

Safe use of agrochemicals

under soil-plant-animal and human system

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The increased demand of foodgrains due to rapid human population growth has triggered the agrochemicals based agricultural production systems. The event of 'Green Revolution' further intensified the use of agrochemicals (fertilizers and pesticides) in Indian agriculture. However, concurrently imbalanced and improper use of agrochemicals deteriorated the environment and pose severe threat to aquatic and terrestrial ecosystems. These had negative impact on balance and energy flow in the soil-plant-animal/human system. Since sustainability of agricultural production systems and environmental health is major concerns to sustain the foodgrains production, the safe and reduced throughputs of hazardous agrochemicals are crucial requirements.

Keywords: Agrochemicals, Foodgrains, Environment, Hazardous

GLOBAL human population is rising at an exponential rate (nearly 70 million people per year) and if this trend continues, the world population will reach 10 billion by the end of the century. In this context, the major challenge for the farming community is to maintain the sustainable food supply for the humans and animals. Since the beginning of green revolution, inclusion of high yielding input responsive crop varieties have a major share in the global food basket. However, due to multiple reasons like deficiency of micronutrients, soil and water pollution, water scarcity, global warming and severe pest and disease incidences, agricultural growth has now become standstill. Under these circumstances, agriculture can play a dual role by providing nutrition and ecosystem services like clean air, water and other benefits to the mankind. In current condition, major agrochemicals used in agriculture are fertilisers, herbicides and pesticides (insecticides and fungicides). Agrochemicals can reach the soil system directly such as fertiliser, seed

treatment with different pesticides (fungicides and insecticides), and herbicide spray or indirectly by aerial spraying into the above ground plant parts and subsequent movement of contaminated water on the surface and within the soil profile (Fig. 1).

Fertilisers are backbone of modern day agriculture and without this, higher yield is hardly achievable. In the year 2019-20, total 193.69 lakh tonnes of fertiliser (major nutrients only) are being consumed and of which 98.84 lakh tonnes of material has been imported (Table 1). Congruous nutrient management is the key to sustainable practice but, very often farmers apply more than the recommended dose and as a consequence 50-70% of fertilisers get lost in the environment due to leaching, volatilisation or fixation in to non-labile forms. So, eco-friendly, economic and integrated nutrient management (INM) options are need of the hour. Weeds are the unwanted plants not only reduce the potential yield but increase cost of cultivation, reduce input use efficiency, loss of potentially productive lands, loss of

grazing areas and livestock production. Conventional methods of weed control are not practical and economically feasible thus globally the use of herbicide is increasing rapidly. But, application of same herbicide in the field possesses serious threats like herbicide resistance, pollution to the ground water bodies and shift in weed flora. Thereby, holistic sustainable need based weed management programmes must be exceptional alternatives throughout the farming period. According to study, there are 67,000 organisms are reported to affect agricultural crops and without any agrochemicals 70% of the produce could have been lost. Over-application of pesticides causes development of resistant species. Dietary accumulation in the tropic chain, bio-magnification even if in minute amount could cause appalling impact on human/animal system. End-to-end efforts are being made globally like use of slow/controlled released fertilisers, bio-fertilisers, organic farming, microbial inoculants, application of natural

Table 1. Consumption of chemical fertilizers and pesticides in India (2019-20)

Input	Unit	Value
Nitrogen (N)	Lakh tonnes	191.00
Phosphorus (P)	Lakh tonnes	76.62
Potash (K)	Lakh tonnes	26.07
Total (N+P+K)	Lakh tonnes	293.69
Pesticides (technical grade materials)	Thousand tonnes	61.70

Source: Agric. Statistics 2020, DAC, GoI.

enemies, bio-pesticides (synthesis of natural oil based insecticides), nano-formulation based herbicides and fungicides or other integrated pest management (IPM) modules to limit the consumption of synthetics and safeguard society from death-dealing impact of agrochemicals. Thus, achieving modern sustainable agriculture in many ways in contrast to input intensive green revolution is the need of the hour and will be synonymous to food security.

