATANABE, 2003). Their use in agriculture can recycle substantial amounts of nutrients, thus improving soil fertility and increasing rice yield (CLEMENS and MINH, 2005). However, high transport costs and an unfavorable cost-benefit ratio are limiting the use of organic substrates to lowland rice. In addition, the application of organic waste to flooded fields may lead to increased water pollution and microbial contamination from the substrates (RECHENBURG and HERBST, 2006). When applied to an upland crop grown in rotation with rice, the use of organic substrates may be environmentally safer than in lowland fields, and the substrates may contribute to alleviate the prevailing soil-related problems.

We hypothesize that in the rice triple cropping systems on alluvial soils, the replacement of the dry season rice with an upland crop combined with the application of organic substrates can overcome the problem of declining soil fertility and may improve the system's productivity. In the rice double cropping system on acid sulfate soils, the application of organic substrates to upland crops may counteract negative effects of low pH and excess Al^{3+} and permit the cultivation of more acidity-sensitive higher-value crops such as mungbean (*Vigna radiata* L.). Direct and residual effects of organic amendments are likely to depend on the quality and quantity of the substrate applied as well as on the type of upland crop. Accordingly, the following objectives were addressed in both degraded alluvial and acid sulfate soils:

(1) Physico-chemical and mineralization characteristics of major organic substrates of the Mekong Delta;

(2) Quantification of substrate effects on the biomass accumulation of mungbean grown in rotation with rice.

2 Material and Methods

2.1 Study sites

All experiments were conducted in Cantho province of the central Mekong Delta. The area is characterized by a monsoon climate. The length of the growing period for rainfed crops is in excess of 320 days. According to the FAO (1978), the area is classified as a humid forest agroecological zone. The mean annual rainfall ranges from 1,900 to 2,300 mm, falling mainly during the 6 months of summer monsoon (May-October). Three farmers' fields representing the triple cropping situation were selected close to the village of An Binh (105°43'40" – 105°43'45" E latitude and 10°00'05" – 10°00'10" N longitude). Three further farms, representing the rice double cropping pattern, were selected close to the village of Hoa An (108°0'00" – 108°5'00" E latitude and 10°65'00" – 10°70'00" N longitude). While An Binh was characterized by an alluvial clay soil with low organic carbon and total N contents, the Hoa An site was characterized by a typical acid sulfate soil with low available P and a high acidification potential under aerobic conditions. Selected physico-chemical properties of the experimental soils are shown in Table 1.

2.2 Crop plants

The widely grown improved semi-dwarf lowland rice (*Oryza sativa* L.) variety VD 20 with 105-day growth duration was obtained from Cuu Long Rice Research Station, Omon, Vietnam. For homogenizing the field sites, it was pre-germinated for two days and broadcast-seeded at a rate of 120 kg ha^{-1} into the water-saturated lowland field (An Binh) or seeded into a wet bed and transplanted at 21 days after seeding at two seedlings per hill at a 20$\times$20 cm spacing (Hoa An). Mungbean (*Vigna radiata* L.) is commonly

Table 1: Selected physico-chemical properties of the experimental soils (0-20 cm)

Parameter	*Alluvial soil (An Binh)*	*Acid sulfate soil (An Binh)*
Soil type (USDA)	Tropaquept	Sulphaquent
Texture	Silty clay	Clay Loam
Clay (%)	57	44
Silt (%)	34	55
Sand (%)	9	1
pH (H_2O)	5.0	3.4
org. C (%) *	1.52	4.59
Exch. Al^{3+} (mg $100g^{-1}$) †	–	37.2
Tot. N (%) ‡	0.16	0.26
Avail. P (mg kg^{-1}) §	5.81	1.90
Exch. K (mg kg^{-1}) ¶	7.58	38.9

* Walkley-Black, † NaF titration, ‡ Kjeldahl, § Bray-I, ¶ NH_4O-Ac extraction

cultivated in the Mekong Delta and was selected as a substitute of the dry season rice crop. Seeds were obtained from the College of Agriculture, Cantho University. The material was seeded at a 20×40cm spacing onto 10 cm high raised soil beds of 1×5 m, that were constructed in the lowland plots after the harvest of wet season rice.

