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Soil microbial counts and the performance of lowland rice (*Oryza sativa L*) under two water regimes and two organic soil amendments

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Abstract

A field experiment was conducted at the University of the Philippines, Los Banos, Philippines from September 2010 to January 2011 to evaluate soil microbial counts and the performance of lowland rice under two water management regimes and organic soil amendments. Organic amendments had positive effects on grain yield. Cow manure and mungbean green manure produced a grain yield of 3.62 t ha^{-1} and 3.45 t ha^{-1} respectively which was significantly higher than the unfertilized control (3.10 t ha^{-1}). The NPK chemical fertilizer applied at 120-30-30 t ha^{-1} gave a grain yield of 4.90 t ha^{-1}, which was higher than those obtained from the two organic fertilizers. The organic fertilizers had significant positive effects on the microbial counts (bacteria, fungi and actinomycetes) which play a key role in nutrient cycling and improvement of soil quality. On the other hand, owing to the improved rooting environment, non-flooded treatment favoured higher production of productive tillers compared to the flooded treatment. This resulted in better crop performance in terms of crop growth, development and yield attributes compared to its flooded counterpart. Though flooding treatment is generally considered detrimental to crop performance, the application of organic amendments augmented crops with positive crop responses in terms of grain yield and its components. The flooded treatment resulted in a grain yield of 3.65 t ha^{-1} with cow manure and 3.58 t ha^{-1} with mungbean green manure treatments. This indicated that the management of water and organic amendments in lowland rice farming could lead to sustainable soil and farm productivity, which could potentially avert the degradation of natural resources.

Keywords: crop growth, grain yield, flooding and non-flooding water treatment, microbes, organic sources.

Introduction

Organic agriculture in the Philippines accounts for 96,317 hectares which is 0.81% of its agricultural land (Willer, Lernoud & Kilcher, 2013). Although it has started off a low base, there has been a rapid uptake of organic agriculture in the Philippines, with organically managed hectares increasing over 550 times over a decade, with only Uruguay and India having a faster uptake over the decade (Paull, 2011). Organic farming systems aim at maintaining soil and water resources in order to sustain soil fertility and crop yield. With an increasing demand for rice and a decline in soil quality and productivity, tropical lowland rice soils are an intensively exploited soil resource.

The technology farming systems developed to achieve higher levels of production to meet market demands have led to the development of high yielding crop varieties that are highly responsive to external inputs of chemical fertilizers and water resources (IRRI, 2008). This has serious ecological, economic and social repercussions on poor farmers especially on those of the underdeveloped and developing countries. Modern farming has resulted in environment degradation and loss of soil quality which play a significant role in sustaining farm productivity. The consequences of modern chemical-based crop intensification have driven, as a response, the adoption of organic production principles and practices which emphasize the protection of soil, plant, animal and human health while ensuring sustained food production for the present and future generations (Willer et al., 2013).

Organic rice production systems use organic soil amendments which help maintain soil fertility and support soil biological diversity that in turn generates the bulk of soil organic matter (SOM) that is indispensable for the promotion of growth environment, nutrient cycling and plant growth. The integrated interactions of soil organisms and SOM improve the rhizosphere ecosystem and increase the diversity of beneficial organisms promoting root growth (PCARRD, 2008; Uphoff & Kassam, 2009). Soil quality and soil health are most often related to organic matter which are the source of food for soil microbes which in turn interact with soil animals in the biotransformation of organic material into the soil nutrient pool.

Compost and other organic amendments are a valuable source of plant nutrients and soil organic carbon. SOM supports efficient plant growth and development by releasing nutrients through the decomposition process. It helps supply essential plant nutrients required by the crop (SIPPO, 2002). Research on the use of organic sources such as green manures, composts, farm yard manures, poultry manures, vermicompost, etc. have yielded beneficial results in rice production (Mao, 2000; Naing et al., 2010; Sarwar, et al., 2008). Mungbean and Sesbania green manure has been extensively used for increasing rice yield as well as for improving the soil. The addition of organic soil amendments has produced increased nutrient status of soil and improvements in crop yield. Positive responses of rice yield to organic manure application have been reported (Naing et al., 2010; Sarwar, 2008; Myers, 2000; SIPPO, 2002).

Crop response to flooded and non-flooded water conditions could be affected by the type and levels of organic treatments. Under flooded condition, reduced levels of oxygen could impair root growth and physiological processes (Uphoff 2006; Dobermann, 2003). Under non-flooded conditions, there will be more oxygen for better rooting characteristics that help increase efficiency in the uptake of water and minerals with increased metabolism. Use of organic amendments with improved water management has shown positive effects on crop performance as well as on soil properties (SIPPO, 2002; Uphoff, 2006; Doberman, 2003; Uphoff & Kassam, 2009). Escasinas (2009) has reported that non-flooded water management in rice has resulted in higher grain yield in addition to saving water.

