# Azolla as a technology to improve the nitrogen use efficiency of lowland rice

*The small, floating water fern Azolla, considered a «green gold mine» (Wagner, 1997) offers a new significant contribution to agriculture. When used as a cover on the floodwater surface, this nitrogen-fixing fern can drastically reduce ammonia volatilisation losses in lowland rice fields and save N fertilizer, leading to an increase in grain yield. This Azolla approach is especially attractive in lieu of the high N fertilizer cost and the growing need to improve rice grain yield with minimum adverse environmental effects associated with the intensive use of N fertilizer.*

Photo: pbase.com

**The new Azolla technology will ultimately benefit the rice farmers in a positive and self-sustaining way.**

Nitrogen (N) fertilizer is a key factor to the enhancement and sustainability of rice production. It is, however, highly susceptible to losses after their application, contributing highly to the inefficiency of N use. The average loss from applied N fertilizers can be as high as 60 percent, whereas the average N fertilizer recovery efficiency can be as low as 30 percent (Dobermann and Witt, 2000). Nitrogen losses are particularly high at low plant demand during the early growth stages when urea, the major N fertilizer used by farmers, is broadcast onto the floodwater surface (Schnier, 1995). Ammonia volatilisation, the gaseous emission of ammonia ($NH_3$) to the atmosphere, is reportedly an important mechanism for N losses in lowland rice fields and a major cause of the poor N use efficiency (Freney et al., 1993). The high N losses from applied N fertilizers and the low efficiency of N utilization by rice cause substantial economic losses to farmers and contribute highly to a number of environmental problems such as water eutrophication and greenhouse warming.

In the past, management strategies such as gypsum coating of urea (Tripathy et al., 1999) and the use of urease inhibitors to delay urea hydrolysis (Chaiwanakupt et al., 1996) had been devised to address the high N losses and poor N use efficiency problems. These management techniques, however, had met limited success in the field. Most of them are expensive (Damodar Reddy and Sharma, 2000) and entail more costs to farmers than what they can save. It is a challenge, therefore, to develop a technology, which can curtail not only the high N losses and improve the poor N use efficiency by rice, but at the same time, a technology which is also environmental-friendly, simple, and inexpensive and on the whole, beneficial to rice farmers.

A promising alternative management approach towards the improvement of the poor N use efficiency by rice and the reduction of the high ammonia volatilisation losses in lowland rice fields is the use of the multi-purpose aquatic fern Azolla.

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Figure 1: Effect of Azolla cover on the floodwater pH following urea application. Philippines. Dry season, 1998-99.

