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A Review

Microbial Communities and Their Activities in Paddy Fields: a Review

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Abstract

A paddy field is a flooded parcel of land used for growing rice and other semi-aquatic crops e.g. water lettuce. Depending on the environmental conditions, five distinctive types are recognized namely; irrigated, rain-fed/lowland, deep water, upland and tidal environments. Microorganisms found in paddy field soils include bacteria, fungi, viruses, protozoan and actinomycetes. However, bacteria are the most prominent microorganisms. Microorganisms present in rice rhizosphere exhibit several ecological relationships between one another and rice roots. These may be detrimental e.g. competition, predation and immobilization of elements or beneficial e.g. syntrophism, commensalism and saprophitism. The major microbial activities in paddy field include methanogenesis, methane oxidation and biogeochemical cycling of elements. Some of the factors that influence microbial activities in paddy fields are quality and quantity of organic materials, pH, oxygen availability, temperature, seasonal variation, rice cultivars, moisture status, inorganic fertilizers and the presence of inhibitory substances. Paddy fields are among the leading producers of methane, contributing about 10% of all global emissions. Paddy field workers are exposed to many health hazards such as *Ascaris* infection, diarrhea, schistosomiasis, skin irritation and tetanus infection. Paddy field workers should therefore, use foot wears, hands gloves and observe adequate personal hygiene when working in the field in order to prevent the various hazards.

Key words: Paddy field, semi-aquatic crops, microorganisms, methanogenesis, methane oxidation, biogeochemical cycling of elements

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Introduction

A paddy field is a flooded parcel of arable land used for growing rice and other semi- aquatic crops e.g. watercress, lotus, water spinach, water lettuce and water pepper (Wikipedia, 2007). The word paddy is derived from a Malay word Padi, which means rice (Crawford and Gyoung-Ah, 2003). Rice growing environment vary significantly within and between countries but categories based on water regime, drainage, temperature, soil types and topography are recognized. The five categories identified are as stated by Khush (1984):

(i) Irrigated environments, which have sufficient water available during the entire growing season with controlled water depth of between 5 and 10cm.

(ii) Rain-fed lowland environments, which are mainly depended on the duration of rainfall and hence with an uncontrolled shallow water depth varying from 1-50cm.

(iii) Deepwater environments, which are unbound fields with maximum sustained water depth from 0.5 to 3m

(iv) Upland environments, which are bounded or unbounded rain-fed fields with no surface or rhizosphere water accumulation

(v) Tidal wetlands, which are located near the seacoasts and inland estuaries and are influenced by tide.

Nigeria has the largest acreage of rice in which 16 percent is deepwater or floating rice. Deepwater rice grown by traditional methods or the narrow, level covered floodplain along the Niger River and its tributaries, and on the floodplain of other inland rivers of the arid zone and midnorth zone which are seasonally flooded are called *fadamas*. The *fadamas'* deep rice fields are situated along Sokoto River and near Birnin Kebbi and on the Hadejia River downstream of Kano and Maidiguri area nearer to the Lake Chad (Bangura and Goita, 1988).

There are many kinds of microorganisms found in paddy fields. These include algae e.g. *Nostoc* sp.; *Anabaena* sp.; protozoan e.g. *Entamoeba hystolytica*; viruses e.g. cyanophages; fungi e.g. *Epidermophyton* sp., *Microsporum* sp.; *Trichophyton* sp. and bacteria e.g. *Desulphuvibrio* sp., *Beggiatoa* sp., *Clostridium* sp.; *Pseudomonas denitrificans*. However, bacteria are the most prominent microorganisms (Reddy *et al*., 2001; Dubey, 2005; Prescott *et al*., 2005).

The most characteristic condition in paddy field is waterlogging or submergence of the land surface. This brings about anaerobic conditions in the soil due to the very slow diffusion of oxygen through water. After the oxygen reserve in the soil is exhausted and aerobic microorganisms have all died, facultative anaerobes dominate for some times. As anaerobic conditions continue, these microorganisms are gradually replaced by obligate or strict anaerobes (Kazutake, 2007).

