CHAPTER 2

LITERATURE REVIEW

2.1. Green Manures

The use of green manures has been an agricultural practice for improving soil fertility for millennia. They are crops that offer greater potential as nutrient supplements that farmers can grow in their own fields (Palaniappan and Budhar, 1994). They provide a considerable and continuous supply of biomass to the soil, thereby maintaining and even raising, during the course of several years, the organic matter content of the soil. In addition, green manures, in the case of leguminous species, have the ability to fix large quantities of atmospheric N_2 (Singh *et al.*, 1994) by means of bacteria in the root nodules (Coughlin, 2001). This can bring about a significant supply of nitrogenous fertilizer to the commercial crops and to improving the soil nitrogen balance. The growth and decomposition of green manures stimulate many species of soil micro-organisms whose activities improve both the physical and chemical properties of the soil (Sullivan and Diver, 2001; Coughlin, 2001).

2.2. Green manures and productivity of rice soil

Green manure crops are a cornerstone of ecologically sensible agriculture (Michaels, 2001). They are crops that historically were used for plant nutrition and as organic matter for increasing soil fertility, especially soil organic matter and inorganic soil components (Ishikawa, 1988; Sullivan and Diver, 2001), and for improving soil structure (Sullivan and Diver, 2001; Coughlin, 2001). In short, green manures are considered as a source of soil nutrients and an alternative to maintaining soil fertility which has received renewed attention with the emerging emphasis on the long-term sustainability of agriculture systems (Mubarik, 1999).

The potential benefits of green manuring are generally interpreted in terms of the capacity to substitute for inorganic fertilizer N (Abrol and Palaniappan, 1988) which is one of the most important factors governing plant productivity (Rinaudo *et al.*, 1988). In the case of rice, Abrol and Palaniappan (1988) suggested that growing green manure crops before rice is probably among the most efficient ways to improve soil productivity. Because the incorporation of green manures results in increases both the levels of total N and available P (Jiao, 1983; Mann and Garrity, 1994).

The residual effect of green manures on rice yields has been demonstrated to be quite tangible. Bouldin (1988) and Abrol and Palaniappan (1988), for instance, reported that many green manure crops furnish a succeeding rice crop with N equivalent of 50 to more than 100 kg fertilizer N per ha and, consequently, increase rice yields from about 1.5 to 2.5 t ha^{-1}. Approximately 50-80% of the total N content in most green manures decomposes within the first rice crop, while the remaining N decomposes slowly over several years (Bouldin, 1988). Therefore, annual application of green manure has cumulative residual effects on both the N supply and the soil organic matter. These effects produce greater and greater benefits to the soil properties as time goes by.

Another benefit of growing green manure crops is of the improvement of soil structure that associates with the root mass of the crop themselves and the increased amount of organic matter and its decomposition process in the soil. According to Michaels (2001), root mass of the green manure crops plays a very important role in enhancing the soil structure by means of loosening and aerating the soil. Chen (1986) revealed that experiments had demonstrated that organic matter accumulated in different soils; however, after 4-5 consecutive years of green manure incorporation, organic matter increased 0.1-0.2 %, soil bulk density was reduced, and porosity was enhanced. Sullivan and Diver (2001) illustrated the improved soil structure in relation to the microorganisms activities by pointing out that during the breakdown of organic matter by microorganisms, compounds are formed that are resistant to decomposition, such as gums, waxes, and resins. These compounds and the mycelia, mucus, and slime produced by microorganisms help bind together soil particles as granules or aggregates. A well-aggregated soil tills easily, is well aerated, and has a high water infiltration rate.

In summary, green manure crops offer great positive contributions to improved soil physical, chemical, and microbiological conditions. Since they are potential sources of N, the integration of green manure crops, especially legumes, into rice production systems is seen to be an economically and ecologically sound practice for achieving both the short-and-long term increased rice productivity. It was estimated that the average amounts of N accumulated by green manures can entirely substitute for mineral fertilizer N at current average application rates with less prone to loss mechanisms (Becker *et al.*, 1995).