2.3 Substrates

Organic substrates from decentralized waste and wastewater treatment, commonly applied to field and garden crops in the Mekong Delta, were collected from farms in the study area. These organic amendments included five aerobic substrates (vermicompost from pig and goat manure, pig manure – rice straw compost, biogas sludge compost, rice straw compost, and rice mushroom compost) and three anaerobic substrates (young biogas sludge [<4 months], old biogas sludge [>12 months], and fish pond residue [30 – 50 mm depth of deposit]). The substrates differed widely in their N content (1.6 – 3%), C/N ratio (12 - 23), and P (0.15 – 1.65%) and K content (0.28–1.98‰). Selected physico-chemical parameters of the organic amendments are presented in Table 2.

2.4 Chemical analyses

The C mineralization was determined by weight loss from litterbags containing 3 g substrates. The organic substrates were placed into Nylon mesh bags (0.2 mm) and incubated in the dark in three replicates per soil type (about 30 g substrate kg^{-1} soil) for a period of 12 weeks (OKALEMBO *et al.*, 2002). Soils were kept under aerobic conditions at about 75% field capacity. The weight loss of the substrate in the litter bags (dry matter) was recorded after removal, careful washing in distilled water and oven drying for 48 hours at 70°C.

Table 2: Selected physico-chemical properties of the organic substrates used in the field experiments on alluvial and acid sulfate soils in the Mekong Delta in 2003/2004.

Substrate	*Moisture cont. (%)*	NH_4^+-*N* (*mg* kg^{-1})	NO_3^--*N* (*mg* kg^{-1})	*Total* N (*%*)	C/N *ratio*	*Total* P (*%*)	C/P *ratio*	*Total* K (*‰*)	C/K *ratio*
Aerobic Substrates									
Vermicompost (pig / goat)	60.4	1.40	844	2.20	19	1.39	30	0.92	454
Pig manure straw compost	56.0	1.84	940	2.60	16	1.65	25	1.98	209
Biogas sludge compost	38.7	2.68	1832	1.95	20	0.60	71	0.57	737
Rice straw compost	68,7	4.28	19	1.95	22	0.15	274	0.57	732
Mushroom compost	70.1	4.84	575	2.45	17	0.22	190	1.54	273
Anaerobic substrates									
Biogas sludge (> 12 months)	82.5	1.23	t	2.55	12	0.68	53	0.65	470
Biogas sludge (< 4 months)	86.3	1.56	t	2.38	14	0.80	42	0.31	397
Fishpond residue (3 – 5 cm)	78.9	1.76	t	1.35	18	0.40	48	1.81	106

t: traces

The N mineralization potential of substrates applied to the two soils was determined by net ammonium-N release during two weeks of anaerobic incubation (Stanford and Smith, 1972). Substrates were applied at 100 mg N kg^{-1} soil and 20 g of soil-substrate mixture were placed in 50mL test tubes, filled with 30mL of distilled water. Three replicates of each organic substrate and soil type (2 soils $\times$ 11 treatments $\times$ 2 extraction times $\times$ 3 replications = 132 tubes) were incubated in the dark at 30 – 32 °C for 21 days and extracted with 2 N KCl after 7 days (initial value) and after two further weeks of anaerobic incubation. The ammonium content in the extract was determined colorimetrically via flow injection analysis. The net-N mineralization was computed as (Nmin after 1 and 2 weeks of incubation) – (Nmin in the initial sample). Substrate mineralization was calculated as the net-N release in amended minus that in unamended sample tubes.

