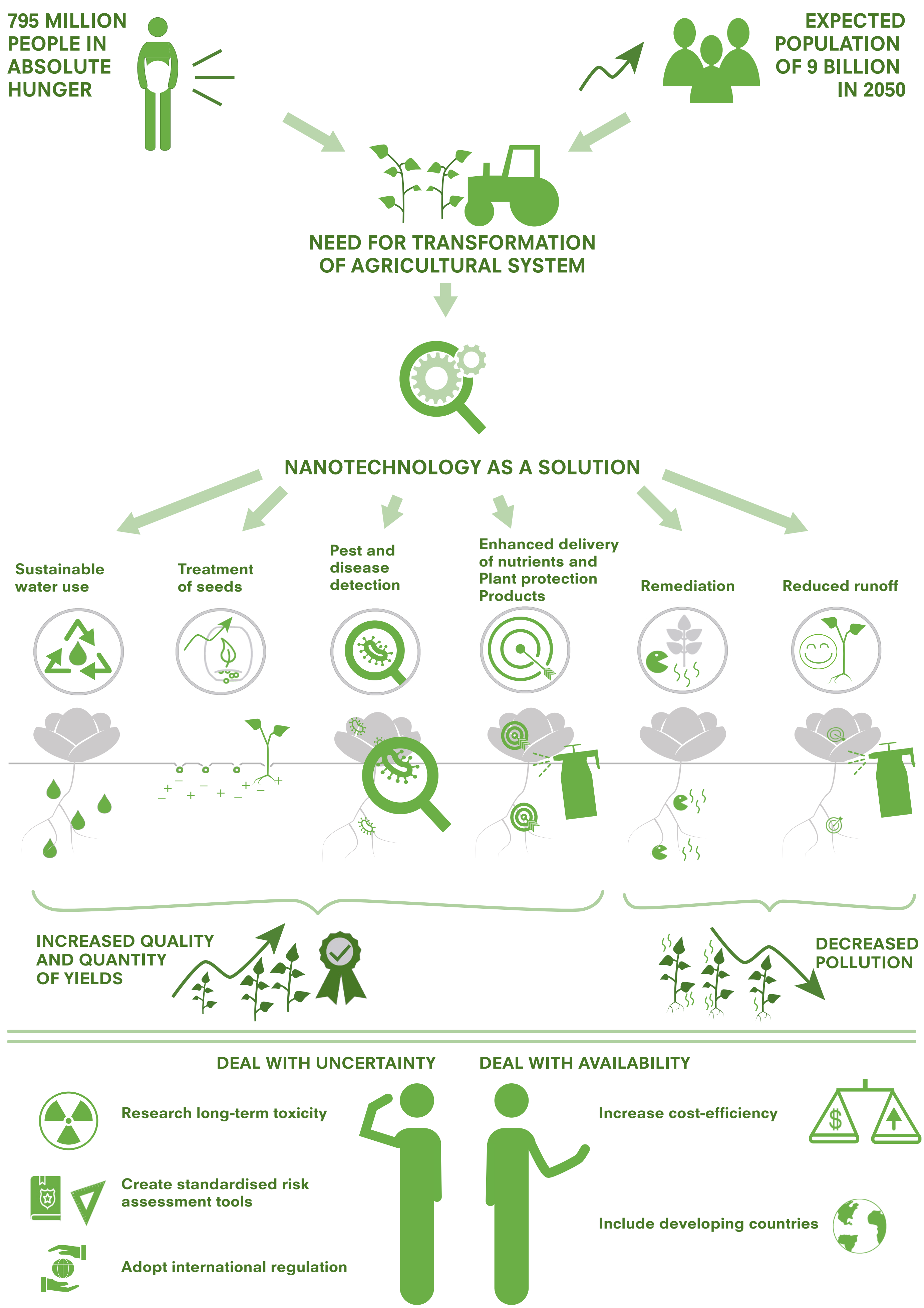
NANOTECHNOLOGY IN AGRICULTURAL PRODUCTION



NANOTECHNOLOGY IN AGRICULTURAL PRODUCTION

KEY MESSAGES

- **Nanotechnology is highly suitable for application in agricultural production because it increases the quality and quantity of yields.**
- **Nanotechnology reduces soil, water and air pollution by agrochemicals, which makes agriculture more sustainable.**
- **Challenges to overcome are uncertainty about the long-term risks of nanoparticles, adoption of international regulation and standardized risk assessment tools, cost-efficiency, and the inclusive availability of nanotechnology applications to both developed and developing countries.**

INTRODUCTION

According to the United Nations Food and Agricultural Organization, 795 million people worldwide lack access to sufficient food to lead a healthy active life [1]. Climate change, population growth and land degradation further challenge ending hunger [2]. To meet the projected demand for food of over nine billion people in 2050, world agricultural production has to increase by approximately 60% [2]. Nanotechnology (NT) can increase the quality and quantity of agricultural production,[3],[4] and make it more sustainable by decreasing pollution from agrochemicals [4],[5],[6], while improving climate resilience (Sustainable Development Goal (SDG) 2: Zero Hunger [7]) [8],[9]. It also has the ability to add valuable nutrients to plants [10] and detect and remediate heavy metals in the soil, and thus contribute to better health (SDG 3: Health and well-being [7]) [11],[12]. Furthermore, NT can foster more sustainable agricultural production (SDG 9: Industry, innovation & infrastructure [7]) [3],[4],[13].