2.3. *Sesbania rostrata* as potential green manure species in lowland rice

S. rostrata is a native, non-palatable legume of West Africa. It is a tall annual species, although becoming perennial under favorable conditions, with the height from 1-3 m, growing during the short rainy season (Houérou, 2002). It is found on deep clayey alluvial soils, periodically flooded or water-logged. The main characteristic of *S. rostrata* is its high nitrogen fixing ability that makes it particularly useful for growing in rotation with rice, as a green manure or for making a rich compost as the plant contains some 4% N_2. It forms a symbiotic relationship with *Azorhizobium caulinodans* and is renowned for it's stem nodulation. Both stem and root nodules fix nitrogen. However root nodules form at the curled root hair while stem nodules occur at the sites of adventitious root primordia via "crack" entry. The stem nodules unlike the root nodules contain functioning chloroplasts in the nodule cortex and are therefore capable of carbon fixation. *S. rostrata* has a very fast growth rate and is very nitrogen rich. Thus, it is viewed as a potential crop, which can be used as a green manure for rice crops. It could be grown in the field before rice crop is sown, then ploughed back into the soil replenishing the nitrogen levels (Parson et al., 1993, 1995).

According to Houérou (2002), the amount of nitrogen added by a good crop of *S. rostrata* is estimated at 60-240 kg ha^{-1} yr^{-1}; that is, the increase in rice yield resulting from the utilization of *Sesbania* as green manure corresponds to a dressing of this amount of pure nitrogen. A good crop of *Sesbania,* with 500,000 plants per hectare, produces 4,000-5,000 kg dry matter in 55-60 days. i.e. 160-200 kg of pure nitrogen equivalent. Specialists in nitrogen fixation research reckon this is a fixing power still higher than in soybean.

The stem-nodulating tropical legume *S. rostrata* has recently shown promise as a green-manure crop in rice-farming systems due to its high N-fixation potential, fast growth and tolerance for flooding (Becker *et al.*, 1988). The levels of N accumulations by *S. rostrata* vary depending upon length of the growing periods and locations. In the Philippines, 40-60 days old *S. rostrata* contained 100-176 kg nitrogen ha^{-1}. In Senegal, the original niche of 52 days old *S. rostrata* crop accumulated 267 kg of nitrogen ha^{-1} (Rinaudo *et al.*, 1983).

With these varying levels of N accumulations in the soils, *S. rostrata* is deemed as a potential determinant affecting many important crop components, especially grain yields (Centeno *et al.*, 1985; Furoc and Morris, 1989; Morris *et al.*, 1989; Mulongoy, 1986). According to Vejpas *et al.* (1990), *Sesbania rostrata* can give a high biomass and N_2-fixation over any leguminous green manure crops (10 to more than 30 t fresh weight per ha and 50-270 kg N ha^{-1} within 30-75 days after sowing) and increase successive rice yield from 0.2 to 2 t ha^{-1} (in Nguyen, 1992). Results of field experiments on the effect of *S. rostrata* on rice in the Philippines also demonstrated a significant increase in grain yields of rice. Diekmann *et al.* (1996), for example, reported that the incorporation of the 49 days old *S. rostrata* accumulated up to 190 kg N ha^{-1} which resulted in increases in grain yields by 1.3-1.7 t ha^{-1} in at in Luzon and 6.5 t ha^{-1} in Los Banõs.

Moreover, many researches on the incorporation of *S. rostrata* with the application of inorganic fertilizers resulted in positive effect on rice yields. In Thailand, Arunin *et al.* (1995) revealed that *S. rostrata* gave the highest rice yield in both the saline and non-saline soils. Although the average N-contents of *S. rostrata* in non-saline soils were higher than those in the saline soils, rice yields obtained from the fields under these two soil types receiving *S. rostrata* green manure plus fertilizers were respectively 90% and 29% greater than those obtained from fields with only

S. rostrata. Bar *et al.* (2000) also found that rice growing in rotation with *S. rostrata* where N was top dressed gave the highest grain yield and highest percentage increase over the control (120%), while incorporating *S. rostrata* alone without N application resulted in a lower yield increase (34%) over control. In a field trial conducted by the Land Development Department, Thailand, it was found that the application of N-P-K at the rate of 50-50-50 kg ha^{-1} along with the incorporation of *S. rostrata* to both non-saline and saline soils increased rice grain yields by 58% and 10% respectively compared to those received from the fields with only *S. rostrata* (Arunin, 1996).

