PRACTICAL MANUAL

On

WEED MANAGEMENT

2019

Jharkhand Rai University

Ranchi

PREFACE

Weeds are probably the most ever-present class of crop pests and are responsible for marked losses in crop yields. Of the total losses caused by pests, weeds have a major share (30%). They reduce the crop yield and deteriorate the quality of produce and hence reduce the market value of the turnout. Therefore, management of weeds in all agro-ecosystems is imperative to sustain our crop productivity and to ensure the food security to the burgeoning population.

There has been a long-felt need for a practical manual on weed management. This manual is a precise account of various practical aspects of weed management presented in a simple language suitable for Weed Management (13A.271) students. The information on weed identification of common weeds present in field crops, aquatic systems, non-cropped areas and preparation of weed herbarium based on leaf, shape, margins and venation, flower and fruits shapes, determination of crop-weed competition will help to know the nature and extent of weed problem so that an efficient weed management strategy could be worked out. The manual also provides useful information on practical use of herbicides-their application techniques, calibration of the spray pumps, herbicide, and different types of calculations in all uses of the herbicides in field supported by photographs, practical exercises and examples.

With all these varied aspects covered in the manual, we hope this will fulfill the requirement of a much needed standard document on practical training on weed management not only for the students but also for the teachers, scientists and others involved the field of weed management. The authors would welcome additional information and suggestions from students and teachers to improve the manual.

18 July , 2019

Dr.A. Kumar

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1. Weed identification

Correct identification is the foremost step in working out strategy for controlling weeds. Knowledge of morphology is most important in the identification of weeds. There are approximately 250,000 species of plants in the world. However, less than
250 plant species, about 0.1% are troublesome enough to be called universally throughout the world. It is surprising that relatively few plant species make up the majority of agricultural weed problems worldwide. Furthermore, nearly 70% of these weed species occur in only twelve plant families and over 40% are found in only two families: Poaceae (grass) and Asteraceae (sunflower or composite). It is sometime necessary to distinguish only broadly among weed species. In such situation distinction among grasses, sedges and broadleaf (dicot) plants may be sufficient, and a much abbreviated system of classification is satisfactory. Such a system was once in common use by weed control specialists and has been described as monocots and dicots.

Monocots: Plants whose seedlings bear only one cotyledon. Monocots are typified by parallel venation and flower parts in three or multiples of three. Most monocot weeds are found in only two groups, grasses and sedges, although other groups exist.

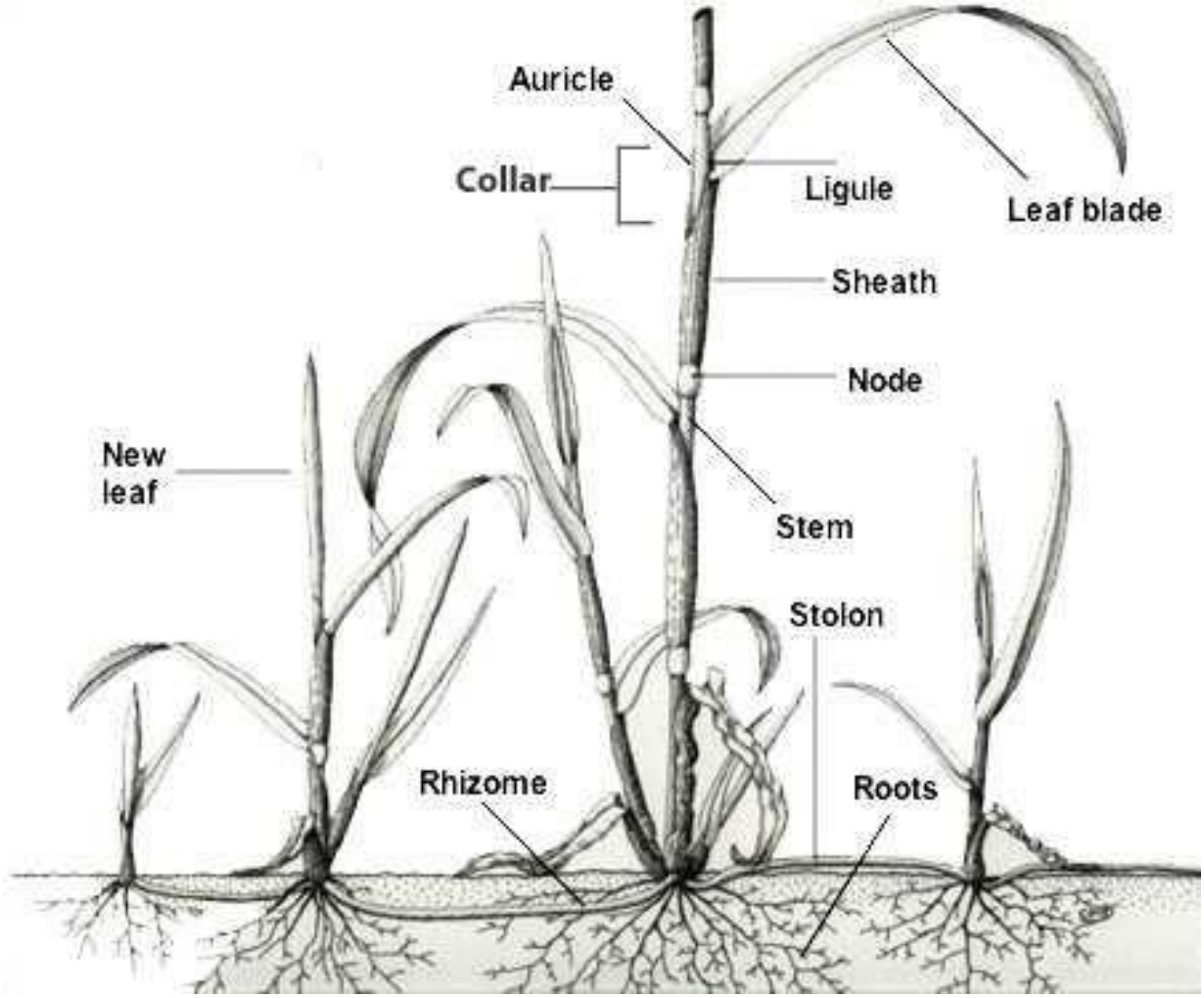
Grasses: Leaves usually have a ligule or at times an auricle. Leaves are narrow, arranged in sets of two. The leaf sheaths are split around the stem, with the stem round or flattened in cross section with hollow internodes.

Sedges: Leaves lack ligule and auricles, and the leaf sheaths are continuous around the stem. Leaves are narrow, arranged in sets of three. In many species the stem is triangular in cross section with solid internodes.

Dicots: Plants whose seedlings produce two cotyledons or seed leaves. Dicots are usually typified by netted leaf venation and flowering parts in fours, fives, or multiples thereof. Leaves are wide. They are commonly called broadleaved plants. Examples include mustards, nightshades and morning glory.

Grass weed characteristics

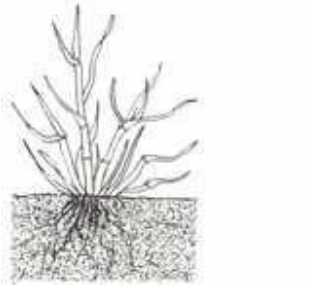
Grasses have narrow leaves with parallel veins and small, inconspicuous flowers. Stems are usually round and have visible bulges or joints where the leaves attach (nodes). They are usually hollow except at the nodes.



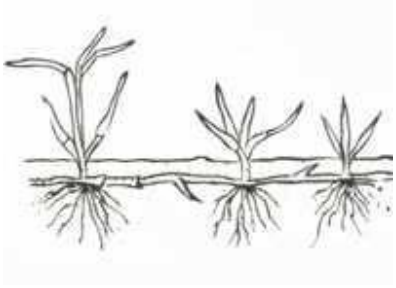
Growth habits

Grasses have either a bunchy growth habit or creeping (spreading) growth habit.

Bunchy



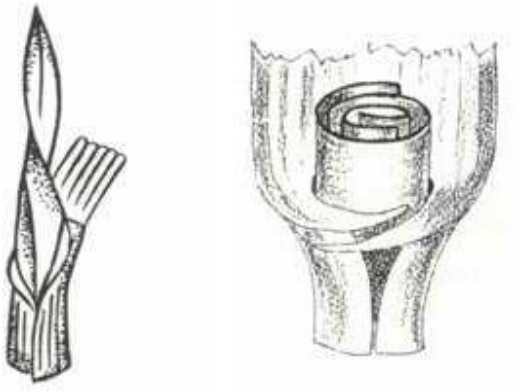
Creeping



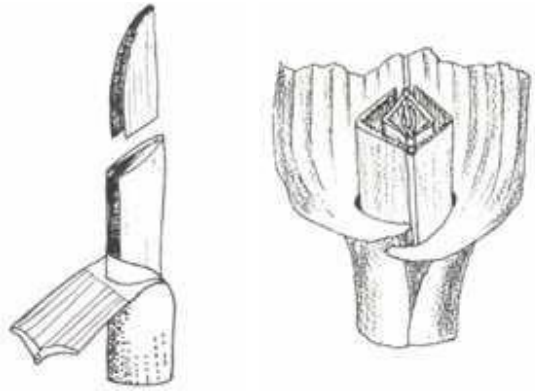
Seedlings (new leaf blades)

New leaves are either rolled or folded in the bud.

Rolled



Folded



Leaves (leaf blades and tips)

Leaves may be flat, rolled, or twisted, and vary by width and by the shape of their tips.

Tips

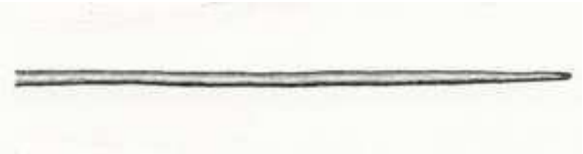
Boat-shaped

Pointed

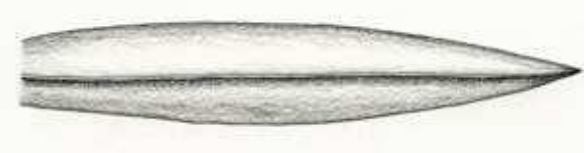
Blades

Parallel sided

Needle-like



Tapering

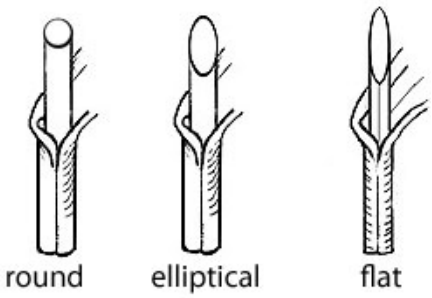


Constricted at base

Twisted

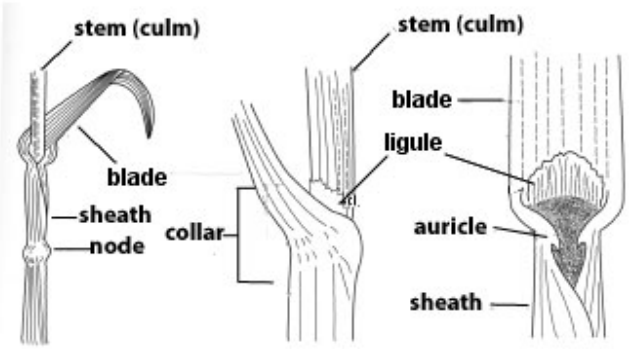
Stems

Stems (culms) grow up from the base of the plant (the crown) and are rounded or angled in cross-section. In most grass species, stems are hollow, except where leaves attach to the stem (joints or nodes).



