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TECHNICAL MANUAL
WEED MANAGEMENT

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PREFACE

Weeds are plants that are an integral part of the natural ecosystem. However, under an agroecosystem, they become unwanted and detrimental to crops, as well as to human interests. Therefore, it is true that a plant may be considered a weed in one place but not in another. Within an agroecosystem, weeds are the most harmful pests in agriculture, causing significant crop yield losses. They also interfere with crop quality, serve as alternate hosts for pests and diseases, and pose problems for both humans and the environment. Estimates indicate that weed-related losses in agricultural production in India contribute to about 33%, which is higher than the losses caused by any other pests or diseases. Therefore, the management of weeds in all agroecosystems is critical to maintaining crop productivity and ensuring food security.

This manual covers various aspects, such as detailed information about weeds, their biology and ecology, classification, the critical period of crop-weed competition, major weeds of Mizoram with illustrations, and herbicide classifications. The manual also provides helpful details on the practical use of herbicides, including application techniques and calibration. It offers detailed information about glyphosate and the fate of major herbicides used in Mizoram. It raises awareness about the invasion of Parthenium in Mizoram and presents eco-friendly ways to manage weeds through intercropping. Furthermore, it includes definitions of important weed terminology and discusses herbicides used in major agricultural and horticultural crops. With such a wide range of topics covered in this manual, we believe it fulfills the requirement for a highly sought-after standard documentation on weed management for Mizoram. It will be beneficial to farmers, students, scientists, and others involved in the field of weed management.

Authors

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We are grateful to the field staff members, Mr. Lalsangkima, Mr. Lalhruaimawia, Mr. Ajay Subba, Mr. G. Kamminliana, Mr. Lalngaiha, Mr. Tommy Lalnunsanga, Mr. Lalthanglura, Mr. C. Lalrinmawia, and Mr. Lalrinchhana, for their contributions in collecting weeds, conducting field experiments, and recording data. The authors are optimistic that this publication will assist the farmers, students, scientists and others working in the sector of weed management.

Errors and omissions, if any, are ours. Although not everyone is included, but we sincerely hope we have included all concerned.

Authors

Abbreviations and Symbols

%	Per cent
@	At a rate of
₹	Rupees
+	Plus
±	Plus or minus used to indicate the precision of an approximation
µ	Microns
a.e.	Acid equivalent
a.i.	Active ingredient
BLW	Board leaved weeds
CAM	Crassulacean Acid Metabolism
cm	Centimetre
CPWC	Critical period of crop-weed competition
cv	Cultivar
d.w	Dry weight
DAE	Days after emergence
DAP	Days after planting
DAS	Days after sowing
DAT	Days after transplanting
DWR	The Directorate of Weed Research
e.g.,	Exempli gratia
EC	Emulsifiable concentrate
ED_{50}	Effective dose 50
EPA	Environmental Protection Agency
et al.	Co-workers
etc	Et cetera
Fig.	Figure
FW	Fresh weight
FYM	Farmyard manure
GM	Genetically modified
GR	Granules
ha	Hectare
hr	Hours

HRAC	Herbicide Resistance Action Committee
IARC	International Agency for Research on Cancer
IPA salt	Isopropyl-amine salt
kg	Kilogram
L	Litre
LAI	Leaf area index
LD_{50}	Lethal dose 50
m^{-2}	Per metre square
mg	Milligram
ml	Millilitre
mm	Millimetre
MSL	Mean sea level
PE	Pre-emergence
PoE	Post-emergence
PPI	Pre-plant incorporation
ppm	Parts per million
SC	Suspension concentrates
SL	Soluble liquid
t	Tonne
USD	United States dollar
USEPA	United States Environmental Protection Agency
viz.	Namely
w/w	Weight by weight
WCE	Weed Control Efficiency
WDG	Water dispersible granule
WG	Water dispersible granules
WI	Weed Index
WP	Wettable power
WSC	Water soluble concentrate
WSE	Weed smothering efficiency
WSL	Water-soluble liquid
WSP	Water Soluble powder
WSSA	Weed Science Society of America
wt.	Weight

CONTENTS

1

Weed: its importance, crop weed competition and classification

"A plant growing where it is not desired"

Weeds are unwanted and undeserved plants that disrupt the utilization of land and water resources further, adversely affecting crop production and human welfare. Thus, a plant out of its place or a plant growing where it is not desired at that time is a weed. It can also be defined as unwanted, pernicious and harmful plants which interfere with agricultural operations, increase labour, add to the cost of cultivation and reduce yield of crops. Weed does not refer to specific species, but the name was suggested as a useless and harmful plant that persistently grows where it is unwanted. Weeds have C, S and R characteristics where C stand for competitiveness, S for stress tolerance and R indicate ruderal habit.

1.1 Crop-weed competition

It indicates competition between crop and weed within a system in response to limited available resources like light, nutrients, moisture and space for their existence.

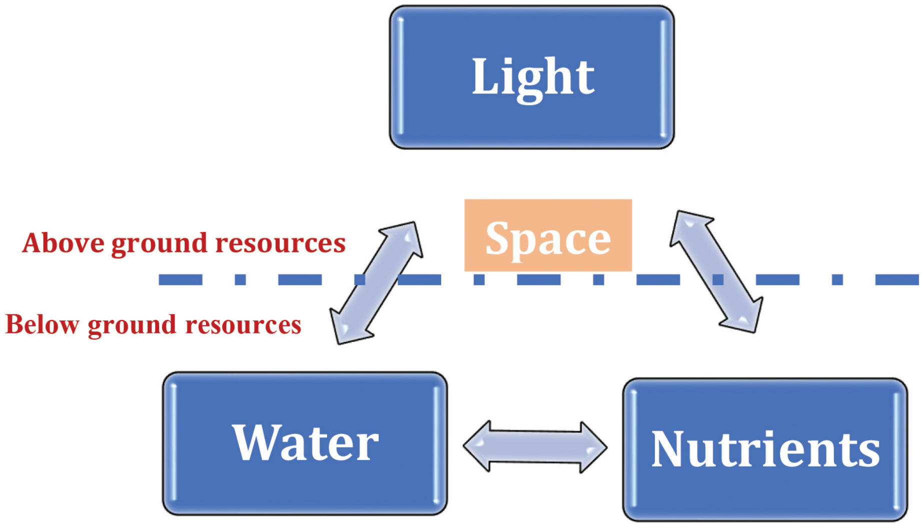


Fig. 1.1 Crop-weed competition for limited resources

1.2 Crop-weed competition occurs in two broad aspects:

a. **Direct competition:** It includes competition for light, nutrient, moisture and space.

b. **Indirect competition:** Competition through exudation and / or allelopathy of one plant and its negative effect on other plant species or sometimes for themselves.

1.3 Critical period of crop-weed competition

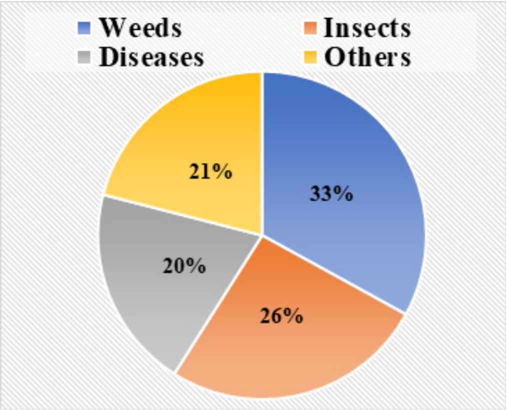
The critical period of crop-weed competition (CPWC) is the shortest time span during crop growth when weeding yields the highest economic returns. This concept suggests that if weeds germinate within the CPWC window, they must be removed / managed in order to prevent them from reducing crop yield. Generally, tall-growing cultivars cover the soil earlier, resulting in a shorter CPWC. Whereas, in the case of upland crops, the CPWC is longer due to their slow growth while for irrigated crops, CPWC is shorter. As a general thumb rule, the first one-third of the crop's life is critical for weed competition.

Table 1.1 The critical period for crop weed competition for major field crops of Mizoram

<table>
<tr><th>Sl. No.</th><th colspan="2">Crop</th><th>CPWC</th><th>Reference</th></tr>
<tr><td>1.</td><td colspan="2">Maize</td><td>7-56 DAE</td><td>Hossain et al., 2020</td></tr>
<tr><td>2.</td><td colspan="2">Upland rice</td><td>Upto 70 DAS</td><td>Shekhawat et al., 2020</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">Lowland rice</td><td>Transplanted</td><td>20 to 40 DAT</td><td rowspan="2">Mukherjee et al., 2008</td></tr>
<tr><td>Wet seeded</td><td>15 to 60 DAT</td></tr>
<tr><td>4.</td><td colspan="2">Soybean</td><td>14-54 DAS</td><td>Walling et al., 2012</td></tr>
<tr><td>5.</td><td colspan="2">Lentil</td><td>22 to 57 DAE</td><td>Smitchger et al., 2012</td></tr>
<tr><td>6.</td><td colspan="2">French bean</td><td>30 to 60 DAS</td><td>Mishra et al., 2000</td></tr>
<tr><td>7.</td><td colspan="2">Field Pea</td><td>20 to 70 DAS</td><td>Singh et al., 2016</td></tr>
<tr><td>8.</td><td colspan="2">Mustard</td><td>15 to 40 DAS</td><td>Yernaidu et al., 2022</td></tr>
<tr><td>9.</td><td colspan="2">Groundnut</td><td>16-66 DAE</td><td>Korav et al., 2020</td></tr>
<tr><td>10.</td><td colspan="2">Ginger</td><td>30-90 DAP</td><td>Wiroatmodjo et al., 1992</td></tr>
<tr><td>11.</td><td colspan="2">Turmeric</td><td>8 to 12 weeks from DAP</td><td>Bharty and Kumar., 2017</td></tr>
</table>

1.4 Losses due to weeds

In the agroecosystem, crops face various biotic and abiotic constraints during production. Among these biotic constraints, weeds cause the highest crop yield losses compared to other insects and pests (**Fig. 1.2**). The extent of yield loss due to weeds depends on multiple factors, such as the seed bank of weeds in the soil, their emergence rate, weed density and type, crop association, soil type, environment, and management practices *etc*. If these weeds are left uncontrolled, they can lead to complete crop yield loss (**Fig. 1.3**).



(Anonymous, 2015)

Fig. 1.2 Crop losses due to weeds and other pests in India

Fig.1.3 Performance of crop without weeding

In India, crop yield monetary loss due to weeds was estimated at USD 11 billion per year (Gharde et al., 2018). However, indirect losses from weeds on crops will be much higher like its effect on human and animal health, nutrient and grain quality depletion, losses of biodiversity, *etc*. The average crop yield loss due to weeds is presented in **Table 1.2**.

Table 1.2. Average crop yield loss due to weed

Sl. No.	Crop	Yield losses (%)
01.	Rice	10-100
02.	Maize	30-40
03.	Groundnut	30-80
04.	Pea	10-50
05.	Soybean	10-100
06.	Vegetables	30-40

1.5 Weed biology and ecology

The lack of fundamental knowledge about weed biology and ecology represents the weakest link in our current weed management strategy, as it hampers our ability to develop an effective weed management program. Understanding the biology and ecological requirements of weeds is crucial for comprehending their establishment, growth, reproduction, and life cycle. This knowledge encompasses various aspects such as seed dormancy, germination, growth and development, competitive ability, and reproductive strategies. Additionally, studying weed ecology helps us explore the interaction and interrelationship between weeds and their environment.

1.6 Weed classification

The world is home to approximately 3,50,000 plant species, of which around 2,50,000 are angiosperms, a category of seed-bearing, flowering plants (Gowgani, 1983). Within this group, 250 species are recognized as weeds in both agricultural and non-agricultural systems. However, globally, there are approximately 30,000 plant species categorized as weeds (Anonymous, 2023). Weed classification involves the grouping of weeds based on specific criteria for convenience. Weed taxonomists utilize a system that relies on morphological similarities to categorize different groups of weeds, considering one or more characteristics that distinguish one group from another.

1.6.1 Based on life span (Ontogeny)

1.6.1.1 Annual weeds: Complete their life cycle in a season or year. Annual weeds are grouped into:

- ❖ **Summer annuals:** *e.g., Ageratum conyzoides*, *Euphorbia spp*.
- ❖ **Monsoon annuals:** *e.g., Celosia argentea*, *Commelina bengalensis*.
- ❖ **Winter annuals:** *e.g., Chenopodium album, Avena fatua*.
- ❖ **Ephemerals:** Short-lived annual weed usually 3-4 weeks. *e.g., Phyllanthus niruri*.

1.6.1.2 Biennial weeds: Complete their life cycle in two seasons or years; vegetative growth (1st year / season) and reproductive stage (2nd year / season) *e.g., Daucas carota, Alternanthera pungens, Asphodelus tenuifolius*.

1.6.1.3 Perennial weeds: These plants complete their life cycle over a span of more than two seasons or years, and they exhibit continuous flowering and production of seeds or propagules. Perennial weeds are grouped into:

- **Shallow rooted:** up to 20-30 cm deep. *e.g., Cynodon dactylon*.
- **Deep rooted:** one meter or deeper. *e.g., Cyperus rotundus, Sorghum halepense.*
- **Simple perennial:** Propagated by seed. *e.g., Sonchus arvensis*.
- **Bulbus perennial:** Propagated by bulb and seed. *e.g., Allium spp*.
- **Corm perennial:** Propagated by corm and seed. *e.g., Timothy spp*.
- **Creeping perennial:** Propagated by seed and other parts like runner, rhizome, roots and tuber.

1.6.2 Based on the nature of stem:

1.6.2.1 Woody weed: Having a woody stem with deep roots called brush weed. *e.g., Lantana camara, Prosopis juliflora*.

1.6.2.2 Semi-woody weed: Having a semi-woody stem. *e.g., Abutilon indicum*.

1.6.2.3 Herbaceous weeds: Having green and succulent stem. *e.g., Amaranthus viridis*.

1.6.3 Based on ecological affinities:

1.6.3.1 Dryland weeds: Occurring under rainfed / dryland condition. *e.g., Tribulus terrestris, Argemone mexicana*.

1.6.3.2 Wetland weeds: Occurring under semi-aquatic or water-logged conditions. *e.g., Ammania baccifera, Monochoria vaginalis.*

1.6.3.3 Gardenland weeds: Occurring under irrigated conditions. *e.g., Trianthema portulacastrum, Potulaca oleracea.*

1.6.4 Based on the origin of weeds:

1.6.4.1 Alien / exotic / introduced weeds: *e.g.,* The following plant species have origins in specific regions: *Eichhornia crassipes* and *Alternanthera philexeroides* are originally from South America, *Phalaris minor* is native to North Africa but was introduced to India from North America through food grain, *Parthenium hysterophorus*, *Solanum elaeagnifolium*, and *Xanthium strumarium* have their origins in the USA. *Lantana camara*, although native to Tropical America, was introduced to India from Sri Lanka by the Myna bird.