Organic crop production also offers scope for climate change adaptive practices. It has the potential to reduce air pollution, sequester CO_2, enhance water availability, and improve soil through the recycling of organic residues. Soils rich in organic matter can contribute to achieving climate-change mitigation objectives by improving input use efficiency through its integrated effect on soil properties and substitution of chemical fertilizers. This experiment set out to evaluate the performance of lowland rice and soil microbial counts under two water regimes and two different organic fertilizer sources.

Materials and Methods

A field experiment was conducted at the Central Experiment Station, UP Los Banos (Philippines) from September 2010 to January, 2011. The experiment was conducted at two separate experimental areas:

(1) at an organically maintained field which was reserved exclusively for experiments related to organic farming by the University which does not allow the use of chemical fertilizers; and

(2) at a chemical field (adjacent to the organic field) where chemical farming practices have been used for long period of time.

Basic soil properties of the chemical and organic fields are presented in Table 1.

The design of the experiment was a split-plot in a randomized complete block design (RCBD) with three replications and plot sizes of 5 x 10 m^2. The experiment involved a series of destructive plant samplings and the plot size facilitated operations such as harrowing or rotovation of the plots at the time of transplanting. The two water regimes (flooded and non-flooded/saturated conditions) were laid as the main plots, while fertilizer sources (cow manure and mungbean green manure for the organically managed field & cow manure, mungbean green manure, and synthetic fertilizer for the chemically managed field) were the sub-plots. The individual treatment plots were separated by a thick bund (45cm broad bunds) with 25-30 cm riser height to prevent the intrusion of water and nutrients into adjacent plots. The results of the experiment were analyzed using ANOVA, and comparison among treatment means were based on Least Significant Difference (LSD) at 5% level using linear model of SAS version 9.1.

Table 1. Basic soil status of the organic and chemical fields (plots) used in the experiment.

Basic soil properties	Organic field	Chemical field
pH	5.6	5.6
N %	0.23	0.2
P ppm	3.7	2.26
K cmol	0.93	0.8
OM %	4.39	3
CEC cmol+/kg	38.26	37

Experimental materials

An early maturing rice variety, NSIC RC-144 (103 days after sowing (DAS)), non-photoperiodic, short statured, high yielding commercial rice variety was used in the experiment. This is a rice variety that has been selectively bred to perform under synthetic chemical management.

Decomposed cow manure and mungbean green manure were used as organic sources in the study. The farmyard manure was applied at 4.79 t ha^{-1} at 10 days prior to transplantation. Mungbean was seeded at the rate of 60 kg ha^{-1} and grown for 35 days, then chopped and plowed into the soil and left for 10 days before the transplanting of rice. The herbage yield from the mungbean was 20 kg/plot which is equivalent to 4.0 t/ha. Before transplanting, the plots were harrowed using a rotary tiller machine. NPK Nutrient content of the cow manure and mungbean green manure used in the experiment is presented in Table 2.

Table 2. NPK Nutrient content of the organic fertilizers.

Organic manure	N(%)	P(%)	K(%)
Cow manure	2.5	0.3	0.5
Mungbean green manure	2.67	0.37	3.43

Cultural management practices

The nursery was raised using the wet bed method and the seedlings were grown for 21 days and were then transplanted into the field spaced at 20 x 20 cm with two plants per hill. Land preparation and application of organic amendments were done 10 days prior to transplanting of rice. Full P and K basal doses and one third of N were applied 10 days after transplanting while the rest of the N split doses were applied at mid-maximum tillering stage (35-40 DAT) and panicle initiation (50-55 DAT) as top dressing. Weeding was done manually starting from three weeks of transplanting.

Soil Sampling and Analysis

Random soil samples were collected from the field from a depth of 0-20 cm for analysis. The soil samples were processed and analyzed at the Soil and Agro-ecosystems Laboratory, Agricultural Systems Cluster of the University of the Philippines, Los Baños following standard procedures and methods.

Soil analysis for microbes (bacteria, fungi and actinomycetes) were carried out using the Most Probable Number (MPN) method in which dilution and plating techniques were used involving microbial growth media viz. nutrient broth, dextrose agar and glycerol agar for bacteria, fungi and actinomycetes, respectively. Microbial colony forming units (cfu) of fungi, actinomycetes, and bacterial growth were detected after incubating for 5-7 days. Microbial count and changes in microbe populations were studied at three different crop stages, at transplanting, active tillering, and after the harvest.

Results

Total dry matter production (TDM)

The application of different fertilizers had a highly significant affect on TDM production in both the organic and chemical plots. Until 25 days after transplanting (DAT), there was no significant difference in TDM production among the fertilizer treatments but significant differences were observed from 35 DAT onwards (Figures 1 & 2). From 35 to 77 DAT, there was significant increase in TDM but started to decline at 77 DAT in both the fields.

Plants with cow manure had a significantly higher TDM than those with mungbean green manure and the control in the organic field. On the other hand, chemical fertilizers resulted in higher TDM over the other fertilizer sources. Similarly, there was a significant effect of the two water regimes on TDM production (Table 3). Flooding had a negative effect on the TDM. The interaction between water regimes and organic fertilizer sources was not significant.

