

IMPACT OF PESTICIDES USED FOR CROP PRODUCTION ON THE ENVIRONMENT

S. Sitaramaraju¹, N.V.V.S.D.Prasad^{*2}, V. Chenga reddy^{*2} and e. Narayana^{*2}

¹Department of Entomology, Agricultural College, Bapatla – 522 101

^{*2} Acharya N.G. Ranga Agricultural University, Regional Agricultural Research Station, Lam, Guntur – 522 034

***Corresponding Author: Email: rajsayala@gmail.com**

ABSTRACT

Manufacturing and consumption of pesticides worldwide have been increasing dramatically in crop production. In this process pesticide misuses become more and more serious, which has resulted in heavy environmental pollution and health risk of humans. Majority of pesticides are not specifically targeting the pest only and during their application they also affect non-target plants and animals. Over time, repeated application leads to loss of biodiversity and increases in pest resistance, while its effects on other species can facilitate the pest's resurgence. Many pesticides are not easily degradable, they persist in soil, leach to groundwater and runoff can carry pesticides into aquatic environment and contaminate wide environment. Depending on their chemical properties they can enter the organism, bioaccumulate in food chains and consequently influence human health. Sprayed pesticides give effects other than on their target species, including effects on non-target sites such as air, water and the soil. Overall, intensive pesticide application results in several negative effects in the environment that cannot be ignored.

1. INTRODUCTION

Pesticides present the only group of chemicals that are purposely applied to the environment with aim to suppress plant and animal pests and to protect agricultural and industrial products. Indiscriminate and excessive use of toxic synthetic pesticides damaged not only environment and agriculture but have also entered into the food chain thereby affecting all living beings. The recent research findings on the presence of pesticide particles in the packaged water are classic cases pointing out the nature and magnitude of the problem.

Pesticides, herbicides and fungicides have been introduced during the mid-sixties on a large scale along with other inputs for propagating green revolution package in Indian agriculture. The main intention of the introduction of pesticides was to prevent and control insect pests and diseases in the field crops and of course, initially the use of pesticides reduced pest attack and paved way for increasing the crop yield as expected. Simultaneously, increased use of chemical pesticides has resulted in contaminating the environment and the long-term implications on the society are found to be many. Knowingly or unknowingly, now the farmers are addicted to using agrochemicals indiscriminately and excessively to make the situation from bad to worse not only in India but also in other parts of world as well (Conway, 1984)

2. Benefits and risks of pesticide application: Pesticide is so indispensable in agricultural production. About one-third of the agricultural products are produced by using pesticides (Liu et al., 2002). Without pesticide application the loss of fruits, vegetables and cereals from pest injury would reach 78%, 54% and 32% respectively (Cai, 2008). Crop loss from pests declines to 35% to 42% when pesticides are used (Pimentel, 1997; Liu and Liu, 1999). Meantime, the risks of using pesticides are serious as well (Pimentel, 2009). Most pesticides are not spontaneously generated. Most of them are high toxic to humans and the environment. Pesticides and their degraded products would flow into the atmosphere, soils and rivers, resulting in the accumulation of toxic substances and thus threatening human health and the environment. The environmental pollution caused by pesticides in Asia, Africa, Latin America, the Middle East and Eastern Europe are now serious. Even in earlier years the residuals of DDT, lindane and dieldrin in fish, eggs and vegetables have been much beyond the safe range in India (Wu, 1986). In India the DDT content in human body was ever the highest in the world.

3. Global use of Pesticides: Over the period 2007 to 2008, herbicides ranked the first in three major categories of pesticides (insecticides, fungicides, herbicides). Fungicides increased rapidly and ranked the second. Europe is now the largest pesticide consumer in the world, followed by Asia. As for countries, China, the United States, France, Brazil and Japan are the largest pesticide producers, consumers or traders in the world. Most of the pesticides worldwide are used to fruit and vegetable crops. In the developed countries pesticides, mainly herbicides are mostly used in maize

4. Pesticide use in India: In India there is a trade-off between agricultural production and increasing soil, air and water pollution and associated health hazards (Gupta, 2004; Agoramoorthy, 2008; Abhilash and Singh, 2009). Currently, India is the largest producer of pesticides in Asia and ranks twelfth in the world for the use of pesticides. Although the average consumption of pesticides is far lower than many other countries, the problem of pesticide pollution is serious in India. Unfortunately, India is one of the few remaining countries still producing and using some of the chlorinated pesticides such as DDT and lindane (Abhilash and Singh, 2009; Vijgen et al., 2011)

Among the various states, Uttar Pradesh is the largest consumer followed by Punjab, Haryana and Maharashtra. Regarding the pesticide share across agricultural crops, cotton account for 45% followed by rice (25%), chillies/vegetables/fruits (13-24%), plantations (7-8%), cereals/millet/oil seeds (6-7%), sugarcane (2-3%) and other (1-2%) (Gupta, 2004; Abhilash and Singh, 2009).