1.6.4.2 Indigenous / native weeds: *e.g., Sorghum halepense, Cynodon dactylon* and *Echinochloa colonum*.

1.6.5 Based on morphology: Weeds can be classified into different groups based on their morphology, with the most common categories being grasses, sedges, and broad-leaved weeds.

1.6.5.1 Grasses: They are characterized by their long, narrow leaves that typically have parallel veins. They have hollow, round stems called culms, which are usually jointed. *e.g., Cynodon dactylon*, *Phalaris minor*, *Avena fatua.*

1.6.5.2 Broad-leaved weeds: Broad-leaved weeds, also known as dicots, are characterized by their broad, flat leaves that have branching veins. They can vary significantly in appearance, with diverse leaf shapes and flower structures. *e.g., Parthenium hysterophorus*, *Amaranthus viridis*, *Chenopodium album.*

1.6.5.3 Sedges: Sedge weeds have a triangular stem shape and typically grow in moist or wet habitats. Unlike grasses, their leaves are arranged in three rows, forming a distinctive shape called a "sedge triangle" *e.g., Cyperus rotundus*, *Cyperus iria, Cyperus esculentus*.

Table 1.3 Comparison between grasses and sedges

Grasses	Sedges
Stem is hollow except the at nodes	Stem angular and solid
Ligulate	Does not possess ligules
Alternate or opposite leaves	Leaves in whorls around the stem
Family: Gramineae	Family: Cyperaceae
e.g., Cynodon dactylon, *Phalaris minor*	*e.g., Cyperus rotundus*, *Cyperus iria*

1.6.6 Based on cotyledon:

1.6.6.1 Monocots: Weed embryo having single cotyledon. *e.g., Echinochloa colonum*, *Cynodon dactylon, Commelina benghalensis, Monochoria vaginalis, Cyperus* spp*.*

1.6.6.2 Dicots: Weed embryo having two cotyledons. *e.g., Parthenium hysterophorus*, *Lantana camara*, *Chenopodium album*.

1.6.7 Based on photosynthetic pathway: It refers to how they convert carbon dioxide (CO_2) into sugars during the process of photosynthesis. The three main categories based on photosynthetic pathway are C_3, C_4, and CAM weeds.

1.6.7.1 C_3 weeds: C_3 weeds, the most common type, utilize the C_3 photosynthetic pathway. They directly incorporate CO_2 into a three-carbon compound during photosynthesis. These weeds typically thrive in moderate temperature and light conditions. *e.g., Chenopodium album, Phalaris minor and Avena fatua***.**

1.6.7.2 C_4 weeds: C_4 weeds employ the C_4 photosynthetic pathway, which allows them to efficiently capture and utilize CO_2, especially in hot and dry environments. These weeds have specialized leaf anatomy, with the ability to concentrate CO_2 in specific cells, leading to enhanced photosynthetic efficiency. C_4 weeds are often highly competitive and can tolerate harsh conditions. *e.g., Cyperus rotundus*, *Amaranthus viridis*, *Cynodon dactylon.*

1.6.7.3 CAM weeds: CAM stands for Crassulacean Acid Metabolism, a photosynthetic pathway adapted by certain plants to survive in arid or water-limited environments. CAM weeds have specialized mechanisms that allow them to conserve water by opening their stomata and collecting CO_2 during the night, then converting it to organic acids. These acids are used during the day for photosynthesis when the stomata remain closed to reduce water loss. CAM weeds are typically found in desert regions or other dry habitats *e.g., Taraxacum officinale, Opuntia spp.* (Prickly pear cactus).

1.6.8 Based on soil type:

1.6.8.1 Black cotton soils: *e.g., Aristolochia bracteata*, *Amaranthus viridis*

1.6.8.2 Red/light soils: *e.g., Commelina benghalensis*, *Tribulus terrestris*

1.6.8.3 Laterite soils: *e.g., Lantana camara*, *Chromolaena odorata.*

1.6.9 Based on soil pH:

1.6.9.1 Acidophile: *e.g., Rumex acetosella, Pteridium spp,*

1.6.9.2 Basophile: *e.g., Chenopodium album*, *Salsola* spp.

1.6.9.3 Neutrophile: *e.g., Acalypha indica*

1.6.10 Based on association: Based on association, weeds can be classified into three main categories: season-bound weeds, crop-bound weeds and crop-associated weeds.

1.6.10.1 Season-bound weeds: They are found in that particular season irrespective of the crop *e.g., Circium arvense* is a winter perennial. *Phalaris minor and Avena fatua* are winter season annuals. They emerge and thrive during particular seasons and may complete their life cycle within that season.

1.6.10.2 Crop-bound weeds: They usually parasite the host crop partially or fully for their nourishment *i.e.,* parasitism also called as parasitic weeds. Crop-bound weeds are strongly associated with specific crops.

1.6.10.3 Crop-associated weeds: Crop-associated weeds are those that are commonly found in proximity to crops but may not be as strongly bound to a specific crop as crop-bound weeds. They often grow in the same habitats or ecological niches as the associated crop and compete for resources. Crop-associated weeds may include both broad-leaved and grassy weed species. These weeds are crop-specific as they mimic with crop and have specific requirements for microclimate, such as *Phalaris minor* and *Avena fatua* in wheat crops.

❖ **Mimicry:** Weeds look exactly like crops morphologically & complete their life cycle. *Echinochloa colonum* mimics the rice crop. *Avena fatuva (wild oat)* and *Phalaris minor* (canary grass) both mimic wheat.

1.6.11 Special classification: They are differentiated into poisonous, parasitic and aquatic weeds.

1.6.11.1 Poisonous weeds: *Datura fastuosa, D. stramonium* and *D. metel* are poisonous to animals and human beings alike. The berries of *Withania somnifera* and seeds of *Abrus precatorius* are poisonous.

1.6.11.2 Parasitic weeds: They are the weeds that are dependent on host plants in order to survive and complete their life cycle.

❖ Plant which depends – **Parasite** and on which it survives – **Host**

❖ Plant survives solely by association with living host – **Obligate parasite**

❖ Obligate weeds are also called **anthropophytes**

Type of parasitism	Name of weed	Family	Host	Trap (T) & Catch (C) crop	Control measure
Stem parasite					
Total	Cuscuta (Dodder, Vasantvel, Amarvel)	Convolvulaceae	Lucerne, Niger, berseem Chilly	-	Paraquat @ 0.1%
Semi/ Partial	Lorenthus	Loranthaseae	Mango, Tea	-	8.0g $CuSO_4$ + 1.0g 2,4-D
Root parasite					
Total	Orobanche (Broomrape)	Orobanchaceae	Tobacco, Tomato	(T)- Cotton, Mustard, Cowpea (C)- Toria	Imazethapyr 75-100g/ ha PE, Glyphosate 0.1-0.2% at 50 DAP
Semi/ Partial	Striga (Witchweed)	Scrophulariaceae	Sorghum, Maize, Sugarcane	(T)- Sunflower, Cowpea, Cotton, Groundnut (C)- Sorghum & Maize	Atrazine @1.5- 2.0 kg a.i./ha PE 2,4-D @0.5- 0.75 kg a.e./ha PoE

- **Trap crop**: Act as false host *i.e.,* stimulate the parasitic weed for germination but they themselves do not get parasitized.
- **Catch crop**: Stimulate the parasitic weed for germination and get themselves parasitized.

1.6.11.3 **Aquatic weeds:** These are unwanted plants that grow in water and spend at least a part of their life cycle in water. They are grouped into four categories submersed, emerged, marginal and floating weeds.

1.6.11.3.1 **Submersed weeds:** These produce all or most of their vegetative growth below the surface of water and are having true roots, stems and leaves *e.g., Hydrilla verticillata* and *Vallisneria spiralis*.

1.6.11.3.2 **Emerged weeds:** These are rooted in the bottom mud, with aerial stems and leaves at or above the water surface *e.g., Nelumbium speciosum*.

1.6.11.3.3 Marginal weeds: These plants are emerged weeds that can grow in moist shoreline areas with a depth of 60 to 90 cm water *e.g., Typha, Polygonum, Alternanthera, Ipomea* spp*., etc*.

1.6.11.3.4 Floating weeds: They feature floating leaves that can be found alone or in groups on the water's surface. Some of these weeds float freely, while others are rooted in the mud, and their leaves rise and fall as the water level rises or falls *e.g., Eichhornea crassipes, Pistia stratiotes, Salvinia* spp*.*

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2

List of common weeds of Mizoram

Mizoram, located in the eastern extension of the Himalayas, falls within the agro-climatic zones of the "Eastern Himalayan Region." This region is characterized by abundant rainfall, extensive forest cover, significant soil erosion, and occasional floods. Mizoram is geographically divided into three sub-agro climatic zones: the Humid Mild Tropical Hill zone in the western part, the Humid Subtropical Hill Zone in the central area, and the Humid Temperate Subalpine Zone in the eastern region. The state boasts a diverse range of flora and fauna, making it rich in biodiversity.

The residents of Mizoram are known as Mizo, and their primary occupation revolves around farming. In the rural areas, shifting cultivation is the predominant practice, serving as the main source of livelihood and subsistence for the local population. However, one of the significant challenges faced by farmers is weed infestation in their Jhum fields. This issue arises due to a high weed seed bank, challenging physical weed removal, limited mechanization, and minimal use of herbicides. To address this concern, an initiative has been undertaken to document and study the major weeds found in Mizoram (**Table 2.1** and **Fig. 2.1**).

Table 2.1 List of common weeds of Mizoram

Sl. No	Botanical name	Common name	Mizo name	Family
1.	*Achyranthes aspera*	Prickly chaff flower	Buchhawl	Amaranthaceae
2.	*Acmella oleracea*	Toothache plant	An-sa-pui	Asteraceae
3.	*Acmella uliginosa*	Marsh para cress	An-sa-te	Asteraceae
4.	*Ageratum conyzoides*	Goat weed	Vailenhlo	Asteraceae
5.	*Alternanthera philoxeroides*	Alligator weed	Ngha-te-ril(thauchi)	Amaranthaceae
6.	*Alternanthera sessilis*	Sessile joyweed	An-ngharil/ Ngha-te-ril	Amaranthaceae
7.	*Amaranthus spinosus*	Solider weed	Len-hling	Amaranthaceae

8.	*Amaranthus viridis*	Pigweed	Len-hling-hlingnei-lo	Amaranthaceae
9.	*Argemone mexicana*	Mexican/Prickly poppy	Ber-bek	Papavaraceae
10.	*Bidens pilosa*	Beggar's stick	Vawk-pui-thai	Asteraceae
11.	*Blumea lanceolaria*	Chapa	Buar-ze	Asteraceae
12.	*Brachiaria ruziziensis*	Congo grass	-	Poaceae
13.	*Calotropis gigantea*	Giant milkweed	Hnah-pawl	Asclepiadaceae
14.	*Cardamine hirsuta*	Hairy bittercress	Phai-an-tam	Brassicaceae
15.	*Cassia alata*	Candle Bush	Tuihlo	Leguminosae
16.	*Celosia argentea*	Cock's comb	Zam-zo	Amaranthaceae
17.	*Centella asiatica*	Indian pennywort	Lam-bak/ Darbeng-bur	Apiaceae
18.	*Chromolaena odorata*	Siam weed	Tlangsam	Asteraceae
19.	*Commelina sinensis*	Dayflowers	Thingpui	Commelinaceae
20.	*Conyza bonariensis*	Asthma weed	Buar-zen/ Buarpa	Asteraceae
21.	*Cuscuta reflexa*	Dodder	Japan-hlo-rat/ Hrui-rul-hut/ Borairal	Convolvulaceae
22.	*Cynodon dactylon*	Bermuda grass	Phai-tualhlo/ Phui	Poaceae
23.	*Cyperus cyperoides*	Common Flat Sedge	Nu-beng-chah/ Tlang-puan-zar	Cyperaceae
24.	*Cyperus difformis*	Rice sedge	-	Cyperaceae
25.	*Cyperus iria*	Rice flat sedge	-	Cyperaceae
26.	*Cyperus rotundus*	Purple nut sedge	Nu-beng-chah	Cyperaceae
27.	*Dactyloctenium aegypticum*	Crow foot grass	-	Poaceae
28.	*Diplazium esculentum*	Fern	Cha-kawk	Athyriaceae
29.	*Digitaria radicosa*	Crab grass	Thang-te	Poaceae
30.	*Drymaria cordata*	Chickweed	Chang-kai-rit	Caryophyllaceae

31.	*Echinochloa colona*	Jungle rice	-	Poaceae
32.	*Echinochloa crusgalli*	Barn yard grass	-	Poaceae
33.	*Eichhornia crassipes*	Water hyacinth	-	Pontederiaceae
34.	*Eleusine indica*	Crow foot grass	-	Poaceae
35.	*Eragrostis nutans*	Grey Lovegrass	Zawng-hrik	Poaceae
36.	*Euphorbia hirta*	Garden spurge	-	Euphorbiaceae
37.	*Fimbristylis dichotoma*	Common fringe sedge	-	Cyperaceae
38.	*Galinsoga parviflora*	Gallant soldier	Sazu(pui)chaw	Asteraceae
39.	*Imperata cylindrica*	Cogongrass/ Thatch grass	Di	Poaceae
40.	*Ipomoea aquatica*	Water morning Glory	Kuang-kua	Covolvulaceae
41.	*Ipomoea batatas*	Morning glory	Kawl-ba-hra	Convolvulaceae
42.	*Lantana camara*	Lantana	Shillong tlang-sam	Verbenaceae
43.	*Marsilea quadrifolia*	Water clover		Marsileceae
44.	*Mikania micrantha*	Mile-A-Minute Weed	Japan-hlo/ Japan-thian	Asteraceae
45.	*Mimosa pudica*	Touch-me-not	Hlo-nuar/ Hlo-zua	Fabaceae
46.	*Mollugo pentaphylla*	Carpet weed	Va-hmim(a)bung	Molluginaceae
47.	*Monochoria vaginallis*	Pickerelweed	-	Pontederiaceae
48.	*Oxalis corniculata*	Yellow sorrel	Sialthur	Oxalidaceae
49.	*Oxalis debilis*	Pink wood sorrel	-	Oxalidaceae
50.	*Parthenium hysterophorus*	Carrot grass	Buleng hnim	Asteraceae
51.	*Pennisetum pedicellatum*	Desho grass	Ngai-te-i-nubeng-dawina	Poaceae
52.	*Persicaria hydropiper*	Water pepper	Kel-hmarcha/ Arahmarcha	Polygonaceae
53.	*Phyllanthus urunaria*	Shatter stone	Mitthi-sun-hlu	Phyllanthaceae