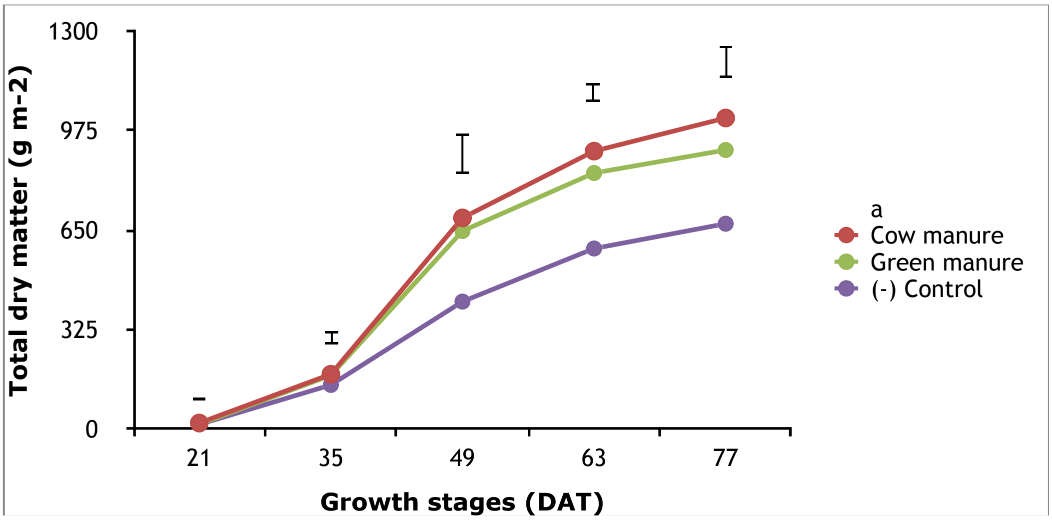

Figure 1. Total dry matter production as influenced by different fertilizers at various growth stages in the organic field. Vertical bars show LSD (p=0.05).

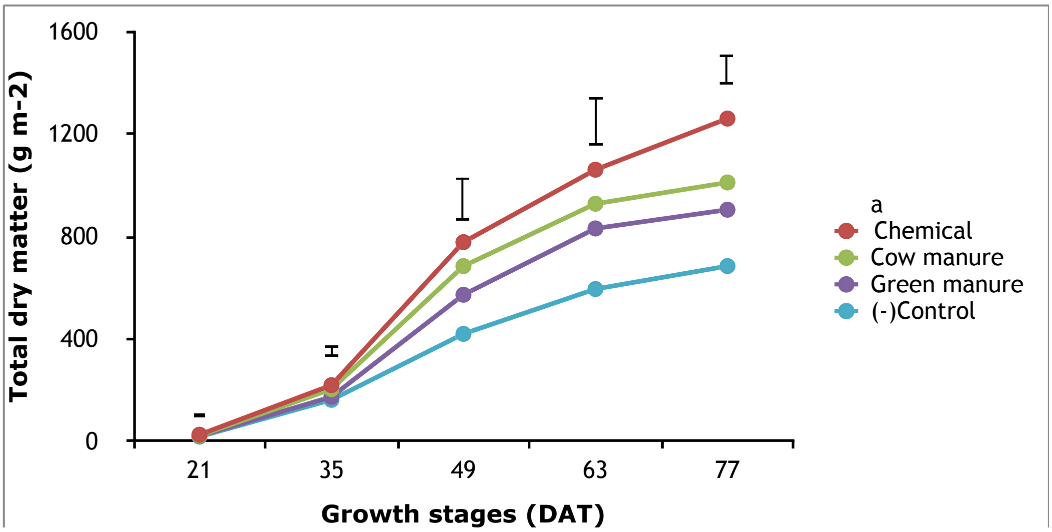

Figure 2. Total dry matter production as influenced by different fertilizers at various growth stages in the chemical field. Vertical bars show LSD (p=0.05).

Table 3. Plant total dry matter (TDM) production (g m^{-2} d^{-1}) as influenced by two different water management measures in organic and chemical fields*.

	TDM (g m^{-2} d^{-1})	
Water management	**49 DAT**	**63 DAT**
Organic field		
Flooded condition	551.17b	805.94a
Saturated condition	619.72a	835.03a
Pr>F	0.0459	0.0593
Chemical field		
Flooded condition	581.70b	818.30b
Saturated condition	633.00a	857.50a
Pr>F	0.0416	0.0374

*Column means followed by a common letter are not significantly different at 5% LSD level.

