

Supporting Information: Nanomaterials in plant protection and
fertilization: current state, foreseen applications and research priorities

ALEXANDER GOGOS,[†] KATJA KNAUER,[‡] AND THOMAS D. BUCHELI,^{*,†}

Agroscope Reckenholz-Tänikon Research Station ART, CH-8046 Zurich,
Switzerland, and Federal Office for Agriculture, 3003 Berne, Switzerland

* Corresponding author. Tel.: +41 44 377 73 42; fax: +41 44 377 72 01; e-mail:
thomas.bucheli@art.admin.ch.

[†] Agroscope ART

[‡] Swiss Federal Office for Agriculture FOAG

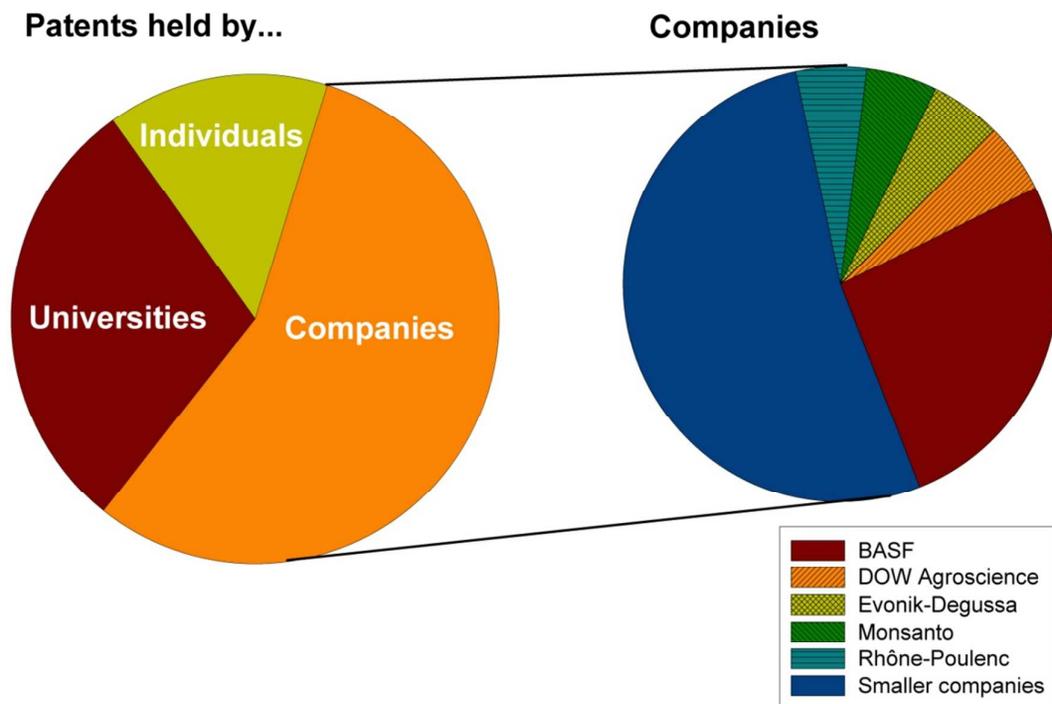


Figure S1: Patents of nano-Plant Protection Products and fertilizer applications distribute as visualized between companies, academia and individuals.

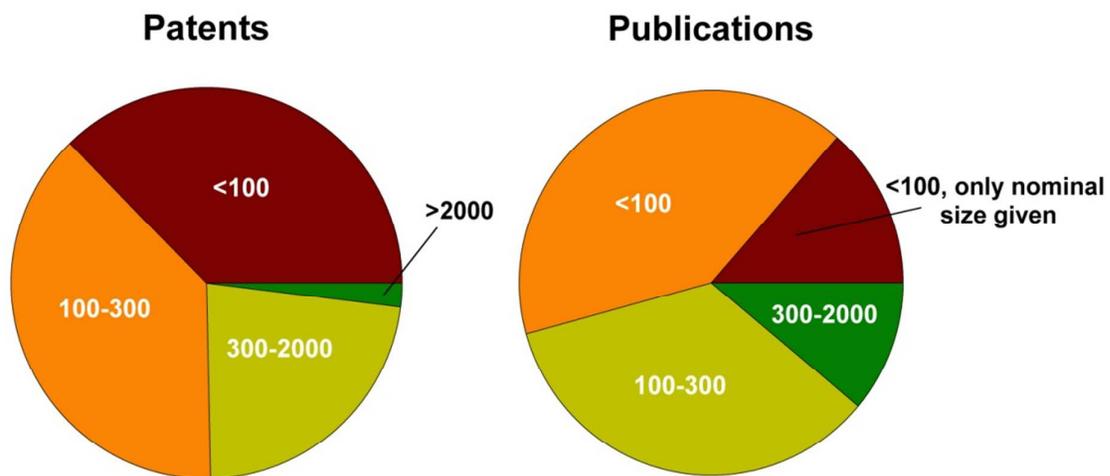


Figure S2: Particle sizes of nano-Plant Protection Product and fertilizer applications. Particle sizes that were reported without verification in the respective formulation were indicated as “nominal sizes”.

