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Review Article

Status and use of pesticides in forage crops in India

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The Indian livestock population is huge. Most (99%) of the livestock owners still follow traditional animal husbandry practices and graze their livestock, especially small ruminants, on natural pastures where no pesticides are used. In order to feed the ever-increasing livestock population, efforts are being made to increase quality fodder productivity from limited land resources. In such situations, pesticides play an important role by minimizing the loss of green fodder due to disease and pest attack. In countries such as Canada, Israel, the UK, and other European countries, pesticides have been registered for forage crops; in India, however, although pesticides have been registered for cultivable grain, horticultural and cash crops, *etc.*, there are no registration guidelines or authenticated information regarding pesticide use with regard to forage crops. Hence, there is a need to take necessary steps in this direction, keeping in view the importance of fodder and livestock in the country. In this review, detailed aspects of the status and use of pesticides in forage crops in India are discussed.

Keywords: pesticides, forage crops, livestock, India.

Electronic supplementary material: The online version of this article contains supplementary material (Supplemental Table S1–S4), which is available at http://www.jstage.jst.go.jp/browse/jpestics/

Introduction

India accounts for around 15% of world's livestock population and 2% of the world's total geographical area, which indicates enormous biotic pressure on the land. The Indian livestock population is more than 512 million heads at present and is expected to rise at a rate of 0.55% per year in the coming years, reaching about 780.7 million by the year 2050.[1] The present production of milk and meat is about 155 million tons and 7 million tons, respectively, whereas demand for milk and meat will be around 400 million tons and 14 million tons, respectively, in the year 2050.[2] Thus, in order to sustain this vast livestock population and to meet the growing demand for milk and meat, forage crops will certainly play a very important role. There is a wide scope of pesticide usage to improve forage crop productivity. The per hectare consumption of pesticides in India is amongst the lowest in the world and stands at 0.6 kg/ha against 5–7 kg/ha in the UK and 13 kg/ha in China. In India, around 40% of the total cultivated area is treated with pesticides, and approximately 65–70% of the cultivated area treated with pesticides is irrigated. On average, 65% of the area for fiber crops in India is treated with pesticides, followed by treatment for fruits (50%), vegetables (46%), spices (43%), oilseeds (28%), and pulses (23%) (Fig. 1).[3] However, there is no clear information on the extent of pesticide use in forage crops in India. In this review, we attempted to collect and compile information regarding the status of pesticide use in different forage crops in India from various available sources.

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1. Forage crops in India

The agricultural sector remains the backbone of India's economy, accounting for about 15% of the country's Gross Domestic Product. However, it must be understood that Indian agriculture is highly monsoon dependent, and irrigation facilities are available to only 45%, or 64 million ha, of the 142 million ha of net sown area. Out of the total cultivated area, only 4% of the land in India is used for forage production, a proportion that has remained stagnant for the last four decades.[4] The cultivated forage crops include many plant species, such as sorghum, maize, pearl millet, cowpea, guar, berseem, lucerne, oats, and several grasses. The status of grasslands is highly variable, and the area and productivity are decreasing because of increasing human pressure for the cultivation of food grain crops and the increase in animal population, including wild animal population, which results in overgrazing and ultimately shrinking the grasslands area. Pasture areas have been reduced from about 70 million ha in 1947 to just about 38 million ha in 1997, and the major portion of this loss is from village common lands.

1.1. Area and production

Forage crops are plant species cultivated and harvested for feeding animals, in the form of forage (cut green and fed fresh), silage (preserved under anaerobic conditions), and hay (dehy-

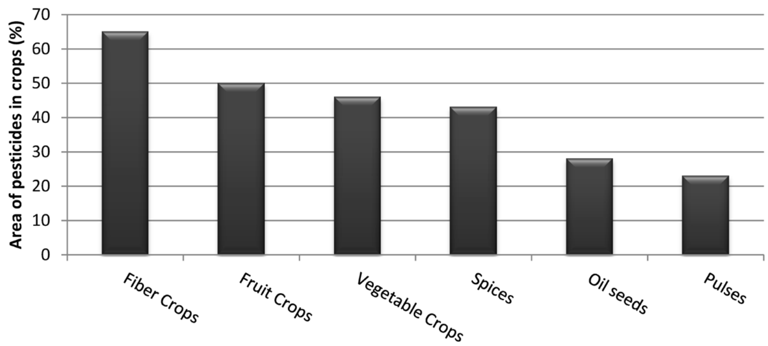

Fig. 1. Pesticides application area of each crops (Source: FICCI, 2016)[3]

