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NITRIFICATION INHIBITORS FROM PLANT RESOURCES : A STRATEGY FOR RESEARCH

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Introduction

Nitrification inhibitors are chemical agents that inhibit or rather retard nitrification in soil or microbial culture by a sort of family planning among the nitrifying bacteria. Nitrification is referred to as the biological oxidation of ammonium to nitrate via nitrite, effected respectively by *Nitrosomonas* and *Nitrobacter* species of the nitrifying bacteria. Nitrification is important for the conversion of ammonium formed from urea and other organic materials and compounds applied to the soil, to nitrate. The nitrate formed is the source of nitrogen (N) nutrition of plants under arable cropping.

The fact that nitrification converts relatively immobile ammonium N to highly mobile nitrate, has serious implications for N utilization by agricultural production systems, crop quality and the fate of N in the soil-crop-environment system[1-3]. The poor efficiency of fertilizer N use by crops is largely due to the loss of applied and soil N by denitrification, leaching or ammonia volatilization. With the exception of ammonium volatilization, the loss of N is associated with and follows the nitrification of ammonium to nitrate. Nitrate is mobile and liable to loss by leaching and denitrification. Leaching of nitrate is the source of pollution of surface and ground waters and is of great concern for health reasons[3]. Thus it would not be an exaggeration to term nitrification a necessary evil.

Specific nitrification inhibitors are compounds and materials that retard the oxidation of ammonium to nitrite, without affecting the subsequent oxidation of nitrite to nitrate. Interest in the use of nitrification inhibitors stems from the fact that retardation or slowing down of nitrification in the soil reduces the N loss by leaching and denitirfication following nitrification. The interest in the use of nitrification inhibitors for agricultural production and environment management was especially intensified following the development of nitrapyrin [2-chloro-6 (trichloromethyl) pyridine] by the Dow Chemical Company of the USA as an effective inhibitor of nitrification[4]. Inhibition of nitrification results in preferential accumulation of ammonium N over nitrate in the soil. Ammonium is not liable to loss by leaching or denitrification and may lead to conservation of N in the soil and its better utilization by growing plants in situations where the loss of N by leaching and denitrification is significant[3, 5].

The literature on nitrification inhibitors is vast and is indicative of the interest in the use nitrification inhibitors for controlling nitrification of ammonium and ammonium-forming fertilizers in soils for improving N utilization by crops and for checking nitrate contamination of surface and ground waters[1-3, 5-8]. The above-cited reviews on nitrification inhibitors deal with their effects on the retardation of nitrification and other associated effects on N transformation in the soil and effects in the plant on yield and chemical composition (especially nitrate accumulation in the tissue) and environment pollution (nitrate in surface and ground waters and nitrous oxide emission from soils).

However, despite a great interest in nitrification inhibitors, only a few compounds have been adopted for agricultural and environmental use. The main problem seems the high cost involved in the development and subsequent use of the nitrification inhibitors in the low-input, practical agriculture in the developing countries like India. In addition, the variable results often obtained in their use under field conditions in the tropical regions[9]. There is, however, a continuing need to direct research efforts to develop nitrification inhibitors that are inexpensive, readily available locally, and most of all, are effective at reasonable rates of application[8].

Nitrification Inhibitors of Plant Origin

In India, there exists a wealth of plant resources that possess biocidal activity. In the earlier research in this area, a number of plant products were used as sources of plant nutrients especially, with advantage. Following this finding a number of non-edible oilseed cakes, their extractives and isolates possessing biological activity were evaluated as N fertilizer amendments for regulating nitrification in the soil and their effects on utilization of N by crops[8]. Among these neem (*Azadirachta indica* L.) and karanj (*Pongamia glabra* Vent) seed cakes (obtained by defatting of the seeds) and their various extractives and isolates have been most researched. In addition, plant polyphenols, vegetable tannins and waste tea products have been found to retard nitrification in the soil[8]. Recent research with mint essential oils from *M. arvensis* and *M. spicata* demonstrated that the *M. spicata* whole essential oil and the *M. arvensis* dementholated essential oil possess nitrification inhibitory activity. Application of these materials, rich in specific terpenes and the semi-synthetic products of individual terpenes of these oils have been found to possess a variety of microbiocidal activity, was reported to improve N utilization by wheat and rice crops in the field[10].