There is a growing body of knowledge on the benefits of applying NT in agriculture, however it has proven difficult to coordinate findings between important stakeholders and to integrate knowledge from different fields and scientific disciplines [7]. Currently NT is not widely applied in agricultural production because of uncertainty regarding environmental and health risks and low cost-efficiency [14],[15]. This policy brief will provide an overview of the benefits and challenges regarding the use of NT in agricultural production. It will also discuss its current status and give recommendations on what is needed to apply NT in agricultural production successfully in the future.

CURRENT STATUS

Research on agricultural NT has been ongoing for over a decade now [16] .Though the share of publications on NT in agriculture is smaller than for other sectors, recognition of the potential of NT in agriculture is growing [17],[18]. For instance, between 2005-2009 literature on NT in the agri-food sector doubled [19]. Currently Europe, the USA, China and India produce the bulk of research and development (R&D) on NT in agriculture [19]. Of all NT applications only 9% target agriculture [20]. Some applications are already in use to increase the distribution, efficacy and controlled release of pesticides, nutrients and agrichemicals, and to detect bacteria and viruses [21],[22].

Nanotechnologies are technologies that contain at least 50% natural or manufactured particles in the size range from 1 to 100 nanometres (up to a billionth of a meter) [16]. Nanotechnology thanks its potential to the unique properties of nanoparticles (e.g. high volume to surface ratio and high solubility). Therefore, nanoparticles show an increased reactivity and efficiency [23].
This is however not a universal definition of nanotechnology as definitions differ regarding size and properties of nanomaterials [16],[24],[25].

BENEFITS

Increased Quality and Quantity of Yields

Sustainable water use: In order to make agricultural production more sustainable and optimize water use, nano-hydrogel can be applied. It is able to absorb and release water and nutrients in cycles, leading to more efficient use of water [26]–[28]. A study on silver coated hydrogel showed that soils to which this hydrogel is added can hold 7.5% more water than soils without [26]. Furthermore, the hydrogel can store between 130 and 190 times its own weight of rainwater or irrigation water [22],[26]. Bio- degradable hydrogels are especially promising since it decreases the amount of contaminants [27]–[30]. Hence, NT can be especially useful in dry areas. This is highly needed as drought is considered the largest environmental risk for crop production [31].

Treatment of seeds: Through treatment with NT seeds can germinate faster and steadier while increasing their resilience to environmental stress [8]. NT also increases seedling strength, growth and seed longevity [32]–[34]. A laboratory study showed that crops grown from seeds coated with nanomaterials like nano-silver recorded increased water absorption [8]. Another study on seeds treated with nanoparticles found a 73% increase in vegetable dry weight and a three times higher vitamins content in seeds [23],[25],[31],[33],[35] which increases crops yields. Moreover, seeds that had undergone treatment with nanoparticles indicated a 90% increase in drought resistance [36]. In addition, a

16.5% increase in seed longevity during storage was recorded [34]. These advantages contribute to increased quality and quantity of yields and climate resilience [32].

Pest and disease detection: Pollutants, pests and plant diseases cause severe damage to crops. For instance, insect pests cause 25% loss in rice yields and 50% for cotton [37],[38]. Bio-sensors, consisting of an organic-based detection mechanism, such as enzymes, are able to detect these specific threats [39],[40]. Due to their size-related properties, nano-biosensors show an increase in accuracy, detection limits, sensitivity, selectivity, temporal response and reproducibility, compared to conventional biosensors [41]. They are able to detect single viruses and contaminants at the molecular level. These particles are smaller than is approved by EU standards [42]. Therefore, nano-biosensors provide a very precise tool that can be used to prevent pest outbreaks and monitor soil quality, which enhances quality and quantity of yields [37],[41],[43],[44].

