Biological Nitrification Inhibition Technology to Tackle Agricultural Greenhouse Gas Emissions

Guntur V Subbarao
Japan International Research Center for Agricultural Sciences
1-1 Ohwashi, Tsukuba, Ibaraki 305-8686, Japan
subbarao@jircas.affrc.go.jp

Keywords: Biological nitrification inhibition, BNI-technology, climate change, genetic-mitigation, global warming, nitrification control, N_2O emissions

Farming has become the largest source of man-made greenhouse gases (GHGs) on the planet, generating about 14,000 Tg CO_2.eq.yr^{-1}, about 24% of total GHG emissions. A major portion of these GHG emissions are associated with the production and use of N-fertilizers, which is energy and carbon intensive. Nitrous oxide (N_2O), the 3rd most important GHG (after CO_2 and CH_4), is 300 times more potent than CO_2. N_2O is generated primarily during nitrification and denitrification - soil-biological processes associated with nitrifier and denitrifier activity. Globally, 80% of N_2O emissions come from production and utilization of N-fertilizers in agriculture. A major portion (>70%) of N-fertilizers applied to agricultural soils is lost (from NO_3^- leaching and gaseous N-emissions) due to nitrification and denitrification processes. Modern production systems and changes in crop management practices, have accelerated soil-nitrifier activity, led to a decline in nitrogen-use efficiency (NUE) and enhanced N_2O emissions from farming. Annual N-fertilizer use will reach 300 Tg by 2050, a 30-fold increase from 1960s (i.e. the beginning of Green Revolution, which is dominated by fertilizer-responsive crop cultivars combined with large amounts of N-fertilizer applications to production systems). Global N_2O emissions will double from present levels to reach 7.5 Tg N_2O-N. The Paris Agreement (PA) signed in 2015, set the goal to reduce GHG emissions by 80% from 2005 levels by 2050 to limit global temperature rise to <2° C. Reducing GHG emissions from agriculture is thus critical in meeting PA emission targets.

Current agricultural practices need transformative changes. New biological technologies must be developed for the agriculture sector to reduce N-losses and improve productivity, which require a tight control over soil-nitrifier activity. Biological nitrification inhibition (BNI) is the ability of certain plant roots to suppress soil nitrification, through production and release of biological nitrification inhibitors (BNIs); these BNIs suppress soil-nitrifier activity (which converts immobile soil-NH_4^+ to mobile soil-NO_3^-) and retain soil-N in NH_4^+-form to facilitate plant absorption and direct N-movement towards immobile microbial/organic-N. Soil-NO_3^-, once formed, is highly prone to leaching and denitrification. Root systems from BNI-enabled crops/pastures can suppress N_2O emissions by reducing nitrate formation and limiting NO_3^- availability to denitrifiers. BNI-technology exploits the understanding of BNIs chemistry, and its impact on soil microbiome to develop genetic components that include BNI-enabled genetic stocks, genetic tools and cropping systems to exploit this plant function by controlling soil nitrifier activity. These would facilitate introduction of BNI-traits into major food/feed crops in the near future.

Production and release of BNIs from plant roots require the presence of NH_4^+ in the rhizosphere and soil-micro-sites where NH_4^+ is present, are also hot-spots for nitrifier populations. As the BNIs release from roots is localized, the delivery of BNIs is essentially targeted to where there is a high probability of nitrifier activity. In addition, sustained BNI release from root systems is functionally linked with NH_4^+ uptake and assimilation that acts as a "switch" mechanism for regulating BNIs release. This results in a more effective targeted-delivery of BNIs to nitrifier-sites. In addition, the diverse chemical structures of BNI molecules and their multi-mode of inhibitory action on *Nitrosomonas*, could provide a lasting-control over nitrifier activity in agricultural soils compared to synthetic nitrification inhibitors. The inhibitory effect from synthetic nitrification inhibitors does not last more than a few weeks at the most (often less than a week) and their delivery in the field is fraught with many challenges. They are also expensive to apply and are often ineffective in the field, which may explain lack of wide-spread adoption in production agriculture. BNI-technology could thus become a viable genetic-mitigation option when it is fully developed and operationally deployed. The challenge is to redesign agricultural systems with BNI-enabled crops/pastures that produce sufficient BNIs to suppress wasteful nitrification and move towards developing low-N_2O emitting production systems that are nitrogen-efficient.

References

Gilbert, N., 2011. Summit urged to clean up farming. *Nature*, 479:279

Vermeulen, S.J., *et al*. 2012. Climate change and food systems. Annu. *Rev. Environ. Res.*, 37:195-222.

Subbarao, G.V., *et al*. 2015. Suppression of soil nitrification by plants. *Plant Sci.*, 233:155-164.

Schlesinger, W.H., *et al*. 2009. On the fate of anthropogenic nitrogen. *PNAS (USA)*, 106:203-208.

Subbarao, G.V., *et al*. 2009. Evidence for biological nitrification inhibition in *Brachiaria* pastures. *PNAS (USA)*, 106:17302-17307.

Subbarao, G.V., *et al*. 2012. Biological nitrification inhibition - a novel strategy to regulate nitrification in agricultural systems. *Adv. Agron.*, 114:249-302.

Subbarao, G.V., *et al*. 2017. Genetic mitigation strategies to tackle agricultural GHG emissions: The case for biological nitrification inhibition technology. *Plant Sci.*, 262:165-168.