5. First warning signals about pesticides danger: In 1962, Rachel Carson, an American courageous woman and scientist, wrote down her nature observation and pointed out sudden dying of birds caused by indiscriminated spraying of pesticides (DDT). Her book, Silent Spring, became a landmark. It changed the existing view on pesticides and has stimulated public concern on pesticides and their impact on health and the environment. Silent Spring facilitated the ban of the DDT in 1972 in

the United States. More research has been done and several dangerous and persistent organic pesticides like Dieldrin, Endosulfan and Lindane have been banned or restricted since that time.

6. Environmental Effects of Pesticides, in Different Compartments.

6.1. Soil contamination: Many of the chemicals used in pesticides are persistent soil contaminants, whose impact may endure for decades and adversely affect soil conservation. Pesticides enter the soil via spray drift during foliage treatment, wash-off from treated foliage, release from granulates or from treated seeds in soil. Some pesticides such as soil fumigants and nematicides are applied directly into soil to control pests and plant diseases presented in soil.

The transport, persistence or degradation of pesticides in soil depend on their chemical properties as well as physical, chemical and biological properties of the soil. All these factors affect sorption/ desorption, volatilisation, degradation, uptake by plants, run-off, and leaching of pesticides.

6.2. Persistent organochlorine pesticides (OC) in soils: Persistence of pesticides in soil can vary from few hours to many years in case of OC pesticides. Despite OC pesticides were banned or restricted in many countries, they are still detecting in soils (Shegunova et al., 2007; Toan et al., 2007; Li et al., 2008; Hildebrandt et al., 2009; Jiang et al., 2009; Ferencz and Balog 2010).

Sorption is the most important interaction between soil and pesticides and limits degradation as well as transport in soil. Pesticides bound to soil organic matter or clay particles are less mobile, bio available but also less accessible to microbial degradation and thus more persistent.

Soil organic matter is the most important factor influencing sorption and leaching of pesticides in soil. Addition of organic matter to soil can enhance sorption and reduce risk to water pollution. It has been demonstrated that amount and composition of organic matter had large impact on pesticides sorption. For example soil rich on humus content are more chemically reactive with pesticides than nonhumified soil (Farenhorst 2006).

Fast sorption usually occurs in short time after pesticide application. With time sorption is much slower. However, it has been observed for many pesticides that increasing time, repeated application could increase their sorption and formation of bound, non-extractable residues.

A review is published showing that about 50 % of plant protection products from EU registration dossiers exhibit a low proportion (up to 30% of initial amount) of non-extractable residues and about 12 % proportion exceeding 70%. The largest proportion of bound residues was found for carbamates, and in particular, for dithiocarbamates. In this study authors further summarized and discussed factors that affect formation of bound residues, chemical properties as well as soil and environmental condition (Barriuso et al., 2008).

6.3. Water contamination: Pesticides can get into water via drift during pesticide spraying, by runoff from treated area, leaching through the soil. In some cases pesticides can be applied directly onto water surface e.g. for control of mosquitoes. Water contamination depends mainly on nature of pesticides (water solubility, hydrophobicity), soil properties, weather conditions, landscape and also on the distance from an application site to a water source. Rapid transport to groundwater may be caused by heavy rainfall shortly after application of the pesticide to wet soils.

During nineties, herbicide Atrazine and Endosulfan were found most often in surface waters in the USA and Australia due to their widespread use. Other pesticides detected included Pronofos, Dimethoate, Chlordane, Diuron, Prometryn and Fluometuron (Cooper 1996).

