2 Review of literature

2.1 Fertilizer trend and usage

By the year 2050, the world population will double its current level of more than 6 billion. The Asian population, in particular, is expected to rise by 53% over the next 30 years (Hossain and Singh, 2000). Consequently, the demand for food grains will also escalate. The International Food Policy and Research Institute (1996) forecasts a 39% increase in cereal demand between 1995 and 2020, while Hossain and Singh (2000) report a 65% increase by the year 2020.

To meet this high demand, 80% of the additional grain will have to come from yield increases rather than from farmland expansion (Maene, 2000). The developing world, where the potential for crop area expansion is limited, will be responsible for most of these increases. Therefore, the growing demand for staple grains will rely on the intensive use of chemical fertilizers.

FAO data show that chemical fertilizer use has steadily increased over the last decades and this trend is likely to continue in the coming years. The annual fertilizer use is expected to rise from an average of 134 million tons between 1995 and 1997 to about 180 million tons by 2030, with a range of plus or minus 10% depending on the improvement in the efficiency of fertilizer use. This represents an annual growth rate of about 1% per annum (FAO, 2000).

Nitrogen fertilizer consumption, in particular, increased from 12 to 81 million tons between 1960 and 1998 (Maene, 2000). Other statistics report a rise from 3.6 million tons in 1950 to 85 million tons in 1990 (Ayoub, 1999). Gilland (1998) asserts that the 74 million tons per year of nitrogen fertilizer currently used for agricultural production will increase to 200 million tons by 2050 – an annual growth rate of ~1.9%. This intensive use of nitrogen and other fertilizers was one of the main factors in the increase in the average world cereal grain yields from 1.13 t ha^{-1} in 1950 to 2.76 t ha^{-1} in 1990 (Brown, 1996).

Rice, wheat and maize are the major users of fertilizer, and account for over 50% of the global fertilizer use (FAO, 2000). Rice, in particular, accounts for more than

40% of the total fertilizer consumption, and 20% of all N fertilizer production (Hossain and Singh, 2000).

In the Philippines, there was a significant positive correlation (r=0.73*) between the growth of rice production and urea consumption from 1981 to 1999. Urea consumption has been increasing for the last two decades. In 1999 alone, Filipino farmers used ~294,172 Mt of urea which is equivalent to ~135,319 Mt of nitrogen. For the same year, the Philippines imported 313,719 Mt of urea, an increase of 23.9% from the previous year (FAO statistics). With price of US$ 267 per Mt, cost to the country amount to about US$ 8.4 M, 15% higher than the 1998 cost of urea imports.

Nitrogen fertilizers are produced using natural gas, petroleum and coal that supply the energy and hydrogen required to convert atmospheric N to ammonia. The process, therefore, draws fossil fuel reserves, which are non-renewable resources. In this sense, modern agricultural production systems are non-sustainable (Hossain and Singh, 2000).

2.2 Nitrogen use efficiency

Nitrogen use efficiency (NUE) is defined as the production of grain per unit of N absorbed from the soil. The efficiency with which N is used by rice depends on factors such as the physiological efficiency with which plant N is used to increase grain yield; the uptake per unit of N applied; and the agronomic efficiency which is the increase in grain yield per unit of N input (Moll *et al*., 1982).

Nitrogen use efficiency is commonly studied in terms of the amount of fertilizer N applied and referred to as fertilizer N use efficiency (Liu, 2000). Parr (1973) defined fertilizer N use efficiency as the percentage recovery of fertilizer N by a crop. It is calculated by taking the difference in the N uptake by the aboveground parts of fertilized plants with that of the unfertilized plants.

Fertilizer N use efficiency is determined primarily by the crop's growth rate and its nutrient demand, and also by the ability of the plant to compete effectively with other processes that draw off nutrients (Zaman, 1987; Buresh *et al*., 1988a; De Datta *et al*., 1990). The amount of N taken up by plants depends on several factors such as the Nsupplying capacity of the soil, the previous N uptake, the developmental stage of the plant when N was applied, and the crop's yield potential (Wuest and Cassman, 1992b).

There seems to be a general consensus that recovery of applied N by rice is very inefficient (Craswell and Vlek, 1979; Vlek and Fillery, 1984; Vlek and Byrnes, 1986) and thus, is a major drawback in achieving high agronomic efficiency (Rasmussen and Rohde, 1991; Finck, 1992; Awasthi, 1999). The uptake efficiency of applied N ranges from 20 to 60% with an average efficiency of only 30 to 40% in most areas (http://riceweb.org). Recent on-farm studies found no strong evidence to indicate that this low fertilizer N efficiency by rice has increased over the past years (Dobermann *et al*., 2002). This low N efficiency reflects poor agronomic management and the highly dynamic nature of N in the soil-floodwater system, which leads to gaseous losses. Aside from high losses as gas, N is transported to the ground and surface waters. These factors cause direct economic loss to farmers and exert negative impacts on the atmosphere and water quality (Xing, 2000).

An article from the Rice Web (http://riceweb.org) reported that in most Asian countries, irrigated rice farmers apply N at the rate of 60 to 90 kg N ha^{-1} during the wet season and 100 to 150 kg N ha^{-1} during the dry season. If a grain yield of 6 t ha^{-1} is to be achieved, the crop should take up approximately 100 kg N ha^{-1}. Assuming that the N uptake efficiency is 50%, and that the soil can support a yield of 3 t ha^{-1} without any N fertilizer being applied (N uptake of 45 kg ha^{-1}), a farmer must apply N at the rate of 110 kg N ha^{-1} to obtain a 6 t ha^{-1} grain yield. If the average N uptake efficiency of 30 to 40% is used, the N rate would have to be increased to ~180 and 135 kg N ha^{-1}, respectively.

In view of the large quantities of N involved, poor N use efficiency by rice not only causes significant economic loss to farmers but to the national economy as well. For example, at a wholesale price of US$ 0.66 per kg of N in urea, US$ 10.6 billion could be lost if only 80% of the approximately 80 Mt of N used in world agriculture in 1998 was utilized. According to the International Fertilizer Industry Association (IFIA), a 1% increase in cereal NUE would today be worth US$ 400,000,000 (http://fertilizer.org/ifa).