Table S1: Reviews published on nanomaterials and agriculture and related fields (in order of appearance, non-exhaustive)			
Title	Focus	Differs from current review by...	Reference
Nanosilica – from medicine to pest control	Broad, all kind of applications, reviews nanosilica as a nanobiopesticide	Covering one type of NM only, reviews published literature only (no patents)	(1)
Nanotechnology applications in pollution sensing and degradation in agriculture: a review	Reviews mainly applications in sensors and in photocatalysis of pesticides	Focused on remediation (not covering PPP and fertilizer applications), reviews published literature only (no patents)	(2)
Review of health safety aspects of nanotechnologies in food production	Overview on the current state of risk assessment (RA) and on scientific issues that need to be addressed for improved RA of NM in food production	Not specifically focused on PPP and fertilizer applications	(3)
Nanotechnology for parasitic plant control	Reviews “nanocapsules” as herbicides and “smart delivery systems” such as viruses	Covering one type of NM only (“Nanocapsules”), only herbicides, one patent cited	(4)
Agri-food nanotechnology: a tiny revolution in food and agriculture	Very broad overview over potential agricultural NM applications	Does not cover risks, reviews published literature only (no patents)	(5)
Nano-particles - A recent approach to insect pest control	Shortly reviews insecticide applications of NM	Only covers insecticides and very few materials, does not cover potential risks	(6)
Mycogenic metal nanoparticles: progress and applications	Large section on NM synthesis in fungi. Also mentions applications of NM in medicine	Does very briefly cover PPP and fertilizers, reviews published literature only (no patents)	(7)
Potential applications of nanotechnology in the agro-food sector	Reviews a broad variety of applications, such as food packaging, pathogen detection, delivery system as food additives	Not focused on PPP and fertilizers, reviews published literature only (no patents)	(8)
Nanoparticulate material delivery to plants	Focused on transport and effects of NM in plants, short excursion on NM in PPP and fertilizer applications	Focus clearly on reviewing uptake and effect studies, reviews published literature only (no patents)	(9)
Nanotechnology in agricultural diseases and food safety	Very broad	Does not cover risks, reviews published literature only (no patents)	(10)
Perspectives for nano-biotechnology enabled protection and nutrition of plants	Very broad, covers some PPP and fertilizer applications, but also delivery of genetic material, nanosensors, remediation	Does not cover patents and legislation as well as risk/risk assessment	(11)
A brief review of the occurrence, use, and safety of food-related nanomaterials	Focused on food processing, packaging and storage. Provides a ranking approach for quality assessment of nano-tox studies	Does not cover PPP/Fertilizer applications, does not cover patents	(12)
Interaction of Nanoparticles with Edible Plants and Their Possible Implications in the Food Chain	Reviews NP-plant interactions and toxicity studies	Reviews published literature only (no patents), not focused on PPP/Fertilizers	(13)
Nanotechnology in agriculture	Short and broad insight into NM in agriculture in general	Does not cover risks, reviews published literature only (no patents), not focused on PPP/Fertilizer applications	(14)

Role of nanotechnology in agriculture with special reference to management of insect pests

Large section on conventional and biological insect pest control, NM for pesticide applications and as antimicrobial agents for plant pathogens

Not covering other applications of PPP or fertilization; (15) reviews published literature only (no patents)