BENEFITS AND ASSOCIATED RISKS OF AGROCHEMICALS

Present agricultural production systems are challenged by several biotic (weeds, insects and diseases) and abiotic (nutrient deficiency / soil fertility) factors which are managed by extensive use of fertilizers and pesticides. These chemicals are behind the tremendous increase in foodgrains production in the world including making India self-sufficient. The 'Green Revolution' in developing

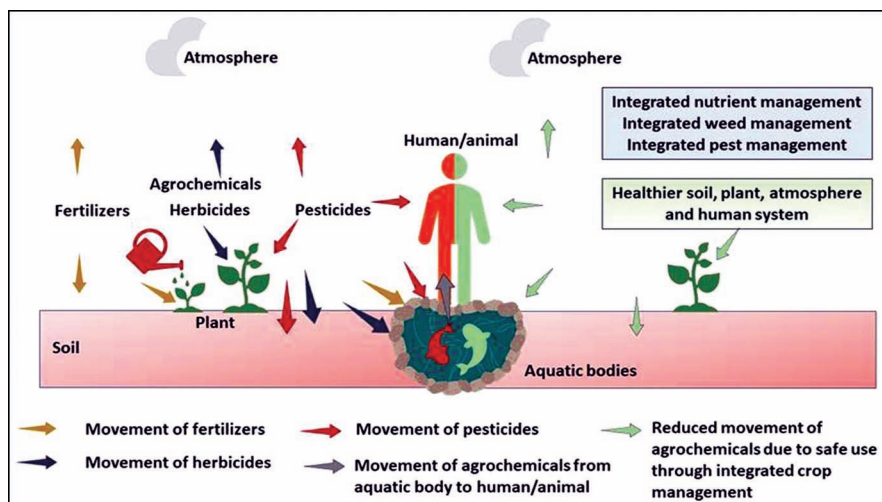


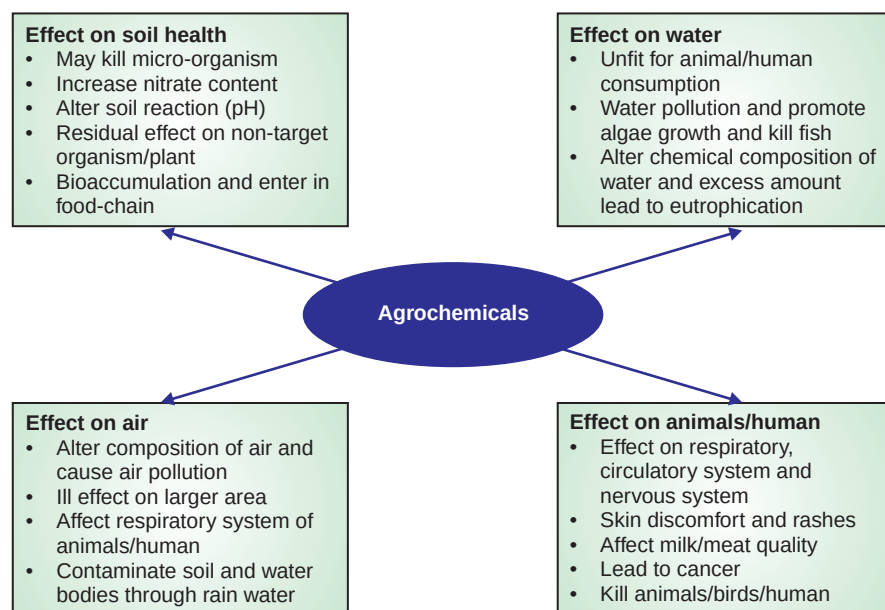
Fig. 1. Agrochemicals in soil-plant-animal/human system.

countries like India is possible only because of use of agrochemicals and irrigation. Therefore, fertilizer and pesticide use in agriculture have been substantially increased in both developed and developing countries in the recent past for attaining maximum yield of crops. In spite of that, there is a growing concern worldwide on the use of synthetic agrochemicals in agriculture (Fig. 2). The other risks are development of resistant strains of weeds and insect-pests, and ecological instability including the adverse effects on aquatic and terrestrial ecosystems. Thus, it is necessary to consider the risks associated with use of agrochemicals in agriculture for safeguarding the health of soil-plant-animal/human and environment.