drated green fodder). The total area under cultivated fodder is 8.3 million ha on an individual crop basis. Sorghum (among the kharif crops, with an area of 2.6 million ha) and berseem, or Egyptian, clover (among the rabi crops, with an area of 1.9 million ha) occupy about 54% of the total cultivated fodder crop area[5)] (Table 1). The area under fodder crops has remained almost static for the last three to four decades. This is mainly for want of proper land cover data reporting. However, the area under fodder crops has increased in peri-urban areas that have been developed as milksheds under intensive dairy production systems during the past years. The area under permanent pasture has been declining for years, and that trend could continue into the future. Due to overgrazing, pasture productivity has also been declining.

1.2. Major biotic stresses affecting forage crops

India's livestock population is one of the largest in the world, at around 529.7 million, and is expected to grow at a rate of 0.55% in the coming years. The average yield of milk and meat from animals in India is 20–60% lower than the global average. Moreover, their production potential is not completely realized because of various constraints related to feeding, breeding, health, and management. The deficiency of feed and fodder (50.2%) accounts for half of the total loss, followed by the problems of breeding and reproduction (21.1%), disease (17.9%), and management (10.5%). There is an urgent need to meet the demand of the increasing number of livestock and to enhance their productivity, for which the availability of feed resources must be increased. Forage-based economical feeding strategies are required to reduce the cost of quality livestock product, as the feed alone constitutes 60–70% of the milk-production cost. The increasing livestock population places great pressure on the total available feed and fodder, as land available for fodder production has been decreasing. At present, the country faces a net deficit of 35.6% in green fodder, 11% in dry crop residue, and 44% in concentrated feed ingredients. At the current level of growth in forage resources, there will be a 18.4% deficit in green fodder and a 13.2% deficit in dry fodder in the year 2050, as the livestock population is increasing concurrently. To decrease the net deficit of green fodder, the supply should grow at 1.7% annually, and efforts are underway in this direction *via* the adoption of high-yield fodder varieties, improved fodder production, and protec-

Table 1. The area and productivity of fodder crops grown in India[a)]

Crop	Botanical name	Area ('000 ha)	Green fodder productivity (t/ha)
Berseem (Egyptian clover)	*Trifolium alexandrinum*	1900	60–110
Lucerne (Alfalfa)	*Medicago sativa*	1000	60–130
Senji (Sweet clover)	*Melilotus indica*	5	20–30
Shaftal (Persian clover)	*Trifolium resupinatum*	5	50–75
Metha (Fenugreek)	*Trigonella foenum-graecum*	5	20–35
Lobia (Cowpea)	*Vigna unguiculata*	300	25–45
Guar (Clusterbean)	*Cyamopsis tetragonaloba*	200	15–30
Rice bean	*Vigna umbellata*	20	15–30
Jai (Oat)	*Avena sativa*	100	35–50
Jau (Barley)	*Hordeum vulgare*	10	25–40
Jowar/Chari (Sorghum)	*Sorghum bicolor*	2,600	35–70
Bajra (Pearl millet)	*Pennisetum glaucum*	900	20–35
Makka (Maize)	*Zea mays*	900	30–55
Makchari (Teosinte)	*Zea mexicana*	10	30–50
Chara sarson (Chinese cabbage)	*Brassica pekinensis*	10	15–35

[a)] Source: Handbook of agriculture, (2013)[5)]

tion technologies. However, additional efforts are required to increase the productivity of forage crops from the limited land area to ensure future fodder security.[6)]