The major activities of microorganisms in paddy fields include methanogenesis, methane oxidation and biogeochemical cycling of carbon, nitrogen and sulphur (Reddy *et al.*, 2001; Dubey, 2005; Kazutake, 2007). Paddy fields are among the leading producers of methane, contributing about 10% of all global emissions. Methane is the second leading gas responsible for the greenhouse effect and it accounts for 20% of global warming. During nitrification and denitrification, nitrogen and nitrous oxide are evolved. These gases also contribute to global warming (De Datta *et al*., 1988; Reddy *et al*., 2001; Dubey, 2005).

This write up discusses the microorganisms found in paddy fields and their activities. Hazards associated with paddy fields are also highlighted.

Activities of Microorganisms in Paddy Fields

Methanogenesis and methane oxidation

In paddy fields, methanogens play an important role in degradation of complex organic compounds. They mainly use acetate as a carbon substrate but other substrates like H_2/CO_2 and formates also contribute 10-30% to CH_4 production (Chin and Conrad, 1995; Yao and Conrad, 1999). Methane is produced in the anaerobic layers of paddy soil by bacterial decomposition of organic matter (Dubey, 2001). CH_4 is produced in rice fields after the sequential reduction of O_2, nitrate, manganese, iron and sulphate, which serve as electron acceptors for oxidation of organic matter to CO_2 (Yao *et al*., 1999).

Methanogenesis from all substrates require a number of unique coenzymes, some of which are exclusively found in methanogens (Ludmila *et al*., 1998). The organic matter converted to CH_4 is derived mainly from plant-borne material and organic manure (Dannerberg and Conrad, 1999). The anaerobic degradation of organic matter involves four main steps: (i) hydrolysis of polymers by hydrolytic microorganisms e.g *Bacillus* sp. and *Vibrio* sp. (ii) acid formation from simple organic compound by fermentative bacteria e.g. *Lactobacillus* sp. and *Pseudomonas* sp. (iii) acetate formation from metabolites of fermentations by homoacetogens e.g. *Clostridium* sp. and (iv) CH_4 formation from H_2/CO_2, acetate, simple methylated compounds or alcohols and CO_2 by methanogens e.g. *Methanobacteria* sp., *Methanosarcina* sp., and *Methanospirillum* sp. (Yao and Conrad, 1999).

The methane produced is oxidized to carbondioxide and water by methanotrophs. The oxidation of methane by methanotrophs is initiated by methane monooxygenase (MMO) enzyme. The MMO occurs in two forms: as a membrane bound particulate form, in all types of methanotrophs and as a soluble form in Type-II and Type-X methanotrophs (Mancinelli, 1995).

Methane emission

There are different ways green house gases can be produced and emitted to the environment, these include, through agricultural activities (Sejian *et al*., 2011), enteric fermentation in cattle (Kebreab et al., 2008) and from paddy fields. The net amount of methane emitted from soil to the atmosphere is the balance of two opposite processes-production and oxidation. Methane, the product of methanogenesis, escapes to the atmosphere from soil via aerobic interfaces where CH_4 oxidation takes place. There are three pathways of CH_4- transport into the atmosphere, namely; molecular diffusion: movement of gaseous molecules from region of higher concentration to lower concentration (Shutz *et al*., 1989), ebullition: gas transport via gas bubbles (Denier Van Gon and Nueue, 1993) and plant transport in which methane in the soil-water surrounding the roots dissolves into the surface-water of the roots, diffuses into the root epidermis and then diffuse through the cell-wall of the root-cortex, depending upon the concentration gradient between the soil-water surrounding the roots and the lysigenous inter-cellular spaces in the roots, methane is then gasified in the root cortex and transported to the shoots via lysigenous intercellular spaces and aerenchyma. Eventually, CH_4 is released primarily through the micro pores in the leaf sheath of the lower leaf position and also through the stomata in the leaf blade (Nouchi *et al*., 1990). In the temperate rice fields, more than 90% of the CH_4 is emitted through plant transport (Shutz *et al*., 1989) while in the tropical rice fields, significant amounts of CH_4 may evolve by ebullition in particular during the early period of the season and in the case of high organic input (Denier van der Gon and Nueue, 1995).