WAYS TO SAFE USE OF AGROCHEMICALS

Fertilisers

In nutrient management, there are certain loop holes like violating the rules of 4R's, focusing more on chemical fertiliser and avoiding organic nutrient sources, indiscriminate application without deciphering future environmental consequences for e.g. nitrogen (N) is applied at 15 times higher than the recommended dose since last 5 decades but, its uptake in the grains has been increased only 4 times. Most of the applied N gets lost through leaching and deposited in the fresh water bodies creating congenial condition for eutrophication. Among the present options, most eco-friendly one should curtail the dose of synthetics and substitute the same with INM and use of novel compounds that can sustain the nutrient flow for prolonged condition without getting lost. In INM, a portion of chemical fertiliser is being replaced with organics like farm yard manure (FYM) and using microbial inoculants such as, bio-fertilisers and plant growth promoting rhizobacteria (PGPRs). Organic manures are C-enriched compounds which stores little amount of macro- and micro-nutrients. Besides nutrients, organic manures helps to improve the soil physicochemical conditions, increases water holding capacity, infiltration, microbial biomass and prevents fluctuations in soil temperature. Organic manures



prepared from dung of household animals such as livestock, sheep, poultry or crop residues are wealth in disguise. Efforts are being made to synthesize enriched composts where organic manures and low grade rock phosphates/micas are co-composted together to get final products with higher phosphorus (P) or potassium (K) content. But, on the other side, the reasons behind poor adaptability and popularisation are inaccessible in bulk amount, low quality of available materials, higher C:N ratio, decline in domestic cattle population due to rapid industrialization etc. Practical facilities on large scale conversion of agricultural and municipal waste into compost need to be established. One more important approach for scaling down consumption of synthetics is bio-fertilisers and PGPRs. Numerous genera, species, strains, and ecotypes of microbial inoculants have been identified as N₂-fixers and P-solubilizers. A significant number of PGPRs are commercially available to public and private agencies irrespective of crops. Responses of different crops to bio-fertilisers are presented in Table 2.

However, bio-fertilizers have not been welcomed by the farmers at large scale to replace chemical fertilizers primarily due to their low efficacy, less awareness on the environmental and health related problems using chemical fertilizers, and poor technical support to farmers about sustainable handling and affectivity of microbial bio-fertilizers, as they are living organisms and may suffer from the stresses during storage, transport, and availability. The concept of slow/controlled release fertiliser (SRFs) is to slow down the rate of solvation and supplement the plants when their physiological demand is at peak. Generally, applied urea gets dissolved within 3-7 days of application and lost subsequently. For that, numerous natural and synthetic products are used in practise for quenching the crop need and minimize the pollution. The most commonly used slow release materials are urea super granule (USG), sulphur coated urea (SCU), neem coated urea (NCU) and polymer coated products.

Table 2. Response of crops on application of bio-fertilisers

Crop	Bio-fertilisers/PGPRs	Remarks
Soybean	<i>T. harzianum</i> , <i>T. virens</i>	Improves nitrogen use efficiency (NUE) by 6%-16%
Cucumber	<i>T. viride</i>	Improves NUE by 5.9%
Tomato	<i>T. harzianum</i>	Improves NUE by 2.5%
Tea	<i>T. harzianum</i>	Improves NUE by 65%
Rice	<i>Azolla microphylla</i> , BGA	Increases grain and straw yield
Wheat	<i>Azotobacter</i> , <i>Pseudomonas</i>	Improves biological N-fixation and growth parameters
Maize	<i>Pseudomonas fluorescens</i> , <i>Enterobacter radicincitans</i>	P-uptake and yield
Barley	N-bio-fertilizers: Nitroksin, Nitrokara P-bio-fertilizers: phosphate Barvar 2, biozarr	Seed yield
Mustard	<i>Azotobacter chroococcum</i> , <i>Bacillus</i> sp.	Improves yield attributing parameters
Wheat	<i>Azospirillum brasilense</i> , <i>Streptomyces</i> sp.	Higher nutrient uptake in grains

Source: Singh et al. (2017).

