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Opinion

Are Nanomaterials a Real Solution for Sustainable Agriculture?

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Malthus' prediction that "the power of population is indefinitely greater than the power in the earth to produce subsistence for man" [1] generated an endless search for better crop production strategies. The response to such a prediction was almost immediate. In 1880, just two years after the prediction, farmers were able to increase crop production in low fertility soils with the help of an unexpected ally, chemical fertilizers [2]. Chemical fertilizers proved to be so efficacious that by 1950, they were considered as a "sine qua non" component for high crop production [2]. Of course, success cannot not be attributed solely to the use of chemical fertilizers; pesticides, including insecticides, fungicides, and herbicides, had a relevant contribution. The end of World War II marked a difference between the use of cultural practices and the boom in the use of inorganic pesticides [3]. However, yield increases due to chemical fertilizers, aided by inorganic pesticides, began to stabilize. In addition, the use of pesticides created social controversies due to undesirable environmental effects. At this stage, plant breeders contributed a third variable to boost crop yield. Geneticists manipulated plant materials, at all levels, generating high yielding varieties (HYVs) of crops tolerant to several pests. By 1960, HYVs, cultivated in soil amended with chemical fertilizers, treated with chemical pesticides, and irrigated with enough water, increased yields in such a manner that the achievement was called the "green revolution" [2]. However, six decades after the flourishing of the green revolution, a great number of publications are emphasizing the need for an increase in food production to feed the ever increasing global population, which has been estimated to reach 9 billion by 2050 and will require 70% more food [4]. It is evident to agricultural experts and farmers that the high input agricultural systems, which rely on abundant water supply, oil, chemical fertilization, and inorganic pesticides, are unsustainable [5,6].

In the last decade, a new component, nanotechnology, was introduced into all agricultural sectors. Nanotechnology is offering solutions for problems confronted by agriculture, from the production stage to the shelf life [7-9]. This topic has caught the attention of researchers worldwide, and the number of publications highlighting different aspects of nanotechnologies in agriculture is continually growing. A search in ScienceDirect.com, using as keywords "nanotechnology and agriculture," showed that the number of publications in 2017 (1041) was 386% higher, compared to 2009 (227) (Figure 1). The number of publications is increasing so quickly that in the first month of 2018, there is already an increase of 30%, compared to the entire number of publications in 2009.

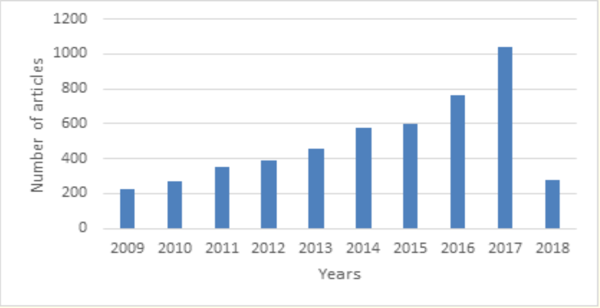

Figure 1: Number of articles on nanotechnology in agriculture published from 2009 to 2018. (ScienceDirect.com, January 10, 2018).

There are several advantages that can be attributed to the use of nanotechnology in agriculture. Obviously, the most notorious is a reduction in the amount of chemicals reaching the environment. However, it would be unwise to ignore the environmental effects of nanomaterials. For example, some nanomaterials, such as silver nanoparticles (Ag NPs), which have been proposed as a nanopesticide, dissolve in environmental media. Then, the released Ag ions form other compounds [10], while the remaining nanoparticulate portion has shown to be toxic to aquatic organisms, even at very low concentrations [11]. Unweathered copper oxide nanoparticles (CuO NPs), a product also considered as a nanopesticide, accumulates in lettuce leaves and translocates to crickets (*Acheta domestica*) [12]. Titanium dioxide nanoparticles (TiO_2 NPs) have shown to promote spinach growth [13], increase nutritional components in wheat (*Triticum aestivum*) [14], and root length in cucumber (*Cucumis sativus*) plants [15], but they accumulate in cucumber fruits [16]. Notwithstanding, Ag and CuO are proposed as agronanopesticides and TiO_2 NPs are suggested as a nanofertilizer [17].

Currently, there are low chances for increasing arable land, the climate change is affecting some regions, and the amount and quality of irrigation water is declining worldwide [17]. The specialized literature is mentioning more and more insistently that nanotechnologies have the potential to solve these problems. However, there are still more questions than answers regarding the use of nanomaterials in the agricultural industry. Very few studies have been focused on the translocation of nanomaterials into the food chain, or the transgenerational effects of engineered nanomaterials [18,19]. In addition, there has been a lack of uniformity in the test conditions [20] and nothing is known about varietal effects. This makes it difficult to predict results when the environmental conditions change. Another important aspect is the toxicity to human health, either by handling of the nanomaterials or by ingesting the contaminated produce [21]. All of these uncertainties generate the question: are nanomaterials a real solution for sustainable agriculture?

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