Biogeochemical Cycles of Elements

Microbial mineralization of nitrogen

A rice rhizosphere is colonized by many strains of N-fixing bacteria with different physiological features. It also habours in addition to N fixers, other microorganisms that behave as synergists or antagonists. N-fixation in the rhizosphere depends primarily on the plant and the N-fixing bacteria (Dommergues and Rinaudo, 1985; Reddy *et al*., 2001). Although, blue green algae either free living or associated symbiotically with *Azolla* are thought to be free living agents of N-fixation in paddy fields. Heterophitic N-fixing bacteria in the rice rhizosphere could also contribute to the N input when no liming factor impedes their activity (Prescott *et al*., 2005; Dubey, 2005; Kazutake, 2007).

Miscellaneous heterophitic bacteria are known to fix nitrogen, some of them especially *Azotobacter* sp., Beijerinckia sp., *Clostridium* sp., *Desulphuvibrio* sp. and *Desulphotomaculum* sp. have been found in paddy field soils (Prescott *et al*., 2005).. In the tropics, rice roots are colonized chiefly by *Spirillum* sp., *Clostridium* sp. and *Enterobacter* sp. (Asakawa and Hayano, 1995). *Azotobacter* and *Beijerinckia* occur only sporadically (Reddy *et al*., 2001; Dubey, 2005; Kazutake, 2007).

Organic nitrogen is mineralized to form ammonium ions by several species of microorganisms. Ammonium produced is either immobilized into rice roots or oxidized to nitrite by species of *Nitrosomonas* and *Nitrosococcus* through a process called nitrification. Nitrite is further oxidized to nitrate by *Nitrobacter* and *Nitrococcus* sp. The nitrate thus formed can then be used by rice plant or can further undergo denitrification process in which nitrate is used as an electron acceptor in anaerobic respiration by microorganisms such as *Pseudomonas denitrificans* to form nitrogen gas and nitrous gas and nitrous oxide; although nitrite can also accumulate. Finally nitrogen can be transformed to ammonia in dissimilatory reduction by some varieties of bacteria including *Geobacter metallireducens*, *Desulphuvibrio* sp. and *Clostridium* sp. (Prescott *et al*., 2005). N-fixers are not the sole inhabitant of the rice rhizosphere, they exist in the presence of other microorganisms, which behave as antagonists by competing for the energy provided by the root system or as synergists. Examples of other organisms include actinomycetes and protozoan (Dommergues and Rinaudo, 1985; Reddy *et al.*, 2001; Kazutake, 2007).

Microbial mineralization of sulphur

Sulphide can serve as an electron source for both photosynthetic microorganisms and chemolothotrophs such as *Thiobacillus*, *Beggiatoa*, *Thiothrix* and aerobic anoxygenic phototrophs and anaerobes such as *Chlorobium* and *Chromatium* and it is oxidized to elemental sulphur, sulphite and sulphate. Other microorganisms have been found to carry out dissimilatory elemental sulphur reduction; such as *Desulphoromonas* and cyanobacteria. Sulphate can also be reduced to sulphide by *Clostridium*, *Desulphuvibrio* and *Desulphotomaculum* and *Desuphuromonas* sp. (Reddy *et al.*, 2001; Prescott *et al*., 2005; Dubey, 2005; Kazutake, 2007).

Elemental sulphur is commonly used as fertilizer in S-deficient agricultural systems but can also be a soil pollutant in the form of wind-blown dust from stockpiles near sour gas processing plants (Maynard *et al.*, 1986). The elemental S is oxidized to sulphite by the soil microbial population. This conversion is necessary to render the S plant available with the rate of oxidation being a major factor influencing the effectiveness of elemental S fertilizer. Oxidation of S occurs readily in some soils, but chemical, physical and biological factors limit oxidation rates in other soils (Dubey, 2005; Kazutake, 2007).