Numerous experimental evidences, reported positive crop response in case of SRFs as compared to conventional urea in rice. Nitrogenase inhibitors not only save costly inputs but also duration of NH₄⁺ in the soil increases. In India, huge money is being spent every year for purchasing either finished product or ore, there is a need for adoption of SRFs on mainstream agriculture. The major drawbacks need to be addressed are (a) making economically acceptable for the farming community by reducing

production cost or imposing subsidy to whole range of products starting from SRFs to bio-fertilisers; (b) development of indigenous technology; (c) creating awareness among the farming community regarding negative impact of conventional urea in the existing agricultural network. The concept of organic farming which insists on organic input and organic products is also not tenable as most of the biochemical and metabolic reactions which support life systems are based on chemical reactions and energy

Table 3. Sustainable weed management strategies

A. Cultural approaches: Cultural approaches ensure better field and soil management. Sustainable nutrient and water management, better irrigation facility development and cropping system managements are the key to get maximum benefit.	
I. Proper crop stand	VI. Planting techniques
II. Green manure crops	VII. Seed rate
III. Intercropping	VIII. Water management
IV. Selection of competitive cultivars	IX. Cover/smother crops
V. Crop establishment methods	X. Nutrient management
XI. Crop rotation	
B. Physical methods of weed management: Use of physical forces like manual or mechanical is the principle of this technique. Summer and off-season ploughing are found to be highly effective in managing weeds.	
I. Soil solarisation	III. Use of weeders
II. Hand pulling and digging	IV. Burning and mulching
C. Biological approaches: Biological weed controls means use of living organisms like insects, fungi, pathogen to control the invasive species. Usually the biological control agents are of the same origin that of weed species. Control of <i>Parthenium hysterophorus</i> were some of the pioneering work of biological measures of weed control.	
I. Allelopathic plants	II. Herbicide resistant plants
III. Bio-fertilisers	
D. Integrated weed management (IWM): IWM includes more than one method of control, viz. seed purity, crop varieties, spacing and methods of planting, cultivations, soil solarisation, intercropping, crop rotation, water management, manure application, biological control and herbicides. Overall frame work for IWM is presented in Fig. 3.	

based regulations. However, crop specific long term, multi-location field experiments should be carried out with different organic manures/bio-fertilisers/SRFs to get concrete evidences and spread awareness among the farming community.

Herbicides

In modern day farming, due to faulty agricultural practices, weeds have become a widespread menace and any single control measure may not solve the problem. So depending upon agro-ecologies, ecologically and economically best management practices should be integrated to get the best results. Generally, sustainable weed management can be categorised in three possible ways. These are briefly outlined in Table 3.

Use of non-chemical method of weed control is hardly in practice in modern day farming and farmers mostly rely on chemical weed control method. Present day purification and extraction strategies contentedly paved the way for exploration of bio-herbicidal compounds. Bio-herbicides include corn gluten meal (anti-germination effects on weeds), acetic acid (diluted 20% solution), fatty acids (pelargonic acid), essential oils (e.g. pine oil, citronella oil, clove oil and lemon grass oil etc.), microbial compound (bialaphos- a fermentation product of *Streptomyces hygroscopicus* L.) and brassicaceae seed meal. Novel strategies like nano-adjuvants, remote sensing and image processing, machine vision analysis, functional genomics, RNA interference (RNAi) technology and plant genome editing are the strategies to think upon. These novel strategies are helpful in distribution and application of applied herbicides and also, overcome the field based problems hampering the practical applications of bio-compounds. In the end it can be said that herbicides are the most cheap and reliable method of weed control but, taking