Table S2: Nanomaterials in Plant Protection Product and fertilizer formulations:scientific literature							
Reference	Nanomaterial	Reported particle size [nm]	Application	Function of nanomaterial	Country	Institution	Year
(16)	TiO ₂	30 (nom.)	Pesticide	Additive (Photocatalyst)	China	University	2008
(17)	TiO ₂	30 (nom.)	Pesticide	Additive (Photocatalyst)	China	University	2011
(18)	Al-Nanoclay	40-100	Fertilizer	Additive (Controlled release)	China	University	2007
(19)	Al-oxide	n/a	Pesticide	Active ingredient	USA	University	2010
(20)	Ag-NP	20-30 (nom.)	Pesticide	Active ingredient	USA	University	2009
(21)	Ag-NP	1.5 (nom.)	Pesticide	Active ingredient	Korea	Company	2008
(22)	Ag-NP	4-8 (nom.)	Pesticide	Active ingredient	Korea	University	2009
(23)	Ag-NP	1-5 (nom.)	Pesticide	Active ingredient	Korea	Company	2006
(24)	CNT	10-30 (OD), 4-6 (ID)	Fertilizer	Active ingredient	India	University	2011
(25)	SiO ₂	n/a	Pesticide	Active ingredient	Germany	University	2007
(26)	SiO ₂	140-180	Pesticide	Additive (Controlled release)	China	University	2006
(27)	SiO ₂	80	Pesticide	Additive (Controlled release)	China	University	2006
(28)	Al,Zn,Ti,Si,S	40-1106	Pesticide	Active ingredient	India	University	2010
(29)	TiO ₂	5 (nom.)	Fertilizer	Active ingredient	China	University	2007
(30)	Ag-NP	Not provided	Pesticide	Active ingredient	Iran	University/Research center	2010
(31)	Polymer/Bifenthrin	60-200	Pesticide	Active ingredient	USA	University	2008
(32)	Polymer	200-250	Pesticide	Additive (Carrier, Biodelivery)	France	University/Company	2000
(33)	SiO ₂	15-20 (nom.)	Pesticide	Active ingredient	India	University	2010
(34)	O/W Emulsion / Novaluron	200	Pesticide	Active ingredient	Israel	University	2010
(35)	Ag-NP	n/a	Pesticide	Active ingredient	Korea	n/a	2011
(36)	Ag-NP	n/a	Pesticide	Active ingredient	Korea	University	2010
(37)	TiO ₂	n/a	Pesticide	Active ingredient	China	University	2006
(38)	Polymer	69-127	Pesticide	Additive (Controlled release)	China	University	2009
(39)	Cu, Fe, Zn	n/a	Pesticide	Active ingredient	Russia	n/a	2009
(40)	Nano-Emulsion	31 (nom.)	Pesticide	Active ingredient	India	University	2011
(41)	Nano-Emulsion	20-200	Pesticide	Additive (Controlled release, stabilizer)	China	University	2009
(42)	CNT	Not provided	Fertilizer	Active ingredient	USA	University	2009
(43)	Al-nano clay	<100	Fertilizer	Additive (Controlled release)	Sri Lanka	University	2011
(44)	Polymer	<240	Pesticide	Additive (Controlled release)	China	University	2009
(45)	Fe	<50	Pesticide	Additive (Carrier, Biodelivery)	Spain	University	2008
(46)	Polymer	50-1000/2000	Pesticide	Additive (Carrier)	USA	University	2002

(47)	Al-nano clay	30-110	Fertilizer	Active ingredient	China	University	2006
(48)	CNT	30 (nom.)	Fertilizer	Active ingredient	India	University	2011
(49)	Polymer	78	Fertilizer	Additive (Controlled release)	Brazil	University	2010
(50)	Al-nano clay	n.d.	Fertilizer	Additive(Controlled release)	Malaysia	University	2002
(51)	Polymer	80 ±30	Pesticide	Additive (Controlled release)	Bulgaria	University	2011

Table S3: Nanomaterials in Plant Protection Product and fertilizer formulations: patents

Reference	Patent No.	Nanomaterial	Reported particle size [nm]	Application	Function of nanomaterial	Country	Applicant	Year
(52)	WO/2003/039249	Polymer	50-2000	Pesticide	Additive (Dispersing agent)	Germany	BASF	2003
(53)	DE69126275T2	TiO ₂	200-300	Pesticide	Additive (Dispersing agent)	France	Rhône-Poulenc	1998
(54)	WO/2009/153231	TiO ₂ , ZnO, CeO ₂	1-100	Pesticide	Additive (UV-Protection)	Germany	BASF	2009
(55)	WO/2003/059070	TiO ₂	3-200	Pesticide/ Fertilizer	Active ingredient	Korea	Choi et al.	2003
(56)	WO/2008/135093	TiO ₂ , ZnO	10-5000	Pesticide	Additive (Carrier)	Great Britain	NM Tech Nanomaterials Ltd.	2008
(57)	WO/2010/068275	CuO	1-3 (CuO), 7 (SiNP)	Pesticide	Active ingredient	USA	University	2010
(58)	WO/2011/067186	Cu	1-200	Pesticide	Active ingredient	Germany	BASF	2011
(59)	WO/2010/083319	Cu	Not provided	Pesticide	Active ingredient	USA	DOW	2010
(60)	WO/2011/059507	CNT	Not provided	Fertilizer	Active ingredient	USA	Agroscience Khodakovskaya et al.	2011
(61)	WO/2011/031487	CdSe-Quantum dots	2-10	Pesticide	Additive (Biodelivery)	USA	University	2011
(62)	WO/2010/051607	Nano-Emulsion	<400	Pesticide	Additive	Brazil	Oxiteno SA.	2010
(63)	US20080194406	Al-nano clay	Not provided	Pesticide	Additive (Controlled release)	USA	NaturalNano, Inc.	2008
(64)	WO/2008/032328	Nano-Emulsion	<300	Pesticide	Additive (Dispersing agent)	Israel	University	2008
(65)	US20090075818	Ag-NP	4.5	Pesticide	Active ingredient	Iran	Raman Nia, J.	2009
(66)	US20100041629	Nano-Emulsion	10-300	Pesticide	Additive (Dispersing agent)	Germany	Giessler-Blank et al.	2010
(67)	WO/2010/035118	Polymer	<100	Pesticide	Additive (Controlled release)	USA	Vive Nano, Inc.	2010
(68)	CN1433697	Polymer/Pyrethrines	n/a	Pesticide	Active ingredient	China	University	2003
(69)	US2011000411	Si-clay	1µm-2mm (with ~50 nm Pores)	Fertilizer	Additive (Controlled release)	USA	Polymate Ltd.	2011
(70)	DE102009030121	Ag, Au, Cu, Zn	1-100	Fertilizer	Active ingredient	Germany	Rent a scientist GmbH	2010