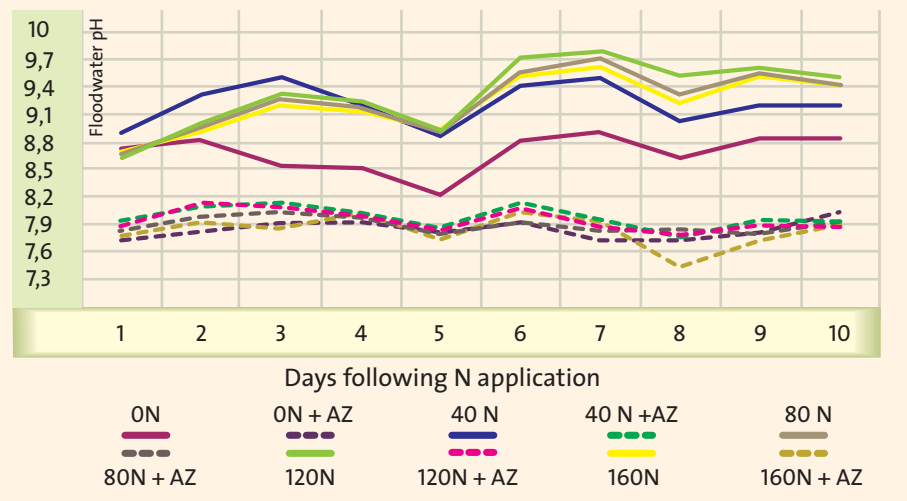
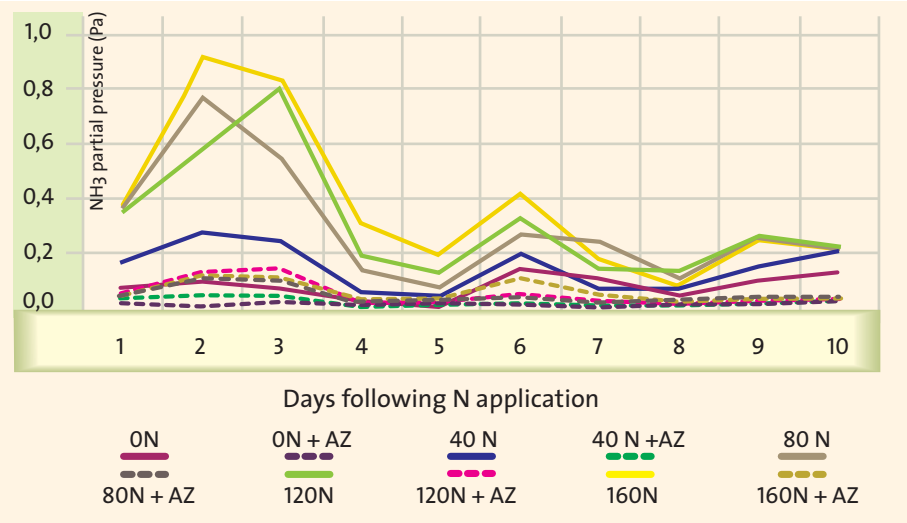



Figure 2: Effect of Azolla cover on the NH3 partial pressure following urea application.




The Azolla technology is an adaptation of a traditional system, which aims to minimize the dependence on the use of inorganic N fertilizers. Its most outstanding feature is its use as bio-fertilizer in lowland rice. Though relatively new, the use of Azolla to curb the high $NH_3$ volatilisation losses and improve the inefficiency of N use is now considered as one of its most important practical roles in lowland rice. An actively growing Azolla intercropped with rice can act as a physical barrier on the floodwater surface and bring about certain changes in the physical, chemical and microbiological properties of the floodwater, which conserve N and benefit the rice.

The use of Azolla to reduce high volatilisation losses was first demonstrated under greenhouse conditions in the Philippines (Villegas and San Valentin, 1989). The presence of an Azolla cover prevented the large increase in floodwater pH by reducing it by about two units, and lowered the floodwater temperature by 1°Centigrade to 20°C. Further greenhouse experiments in Germany demonstrated that with the proper integration of Azolla with urea into the rice culture, the biological N fixation of the fern is not negatively affected (Cissé and Vlek, 2003a ). More so, if the application of Azolla is properly timed, synergism between Azolla and urea can exist. These results were encouraging, and prompted their replication and verification under field conditions.

As part of a four-year doctoral study funded by the Center for Development Research (ZEF) and under the supervision of Professor Paul Vlek, several field experiments were conducted for three cropping seasons in different municipalities in a province in the Philippines. The aim was to provide concrete evidence of the positive impacts of an Azolla cover in minimizing the high $NH_3$ volatilisation losses and enhancing the poor urea efficiency by rice in order to promote the adoption of this alternative management approach to farmers. Five nitrogen levels (0, 40, 80, 120, and 160 kg N $ha^{-1}$) were applied alone or combined with an Azolla cover in researchers' fields. Four days before the first urea application, fifty percent of the floodwater surface was inoculated with Azolla at the rate of 5 tons (t) $ha^{-1}$ (0.5 kg $m^{-2}$) such that at the time of urea application, the floodwater surface was completely covered with Azolla. The floodwater pH, floodwater temperature, and the ammoniacal-N concentration, main factors that influence the rate of $NH_3$ volatilisation, were measured daily between 12.00 and 14.00 hours for ten days after the initial urea application. The partial pressure of ammonia, an indicator of volatised nitrogen, was subsequently computed. To determine if the presence of an Azolla cover improves the N use efficiency by rice, the fate of urea was traced in using $^{15}N$-labeled urea. The Azolla-cover approach was further evaluated in farmers' fields in multi-location trials using lower rates of nitrogen (i.e., 40 and 80 kg N $ha^{-1}$ during the wet season, and 50 and 100 kg N $ha^{-1}$ during the dry season) to show the benefits of a full Azolla cover on grain yield.