Karanjin, a furanoflavonoid from karanja (*Pongamia glabra* Vent) seeds, has been found to be a potent inhibitor of nitrification in the soil[11]. Karanjin and Nimin (a commercial derivative of neem) not only retard nitrification and increase N efficiency; they also mitigate emission of nitrous oxide (N_2O) from soils fertilized with urea and ammonium N sources[8, 12-13]. Basic research on the structure-nitrification inhibitory activity relationships with karanjin (3-methoxy furano-2', 3', 7, 8-flavone), karanj ketone (4-hydroxy-5-w-methoxyacetyl coumarine), karanjonol (3-hydroxy furano-2', 3', 7, 8- flavone) and dihdrokaranjin showed that the furan ring present in the molecule is the crucial structural factor for nitrification inhibitory activity. All the compounds with the exception of dihdrokaranjin, where furan was absent, showed nitrification retarding activity to varying degrees[11]. The conclusion that the furan ring imparts inhibitory activity was supported by the later studies in which several compounds based on furfuraldehyde including furfuraldehyde and furfuryl alcohol retarded nitrification to varying degrees in soil treated with urea[14].

Retardation of nitrification in soils is a way of increasing the persistence of N in the soil and increasing the opportunity for better utilization of N by agricultural production systems because ammonium is

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not liable to leaching and denitrification loss as nitrate is. Also, nitrification inhibitors can enhance the persistence of fertilizer N by affecting N transformations, other than nitrification[2]. For the nitrification inhibitors to be of practical use in low-input agriculture, they need to be effective in regulating nitrification in the soil as well as being cost-effective.

A Strategy for Development of Nitrification Inhibitors

There is obvious need to further exploit indigenously available materials as sources and for developing nitrification inhibitors using a structured approach[9]. This research would involve a coordinated research effort from various disciplines (organic chemistry, microbiology, soil chemistry and agronomy) based on two approaches: (1) by empirical evaluation of a large number plant products and materials possessing general biocidal activity for retarding nitrification in soil, and (2) by identification of the functional groups responsible for the nitrification inhibitory activity and then incorporating these functional groups in suitable synthetic compounds. For example, employing the second approach, it was discovered that furan ring in the compounds imparts the nitrification inhibitory property to varying degrees[11, 14]. However, it must be stated that the first approach is simple and could be used for short-term research goals for developing nitrification inhibitors from locally available natural products. On the other hand, the second approach is needed for a longer-range research. Through an integrated research in laboratory (in microbial culture and soil), greenhouse (with plant) and the field, suitable compounds would be identified along with functional groups that impart nitrification inhibitory activity. Initially, prospective compounds/materials would be evaluated in the laboratory tests using soil and or microbial culture and those found effective would be evaluated in the greenhouse assay. Materials/compounds found effective in greenhouse test would qualify for evaluation in the field under well-characterized soil and environmental conditions.

The synthesis of compounds with nitrification inhibitory activity would remove any constraints related to the non-availability of the compounds/materials, once found effective. It has been observed that at times plant products have limited availability and their amounts required for the regulation of nitrification are rather large compared to pure compounds[8].

To sum up, basic research is also needed for delineating the beneficial effects of plant products in the retardation of nitrification and slow-release effects through immobilization-mineralization[15]. For achieving this objective, the use of N-15 labelled fertilizers are useful as researcher can follow the fate of N as to how retardation of nitrification affects ammonium fixation and release, mineralization, immobilization and remineralization of N and other processes of the N cycle[2, 15].

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