Recent studies also reported presence of pesticides in surface water and groundwater close to agriculture lands over the world (Cerejeira et al., 2003; Konstantinou et al., 2006; Gilliom 2007; Woudneh et al., 2009; Añasco et al., 2010). In general, the compounds most frequently detected were currently used pesticides (herbicides Atrazine, Simazine, Alachlor, Metolachlor and Trifluralin, insecticides Diazinon, Parathion methyl, and organochlorine compounds due to their long persistence (lindane, endosulfan, aldrin, and other organochlorine pesticides).

The geographic and seasonal distribution of pesticide occurrence follows patterns in land use and pesticide use. Streams and rivers were frequently more polluted than groundwaters and more near the areas with substantial agricultural and/or urban land use. Pesticides usually occurred in mixture of multiple compounds, even if individual pesticide were detected below limits. This potentially can lead to underestimation of toxicity when assessments are based on individual compounds.

High levels of pesticides chlordecone were detected in coastline, rivers, sediments and groundwater in the Caribbean island of Martinique due to its massive application on bananas plantations (Bocquené and Franco 2005).

7. Effects on organisms

7.1. Soil organisms and processes: Soil microorganisms play a key role in soil. They are essential for maintenance of soil structure, transformation and mineralization of organic matter, making nutrients available for plants. Soil microorganisms are also able to metabolise and degrade a lot of pollutants and pesticides and thus are of great concern for using in biotechnology. On the other hand, microbial degradation can lead to formation of more toxic and persistent metabolites. Although soil microbial population are characterized by fast flexibility and adaptability to changed environmental condition, the application of pesticides (especially long-term) can cause significant irreversible changes in their population. Inhibition of species, which provide key process, can have a significant impact on function of whole terrestrial ecosystem.

Studies show that some organochlorine pesticides suppress symbiotic nitrogen fixation resulting in lower crop yields. Authors found out that pesticides Pentachlorophenol, DDT and Methyl parathion at levels found in farm soils interfered signalling from leguminous plant such as alfalfa, peas, and soybeans to symbiotic soil bacteria. As consequence increased

dependence on synthetic nitrogenous fertilizer, reduced soil fertility, and unsustainable long-term crop yields occur. (Fox et al., 2007; Potera 2007).

7.2. Soil invertebrates: Nematodes, springtails, mites and further micro-arthropods, earthworms, spiders and insects make up the soil food web and enable decomposition of organic compounds such as leaves, manure, plant residues and they also prey on crop pests. Soil organisms enhance soil aggregation and porosity and thus increasing infiltration and reducing runoff.

Earthworms represent the greatest part of biomass of terrestrial invertebrates (>80 %) and play an important role in soil ecosystem. They are used as bioindicator of soil contamination providing an early warning of decline in soil quality.

- A review of pesticides effects on earthworms showed on negative effects on growth and reproduction by many pesticides (Shahla and D'Souza 2010).
- A microcosm study conducted in orchards in the South Africa indicated adverse effects of spraying by pesticides (Chlorpyrifos and Azinphos methyl) on earthworm's biomass and cholinesterase activity. Authors concluded that earthworms were detrimentally affected by the pesticides due to chronic and intermittent exposure (Reinecke and Reinecke 2007).
- Glyphosate, nonselective herbicide, and chlorpyrifos, insecticide, belong to the most worldwide used pesticides, especially on transgenic resistant crops. An integrated study on a Roundup resistant soya field in Argentina showed deleterious effect of these pesticides on earthworm population (Casabé et al., 2007).

Other soil species are also often affected by pesticides application and non-target soil community structure can be strongly affected.

As reported in another study, glyphosate affected predatory arthropods (spiders and ground beetle) in agricultural field, caused behavioural changes and influenced long-term surviving even in residual exposure. These Results also suggest that herbicides can affect arthropod community dynamics separate from their impact on the plant community and may influence biological control in agroecosystems (Evans et al., 2010). Decrease in number of spiders and diversity, and species richness of Collembolan after application of insecticide chlorpyrifos has been reported on grassland pasture in UK (Fountain et al., 2007).