The rhizosphere of rice contains abundance of microorganisms which exhibit several ecological relationships between one another and the rice roots. For example, *Beggiatoa gigantoa* is a chemolithotroph that uses the reduction of various sulphur compounds to create energy. The most common sulphur compounds that are reduced are hydrogen sulphide, elemental sulphur and thiosulphate. *B. gigantoa* lives in the rhizosphere of plant especially rice. The bacterium lives on the roots of such plant and help the plant by oxidizing and detoxifying the hydrogen sulphide gas found in the paddy soil which could otherwise poison the cytochrome system of the rice roots, although the bacterium also benefits from the oxygen and catalase enzyme provided by the rice rots (Reddy *et al.*, 2001; Dubey, 2005; Kazutake, 2007).

Factors Affecting Microbial Activities in Paddy Fields

Contents of organic material

Methanonogenesis and microbial mineralization of nitrogen and sulphur is favoured by adequate supply of organic material. For instance, the extent of mineral sulphur formation is influenced by the sulphur content and the C: S ratio of the decomposing substrates. Sulphate accumulates only when the sulphur level in the organic matter exceeds the microbial needs (Alexander, 1971).

Soil pH

Methane production in flooded rice soils is very sensitive to pH with an optimum range between 6.7 and 7.1. Sulphur mineralization is increasingly mineralized at alkaline pH. In acidic environment, nitrification proceeds slowly. Even in the presence of an adequate supply of substrate, responsible species are rare or totally absent at great acidities (Wang *et al*., 1993).

Temperature

Methane production and emission is much more responsive to temperature because methanogens are thermophiles. Temperature not only has an effect on methane production itself but also has an effect on the decomposition of organic materials from which the methanogenic substrates are produced (Chin and Conrad, 1995).

Fertilizers

Numerous studies revealed the impact of chemical fertilizers on CH_4 emission (Adhya *et al*., 2000; Sethunathan *et al.*, 2000). The effects of fertilizers on CH_4 emission depends on rate, type and mode of applications. Urea application enhances CH_4 fluxes over the growth season possibly by increasing soil pH following urea hydrolysis and the drop in redox potential, which stimulates methanogenic activities (Wang *et al*., 1993). Lindau (1994) reported decrease in CH_4 emission rate with ammonium nitrate application due to competitive inhibition of nitrate reduction in favour of methane production. Inorganic N influences CH_4 oxidation due to shifts in the population structure and the kinetics of methanotrophs (Dubey *et al*., 2000). This may affect the threshold value of CH_4 oxidation (King, 1992). NO_3^{-}N fertilization did not affect the CH_4 consumption but NH_4^{-}+N fertilization completely ceases CH_4 oxidation (Husch *et al*., 1994).

Presence of inhibitory substances

A variety of chemicals used in agriculture such as pesticides and herbicide and nitrification inhibitors are known to affect microbial processes. It is well established that CH_4 production is inhibited by acetylene, aminopurine, ammoniumthiosulphate, carbofurane, calcium carbide (capsulated), DDT, dicyandiamide, methyl chloride, methyl fluoride, nitrapyrine, pyridine, organochlorine, sodium azide, CH_4-acetylene, bromoxynil, dicyandiamide, 2,4-D ethylene, hexacholorocyclohexane, hydrazine, methomyle, nitrapyrine, phenylalanine, sodium thiosulphate, threonine and thiourea (Topp and Pattey, 1997). Nitrification inhibitors such as acetylene and nitrapyrin can also inhibit the growth of nitrifiers, methanogens and methanotrophs (McCarthy, 1999). Lindau *et al*. (1993) found that CH_4 emissions from rice fields decreased by 35% and 14% following the application of encapsulated calcium carbide and dicyandiamide respectively. Topp (1993) found that the pesticides, bromoxynil, nethomyl and nitrapyrin were inhibitory to CH_4 oxidation at 50g/l. High application of N fertilizers inhibit rhizosphere N-fixation (Dommergues and Rinaudo, 1985).