Crop growth rate (CGR)

The influence of different fertilizer sources on CGR was highly significant in both organic and chemical treatments at 35-49 DAT and 49-63 DAT (Figures 3 & 4). After 49-63 DAT, there was a gradual decline in CGR but the organic sources resulted in significantly higher CGR as compared to the unfertilized control in the organic field (Figure 3). The highest CGR values obtained in the present experiment were 33.0 g m^{-2} d^{-1} for the plots in the organic plots applied with cow manure and 34.6 g m^{-2} d^{-1} for the plots in the chemical field applied with chemical fertilizer. Chemical fertilizer and cow manure did not show a significant difference but chemical fertilizer gave the highest values of CGR in the experiment.

The GCR also showed a significant response to water management at 35-49 and 49-63 DAT (Table 4) in the organic field, and a similar pattern was exhibited in the chemical field. The interaction between fertilizer treatments and two water regimes did not show any significant effect.

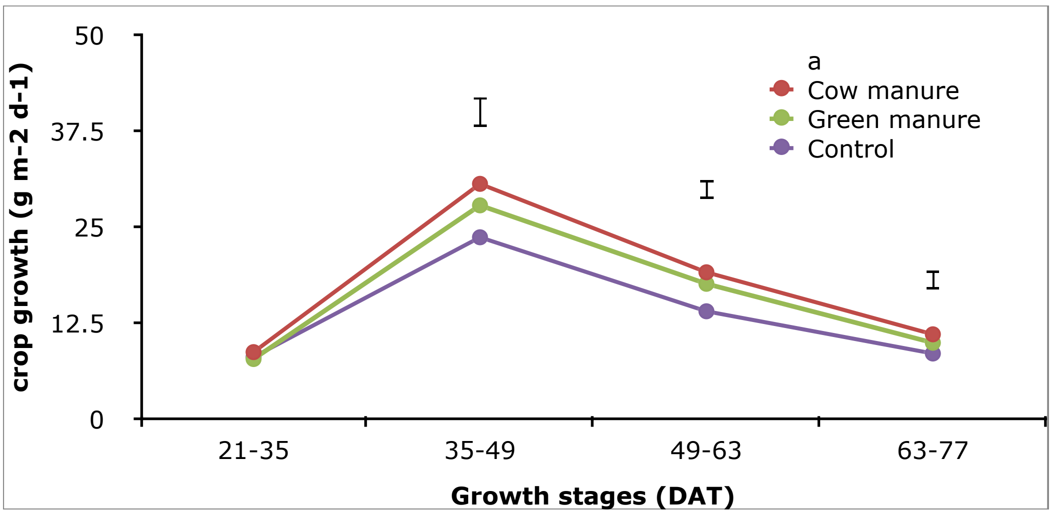

Figure 3. Crop growth rate as affected by different fertilizers at different growth stages for organic field. Vertical bars shows LSD (p=0.05).

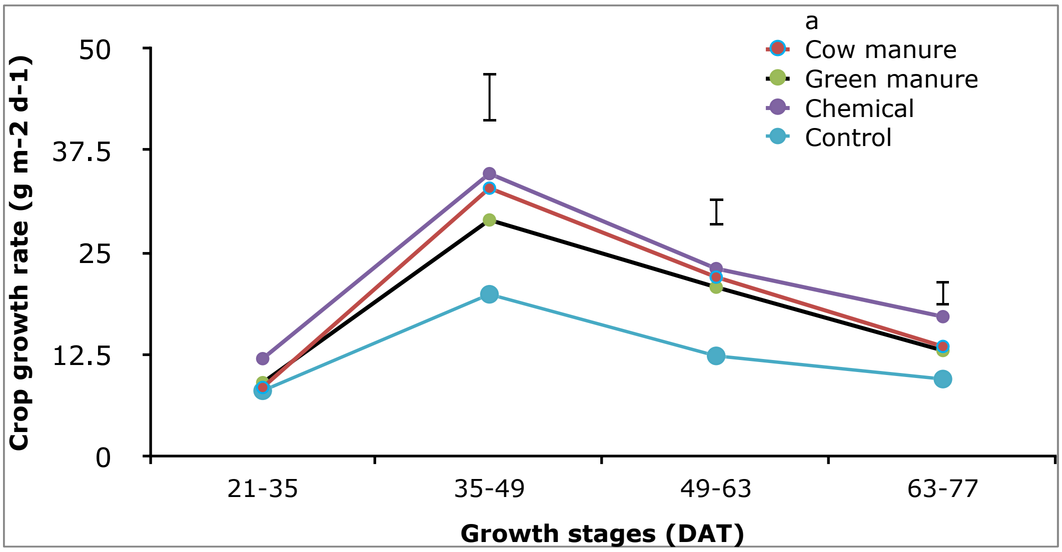

Figure 4. Crop growth rate as affected by different fertilizers at different growth stages for chemical field. Vertical bars shows LSD (p=0.05).

Table 4. Crop growth rate (g m^{-2} d^{-1}) as influenced by water management in the organic field*.

	CGR (g m^{-2} d^{-1})		
Water management	**35-49 DAT**	**49-63 DAT**	**Mean**
Flooded condition	28.4b	15.78d	22.09
Saturated condition	32.78a	19.66c	26.22
Mean	30.59	17.72	
Pr>F	0.0500	0.0475	

*Means followed by common letters within the columns and across rows are not significantly different based on LSD 5% level.

