7. The efficacy and loss of fertilizer N in lowland rice

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Abstract. Nitrogen fertilization is a key input in increasing rice production in East, South, and Southeast Asia. The introduction of high-yielding varieties has greatly increased the prospect of increasing yields, but this goal will not be reached without great increases in the use and efficiency of N on rice. Nitrogen enters a unique environment in flooded soils, in which losses of fertilizer N and mechanisms of losses vary greatly from those in upland situations. Whereas upland crops frequently use 40–60% of the applied N, flooded rice crops typically use only 20–40%. There is a great potential for increasing the efficiency of N uptake on this very responsive crop to help alleviate food deficits in the developing world.

This article reviews current use of N fertilizers (particularly urea) on rice, the problems associated with rice fertilization, and recent research results that aid understanding of problems associated with N fertilization of rice and possible avenues to increase the efficiency of N use by rice.

Approximately 40% of the world's population depend on rice (Oryza sativa L.) as their major caloric source, and in many of the less-developed countries of Asia, 80 to 90% of the population rely on rice as their staple food [11]. A native of monsoonal Asia, rice has been spread into many diverse environments, both in Asia and elsewhere. On a world basis Asia accounts for about 90% of the total area cultivated in rice [11]. Rice is unique in that it is the only major food crop that is semiaquatic, that grows best in a flooded soil. This preferred habitat is a major source of difficulty in the maintenance of nitrogen (N) added as chemical fertilizers. This paper attempts to review (1) the importance of N fertilizers in increasing rice production and (2) recent research findings related to N fertilization of rice.

The rice environment

The environment in which rice is grown varies enormously. Rice is found as far north as Hokkaido, Japan, and as high as 3000 m in Nepal. It is raised successfully in desert areas of the Middle East and Peru and in the tidal
swamps of major river floodplains such as the Niger or Brahmaputra. However, except for the latter environment, rice would not be found in these places without human intervention. The climatic conditions in which rice naturally occurs are very warm and humid, with strong monsoonal influence and low indirect solar radiation [22].

Although by origin and preference a lowland crop [34], rice can be grown as an upland crop through varietal adaptation. Upland rice in freely drained fields is restricted to areas with adequate rain and probably constitutes less than 10% of all rice lands. Irrigated rice dominates in China and subtropical areas, whereas upland rice is most common in Africa and Latin America. Rainfed lowland rice is predominant in South and Southeast Asia, accounting for probably 75% of the total planted [11]. The majority of the studies on the fate of fertilizer N under rice have concentrated on transplanted, irrigated rice, in both the tropics and temperate zones.

Fertilizer applied to lowland rice enters a unique flooded field soil-plant-water-atmosphere system which was first described by Pearsall [43]. The soil is overlaid by floodwater, which restricts movement of oxygen into the soil. The surface layer of soil is somewhat oxidized to a thickness which varies from 0 to 3 cm, depending on oxygen concentrations in the floodwater and the rates of oxygen consumption [21] or production [19]. To maintain respiration under water, rice has highly developed aerenchyma which allow the plant to develop an oxidized rhizosphere, the importance of which to the N economy is still in question [2, 18]. Once entered into this system, fertilizer N (urea or ammonium salts) is subject to a complex set of processes (Figure 1) discussed elsewhere [8] and in this issue. The net result of these transformations and processes is reflected in the response and fertilizer use by the crop.

Fertilizer N applications for rice are principally designed to complement the N available from soil organic matter, including plant residues, manure additions, and biologically fixed N. The amounts of N derived from sources other than fertilizer vary with environment, season, time, and crop management [9]. Although vast amounts of N are potentially available in organic wastes in rice-growing countries, the extent to which these are used varies greatly [55]. In China, where use of organic manures has been exemplary, the recently installed capacity of nearly 7 million mt of N per annum [51] will probably result in greater reliance on fertilizer N for rice production.

Rice production in the tropics has been increased through the combined adoption of high-yielding varieties (HYV), fertilizers, and chemical crop protection. Progress in this area was rapidly promoted by the development of short-statured, stiff-strawed, photoperiod-insensitive HYV in the mid-sixties. The cost of adopting the HYV was attractive in regions where rice could be produced under reliable rainfall or irrigation. However, the areas with more risky environments for rice production, e.g., deepwater and upland rainfed rice regions, have been largely bypassed by the 'Green Revolution'.

Recent increases in Asian rice production have been impressive. From