54.	*Physalis angulata*	Groundcherry	Kei-a-sai-rawphit/ Chalpang-puak	Solanaceae
55.	*Portulaca oleracea*	Common purslane	An-thau/ Hlothau	Portulacaceae
56.	*Saccharum arundinaceum*	Devil sugarcane	Rai-ruang	Poaceae
57.	*Scoparia dulcis*	Sweet Broom Weed	Perh-pawngchaw/ Thlumdem-dem	Scrophulariaceae
58.	*Sida acuta*	Common wire weed	Khing-khih/ Val-a-tha	Malvaceae
59.	*Stellaria media*	Common chickweed	-	Caryophyllaceae
60.	*Xanthium strumarium*	Cockle bur	Cha-bet	Asteraceae

Fig. 2.1 Photographs of common weeds of Mizoram

Broadleaf weeds

Acmella uliginosa

Ageratum conyzoids

Bidens pilosa

Cardamine hirsuta

Conyza sumatrensis

Drymaria cordata

Erigeron canadensis

Galinsoga parviflora

Mikania micrantha

Monochoria vaginallis

Oxalis debilis

Parthenium hysterophorus

Persicaria hydropiper

Portulaca oleracea

Scoparia dulcis

Lantana camara

Mimosa pudica

Amaranthus viridis

Grassy weeds

Axonopus compressus

Cynadon dactylon

Digitaria sanguinalis

Echinochloa colona

Echinochloa crusgalli

Eleusine indica

Pennisetum pedicellatum

Saccharum spontaneum

Setaria viridis

Sedges

Cyperus difformis

Cyperus iria

Cyperus rotundus

Fimbristylis miliacea

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3

Herbicides and its classification

- The word "herbicide" is derived from Latin words 'herba' meaning plant and 'caedere' meaning to kill.
- The term "weedicide" is inappropriate because it is supposed to kill only weed, however, at higher concentrations or even in lower concentrations, it also kills crops.
- $CuSO_4$ was the earliest inorganic salt used as a selective herbicide for controlling broad leaf weeds in 1896 in France, Germany and USA.
- 2,4-D was first synthesized by Pokorny (1941), but its herbicidal activity to selective control of broad-leaved weed was reported by Marth and Mitchell (1944).
- The real breakthrough in selective chemical weed control was achieved in 1945.
- In 1945, 2,4-D was developed in the USA by Zimmerman and Hitchcock, and MCPA in England by Templeman and Sexton.
- **Agent orange**: 50:50 herbicide mixture of 2,4-D and 2,4,5-T used by US military during the Vietnam war to defoliate forest and chemically called Dioxin.
- In India (as of Oct 2022) a total of 97 sole and 47 pre-mix herbicide formulations have been registered under the Insecticides Act, 1968.

3.1 Herbicide classification:

3.1.1 Based on time of application: This classification helps determine the appropriate timing of herbicide use for optimal effectiveness.

3.1.1.1 Pre-plant incorporation (PPI): Under this category, herbicides are applied before sowing of the crop and incorporated into the soil as these herbicides are highly volatile or have early photo decomposition. *e.g.*, fluchloralin, EPTC.

3.1.1.2 Pre-emergence (PE): Herbicide applied after sowing of crop but before weed and crop emergence. *e.g.*, pendimethalin, atrazine.

3.1.1.3 Post-emergence (PoE): Herbicide applied after the emergence of crop and weed both, although on principle it is after the crop emergence. *e.g.*, 2,4-D, isoproturon, glyphosate, paraquat.

Note: Early post-emergence: In case of slow-growing crop like potato, sugarcane, the non-residual herbicide is applied to destroyed weed before the crop emergence *e.g.*, Paraquat.

3.1.2. Based on selectivity: Herbicides can also be classified based on their selectivity, which refers to their ability to target specific types of plants while sparing others. Selectivity is a crucial factor in herbicide use as it allows for targeted weed control without causing significant damage to desirable crops or vegetation.

3.1.2.1 Selective herbicide: Kills only targeted weed but not the crop *e.g.*, 2,4-D, atrazine, sulfosulfuron.

3.1.2.2 Non-selective herbicide: Kills all the vegetation under its cover *e.g.*, paraquat, diquat, glyphosate, glufosinate-AM, picloram.

3.1.3. Based on translocation: Herbicides can be classified based on their mode of translocation within the target plants after application. Translocation refers to the movement of herbicide molecules from the point of application to other parts of the plant. This movement is crucial for effective weed control, as it allows the herbicide to reach and impact various plant tissues.

3.1.3.1 Contact herbicide: Kills all the vegetation that comes in its contact *e.g.*, paraquat, diquat, bromoxynil.

3.1.3.2 Systemic herbicide: Herbicide moves from the site of application to site of action *e.g.*, pendimethalin, 2,4-D, glyphosate, atrazine.

3.1.4 Based on residual action in soil: Herbicides can also be classified based on their residual action in the soil, which refers to their persistence and ability to remain active in the soil after application. Residual action is important in weed management, as it provides extended control of weeds over time.

3.1.4.1 Temporary soil sterilant: Remain active in soil for a short period usually for 15-16 weeks *e.g.*, methyl Bromide, metham.

3.1.4.2 Permanent soil sterilant: Remain active in soil for two or more seasons. *e.g.*, Triazines and Phenylureas at high rate, Sodium Chlorate.

3.1.5 Based on spectrum of weed control: Herbicides can be classified based on their spectrum of weed control, which refers to the range of weed species that a particular herbicide can effectively target. The classification is essential for selecting the most appropriate herbicide to manage specific weed problems.

3.1.5.1 Narrow spectrum herbicide: Control a particular group of weeds like grasses or BLW weeds *e.g.*, 2,4-D kills BLWs whereas Clodifafop-Propargyl kills only grassy weeds.

3.1.5.2 Broad-spectrum herbicide: Control a wider array of weeds constituting grasses, BLW and/or sedges *e.g.*, atrazine, isoproturon, glyphosate.

3.1.6 Based on window of application: Which refers to the specific period during which they are most effective and safe for use.

3.1.6.1 Narrow-window herbicides: Limited length of time for herbicide application *e.g.*, pendimethalin.

3.1.6.2 Wider-window herbicides: Wider length of time for herbicide application *e.g.*, butachlor (in rice).

3.1.7 Based on chemical structure: Herbicides can be classified based on their chemical structure, which refers to the composition and arrangement of molecules in the herbicide formulation. Understanding the chemical structure of herbicides is important for predicting their mode of action, selectivity, and potential interactions with other chemicals or environmental factors.

3.1.7.1 Inorganic: Inorganic herbicides are compounds that do not contain carbon-hydrogen (C-H) bonds and are typically derived from minerals or other inorganic sources. Before the discovery of organic herbicide, it was used. *e.g.*, H_2SO_4.

3.1.7.2 Organic: Organic herbicides are compounds that contain carbon-hydrogen (C-H) bonds. This category includes a wide range of herbicides with diverse chemical structures. Organic herbicides can be further classified into different groups based on their chemical families, such as phenoxies, triazines, sulfonylureas, imidazolinones, and many others. Each chemical family has specific properties, modes of action, and selectivity towards different weed species and crops. It is classified into the following groups:

Herbicide group		Examples	Mechanism of action
Phenoxy alkanoic acid		2,4-D, 2,4,5-T, MCPA	Excess cell division and cell enlargement
Arylcarbo-xylic acid	Benzoic	2,3,6, TBA, Dicamba	Excess cell division and cell enlargement
	Picolinic	Chlopyralid, Picloram	
	Terephthalic	Chlorthal dimethyl	Inhibit cell division
Aryloxyphenoxy propionates		Diclofop methyl, Clodinafop ethyl, Quizalofop	Inhibit of enzyme ACCase (acetyl Co-A)

Halogenated alkanoic acid derivates		TCA (Trichloro acetic acid), Dalapon	Effect carbohydrate, lipid, and N metabolism,
Triazines		Symmetrical: Atrazine, Simazine; Asymmetrical: Metribuzin	Block PS II of ETC
Ureas		Diuron, Isoproturon, Linuron	Block PS II of ETC
Sulphonyl ureas		Chlorimuron-ethyl, Chlorsulfuron, Sulfosulfuron, Ethoxysulfuron	Inhibit ALS (acetolactate synthase) and AHS (acetohydroxy acid synthase)
Carbamates		Chlorpropham, Propham	Inhibit microtubule organizing centre
Thiocarbamate		EPTC, Moliate, Diallate, Triallate	Inhibit the long-chain fatty acid formation
Dinitroanilines		Pendimethalin, Fluchloralin, Nitralin	Inhibit cell division by interacting with the microtubule system
Amide		Isoxaben, Propyzamide	Affect cell division and enlargement
Anilides	2-chloro Acetanilides	Acetochlor, Alachlor, Butachlor	Germination & cell division inhibitor
	Esters of N-aryl alanine	Benzoyl prop-ethyl, Flam prop methyl	Inhibit auxin action
	Miscellaneous anilids	Propanil, Pentanochlor	Causes chlorosis, bleaching and inhibit ETS
Phenols		DNOC, Nitrophenol, Dinoseb	Uncoupled oxidative phosphorylation & prevent ATP formation
Diphenyl ethers		Nitofen, Oxyfluorfen	Inhibit PPO (protoporphyrinogen oxidase) *i.e.,* chlorophyll synthesis

Nitriles	Dichlobenil	Inhibition of cellulose biosynthesis
	Bromoxynil, Ioxynil	Effect on chloroplast
Uracil (pyrimidines)	Bromacil, Lenacil, Terbacil	Interfere PS electron transport
Bipyridinium compound	Paraquat, Diquat	Block PS I of ETC
Miscellaneous heterocyclic compound		
Amitrole	Inhibit carotenoid synthesis	
Oximes	Tralcoxydin, Sethoxydim Na	Inhibit ACCase
Organophosphorus compound	Glyphosate	Inhibit EPSPase
	Glufosinate	Inhibit glutamine synthatase
Imidazolinones	Imazethapyr, Imazaquin	Inhibit ALSase
Pyrimidinyloxybenzoic	Bispyribac, pyriminobac	Inhibit ALSase
Triazolone	Carfentrazone	Inhibit PPO enzyme
Oxadiazolone	Oxadiargyl	Inhibit PPO enzyme

Fig. 3.1 Common herbicides used in Mizoram

3.1.8 Based on physiological/biological nature:

- This classification helps to tackle the problem of **resistance**.
- **Herbicide Resistance Action Committee (HRAC)** in collaboration with **Weed Science Society of America (WSSA)** has developed this classification based on the mode of action of herbicide.
- **Classified into:**

3.1.8.1 High-risk herbicides for resistance development *viz*., group **A & B** (**ACCase** & **ALSase** inhibitors).

3.1.8.2 Medium risk herbicide for resistance development *viz*., group C, D, E & F (PS I, II, PPO & carotenoid biosynthesis inhibitors).

3.1.8.3 Low-risk herbicide for resistance development *viz.,* G, H, I, J, K, M, N and O group.

3.2 Herbicide formulation (Combination of Active ingredient + solvents / carrier + adjuvants)

➢ The process by which a toxic / active ingredient is made ready for utilization by blending with liquid or dry diluents by grinding and / or by adding inert material such as surfactant, wetting agent *i.e.*, adjuvants.

3.3 Types of formulation: Common herbicide formulations are grouped as

3.3.1 Liquid formulations: The majority of herbicides are marketed in liquid form as follows:

3.3.1.1 Emulsifiable concentrates (EC): It is a heterogeneous system, in which each component maintains its original identity in the form of minute globules. The emulsifying agent is added to the solution *e.g.*, pendimethalin 30% EC, butachlor 50% EC, pretilachor 50% EC.

3.3.1.2 Water soluble concentrate (WSC) / soluble liquid (SL) / water-soluble liquid (WSL): These types of formulations are usually water-based products that contain a dissolved *a.i*. This is one of the formulation types that actually contains dissolved molecules, not suspended particles *e.g.*, glyphosate 41% SL, paraquat 24% SL.

3.3.2 Solid Formulations:

3.3.2.1 Wettable powder (WP): Finely milled powder (<3μ), form suspension on mixing with water *e.g.*, atrazine 50% WP, isoproturon 50% WP.

3.3.2.2 Water Soluble powder (WSP): Soluble in water and forms a solution *e.g.*, Na salt of 2,4-D, TCA.

3.3.2.3 Granules (GR): Contain 1-20% *a.i.* in particulate solid carriers, suited for direct field application *e.g.*, butachlor 5% GR.

3.4 Toxicity classes of herbicide:

Toxicity classes of herbicide: Herbicides are classified into toxicity classes based on their potential to cause harm to humans, animals, and the environment. The classification is used to indicate the level of toxicity and the appropriate precautions needed during handling, application, and disposal of herbicides. The United States Environmental Protection Agency (EPA) and other regulatory agencies commonly use toxicity classes for herbicides.

3.4.1 Red colour: Extremely hazardous (Class I)

3.4.2 Yellow colour: Highly hazardous (Class II)

3.4.3 Blue colour: Moderately hazardous (Class III)

3.4.4 Green colour: Moderately safe (Class IV)

Fig. 3.2 Toxicity classes of herbicide

4

Calculation of herbicide doses, equipment used for its application and precaution

4.1 Calculation of herbicide doses

Herbicides are applied either as a solution or granule form. The most common method of herbicide application is by spraying. The efficacy of herbicide towards weeds and its selectivity towards crops depend upon its dose, time and method of application. Herbicides are mainly available either in powder, granules or liquid forms. Generally, the recommended dose of herbicide is made either on the active ingredient (*a.i.*) or acid equivalent (*a.e.*) and the same herbicide may be sold under different trade names with different concentrations. Therefore, herbicide recommendations are generally made on kg *a.i*. basis. Thus, the calculation of the proper dose of herbicide is of prime importance for its efficacy. Calculation of herbicide requirement can be done by the following formula:

$$\textit{Dose of commercial product (kg/ha)} = \frac{\textit{Dose in kg a.i. per ha x 100}}{\textit{\% concentration in the product}}$$

Example 1.