Enhanced delivery of nutrients and plant protection products (ppp): Up to 70% of conventional fertilisers and ppp's do not reach their target because they are unstable in the environment and difficult to be taken up [3],[45]. Nano-based smart delivery systems have the ability to provide more efficient and targeted delivery to specific plant cells due to their size-related properties [3],[4],[46],[47]. Also, they show enhanced stability in the environment, which improves the availability of nutrients and ppp's to crops [3],[37],[48],[49]. Smart delivery systems further enhance the delivery of nutrients and ppp's through their ability of slow or controlled release [3],[48]. This is shown to extend the effectiveness of ppp's from three to over thirty days [50]. In addition, the effect of pesticides was found to be twice as strong with half the dose applied [51],[52]. Enhanced delivery of nutrients and ppp's improves the resistance of crops towards threats like droughts, pests and pollution [6]. Therefore it improves the quality and quantity of yields [3],[4],[17]. Nano-biosensors can enhance this process even further by enabling smart delivery systems to precisely release nutrients and ppp's in response to environmental triggers and biological demands [3],[53]. This provides opportunities for real-time monitoring and control [49],[54].

Decreased Pollution

Reduced runoff: The application of NT in agricultural production has the potential to reduce pollution resulting from fertilisers and ppp's and remediate soils polluted with heavy metals [6],[12],[14],[48],[55]. Up to 90% of agrochemicals (in)directly run-off in the environment due to their uncontrolled application. Through increased efficiency, smart delivery systems also decrease pollution and subsequently environmental and health risks [9],[56]–[60].

Remediation: In addition, soils polluted with heavy metals can be remediated using NT, making them productive again [12]. This is particularly promising for China and African countries, where soil pollution with heavy metals is severe [61]. NT based soil remediation techniques are proclaimed to be effective, of low cost and environmentally friendly [62]. A case study using iron nanoparticles for remediation shows a 99% reduction of Trichloroethane (a solvent in pesticides) within a few days [63].

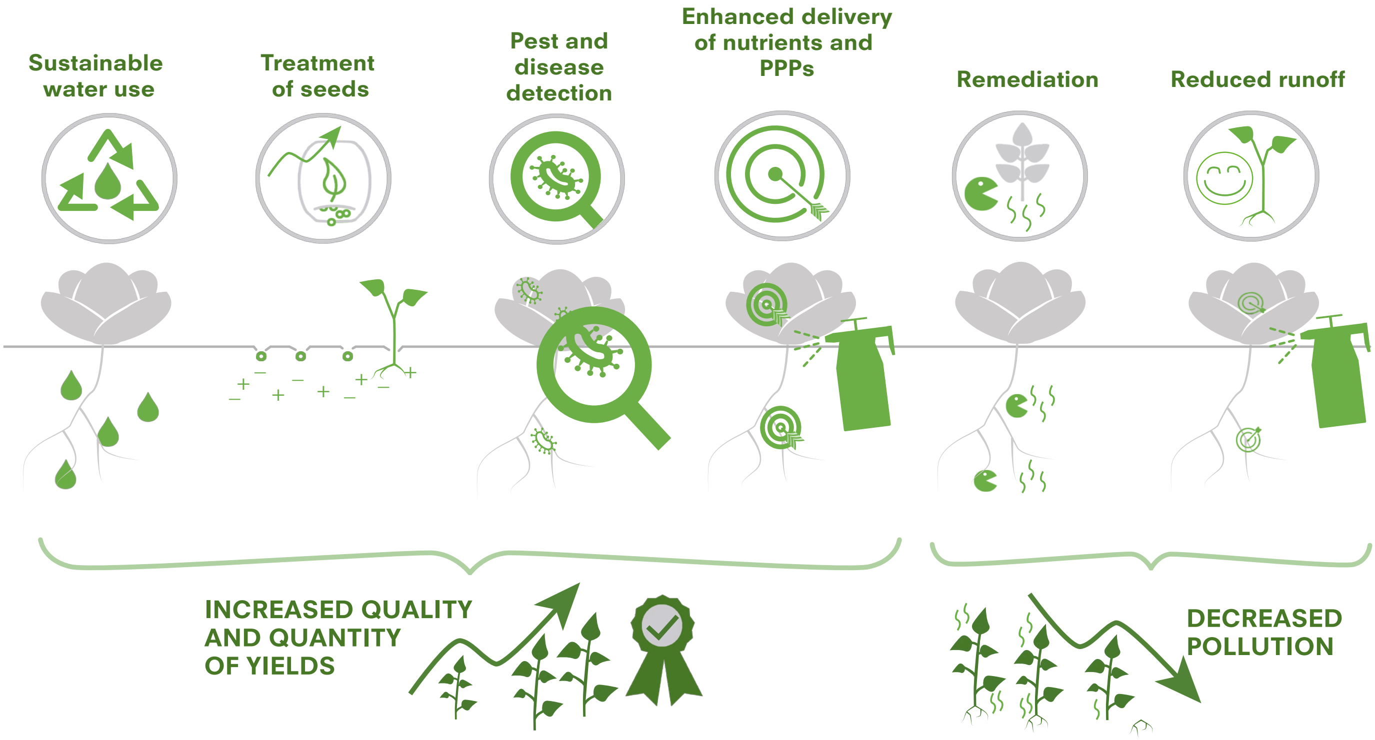


Figure 1: Benefits of nanotechnology in agriculture

Promising case studies

Treatment of seeds: A 29,5% and 26.3% increase yield of peanuts while using 15% less nanomaterial (zinc) in comparison to its bulk counterpart was found in two field researches in India (SDG 2.1) [64].