Collar

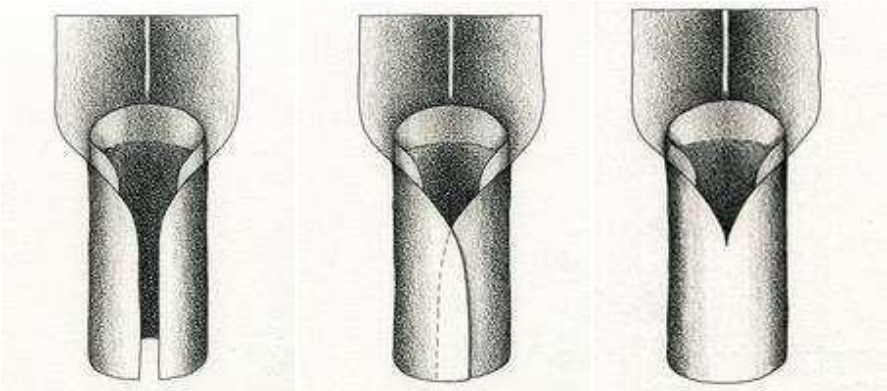
The collar region of the leaf blade is most useful for identifying grasses before they flower (flower heads may provide a more obvious means for identification). The collar marks the junction between the blade and the outer sheath on the outside of the leaf. It consists of the leaf blade, sheath, ligule, and auricles. These parts vary in appearance according to plant species, and therefore are used in identification.



Sheaths

The lower portion of the leaf blade that encircles the stem is the sheath. Sheaths vary in structure and, therefore, are used in identification. Below are different sheath types.

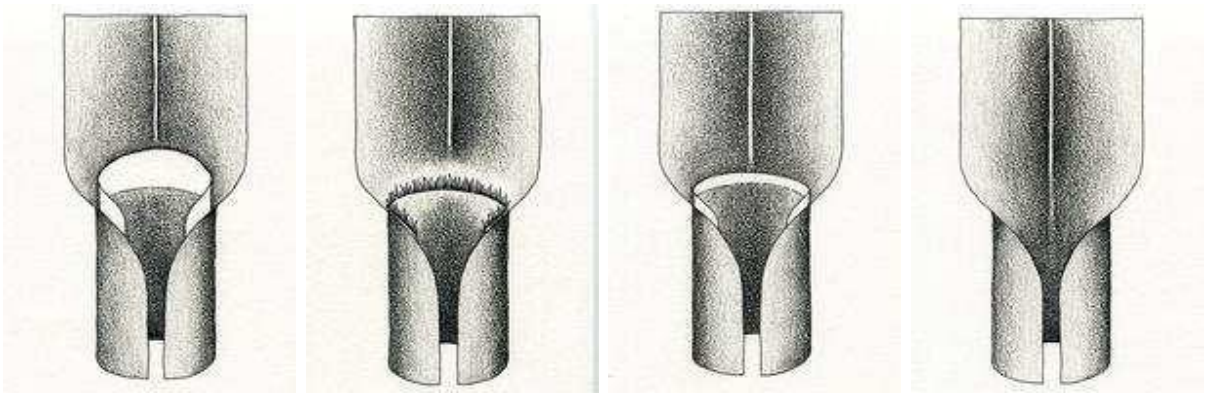
Split **Overlap** **Fused**



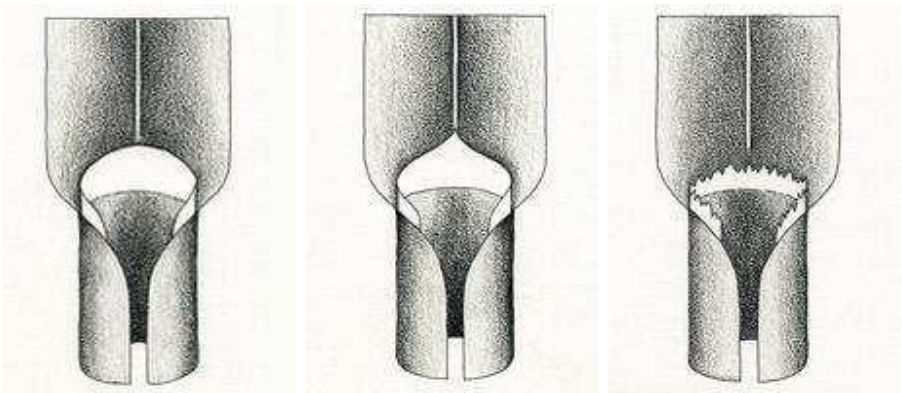
Ligules

A ligule is an outgrowth from the sheath. Because they vary in size, shape, and texture, they are used in the identification process. Below are several examples of ligule types.

Membranous **Fringe of hairs** **Truncate** **Absent**



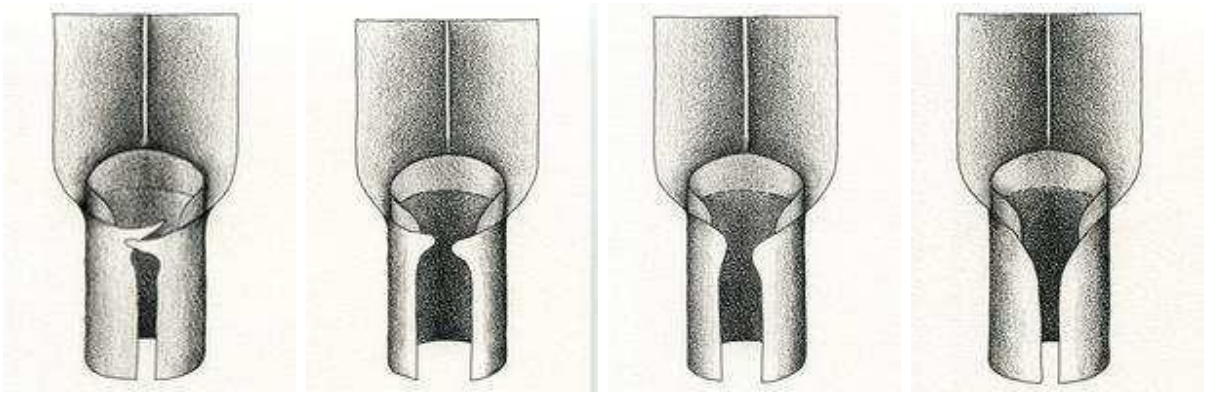
Rounded **Tapered** **Scalloped or toothed**



Auricles

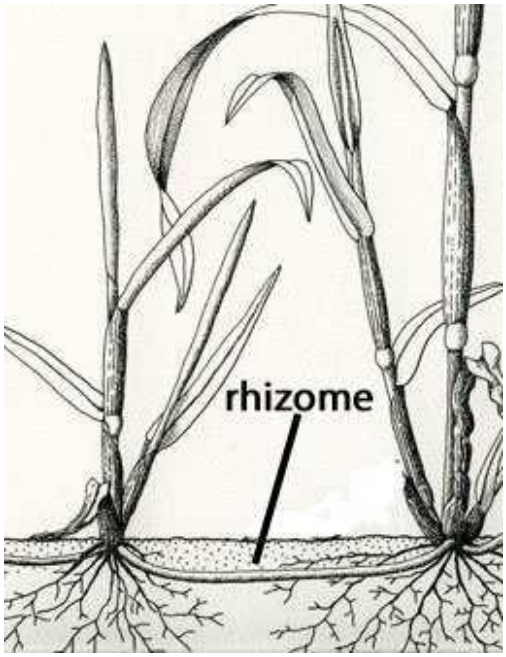
Auricles are small, clasping outgrowths that may or may not be present on the leaf collar. Because they vary in size and shape, they are used in the identification process. Below are examples of different types of auricles.

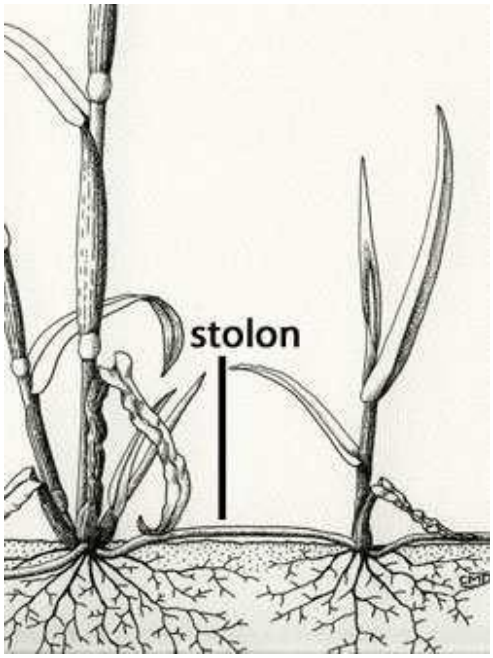
Claw-like **Rounded** **Not fully developed** **Absent**



Specialized Stems

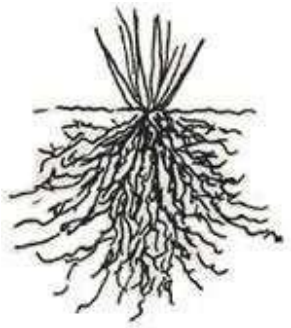
Stolons and rhizomes are specialized stems that send out roots and shoots from their joints (nodes). Rhizomes are usually found under the ground, and stolons, along the soil surface. Both provide plant with a creeping, spreading grown habit.





Roots

Grasses have fibrous roots.

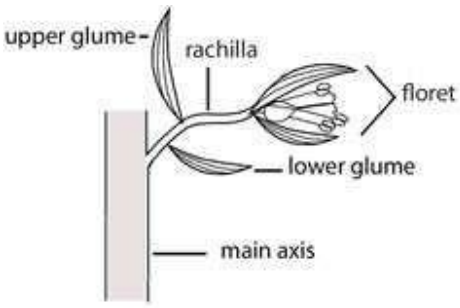


Grass flower heads

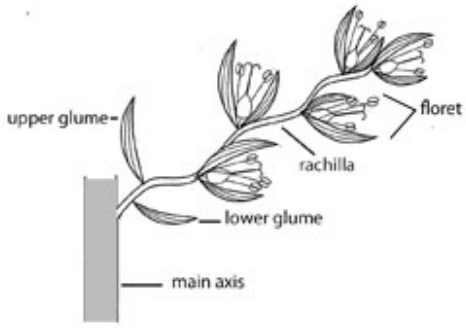
The flowering stem (flower head) is useful in the identifications of grasses. Flower heads of grasses are described according to the arrangement of a special floral unit called a spikelet rather that of the individual flowers.

A spikelet consists of one or more flowers (florets) plus two basal membranes (glumes). The spikelet is attached to an un-branched axis called the rachilla (see illustrations below).

Spikelet with one floret



Spikelet with several florets

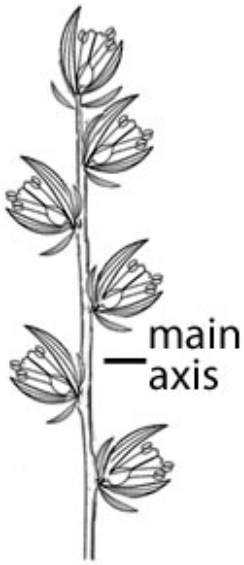


Different flowering head structures can be distinguished by the presence or absence of branching along the flower stem (main axis) and the presence or absence of stalks beneath the spikelets. The three basic arrangements in grasses are spike, raceme, and panicle flower heads.

Spike

Main axis does not branch.

Spikelets are stalkless.



Raceme

Main axis does not branch.

Spikelets are stalked.

Panicle

Main axis branches. Spikelets are stalked.