The total N in soil samples and in the biomass of 12 week-old mungbean was determined by Kjeldahl method. Soil exchangeable K was extracted with NH_4O-Ac, followed by flame photometer determination. Soil P was determined according to the Bray-I procedure and determined spectrophotometerically after vanadate coloration. Soil pH, total acidity, and exchangeable Al^{+3} were based on a soil: extractant ratio of 1:5 (pH-H_2O). Soil total acidity and exchangeable Al^{+3} were determined only in the acid sulfate soil. Soil samples (0-10 cm) were taken from individual planting holes of the test crops extracted with 2N KCl and subsequently titrated with $NaOH$ and NaF for total acidity and exchangeable Al^{3+}, respectively (McLean, 1965).

2.5 Treatment application

Dry season field experiments were conducted at each of the two study sites during the dry season of 2003/2004, following the field homogenization with an unfertilized crop of lowland rice during the 2003 wet season. In addition, experiments were conducted under controlled conditions in the laboratory of the Institute of Technology at Cantho University (substrate C and N mineralization). The field experiments were established at both the Hoa An (acid sulfate soil) and An Binh (alluvial soil) sites. Three adjacent farms were used as replications at each site with treatments being randomized within the farms (Randomized Complete Block Design - RCBD). The experimental area at each site was 1500 m^2 (500 m^2 per farm), on which 10cm high soil ridges of 5.0×1.0 m were built after the harvest of wet season rice in November 2003 for the cultivation of upland crops.

Field experiments studied (1) the response of mungbean to different substrates at one substrate application rate and (2) the response of mungbean to one substrate at different application rates. Twelve weeks after seeding of mungbeans, the dry matter accumulation was determined from 1×3m harvest areas (alluvial soil) or from individual plants (acid sulfate soil) after oven drying at 70°C for 48 hours. *Experiment 1*: The differential effect of organic amendments on a test crop of mungbean (involved the application and manual incorporation (0-0.1 m) of eight substrates (Table 2) at a rate of 3 Mg ha^{-1} (dry matter basis) in comparison to an unamended control. *Experiment 2*: The effect of different application rates on a test crop of mungbean focused solely on the "old" biogas sludge, applied at rates of 0, 1.5, 3.0, 4.5, and 6.0 Mg ha^{-1} (dry matter basis).

2.6 Data analysis

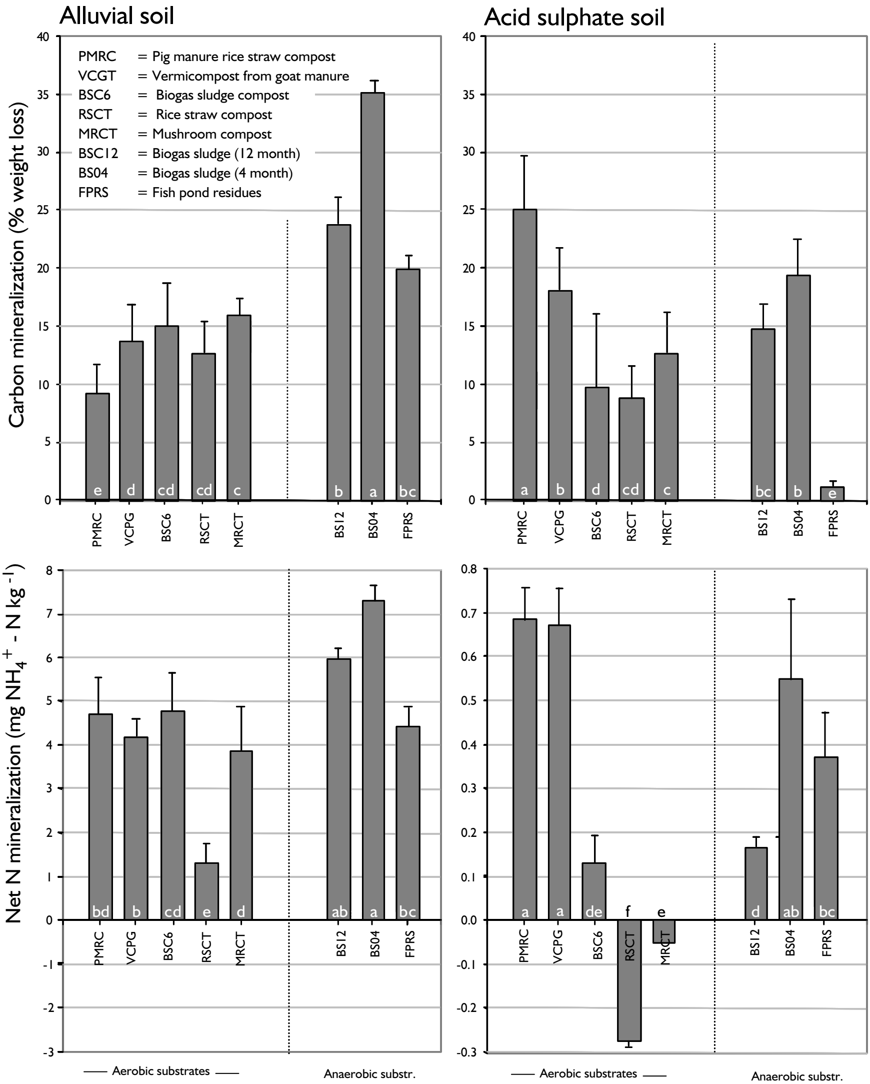
Data were analyzed for basic statistics (means and standard errors) by Microsoft EXCEL and subsequently subjected to ANOVA using SPSS 11.5. Mean separation was done by Tuckey Test at 5% error probability. Graphical presentations were made with SIGMAPLOT 5.3.