Microbial counts

Populations of microbes (bacteria, fungi and actinomycetes) differed both with water and fertilizer treatments during different crop stages (at transplanting, active tillering and after the harvest). Use of cow manure and mungbean green manure had a significant effect on the soil microbial population which forms the most basic and most important component in the organic residue mineralization. At all the three crop stages, bacteria were the most dominant microbe and the least was the fungi (Figure 5). The trends in population changes in both fields were similar.

In the organic plots, the microbial populations were much higher than those in the chemical plots. The differences were more pronounced under non-flooded (saturated) conditions as compared to the flooded conditions. At tillering stage in the organic plots, the bacterial, fungal and actinomycete populations were 3.64 x 10^7, 4.46 x 10^5, and 3.81 x 10^6 cfus under flooded condition while it was 4.29 x 10^7, 6.19 x 10^5, and 5.92 x10^6 cfus under non-flooded conditions. The bacterial, fungal and actinomycete population at the same crop stage in the chemical plots were 4.38 x 10^7, 3.79 x 10^5 and 2.82 x 10^6 cfus under flooded condition with 3.83 x 10^7, 5.28 x 10^5 and 4.93 x 10^6 cfus under the non-flooded condition.

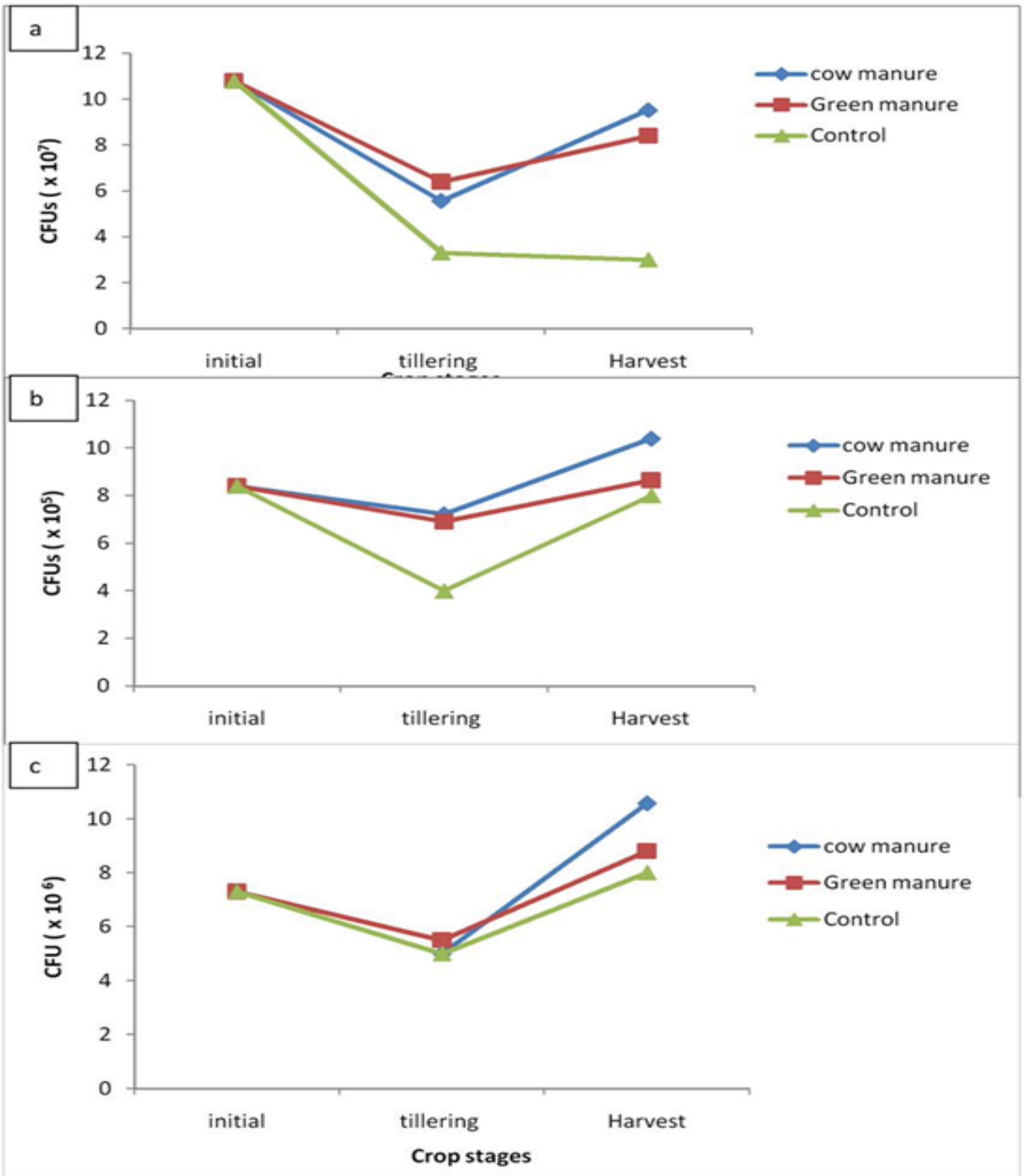

Figure 5. Change in microbial populations with growth stage of rice as affected by the application of different fertilizer treatments (a=bacteria, b=fungi and c= actinomycetes).