Below are examples of grasses

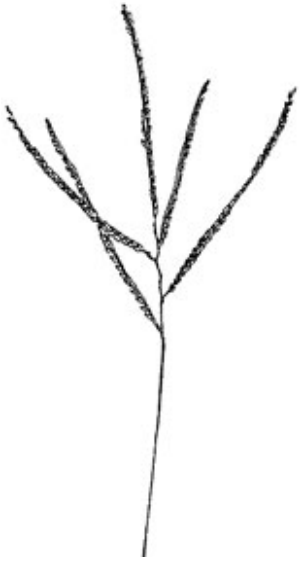
Examples of spike flower heads

Quackgrass

Hare barley

Foxtail barley

Examples of raceme flower heads



Smooth crabgrass

Dallisgrass

Examples of panicle flower heads

Fall panicum

German velvetgrass

Wild oats

Sedges characteristics

Sedges are perennial plants that are commonly found in shallow water or moist soils and can reach 4 feet in height. They resemble grasses and often grow in thick clusters.

Stems

Sedge stems are usually solid and triangular in cross section, which differentiates them from grasses, which are usually round and hollow (except for where the leaves attach to the stem).

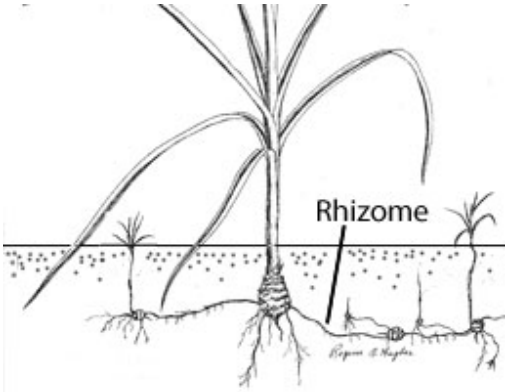
Leaves

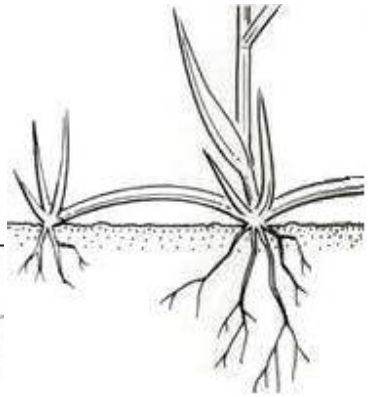
Many species have long, thin-textured, narrow, flat leaves which are usually arranged in threes.

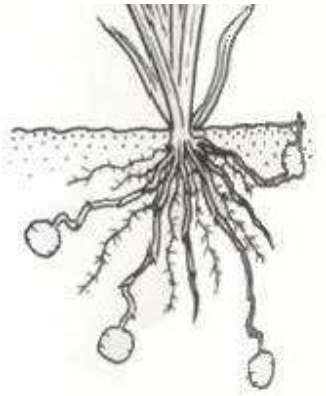
Root systems and tubers

Sedges have a fibrous root system and may spread by underground rhizomes and/or aboveground stolons. Many sedges have tubers from which new plants can form.

Creeping growth habit, spreading by underground rhizomes	**Creeping growth habit, spreading by aboveground stolons**	**Root system with tubers**

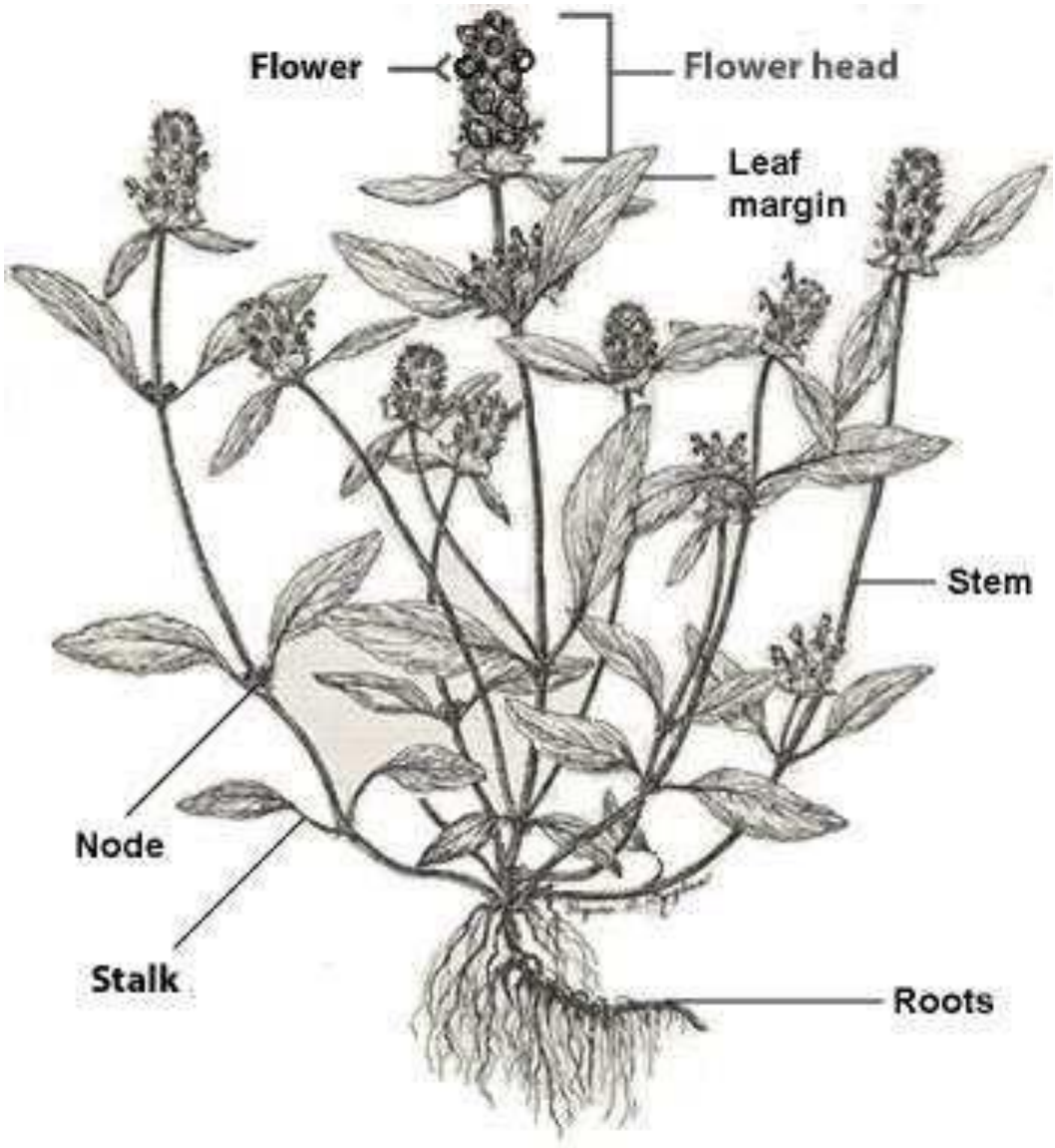






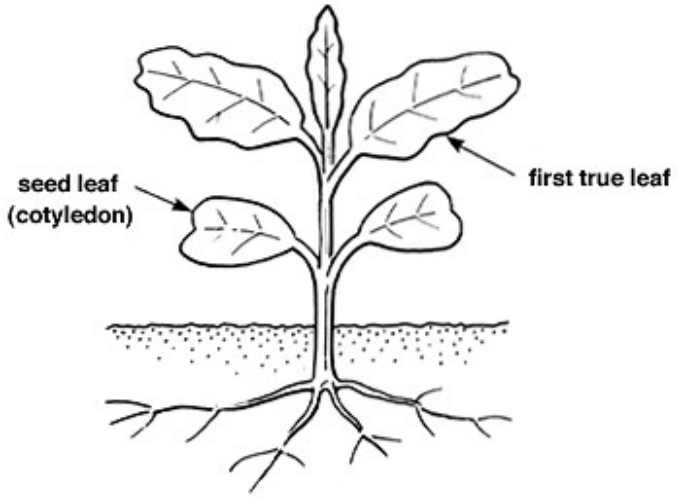
Broadleaf characteristics

Broadleaf plants have relatively broad leaves, whereas leaves of grasses and sedges are bladelike. Leaves of broadleaves have one main vein from which smaller veins branch.



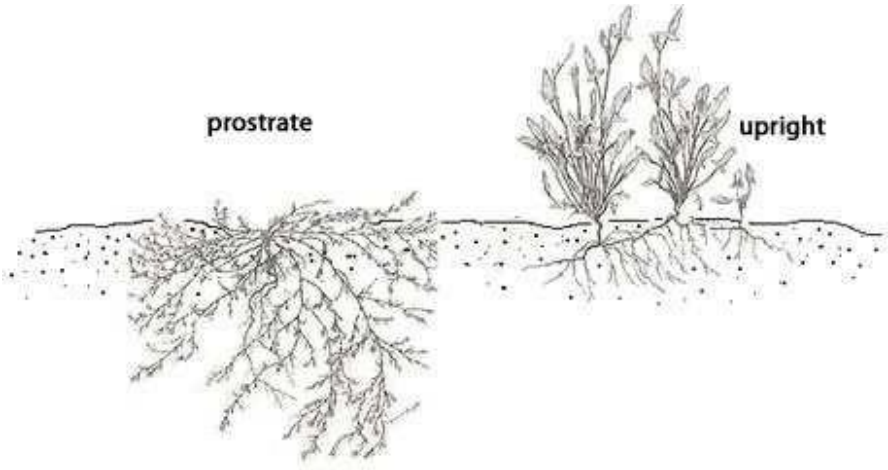
Seedlings

The cotyledon (seed leaf) and first true leaf are characteristics commonly used in identifying broadleaf weeds.



Growth habit

Broadleaves may grow prostrate and form a mat or they may grow upright.

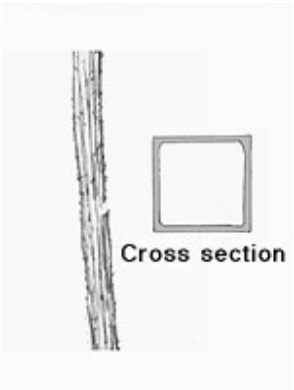


Stems

Stems may be rounded or angled in cross section.

Round

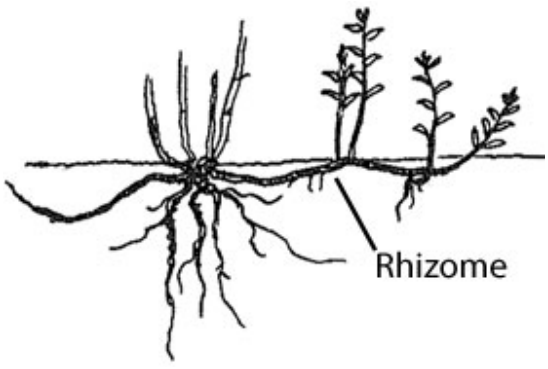
Square



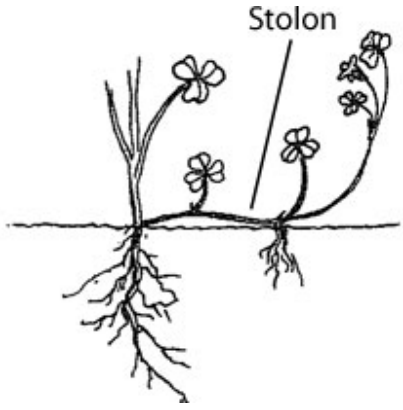
Specialized stems

Specialized stems, rhizomes and stolons, typically spread horizontally. Rhizomes are belowground creeping stems that often send out roots and shoots from their nodes. Stolons are creeping stems that form near the surface of the ground. They produce rooted plantlets at their nodes and ends.

Creeping growth habit, spreading by underground rhizomes.



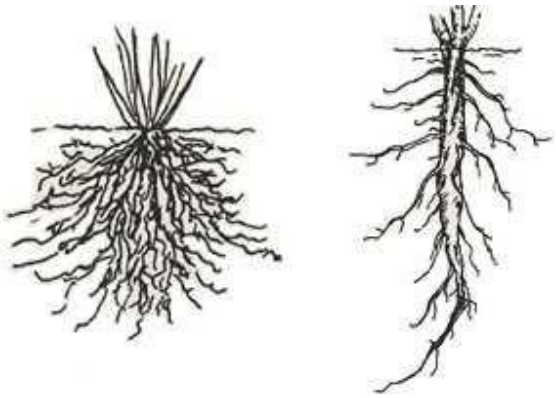
Creeping growth habit, spreading by aboveground stolons.