2.4. Nitrogen forms and availability fluctuation within the soil.

Of all mineral nutrients, nitrogen is quantitatively the most important for plant growth (Engels and Marschner, 1995; Schrader, 1984). However, most agricultural soils are deficient in nitrogen (Freney *et al.*, 1995). An increase in availability of nitrogen in the soils in order to meet crop demands is achieved primarily through application of inorganic and organic fertilizers to the soil. Furthermore the availability of nitrogen is increased through bacterial fixation of gaseous nitrogen (N_2) to ammonium (NH_4^+) compounds, which can be absorbed by plants. Besides nitrogen availability to plants also increases through mineralization, a process of decomposition and transformation of organic matter (crop residues, manure, etc.) to available forms of inorganic nitrogen such as NH_4^+ (Kasica, 1996). In spite of these, the availability of nitrogen in the soil is often vulnerable to losses *via* many processes, such as, leaching, erosion and runoff, or by gaseous emissions (Freney, 1995; Strong, 1995). As pointed out by Freney (1995), the relative importance of these processes can vary widely, depending on the agricultural systems and the environment. For example, the N may be leached whenever the rainfall or water supply from other sources exceeds evapotranspiration. Water and wind erosion or runoff can be sources of fertilizer losses where bare soil is left fallow, and in irrigation systems where water is allowed to flow down slopes from one field to another, or where overflows occur following heavy rainfall. In general, however, gaseous emissions of N *via* ammonia (NH_3) volatilization, and denitrification have been identified as the dominant mechanisms of fertilizer N loss in many different agricultural systems (Peoples *et al.*, 1995).

The forms of nitrogen available to plants are nitrate (NO_3^-) and ammonium (NH_4^+) nitrogen. Their available amounts in the soils are varied through nitrification-denitrification (Kasica, 1996; Mikkelsen, 1995). Nitrification is a biological oxidation by microorganisms, carried out by two chemoautotrophic bacteria, *Nitrosomonas* and *Nitrobacter*, (Mikkelsen, 1995) of NH_4^+ to NO^-_2 and NO_3^- (Hauck, 1984) that are taken place before the absorption by crops, and are governed by soil temperature and pH (Kasica, 1996). The warmer the soil temperature is, the quicker the transformation processes are. In regards to pH, however, nitrification occurs most efficiently when soil pH is between 5.5 to 6.5. Denitrification is carried out by facultative anaerobic bacteria in the soil when the partial pressure of soil oxygen falls to low levels. In the absence of oxygen and with adequate organic substrate, a wide range of denitrifying organisms can use nitrate-N as an electron acceptor during respiration to reduce NO^-_3-N to gaseous N_2 and N_2O. Factors that favor denitrification are the absence of oxygen, a supply of decomposable organic matter, a pH near 7.0 and alternate drying and wetting of soil, as described by Mikkelsen (1995).

Volatilization is also another potential mechanism leading to the loss of N available to plants. Through the volatilization process, which normally occurs in the flooded conditions, ammonium $NH4^+$ is converted to volatile ammonia (NH_3) (Kasica, 1996; Mikkelsen *et al.*, 1995). This gaseous ammonia is lost into the atmosphere. According to Mikkelsen *et al.* (1995) the NH_3 volatilization process is affected directly by five primary factors, including NH_4^+-N concentration in the floodwater, pH, temperature, wind speed, and depth of floodwater. Each of the primary factors is a function of several secondary factors which include such elements as nitrogen source, rate and method of application, soil pH and CEC, water alkalinity, and so on. The concentration of NH_4^+-N in the floodwater has a linear relationship to the amount of ammonia volatilized when factors such as floodwater pH, temperature, wind speed, and water depth are kept constant. While it is not possible to generalize on the effect of one variable without considering the interacting factors, volatilization generally increases about 10-fold in a pH range from 7 to 10. Ammonia losses increase in a curvilinear manner with wind speed and by about 0.25% per °C degree temperature increase in the range from 20°C to 45°C. Increased depth of flooding from 0 to 20 cm generally decreases ammonia volatilization losses.