(71)	WO/2006/049379	SiO ₂ -Ag	0.5-30	Pesticide	Active ingredient	Korea	Bio Dreams, Co. Ltd.	2006
(72)	WO/2007/014826	TiO ₂ , ZnO	<200 /aggregates	UV-Protection of plants	Active ingredient	Germany	Evonik-Degussa	2007
(73)	CN1491551	Polymer/Ivermectin	<100	Pesticide	Additive (Dispersing agent)	China	University	2004
(74)	CN1491558	Polymer/Acetamiprid	<100	Pesticide	Additive (Dispersing agent)	China	University	2004
(75)	WO/2002/082900	Polymer	<1000	Pesticide	Additive (Controlled release)	USA	Rhodia, Inc.	2002
(76)	WO/2008/056234	SiO ₂	<2000	Fertilizer	Additive (Controlled release)	India	Bijam Bioscience, Ltd.	2008
(77)	US8017061	Polymer	1000-2000	Pesticide	Additive (Controlled release)	Germany	University	2011
(78)	US7070795	Polymer	100nm-200µm	Pesticide	Additive (Controlled release)	USA	Monsanto	2006
(79)	US7994227	Polymer	<500	Pesticide	Additive (Controlled release)	Germany	BASF	2011
(80)	WO/2005/115143	Polymer	10-4000	Pesticide/Fertilizer	Additive (Controlled release)	Germany	University	2005
(81)	WO/2011/053605	Polymer	n/a	Pesticide	Additive (Controlled release)	USA	Dendritic Nanotechnologies Inc.	2011
(82)	US7494526	Cochleates (Lipid vesicles)	<1000	Fertilizer	Additive (Controlled release, Biodelivery)	USA	Yavitz, E.	2005
(83)	WO2011138701	Nano-Emulsion	50-800	Pesticide	Additive (Controlled release)	Germany	BASF	2011
(84)	WO2011010910	Nano-Emulsion	<100	Pesticide	Additive (Biodelivery)	Malaysia	University	2011

Table S4: Nanomaterials in Plant Protection Product and fertilizer formulations: products				
Product	(Potential) Nanomaterial	Reported particle size [nm]	Application	Manufacturer
Primo MAXX	(Nano-)Emulsion	n/a	Pesticide	Syngenta
Banner MAXX	(Nano-)Emulsion	n/a	Pesticide	Syngenta
Karate ZEON	Capsules with λ -cyhalotrin	>100	Pesticide	Syngenta
Demand CS	Capsules with pyrethroid (λ -cyhalotrin)	>100 (>1000 (85))	Pesticide	Syngenta
ECOFLEX	Aliphatic copolyester, "nanofibre" as a pheromone dispenser	n/a	Pesticide	BASF
Aerosil 200	SiO ₂	12	Various purposes	Syngenta
Trico	TiO ₂ 23.2%, Sheepgrease	n/a	Pesticide	Omya AG
FEROX	Zero-valent iron nanopowder	10-100	Example of a Nanomaterial for soil remediation	ARS Technologies, Inc.
SoilSet	SiO ₂	n/a	Example of a Nanomaterial for soil management	Sequoia Pacific Research Company

Literature cited:

1. Barik, T. K.; Sahu, B.; Swain, V., Nanosilica - from medicine to pest control. *Parasitology Research* **2008**, 103, (2), 253-258.
2. Baruah, S.; Dutta, J., Nanotechnology applications in pollution sensing and degradation in agriculture: a review. *Environmental Chemistry Letters* **2009**, 7, (3), 191-204.
3. Bouwmeester, H.; Dekkers, S.; Noordam, M. Y.; Hagens, W. I.; Bulder, A. S.; de Heer, C.; ten Voorde, S. E. C. G.; Wijnhoven, S. W. P.; Marvin, H. J. P.; Sips, A. n. J. A. M., Review of health safety aspects of nanotechnologies in food production. *Regulatory Toxicology and Pharmacology* **2009**, 53, (1), 52-62.
4. Perez-de-Luque, A.; Rubiales, D., Nanotechnology for parasitic plant control. *Pest Manag. Sci.* **2009**, 65, (5), 540-545.
5. Shrivastava, S.; Dash, D., Agrifood Nanotechnology: A tiny revolution in food and agriculture. *Journal Of Nano Research* **2009**, 6, 1-14.
6. Bhattacharyya, A.; Bhaumik, A.; Rani, P. U.; Mandal, S.; Eparti, T. T., Nano-particles - A recent approach to insect pest control. *African Journal of Biotechnology* **2010**, 9, (24), 3489-3493.
7. Gade, A.; Ingle, A.; Whiteley, C.; Rai, M., Mycogenic metal nanoparticles: progress and applications. *Biotechnology Letters* **2010**, 32, (5), 593-600.
8. Garcia, M.; Forbe, T.; Gonzalez, E., Potential applications of nanotechnology in the agro-food sector. *Ciencia E Tecnologia De Alimentos* **2010**, 30, (3), 573-581.
9. Nair, R.; Varghese, S. H.; Nair, B. G.; Maekawa, T.; Yoshida, Y.; Kumar, D. S., Nanoparticulate material delivery to plants. *Plant Science* **2010**, 179, (3), 154-163.
10. Sharon, M.; Choudhary, A.; Kumar, R., Nanotechnology in agricultural diseases and food safety. *Journal of Phytochemistry* **2010**, 2, (4), 83-92.
11. Ghormade, V.; Deshpande, M. V.; Paknikar, K. M., Perspectives for nano-biotechnology enabled protection and nutrition of plants. *Biotechnology Advances* **2011**, 29, (6), 792-803.
12. Magnuson, B. A.; Jonaitis, T. S.; Card, J. W., A Brief Review of the Occurrence, Use, and Safety of Food-Related Nanomaterials. *Journal of Food Science* **2011**, 76, (6), R126-R133.
13. Rico, C. M.; Majumdar, S.; Duarte-Gardea, M.; Peralta-Videa, J. R.; Gardea-Torresdey, J. L., Interaction of Nanoparticles with Edible Plants and Their Possible Implications in the Food Chain. *Journal Of Agricultural And Food Chemistry* **2011**, 59, (8), 3485-3498.
14. Srilatha, B., Nanotechnology in agriculture. *Journal of Nanomedicine and Nanotechnology* **2011**, 2, (7), 123.
15. Rai, M.; Ingle, A., Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied Microbiology And Biotechnology* **2012**, 94, (2), 287-293.
16. Guan, H. N.; Chi, D. F.; Yu, J. C.; Li, X., A novel photodegradable insecticide: Preparation, characterization and properties evaluation of nano-imidacloprid. *Pestic. Biochem. Phys.* **2008**, 92, (2), 83-91.
17. Guan, H.-N.; Chi, D.-F.; Yu, J.; Zhang, S.-Y., Novel photodegradable insecticide W/TiO₂/Avermectin nanocomposites obtained by polyelectrolytes assembly. *Colloids and Surfaces B: Biointerfaces* **2011**, 83, (1), 148-154.
18. Liang, R.; Liu, M. Z., Preparation of poly(acrylic acid-co-acrylamide)/kaolin and release kinetics of urea from it. *J. Appl. Polym. Sci.* **2007**, 106, (5), 3007-3015.
19. Stadler, T.; Buteler, M.; Weaver, D. K., Novel use of nanostructured alumina as an insecticide. *Pest Management Science* **2010**, 66, (6), 577-579.
20. Jo, Y. K.; Kim, B. H.; Jung, G., Antifungal Activity of Silver Ions and Nanoparticles on Phytopathogenic Fungi. *Plant Disease* **2009**, 93, (10), 1037-1043.
21. Kim, H.; Kang, H.; Chu, G.; Byun, H., Antifungal effectiveness of nanosilver colloid against rose powdery mildew in greenhouses. In *Nanocomposites and Nanoporous Materials VIII*, Rhee, C. K., Ed. Trans Tech Publications Ltd: Stafa-Zurich, 2008; Vol. 135, pp 15-18.
22. Min, J. S.; Kim, K. S.; Kim, S. W.; Jung, J. H.; Lamsal, K.; Bin Kim, S.; Jung, M.; Lee, Y. S., Effects of Colloidal Silver Nanoparticles on Sclerotium-Forming Phytopathogenic Fungi. *Plant Pathology Journal* **2009**, 25, (4), 376-380.
23. Park, H.; Kim, S.; Kim, H.; Choi, S., A New Composition of Nanosized Silica-Silver for Control of Various Plant Diseases. *The plant pathology journal* **2006**, 22, (3), 295-302.
24. Tripathi, S.; Sonkar, S. K.; Sarkar, S., Growth stimulation of gram (*Cicer arietinum*) plant by water soluble carbon nanotubes. *Nanoscale* **2011**, 3, (3), 1176-1181.
25. Ulrichs, C.; Goswami, A.; I., M., Nano-structured silica—physical active pesticides for urban settings. *Proceedings of the second international symposium on plant protection and plant health in Europe* **2007**.