Roots

Broadleaves have a fibrous root system made up of several thin roots, a large primary taproot with smaller lateral roots, or a hybrid of both.

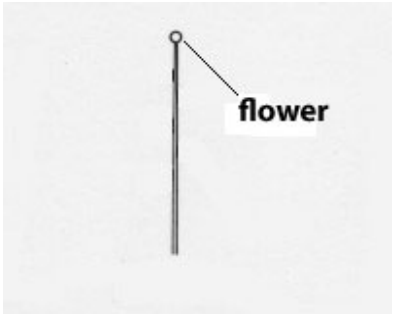
Fibrous root system **Tap root**



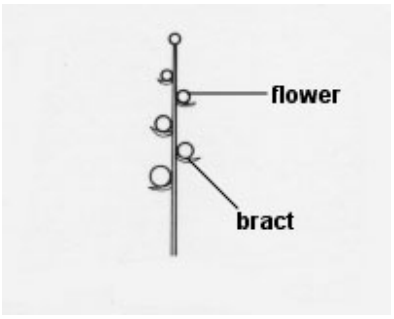
Flowers and flower heads

Some plants bear one flower per stem. Others bear many flowers per stem.

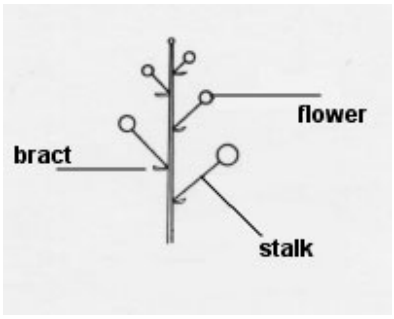
Single Flower



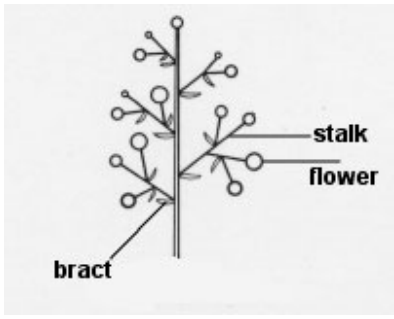
Flower Clusters



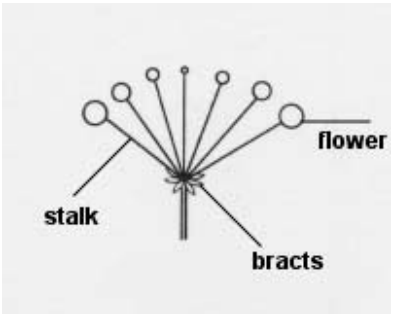
Spike



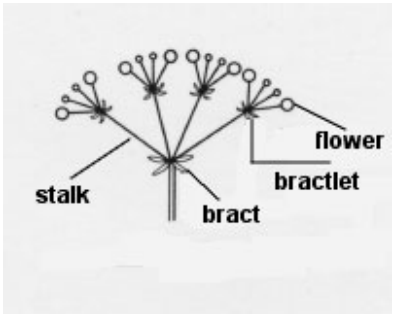
Raceme



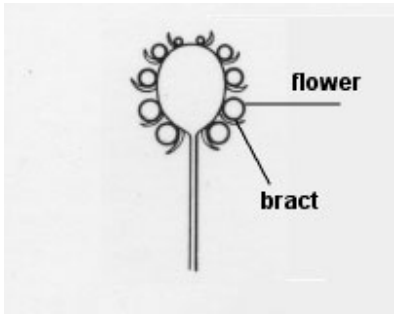
Panicle



Umbel



Compound umbel

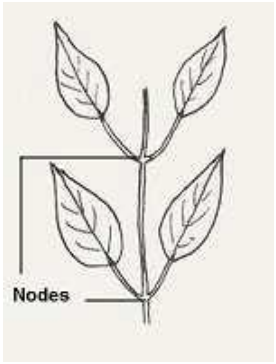


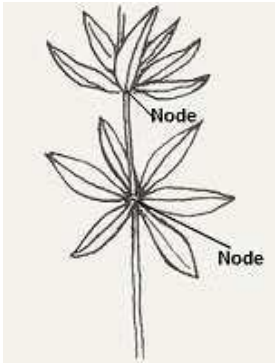
Composite head

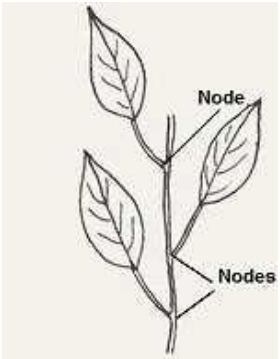
Leaf arrangements

Leaves are arranged along the stem in a variety of ways according to how they attach at stem joints (nodes).

Leaves are opposite (2 leaves per node)	Leaves are whorled (3 or more leaves arranged around a node)	Leaves are alternate (1 leaf per node)	Leaves form a basal rosette (1 leaf per node, but clustered around the stem at ground level)


Nodes


Node
Node


Node
Nodes

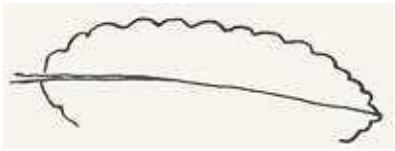

Node

Leaf margins

The type of leaf edge (margin) is another way to identify a plant.

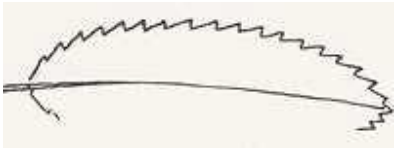
Smooth (enitre)

Rounded teeth (crenate)

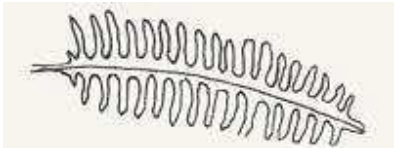


Lobed

Pointed teeth (serrate)



Feathered (pinnatifid)



Leaf shapes

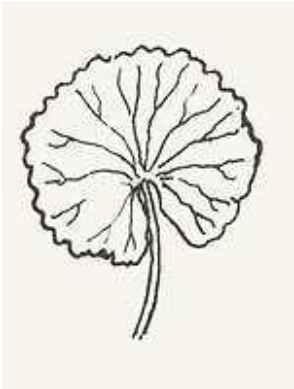
Leaves vary in shape.

Deeply cut (dissected)

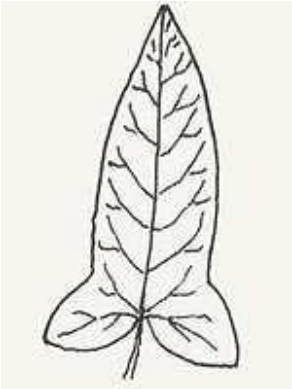
Heart (chordate)

Football (elliptic)

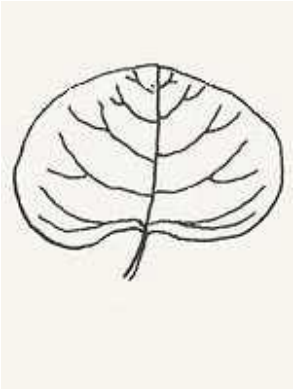
Round (orbicular)



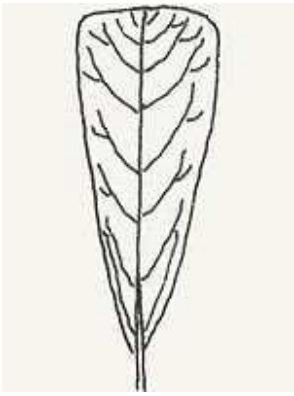
Arrow (hastate)



Kidney (reniform)

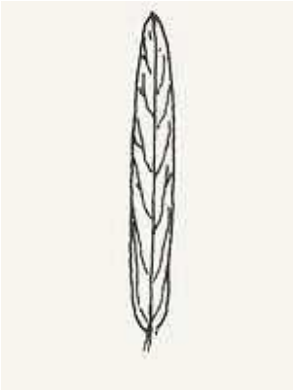


Wedge (cuneiform)



Lance (lanceolate)

Narrow (linear)



Oblong

Egg (obovate—tip rounded)

Egg (ovate—tip narrowed)

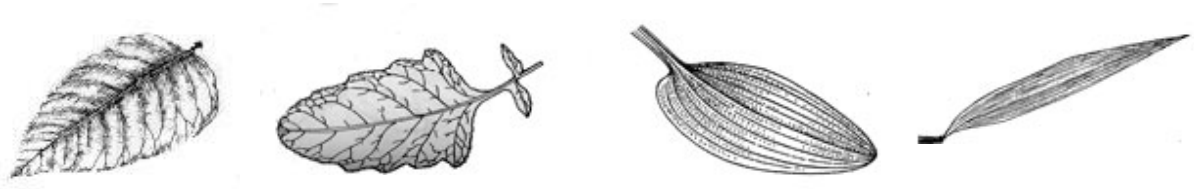
Leaf veins

Depending on the type of plant, leaf veins are either parallel or netted in pattern.

In leaves with netted veins, major veins branch from the main ribs and subdivide into finer veinlets. Fruit and deciduous trees, vegetable plants (not corn), most wildflowers, and many shrubs and flowers are examples of plants with netted veins. In leaves with parallel veins, major veins most commonly run parallel to each other the length of the leaf. Less typically parallel veins run laterally from the midrib of the leaf to the leaf edge (not shown). Examples of plants with parallel veins are sedges, cattails, lilies, irises, and grasses (e.g., corn, rice, wheat, turf grasses).

Netted veins **Parallel veins**

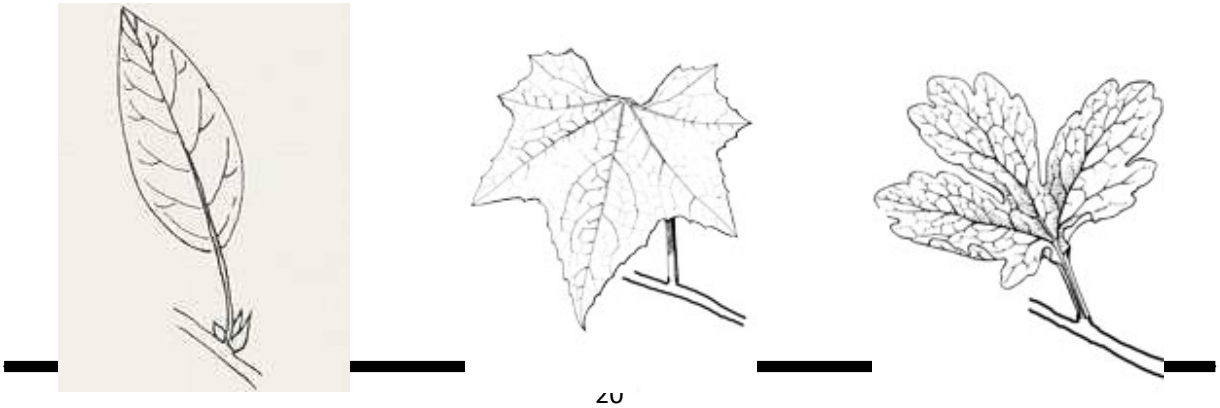
(broadleaves) **(broadleaves)** **(grasses, sedges)**



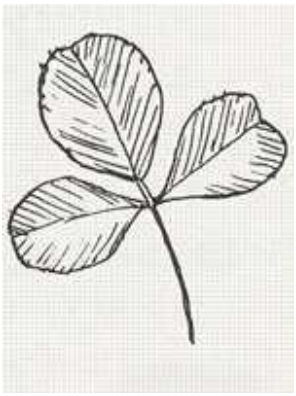
Simple and compound leaves

A simple leaf is a leaf blade that is one piece, although it may be deeply lobed, divided or dissected. A compound leaf is a leaf with 2 or more distinct leaflets.