In addition to the above-mentioned problems, pests and diseases can have a significant effect on the establishment, yield, and longevity of grass and forage crops. As with other agricultural crops, forage crops are subject to damage from pests and diseases that hamper crop establishment, impair forage quality, and reduce green fodder and seed yield. Pests and diseases also cause indirect losses, such as reduced nodule formation in legumes, eventually resulting in the reduction of nitrogen fixation capacity. Plant–pathogen (toxin-producing fungal pathogens) interaction could lead to the production of toxins (mycotoxins such as aflatoxins, zearalenone, and vomitoxin), which can adversely affect animal health if consumed. Mycotoxins have significant economic and commercial impacts, as both the productivity and nutritive value of the infected cereal/forage are affected by them.[7)] The economic impact of reduced animal productivity, increased incidence of disease, damage to vital organs, and interference with reproductive capacity is far greater than death due to mycotoxin poisoning.[8)] Many diseases and insect pests (Table 2) have been associated with significant damage in forage crops grown in various parts of the country. Plant protection in general has an obvious role to play in meeting the growing demand for food quality and quantity.[9)] In order to sustain any fodder production system, biotic stresses such as insect pests, plant pathogens, and plant parasitic nematodes should be contained below a threshold level. In addition to high dependency on monsoons and limited irrigation facilities, direct yield losses ranging between 20 and 40% from pathogens, animals, and weeds make the agriculture situation in India even worse.[10–13)] The quantitative and qualitative losses caused by these biological stress factors in major forage crops have been reviewed previously.[14)] In order to meet the growing demand borne out of increasing livestock population, crop productivity and efficient utilization of arable land become essential factors. In such circumstances, pesticides play a vital role by curtailing pest damage, which in turn enhances productivity.

While pests are not considered to have great importance with regard to forage crops, factors such as climate change could lead to epidemics of particular pests and diseases in the near future, which could cause significant losses in forage production and aggravate the present deficit of green and dry fodder. The use of pesticides in forage crops has certain constraints, such as low feasibility due to high cost/benefit ratio, risk of pesticide residue accumulation in the food chain through milk and milk products, and even direct toxicity to livestock.[15)] In spite of these facts, farmers still opt for pesticides, as other pest management practices may not produce instant results. However, information on the extent of pesticide use in forage crops remains obscure.

2. Role of pesticides in pasture management

Pesticides have played an important role in the management of pasture and forage crop pests. Often, pesticides are applied to pastures or forage crops to protect vulnerable seedlings; however, established crops and pastures have also been treated with pesticides to reduce resident and damaging pest populations. The effective management of many pastures and forage crop pests poses a range of challenges for farmers:

- The damaging larval stages are often concealed (in soil, stems, root nodules, and seeds) and are difficult to detect.
- Failure to detect insect and other pests can result in poor pasture or forage crop establishment and production, thereby affecting the capacity to support livestock.
- Some pests occur sporadically and cause large outbreaks, which are often invoked by suitable weather conditions, and require immediate and rapid action to minimize pest damage.
- For a range of pests, few alternative (non-insecticide) controls are available, or if they are available, their effectiveness may be limited, or they may not be applicable at a particular time, *e.g.*, some cultural controls. Furthermore, they may not be sufficiently fast acting to contain pest outbreaks or offer sufficient protection to seedlings.

3. Current status of registered pesticides for crops

The Central Insecticides Board and Registration Committee (CIBRC) and the Food Safety and Standards Authority of India (FSSAI) are the two bodies that deal with pesticide regulations in India. The CIBRC, established in 1968 under the Department of Agriculture and Co-operation of Ministry of Agriculture, is responsible for advising central and state governments on technical issues related to the manufacture, use, and safety of pesticides.[16)] The registration committee is responsible for registering pesticides after verifying manufacturer or importer claims about the efficacy and safety of the pesticides.[17)] The FSSAI is responsible for recommending tolerance limits of various pesticides in food commodities. The FSSAI was established under the Food Safety and Standards Act of 2006.[18)] The State Agriculture Universities, State Agriculture Departments, and other institutions related to specific crops, such as the National Horticulture Board and the Spices Board of India, make another set of recommendations for agricultural practices, including the use of pesticides. These recommendations are important, considering the local needs of the states and research about specific crops and their diseases and insects.