A farmer wants to apply glyphosate on his uncultivated weedy land of 2 ha area @1.0 kg *a.i.*/ha. He has Glycel (trade name), which contains 41% SL glyphosate.

$$\text{Quantity of Glycel required for 2 ha area} = \frac{1 \text{ x } 100 \text{ x } 2}{41}$$

Therefore, the quantity of Glycel required for 2 ha area is 4.87 lit

4.2 Determination of the amount of commercial herbicide's formulation from acid equivalent (*a.e.*) of formulation:

Example 2.

Given: Isooctyl ester of MCPA: 53.4%

Area to be applied: 1.5 ha

$$\textbf{Percent acid equivalent} = \frac{\text{Molecular wt. of acid x Salt in formulation}}{\text{Molecular wt. of salt}}$$

a.e. = (201 x 53.4)/(313)

= 34.3% a.e.

Amount of commercial formulation

$$= \frac{\text{Recommended rate (kg a.i. per ha) x Area (ha) x 100}}{\text{\% of a.i. of commercial formulation}}$$

But substitute % a.e. to % a.i. of commercial formulation

$$\textbf{Amount of commercial formulation} = \frac{1.4 \times 1.5 \times 100}{34.3}$$

= **6.12 liters**

4.3 Herbicide equipment

Application of herbicide (mostly liquid) requires special equipment called herbicide equipment. Herbicide equipment is the tool that store, meter, atomize and distribute herbicide accurately on the target weeds.

- A sprayer atomizes the spray solution into small droplets and ejects the same with force for distributing it properly.

4.3.1 Type of sprayers:

Sprayers are divided into two groups based on the force required:

4.3.1.1 Manually operated

4.3.1.1.1 Compressed air sprayer

4.3.1.1.2 Hydraulic sprayer

4.3.1.2 Power operated

4.3.1.2 Manually operated

4.3.1.1.1 Compressed air or Pneumatic sprayer

4.3.1.1.1.1 Domestic sprayer - These sprayers are used to spray against flies, mosquitoes and in poultry farms, kitchen gardening and hospitals, *etc.*, **(Fig. 4.1)**.

Fig. 4.1 Domestic sprayer

4.3.1.1.1.2 Hand compressing sprayers - The most common type is Knapsack sprayer. This pump is very ideal and affordable for spraying pesticides including insecticides, herbicides, fungicides, *etc.,* **(Fig. 4.2)**.

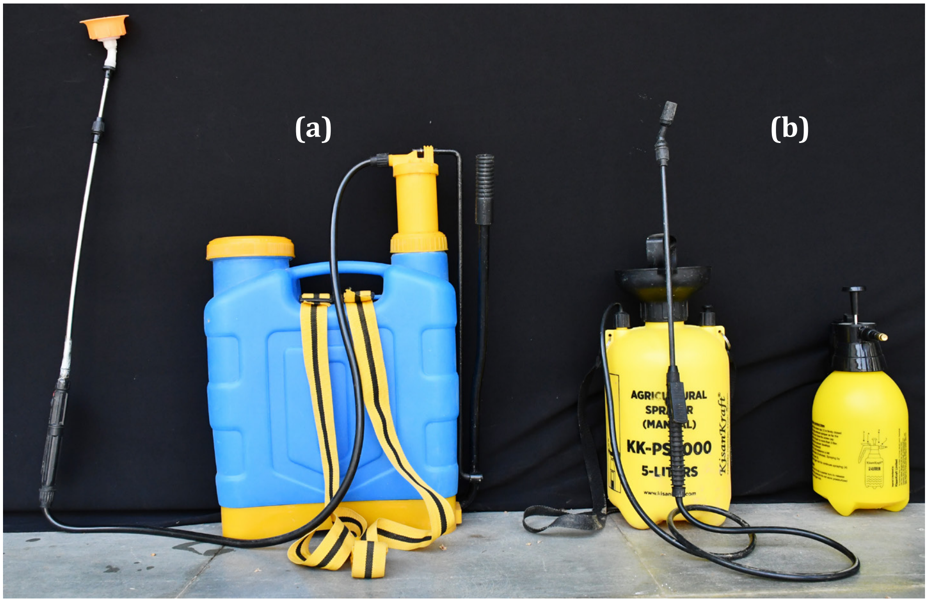

Fig. 4.2 Manually operated sprayer (a) knapsack sprayer (b) hand compression sprayer

4.1.1.1.1.3 Pressure retaining or Battery sprayer - Over the duration of the spraying, pressure is maintained and operated by battery **(Fig. 4.3)**.

4.3.1.1.2 Hydraulic Sprayers

4.3.1.1.2.1 Pedal Pump (foot sprayer) - For spraying herbicides, this pump is not suitable. This can be used for spraying fungicides and insecticides especially in orchards and plantations.

4.3.1.1.2.2 Power operated sprayers - These sprayers use mechanical pressure and is usually generated powered by diesel or petrol engines with varying

Fig. 4.3 Power operated knapsack sprayer

HP. These sprayers include, among other things, a power-generating pump, a suction chamber, delivery lines, and discharge lines. The blower's powerful air current is used to blow out the spray fluid. Through a PVC tube, the spray liquid travels to the nozzle where it is blasted into tiny, micron-sized droplets by the swift air from the blower. These power sprayers may hold anywhere between 15 to more than 500 litres of liquid. These pieces of equipment are excellent for spraying herbicides with foliar uptake. **(Fig. 4.4)**.

Fig. 4.4 Tractor mounted sprayer spraying of herbicide on wheat crop

4.3.2 Parts of knapsack sprayer

For effective operation, maintenance, and repair, one must be aware of the various components and functions of the sprayer. Major parts of knapsack are given below (**Fig. 4.5**):

Fig. 4.5 Parts of the knapsack sprayer

4.3.2.1 Tank container: It holds the spray fluid. The total capacity of tank of the knapsack sprayer is 15 litres.

4.3.2.2 Pressure pump: Pressure must be increased in the system in order to atomize the spray fluid into smaller droplets.

4.3.2.3 **Discharge line/delivery line:** It is the line through which liquid comes out of the sprayer with force after converting to mist form.

It consists of the following parts:

4.3.2.3.1 **Delivery hose:** A flexible rubber or plastic tube attached to the tank / container at one end.

4.3.2.3.2 **Lance:** It is a metal tube connected up to the nozzle and the other end of hose.

4.3.2.3.3 **Cut off/ Shut off:** When spraying is halted, it is generally installed at the intersection of the delivery hose and lance to cut off the flow of liquid.

4.3.2.3.4 **Nozzles** (Heart of the sprayer): It is an equipment that performs four basic functions *viz.*, 1. Atomizes liquid into droplets. 2. Disperses the droplets at a certain flow rate. 3. Meters liquid at a certain flow rate. 4. Provides hydraulic momentum.

4.3.2.3.4.1 **Types of nozzels:** There are three types *viz.*, Flat fan, Flood jet and Cone (solid cone, hollow cone, tapered cone and triple action cone) (**Fig. 4.6**)

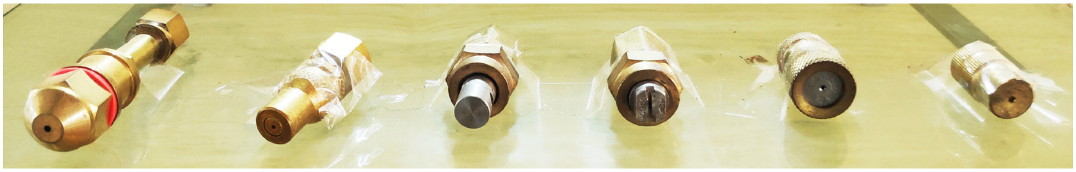

Fig. 4.6 Different types of nozzles used in sprayers

- Generally flat fan nozzle used for application of pre- and post-emergence herbicides and for application of non-selective herbicide under barren land-flood jet nozzle is used.

4.3.2.3.5 **Handle:** It is moved up and lowered to create pressure.

4.3.2.3.6 **Agitators:** The substance should be kept thoroughly, mixed in order to ensure an equitable distribution of herbicides because the active ingredients in any spray fluid are not always in solution but rather are maintained in suspension form.

4.3.2.3.7 **Filters / strainers:** The function of the filter is to stop solid particles from clogging the system.

4.3.2.3.8 Washers and gaskets: To stop leakage, these are present at all junctions.

4.3.2.3.9 Shoulder straps and hooks: They serve to keep the sprayer on the man's shoulder engaged for spraying.

4.4 Calibration of knap-sack sprayer

Add the appropriate amount of water into the sprayer's tank or container. Spray across a certain area. Calculate the amount of water utilized for spraying after measuring the amount of leftover water in the pump's container. Then, determine how much water is required to spray one acre or one hectare. When spraying herbicides on a crop, always assign the same person with the same pump and nozzle who has performed the calibration.

The following calculation can be used to determine the quantity of water needed to spray a specific area:

$$Q = \frac{(V1\text{-}V2)}{a} x\, A$$

where,

Q = Quantity of water required for area to be sprayed (litres)

V_I = Quantity of water taken initially

V_2 = Quantity of water remained after spraying

A = Area to be sprayed m^2

a = Measured area sprayed m^2

4.5 Spray technique

- Spray some plain water on a pucca floor to check the sprayer nozzle before spraying the herbicide.
- Watch the pattern of wetting. If the floor is not evenly moistened, adjust the nozzle or nozzle tip.
- The field application should be carried out by the same person who did the calibration.
- Beginning at one field corner, apply a band of spray. The second band should be parallel to the first and slightly overlap it.
- Wear a full sleeve shirt, a pair of pants, shoes, hand gloves, and a gas mask while spraying (**Fig. 4.7**).
- The nozzle's height should be 50 cm above the canopy or the ground (**Fig. 4.8**).

- Spraying must be as even as possible. Instead of being re-sprayed, the leftover solution must be dropped on a dry surface.
- Avoid moving the nozzle.
- Do not spray along or across the direction of wind but always spray at right angle to the direction of wind.
- Do not spray if the wind is blowing heavily.
- Prevent eating or drinking while spraying, and avoid spraying on an empty stomach.
- After spraying, take a thorough bath with soap and change into new clothing.

Fig. 4.7 Safety measures during herbicide spray

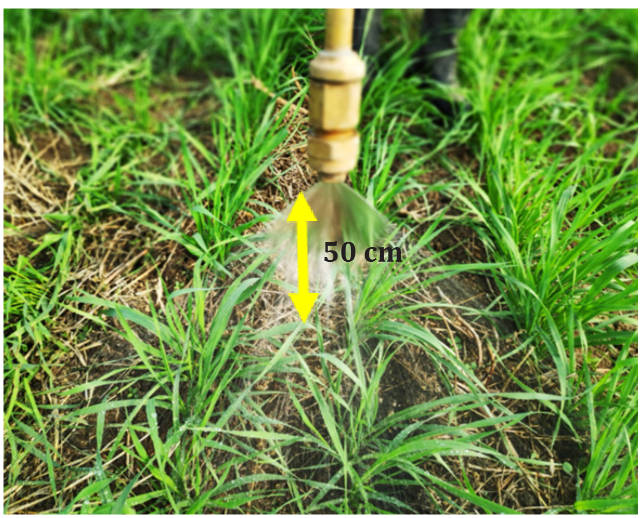

Fig. 4.8 Height of nozzle from the ground or canopy level during spray

4.6 Prepare of herbicide spray solution

- Calculated dose of herbicide should be thoroughly mixed in small quantity of water and then makeup the solution up to calibrated volume in a big non-metallic container.
- When making the solution and applying the herbicide in the field, wear hand gloves and a gas mask.
- Before each filling, thoroughly mix the spray fluid with a plastic or wooden stick.
- If not, the first stock solutions can be made in a tiny container.
- Fill the pump with one litre of stock solution and the make up the volume by adding water.
- One or two litres of water should be added to the container before making the stock solution.

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5

Glyphosate: A non-selective translocated herbicide

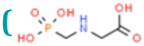
5.1 Glyphosate ()

Fig. 5.1 Glyphosate 41% SL trade name Glycel

Glyphosate is a widely used systemic herbicide known for its non-selective broad-spectrum weed control capabilities in various sectors, including agriculture, forestry, plantations, and non-cropped areas like industrial sites and roadside vegetation. Applied by spraying onto plant leaves, it effectively targets and eliminates both broadleaf weeds, grasses, and sedges. Given its remarkable efficacy, Glyphosate has earned the reputation of being referred to as the "once-in-a-century herbicide" (Duke and Powles, 2008). Having been in use in India since the 1980s, it has become one of the top-selling herbicides in the country, highly favoured by farmers for its effectiveness in managing weed problems.

Glyphosate-based herbicides are allowed and regulated for weed control in tea gardens and other non-crop areas in India. However, their usage extends beyond these regions, being employed in over 20 field crops, including 16 food crops, as well as in conservation agriculture and non-crop areas (Anonymous, 2021). As of October 1, 2022, a total of nine glyphosate formulations have been officially registered under the Insecticide Act 1968 for commercial use in the country:

Glyphosate formulation	Remarks
Glyphosate Ammonium Salt 5% SL	Pesticide Formulations Registered for Use in The Country Under the Insecticides Act, 1968: (As on 01.10.2022) **Source**: https://ppqs.gov.in/divisions/cib-rc/registered-products accessed on 07.03.2023
Glyphosate Ammonium Salt 20 % SL	
Glyphosate 20.2% SL (IPA Salt)	
Glyphosate 41% SL (IPA Salt)	
Glyphosate 54% SL (IPA Salt)	
Glyphosate Ammonium Salt 71% SG	
Carfentrazone ethyl 0.43% + Glyphosate 30.82% EW	
Indaziflam 1.65% + Glyphosate Isopropyl Ammonium 44.63% SC	
Oxyfluorfen 2.5% + Glyphosate (Isopropyl amine salt) 41% SC	

Glyphosate is a non-selective herbicide that is effective in killing almost all plants it comes into contact with. It is applied post-emergence directly to the foliage of weeds, and it can enter the plant through its leaves, roots, trunk, or emerging shoots. Within 1-3 weeks after glyphosate application, the targeted weeds die (Kanissery et al., 2019). The herbicide acts by inhibiting the production of certain proteins that are essential for plant growth. Specifically, glyphosate blocks the activity of a specific enzyme called 5-enol-pyruvyl-shikimate-3-phosphate synthase (EPSPS), which catalyzes the sixth step in the shikimic acid pathway. By inhibiting EPSPS, glyphosate prevents the biosynthesis of aromatic amino acids such as phenylalanine, tyrosine, and tryptophan (Gravena et al., 2012). These amino acids are essential for the growth of plants and some microorganisms.