7.3. Other non-target species:

- Effect of pesticides on bees are closely watched because their crop pollination. However, little is known about the impacts of pesticides on wild pollinators in the field. In recent study conducted in Italian agricultural area, authors monitored species richness of wild bees, bumblebees and butterflies were sampled after pesticides application. They detected decline of wild bees after repeated application of insecticide fenitrothion. Lower bumblebee and butterfly species richness was found in the more intensively farmed basin with higher pesticide loads (Brittain et al., 2010).
- Of the 80–98% of the active ingredient in seed dressing of neonicotinoids, which is not absorbed by the crop, a small proportion (<2%) is lost as dust during sowing (Tapparo et al. 2012). This aerial dust can be sufficient to cause direct mortality in honeybees flying nearby (Marzaro et al. 2011; Tapparo et al. 2012)
- Several articles reported negative effects of pesticides and intensive agriculture on butterflies populations (Adamski et al., 2009), and showed positive impact of organic farming (Saarinen 2002; Feber et al., 2007).
- It has been shown that using herbicides to control of invasive plants can significantly reduce survival, wing and pupa weight of butterfly at treated areas. (Russell and Schultz 2009).

7.4. Amphibians and fishes

- For example, Carbaryl has been found toxic for several amphibian species, additional combination with predatory stress caused higher mortality (Relyea 2003). Also herbicide Roundup, glyphosate, caused high mortality of tadpoles and juvenile frogs in a outdoor mesocosms study (Relyea 2005).
- Impact of Malathion a broad spectrum insecticide, on aquatic ecosystem has been demonstrated. Malathion is the most commonly applied insecticide around the world and can be legally directly sprayed over aquatic habitats to control the mosquitoes. This study showed that relatively small concentration of malathion caused direct and also indirect effect on aquatic food web. Changes in plankton and periphyton abundance and composition consequently affected growing of frog tadpoles and reduced predation rates on amphibians (Relyea and Hoverman 2008).

7.5. Birds

Decline of farmland bird species has been reported over several past decades and often attributed to changes in farming practises, such as increase agrochemical inputs, loss of mixture farming or unfarmed structures. Besides lethal and sub lethal effects of pesticides on birds, concern has recently focused on the indirect effects. These effects act mainly via reduction of food supplies (weeds, invertebrates), especially during breeding or winter seasons. As consequence insecticide and herbicide application can lead to reduction of chick survival and bird population.

- Evidences of this important indirect effect of pesticides has been reported by Boatman et al., 2004; Taylor et al., 2006.
- A recent review about this topic and possible mitigation measure were published by Royal Society for the Protection of Birds in UK (Bright et al., 2008).

8. CONCLUSIONS

Pesticides have contaminated almost every part of our environment and pesticide residues are found in soil, air and in surface and groundwater. Pesticide contamination poses significant risks to the environment and non-target organisms ranging from beneficial soil microorganisms to insects, plants, fish, and birds. Recent studies have indicated that our environment is

chronically polluted by pesticides and levels of biocidal contamination have increased tremendously. The environmental deterioration due to pesticides is endangering the situation of future.