The farmers of India, who lack a technical understanding of pesticides, their uses, and safety aspects, are vulnerable to misguidance, which increases the chance of unnecessary and inappropriate use of pesticides. The ever-increasing population of India also puts constant pressure on agriculture to improve productivity. The misuse of pesticides in such a scenario is very likely. The harmful effects of pesticides are now established worldwide. Farmers and agricultural laborers are the direct users of pesticides and are more likely to be affected by the acute toxicity of pesticides. However, around 550 crops grown in India do not have label claims to all these pesticides (http://cibrc.nic.in/). India is the fourth largest global producer of pesticides after the USA, Japan, and China. Approximately 50% of the demand

Table 2. Major Diseases and insect-pests of important fodder crops and grasses in India

Berseem (*Trifolium alexandrinum*)	
Root rot complex	*Rhizoctonia solani, Fusarium semitactum, Tylenchorhynchus vulgaris*
Stem rot	*Sclerotinia trifoliorum*
Pod borer	*Helicoverpa armigera*
Stunt nermatode	*Tylenchorrhyncus vulgaris, T. mashhoodi*
Oats (*Avena sativa*)	
Leaf blotch	*Helminthosporium avenae*
Crown rust	*Puccinia coronata*
Stem rust	*Puccinia graminis avena*
Sclerotial wilt	*Sclerotium rolfsii*
Aphids	*Rhapalosiphum maidis*
Cyst nematode	*Heterodera avenae*
Cowpea (*Vigna unguiculata*)	
Root rot	*Macrophomina phaseolina*
Mosaic	Cowpea mosaic virus
Flea beetles	*Monolepta signata*
Semilooper	*Plusia nigrisigna*
Leaf hoppers	*Empoasca kerri*
Root knot nematode	*Meloidogyne incognita*
Reniform nematode	*Rotylenchulus reniformis*
Pigeon pea cyst nematode	*Heterodera cajani*
Lucerne (*Medicago sativa*)	
Downy mildew	*Peronospora trifoliorum*
Rust	*Uromyces striatus*
Common leaf spot	*Pseudopeziza medicagenis*
Lucerne weevil	*Hypera postica*
Aphids	*Acyrthosiphon pisum and Theriophis trifolii f. maculata*
Stem nematode	*Ditylenchus dipsaci*
Lesion nematode	*Pratylenchus penetrans*
Root-knot nematode	*Meloidogyne spp.*
Clover cystnematode	*Heterodera trifolii*
Sorghum (*Sorghumbicolor*)	
Anthracnose	*Colletotrichum graminicola*
Sooty stripe	*Ramulisporia sorghi*
Zonate leaf spot	*Gloeocercospora sorghi*
Downy mildew	*Scleropsora sorghi*
Shoot fly	*Atherigona varia soccata*
Stem borer	*Chilo partellus*
Aphids	*Rhapalosiphum maidis*
Sorghum mildge	*Contarinia sorghicola*
Army worm	*Mythimna separata, Spodoptera exigua*
Sorghum cyst nematode	*Heterodera sorghi*
Maize (*Zea mays*)	
Brown stripe downy mildew	*Scleropthorarayssi* var. *zeae*
Turcicum leaf blight	*Helminthosporiumturcicum*
Maydis leaf blight	*Dreschsleramaydis*
Bacterial stalk rot	*Erwiniacarotovora* var. *zeae*
Shoot fly	*Atherigona varia soccata*
Stem borer	*Chilo partellus*
Aphids	*Rhapalosiphum maidis*
Maize cyst nematode	*Heteroderazea*
Pearl millet (*Pennisetum glaucum*)	
Downy mildew	*Sclerospora graminicola*
Ergot	*Clavicepsfusiformis*
Smut	*Tolyposporiumpenicillariae*
Rust	*Pucciniapennisetl*
Shoot fly	*Atherigona varia soccata*
Stem borer	*Chilo partellus*
Blister beetle	*Zonabrispustulata*
Range grasses	
Rust	*Puccinia and Uromyces* spp.
Leaf spots	*Curvularia, Pyricularia, Scrossporium, Colletotrichum* spp.
Grasshoppers	*Hieroglyphus nigrorepletus, Catantops pinguis, Oedaleus abruptus, Chrotogonus trachypterus, Aelopus tamulus, Colemania* sp., *Oxya* sp., *Locusta migratoria, Attractomorpha* sp.
Cyst nematode	*Heterodera avenae, H.sorghi, H.zeae, H.mothi, H.graminis, H.cyperi, H.sacchari, H.delvi*
Root-knot nematode	*Meloidogyne* spp.
Seed gall nematode	*Anguina* spp.
Lesion nematode	*Pratylenchus* spp.
Stunt nematode	*Tylenchorhynchus* spp.
Lance nematode	*Hoplolaimus* spp.
Spiral nematode	*Helicotylenchus* spp.