Soil moisture

Because moisture affects the aeration regime of soil, the water status of the microbial habitat has a remarkable influence on mineralization of nitrogen and sulphur. For example, at one extreme, water logging limits the diffusion of oxygen and nitrification is suppressed. At the opposite pole, in arid conditions, bacterial proliferation in rice rhizosphere is retarded by insufficient water supply (Dommergues and Rinaudo, 1985). Also methane production is greatly reduced in a waterlogged condition.

Hazards Associated With Paddy Fields

Health hazards

Paddy field workers are exposed to various agents viz: irritant like mud, cowdung or other manure, fertilizers, pesticides and dusts from the dried plant and grain during threshing. During the ploughing and planting season and sometimes in the harvesting season, the feet are constantly immersed in water. These factors can predispose workers to dermatoses of the face, hand and feet and infections by bacteria and fungi. Cercarial dermatitis has equally been reported with snails in the water acting as intermediate hosts (Narian *et al.*, 1994). Farm workers in contact with waste water through irrigation and play have a significant higher prevalence of *Ascaris* infection and diarrhea diseases (Peasey *et al*., 2000; Jung *et al*., 2007).

Many grasses, including paddy can traumatize the skin by their thin prickly spikes or by laceration (Woodgyer *et al*., 1985). They can produce urticarial papules in workers handling crops or litter straw (Mitchell and Rook, 1979). Parasites of grain can cause skin irritation from grain dusts due to parasito-phytodermatitis or pseudophyto-dermatitis (Uenotssuchi *et al*., 2000).

Other diseases commonly associated with paddy workers include melasma and freckles, this can worsen after sun exposure. *Tinea versicolor*, a superficial infection is also implicated especially in hot and humid weather (Halder *et al.*, 2003), chronic paronychia of the finger nails, toe nails and pitted keratolysis (Zais, 1982), infections of *Micrococcus sedentarius* (Nordstrom *et al.*, 1987), *Dermatophilus angolensis* (Woodgyer *et al*., 1985), *Acinetobacter* sp., *Klebsiella* sp., *Pseudomonas* sp., *Aspergillus* sp., *Staphylococcus* sp., *Clostridium* sp., especially *Cl. tetani* (Shenoi *et al*., 2005), foot intertrigo (Kate *et al.*, 1999), palmer, planter hyperkeratosis, fissuring, scaling, feet lesions, dystrophy of fingernails and toe nails (Shenoi *et al*., 2005).

Gas emissions

Paddy fields have been emitting methane since time immemorial. Paddy field soils are estimated to contribute about 25% of the total budget of global methane emissions and therefore have a major impact on world climate due to their contribution to the greenhouse effects (Neue, 1993). In relation to the global environment, air pollution from paddy soil is receiving more and more attention. The production of nitrous oxide from N-fertilizers and manure is now considered to have an environmental impact. The gas is evolved in both nitrification and denitrification processes. The former is considered more important at present. It affects the destruction of ozone to oxygen and also acts as a greenhouse gas. However, nitrous oxide from paddy fields is considered to be very low (De Datta *et al*., 1988). Some of the effects of global warming include increased temperature, rainfall, increased evaporation and erosion (Mayhew *et al*., 2007), acidifications (Intergovernmental Panel on Climatic Change, IPCC, 2007), disruption of the ecosystems (Mayhew *et al*., 2007) and spread of disease (McMichael *et al*., 2003).

Conclusion

Because of the enormous effects caused by CH_4 emissions from paddy fields, flood management which includes intermittent drainage of rice fields may be a good option to mitigate CH_4 emission into the atmosphere. Other methods of reducing CH_4 emissions into the atmosphere include optimizing rice productivity, genetic engineering which produces more spikelets (the crucial factor in lessening carbon deposits is the number of spikelets that a plant produces), addition of Fe (II), relying on its continuous regeneration by Fe (II) oxidation in the rice rhizosphere.

Because of the possibility of contraction of infection, paddy fields workers should use foot wares and hand gloves when working in the fields in order to prevent exposure to various agents. Besides, less research has been conducted in the areas of microbial activities in paddy fields in Nigeria; therefore, innovative research in this area is encouraged.

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