9. REFERENCES

- Abhilash PC, Singh, N (2009) Pesticides use and application: An Indian scenario. *J. Hazard. Mater.* 165:1-12
- Adamski, Z., Machalska, K., Chorostkowska, K., Niewadzi, M., Ziemnicki, K., Hirsch, H.V.B. (2009): Effects of sublethal concentrations of fenitrothion on beet armyworm (Lepidoptera: Noctuidae) development and reproduction. *Pesticide Biochemistry and Physiology* 94(2-3), pp 73-78.
- Agoramoorthy G (2008) Can India meet the increasing food demand by 2020? *Futres* 40:503-506.
- Amalin, D.M., Peña, J.E., Duncan, R., Leavengood, J., Koptur, S. (2009): Effects of Pesticides on the Arthropod Community in the Agricultural Areas near the Everglades National Park. *Proceedings of the Florida State Horticultural Society* 122.
- Añasco, N., Uno, S., Koyama, J., Matsuoka, T., Kuwahara, N. (2010): Assessment of pesticide residues in freshwater areas affected by rice paddy effluents in Southern Japan. *Environmental Monitoring and Assessment* 160(1), pp 371-383.
- Barriuso, E., Benoit, P., Dubus, I.G. (2008): Formation of pesticide nonextractable (bound) residues in soil: magnitude, controlling factors and reversibility. *Environmental Science and Technology* 42(6), pp 1845-1854.
- Boatman, N.D., Brickle, N.W., Hart, J.D., Milsom, T.P., Morris, A.J., Murray, A.W.A., Murray, K.A., Robertson, P.A. (2004): Evidence for the indirect effects of pesticides on farmland birds. *Ibis* 146, pp 131-143.
- Bocquené, G., Franco, A. (2005): Pesticide contamination of the coastline of Martinique. *Marine Pollution Bulletin* 51(5-7), pp 612-619.
- Bright, J.A., Morris, A.J., Winspear, R. (2008): A review of Indirect Effects of Pesticides on Birds and mitigating land-management practices. Research Report 28, Royal Society for the Protection of Birds, UK.
- Brittain, C.A., Vighi, M., Bommarco, R., Settele, J., Potts, S.G. (2010): Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic and Applied Ecology* 11(2), pp 106-115.
- Cai DW. 2008. Understand the role of chemical pesticides and prevent misuses of pesticides. *Bulletin of Agricultural Science and Technology*, 1: 36-38
- Casabé, N., Piola, L., Fuchs, J., Oneto, M.L., Pamparato, L., Basack, S., Giménez, R., Massaro, R., Papa, J.C., Kesten, E. (2007): Ecotoxicological Assessment of the Effects of Glyphosate and Chlorpyrifos in an Argentine Soya Field. *Journal of soil sediments* 7(4), pp 232-239
- Cerejeira, M.J., Viana, P., Batista, S., Pereira, T., Silva, E., Valério, M.J., Silva, A., Ferreira, M., Silva-Fernandes, A.M. (2003): Pesticides in Portuguese surface and ground waters. *Water Research* 37(5), pp 1055-1063.
- Conway G R, 1984 Strategic Models, in G R Conway (Ed) *Pest and Pathogen Control: Strategic, Tactical and Policy Models*, International Series on Applied Systems Analysis, John Wiley and Sons.
- Cooper, B. (1996): Central and North West Regions Water Quality Program 1995/1996. Report on Pesticide Monitoring. TS96.048, NSW Department of Land & Water Conservation, Sydney, Australia.
- Evans, S., Shaw, E., Rypstra, A. (2010): Exposure to a glyphosate-based herbicide affects agrobiont predatory arthropod behaviour and long-term survival. *Ecotoxicology*, pp 1-9.
- Farenhorst, A. (2006): Importance of Soil Organic Matter Fractions in Soil-Landscape and Regional Assessments of Pesticide Sorption and Leaching in Soil. *Soil Sci. Soc. Am. J.* 70(3), pp 1005-1012.
- Feber, R.E., Johnson, P.J., Firbank, L.G., Hopkins, A., Macdonald, D.W. (2007): A comparison of butterfly populations on organically and conventionally managed farmland. *Journal of Zoology* 273(1), pp 30-39.
- Ferencz, L., Balog, A. (2010): A pesticide survey in soil, water and foodstuffs from entral Romania. *Carpathian Journal of Earth and Environmental Sciences, April 2010*, 5(1), pp 111-118
- Fountain, M.T., Brown, V.K., Gange, A.C., Symondson, W.O.C., Murray, P.J. (2007): The effects of the insecticide chlorpyrifos on spider and Collembola communities. *Pedobiologia* 51(2), pp 147-158.
- Gilliom, R.J. (2007): Pesticides in U.S. Streams and Groundwater. *Environmental Science & Technology* 41(10), pp 3408-3414.
- Gupta PK. (2004) Pesticide exposure-Indian scene. *Toxicol.* 198:83-90.
- Hildebrandt, A., Lacorte, S., Barceló, D. (2009): Occurrence and Fate of Organochlorinated Pesticides and PAH in Agricultural Soils from the Ebro River Basin. *Archives of Environmental Contamination and Toxicology* 57(2), pp 247-255.
- Jiang, Y.-F., Wang, X.-T., Jia, Y., Wang, F., Wu, M.-H., Sheng, G.-Y., Fu, J.-M. (2009): Occurrence, distribution and possible sources of organochlorine pesticides in agricultural soil of Shanghai, China. *Journal of Hazardous Materials* 170(2-3), pp 989-997.
- Konstantinou, I.K., Hela, D.G., Albanis, T.A. (2006): The status of pesticide pollution in surface waters (rivers and lakes) of Greece. Part I. Review on occurrence and levels. *Environmental Pollution* 141(3), pp 555-570.
- Li, X.-h., Wang, W., Wang, J., Cao, X.-l., Wang, X.-f., Liu, J.-c., Liu, X.-f., Xu, X.-b., Jiang, X.-n. (2008): Contamination of soils with organochlorine pesticides in urban parks in Beijing, China. *Chemosphere* 70(9), pp 1660-1668.
- Liu CJ, Men WJ, Liu YJ, et al. 2002. The pollution of pesticides in soils and its bioremediation. *System Sciences and Comprehensive Studies in Agriculture*, 18(4): 295-297
- Liu ZJ and Liu ZB. 1999. The Status of the world agrochemicals. *Chemical Technology Market*, 22(12): 14-17