The microbial populations after the crop harvest were higher in the organic plots under both flooded and non-flooded conditions (Table 5). Thus, saturated treatment favoured microbial growth resulting in significantly higher microbe populations than those of the flooded treatments at both the active tillering stage and after crop harvest. There was a significant reduction in microbial populations from the initial to active tillering stage, then followed by a sharp rise after harvest (Figure 5).

Table 5. Microbial populations at tillering and after harvest as affected by water management in organic and chemical fields*.

Water management	Tillering stage (cfu g^{-1})			After the harvest (cfu g^{-1})		
	Bacteria (x10 ^{7})	Fungi (x10 ^{5})	Actinomycetes (x 10 ^{6})	Bacteria (x10 ^{7})	Fungi (x10 ^{5})	Actinomycetes (x 10 ^{6})
Organic field						
Flooded condition	3.64b	4.46b	3.81b	8.96b	6.10b	8.78b
Saturated condition	5.29a	6.19a	5.92a	10.99a	8.32a	11.83a
LSD	1.30	1.70	2.10	2.00	2.10	2.44
Chemical field						
Flooded condition	4.38a	3.79b	2.82b	6.80b	4.50b	7.90b
Saturated condition	3.83a	5.28a	4.93a	9.88a	6.08a	9.10a
LSD	4.96	2.16	2.05	3.10	1.99	1.22

*Column means followed by same letters are not significantly different at 5% LSD level.

Grain Yield and yield components

There was a highly significant effect of different fertilizer treatments on the grain yield and its components in both the organic and chemical plots. In the organic plots, cow manure and mungbean green manure gave grain yields of 3.62 t ha^{-1} and 3.45 t ha^{-1} respectively. The grain yield from these two organic fertilizer sources were 3.25 t ha^{-1} and 3.34 t ha^{-1} in the chemical plots. Cow manure and mungbean green manure, gave significantly higher grain yields than the unfertilized controls (Table 6). Chemical fertilizer application in the chemical plot resulted in the highest grain yield at 4.9 t ha^{-1}.

Table 6. Grain yields (t ha-1) and yield components as affected by different fertilizers under organic and chemical fields*.

Plots	No of panicles $hill^{-1}$	1000 grain weight (g)	Productive tillers $hill^{-1}$	Grain yield (t ha^{-1})
Organic plot				
Cow manure	14.80a	25.61a	13.66a	3.62a
Green manure	13.50a	24.47a	12.33a	3.45a
Control	9.80b	22.43b	8.33b	3.10b
LSD	1.747	4.239	2.389	0.179
Chemical plot				
Cow manure	14.20b	26.66b	13.33ab	3.25b
Green manure	12.80b	26.86b	11.33b	3.34b
Chemical fertilizer	18.60a	30.06a	15.16a	4.96a
Control	9.50c	19.60c	9.00c	2.85c
LSD	2.40	2.825	1.839	0.492

*Column means followed by common letters in a column within plots are not significantly different at 5% LSD level under different parameters.

The yield response to water treatment was significant and the non-flooded condition had higher values of productive tillers and 1000 grain weight which contribute to ultimate grain yield (Table 7). The cow manure and green manure under non-flooded condition registered a grain yield of 3.65 t ha^{-1} and 3.58 t ha^{-1} whereas the two fertilizer sources resulted to just 3.59 t ha^{-1} and 3.32 t ha^{-1} under the flooded water regime (Table 7).

Table 7. Percent filled grains and grain yield (t ha-1) as affected by two different organic fertilizer sources and water management treatments.

Fertilizer sources	% Filled grains		Grain yield	
	Flooded condition	Non-flooded condition	Flooded condition	Non-flooded condition
Cow manure	82bc	87a	3.59a	3.65a
Green manure	78cd	84ab	3.32c	3.58ab
Control	71de	75cd	2.70d	3.00e
LSD	7.061		0.179	

*Column means followed by a common latter are not significantly different at 5% LSD level under different parameters.

Discussion

Total dry matter (TDM) production

Significantly higher TDM in cow manure as compared to those with mungbean green manure and the control in the organic field showed that organic manure has potential for increasing grain yield in lowland rice. Rahman et al (2007) have also showed that proper manuring produced maximum plant dry matter with luxuriant growth and highest number of tillers plant^{-1} in rice. The lower initial crop response to different organic fertilizers at early growth stage could be due to initial transplantation shock and delay in decomposition and release of nutrients from the organic sources of fertilizers. From 35 to 77 DAT, the significant increase in TDM production could be due to active vegetative growth and tillering. There was a reduction in TDM at the later growth stages contributed by rapid senescence of leaves coupled with a decline in photosynthetic efficiency of older leaves.