Simple leaves



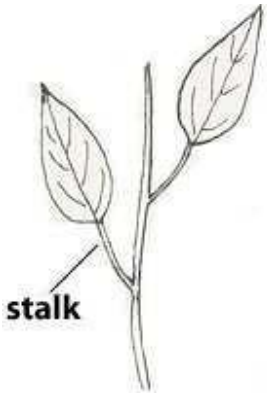
Compound leaves

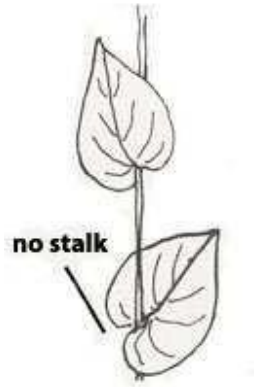


Leaf Stalks (petioles)

Leaves may be attached to the stem by a petiole (short stalk) or may be sessile (attached directly to the stem). Some sessile leaves clasp the stem.

Leaves are attached to the stem by a stalk (petiole).	Leaves are stalkless and attached directly to the stem.	Leaves are stalkless, attached directly to the stem, clasping it.





RABI WEEDS

Phalaris minor

Avena ludoviciano

Polypogon mospliensis

Poa annua

Lolium rigidum

Chenopodium album

Coronopus didymus

Rumex dentatas

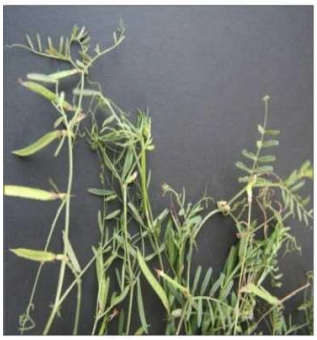
Fumaria parviflora

Convoluvulus arvensis

Chenopodium muerale

Asphodelus tenuifloius

RABI WEEDS



Vicia sativa

Melilotus indica

Medicago denticulata

Cichorium intybus

Anagallis arvensis

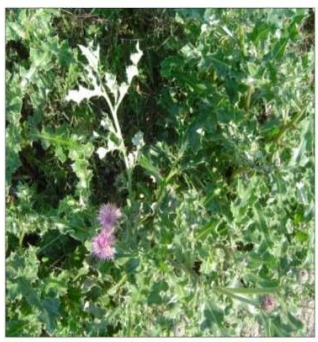
Malwa parviflora

Stellaria media

Rumex spiniosus

Argemone maxicana

Lathyrus aphaca



Cirsium arvense

Pluchea lanceolata

KHARIF WEEDS

Trianthema portulacastrum

Digera arvensis

Physallis minima

Euphorbia hirta

Corchorus tridems

Celosis argentia

Crotolaria medicaginea

Cleome viscosa

Mollugo cerviana

Cenchrus ciliaris

Cyperus rotundus

Cenchrus longispinosus

KHARIF WEEDS

Dactyloctenium aegypticum

Brachiaria reptans

Eleusine indica

Bulbostyllis barbata

Digitaria sanguinalis

Amaranthus viridis

Tribulus terrestris

Amaranthus spinosus

Phyllanthus niruri

Ipomoea pestigridis

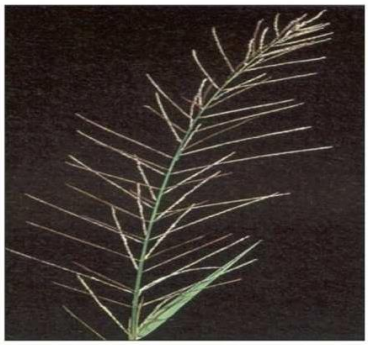
Corchorus olitorius

Ipomoea lacunosa

GRASSY WEEDS AND SEDGES IN RICE

Echinochloa colona

Echinocnloa glabrescens



Leptochloa chinensis

Ischaemum rugosum

Eleusine indica

Cyperus difformis

Eleocharis

Cyperus rotundus

Cyperus iria

Scirpus supinus

Paspalum distichum

Scripus maritimus

BROADLEAF WEEDS OF RICE

Sphenoclea zeylenica

Ammania baccifera

Caesulia axillaris

Eclipta alba

Ipomoea aquatica

Lemna minor

Ludwigia parviflora

Marsilea qauderifolia

Saggitaria guanensis

Commelina benghlensis

Monochoria vaginallis

Mazus spp.

PERENNIAL WEEDS

Desmostachya bipinnata

Imperata cylindrica

Cynodon dactylon

Achyranthus aspera

Lantana camara

Abutilon indicum

Croton sparsiflorus

Calotropis procera

Ipomoea carnea

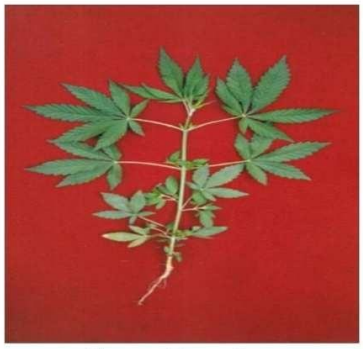
Sorghum halepense

Ageratum conyzoides

Suaeda fruticosa

NONCROPPED AREA WEEDS

Parthenium hysterophorus



Cannabis sativa

Xanthium strumarium

Helianthus annus

Carthamus oxycantha

Cirsium arvense

Boerhavia diffusa

Argemone maxicana

Datura stramonium

Cassia occidentalis

Cassia tora

Sida acuta

AQUATIC WEEDS

Eichhornia crassipes

Typha angustata

Salvinia molesta

Potamogeton nodosus

Hydrilla verticillata

Nymphea odrata

Nelumbo lutea

Vallisneria spiralis

Trapa natans

Pistia stratiotes

Najas minor

Alterneenthra philoxeroides

PARASITIC WEEDS

Inflorescence of Orobanche

Orobanche aegyptiaca infestation in mustard

Cuscuta chinenesis infestation on clordendron and lucern

Loranthus infestation on tree

Loranthus

Striga asiatica

Striga asiatica flower and seeds

2. To become familiar with mode of propagation of weeds and their Biology & occurrence.

Objectives

(i) To identify weed seeds and their propagules viz., root stocks, rhizomes, stolons, tubes, bulbs, bulbils, stem, roots etc.

(ii) to recall methods of propagation and agents of weed seed dispersal,

(iii) to study various appendages which help weeds in their dissemination,

(iv) to know the importance of seeds and,

(v) to acquaint about the habitat or occurrence of weeds.

Propagation of weeds

A sound knowledge of the biology of weeds with particular reference to their propagation and dispersal behaviour is essential for planning their management.

Methods of propagation

A. Sexual reproduction/propagation through seeds

In this method, fusion of male (pollen) and the female gametes (egg) takes place to form the embryo. The majority of weeds reproduce by distinct seed formation which is prolific particularly the annuals and biennial species. Such weeds are capable of producing easily thousands of seeds per plant every season at the termination of their vegetative stage. In the perennial species, on the other hand, the viable seed production capacity is much limited. e.g. *Cyperus rotundus* and *Cynodon dactylon* produce only 40-170 seeds per plant. But there are exceptions of this generalization. The perennial weeds like *Sorghum halepense* and *Saccharum spontaneum* produce thousands of seed per plant every year in the same fashion as the annual weeds. Weed seeds (and fruits) differ widely in their shape and size as well as in their viability. Many of these can germinate immediately after harvest, whereas, others remain dormant for short or long periods/ before reviving their viability. Weedy ferns, algae and *equisetums* reproduce by spore formation.

B. Propagation through vegetative propagules

In this method, either stem or root fragments of weeds cut or detached from mother plant grow into new plants or the weeds may produce specific vegetative organs for this purpose, both above and under the ground. These modifications may be in the form of rhizomes, root stocks, runners, stolons, suckers, offsets, tubers, bulbs or bulbils. Collectively these are termed as vegetative propagules. The vegetative propagation is primarily a feature of perennial weeds which employ one or more of the above cited propagules to achieve the objective, depending upon the weed species.

Besides the perennial weeds, some annual weeds can also adopt specific propagation mechanism. Such weeds vigourate their crown buds to produce new plants when the parent plants are cut at the ground level. Carrot grass (*Parthenium hysterophorus*), *Lantana camara* and arrow weed (*Pluchea lanceolata*) are some weeds of this type.

Weeds equipped with vegetative propagation are extremely difficult to manage since their propagules are located upto 100 cm soil depth where these are not easily approachable even with deep tillage or any available herbicide. . Roots of *P. lanceolata* may hit several metres deep and remain undisturbed by any deep tillage tool. Even if shallow roots and rhizomes of weeds are reached by tillage, it only tends to fragment and disseminate them to help their further propagation. In the destruction of perennial weeds with herbicides too, the depth of their propagules is vitallyobstructive.

Biology of weeds

Biology and habitat of few weeds are discussed below:

Bermuda grass

Cynodon dactylon is a perennial weed growing largely from rootstocks and stolons. Although it produces seeds, yet these are not important in its dissemination. Bermuda grass rootstocks form dense sod inside the soil and its stolon creep over the land , extensively. The grass grows round the year but vigorous under warm and moist conditions.

Diagram

Nutsedge *(Cyperus* spp.)

There are two common species of nutsedge,namely,*Cyperus esculentus* L(yellow) and

C. *rotundus*(purple).A purple nutsedge plant possesses a prominent basal bulb just below the ground level .This basal bulb produces a chain of tubers which ramify as deep as 60 cm in the soil. But in yellow nutsedge, instead of basal bulb there are crown buds a little below the soil surface which give rise to cluster of short rhizomes ending in small tubers. When mother shoots of yellow nutsedge are destroyed by tillage, new aerial shoots are borne by these crown buds.

Chief mode of propogation of yellow nutsedge is from seeds(nuts). Its tubers are small and slow growing.During the first one month of purple nutsedge, a mother tuber can produce four daughter tubers, and in three months the tuber population may reach almost 100. This makes purple nutsedge much more problematic than yellow nutsedge.

Diagram

Carrot grass (*Parthenium hysterophorus*)

Carrot grass is an annual plant,with wide amplitude of ecological adaptability;being both photo and thermo insensitive.It reproduces itself freely from numerous seeds(5000-10000 per plant). When mother plant is cut , its cropwn bud produces new shoots.

The weed is notorious for causing allergic dermatitis and mental depressions in human beings.The main toxin responsible is parthenin. In summers , carrot grass tends to stunt its growth and remain in rosette form.It shoots up new growth in the rainy season and

grows fast through the winters, attaining a height oup to 90 c, with profuse branching The plant flowers and sets seeds throughout its growing period.

Diagram

Safed murga (*Celosia argentia*)

It is a herbaceous annual weed. It propogates through seeds which germinate with the onset of rains. The inflorescense is pinkish- white and can be recognized from a distance in a crop field. The plants have numerous lateral roots just a few centimeters below the soil surface which enable efficient absorption of nutrients from the soil. The plant has shallow root system.

Diagram:

Ex. 1 Different methods of sexual and vegetative propagation of important weeds

Weed species	Common name	Propagation methods
Annuals / biennials Perennials		

3. Weed herbarium

A herbarium is a museum and a database of dried, pressed plant specimens. Each specimen is a voucher deposited for future reference because a herbarium is a repository of information: geographical distributions, taxonomic, biological and ecological data. Collection of weeds and keeping in herbarium is the foremost and best approach in weed science teaching, research and extension. Rich collection of weeds is a reliable reference for weed researchers in the identification of weeds. Herbarium preparation is a very difficult task. It involves several steps from collection to identification.