3 Results

3.1 Substrate mineralization

The substrates from waste and wastewater treatment were characterized based on physico-chemical parameters (Table 2) and on their C and N mineralization characteristics in both experimental soils (Figure 1). The C mineralization (weight loss) of soil-applied substrates tended to be generally lower in the acid sulfate than in the alluvial soil. In general, larger mineralization rates were observed from anaerobic sludge than from the aerobic composts. In the alluvial soil, the aerobic C mineralization varied between 8 and 35% weight loss. Rice straw compost showed the lowest (9-15%), young biogas sludge the highest C mineralization (24-35% weight loss). Vice versa, the sub-

Figure 1: Carbon mineralization (% weight loss in litterbags during 12 weeks of aerobic incubation – upper graph) and net-N mineralization (NH_4-N in amended minus unamended soil during 2 weeks of anaerobic incubation – lower graph) of organic substrates applied to an alluvial soil – left side, and an acid sulfate soil – right side (incubation experiments under controlled conditions). Bars present standard errors of the mean (n=3); value bars with the same letter are not significantly different by Tuckey Test (0.05).



strates with highest P content tended to mineralize more rapidly than the substrates low in P in the acid sulfate soil (up to 25% weight loss in pig manure-rice straw compost).

In the alluvial soil, anaerobic net-N mineralization varied between 1.2 and 7.2 mg N kg^{-1} soil. It followed a similar pattern as the aerobic C mineralization, whereby rice straw compost showed the lowest, young biogas sludge the highest net-N mineralization. In contrast to the alluvial soil, substrate N mineralization in the acid sulfate soil was by one order of magnitude lower. Highest net-N release was observed from aerobic substrates, particularly those with high P content (e.g., vermicompost and pig manure compost). Lowest N mineralization was observed with rice straw compost with –2.8 mg kg^{-1} soil (net-N immobilization).

3.2 Effects of substrates application to an alluvial soil

In *experiment 1*, all substrates were applied at 3 Mg ha^{-1} to soil ridges build in the paddy fields after the harvest of wet season rice. The biomass accumulation of mungbean after 12 weeks of growth responded differentially to substrate application (Table 3). Incorporation of biogas sludge resulted in the largest mungbean biomass (3.9 - 4.8 Mg ha^{-1}). The low-quality substrates, such as the aerobic rice straw compost, the compost from rice mushroom production and the anaerobic fishpond residue resulted in a low and not significant mungbean response (dry matter of 1.6-2 Mg ha^{-1}). Biomass response and crop nutrient uptake correlated significantly with the amount of added P (P<0.01) and N (P<0.05) but showed little apparent relation to other substrate attributes. Increasing the application rates of young biogas sludge (*experiment 2*), resulted in N additions of 0 - 144 kg ha^{-1}, corresponding to P additions of 0 - 48 kg ha^{-1}. While N and P accumulation in the biomass increased nearly linearly with increasing substrate application rates, no significant differences were observed in the dry biomass accumulation of mungbean at application rates beyond 3.0 Mg ha^{-1}.