In the chemical field, chemical fertilizers with readily available NPK had supported plants with higher TDM over the rest of the fertilizer treatments. This TDM production was highest with 1259.75 g m^{-2} (Figure 2). Application of N fertilizers improved dry matter production and overall plant performance in rice (Amin et al, 2006).

Flooding at different growth stages significantly reduced TDM compared to the non-flooded saturated field. The significantly higher TDM under non-flooded condition could be attributed to increased production of tillers. Under such conditions, rice produces more tillers increasing biomass and subsequently contributing to grain yield. Keeping the soil saturated but not flooded continuously in the SRI production system resulted in increased plant biomass production with increased number of tillers (Uphoff & Kassam, 2009; Uphoff, 2006; Sato, 2005). This led to increased LAI (Zulkarnain et al, 2009) increasing efficiency in harvesting solar radiation. Maximum difference between water treatments in TDM was obtained at 45 DAT and 63 DAT which coincided with maximum tillering and increased crop growth in both the organic and chemical fields (Table 3).

The lowest TDM in both cases were recorded in the unfertilized control. TDM production is a function of photosynthetic efficiency of plants which determine the ultimate grain yield, and is affected by various factors such as genetic, nutritional, temperature and environmental factors. Grain yield in rice increases with enhanced dry matter production (Wu et al, 2008; Amin et al, 2006; Hasanuzzaman et al, 2010).

Crop growth rate

The higher crop growth rate at the initial stages (35-49 and 49-63 DAT) of growth could be due to the full development of plant canopy and attainment of reproductive age. Rice plants showed reduced CGR at a later stage coinciding with grain filling and gradual senescence of older leaves. The decline in CGR after attaining maximum values towards crop maturity is due to tiller mortality and leaf senescence (Hasanuzzaman et al, 2010). A lower CGR in mungbean as compared to two other fertilizer sources could be attributed to lower biomass production. Continuous rain during the cropping period hampered growth and development of mungbean. Mungbean was found to be sensitive to waterlogged conditions and it is best suited for rice cultivation with short duration (Toomsan et al, 2000).

The significant difference in CGR at different stages of crop could be due to differences in tillering under flooded and non-flooded saturated conditions. Higher crop biomass corresponded to higher CGR under non-flooded condition with increased tillering. Organic amendments improve the soil physico-chemical properties and biological properties which are directly related to crop growth and its physiological processes (PCARRD, 2008; Uphoff 2002). The crop growth patterns in both the fields were similar.

Microbial counts

Increased populations of bacteria and other microbes are healthy signs of soil quality. One way of improving soil quality is through the application of manures. The higher presence of microbial populations at all three crop stages in organic plots indicated the positive effects of organic manures on the soil quality. This corroborated the findings of Krishnakumar et al (2005) and Tetsuya et al (2010) who showed increased bacterial population in rice paddies when organic manures were applied. Cow manure and mungbean green manures are good sources of nutrients especially N,P,K,S and carbon which are required by the microorganisms (SIPPO,2002; Sarwar, 2008).

Studies on microbes in lowland rice as well as upland conditions revealed that bacteria were the most dominant species (Gaythry, 2002; Mamaril, 2009). The Community Bio-diversity Development and Conservation program (CBDC, 2001), a non government organization which initiated various organic programs in the Philippines has reported that green manures were increasingly being used for improving soil through biological nitrogen fixation in lowland rice paddies. It also stated that animal manures were important sources of organic fertilizer with high NPK content and these organic fertilizers were good for growth and multiplication of microorganisms which recycle nutrients required by the plants. At harvest, cow manure was most effective in maintaining microbial populations and it accounted for the highest counts of microbes compared to those of the other fertilizer treatments.

SRI experiments recorded higher total bacterial counts under non-flooded treatments compared to chemical flooding in India (Gaythry, 2006, as cited by Uphoff, 2006). The effect of water management on microbial count during active tillering and after the crop harvest indicated that chemical flooding is detrimental for growth of soil microorganisms while non-flooded soil condition with organic manure resulted to higher microbial counts. Flooding is detrimental for aerobic microbes reducing their population at tillering stage but which rise again after the harvest. The rise in the populations after harvest could be due to favourable environment and the availability of food sources at that stage due to the residual organic materials.

Organic fertilizers release nutrients at a slow rate making these nutrients available for the microbes even after crop harvest. The absence of standing water coupled with sufficient residual nutrients in soil could favour growth of microbes. According to Satyanarayana et al (2002), the application of organic materials could result in a substantial amount of residual N and other nutrients in the soil for the succeeding crop which could favour enhanced soil microbial properties. Lower levels of soil microbes in chemical plots as compared to organic plots could be due to intensified chemical farming and its negative effects on soil physico-chemical properties such as poor soil aeration, compaction, loss of structures and depletion of changes in soil nutrient levels.