Collection

Healthy and ideal plants which are free from insect-pests and diseases are selected. The specimen(s) should include if possible all plant parts (underground parts, stems, leaves, flowers and fruits). As a general rule, sterile (non-flowering or -fruiting) specimens will not be accepted. When collecting, keep in mind that the "final" specimen, after pressing and drying has to fit on a herbarium sheet of
41.5 x 29 cm. The collected plants are placed in polythene bags separately to avoid mixing of species. Two to three specimens may be collected to select the best one. Every species should be given identification number. The detail such as habitat, morphology etc may be noted. The identification number should accompany throughout every stage of herbarium preparation process. The following information has to be recorded in the field note book,

a. Collection number
b. Vernacular name
c. Plant habit (erect or prostate, herbaceous or woody etc.)
d. Colour of leaves/flowers
e. Types of leaves/flowers
f. Habitat (soil, water regime, soil texture, associated crop etc)
g. Date of collection
h. Place of collection

Also make notes on any plant characteristic that may not be obvious from the dried specimen; e.g. colour, fragrance, etc. Collection should be made during afternoon hours of sunny days.

Pressing

The purpose is to extract the moisture, so that plants do not rot or go moldy. Pressing and drying preserve the morphological integrity of the plants, which can be then mounted on herbarium paper and stored for a long time. Pressing plants immediately after collection results in the best herbarium specimens. Wash the specimens with fresh water. Wipe them with a dry cloth. Press the specimen when it is still fresh. The specimens are carefully arranged in folded newspapers. Each newspaper should hold one weed specimen with an accompanying label. The specimen should not be larger than the herbarium sheet. Thinning of some branches and leaves is done to avoid excess overlapping. Specimen should not be folded or crumbled. Long specimens should be cut in pieces at the most in three. The plant should be arranged exactly as it is to be shown on the herbarium.

A plant press consists of a wooden frame (for rigidity), corrugated cardboard ventilators (to allow air to flow through the press), blotter paper (to absorb moisture), and folded newspaper (to contain the plant material). For pressing the specimens, lay a piece of corrugated cardboard over a wood or steel frame. Follow this by a blotting paper containing plant specimen and then another blotting paper. Repeat this sequence until all specimens are arranged and the pile is large enough to be pressed conveniently. Press the pile gently between a pair of wooden presses by applying light pressure. Tie the pile and an identifying tag.

Drying

The pressed plants must be thoroughly dried prior to storage and mounting. Best results are obtained with the use of an electric drier that holds the presses and provides steady bottom heat between 45°C and 60°C. In the absence of a drier make sure you replace the blotter paper periodically until the specimens are dry. Rapid drying promotes the best retention of plant color, but excessively high temperatures or long drying periods can result in blackened, discolored, and brittle specimens. Sun drying is slower than artificial drying but natural colour retention is achieved. In sun drying corrugated cardboards are

used on top and bottom of the pile. The absorbent papers need to be changed every day to prevent mould growth on specimens.

Poisoning

In warm countries herbarium are frequently prone to termite attack. It is very difficult to control these pests due to humid weather. The weed specimen once dried need chemical treatment to protect them from insect attack and other destructive organisms. Thus dipping of specimens is essential. The following solutions are used for the treatment.

1. Mercuric chloride (25 g) + cresol (25 g) in one litre industrial alcohol.
2. Mercuric chloride (15 g) + phenol crystals (10 g) in one litre denatured alcohol.
3. 20% lauryl pentachloro phenate in methylated sprits

The plants are re-dried as discussed earlier. These solutions are corrosive and proper care is needed to handle them.

Mounting

After the specimens are dried and poisoned, they are mounted on herbarium sheets. Generally the size of the herbarium sheet is 42 cm x 29 cm. The herbarium sheet should be of good quality and medium in weight. The specimens are placed in the centre of the sheet. Glue or narrow strips of adhesive tape (preferable transparent) are used to mount the specimens on the herbarium sheet. Several herbarium glues are available in the market. If these are not available prepare the following gum,

1. 500 g gum Arabic, 200 g sugar and 15 g phenol dissolved in 1 litre of 8% methylated spirit solution.
2. Dissolve the 500 g gum Arabic in 800 ml boiling water. Add 30 g mercuric chloride and 15 g phenol.

Glue is applied to plant specimen only. The lower right hand corner of the herbarium sheet should bear the label containing the information as,

1. Vernacular name
2. Common name

3. Scientific name
4. Family
5. Place of collection
6. Date of collection

Storage

The herbarium sheets are stored in closed containers. To prevent further insect attack, a handful of 1:1 mixture of paradichlorobenzene and naphthalene should be placed in cloth bag in the container. This is replenished at regular intervals. The place of keeping herbarium cabinets need spray of mild insecticides regularly.

Identification

To identify a given species and family refer to previously identified specimens in herbarium, manuals, weed flora monographs, illustrated books or seek the assistance of competent plant taxonomist. The specimens those cannot be identified, it is necessary to send them to experts/specialists. Weeds are identified by scientific names.

Arrangement of specimens in the cabinet

For larger collections it is better to use family wise system. The weed species belong to one family should be placed in the one rack and then arranged in alphabetically order. For small collections weeds are arranged alphabetically by scientific name. It is a necessity to arrange weed specimens by standard methods to enable easy retrieval for future reference.

For long lasting collection, the weeds should be kept in metal cabinets. They should be frequently fumigated to protect them from insect damage.

4. Weed survey in crops and cropping systems

Aim: To provide an inventory of the arable land weeds and phytosociological attributes of major crops and cropping systems.

The methodology Phytosociological

studies

Select crops and cropping systems for the phytosociological investigations. Conduct study before weeding and after weeding during Kharif season.

Collect and identify all the weeds encountered in the field sites carefully.

Random quadrat method is adopted for studying phytosociological attributes of weeds.

In each field site, lay down 50-100 or more quadrats of 100 cm^2 for each crop and cropping system.

Collect all the weeds from each quadrat separately in polythene bags.

List all the plant species encountered in quadrats for further analysis of the survey as below.

SN	Weed species	Quadrat No			
		1	2	……	n

The phytosociological attributes: abundance, density and frequency and their relative values and importance value index (IVI) are calculated according to the principles of Curtis and Mclntosh (1950), Misra (1968) and Dombois and Ellenberg (1974).

The following are the different formulae for calculation of the relevant attribute(s):

Density

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrates is divided by the total number of quadrates studied. It is calculated by the equation as below:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates studied}}$$

Frequency (%)

This term refers to the degree of dispersion of individual species in an area and usually expressed in terms of percent occurrence. It was studied by sampling the study area at several places at random and recorded the name of the species that occurred in each sampling units. It is calculated by the equation:

$$\text{Frequency (\%)} = \frac{\text{Total number of quadrates in which the species occurred}}{\text{Total number of quadrates studied}} \times 100$$

Abundance

It is the study of the number of individuals of different species in the community per unit area. By quadrats method, samplings are made at random at several places and the number of individuals of each species was summed up for all the quadrats divided by the total number of quadrats in which the species occurred. It is represented by the equation:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates in which the species occurred}}$$

Relative density

Relative density is the study of numerical strength of a species in relation to the total number of individuals of all the species and can be calculated as:

$$\text{Relative density} = \frac{\text{Total number of individuals of the species}}{\text{Number of individuals of all the species}} \times 100$$

Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurred is termed as relative frequency. It is calculated as below

$$\text{Relative frequency} = \frac{\text{Total number of occurrence of the species}}{\text{Number of occurrence of all the species}} \times 100$$

Relative abundance

It is the abundance of a species (by any measure) divided by the total abundance of all species combined. Alternatively, relative abundances can be expressed as a percentage.

$$\text{Relative abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of individuals of all species in all quadrats}} \times 100$$

Importance Value Index

This index is used to determine the overall importance of each species in the community structure. In calculating this index, the percentage values of the relative frequency, relative density and relative abundance are summed up together and this value is designated as the Importance Value Index or IVI of the species (Curtis, 1959).

Summed dominance ratio = IVI/3

Based on Raunkiaer (1934), the frequency classes of weed species are determined. Accordingly there were five frequency classes, i.e. 'A' class with the species of frequency ranging from 1- 20%; 'B' class 21-40%; 'C' class 41-60%; 'D' class
61-80% and 'E' class 81-100%.

Furthermore, compare the weed community frequency patterns with the normal frequency pattern of Raunkiaer (A>B>C>=D<E).

Based on the frequency pattern of the community, determine the homogeneity and heterogeneity of the vegetation. If the values are high with respect to B, C and D, then the community is said to be heterogeneous where as higher values of E indicates the homogeneous nature.

Identification of specimens

After completing the weed collection from the crop fields, the specimens a r e identified comparing with the authentic certified specimens at University herbarium or in the laboratory with the help of floras, monographs and other relevant literature and consequently provided the correct name to each plant. Study each plant critically and identify using the 'Flora of British India' (Hooker, 1872- 1897), 'Flora of Presidency of Madras' (Gamble and Fischer, 1915-1935), The grasses of Burma, Ceylone, India and Pakistan (Bor, 1960), 'Forest flora of Andhra Pradesh' (Reddy *et al.*, 1991), 'Flora of Andhra Pradesh' (Pullaiah and Chennaiah, 1997), and district floras of Srikakulam (Rao and Sriramualu, 1986), Visakhapatnam (Rao and Kumari, 2002) and Vizianagaram (Venkaiah, 2004).

Diversity indices Species

richness

Species richness is a measure of the number of different kinds of organisms present in a particular area.

Similarity index

Similarity index is a measure of the relative abundance of the different species making up the richness of an area.

Shimpson's Diversity index

Shimpson Diversity index is often used to quantify the biodiversity of a habitat. It takes into account the number of species present, as well as the large quantity of

each species. It measures the probability that two individuals randomly selected from a sample will belong to same species. It can be measured with the following formula:

$$D = \frac{n\ (n-1)}{N\ (N-1)}$$

n= total number of organisms of a particular species

N=total number of organisms of all species Shimpson's

Diversity index = 1-D

Shannon Index

This was originally developed for use in information science. It accounts for the order or abundance of a species within a sample plot. This is often used for identifying areas of high natural or human disturbance.

Ecosystem diversity [Beta diversity]

At the ecosystem-level, measures of biodiversity are often used to compare two ecosystems or to determine changes over time in a given region. Beta diversity measures the present and changes of species diversity between ecosystems; this involves comparing the number of taxa that are unique to each of the ecosystems. In simpler terms, it calculates the number of species that are not the same in two different environments.

Beta diversity is the total number of species that are unique between communities. This can be represented by the following equation:

$$\mathbf{B = (S\text{-}c) + (S\text{-}c)_{12}}$$

S1 = the total number of species recorded in the first community.

$\mathbf{S_2}$ **=** the total number of species recorded in the second community.

C = the number of species common to both communities.

B = Beta diversity

Exercise: Phytosociological studies on weeds

Pytosociological attributes of rice weeds (after Prayaga Murty Pragada1 and Molleboyena Venkaiah 2012. PHYTOSOCIOLOGICAL ATTRIBUTES OF WEED FLORA IN MAJOR CROPS OF NORTH COASTAL ANDHRA PRADESH, INDIA . Pak. J. Weed Sci. Res. 18(1): 107-126.) are given in Table as below:

Abundance, Density, Frequency and their relative values for determining the distribution pattern and Importance Value Index (IVI) of the weeds encountered in rice crop fields are presented in Table-1. A total of 65 weed species (29 dicots, 36 monocots) were recorded from the 60 randomly thrown quadrats combining three field sites. *Wolffia globosa* was the most abundant weed in rice fields followed by *Polygonum glabrum, Chloris montana, Fimbristylis miliace, Aeschynomene indica* and C*oix lacrymajobi*. The Important Value Index calculated for the individual weed species encountered in the rice crop fields revealed interesting results. *Wolffia globosa* was the most important species followed by *Echinochloa cruss-galli, Cyperus rotundus, Cynodon dactylon* and *Dactyloctenium aegyptium*.