26. Li, Z. Z.; Xu, S. A.; Wen, L. X.; Liu, F.; Liu, A. Q.; Wang, Q.; Sun, H. Y.; Yu, W.; Chen, J. F., Controlled release of avermectin from porous hollow silica nanoparticles: Influence of shell thickness on loading efficiency, UV-shielding property and release. *J. Control. Release* **2006**, 111, (1-2), 81-88.
27. Liu, F.; Wen, L. X.; Li, Z. Z.; Yu, W.; Sun, H. Y.; Chen, J. F., Porous hollow silica nanoparticles as controlled delivery system for water-soluble pesticide. *Mater. Res. Bull.* **2006**, 41, (12), 2268-2275.
28. Goswami, A.; Roy, I.; Sengupta, S.; Debnath, N., Novel applications of solid and liquid formulations of nanoparticles against insect pests and pathogens. *Thin Solid Films* **2010**, 519, (3), 1252-1257.
29. Yang, F.; Liu, C.; Gao, F. Q.; Su, M. Y.; Wu, X.; Zheng, L.; Hong, F. S.; Yang, P., The improvement of spinach growth by nano-anatase TiO₂ treatment is related to nitrogen photoreduction. *Biological Trace Element Research* **2007**, 119, (1), 77-88.
30. Alavi, S. V.; A., D. A., Evaluation of the nanosilver colloidal solution in comparison with the registered fungicide to control greenhouse cucumber downy mildew disease in the north of Iran. *Acta Hort.* **2010**, ISHS, (877), 1643-1646.
31. Liu, Y.; Tong, Z.; Prud'homme, R. K., Stabilized polymeric nanoparticles for controlled and efficient release of bifenthrin. *Pest Manag. Sci.* **2008**, 64, (8), 808-812.
32. Boehm, A. L. L.; Zerrouk, R.; Fessi, H., Poly epsilon-caprolactone nanoparticles containing a poorly soluble pesticide: formulation and stability study. *J. Microencapsul.* **2000**, 17, (2), 195-205.
33. Debnath, N.; Das, S.; Seth, D.; Chandra, R.; Bhattacharya, S.; Goswami, A., Entomotoxic effect of silica nanoparticles against *Sitophilus oryzae* (L.). *Journal of Pest Science* **2010**, 84, (1), 99-105.
34. Elek, N.; Hoffman, R.; Raviv, U.; Resh, R.; Ishaaya, I.; Magdassi, S., Novaluron nanoparticles: Formation and potential use in controlling agricultural insect pests. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* **2010**, 372, (1-3), 66-72.
35. Lamsal, K.; Kim, S.-W.; Jung, J. H.; Kim, Y. S.; Kim, K. S.; Lee, Y. S., Inhibition Effects of Silver Nanoparticles against Powdery Mildews on Cucumber and Pumpkin. *Mycobiology* **2011**, 39, (1), 26-32.
36. Jung, J.-H.; Kim, S.-W.; Min, J.-S.; Kim, Y.-J.; Lamsal, K.; Kim, K. S.; Lee, Y. S., The Effect of Nano-Silver Liquid against the White Rot of the Green Onion Caused by *Sclerotium cepivorum*. *Mycobiology* **2010**, 38, (1), 39-45.
37. Lu, J. W.; Li, F. B.; Guo, T.; Lin, L. W.; Hou, M. F.; Liu, T. X., TiO₂ photocatalytic antifungal technique for crops diseases control. *Journal of Environmental Sciences-China* **2006**, 18, (2), 397-401.
38. Luo, D. Q.; Guo, J. H.; Wang, F. J.; Jin, Z. X.; Cheng, X. L.; Zhu, J. C.; Peng, C. Q.; Zhang, C., Anti-fungal Efficacy of Polybutylcyanoacrylate Nanoparticles of Allicin and Comparison With Pure Allicin. *Journal of Biomaterials Science-Polymer Edition* **2009**, 20, (1), 21-31.
39. Panichkin, L. A.; Raikova, A. G., Use of metal nano powder in presowing treatment of seeds. *Izvestiya Timiryazevskoi Sel'skokhozyaistvennoi Akademii* **2009**, (1), 59-65.
40. Anjali, C. H.; Sharma, Y.; Mukherjee, A.; Chandrasekaran, N., Neem oil (*Azadirachta indica*) nanoemulsion—a potent larvicidal agent against *Culex quinquefasciatus*. *Pest Management Science* **2011**, n/a-n/a.
41. Song, S. L.; Liu, X. H.; Jiang, J. H.; Qian, Y. H.; Zhang, N.; Wu, Q. H., Stability of triazophos in self-nanoemulsifying pesticide delivery system. *Colloids And Surfaces A-Physicochemical And Engineering Aspects* **2009**, 350, (1-3), 57-62.
42. Khodakovskaya, M.; Dervishi, E.; Mahmood, M.; Xu, Y.; Li, Z. R.; Watanabe, F.; Biris, A. S., Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. *ACS Nano* **2009**, 3, (10), 3221-3227.
43. Kottegoda, N.; Munaweera, I.; Madusanka, N.; Karunaratne, V., A green slow-release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood. *Current Science* **2011**, 101, (1), 73-78.
44. Yang, F.-L.; Li, X.-G.; Zhu, F.; Lei, C.-L., Structural Characterization of Nanoparticles Loaded with Garlic Essential Oil and Their Insecticidal Activity against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal Of Agricultural And Food Chemistry* **2009**, 57, (21), 10156-10162.
45. Gonzalez-Melendi, P.; Fernandez-Pacheco, R.; Coronado, M. J.; Corredor, E.; Testillano, P. S.; Risueno, M. C.; Marquina, C.; Ibarra, M. R.; Rubiales, D.; Perez-De-Luque, A., Nanoparticles as smart treatment-delivery systems in plants: Assessment of different techniques of microscopy for their visualization in plant tissues. *Annals of Botany* **2008**, 101, (1), 187-195.