Higher microbial populations under reduced water condition could promote increased rate of decomposition that could result into better crop growth benefitting from favourable soil microbial properties. In general, there was a gradual change in the populations of microbes indicating phase changes in the soil environment. The nutrient level and environmental conditions could play a crucial role in the growth of microbes implying that healthy soils support microbial growth which has positive effects on the overall plant performance.

Yield and yield components

The effects of different fertilizer sources were significant on grain yield and its components. This increased grain yield in both the organic manure and chemical fertilizer applied plots was attributed to significantly higher numbers of panicle hill^{-1}, number of productive tillers hill^{-1} and 1000 grain weight than those in the unfertilized control (Table 6). These result corroborate the findings of Sarwar et al (2007) who showed that farm yard manure has a potential to increase rice and wheat yield in Pakistan. Usman et al (2003) reported that application of up to 20 t ha^{-1} farmyard manure in lowland rice increased tillering giving maximum panicle bearing heads which was further supported by Naing et al (2010). Farmyard manure and green manure significantly increased the number of productive tillers in rice and wheat in rice-wheat farming system in Pakistan and also produced heavier grains (Sarwar, 2008) resulting in a significantly higher grain yield over the control.

Mungbean green manure is very feasible for rice offering good nitrogen fixing capacity and short biomass production cycle (Myers et al, 2000). Some researchers have inferred that rice yield response was better when NPK chemical fertilizer was supplemented with organic manures. The overall yield performance involving different fertilizer sources in both organic and chemical plots indicated a narrow yield gap between them. Among the different fertilizer sources, the application of chemical fertilizer in the chemical plots was most effective in increasing the grain yield and its attributes. The variety in the present experiment was developed for its response to chemical fertilizers.

The yield attributes under the two water regimes showed that non-flooded saturated soil conditions favoured higher tillering leading to higher yield than flooded condition. Increased tillering under non-flooded saturated conditions was an important factor governing crop performance. Non-flooding led to better root growth, favouring more tiller production (Uphoff & Randriamiharissoa, 2002). This supposedly led to a parallel increase in the number of productive tillers hill^{-1} with higher 1000 grain weight. All such positive factors resulted in a higher grain yield under non-flooded condition. The same trend was reported by Uphoff (2001) and Uphoff & Kassam (2009) in their experiments related to SRI. Mao (2000) further supported this view from his experiment involving alternate wetting and drying (AWD) techniques.

The interaction between different fertilizers and water management was significant on grain yield in the organic field. Cow manure in flooded condition gave significantly higher grain yield than the green manure and unfertilized control that were not significantly different from each other. In saturated conditions, the two manures produced statistically similar grain yields but were significantly higher than those of the unfertilized control. Maximum grain yield of 3.59 t ha^{-1} was obtained in those plots applied with cow manure under flooded conditions and 3.65 t ha^{-1} from saturated conditions, whereas from green manure applied plots, grain yields were 3.32 t ha^{-1} in flooded conditions and 3.58 t ha^{-1} in saturated conditions. The lowest grain yield of 2.8 t ha^{-1} was obtained in the unfertilized control condition.

Conclusion

Both water management and different fertilizers had significant impacts on the plant growth, development and yield performance of lowland rice. The non-flooded saturated condition resulted to significantly higher values of crop physiological parameters such as TDM production and CGR. The higher values for these parameters under such field conditions could be attributed to increased production of tillers which contribute to increased biomass and subsequently crop yield. These increases were, in turn, attributed to improved rooting environment. Such plant responses in the non-flooded condition indicated better root growth and increased nutrient uptake efficiency leading to higher production of tillers, which in turn positively contributed to better yield components and grain yield.

Cow manure and mungbean green manure as organic fertilizers performed significantly better than the unfertilized control in terms of TDM production, crop growth and yield performance. The effects of the two manures were similar on both physiological and agronomic parameters governing final yield. Cow manure produced the highest grain yield of 3.62 t ha^{-1} while it was 3.45t ha^{-1} for green manure, and unfertilized control recorded the lowest grain yield of 3.1 t ha^{-1} indicating that organic manures were effective in increasing the grain yield over the control. On the other hand, the application of recommended NPK chemical fertilizer which readily supplies available nutrients had significantly higher grain yield (4.9 t ha^{-1}) over those of the organic manures.

Organic fertilizers were superior to NPK chemical fertilizers in terms of their effects on soil microbes which are the indicators of favourable soil quality. Soil organisms play important roles in nutrient recycling through the processes of decomposition and mineralization. Positive effects on these organisms could mean that the organic fertilizers have a huge potential in lowland soil with proper water management strategies. Organic fertilizers could be applied as fertilizer sources to improve the lowland soil fertility without much affecting the crop performance as they could supply plant nutrients through slow release over time.

It should noted that the rice variety used in the present experiment was bred for good performance under a chemical fertiliser regime. Attention could usefully be applied to the selection and breeding of rice varieties specifically suited for growing under organic conditions and considering the requirements of organic agriculture production practices.

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