Enhanced delivery: 30% of people worldwide and 40% of schoolchildren suffer from iron deficiency. This is further aggravated by TBC, HIV and malaria [65]. A study on fertilizers containing nano-iron particles has shown nanotechnology can increase the iron level in watermelons substantially [66].

Pollution detection: Mercury is toxic in small amounts and identified by the WHO [67] as a serious threat to the health of young children and especially fetuses. Nanosensors based on silver particles are able to detect these small amounts of mercury in soil and plants [65],[66],[68],[69].

Sustainable water use: Biodegradable hydrogels show an increased soil moisture of up to 400% compared to soil that hasn't been amended with hydrogel [29].

CHALLENGES

Uncertainty

Toxicity: While nanotechnology has great future potential, its novelty and its pace of development cause uncertainty regarding the long-term effects of nanoparticles on the environment and human health [70]. In the short-term, no hazards are identified but in the long-term they might affect humans through bio-accumulation of toxins in plants and animals [48],[57],[70],[71] The toxicity of nanoparticles depends on their size-related properties and concentration. This affects their exposure to and mobility within the environment [14],[23],[48],[70]. In order to overcome toxicity and decrease the environmental damage caused by certain nanoparticles, they can be redesigned [9],[72]–[74]. Materials that might be applicable in agriculture, because they are biodegradable and non-toxic [76],[77].

Risk assessment: Risk assessment consists of testing exposure and potential risk [25]. The great variety of nanoparticles and the lack of data on their toxicity under various conditions impedes the creation of standardized risk assessment tools [13]–[15],[24],[25],[70]. Grouping nanoparticles with the same properties increases the feasibility of risk assessment, but is not yet reliable [23],[70],[78]–[80]. This is also hampered by the lack of an internationally agreed upon workable definition of NT [14],[24]. Risk assessment differs per region and sometimes per sector [25]. Currently, risk assessment becomes more holistic: scientists, regulators, industries and non-governmental organisations work together in a multi-disciplinary setting [25],[80]. Risk assessment will continuously change and adapt as a result of the continuous development of NT [23],[25], [70]. Standardized tools developed by the OECD and the EU are expected in the next two years [70].

Regulation: Due to their size-related properties, which may differ from their bulk counterpart, adopting regulatory frameworks that adequately deal with NT can be challenging [81],[82]. While some argue current regulatory frameworks are sufficient to deal with the risks and uncertainty of NT [83], others state there is a need for nano-specific provisions and regulation [70],[82]. The lack of an internationally agreed upon workable definition of NT makes this difficult however [14],[24]. Adopting nano-specific regulation and formulating a common definition is needed to stimulate countries to share knowledge, trade in products containing nanomaterials and mitigate associated risks [84].

Inclusive Availability

It needs to be ensured that the benefits of NT will be shared inclusively between a wide range of countries and stakeholders [85],[86]. Currently most of the R&D is taking place in a select number of countries and knowledge is unequally distributed [87]. Relatively little efforts are made to make products that benefit the poorest countries as this is often unattractive from a financial point of view [86],[88]. Therefore, the gap in production and innovativeness between developed and underdeveloped nations and between large and small corporations may be widened [86]. Because large companies possess most patents, it is difficult for small companies to gain entry to the market [86],[88]. However there are techniques to create NT that are cheap and affordable for developing countries and small companies [20]. This can for instance be achieved by lowering the administrative burden when registering products or establishing support structures for small companies or underdeveloped nations [89]. In addition, NT needs to become more cost-efficient and to be transferred to the field, to become relevant in agricultural production and for developing countries [13],[90]. Because NT applications in agricultural production are entering the market phase, it is important to look at this now.

RECOMMENDATIONS

UNCERTAINTY	– Focus R&D on long-term toxicity and exposure of nanoparticles in the environment and their implications for human health. – Select non-toxic, environmentally friendly nanomaterials for their application in agricultural production. – Develop international standardized risk assessment methods in close collaboration with scientists and private companies in order to reduce costs and integrate knowledge. – Reach international consensus on a workable definition of NT in order to coordinate legislation and risk assessment.
AVAILABILITY	– Focus R&D on improvement of cost-efficiency of NT to make it more affordable for developing countries. – Form collaborations between countries that have advanced research and applications of NT and those that could benefit from NT to ensure inclusive availability of NT.

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