5.2 Fate in soil and environment

Glyphosate is a non-volatile, chemically stable compound. It is quickly inactivated in the soil through adsorption, followed by degradation by microorganisms (Duke, 2020), which contributes to its reputation as a generally safer herbicide for the environment compared to other herbicides (Quinn et al., 1988). Glyphosate has a low probability of leaching or percolation losses through water and is susceptible to microbial degradation (Hagner et al., 2019). The half-life of glyphosate varies between 5.7 to 40.9 days, with an average of about 30 days (Blake and Pallett, 2018). The rate of degradation depends on factors such as soil type, climatic conditions, soil moisture availability, soil microbial biomass, and more. Despite its favourable characteristics, the widespread use of glyphosate has led to increasing research and concerns regarding its impact on plants and the environment (Kanissery et al., 2019). As a result, ongoing studies are exploring various aspects of glyphosate's effects to ensure its responsible and sustainable use in weed control practices.

5.3 Toxicity

Glyphosate was assigned a "Category 2a" classification by the International Agency for Research on Cancer (IARC), indicating that it is a probable carcinogen to humans. On the other hand, the United States Environmental Protection Agency (USEPA) classifies this herbicide as a "Category E carcinogen," suggesting that it is not carcinogenic to people. Although residues of glyphosate have been detected in human urine samples, demonstrating its persistence, bioaccumulation, and potential health concerns, experimental evidence does not fully support the European Food Safety Authority's assessment that glyphosate is a potent human carcinogen. Despite the fact that glyphosate residual concentrations have never exceeded the threshold level, the negative consequences of its use cannot be disregarded (Singh et al., 2020).

5.4 Resistance development on weeds due to Glyphosate

Glyphosate generally falls under the category of a low-risk herbicide regarding the selection of resistance; however, low risk does not imply "no risk". Currently, due to the extensive and indiscriminate application of glyphosate over crop fields, uncultivated areas, and genetically modified (GM) crops, glyphosate-resistant weeds have emerged, encompassing 51 different species (**Fig. 5.2**; Heap, 2023).

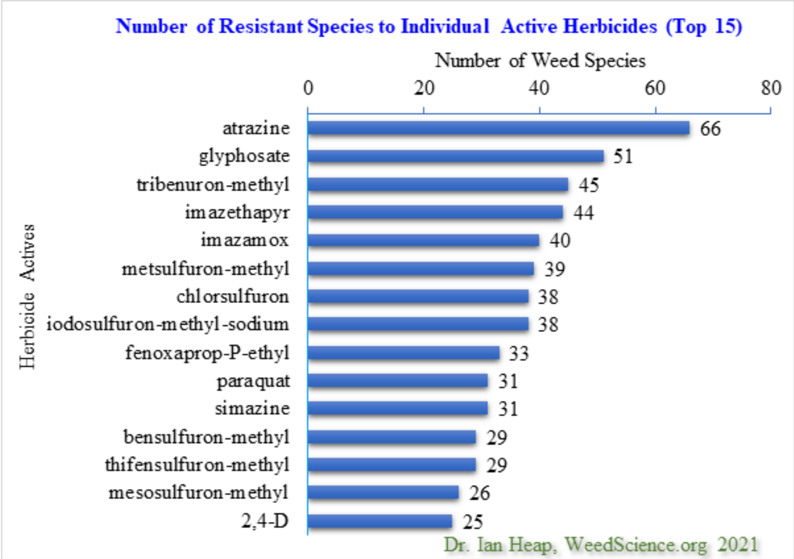


Fig. 5.2 Number of weed species resistance towards different herbicide worldwide

5.5 States approach towards glyphosate

As per the Statistical Database, Pesticide Monitoring and Documentation Unit, PPQ&S, Ministry of Agriculture, Government of India, the usage of glyphosate has increased from 435 MT technical grade to 571 MT from 2010-11 to 2021-22 (Kumar, 2020; Anonymous 2023). Some State Governments (such as Andhra Pradesh, Kerala, Punjab, Telangana) attempted strict regulations and/or a temporary ban of glyphosate-based herbicide formulations in their jurisdiction in the past few years due to the rising issues related to health and safety of the environment at many forums due to the illegal and indiscriminate use of glyphosate. However, the sale, usage, and distribution of pesticides cannot be ban by state governments for longer than 60 days (Section 27 of the Insecticide Act, 1968). Only the CIB & RC, Govt. of India has the authority to decide the prohibition of the use and sale of agrochemicals. The Kerala government submitted a report to the Central Government in 2019 calling for the ban on the use, sale, and distribution of glyphosate and its derivatives.

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6

Parthenium: a new problematic weed of Mizoram

Parthenium hysterophorus is widespread and declared to be one of the worst weeds globally. It predominantly infests bare lands, railway tracks, agricultural fields, orchards, and forests. Numerous methods exist to control this weed, but no single management option is sufficient, necessitating the integration of control methods. The primary objective of this chapter is to offer insights into the general information, physiology, distribution, harmful effects, and control methods for Parthenium, thereby enhancing knowledge and understanding of this invasive weed.

6.1 Introduction

A weed is a plant that grows where it is not desired and is considered undesirable in a particular environment. Invasive weeds, on the other hand, are weeds that persist, establish, and widely spread in natural environments beyond their native range. Invasive weeds can pose a more significant threat compared to native weeds due to their potential to displace native species and disrupt local ecosystems. Invasion is recognized as a major threat to biodiversity (Akter and Zuberi, 2009). *Parthenium hysterophorus* is a primary invasive alien weed known for outcompeting native species and causing harm to biodiversity. It is considered one of the most destructive invasive plant species globally, posing threats to biodiversity, food security, and human health across numerous countries.

To raise awareness about the harmful effects of Parthenium and its effective management, various ICAR institutes in India have been organizing the "Parthenium Awareness Week" annually from August 16th to 22nd since 2004. Parthenium hysterophorus belongs to the Asteraceae family, and its name is derived from the Latin word 'parthenice,' referring to "feverfew," and 'hysterophorus' from the Greek words 'hystera' (womb) and 'phoros' (bearing), denoting the plant's prolific seeding habit (Parsons and Cuthbertson, 1992). Commonly known as whitetop weed, Santa-Maria, Santa Maria feverfew, famine weed, and locally referred to as Carrot grass, Congress grass, Gajar Ghas, or Dhanura, it has earned the ominous nickname "Scourge of India."

Parthenium infests pastures and fields, causing significant losses in productivity, hence the name famine weed. The weed's prolific seed production also exerts allelopathic effects on nearby plants and competes with commercially significant crops. In-depth knowledge of this weed, its habits, and biology is crucial for effective management and control using various approaches. The "Parthenium Awareness Week" serves as a platform to disseminate detailed information to stakeholders, including farmers, students, researchers, government officials, and the general public, encouraging their active involvement in combatting the adverse impacts of Parthenium and safeguarding the productivity of agricultural lands.

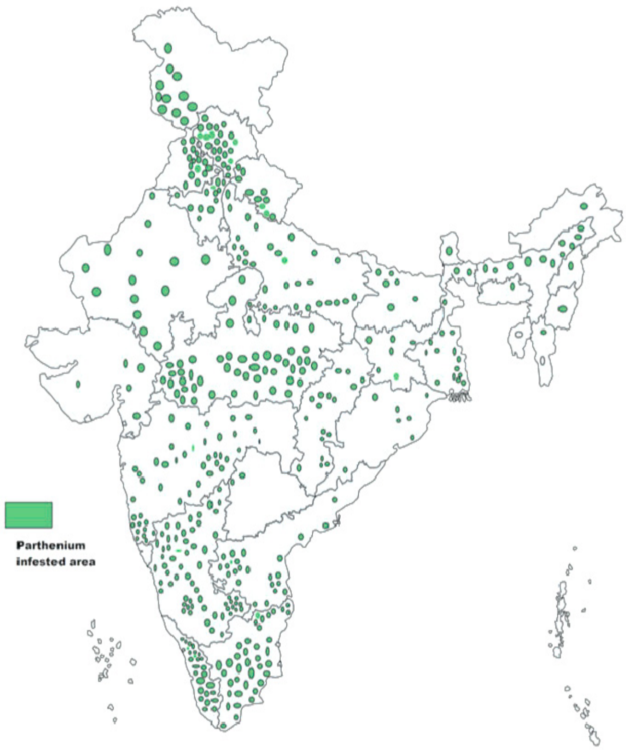

Fig. 6.1 Map of location in different states of India where Parthenium hysterophorus is known to be present (Lalita and Ashok, 2017)

6.2 Origin and distribution

Parthenium hysterophorus is native to Central America, Central South America, Southern North America, Gulf of Mexico, and the West Indies. Over time, the weed has spread to more than 20 countries across the globe, including both mainland areas and numerous islands. It was introduced into Asia during the 1950s through shipments of cereal and grass seeds from America (Bhowmik and Sarkar, 2005). In India, Parthenium probably entered around 1910 through cereal-infected germplasm but remained unrecorded until 1956. It was in 1956 that the weed was first identified and subsequently spread throughout India (Aneja, 1999). Presently, Parthenium is found in all states of the country and poses a significant threat to states with large areas of agricultural land, grazing land, and non-cropping areas (Kumar, 2009).

6.3 Status of Parthenium incidence in Mizoram

In Mizoram, infestation of *Parthenium hysterophorus* was low compared to other state. Systematic surveys of Parthenium infested areas on 12 selected national high-ways of North-Eastern India conducted by Devi et al., (2013) during 2009-2011 revealed that the presence of *P. hysterophorus* is severely infested in NH-54 (Aizawl, Mizoram).

6.4 Habitat

Parthenium mainly grows in wastelands, orchards, public lawns, industrial areas, urban areas *etc*. The weed also grows actively in forests, gardens and agricultural fields. It may produce approximately 15,000 seeds per plant because of its great luxuriance development, which can distribute and germinate to various areas in a significant amount. It also has a potential to adjust to a variety of habitat conditions. Under favourable climatic conditions with 500 mm average rainfall and 30°C mean temperatures it can grow to heights of 1.5 to 2.0 m. It mostly prefers alkaline clay, loam soil to heavy black clay soils to grow vigorously. It can grow in a wide range of pH, moisture, and temperature conditions but it requires high soil moisture for seed germination.

6.5 Botanical description

Parthenium hysterophorus is a branched, short-lived (annual), erect herbaceous plant that forms a basal rosette of leaves during the early stage of growth. It generally grows 0.5-1.5 m tall but can reach up to 2 m or more. Leaves are alternately arranged up to 2 cm long of stalks (petioles) and during the early stages of growth it form a basal rosette. The lower leaves are 3-30 cm long and 2-12 cm wide and are bi-pinnatifid whereas leaves on the upper branches decrease in size and are less divided than the lower leaves. Numerous small flower head (capitulum) are organized in clusters at the top of the branches and each flower-head is borne on a stalk (pedicel). Flowers are creamy white which contain ray florets (0.3-1 mm long) of several small flowers (tubular florets) in the centre and is surrounded by two rows of small green bracts. Each flower head produces five tiny seeds called achenes that are black, oblong, and are 2 millimetres long by 1.5 millimetres broad. They also have two or three tiny scales called pappus that are 0.5-1 millimetres tall, two straw-coloured papery structures, and a flat bract (**Fig. 6.2**).

Fig. 6.2 Photo of *Parthenium hysterophorus*

6.6 Harmful effects of Parthenium

6.6.1 Effects on biodiversity: Due to its allelopathic potential and rapid invasive nature, parthenium has the ability to disrupt natural ecology, thriving year-round in various extreme conditions and outcompeting native vegetation. It aggressively colonizes wastelands, roadsides, railroad sides, cultivated fields, watercourses, and overgrazed pastures, resulting in a significant invasion of 14.25 million hectares of farmland during 2001-2007, in contrast to 2 million hectares between 1991-2000 (Javaid and Adrees, 2009). Consequently, in areas where this plant is present, local biodiversity experiences a steady decline.

6.6.2 Effects on crop production: Parthenium contains chemicals, like parthenin, hysterin, hymenin, and ambrosin, and due to which, the weed exerts strong allelopathic effects on different crops. It affects nodulation in legumes due to inhibition of activity of nitrogen fixing and nitrifying bacteria, namely Rhizobium, Azotobacter, Actinomycetes and Azospirillum. In India, it causes a yield decline in agricultural crops up to 40% (Khosla and Sobti, 1981). Parthenium produces about 700 million of pollen grains which travel a long distance between plant, preventing the fruit setting in these crop plants such as tomato, beans, brinjal and cereals.

6.6.3 Effects on animals: Animals that are exposed to *Parthenium hysterophorus* develop dermatitis and skin sores, including cattle and horses. It can cause pruritus, anorexia, alopecia, diarrhoea and eye irritation in dogs. This plant extract lowers animal total WBC counts, which weakens the immune system. If excess amount of this weed is consumed by animals, it can cause fatal.

6.6.4 Effects on human beings: Up to 73% of people who live with the weed are sensitive to Parthenium plants, which have the potential to be hazardous. Females are twice as sensitive as males. The main health issues that pollen grains and other plant parts from Parthenium induce in people include hay fever, asthma, dermatitis, and bronchitis. This plant can spread dermatitis from direct contact and affect the entire body. The major allergies found in this plant are coronopilin, tetraneuris, parthenin and ambrosin. Parthenium dermatitis is of five types: the classical pattern, the chronic actinic dermatitis (CAD), the mixed pattern (classical and chronic actinic dermatitis pattern combination), the prurigo nodularis like pattern and photosensitive lichenoid eruption.