3.3 Effects of substrate application on the acid sulfate soil

During the aerobic soil phase (dry season), the field site was characterized by a large and small-scale heterogeneity in soil pH (2.8-4.3), total acidity (3-23 cmol kg^{-1}) and exchangeable Al^{3+} (7-18 cmol kg^{-1}). Based on the analysis of 264 individual soil samples, significant linear correlations were observed between pH and total acidity (r^2=0.64***) and between total acidity and exchangeable Al^{3+} (r^2=0.59***) (date not shown). As crop growth strongly responded to aluminum, the soil exchangeable Al^{3+} was used as a covariate in the statistical analysis and data are presented as dry matter per plant in relation to the exchangeable Al^{3+} in the rhizosphere soil (soil collected from the individual planting holes before treatment application).

In *experiment 1*, eight aerobic and three anaerobic substrates were applied to mungbean at a rate of 3 Mg ha^{-1}. Mean biomass accumulation did not differ between treatments. However when using soil Al^{3+} as a covariant, the application of the aerobically composted substrates resulted in significantly more biomass than the unamended control. Anaerobic substrates produced an intermediate response, which was not significantly different from either the unamended control or the application of aerobic substrates

Table 3: Nutrient addition by substrates and the response in dry matter accumulation and nutrient uptake of 12 week-old mungbean plants to the application of organic substrates at 3 Mg ha^{-1} and to increasing application rates of biogas sludge on an alluvial soil (An Binh, Vietnam, 2004).

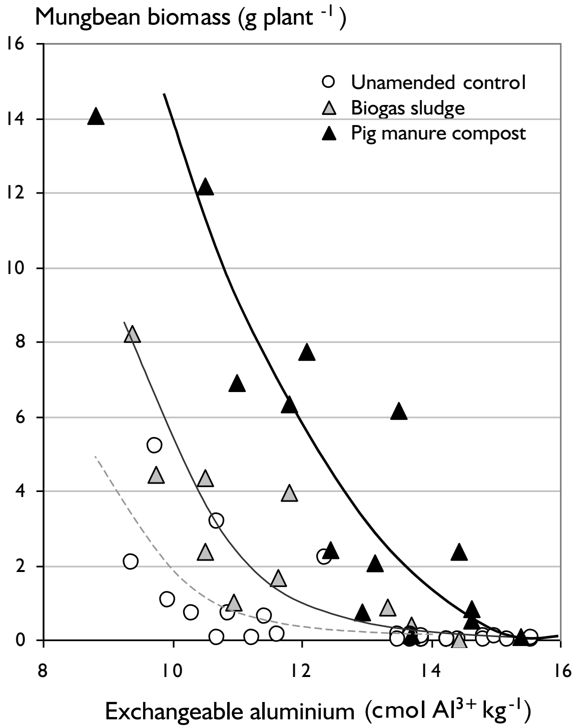
Substrate	*Amount of nutrient added (kg ha^{-1})*			*Mungbean dry matter (Mg ha^{-1})*	*Mungbean nutrient content at harvest (%)*		
	N	*P*	*K*		*N*	*P*	*K*
Unamended control	0	0	0	1.58^{e}	1.40^{d}	0.31^{e}	1.74a
Aerobic substrates							
Vermicompost	88.5	9.0	4.1	4.01^{c}	1.28^{e}	0.38^{c}	1.31^{c}
Pig manure compost	78.0	49.5	5.9	4.81^{ab}	1.20^{g}	0.49^{a}	1.33^{c}
Biogas sludge compost	55.5	18.0	1.7	3.92^{d}	1.24^{e}	0.40^{bc}	1.28^{d}
Rice straw compost	62.5	4.8	1.8	2.50^{e}	1.02^{fg}	0.27^{f}	1.34^{c}
Mushroom compost	53.5	6.6	4.4	2.04^{e}	1.34^{de}	0.41^{a}	1.27^{d}
Anaerobic substrates							
Biogas sludge (<4 months)	86.5	20.4	1.5	4.81^{a}	1.62^{d}	0.47^{b}	1.79^{a}
Biogas sludge (>12 months)	72.0	24.0	1.1	3.68^{cd}	2.18^{a}	0.46^{b}	1.58^{b}
Fishpond residue	48.0	12.0	5.4	1.57^{e}	1.06^{fg}	0.47^{b}	1.52^{b}
Increasing rates of biogas sludge							
0 Mg ha^{-1}	0	0	0	1.58^{e}	1.42^{d}	0.31^{e}	1.74^{a}
1.5 Mg ha^{-1}	36.0	12.0	0.4	3.11^{d}	1.06^{f}	0.33^{d}	1.12^{d}
3.0 Mg ha^{-1}	72.0	24.0	0.8	3.68^{cd}	1.52^{b}	0.35^{cd}	1.08^{f}
4.5 Mg ha^{-1}	108.0	36.0	1.3	4.21^{bc}	1.60^{b}	0.33^{de}	0.97^{f}
6.0 Mg ha^{-1}	144.0	48.0	1.7	4.40^{bc}	1.55^{f}	0.38^{cd}	1.19^{de}