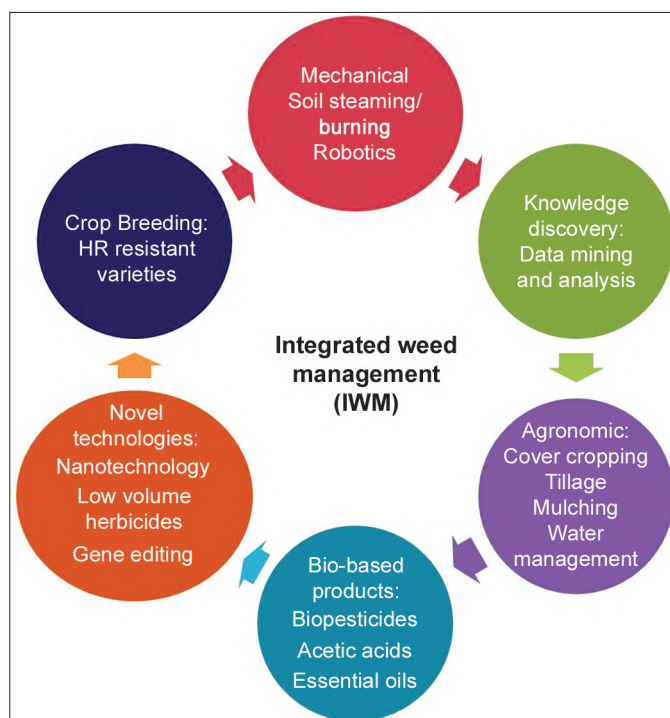


Fig. 3. Overall concept of Integrated Weed Management (IWM).

environmental consequences into account of the formers, need of more eco-friendly and practical methods are coming forward. Integrated strategies encompassing all sorts of management options along with novel breeding strategies based spatio-temporal variations should be brought back in practices.

Insecticides

Like fertilisers and herbicides, insecticides do harm living organisms a lot. Pesticides upon application move to the ground water resources via leaching and surface run-off and as time progresses subjected to

different reactions like hydrolysis, photolysis and chemisorption and microbial degradation. As an outcome, pesticides or their metabolites can reach the water bodies, bio-accumulated in the food-chain and persist for longer duration. Concentrations of different pesticide residue in the groundwater of different Indian states are presented in Table 4.

Since the beginning of the green revolution, use of agro-chemicals enhanced the production capacity but, at the cost of environmental degradation. So, in this scenario, non-polluting pest management concept step forward and botanicals are the course of action for doing so. The

main botanical pesticides are essential oils produced as secondary metabolites in plants. These oils play important role in the life cycle of plants, acting as defences against pathogen and herbivore attacks, or attracting pollinators and seed disseminators. List of few botanicals with their mode of actions are presented in Table 5.

Sustainability in botanicals remains the major drawback for large scale application and higher use efficacy. Higher cost, longer registration process, limited scale of production of essential oil producing plants, immediate effects are the

Table 4. Pesticide concentration of ground water in different parts of India

State	Areas	Pesticides	Concentration
Uttar Pradesh	Unnao	Chlordane	7.2 ng/l
	Kanpur	α -HCH	0.189 μ g/l
Rajasthan	Jaipur (Summer)	Heptachlor epoxide	0.609 mg/kg
	Jaipur (Winter)	Aldrin	0.350 mg/kg
Delhi	-	α -HCH	0.005–0.009 μ g/l
	-	β -HCH	0.01–0.015 μ g/l
Andhra Pradesh	Hyderabad (South)	Lindane	0.6812–0.7014 μ g/l
	Hyderabad (East)	β -Endosulfan	0.2896–0.8698 μ g/l
Maharashtra	Nagpur	Dicofol	0.411 ppb
	Bhandara	γ -HCH	0.003–0.136 ppb
Haryana	Ambala	Σ HCH	7.1–298.6 ng/l
	Gurgaon	Σ HCH	8.4–288.6 ng/l
West Bengal	Sonarpur, Kolkata	Aldrin/dieldrin	0.01–0.03 μ g/l
	Palta, Kolkata	Heptachlor	0.01–0.01 μ g/l

Source: Agarwal et al. (2015)

Table 5. List of bio-compounds extracted for sustainable pest management

Compound	Plant species	Mode of action
Pyrethrin	<i>Chrysanthemum cinerarifolium</i>	Agonists of voltage-sensitive sodium channels (GABAergic system)
Thujone	<i>Artemisia absinthium</i>	Reversible modulator of GABAA receptors
Thymol	<i>Thymus vulgaris</i>	Stimulates GABAA receptors
Azadirachtin	<i>Azadirachta indica</i>	Inhibits the activity of acetylcholinesterase
Linalool	<i>Aniba roseaodora</i>	Competitive and reversible inhibition of acetylcholinesterase activity
Carvacrol	<i>Origanum vulgare</i>	Binds to nicotinic acetylcholine receptors
Eugenol	<i>Syzygium aromaticum</i>	Stimulates octopamine receptors
Menthol	<i>Mentha piperita</i>	Positive allosteric modulator of the GABAA receptor
Citronellal	<i>Cymbopogon nardus</i>	Antagonist of octopamine