46. Liu, Y.; Laks, P.; Heiden, P., Controlled release of biocides in solid wood. III. Preparation and characterization of surfactant-free nanoparticles. *Journal Of Applied Polymer Science* **2002**, 86, (3), 615-621.
47. Liu, X.-m.; Feng, Z.-b.; Zhang, F.-d.; Zhang, S.-q.; He, X.-s., Preparation and Testing of Cementing and Coating Nano-Subnanocomposites of Slow/Controlled-Release Fertilizer. *Agricultural Sciences in China* **2006**, 5, (9), 700-706.
48. Mondal, A.; Basu, R.; Das, S.; Nandy, P., Beneficial role of carbon nanotubes on mustard plant growth: an agricultural prospect. *Journal Of Nanoparticle Research* **2011**, 13, (10), 4519-4528.
49. Corradini, E.; de Moura, M. R.; Mattoso, L. H. C., A preliminary study of the incorporation of NPK fertilizer into chitosan nanoparticles. *eXPRESS Polymer Letters* **2010**, 4, (8), 509-515.
50. bin Hussein, M. Z.; Zainal, Z.; Yahaya, A. H.; Foo, D. W. V., Controlled release of a plant growth regulator, alpha-naphthaleneacetate from the lamella of Zn-Al-layered double hydroxide nanocomposite. *Journal Of Controlled Release* **2002**, 82, (2-3), 417-427.
51. Spasova, M.; Manolova, N.; Naydenov, M.; Kuzmanova, J.; Rashkov, I., Electrospun biohybrid materials for plant biocontrol containing chitosan and *Trichoderma viride* spores. *Journal of Bioactive and Compatible Polymers* **2011**, 26, (1), 48-55.
52. Schrof, W.; Heger, R.; Koltzenburg, S.; Bratz, M.; Zagar, C.; Horn, D. Nanoparticles comprising a crop protection agent. WO/2003/039249, 2003.
53. Dookhith, M. R.; Linares, H. Stabilisierte Öl-in-Wasseremulsion. DE69126275T2, 1998.
54. Ishaque, M.; Schnabel, G.; Anspaugh, D. Agrochemical formulations comprising a pesticide, an organic UV-photoprotective filter and coated metal-oxide nanoparticles. WO/2009/153231, 2009.
55. Choi, K.; Lee, S.; Choi, H. The liquid composition for promoting plant growth, which includes nano-particle titanium dioxide. WO/2003/059070, 2003.
56. Bignozzi, C.; Dissette, V.; Della Valle, R. Products comprising an anti-microbial composition based on titanium dioxide nanoparticles. WO/2008/135093, 2008.
57. Santra, S. Silica-based antibacterial and antifungal nanoformulation. WO/2010/068275, 2010.
58. Schneider, K.-H.; Karpov, A.; Voss, H.; Dunker, S.; Merk, M.; Kopf, A.; Kondo, S. Method for treating phytopathogenic microorganisms using surface-modified nanoparticulate copper salts. WO/2011/067186, 2011.
59. Young, D.; Shaber, S.; Avila-Adame, C.; Breaux, N.; Ruiz, J.; Siddall, T.; Webster, J. Fungicidal compositions including hydrazone derivatives and copper. WO/2010/083319, 2010.
60. Biris, A.; Khodakovskaya, M. Method of using carbon nanotubes to affect seed germination and plant growth. WO/2011/059507, 2011.
61. Treseder, K. K.; Whiteside, M. D. Nanotechnological delivery of microbicides and other substances. WO/2011/031487, 2011.
62. Da Silva, A.; Nunes, C.; Da Silva, N.; Cossiello, R.; Sousa, U. Water Dispersible Agrochemical Formulations. WO/2010/051607, 2010.
63. Price, R.; Wagner, A. Method for treating agricultural crops using materials associated with tubular carriers. US20080194406, 2008.
64. Magdassi, S.; Dayan, B.; Levi-Ruso, G. Pesticide Nanoparticles obtained from Microemulsions and Nanoemulsions. WO/2008/032328, 2008.
65. Rahman Nia, J. Nanosilver for preservation and treatment of diseases in agriculture field. US20090075818, 2009.
66. Giessler-Blank, S.; Scheuermann, R.; Venzmer, J.; Lindsay, D. Nanoemulsions and Processes for their Preparation, And Their Use as Formulations of Plant Protection Agents and/or Pesticides and/or Cosmetic Preparations US20100041629, 2010.
67. Li, F. B.; Pham, H.; Anderson, D. Methods to produce polymer nanoparticles and formulations of active ingredients WO/2010/035118, 2010.
68. Qiu, M.; Li, Z. Ultrafine powder or nano preparation of pyrethrins and preparation process thereof CN1433697, 2003.
69. Dadajanov, T. K.; Figovsky, O. L.; Ruban, I. N.; Sharipov, M. D.; Voropaeva, N. L. Biologically active nanochips for treating seeds of agricultural plants e.g. rice seed comprises carrier; and biologically active component such as binder, nanochip stabilizer, herbicide, plant-growth regulator, seed-germination stimulator. US2011000411-A1, US2011000411-A1 06 Jan 2011 A01C-007/00 201109, 2011
70. Maier, G.; Schneider, G. Verbesserung des Wachstums von Mikroorganismen. DE102009030121A1, 2010.
71. Park, H. Composition for controlling pathogenic microorganisms in plants WO/2006/049379, 2006.
72. Vormberg, R.; Lortz, W.; Schumacher, K.; Scheffler, J.; Fleute-Schlachter, I.; Sieverding, E. Preparation containing UV radiation absorbing metal oxide powder and a superspreading agent. WO/2007/014826, 2007.