Table 1. Phytosociological attributes of rice weeds (after Pragadal and Venkaiah 2012)

Total quadrats studied = 60

SN	Name of the species	TOI	TNI	A	D	F	RA	RD	RF	IVI	SDR
1	*Aeschynomene indica* L.	4	6	1.5	0.1	6.7	1.6	0.7	0.6	2.9	1.0
2	*Ageratum conyzoides* L.	16	18	1.1	0.3	26.7	1.2	2.1	2.3	5.6	1.9
3	*Ammannia baccifera* L.	17	18	1.1	0.3	28.3	1.2	2.1	2.4	5.6	1.9
4	*Aponogeton echinatus* Roxb.	5	6	1.2	0.1	8.3	1.3	0.7	0.7	2.7	0.9
5	*Aponogeton natans* (L.) Engler&Krause	4	4	1.0	0.1	6.7	1.1	0.5	0.6	2.1	0.7
6	*Bacopa monnieri* Wettst	28	32	1.1	0.5	46.7	1.2	3.7	3.9	8.9	3.0
7	*Basilicum polystachyon* (L.) Moench	8	10	1.3	0.2	13.3	1.4	1.2	1.1	3.7	1.2

8	*Chloris barbata* (L.) Sw	7	10	1.4	0.2	11.7	1.6	1.2	1.0	3.7	1.2
9	*Chloris montana* Link	6	11	1.8	0.2	10.0	2.0	1.3	0.8	4.1	1.4
10	*Coix lacrymajobi* L.	4	6	1.5	0.1	6.7	1.6	0.7	0.6	2.9	1.0
11	*Commelina erecta* L.	5	6	1.2	0.1	8.3	1.3	0.7	0.7	2.7	0.9

SN	Name of the species	TOI	TNI	A	D	F	RA	RD	RF	IVI	SDR
12	*Commelina longifolia* Lamk	16	18	1.1	0.3	26.7	1.2	2.1	2.3	5.6	1.9
13	*Cynodon dactylon (*L.) Pers	38	38	1.0	0.6	63.3	1.1	4.4	5.3	10.9	3.6
14	*Cyperus difformis* L.	13	13	1.0	0.2	21.7	1.1	1.5	1.8	4.4	1.5
15	*Cyperus diffusus* Vahl	16	18	1.1	0.3	26.7	1.2	2.1	2.3	5.6	1.9
16	*Cyperus iria* L.	17	19	1.1	0.3	28.3	1.2	2.2	2.4	5.8	1.9
17	*Cyperus rotundus* L.	37	44	1.2	0.7	61.7	1.3	5.1	5.2	11.6	3.9
18	*Dactyloctenium aegyptium* (L.)P.Beauv.	32	36	1.1	0.6	53.3	1.2	4.2	4.5	9.9	3.3
19	*Dentella repens* (L.)Forst.&Forst.f	22	22	1.0	0.4	36.7	1.1	2.6	3.1	6.7	2.2
20	*Echinochloa colona* (L.) Link.	2	2	1.0	0.0	3.3	1.1	0.2	0.3	1.6	0.5
21	*Echinochloa crusgalli* (L.)Beauv	42	58	1.4	1.0	70.0	1.5	6.8	5.9	14.2	4.7
22	*Eclipta prostrata* (L.)L.	24	28	1.2	0.5	40.0	1.3	3.3	3.4	7.9	2.6
23	*Eichhornia crassipes* (Mark.)Solms	13	13	1.0	0.2	21.7	1.1	1.5	1.8	4.4	1.5
24	*Eleusine indica* (L.)Gaerth	7	8	1.1	0.1	11.7	1.2	0.9	1.0	3.2	1.1
25	*Eragrostis atrovirens*	1	1	1.0	0.0	1.7	1.1	0.1	0.1	1.3	0.4
26	*Eragrostis diarrhena* (Schult.)Steud.	4	4	1.0	0.1	6.7	1.1	0.5	0.6	2.1	0.7
27	*Fimbristylis dichotoma* (L.)Vahl	6	7	1.2	0.1	10.0	1.3	0.8	0.8	2.9	1.0
28	*Fimbristylis bisumbellata* (Forssk.)Bubani	2	2	1.0	0.0	3.3	1.1	0.2	0.3	1.6	0.5
29	*Fimbristylis miliacea* (L.) Vahl	8	12	1.5	0.2	13.3	1.6	1.4	1.1	4.2	1.4
30	*Gynura lycopersifolia* DC	6	8	1.3	0.1	10.0	1.5	0.9	0.8	3.2	1.1
31	*Hedyotis corymbosa* (L.) Lamk	14	19	1.4	0.3	23.3	1.5	2.2	2.0	5.7	1.9
32	*Hydrolea zeylanica* (L.) Vahl	2	2	1.0	0.0	3.3	1.1	0.2	0.3	1.6	0.5
33	*Hygrophila auriculata* (Schum.)Heine	16	18	1.1	0.3	26.7	1.2	2.1	2.3	5.6	1.9
34	*Ipomoea aquatic* Forsk	5	5	1.0	0.1	8.3	1.1	0.6	0.7	2.4	0.8
35	*Ischaemum indicum* Merr	5	6	1.2	0.1	8.3	1.3	0.7	0.7	2.7	0.9
36	*Ischaemum rugosum* Salisb	4	5	1.3	0.1	6.7	1.4	0.6	0.6	2.5	0.8
37	*Lemna gibba* L.	6	8	1.3	0.1	10.0	1.5	0.9	0.8	3.2	1.1

38	*Limnophila indica* (L.)Druce	3	3	1.0	0.1	5.0	1.1	0.3	0.4	1.9	0.6
39	*Limnophila rugosa* (Roth)Merr	16	18	1.1	0.3	26.7	1.2	2.1	2.3	5.6	1.9
40	*Lindernia antipoda* (L.)Alston	15	16	1.1	0.3	25.0	1.2	1.9	2.1	5.1	1.7
41	*Lindernia ciliate* (Colsm.) Pennell	8	8	1.0	0.1	13.3	1.1	0.9	1.1	3.1	1.0
42	*Lindernia crustacean* (L.)F.Muell	11	14	1.3	0.2	18.3	1.4	1.6	1.5	4.6	1.5
43	*Ludwigia octovalvis* (Willd.)Bold	8	10	1.3	0.2	13.3	1.4	1.2	1.1	3.7	1.2
44	*Ludwigia perennis* L.	14	16	1.1	0.3	23.3	1.2	1.9	2.0	5.1	1.7
45	*Marsilia quadrifolia* L.	6	6	1.0	0.1	10.0	1.1	0.7	0.8	2.6	0.9
46	*Monochoria hastate* (L.)Solms-Laub	6	6	1.0	0.1	10.0	1.1	0.7	0.8	2.6	0.9
47	*Monochoria vaginalis* (Burm.f.)Presl	4	4	1.0	0.1	6.7	1.1	0.5	0.6	2.1	0.7
48	*Nymphoides hydrophylla* (Lour.)O.Ktze	6	6	1.0	0.1	10.0	1.1	0.7	0.8	2.6	0.9
49	*Ottelia alismoides* (L.)Pers	5	6	1.2	0.1	8.3	1.3	0.7	0.7	2.7	0.9
50	*Panicum repens* L	6	7	1.2	0.1	10.0	1.3	0.8	0.8	2.9	1.0

SN	Name of the species	TOI	TNI	A	D	F	RA	RD	RF	IVI	SDR
51	*Paspalidium flavidum* (Retz.)Camus	10	11	1.1	0.2	16.7	1.2	1.3	1.4	3.9	1.3
52	*Paspalidium punctatum* (Burm.f.) Camus	8	10	1.3	0.2	13.3	1.4	1.2	1.1	3.7	1.2
53	*Pennisetum polystachyon* (L.) Schult.	2	2	1.0	0.0	3.3	1.1	0.2	0.3	1.6	0.5
54	*Phyla nodiflora* (L.) Greene	24	24	1.0	0.4	40.0	1.1	2.8	3.4	7.3	2.4
55	*Pistia stratiotes* L.	2	2	1.0	0.0	3.3	1.1	0.2	0.3	1.6	0.5
56	*Polygala arvensis* Willd.	15	20	1.3	0.3	25.0	1.5	2.3	2.1	5.9	2.0
57	*Polygonum barbatum* L.	18	24	1.3	0.4	30.0	1.5	2.8	2.5	6.8	2.3
58	*Polygonum glabrum* Willd.	4	9	2.3	0.2	6.7	2.5	1.0	0.6	4.1	1.4
59	*Polygonum hydropiper* L.	5	5	1.0	0.1	8.3	1.1	0.6	0.7	2.4	0.8
60	*Polygonum plebeium* R.Br.	4	5	1.3	0.1	6.7	1.4	0.6	0.6	2.5	0.8
61	*Portulaca quadrifida* L.	13	13	1.0	0.2	21.7	1.1	1.5	1.8	4.4	1.5
62	*Pycreus polystachyos* (Rottb.) Beauv	13	16	1.2	0.3	21.7	1.3	1.9	1.8	5.0	1.7
63	*Rotala densiflora* (Roem.&Schult.) Koehne	16	17	1.1	0.3	26.7	1.2	2.0	2.3	5.4	1.8
64	*Wolffia globosa*(Roxb.) Hartog& Plas	2	33	16.5	0.6	3.3	18.0	3.8	0.3	22.1	7.4
65	*Xanthium strumarium* L.	5	6	1.2	0.1	8.3	1.3	0.7	0.7	2.7	0.9
				91.6	14.3	1185.0	100	100	100	300	100

TOI = Total Occurrence of Individuals, **TNI** = Total Number of Individuals, **A** = Abundance, **D** = Density, **F** = Frequency, **RA** = Relative Abundance, **RD** = Relative Density, **RF** = Relative Frequency, **IVI** = Importance Value Index, and SDI = Summed dominance ratio

6. Crop-weed competition studies

Competition is the rivalry between crop and weeds for a common demand which becomes in short supply and eventually the demand and supply gap reflected in supply and productivity of weed and crop. Competition can also be defined as 'the action of endeavoring to gain what another endeavors to gain at the same time'. **T**he competition occurs when the weed and crop grow in mixed stand, influence growth mutually and reduce growth of some plants in comparison to others. Plant competition is a powerful natural force responsible for the suppression of weaker plants. There may be intra-plant (as among crop plants or weed plants) or inter plant (between crop and weed plants) competition. A principle of plant competition is that the plants occupying an area first have an advantage over late comers. Rapidly growing plants like weeds with rapid coverage of both above and below ground areas have an advantage over slow growing ones. Weeds compete with crop plants for water, light, nutrients, space, air and the micro-environment. The crop weed competition must include the following aspects:

Weeds-crop association

Critical period of crop-weed competition

Threshold levels of weeds and

Losses caused by weeds

Weeds-crop association

The detail about the in-depth analysis of the weeds-crop association has been made in the weed survey section of this document.

Critical period of crop-weed competition (CPWC)

Critical period of crop-weed competition has two aspects. First is length of time a crop has to be kept weed free after planting so that weeds which will be emerging later will not reduce the grain yield. The second is the length of time in which weeds emerging with the crop can remain before they begin the interference with crop

growth and finally reduce the yield. It is important to reduce the critical period of crop-weed competition in order to maximize economic returns.

Critical period is defined as the shortest time spell during the life cycle of crop when weeding will result in the highest yield of crop or economic returns.

Unequal growth between weed and crop is necessary part of creating competitive advantage in favour of crop. Aim of unequal growth manipulations should coincide with the rapid growth stages of crop. Tall growing cultivars cover the soil earlier and therefore critical period of competition is shorter. However for dwarf cultivars, critical period of weed competition is longer. In the case of upland crop, CPWC is longer because of slow growth. However for irrigated crop, CPWC is shorter. In general first one third duration of crop is critical for weed competition.