## Influence of Azolla on ammonia volatilization

The researchers found strong evidence that Azolla used as a cover on the floodwater surface of rice can indeed curb volatilisation losses through its influence on floodwater pH, the most important factor influencing $NH_3$ volatilization. A full Azolla cover on the floodwater surface at the time of the first urea application effectively prevented the rapid and large increase in floodwater pH associated with urea hydrolysis (Reddy et al., 1990) and the algal photosynthetic activities. It significantly suppressed the rise in floodwater pH by 0.9 to 1.4 pH units and maintained pH below 8.0 (Figure 1). This pH-reducing Azolla effect is important because in order to reduce $NH_3$ volatilization losses, it is essential to avoid the large pH increase in the floodwater. In contrast, without the Azolla cover, floodwater pH rose above 8.5, reaching a maximum of 10.1, a condition highly conducive to N losses via ammonia volatilization.

The lower floodwater pH under an Azolla cover is explained by the fern's influence on the absorption of light. By providing a cover on the floodwater surface, Azolla directly absorbs the incoming solar radia-

tion. Light intensity, which is essential for the photosynthetic activities of algae, is then reduced and the consequent pH elevation is abated. Furthermore, Azolla in combination with urea acts as a counterbalance against the rise in pH associated with urea hydrolysis (Cissé, 2001).
Because of the lower floodwater pH under an Azolla cover, the partial pressure of ammonia ($pNH_3$) was reduced by more than 85 percent, virtually eliminating the danger of $NH_3$ losses (Figure 2, page 58). The minimal $pNH_3$ in Azolla-covered surfaces provided evidence that under the conditions of the field experiments, Azolla is capable of curtailing $NH_3$ volatilization losses. As a result, the large $NH_3$ losses that commonly occur when urea is broadcast onto the floodwater of rice shortly after transplanting were reduced. In minimizing $NH_3$ volatilization losses, the N use efficiency was improved.

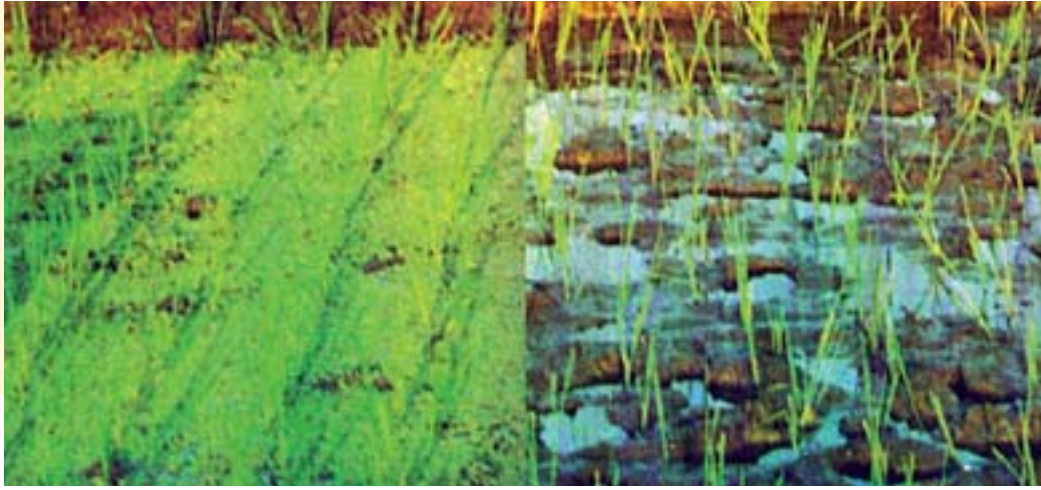


Photo: Kern

Floodwater surface with and without Azolla cover at the time of urea application (Philippines).