6.7 Control of Parthenium

Controlling Parthenium weed is a formidable challenge due to its aggressive and rapid spread. Despite various methods being employed, no single approach has been deemed fully effective, as each solution comes with drawbacks like impracticability, temporary relief, environmental concerns, and high costs. Below are different methods suggested for controlling *Parthenium hysterophorus*:

6.7.1 Physical control: The most effective method to eradicate the weed is to remove it before it flowers and sets seed; otherwise, the infestation will continue to spread. Physical control involves manual weeding, which is time-consuming and poses health hazards. Burning is another method used for weed control, but it is found to be ineffective for Parthenium. However, certain studies suggest that if pastures are allowed time to recover before introducing stock, burning for other purposes (e.g., controlling woody weeds) may not lead to increased Parthenium invasion.

6.7.2 Chemical control: Chemical control is a productive method in areas where Parthenium's natural enemies are lacking. Chemical herbicides, such as glyphosate, atrazine, ametryn, chlorimuron, bromoxynil and metsulfuron, are effective in controlling this weed. were found more effective. At 15 days after sowing (DAS), application of Metribuzin (0.25 and 0.50%) and 2,4-D EE (0.2%) was shown to be more effective, leading to a control of Parthenium population (Gaikwad et al., 2008). The most effective for Parthenium control weed were metribuzin and glyphosate, having higher mortality at 4 weeks after treatment (WAT) rosette and bolted stages than 2,4-D, terbutryn+ triasulfuron, bromoxynil + MCPA and, atrazine, s-metolachlor. In non-cropped areas, open wasteland and along railway tracks and roadsides, spraying a solution of common salt (sodium chloride) at 15–20% concentration is found to be effective. Using chemical herbicides have a number of drawbacks, including environmental hazards and the emergence of resistance against many herbicides, like atrazine 2, 4-D, metribuzin, trifluralin, paraquat (gramoxone), and glyphosate and diphenamid (Vila-Aiub et al., 2008).

6.7.3 Biological control: Biological control is a productive means of mitigating pests and its effects through the use of natural enemies. Biological control of weeds by pathogen has gained acceptance as a safe, practical and environmentally beneficial method applicable to agroecosystem (Aneja, 2009). The main strategies are the introduction of foreign pathogenic organisms known as "classical approach" and the "augmentative" or "bioherbicidal approach" where the pathogenic organisms are already present and their population is increased by mass rearing. Insects like the stem galling moth (*Epiblema strenuana*) and the leaf-feeding beetle (*Zygogramma bicolorata*), both imported from Mexico, have shown good potential to eradicate this plant. Fungal agents to manage Parthenium are *Entyloma compositarum* De Bary (Ustilaginales), *Plasmopara halstedii* (Farlow) Berl. and De Toni (Peronosporales), *Puccinia abrupta var. partheniicola* (Jackson) Parmelee, and *Puccinia xanthii var. parthenii-hysterophorae* (previously known as *P. melampodii* Diet. and Holw.) (Uredinales).

6.8 Methods to use Parthenium

6.8.1 Use as biopesticide: Parthenium has been utilized as an insecticide, nematicide, and herbicide. It demonstrates antifeedant activity against forest pests (Singh and Sushilkumar, 2004). Pandey (1996) discovered that the sesquiterpene lactone parthenin, one of the major toxins in Parthenium, exhibited toxicity at 50 ppm to floating aquatic weeds such as Lemna (*Lemna pausicostata*) and Pistia (*Pistia stratiotes*), and at 100 ppm to Water hyacinth (*Eichhornia crassipes*), Spirodella (*Spirodela polyrhiza*), Salvinia (*Salvinia molesta*), and Azolla (*Azolla nilotica*).

6.8.2 Use as compost and vermi-compost: The use of Parthenium for making compost and vermicompost has emerged as one of the most economical and practical methods for farmers. The Directorate of Weed Research (DWR) in Jabalpur, Madhya Pradesh, has standardized and developed a pit method that ensures the seeds are killed during the composting process. In this method, Parthenium is layered with dung slurry, soil, and urea in a trench at least 90 cm deep, creating anaerobic conditions that effectively kill the Parthenium seeds. Notably, the quality of the resulting compost was found to be superior to traditional farmyard manure (FYM) (Sushilkumar and Varshey, 2010). This innovative approach not only helps manage the spread of Parthenium but also provides farmers with a valuable organic resource to enrich their soils and improve agricultural productivity.

6.8.3 Use as antifungal: Several types of fungi are resistant to Parthenium's antifungal properties. It can be utilised to treat both human and fungal diseases. This weed contains a sequestoterpene lactone that is sensitive to dermatitis-related fungi and is used to treat skin conditions (Rai and Mares, 2003).

6.8.4 Use as antioxidant: The methanolic extracts of Parthenium has a strong antioxidant activity. It can be utilized as natural antioxidants. It is a naturally occurring antioxidant that can take the place of synthetic antioxidants, which, if commercially available, have detrimental effects on human health (Khan et al., 2011).

6.9 Conclusions

Compared to other weeds, *Parthenium hysterophorus* exhibits a remarkably rapid spread, covering a significant portion of agricultural land. To effectively manage this weed, it is crucial to have a comprehensive understanding of both its positive and negative impacts. An integrated approach, combining various control methods at different stages, can prove to be efficient. Parthenium affects not only the above-ground vegetation but also the soil nutrients beneath the surface, thriving in diverse environments. These changes can influence the functioning of ecosystems and impact other trophic levels. To mitigate potential threats to biodiversity and avoid financial losses, implementing effective methods for controlling this weed is essential.

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7

Weed management through cereal-legume intercropping

The major cereal crop of Mizoram is rice and maize. Whereas, cowpea, groundnut, french bean and rice bean are the major legume crops cultivated in Mizoram. However, the productivity of these above crops is far behind the national average productivity. One of the major regions behind this is poor agronomic management. Among them, weed infestation is the major problem associated with the hilly ecosystem of Mizoram. Weed competition is high when cereal crop is sown with wide spacing, which allows a high portion of ambient light to penetrate. It is possible these cereals could be intercropped with a short-duration legume crop that fills the uncovered spaces between the rows and thus (legume crop) acts as the suppressed weed. However, a suitable combination of component crops, time of sowing for both component crops and other management practices need to be considered during intercropping. Legumes act like living mulch that reduce weed emergence and growth.

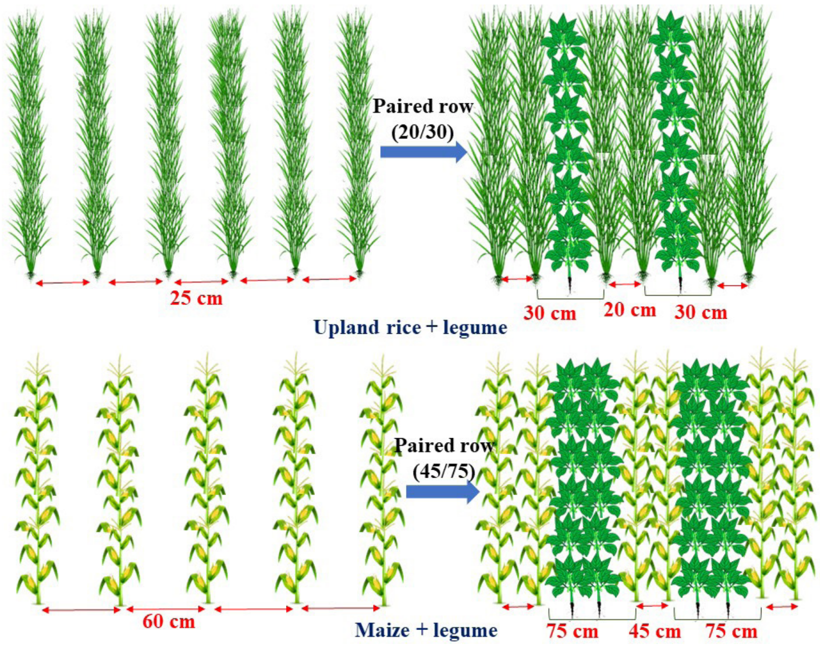

Fig. 7.1 Layout of paired row intercropping of legumes with cereals

But legume intercrops are valuable only if the productivity of the main crop is preserved and causes minimum competition with the main crop. Therefore, the finding from the experiments at ICAR Kolasib showed that when upland rice was intercropped with legumes *viz*., cowpea, groundnut, french bean and rice bean at 2:1 paired row cropping (20/30) with hand weeding at 20 DAS resulted in weed smothering efficiency (WSE) of 45-65% and 40-60% at 60 and 90 days after sowing (DAS), respectively. However, upland rice intercrop with rice bean showed the highest WSE than the others legumes. Similarly, under maize with legume intercrops *viz*., cowpea, groundnut, french bean and rice bean at 2:2 paired row cropping (45/75) with hand weeding at 20 DAS resulted in WSE of 45-70% and 35-88% at 60 and 90 DAS, respectively with highest under rice bean intercrop (**Fig. 7. 1 and 7.2**).

Maize + rice bean | Upland rice + rice bean

Fig. 7.2 Cereal with rice bean as intercropping

7.1 Yield and system productivity under cereal-legume intercropping

A recent shift in research priorities has helped to develop strategies to reduce crop–weed competition in cereals-legume intercropping systems, no much information is available for the hilly ecosystem of Mizoram. Such as appropriate crop species combination, particularly legumes on pre-dominantly upland rice and rainfed maize-based intercropping systems (*e.g.* optimum planting density or row spacing in the uplands) that holds immense importance in improving the productivity, food grain *vis-à-vis* nutritional security of the small farm holdings in the Mizoram. The finding shows that maize + groundnut (2:2 paired row cropping 45/75) with hand weeding at 20 DAS shows higher grain yield (276% higher than weedy check *i.e* 1022 kg/ha and 7.8% lower than sole maize with hand weeding at 20, 40 and 75 DAS) and higher system productivity (600% higher than weedy check and 76% higher than sole maize with hand weeding at 20, 40 and 75 DAS) (**Fig. 7.3)**.

Maize + groundnut (2:2 paired row cropping 45/75) with hand weeding at 20 DAS

Weedy check

Sole maize with hand weeding at 20, 40 and 75 DAS

Fig. 7.3 Comparative presentation of maize + groundnut intercropping system

The intercropping of upland rice with legumes showed that upland rice + groundnut (2:1 paired row cropping 20/30) with hand weeding at 20 DAS shows higher grain yield than any other combination with different legumes and it was 140% higher than weedy check (940 kg/ha) and 6.0% lower than sole upland rice with hand weeding at 20, 45 and 90 DAS (2425 kg/ha). Similarly, upland rice + groundnut (2:1 paired row cropping 20/30) with hand weeding at 20 DAS shows higher system productivity (nearly 350% higher than weedy check and 70% higher than upland rice with hand weeding at 20, 45 and 90 DAS) (**Fig. 7.4)**.

Upland rice + groundnut (2:1 paired row cropping 20/30) with hand weeding at 20 DAS

Weedy check

Upland rice with hand weeding at 20, 45 and 90 DAS

Fig. 7.4 Comparative presentation of upland rice + groundnut intercropping system

7.2 Conclusions

The fundamental characteristic of intercropping is to avoid unfavourable intra or interspecific competitions while facilitating inter-specific complementation for increasing the growth and yield of intercrops, suppressing weeds associated with the system and conserving the ecosystem. Cereal-legume intercropping is very useful in terms of enhancing system productivity, reducing weed infestation, and conserving the environment, soil and biodiversity. Based on results obtained from the study, it could be inferred that intercropping of upland rice and maize with legumes *viz*., cowpea, groundnut, french bean and rice bean provides nearly 50% weed smothering efficiency at different crop growth stages, provides better yield and system productivity. The following recommendations can be drawn from the findings:

- For the effective management of weeds under maize and upland rice, the use of rice bean (pole type) as intercropping is the best feasible eco-friendly option among the tested legumes. Hence, maize + rice bean under 2:2 paired row cropping (45/75) with hand weeding at 20 DAS, and upland rice + rice bean under 2:1 paired row cropping (20/30) with hand weeding at 20 DAS may be considered the best combinations for the hill ecosystem of Mizoram.
- While the best cereal with legume combination for higher yield and system productivity is intercropping with groundnut *i.e.*, maize with groundnut (2:2 paired row cropping 45/75) with hand weeding at 20 DAS, and upland rice with groundnut (2:1 paired row cropping 20/30) with hand weeding at 20 DAS.

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8

Fate of major used herbicides in Mizoram

8.1 Introduction

Herbicides are usually aimed at controlling weeds/unwanted plants interfering with our crop production. However, the methods of application and the subsequent influences of many physical, chemical and biological factors on these chemical often result in a more widespread re-distribution of the herbicides and their products away from the target area causing damage to non-target plants and animals.

In general, the ultimate fate of herbicides depends upon their interaction with different components of the environment. Several factors influence the persistency of applied herbicides. These includes microbial decomposition, chemical degradation, photodegradation, adsorption by the soil, surface runoff, leaching to groundwater, plant absorption and uptake, volatilization from plant and soil surface (**Fig. 8.1**)

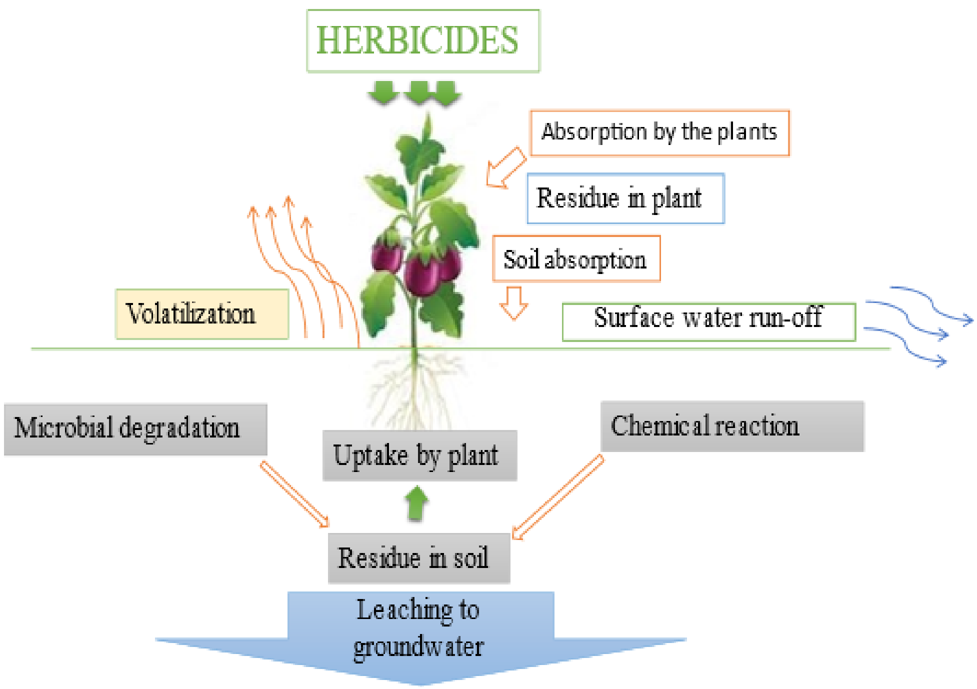

Fig. 8.1 Fate of herbicides after application

8.2 Fate of herbicides used in Mizoram

Owing to its geographical location, Mizoram comes under subtropical climatic region where the temperatures and rainfall are quite suitable for many plant species. These plants in crop field are a menace to crop production affecting the final yield. In order to control/ manage these weeds, herbicides like glyphosate, paraquat, pendimethalin, metribuzin, 2,4-D, imazethapyr, butachlor are commonly use.