Source: Saxena *et al.*, (2013).[15)]

comes from domestic consumers and the rest from exports. At present, the per hectare consumption of pesticides in India is among the lowest in the world and stands at 0.6 kg/ha against 5–7 kg/ha in the UK and 13 kg/ha in China. However, in India, the problem is a high level of pesticide residue in food products, and consignments have often been rejected at foreign ports. The residue problem in food products is mainly due to the persistent use of pesticides as well as to their injudicious use. Following "Good Agricultural Practices" is an option that implies a thorough understanding about the use of various pesticides in an effective and eco-friendly way. During the last five years, the incidence of pesticide residues in various commodities has increased from 1.2 to 2.6%. However, there is no clear understanding of the usage and effect of pesticides on forage crops in India

4. Current pesticides approved for use in grass and forage crops

Overall, the Indian pesticide market is characterized by a wide range of active substances registered (Table S1) or restricted/banned/refused registration (Tables S2–S4) for use in various

crops. While searching the available literature, it came to our attention that there is no recommended pesticide, as such, for forage crops. A few pesticides that are used on a large scale on cereals, pulses, and other crops, have "off-label" approval for use on grasses, legumes, and other fodder crops in India (Table 3). On the other hand, for crops such as sorghum, pearl millet,

Table 3. Approved uses of registered pesticides on grains cum fodder crops in India[a)]

S.N.	Name of pesticide	Forage crop	Common name of the pest and diseases
1.	Carbaryl	Sorghum	Aphid, Earhead midge, Hoppers, Stem borer
		Maize	Stem borer, Shoot fly
2.	Carbofuran	Barley	Aphid, Jassids, Cyst nematode
		Bajra	Shoot fly
		Sorghum	Shoot fly, Stem borer
		Maize	Stem borer, Shoot fly, Thrips
3.	Dimethoate	Bajra	Milky weed bug
		Maize	Stem borer, Shoot fly
		Sorghum	Midge
4.	Imidacloprid	Sorghum	Shoot fly
		Pearl millet	Shoot fly and termites
5.	Malathion	Sorghum	Earhead midge
6.	Monocrotophos	Maize	Shoot fly
7.	Oxydemeton–Methyl	Maize	Shoot fly
		Sorghum	Shoot fly
8.	Phenthoate	Sorghum	Red spider mite, Pink mite, Purple mite, Scarlet mite
9.	Phorate	Bajra	Shoot fly, White grub
		Barley	Aphid
		Maize	Shoot fly, Stem borer
		Sorghum	Shoot fly, Aphids, White grub
10.	Phosalone	Barely	Aphid
		Sorghum	Ear head midge
11.	Quinalphos	Sorghum	Stem borer, Mite, Shoot fly, Earhead bug, Earhead midge
12.	Thiamethoxam	Sorghum	Shoot fly
		Maize	Stem Fly
13.	Thiamethoxam+Lambda cyhalothrin	Maize	Aphid, Shootfly, Stem borer
14.	Carbendazim	Barley	Loose smut
15.	Carboxin	Barley	Loose smut, Covered smut
16.	Mancozeb	Maize	Leaf blight, Downy mildew
		Jowar	Leaf spot
17.	Metalaxyl-M	Pearl millet	Downey mildew
		Sorghum	Downey mildew
		Maize	Sorghum downy mildew, Sugarcane downy mildew, Phillippine downy mildew, Browny stripe downy mildew
18.	Sulphur	Beans	Powdery mildew
		Sorghum	Mites, Grain Smut
		Cowpea	Powdery mildew
19.	Thiram	Maize	Seedling blight
		Barley	Leaf stripe
		Sorghum	Loose smut, Seedling blight
20.	Zineb	Jowar	Red leaf spot, Leaf spot, Leaf blight
		Maize	Leaf Blight
		Bajra	Blast
21.	Azoxystrobin+Difenoconazole	Maize	Blight & Downey Mildew
22.	Metalaxyl+Mancozeb	Pearl millet	Downy mildew