2.5. Nitrogen cycle in paddy soil ecosystem

Figure 1 presents the schematic representation of nitrogen cycle in paddy soil ecosystem. The most characteristic management practice in paddy rice cultivation is waterloggoing or submergence of the land surface (Kyuma, 1995). The N in flooded soils occurs in both inorganic and organic forms, with the later is the predominant (Patrich and Reddy 1976, IRRI, 1979). Ammonium-N is the dominant inorganic form that is derived from mineralization of organic compound. Under anaerobic condition such as paddy rice cultivation the mineralization process stops with NH_4^+-N formation. Nitrate and nitrate-N appear in trace amounts as products of ammonium nitrification. The gaseous forms of N occur either dissolved in the anoxic layer of flooded soil (Mikkelsen *et al.*, 1995).

The losses of N in paddy soil can occur through nitrification-denitrification and ammonium volatilization. In wetland soil such as rice soil systems, nitrification is restricted primarily to the aerobic (oxidized) soil layer and near the oxidized surface of rice roots. Nitrification in wetland soil is undesirable, since it leads to the loss of ammonium NH_4^+-N by biological denitrification and nitrogen losses as nitrous oxide (N_2O) and dinitrogen (NO_2) (Mikkelsen *et al.*, 1995). In lowland rice, large denitrification events occur when the soil is reflooded, and then proceed during flooding in the reduced soil layer (Buresh and De Datta, 1991; Aulakh *et al.*, 1992).

The large losses of NH_3 in flooded rice occur through ammonium volatilization. Researches have shown that NH_3 volatilization can occur for 20% to > 80% of the total N lost from fertilizer sources (Simpson *et al.*, 1984; De Datta *et al.*, 1989; Freney *et al.*, 1990; Mosier *et al.*, 1989; Zhu, 1992). Furthermore, Farquhar *et al.* (1983) revealed that although nitrogen losses from rice into the atmosphere have been reported, the emissions represent only a small portion, probably less than 5% of nitrogen applied (in Freney and Simpson, 1983).