8.2.1 **Glyphosate:** Glyphosate is the most popular and widely used herbicide in Mizoram. This is because of its effectiveness along with safety towards the environment. Chemically, it is highly soluble in water, moderately volatile and does not leach to groundwater. In soils, the persistency of this herbicide is low but may be persistent in certain aquatic systems. It is moderately toxic to mammals, birds and some beneficial organisms. However, glyphosate in pure form is low in toxicity to aquatic animal and wildlife. The toxicity in some glyphosate containing products may be due to other adjuvants in the formulation.

8.2.2 **Paraquat:** Paraquat which gets deposited on plant surfaces are subjected to photodegradation into metabolites with lower toxicity than parent compounds. On soil, it gets adsorbed to the soil surfaces which inactivates the herbicidal activity of the active ingredients. Many soil microorganisms act upon loose paraquat, but decomposition of adsorbed one is relatively slow. As a results, paraquat which gets adsorbed on soil has no adverse effects on soil microbial activities. Paraquat residues does not persists for long in water pertaining to adsorption by aquatic weeds and by strong adsorption to the bottom mud. It has low fish toxicity and very low bioaccumulation implying that normal applications of this herbicide for aquatic weed control are not harmful to aquatic ecosystem.

8.2.3 **Pendimethalin:** After application, pendimethalin gets bind to soil, undergo volatilization and metabolises by microorganisms. Owing to adsorption on soil, it is immobile in nature. When application is done by aerial and ground spray, it may contaminate surface water from spray drift. However, the strong attraction for pendimethalin to soil limits the pendimethalin concentrations in surface waters. If not used judiciously, it may adversely affect non-target organisms in both terrestrial and aquatic ecosystem.

8.2.4 **Metribuzin:** The major degrading factors of metribuzin are microbial metabolism and photodegradation on soil. These degraded compounds being non-volatile, will be leached to ground water and runoff to surface water in many use conditions. Metribuzin persist in ground water due to its stability to hydrolysis and the lack of light penetration. It is moderately toxic to avian species and less toxic to small mammals, but not toxic to bees, freshwater fish, moderately to slightly toxic to aquatic invertebrates, and highly toxic to non-target plants.

8.4.5 2,4-D: It degrades in soil having half-life of 1-14 days. But one of its forms, the butoxyethyl ester has a half-life of 186 days in aquatic sediment. In soil and water, it is decomposed by bacteria. Hydrolysis in presence of water can break down 2,4-D. Some of its ester forms are highly toxic to aquatic organisms. The sensitivity of their toxicity to aquatic animals reciprocates as water temperature rises. It is practically not toxic to honeybees and hazardless to other beneficial insects.

8.2.6 Butachlor: Butachlor use for controlling of annual grasses and some broad-leaved weeds as pre-emergence herbicide has a low water solubility and a low volatility. It is moderately persistent in some soils which does not leach to groundwater. It is moderately toxic to most fauna and flora, but low toxicity to bees and some of beneficial organisms.

8.2.7 Imazethapyr: Imazethapyr has moderate to very high mobility in soil. Its soil adsorption is weak to moderate. Volatilization loss of imazethapyr from the soil is also minimal. Soil microorganisms plays a limited role in the degradation of the formulated product. Under environmental condition, imazethapyr does not to undergo hydrolysis process due to the lack of hydroyl groups, but it undergoes photodegradation in presence of water.

8.3 Conclusions

Once an herbicide is introduced into the environment, it is acted upon by various processes. These processes determine a pesticide's mobility and its ultimate fate. These processes can be beneficial which enhance toxicity of the herbicides. Sometimes they can be detrimental, leading to reduced control of a target weeds, but harming the non-target plants and animals, and polluting the environmental. So, the use of such herbicides should be done judiciously under the guidance of experts with proper recommendation.

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Annexure I

Important terminologies related to weed

Acid Equivalent (*a.e.*): The theoretical yield of parent acid from an active ingredient in acid-based herbicides.

Acropetal: Movement of herbicide from roots to leaves.

Active ingredient (*a.i.*): Chemical in commercial product that is directly responsible for the herbicidal activity.

Acute toxicity: When the effect of herbicide is visible quickly or soon after the treatment.

Adjuvant: Material or chemical that can be added to herbicide in order to improve herbicidal effects and not to increase the innate activity of the herbicide.

Allelopathy: Any process involving secondary metabolites produced by plants, micro-organisms, viruses, and fungi that influence the growth and development of agricultural and biological systems (excluding animals), including positive and negative effects.

Annual weed: Complete their life in a season or year.

Aquatic weed: A weed plant either growing in water or has very high, requirement for water.

Biennial weed: Complete their life in two season or year; vegetative growth (1^{st} year/season) and reproductive stage (2^{nd} year/season).

Bioagent: A living organisms employed to control a pest.

Bioherbicides: It is formulation containing plant pathogen capable of mass production in-vitro that are applied directly to target weed uniformly to kill or suppress the weed growth.

Blanket spray: Application of herbicide uniformly over the entire field.

Broadcast: Uniform distribution of herbicide over the entire field after mixing in sand or fertilizer.

Broadleaf plants: Botanically those classified as dicotyledonous. Morphologically that those have broad and usually compound leaves.

Carrier: The liquid or solid material added to chemical compound to facilitate its application in the field.

Chronic toxicity: When a herbicide is not having quick effect and shows its phytotoxic effect after few days of application.

Compatible pesticides: Compound that can be mixed and applied together without undesirably altering their separate effects.

Competition: The active acquisition of limited resources by an organism that results in a reduced supply and consequently reduced growth of other organisms in an environment.

Concentration: The amount of active ingredient in given volume of diluent or given weight of dry material.

Contact herbicide: A herbicide that kills primarily by contact with plant tissue rather than as a result of translocation.

Critical period: The shortest time span in the ontogeny of a plant growth when a treatment will result in maximum effect.

Crop-weed association: Few weeds are more abundant in a crop but are not found in others.

Degradation: Alteration of herbicide molecule structure in plant or soil, leading to its inactivation.

Dormancy: State of suspended growth of seed or other plant organ due to internal causes even under favourable environmental conditions or it is temporary suspension of visible plant growth.

Early post-emergence treatment: In case of slow growing crop like potato, sugarcane non residual herbicide is applied to destroyed weed before emergence of crop *e.g.* Paraquat.

ED_{50} (Effective dose 50): Dose of a pesticide that would prove lethal to 50% of the population of a test, pest species (cf. LD_{50}).

Emulsifier: A surface active material that facilitates the suspension of one liquid in to another.

Emulsion: Heterogeneous mixtures of two or more products or a emulsion is one liquid dispersed in another liquid both maintaining their original identity.

Epinasty: Increased growth of the upper surface of a plant organ or part (especially leaves) causing it to bend downwards).

Formulation: A mixture of an active pesticide (herbicide) chemical with carriers, diluents or other materials, usually to facilitate handling and in usable form.

Grassy weed: Any weed plant of the Gramineae family characterized by narrow leaves with parallel veins, leaves composed of blade, sheath and ligule, jointed stem, fibrous roots and inconspicuous flowers usually arranged in spikelets.

Half-life: Time needed for half the pesticide to disappear from the scene; usually soil.

Herbaceous plant: A vascular plant that does not develop woody tissue.

Herbicide activity: ability of the herbicide to control a weed.

Herbicide persistence: The length of time that herbicide remains active in the soil.

Herbicide Residue: The quantity of herbicide that remains in soil after its mission is accomplished.

Herbicide Resistance: The ability of weed species to withstand the phytotoxicity of a herbicide at agricultural recommended rate.

Herbicide Selectivity: Ability of the herbicide to control a weed without affecting the other plants in a mixed stand.

Herbicide: A chemical used for killing or inhibiting the growth of plants; phytotoxic chemical.

Hill reaction: Photolysis of water chloroplasts. This process is involved in photosynthesis.

Hydrophilic: The character of substance having greater affinity for water and other polar solvents.

Integrated weed management: It is a system approach which brings all feasible methods of weed control, harmonizing them into a single and co-ordinated system designed to maintain weeds below level at which they cause economic loss.

Interference: It is combined effect of competition and allelopathy among plants.

Invasive alien weed: When any alien weed becomes so aggressive as to fast displace the indigenous flora of new ecosystem.

Lay by: Application of herbicide in between the rows of crop.

LD_{50} (Lethal dose 50): Lethal dose for 50% kill or this value represent the herbicide concentration required to inhibit plant growth by 50% or achieve plant kill by 50% compared to untreated plants (cf. ED_{50}).

Leaching: Refers to down ward movement of water along with herbicides in soil.

Lipophilic (hydrophobic): The character of substances having greater affinity for oil like surfaces and molecules but repelled by water.

Lipophobic (hydrophilic): Molecules or surfaces attracted towards water but repelled by oil-like surfaces or substances.

Mechanism of action: It is primary biochemical or biophysical reactions which bring about the ultimate herbicidal effects.

Mode of action: It refers to entire chain of events from first contact of herbicide with the plant to its final effect which could be death of plant. Mode of action is broader term than mechanism of action.

Non selective herbicide: A herbicide that is toxic to plants generally with regard to species.

Noxious weed: Undesirable, troublesome and difficult to control *e.g. Cyperus rotundus, Cynodon dactylon.*

Objectionable weed: Weed which produced seed that are difficult to separate once mixed with crop seed.

Obligate weed: Weed occur primarily in the cultivated fields where land is distributed frequently *e.g.* crop associated weed.

Perennial weed: A plant that lives for more than two years.

Persistence of herbicide: The duration for which the herbicide remains active in the soil.

Photo decomposition: degradation and loss of herbicide due to light.

Phytotoxicity: Poisonous to plants.

Post-emergence: Application of herbicide on emerged crop and weeds.

Pre-emergence: Application of herbicide before the emergence of crop and weeds.

Rate of herbicide: The amount of herbicide applied in terms of *a.i*. or *a.e*. per unit area.

Rhizome: The horizontal, slender, underground root like stem capable of sending out roots and leafy shoots.

Rogue: Any economical plant growing out of its proper place *e.g.* plants of barley in wheat fields

Rouging: The process of removing these off-type plants is called rouging.

Satellite weed: Weed with same shape and size as grain and extremely difficult to remove.

Selective herbicide: A herbicide that will kill some plant species when applied to a mixed population without serious injury to the other species.

Soil persistence: Refers to length of time that an herbicide remains effective in the soil and exhibits some degrees of phytotoxicity to some plant species.

Soil sterilant: Application of herbicide at higher rates which prevents germination of green vegetation for some period.

Solution: A physically homogenous mixture of solute and the solvent.

Solvent: Substances added to increase the solubility of toxicant.

Spot treatment: Application of herbicide to small patches of weeds, leaving the weed free gaps untreated.

Spray drift: The movement of spray particles by wind from the treated area to adjoining untreated area.

Spray volume: Total quantity of liquid applied as spray per unit area

Stolen: Stem that grow horizontally along the ground surface.

Surfactant: The material used for formulating herbicides which facilitates to improve spreading, wetting, dispersing and other surface-modifying properties.

Suspension: Liquid or gas in which very fine solid particles are dispersed but not dissolved.

Systemic herbicide: A compound which is translocated readily within the plant and has an effect throughout the entire plant system.

Tolerance: It is defined as the natural or normal variability of response to herbicides that exists within a plant species and can easily and quickly evolve.

Translocated herbicide: A herbicide which moves within plant from the point of entry to other plant parts.

Tuber: It is a swollen terminal part of an underground stem.

Vapour drift: The movement of herbicide vapours from the treated surface to non-target areas.

Volatility: The tendency of a chemical to vaporize or to give fumes after spraying *e.g.* 2, 4-D esters.

Weed Control Efficiency (WCE): It usually compares different methods/ treatments of weed control on the bases of their effect on weed density

$$\mathrm{WCE} = \frac{(\mathrm{WDc} - \mathrm{WDt})}{\mathrm{WDc}} \mathrm{x}100$$

WDc: Weed density in control plot

WDt: Weed density in treated plot.

Weed control: It is the process of lowering down the level of weed population by any method to the extent that economic crop production is ensured.

Weed ecology: Study of adaptive mechanism where weeds survive and persist under disturbed conditions.

Weed eradication: The complete elimination of all live plants, plant parts, and seeds of a weed infestation from an area.

Weed hardiness: Weed ability to withstand climatic, Edaphic and biotic stress.

Weed Index (weed competition index): Gain in crop yield due to weed control as percentage of yield from weed free crop.

$$WI = \frac{(X - Y)}{X} x100$$

X= yield from weed free plot (control plot)

Y= yield from treatment for which WI is to be worked out.

Weed management: Rational development of appropriate technology to minimize the impact of weeds, provide systematic management of weed problems, and optimize intended land use.

Weed Persistence: Ability to repeatedly invade an environment even when it was apparently removed from seen by some agent including man.

Weed prevention: Stopping of weeds from invading and contaminating new areas.

Weed shift: It is the change in the composition or relative frequencies of weeds in a weed population or community in response to natural or human made environmental changes in an agricultural system.

Weed smothering effect (WSE): It is the effect of intercrops on smothering of weed.

$$WSE = \frac{(WDs - WDi)}{WDs}$$

WDi: Weed dry matter in intercrop.

WDs: Weed dry matter in sole crop

Weed: Any plant that is objectionable or interferes with the activities and welfare of humans.

Wettable powder: A finely divided dry formulation (powder) that will readily form a suspension in water.