[a)] Source: CIBRC (2017).[16)]

Table 4. Few examples of *MRLs* of pesticides on feed/forage crops as recommended by CODEX[a]

Pesticide	Fodder crop	Maximum residue limit[b] (mg kg^{-1})
Benzovindiflupyr (F)	Barley straw and fodder, Dry; Oat straw and fodder, Dry Rye straw and fodder, Dry; Triticale straw and fodder, Wheat straw and fodder) Peanut fodder	15 (dw)
	Pea hay or fodder, dry	8 (dw)
Bixafen (F)	Barley, straw and fodder; Rye, straw and fodder; Wheat, straw and fodder	20 (dw)
Chlorantraniliprole (I)	Straw, fodder (dry) and hay of cereal grains and other grasslike plants (except corn and rice).	30 (dw)
Fluazifop-P-butyl (H)	Bean fodder	7
	Soya bean fodder	4
	Fodder beet	0.5
Flupyradifurone (I)	Alfalfa hay (dry weight)	30
	Pea hay (dry weight)	50
	Straw and fodder, dry of cereal grains (dry weight)	40
Flonicamid (I)	Wheat straw and fodder	0.3
Imazethapyr (H)	Clover hay or fodder	1.5 (dw)
	Maize fodder	0.1
	Rice straw and fodder, dry	0.15
Pendimethalin (H)	Alfalfa, fodder	4 (dw)
	Bean fodder	0.3 (dw)
	Hay or fodder (dry) of grasses	2500 (dw)
Pinoxaden (H)	Barley straw and fodder, dry; Wheat straw and fodder, dry	3 (dw)
Saflufenacil (H)	Alfalfa fodder, dry	0.06
	Hay or fodder (dry) of grasses	30
	Barley straw and fodder, dry; triticale straw and fodder, dry; wheat straw and fodder, dry	10
Spiromesifen (I)	Maize fodder dry	6
Penthiopyrad (F)	Maize fodder (dry)	10

[a] Source: JMPR Pesticide Residues in Food 2016; Joint FAO/WHO Meeting on Pesticide Residues, Report (2016)[20]
[b] dw: dry weight basis; I: insecticide; F: Fungicide; H: Herbicide

and maize, which are used both as food and fodder crops (dual-purpose crops), there are pesticide recommendations and maximum residue limits. In India, berseem, or Egyptian, clover (*Trifolium alexandrinum*) continues to be one of the major winter forage crops, and it suffers from diseases such as root and stem rot. Unfortunately, however, there is no single pesticide recommended directly for this so-called queen of forage crops, which suggests the extent to which fodder crops are neglected in India when it comes to the use of pesticides in plant protection.

5. Maximum residue limits (MRLs) for pesticides in forage crops

MRLs for pesticides are the maximum concentrations of residue legally permitted in or on food resulting from the use of pesticides according to good agricultural practice.[19] The MRLs for pesticides may also be applicable to animal feed. In the case of food crops, MRLs are well described, and the values are defined respective to the commodity. A few examples related to the MRLs for pesticides on feed/fodder as recommended by Codex Alimentarius Commission (CAC)[20] are shown in Table 4. However, in India, there is no recommended/fixed MRL of pesticides for forage crops.

6. Pesticide contamination in animal feed and fodder

Some of the ways by which pesticides enter the animal system include chemicals used in treatment to control ectoparasites in animals; the ingredients of concentrated feed such as cottonseed cakes, grains, brans, and pulses; the feeding of contaminated unconventional feed, *i.e.*, vegetable waste from local markets; drifting during spray on other crops; the use of contaminated irrigation water in fodder growing fields; and pesticide dusting in orchards where fodder intervention is conducted. Pesticides from major groups such as organophosphate, organochlorine, and pyrethroid compounds may contaminate the feed.[21] Although pesticides are potentially toxic to farm livestock, the main focus centers on residue accumulated in animal products destined for human consumption.