- Marzaro, M., Vivan, L., Targa, A., Mazzon, L., Mori, N., Greatti, M., Petrucoo Toffolo, E., Di Bernardo, A., Giorio, C., Marton, D., Tapparo, A. & Girolami, V. (2011) Lethal aerial powdering of honey bees with neonicotinoids from fragments of maize seed coat. *Bulletin of Insectology*, 64, 119–126
- Pimentel D. 1997. *Techniques for Reducing Pesticide Use: Environmental and Economic Benefits*. John Wiley and Sons, Chichester, USA
- Pimentel D. 2009. Environmental and economic costs of the application of pesticides primarily in the United States. In: *Integrated Pest Management: Innovation-Development Process (Vol. 1)* (P Rajinder and A Dhawan eds). Springer, 88-111
- Reinecke, S.A., Reinecke, A.J. (2007): The impact of organophosphate pesticides in orchards on earthworms in the Western Cape, South Africa. *Ecotoxicology and Environmental Safety* 66(2), pp 244-251.
- Relyea, R.A. (2005): The lethal impact of Roundup on aquatic and terrestrial amhibians. *Ecological Applications* 15(4), pp 1118-1124.
- Relyea, R.A., Hoverman, J.T. (2008): Interactive effects of predators and a pesticide on aquatic communities. *Oikos* 117(11), pp 1647-1658.
- Russell, C., Schultz, C.B. (2009): Effects of grass-specific herbicides on butterflies: an experimental investigation to advance conservation efforts. *Journal of Insect Conservation* 14(1), pp 53-63.
- Saarinen, K. (2002): A comparison of butterfly communities along field margins under traditional and intensive management in SE Finland. *Agriculture, Ecosystems & Environment* 90(1), pp 59-65.
- Shahla, Y., D'Souza, D. (2010): Effects of Pesticides on the Growth and Reproduction of Earthworm: A Review. *Applied and Environmental Soil Science* 2010, pp Article ID 678360, 9 pages.
- Shegunova, P., Klánová, J., Holoubek, I. (2007): Residues of organochlorinated pesticides in soils from the Czech Republic. *Environmental Pollution* 146(1), pp 257-261.
- Tapparo, A., Marton, D., Giorio, C., Zanella, A., Solda, L., Marzaro, M., Vivan, L. & Girolami, V. (2012) Assessment of the environmental exposure of honeybees to particulate matter containing neonicotinoid insecticides coming from corn coated seeds. *Environmental Science and Technology*, 46, 2592–2599. doi: 10.1021/es2035152.
- Taylor, R.L., Maxwell, B.D., Boik, R.J. (2006): Indirect effects of herbicides on bird food resources and beneficial arthropods. *Agriculture, Ecosystems & Environment* 116(3-4), pp 157-164.
- Toan, V., Thao, V., Walder, J., Schmutz, H.-R., Ha, C. (2007): Contamination by Selected Organochlorine Pesticides (OCPs) in Surface Soils in Hanoi, Vietnam. *Bulletin of Environmental Contamination and Toxicology* 78(3), pp 195-200.
- Vijgen J, Abhilash PC, Li YF, Lal R, Forter M, Torres J, Singh N, Yunus M, Tian C, Schäffer A, Weber R (2011) HCH isomers as new Stockholm Convention POPs – A global perspectives on the management of Lindane and its waste isomers. *Environ. Sci. Pollut. Res.* 18: 152-162.
- Woudneh, M.B., Ou, Z., Sekela, M., Tuominen, T., Gledhill, M. (2009): Pesticide Multiresidues in Waters of the Lower Fraser Valley, British Columbia, Canada. Part I. Surface Water. *J. Environ. Qual.* 38(3), pp 940-947.
- Wu M. 1986. Serious crop phytotoxicity by pesticides in India. *World Agriculture*, 4: 37-37