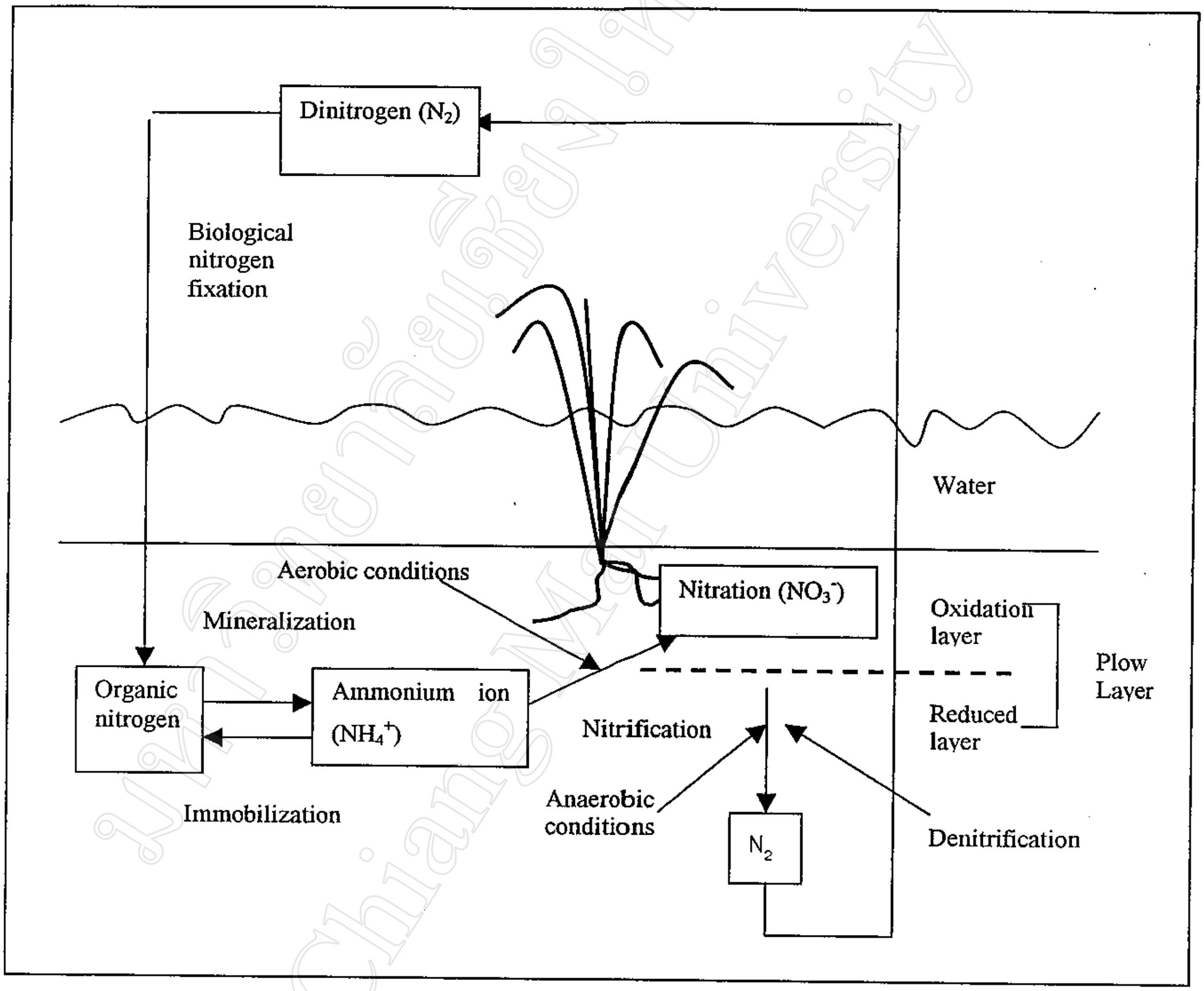

Figure 1. Schematic representation of nitrogen cycle in paddy soil ecosystem (Source: Adapted from Mikkelsen *et al.*, 1995; Kyuma, 1995)

2.6. Dynamics of ammonium nitrogen (NH_4^+-N) in the lowland paddy field following incorporation of *Sesbania rostrata*

Exchangeable NH_4^+ is the most important available soil N fraction for flooded rice. However, NH_4^+ is subject to volatilization, fixation by clay paricles complex, and immobilization by living organisms other than the main rice crop (De Datta, 1981; Freney *et al.*, 1981; Keerthisinghe *et al.*, 1985). This has resulted in a gradual reduction in efficiency of N-uptake by crops.

To maintain a concentration of NH_4^+ -N in flooded soil for rice uptake over time, Nagarajah *et al.* (1989) suggested the incoporation of green manure is necessary because NH_4^+-N released can be retained in the soil. This recommendation was corroborated by Hamman (1991), whose findings were that the incorporation of *S. rostrata* in Utisols and Alfisols in Northeast of Thailand led to rises in NH_4^- -N accumulations in direct proportion to the amount of biomass. Hamman then concluded that more *S. rostrata* meant more biologically fixed N and ultimately greater NH_4^+ -N concentrations. This apparently reveals that *S. rostrata* incorporation does have a close relationship with the N mineralization in the soil, although the process might be varied depending on soil types.

As cited by Clément *et al.* (1998), Becker *et al.* (1994) and Clément *et al.* (1995) reported that, under lowland conditions, the chemical composition of green manure can significantly alter the pattern of N mineralization. Results of the three-season experiment conducted by Clément *et al.* in 1998 at the International Rice Research Institute (IRRI) suggested that all types of green manure crops rapidly released N. Soil NH_4^+ -N with rice increased until about 20 day after transplanting, follow by a decline caused by crop N uptake. In contrast, there was no decline in soil NH_4^+ -N without rice plants. The pattern of soil NH_4^+ -N release through time without rice plants shows that green manure N mineralization was mostly completed by 30 days after transplanting. After that, soil NH_4^+ -N increases were comparable among no-N and green manure treatments, and were presumably originating from native soil inorganic N release.