Source: Campos *et al.* (2018)

primary reasons for unsuccessful venture of botanical pesticides. Therefore, role of nanotechnology come into light and nano-encapsulation of pesticides solve the problems. Nano-encapsulations augment sustained release via warding off premature degradation from photolysis, high temperature and biodegradation. Many nano-formulations loading botanical pesticides have proven biological activity against pre- and post-harvest crop pests. Due to the improvement in the quality and cost-effectiveness of nano-technological products and processes, as well as the social benefits added to this technology, companies have developed strategic business plans and policies in

research, development and innovation with the aim of bringing industrial competitive advantages in several areas. This is one of the keys to the success of integrated pest management, as both nanotechnology and bio-pesticides are tools that can be used in the development of sustainable agriculture with the aim of providing significant improvements in food quality and safety, human health, and environmental preservation.

SUMMARY

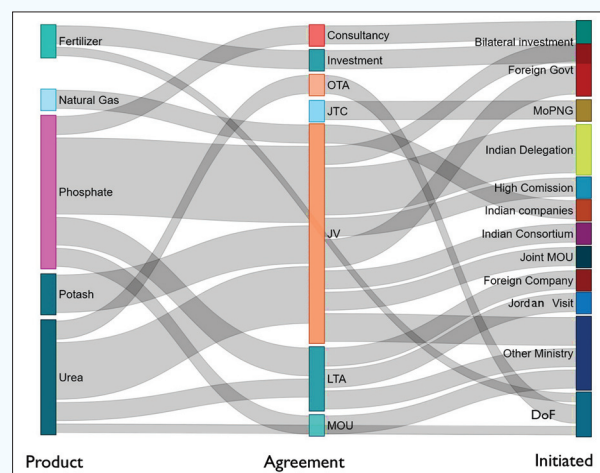
Application of synthetic agrochemicals remains the principal technique for the control of pests and diseases in conventional agriculture, but it is acknowledged that

agricultural production will be seriously threatened if sustainable techniques are not adopted. Many studies have shown that the intensive use of synthetic chemicals leads to irreversible damage to the structure and ecology of soil and living organisms. In present day intensive agriculture, it is not possible to leave the use of chemicals completely. Hence, integrated approaches like tailing down the synthetic load and substitute the same with botanicals, control/sustained release materials, nano-compounds along with mechanical, agronomical and biological measures should be amalgamated to protect our precious natural resources. Pesticides or fertilisers due to their complex reactions easily gets bio-accumulated and enter into food chain so, our practices should prioritise to reduce the risk of accretion. More field based long term studies should be done on multi location basis to get concrete evidences of pest control. Research institutes and government organisations should come forward and work together for promoting the products and creating awareness in the farming communities.

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Framing policy for overseas acquisition of raw material by the Indian fertilizer companies

Study for Department of Fertilizers, Ministry of Chemicals and Fertilizers, on Framing policy for overseas acquisition of raw material by the Indian fertilizer companies and role of the government was undertaken. The study looked into (i) the overall fertilizer's availability scenario, India's import dependence both at present and in future likely scenario, (ii) import mechanism and international market scenario of import of fertilizers, their raw materials, feedstock, natural gas and intermediaries, (iii) comparable policies/policy framework of any other department of GOI and international practices, (iv) develop a policy framework that aims at encouraging international co-operation and (v) possibility and desirable of the revival of either reviving UVL or SPV for international co-operation. The study discussed various approaches such as Joint Venture, Long Term Agreement and direct market purchase for acquiring raw materials and finished products of fertilizers. The study also discussed policies for supporting and encouraging these approaches. The study recommended that Department of Fertilizer should play a facilitator role for both public and private entities (non-discriminatory) for exploring these approaches. (Source: ICAR Annual Report 2020)



Note: OTA– Offtake Agreement, JTC– Joint Trade Commission, JV– Joint Ventures, LTA– Long Term Agreement, MoU– Memorandum of Understanding, DoF– Department of Fertiliser. MoPNG– Ministry of Petroleum and Natural Gas.