Values followed by the same letter in a column are not significantly different by Tuckey Test (0.05)

(Figure 2). In the absence of substrate application (control treatment), the mungbean did not grow when the soil exchangeable Al^{3+} exceeded 11 cmol kg^{-1}, and a maximum biomass of 6 g plant-1 was observed with Al^{3+}concentrations of <9 cmol kg^{-1}. With the addition of 3 Mg ha^{-1} of aerobically composted organic substrates, the critical Al^{3+} value for mungbean growth increased from 11 up to 15 cmol kg^{-1} and the dry matter accumulation reached a maximum of 14 g plant-1 at 9 cmol Al^{3+} (Figure 2). The strongest growth response (and highest Al^{3+} tolerance) was observed with the application of well-rotten substrates with a wide C/N-ratio and high P concentrations (e.g., pig manure compost).

The growth of mungbean responded to increasing application rates of biogas sludge (test substrate in *experiment 2*) and shifted the critical aluminum concentration for mungbean growth from 11 (control) over 13 (3 Mg sludge ha^{-1}) to 15 cmol kg^{-1} (6 Mg sludge ha^{-1}), while increasing the maximal plant biomass at 10 cmol Al^{3+} kg^{-1} from 2 g (unamended control) to 12 g (data not shown). A comparison of the regression equations showed no significant differences of the slopes, while the X-axis intercept (critical Al concentration) shifted from 11 to 15 cmol Al^{3+} kg^{-1} with substrate amendments.

Figure 2: Mungbean response (dry matter accumulation of 12 week-old plants) to the application of 3 Mg ha^{-1} of biogas sludge or of of pig manure compost in relation to soil exchangeable Al^{3+} on an acid sulfate soil (dry season, Hoa An, Vietnam, 2004).



4 Discussion

Stagnating long-term yield trends in intensified rice-based cropping systems have been reported throughout Asia (Cassman *et al.*, 1997; Dawe *et al.*, 2000; Regmi *et al.*, 2002) and changes in soil organic matter quality under constant soil anaerobiosis and a declining soil N and P supplying capacity have been identified as the main culprits (Dobermann *et al.*, 2000; Ladha *et al.*, 2003). Breaking the cycle of permanent soil flooding by replacement of dry season rice with upland crops and in increased addition of organic substrates have been hypothesized to counteract the yield decline (Dawe *et al.*, 2003; Ladha *et al.*, 2003). The present work focused solely on the effect of substrate application on mungbean grown in rotation with rice. Nevertheless, the alleviating effects of various substrates on soil-related problems may also have positive carry-over effects on the subsequent crop of rice and the cropping system at large. In this context, the following chapters will discuss the decomposition dynamics and yield effects of organic amendments.