73. Shang, Q.; Zheng, H.; Qi, T. Ivermectin water suspension nano capsule prepn and its preparing method CN1491551, 2004.
74. Zheng, H.; Shang, Q. Water suspension acetamiprid nano capsule prepn and its preparing method CN1491558, 2004.
75. Crooks, R.; Joanicot, M.; Prud'homme, R. K.; Coret, J. Aqueous suspension of nanoparticles comprising an agrochemical active ingredient. WO/2002/082900, 2002.
76. Prasad, D. Y. Production of novel precision customized control release fertilizers. WO/2008/056234, 2008.
77. Greiner, A.; Hummel, H. E.; Wendorff, J. H.; Becker, M.; Dersch, R. Invention concerning agricultural active substances US8017061, 2011.
78. Botts, M. F.; Kohn, F. C.; Miller, M. L. Particles containing agricultural active ingredients US7070795, 2006.
79. Koltzenburg, S.; Lehmann, S.; Steinmetz, B.; Schrof, W.; Hadel, J.; Mayer, W.; Bratz, M.; Goedel, W. Nanoparticulate active substance formulations. US7994227, 2011.
80. Greiner, A.; Wendorff, J.; Becker, M.; Dersch, R.; Hummel, H. E. Device and use thereof for producing nanoscalar polymer fibres that are used as supports for agricultural active ingredients WO/2005/115143, 2005.
81. Hayes, R. T.; Owen, J. D.; Chauhan, A. S.; Pulgam, V. R. Peham dendrimers for use in agriculture WO/2011/053605, 2011.
82. Yavitz, E. Q. Plant protection and growth stimulation by nanoscalar particle folial delivery US7494526, 2005.
83. Glatter, O.; Engelskirchen, S.; Levy, T.; Auweter, H.; Berghaus, R.; Strathmann, S. Pesticidal dispersion comprising nanostructured dispersed phase WO/2011/138701, 2011.
84. Mahiran, B.; Lim, C. J.; Dzolkhifli, O.; Abu, B. S.; Mohd. Basyaruddin abd. Rahman; Raja Noor, Z. R. A. R. A herbicide formulation. WO/2011/010910, 2011.
85. Wege, P. J.; Hoppe, M. A.; Bywater, A. F.; Weeks, S. D.; Gallo, T. S. In *A Microencapsulated Formulation of Lambda-Cyhalothrin*, 3rd International Conference on Urban Pests, 1999; Robinson, W. H.; Rettich, F.; Rambo, G. W., Eds. 1999.