# Introduction to Plasma Agriculture: Contribution of Plasmas to Global Environmental Issues

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The exquisite balance of the global environment is became unstable by the activities of humankind. In the Planetary Boundary which forms the scientific background for the Sustainable Development Goals, the nitrogen cycle, climate change, and biodiversity loss were pointed out to be in a state of collapse. [1]. The nitrogen cycle refers to the transformation of nitrogen gas into ammonia and nitric acid, which are converted to fertilizers by microorganisms, etc., and finally back into nitrogen gas [2]. Currently, the nitrogen cycle has broken down, partly due to excessive usage of nitrogen fertilizers (hereinafter simply referred to as fertilizers), resulting in increasing nitrate concentrations in soil and groundwater. This situation is creating pressure in the direction of environmental change combined in agricultural production (Fig.1).

Since the 1970s, crop productivity has increased through breeding and fertilizer administration, contributing to solving the food crisis associated with population growth, which was called the Green Revolution. In addition, the Haber-Bosch process, which is the one of the most popular fertilizer production process, emits $CO_2$. Nitrogen fertilizer consumption produced 700 million tons of $CO_2$ in 2014, making it a major source of $CO_2$ emissions, accounting for 1-2% of global $CO_2$ emissions. $CO_2$ emissions associated with increased fertilizer consumption, which will increase due to climate change, are expected to increase by 23% by 2050, creating a food production tetralemma that will advance climate change and accelerate food production decline.

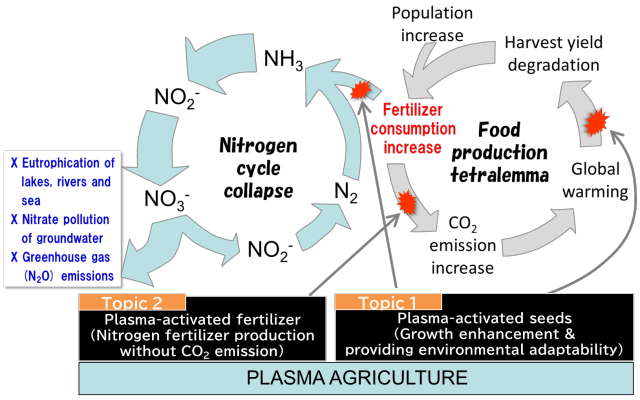


Fig. 1. Connection between nitrogen cycle and food production tetralemma with nitrogen fertilizer.

The key to break the two cycles of nitrogen cycle collapse and food production tetralemma is the development of new plant growth promotion methods that enable food production with less fertilizer application and a fertilizer production method that can be realized anywhere without $CO_2$ emissions. Emissions at all stages from production to transportation, fundamentally change the fertilizer production concept.

Plasma is a promising technology to break the two cycles. It generates chemically active molecules by the collision of electrons with molecules, creating a highly active chemical reaction field at a room temperature in gas phase and at interface of materials. When the plasma is generated in the air, excited molecules are produced by the electron collision. The chemically active molecules such as OH, NO, O, $O_3$, $H_2O_2$, $NO_3^-$, $NO_2^-$ are produced by the secondary reaction of excited molecules. These are so called as reactive oxygen nitrogen species RONS. The RONSs (and the synergetic effects of combination of RONSs and the other factors such as UV and electric field) regulate plant response and produce nitrogen fertilizers, leading to improve plant germination, growth, and harvest. The growth enhancement by irradiating plasma to seeds reduces the fertilizer consumption and provides the environmental adaptability. Plasma-activated fertilizer reduce the $CO_2$ emission for production of nitrogen fertilizer. However, there are many unknowns about the mechanism of this process, and the question of what makes plasma suitable for agricultural applications has not been answered. Therefore, it is necessary to develop agricultural applications based on an understanding of plasma to realize the current achievements in society. In this lecture, the author will show the basic concept of the plasma technology for agricultural applications and present status of the research.

**References**

[1] Johan Rockström et al., Nature 461 (2009) 472

[2] A. Bernhard, Nature Education Knowledge 3(2010) 25