4.1 Substrate mineralization

Organic substrates contain besides a range of C sources, variable quantities of essential nutrient elements, salts, and heavy metals. However, the organic amendments need to undergo microbial decomposition before these elements can become plant available. Mineralization processes and rates are affected by temperature and moisture, microbial activity, soil texture, and substrates properties such as C/N ratio, content of lignin and polyphenols, and the lignin-to-N ratio (Palm and Sanchez, 1991; Becker and Ladha, 1997; Dendooven *et al.*, 1998; Calderón *et al.*, 2004). In the present study, soil texture and moisture conditions among the study sites were similar, while pH and the availability of P strongly differed between the alluvial and the acid sulphate soil. Hence, soil acidity and P limitations were likely to have been responsible for lower C and N mineralization at the Hoa An than the An Binh site. This appears to be confirmed by the observed high substrate mineralization rates of the P-rich pig manure-based substrates at Hoa An. In this acid sulphate soil, substrate decomposition may have been inhibited by soil acidity and possibly by P precipitation with soluble Al^{3+} and Fe. Consequently, the N mineralization of substrates was apparently related to the C/P rather than to the C/N ratio, as previously reported by Whalen *et al.* (2000). From the present data we conclude that the C/N and the C/P ratio may be the key drivers of substrate mineralization in the alluvial and the acid sulphate soil, respectively.

4.2 Soil and crop effects of organic amendments

Irrespective of the site, soil type or substrate, organic amendments generally improved the performance of mungbean. This may have been related to the direct addition of limiting plant nutrients and/or to a possible indirect effect via an alleviation of (H^+ and Al^{3+}) toxicities. On the acid sulphate soil, acidification and Al toxicity are likely to have further exacerbated the prevailing problem of P deficiency (Ren *et al.*, 2004). The extent of the ameliorative effects of organic amendments on P deficiency and Al toxicity depended on both the amount and the quality of the substrate. Similar to the substrate mineralization patterns, direct effects on crop biomass were related to N additions in the alluvial and to P addition and Al toxicity alleviation in the acid sulphate soil. The latter effects were much more pronounced with aerobic (compost) than with anaerobic (sludge) substrates. This may be related to a larger share of stable, non-soluble C-compounds in the composts, which can reportedly immobilise toxic Al^{3+} by forming non-toxic Al–DOM complexes (Hue and Licudine, 1999) or humic complexes with Al and Fe ions (Iyamuremye *et al.*, 1996). While the application of lime can rapidly correct the prevailing soil pH-related constraints, lime is currently hardly available in the Mekong Delta and not affordable to low-input farmers. Organic substrates on the other hand are widely available on farm and may thus provide a short-term alternative to alleviate Al toxicity and nutrient deficiency problems.

On the alluvial soil, the pronounced effect of substrate application on the biomass yield of mungbean was not only related to P but also to the amount of added N ($P<0.01$), which may surprise in the light of mungbean being a nitrogen-fixing legume. Nevertheless, fixation rates were probably very low and few effective (red) nodules were found, possibly related to the heavy soil texture, high bulk density and low plant-available P and exchangeable K in the soil.

The inclusion of an aerobic soil phase by growing an upland crop has been shown to obtain substantial yields of crops that tend to have a much higher market value than rice. The application of the organic substrates not only stimulated the performance of these high-value crops, but may also result in significant residual effects on the subsequent crop of wet season rice (Becker and Ladha, 1997; Eghball *et al.*, 2004). Such longer-term effects of substrate application on soil parameters may include enhanced soil P dynamics, increasing availability of P, Mg, Zn, Fe, and Cu, as well as improving soil biological and chemical properties (Kirk, 2004, pp. 135-164). It may thus be assumed that the effects of substrate application reported in this paper are likely to contribute to longer-term improvements of these production systems. While presenting a promising option, the organic substrates need to be matched with soil-specific needs.

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