Gallium (Ga) and indium (In) used in semiconductor manufacturing and the electro-optical industry: their inhibition of rice plant growth in paddy soils

Gallium (Ga) and indium (In) are widely used in semiconductor manufacturing and the electro-optical industry, and the rapid growth of high-tech industries raises the concern that large amounts of wastewater derived from associated manufacturing processes may easily become a potential source of environmental contamination; thus, these two elements are recognized as emerging contaminants. Once industrial wastewater containing Ga and In is discharged into farmland through irrigation systems, it may affect the growth and yield of crops. Moreover, humans may be exposed to Ga and In through the food chain, which could pose severe health risks. Rice (Oryza sativa L.) is the staple food for most of the population in Asia. Rice consumption is a potential route of Ga and In exposure in humans, especially in agricultural areas near high-tech industrial parks. However, limited information is currently available on the effects of Ga and In on the growth of rice plants. Therefore, Professor Dar-Yuan Lee and his students Mr. Jeng-Yan Su and Dr. Chien-Hui Syu investigated the growth effects and uptake of
Ga and In in rice plants grown in Ga- and In-contaminated soils with different properties. This pioneering study on the rice growth effect of the emerging contaminants Ga and In was published in the *Journal of Hazardous Materials* in February 2018 [1].

In previous hydroponic experiments, the authors revealed differences in the phytotoxicity, uptake, and translocation of Ga and In in rice seedlings. Beneficial effects on the growth of rice seedlings were found by adding Ga to culture solutions, but the In treatments inhibited the growth of rice seedlings [2]. Furthermore, the toxicity mechanism of In was similar to that of aluminum (Al). The fate of Ga and In in paddy soils depended on soil properties such as pH, redox potential, cation exchange capacity (CEC) and organic matter, which may have led to the observed difference in the effects of Ga and In on rice seedlings between hydroponic and soil experiments. Therefore, a pot experiment was conducted in which rice seedlings were grown in two soils of differing pH spiked with various Ga and In concentrations.

The Ga, In and Al concentrations in soil pore water increased with the addition of Ga or In to acidic soils, significantly decreasing growth indices such as shoot height and plant biomass. Based on the results of a previous hydroponic study [2], the growth inhibition of rice seedlings in Ga-spiked acidic soils is mainly due to Al toxicity resulting from competitive adsorption between Ga and Al on the soil surface rather than from Ga toxicity. In acidic soils with a high In level (> 200 mg In kg⁻¹), both In and Al toxicity resulted in growth inhibition. The dynamics of Ga, In and Al in acidic soil are depicted in Figure 1. In contrast, in neutral Ga-/In-spiked soils (low concentration of available Al), there was no significant growth inhibition of rice seedlings due to the low availability of Ga, In, and Al under neutral pH conditions. Based on plant tissue analysis, the concentrations of Ga and In in roots were approximately one order of magnitude higher than those in shoots, which revealed that roots are a major sink for Ga and In in rice plants. In addition, there was no obvious antagonism (competitive absorption) between Al and Ga/In in the rice seedlings.

In conclusion, this research suggests that for rice plants grown in acidic Ga and In-contaminated paddy soils, the phytotoxicity of not only Ga and In but also Al should be considered, but these effects are negligible in neutral soils. In addition to investigating phytotoxic effects, it is worth investigating the accumulation of Ga and In in grains of paddy rice grown in contaminated soils and evaluating the associated health effects on humans in the future.

**Figure 1. Schematic diagram showing the competitive adsorption between Ga/In and Al and the release of Al into the soil solution of acidic soils (modified from Su et al., 2018).**

---

**References**


---

**Dar-Yuan Lee**

Distinguished Professor, Department of Agricultural Chemistry, National Taiwan University.

dylee@ntu.edu.tw

**Dr. Chien-Hui Syu**

Division of Agricultural Chemistry, Taiwan Agricultural Research Institute.

chsyu@tari.gov.tw