Wetting agent: A compound that when added to a spray solution causes it to contact plant surfaces more thoroughly.

Annexure II

Approved use of herbicides for Major field and Horticultural crops in India

Crop	Name of herbicide	Time for application	Type of weeds	Dosage/ha		Dilution in water	Waiting period (last application and harvest of crop in days)
				a.i. (g/kg)	Formulation in (g/ml/kg/L)		
Rice (upland/ aerobic)	Bispyribac Sodium 10% SC	10-15 DAS	*Fimbristylis miliacea, Eclipta alba, Ludwigia parviflora, Monochoria vaginalis, Alternanthera philoxeroides Sphenoclcea zeylenica*	20-25 gm	200-250 ml	300 L	78
	Pendimethalin 30% EC	PE	*Echinochloa colona, E. crusgalli, Fimbristylis miliacea, Marselia, Alternanthera sessilis, Ammonia baccifera, Ludwigra parviflora, Eclipta alba, Cyperus difformi*	light to heavy soil: 1.0-1.5 kg	3.3 –5.0 L	500-700 L	-
	Pretilachlor 30.7% EC	PE	*Echinochloa crus-galli, Echinochloa colona, Cyperus difformis, Cyperus iria*	0.45-0.60 kg	1.5-2.0 L	500 L	110
Rice (Transplanted)	Bispyribac Sodium 10% SC	10-14 DAP	*Ischaemum rugosum Cyperus difformis, Cyperus iria*	20-25 gm	200-250 ml	300 L	78

	Butachlor 50% EC	PE 1-3 DAT	*Cyperus difformis, Cyperus iria, Echinochloa crusgalli, Echinochloa colonum, Eleusine indica, Eclipta alba, Fimbristylis miliacea, Ludwigia parviflora, Sphenoclea zeylanica*	1.25-2.00 kg	2.5-4.0 L	250-500 L	90-120
	Butachlor 5% GR		*Echinochloa Crusagalli, Digitaria sanguinalis, Setaria spp., Commelina benghalensis, Fimbristylis ucullat, Cyperus iria, Eleusine indica, Panicum spp., Echinochloa Colonum, Eclipta alba, Cyperus Defformis, Ludwigia paviflora.*	1.25-1.87 kg	25.00-37.50 kg	-	90-105
	Anilofos 30% EC	3-5 DAT	*Echinochloa crus-galli, Echinochloa colonum, Cyperus difformis, Cyperus iria, Eclipta alba, Ischaemum rugosum, Fimbristylis sp., Marsilea quadrifolia.*	0.3-0.45 kg	1.5 L	375-500 L	30
	Anilophos 2% GR	PE, early post-em, 3-5 DAT)	*Echinochloa crus-galli, Echinochloa colonum, Ischaemum rugosum, Cyperus iria, Cyperus difformis, Fimbristylis sp.,*	0.4-0.5 kg	20-25 kg		30

	Chlorimuron-ethyl 25% WP	PoE, 2-6 leaf stage of weed	*Echinochloa crus-galli, Eclipta alba, Commelina benghalensis, Chenopodium album, Cyperus rotundus, Echinochloa colona*	6 g	24 g	500-600 L	60
	Pretilachlor 50% EC	PE, 3-7 DAT	*Echinochloa crus-galli, Echinochloa colona, Cyperus difformis, Cyperus iria, Fimbristylis miliacea, Eclipta alba, Ludwigia parviflora, Monochoria vaginalis, Leptochloa chinensis, Panicum repens*	0.50-0.75 kg	1.0-1.5 L	500-700 L	75-90
	2,4-D ethyl ester 4.5% GR (having 2,4-D acid 4% w/w)	PoE, 20-25 DAT	*Echinochloa colona, Echinochloa crus-galli, Panicum ischaemum, Cynodon dactylon (germinating), Cyperus rotundus (germinating), Cyperus iria, Cyperus difformis, Ludwigia parviflora, Monochoria vaginalis, Marsilea quadrifolia Cyanotis cucullata, Eclipta alba, Ammannia baccifera*	1.0 kg	25 kg	-	-
	Ethoxysulfuron 15% WDG	10-15 DAT	*Fimbristylis miliacea, Cyperus iria, Cyperus difformis, Scirpus sp., Eclipta alba, Marsilea quadrifolia, Ammannia baccifera, Monochoria vaginalis*	12.5-15 g	83.3-100 g	500 L	110

Maize	Alachlor 50% EC	PE, 0-3 DAS	*Echinochloa colona, Euphorbia hirta, Eleusine indica, Amaranths viridis, Digitaria spp., Echinochloa spp., Euphorbia hirta, Phyllanthus niruri, Portulaca oleracea, Trianthema portulacastrum*	2.5 kg	5 L	250-500 L	90
	Atrazine 50% WP	Early PoE (0-3 DAS)	*Trianthama monogyna, Digera arvensis, Echinochloa spp., Eleusine spp., Xanthium strumarium, Brachiaria sp., Digitaria sp., Amaranthus viridis, Cleome viscosa, Polygonum spp.*	0.5-1.0 kg	1-2 kg	500-700 L	-
	2,4-D dimethyl amine salt 58% SL	PoE	*Trianthema monogyna, Amaranthus sp., Tribulus terristris, Boerhavia diffusa, Euphorbia hirta, Portulaca oleracea, Cyperus sp.*	0.5 kg	0.86 L	400-500 L	50-60
	2,4-D sodium salt technical (having 2,4-D acid 80% w/w)	PoE	*Amaranthus viridis, Trianthema portulacastrum Phyllanthus niruri, Euphobia eniculate, Amaranthus spinosus, Cleome chelidonii, Lagascea mollis*	1.00 kg	1.25 kg	500 L	120 (PE), 90 (PoE)

	2,4-D ethyl ester 38% EC (having 2,4-D acid 34% w/w)	PoE	*Trianthema monogyna, Amaranthus sp., Portulaca oleracea, Tribulus terrestris, Boerhavia diffusa, Euphorbia hirta, Cyperus sp.*	0.9 kg	2.65 L	400-450 L	50-60
	Paraquat dichloride 24% SL	PoE, directed inter row application at 2-3 leaf stage of weeds	*Cyperus iria, Cyperus rotundus, Commelina benghalensis, Amaranthus sp., Echinochloa sp., Trianthema monogyna*	0.2-0.5 kg	0.8-2.0 L	500 L	90-120
Soybean	Alachlor 50% EC	PE, 0-3 DAS	*Amaranthus viridis, Cleome viscosa, Cyperus iria, Dactyloctenium aegyptium, Echinochloa spp., Eleusine indica, Setaria glauca*	2.5 kg	5 L	250-500 L	-
	Chlorimuron ethyl 25% WP	PoE, 15-20 DAS	*Eclipta alba, Commelina benghalensis, Chenopodium album, Cyperus rotundus, Cyperus iria, Parthenium hysterophorus, Acalypha indica, Phyllanthus niruri, Trianthema portulacastrum, Caesulia auxillaris*	9 g	36 g	300 L + surfactant 0.2 % (Iso-octyl phenoxylpoloxethanol 12.5%)	45

	Fluazifop-P-butyl 13.4% EC	PoE	*Echinochloa colona, Echinolchloa crus-galli, Eleusine indica, Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sp., Setaria sp.*	125-250 g	1000-2000 ml	500 L	90
	Imazethapyr 10% SL	PE, early PoE	*Cyperus difformis, Echinochloa colona, Echinochloa crus-galli, Euphorbia hirta, Croton sparsiflorus, Digera arvensis, Commelina benghalensis*	100 g	1.0 L	500-600 L	75
	Pendimethalin 30% EC	Pre-plant or PE	*Echinochloa spp., Euphorbia spp., Amarnanthus viridis, Portulaca oleracea, Trianthema spp., Eleusine indica*	0.75-1.0 kg	2.5-3.3 L	500-700 L	110
	Quizalofop-ethyl 5% EC	20-25 DAS	*Echinochloa crus-galli, Echinochloa coloma, Eragrostis sp.*	37.5-50 g	0.75-1.0 L	500-600 L	95
	Imazamox 35% + Imazethapyr 35% WG	PE, early PoE	*Echinochloa sp., Dinebra arabica, Digitaria sp., Brachiaria mutica, Commelina benghalensis, Euphorbia hirta*	70 g	100 g	375-500 L + surfactant (Cyspread) @ 1.5ml/ litre of water + Ammonium sulphate @ 2.0 gm/ litre of water	56

Groundnut	Alachlor 50% EC	PE, 0-3 DAS	*Acanthosermum hispidum, Flaveria australasica*	1.5-2.5 kg	3-5 L	250-500 L	20-150
	Imazethapyr 10% SL	PE, early PoE	*Cyperus difformis, Commelina benghalensis, Trianthema portulacastrum, Eragrostis pilosa*	100-150 g	1.0-1.5 L	500-700 L	90
	Pendimethalin 30% EC	PE	*Echinochloa colona, E. crusgalli, Fimbristylis miliacea, Marselia quadrifoliata, Alternanthera sessilis, Ammonia baccifera, Ludwigra parviflora, Eclipta alba, Cyperus difformi*	1.0-1.5 kg	3.3 –5.0 L	500-700 L	-
Green gram / Black gram/ Pigeonpea	Alachlor 50% EC	PE, 0-3 DAS	*Cynodon dactylon, Echinochloa spp., Digitaria spp., Cyperus rotundus, Commelina benghalensis, Chenopodium album*	2.0-2.5 kg	4-5 L	250-500 L	-
	Fluchloralin 50% EC	Pre-plant incorporation into the soil	*Digiteria sanguinalis, Echinochola crus-galli, Chenopodium sp., Argemone mexicana, Amaranthus spinosus, Portulaca sp.*	0.75-1.00 kg	1.5-2.0 L	750-1000 L	-

	Pendimethalin 30% EC	PE, 0-3 DAS	*Digiteria sanguinalis, Echinochola crus-galli, Chenopodium sp., Argemone mexicana, Amaranthus spinosus, Portulaca sp.*	0.75-1.00 kg	2.5-3.0 L	400-600	-
Tomato/Brinjal/ Chilli	Alachlor 50% EC	Pre-plant	*Chenopodium album, Anagalis arvensis, Convolvulus arvensis, Cyperus iria, Portulaca oleracea*	2.0 kg	4 L	250-500	-
	Fluchloralin 50% EC	Pre-plant incorporation into the soil	*Anagallis arvensis, Chenopodium sp., Portulaca oleracea, Fumeria parviflora, Commelina sp., Trianthema sp., Amaranthus spinosus*	1.0 kg	2.0 kg	750-1000	-
	Metribuzin 70% WP	Pre-transplanting or early PoE	*Anagallis arvensis, Chenopodium sp., Portulaca oleracea, Fumeria parviflora, Commelina sp., Trianthema sp., Avena fatua, Parthenium hysterophorus, Amaranthus spinosus, Euphorbia sp.*	0.525 kg	0.750 L	400-600	-
	Pendimethalin 30% EC	Pre- or post-transplant	*Digiteria sanguinalis, Echinochola crusgalli, Chenopodium sp., Argemone mexicana, Amaranthus spinosus, Portulaca sp.*	1.0 kg	3.0 L	400-600	-

Cabbage/ Cauliflower/ Onion/ Garlic	Fluchloralin 50% EC	Pre-plant incorporation into the soil	*Anagallis arvensis, sp., Portulaca oleracea, Fumeria parviflora, Commelina sp., Trianthema sp., Amaranthus spinosus*	1.0 kg	2.0 kg	750-1000	-
Potato	2,4-D dimethyl amine salt 58% SL	PE, PoE	*Chenopodium album, Asphodelus tenuifolius, Anagallis arvensis, Convolvulus arvensis, Cyperus iria, Portulaca oleracea*	2.0 kg	3.44 L	400	-
	Fluchloralin 50% EC	Pre-plant incorporation into the soil	*Anagallis arvensis, Chenopodium sp., Portulaca oleracea, Fumeria parviflora, Commelina sp., Trianthema sp., Parthenium hysterophorus, Amaranthus spinosus*	1.0 –1.5 kg	2.0-3.0 kg	750-1000	-
	Metribuzin 70% WP	PE, early PoE, 3-4 DAP	*Chenopodium album, Asphodelus tenuifolius, Anagalis arvensis, Convolvulus arvensis, Cyperus iria, Portulaca oleracea, Fumeria parviflora, Portulaca oleracea*	0.525 kg	0.750 L	400-600	-
	Oxyfluorfen 23.5% EC	PE	*Chenopodium sp., Coronpus sp. Trianthema sp., Cyperus sp., Heliotropium sp.*	100-200 g	425-850 mL	500-750	-

	Paraquat dichloride 24% SL	PoE inter-row application at 5-10% emergence	*Chenopodium sp., Anagallis arvensis, Trianthema monogyna, Cyperus rotundus, Fumaria parviflora*	0.5 kg	2.0 L	500	100
Turmeric/ turmeric	Pendimethalin 30% EC	PE	*Digiteria sanguinalis, Echinochola crus-galli, Chenopodium sp., Argemone, Amaranthus spinosus, Portulaca sp.*	1.00 kg	3.3 L	400-600	-
Non-cropped area	Glyphosate IPA salt 20.2% SL	PoE	All kind of weeds	0.82-1.23 kg	4.1-6.15 L	400-500	-
	Glyphosate IPA salt 41% SL	PoE	All kind of weeds	0.82-1.23 kg	2.0-3.0 L	500	-
	Glyphosate IPA salt 54% SL	PoE	All kind of weeds	1.8 kg	3.33 L	400-500	-
	Glyphosate ammonium salt 5% SL	PoE	All kind of weeds	2 kg	40 L	500	-
	2,4-D sodium salt technical (having 2,4-D acid 80% w/w)	PoE	*Parthenium hysterophorus Cyperus rotundus* *Solanum elaeagnifolium*	2.5-6.0 kg 4-8 kg 1.8 kg	3.2-7.5 kg 5-10 kg 2.25 kg	600-1000 500-600 500-600	-
	Paraquat dichloride 24% SL	PoE	All kind of weeds	1.0 kg	4.16 kg	400-600	-

PE: Pre-emergence, PoE: Post-emergence

Source:

Anonymous 2023a. Central Insecticide Board & Registration Committee, Directorate of Plant Protection, Quarantine & Storage , Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. https://ppqs.gov.in/divisions/cib-rc/major-uses-of-pesticides (Accessed on 12.03.2023).

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