## Influence of Azolla on nitrogen use efficiency

At harvest, the presence of an Azolla cover led to a relative increase in the total $^{15}N$ recovery of applied urea of up to 89 percent. Of the total $^{15}N$ recovered in the Azolla-rice-soil system, 32 to 61 percent of the N applied was recovered by the aboveground biomass (grain and straw). Without the cover, only 30 to 40 percent was recovered. Interestingly, 6.5 to 13.9 percent of the labeled N was found in the Azolla plants (Figure 3). Initially, this would mean a limited availability of N to the rice plants. Through this process, however, the Azolla also contributes to the reduction of $NH_3$ volatilization losses. The fern, by assimilating part of the urea applied, protects N from immediate gaseous N losses. Consequently, the fraction of the $^{15}N$ unaccounted for and presumably lost through $NH_3$ volatilization was lower in Azolla-covered plots, with losses not exceeding 23 percent. In contrast, $^{15}N$ losses were extensive (21 to 49 %) in the absence of an Azolla cover.

## Influence of Azolla on grain yield

The benefits of having an Azolla cover on the floodwater surface prior to urea application were subsequently reflected on the grain yields of rice. Combining Azolla with urea produced yields approximately 40 and 19 percent higher at lower N rates (40 and 50 kg N $ha^{-1}$) and higher N rates (80 and 100 kg N $ha^{-1}$), respectively, than those without cover. Moreover, the grain yield at lower N rates with an Azolla cover was comparable to the yield at higher N rates without cover. Interestingly, an increase in the grain yield due to the interaction of Azolla with N was also observed. The highest increase in the grain yield at lower N rates due to an Azolla cover was 1.86 and 1.15 t $ha^{-1}$ in the wet and dry seasons, respectively. Of this increase, 1.71 and 1.09 t $ha^{-1}$ were due to the interaction of Azolla with N. At higher N rates, of the maximum yield increase of 1.17 and 0.79 t $ha^{-1}$ in the wet and dry seasons, 1.01 and 0.74 t $ha^{-1}$ were attributed to the interaction effect. This means that in addition to the additive effects of urea and the biological N fixation by Azolla, an extra yield increase can be achieved, attributed mostly to the conservation of applied N. As such, a considerable amount of urea can be saved when it is combined with Azolla. These benefits can surpass those from either urea or Azolla alone.

## Prospects of this Azolla management approach

These findings illustrate that the use of an Azolla cover on the floodwater surface can be an effective management approach in curbing the high $NH_3$ volatilization losses and improving the low N use efficiency by rice. Thus, contributing significantly to the N fertilizer issue. It should be actively promoted to rice farmers, especially in areas where farmers apply a high amount of N fertilizer. Considering the unavoidable increase in the consumption of N fertilizers in the future, this Azolla management approach can be an economical method for rice farmers to save large amounts of N fertilizer in their fields.
The fine-tuned system should time the Azolla inoculation such that an Azolla cover is present at the time of fertilizer N application. An initial cover of 50 percent, four days before fertilizer N application is sufficient to assure full coverage at the time of N fertilization. Less Azolla may be applied if the time span between inoculation and urea application can be extended. Availability of Azolla will not be a constraint as Azolla can be easily propagated and can thus be readily available to farmers.
Overall, this Azolla technology will ultimately benefit the rice farmers in a positive and self-sustaining way.

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A full list of references can be obtained from the author.

Figure 3: Effect of Azolla cover on the $^{15}N$ recovery of harvest. Philippines. Dry season, 1998-99.