7. Reported cases of pesticide residue accumulation in fodder crops and livestock products

About 56.7% of the population in India is engaged in agriculture and is exposed to the pesticides used in agriculture.[22] There is increasing concern about pesticide residue in drinking water, food, livestock, and livestock products. Pesticide residues in livestock generally accumulate in two ways: either through direct

application to animals or through direct application to agricultural and fodder crops.[23] The livestock reared on pesticide-contaminated soils, crops, and fodders may accumulate considerable residues in edible tissues. Animals can accumulate these substances from contaminated feed and water. Moreover, due to the lipophilic nature of pesticides, they easily accumulate in milk and other fat-rich substances,[24] which relates to an indirect source of pesticide accumulation represented by animal-derived products. Endosulfan, an organochlorine insecticide previously used widely in agriculture for the control of various crop pests in India, has been reported to be present as a residue in various green fodders and feed concentrates up to a concentration of 6 ppm.[25–29] However, unlike other organochlorine insecticides, endosulfan apparently does not pass into the milk of cattle when ingested in feed, even at a high concentration for a prolonged period of time. Residues of organochlorine pesticides (OCPs) and endosulfan stereoisomers analyzed in dry and green fodder samples from rural areas of Ambala, Gurgaon, and Hisar (Haryana, India) revealed the persistence of OCP residues in both dry and green fodder samples as total OCPs, and endosulfan was found to be the highest in wheat straw (1.1–1.2 $mg\,kg^{-1}$) from Ambala and Gurgaon, followed by sorghum straw (0.46 $mg\,kg^{-1}$) from Hisar. Moreover, dry fodder samples were found to have higher residue levels than green fodder samples. In the case of green fodder samples, maximum OCP residues of 0.44 $mg\,kg^{-1}$ were found in whole plant samples of sorghum from Gurgaon, followed by pearl millet (0.40 $mg\,kg^{-1}$) from Ambala.[30]

Among various meat products, the greatest contamination was observed in chicken muscle, followed by goat and beef, collected in Lucknow, India.[31] Milk samples from Kumaon and Tarai in the Indian state of Uttarakhand, which were analyzed using an HPLC technique, showed that 4.7% of total milk samples were detected to have chloropyrifos residue above the MRL (0.02 $mg\ kg^{-1}$).[32] In another study, milk and fodder samples around the Musi River belt revealed a dicofol concentration of 0.07 ppm in fodder samples and a dimethoate concentration of 0.13 ppm in milk samples, which were above the MRL values established by the EU and CAC.[33] The increasing presence of pesticide residues in the meat[34] and milk[35–38] is of great concern with regard to ensuring food safety and human health and might be responsible for lack of pesticide recommendations specific to forage-crop protection by pesticide manufacturers and policy makers in India. However, a well-planned strategy involving the use of green pesticides along with good agricultural practices could enable the efficient use of pesticides for forage crops at a time when the country is faced with the challenge of feeding an increasing livestock population from limited land resources. This is possible only by increasing the productivity of fodder crops, in which effort pesticides can play an important role by curtailing serious pest outbreaks that are inevitable in this changing climate scenario.

Conclusions

Although pesticide use in forage crops can cause health problems in animals when exposure is high, such use cannot be neglected in forage crops in today's changing climate scenario, which promotes more epidemics of new and emerging pathogens and insect pests in forage crops. In India, however, there is no working policy for pesticide regulation and safety issues with regard to forage crops. In other countries, such as Canada, Israel, the United Kingdom, and other European countries, in which livestock contribute significantly to economic development, there is a designated pesticide regulatory agency that regulates most pesticide-related matters in forage crops. In India, there is a genuine and urgent need to take steps and implement policies to establish the following:

➤ A forage policy encompassing plant protection chemical research and achieving forage security in combination with food security in the future.

➤ Tolerance limits, safety limits, and acceptable daily intake of pesticides in animal feed and fodder based on large-scale field trials.

➤ Maximum residue limits for pesticides in forage crops.

➤ Environmental risk assessment of the pesticides in a forage-based cropping system.

➤ Legal recommendations for pesticides through the approval of apex pesticides by a regulatory body (CIBRC) against diseases and pests of economic importance in forage crops.

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