Procedure

Select a crop field of convenient size which has just been sown or planted with the weed. Divide the field into several small plots (e.g. 5 x 5 m size) and make bunds around each plot.

- Keep the first plot weed free up to 15 DAS (days after sowing) or planting by removing all the weeds.
- Keep the second plot weed free up to 30 DAS or planting by removing all the weeds.
- Keep the third plot weed free up to 45 DAS or planting by removing all the weeds.
- Keep the fourth plot weed free up to 60 DAS or planting by removing all the weeds.
- Keep the fifth plot weed free up to harvest by removing all the weeds. This is considered as completely weed free.
- Keep sixth plot weedy up to 15 DAS and then weed free up to harvest
- Keep seventh plot weedy up to 30 DAS and then weed free up to harvest
- Keep eighth plot weedy up to 45 DAS and then weed free up to harvest
- Keep ninth plot weedy up to 60 DAS and then weed free up to harvest
- Keep tenth plot weedy up to harvest

Harvest the crop and record the crop yield of each plot. Compare the yield of each plot with the yield of completely weed free one. Observe up to which weed free period, crop yield is increasing significantly and at par with treatment of weedy conditions up to a particular period.

During a study on crop weed competition in potato (Table 2 given below), tuber yield of potato is increasing significantly when crop is kept weed free up to 45 DAS and is at par with tuber yield of potato when it kept weedy up to 15 DAS and kept weed free up to harvest. When weeds are allowed to infest the crop up to 30 DAS and then weed free conditions are kept up to harvest, tuber yield decreased significantly. Similarly, if crop weed free conditions are maintained beyond 45 DAS, yield increase is observed but not significantly. So, it is of no use to keep the potato crop weed free beyond 45 DAS. Therefore, the critical period of crop weed completion in potato is found to be 15-45 DAS. The critical period of crop-weed competition as determined in some other crops has been given in Table 3.

Table 2. Effect of weedy and weed free periods on tuber yield of potato

Treatment	Tuber yield (t/ha)
Weed free up to 15 DAS	13.50
Weed free up to 30 DAS	18.15
Weed free up to 45 DAS	21.02
Weed free up to 60 DAS	22.37
Weed free up to Harvest	22.62
Weedy up to 15 DAS	21.0
Weedy up to 30 DAS	17.25
Weedy up to 45 DAS	14.5
Weedy up to 60 DAS	11.92
Weedy up to Harvest	10.69
CD at 5 %	2.62

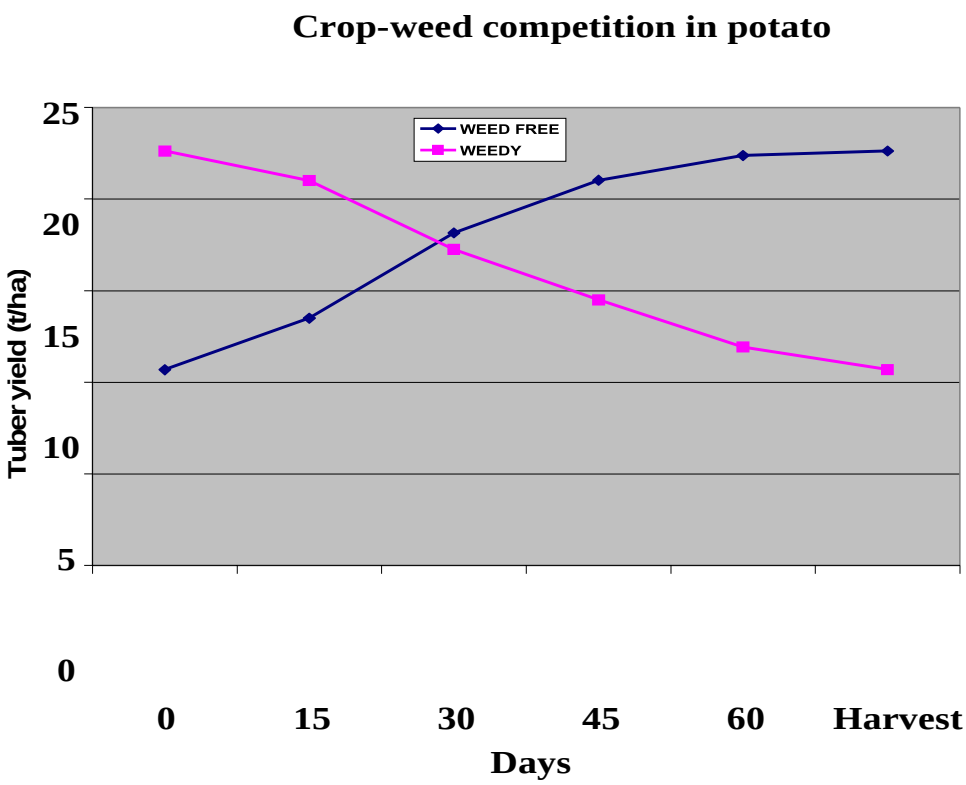


Table 3. Critical period of crop- weed competition in different crops

SN	Crop	Critical Period
1.	Maize	15-60 DAS
2.	Potato	30-45DAS
3.	Rape-seed mustard	15-40 DAS
4.	Sunflower	45-60 DAS
5.	Soyabean	15-45DAS
6.	Linseed	45-50 DAS
7.	Castor	30-40 DAS
8.	Sesamum	15-45 DAS
9.	Safflower	40-50 DAS
10.	Mungbean, Urd and Pigeon pea	20-45 DAS
11.	Cotton	25-60 DAS
12.	Groundnut	40-60 DAS
13.	Wheat	30-45 DAS
14.	Rice	15-45 DAT
15.	Chickpea	30-60 DAS

16.	Pea	30-60 DAS
17.	Urd	15-30 DAS
18.	Sugarcane	40-70 DAS

Threshold

Agricultural producers today cannot tolerate excessive yield losses from weeds. To avoid such losses, the determination of two distinct weed threshold concepts can be useful. First, a competitive threshold can be defined from field research data as the weed density and duration of interference above which crop yield is reduced significantly, generally from 10-20%. Second, an economic threshold occurs where the monetary yield loss exceeds cost of control. The producer usually is most concerned about the economic threshold because of its immediate role in production decisions. However, along with the impact of weeds on the current crop, the producer should consider the complete crop rotation cycle, the future weed infestation, and even the future generations who will farm the land. The three additive research techniques to determine competitive weed thresholds are removal or plant-back, paired plot and area of influence. Each method has advantages and disadvantages and must be conducted in a specific manner in the field. The area of influence technique is the most accurate for determining the influence of a single weed. Data must be reported in a usable form such as percent yield reduction. Generally the economic threshold is one-half to one-third the competitive threshold. The economic threshold (=economic injury levels), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, may be calculated after modifying the formula presented by Uygur & Mennan (1995) as well as those given by Stone and Pedigo (1972) as below

Uygur & Mennan:

$Y= [\{(100/He*Hc)+A_C\}/(Gp*Yg)]*100$

Where, Y is percent yield losses at a different weed density; He, herbicide efficiency; Hc, herbicide cost; Ac, application cost of herbicide; Gp, grain price and Ywf, yield of weed free.

Stone and Pedigo:

Economic threshold = Gain threshold/Regression coefficient

Where, gain threshold = Cost of weed control (Hc+Ac)/Price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/biomass (x), Y = a + bx.

Exercise

The weed count and dry weight and yield data on wheat as influenced by different weed control treatments after Kumar et al 2013 (Kumar Suresh, **SS Rana**, Ramesh and Navell Chander 2013. Herbicide combinations for broad-spectrum weed control in wheat. Indian Journal of Weed Science 45(1):29-33.) and the subsequent analysis are presented in Table 4. The linear relationship between weed count/weed dry weight (x) and grain yield (Y) of wheat is given hereas under,

Weed count

$Y = 4074 - 26.02x$ $(R^2 = 0.734)$…….(i)

Weed weight

$Y = 3893 - 41.55x$ $(R^2 = 0.875)$…….(ii)

The equation (i) explains that 73.4% variation in yield due to weed count could be explained by the regression equation. The further analysis indicated that decrease in yield per unit increase in weed count (1 weed/m^2) is estimated to be 26.02 kg/ha. Similarly from the equation (ii) it may be inferred that 87.5% of variation in grain yield of wheat due to weed dry weight could be explained by the regression equation. With every 1 g/m^2 increase in weed dry weight, the grain yield of wheat was expected to fall by 41.55 kg/ha.

The economic threshold levels of weeds at the current prices of treatment application and the crop production on the basis of weed infestation (population) in wheat are also given in Table 4. The economic threshold levels (number of weeds/unit area) with the weed management practices studied varies between 2.6- 45.4/m^2 when determined after Pedigo and Stone (1972) and 2.2-38.5/m^2 after Uygur & Mennan (1995). The trend was almost similar under the methods of determination. It is clearly indicated that any increase in the cost of treatment

would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in lowering the economic threshold.

Table 4. Economic thresholds

Treatment	Dose (g/ha)	Weed Weight	Weed count	Grain yield	WCE	WI	Spray cost	Herbicide cost	CWC	Gt	Et	
											SP	UM
Clodinafop	60	22.3	44.0	3175	61.8	13.0	480	1125	1605	128	4.9	5.0
Sulfosulfuron	25	28.5	51.7	2643	51.2	27.6	480	556	1036	83	3.2	3.4
Metribuzin	175	18.9	27.4	3020	67.6	17.3	480	350	830	66	2.6	2.2
Pinoxaden	50	14.1	41.4	3480	75.8	4.7	480	1800	2280	182	7.0	6.3
Clodinafop + metribuzin	60+105	11.0	28.7	3435	81.1	5.9	480	1335	1815	145	5.6	4.7
Clodinafop + metribuzin	60+122.5	8.5	26.9	3764	85.5	-3.1	480	1369	1849	148	5.7	4.6
Sulfosulfuron + metribuzin	25+105	15.9	28.7	2673	72.7	26.8	480	766	1246	100	3.8	3.4
Sulfosulfuron + Pinoxaden	25 + 40	14.6	33.4	3194	74.9	12.5	480	1996	2476	198	7.6	6.9
Weed free	-	9.4	16.0	3650	83.9	0.0		14760	14760	1181	45.4	38.5
Weedy check	-	58.3	93.0	1534	0.0	58.0			0			
LSD (P=0.05)	-	1.3	1.7	671								

WCE, weed control efficiency (%); WPI, weed persistence index; CRI, crop resistance index; EI, efficiency index; WI, weed index. CWC, cost of weed control (`/ha); $NR_{WC}$, net return due to weed control (`/ha); MBCR, Marginal benefit cost ratio; Gt, gain threshold; Et, economic threshold; SP, after Stone and Pedigo (1972); UM, after Uygur & Mennan (1995).

Losses due to weeds

Losses due to weeds may be depicted by calculating weed index.

Weed Index (WI): It is a measure of the efficacy of particular treatment when compared with weed free treatment and is expressed as percentage of yield potential under weed free. Higher weed index means greater loss due to weeds:

$$\text{Weed index} = \frac{X - Y}{X} \times 100$$

Where, X - Yield from weed free and Y - Yield of a particular treatment

From the data given in Table 4, it may be inferred that uninterrupted growth of weeds reduced the yield of wheat by 58%. The magnitude of loss was reduced with the adoption of weed management practices.

7. Calculation of herbicide doses and preparation of spray solutions of herbicides for high and low volume sprayers

Herbicides are applied in the form of solutions or granules. Spraying is the most common method of applying herbicide formulations. The effective and selective control of weeds in different crops depends upon accurate dose, time and method of application. Preparation of herbicide solutions therefore needs due attention. It is necessary to know the method of calculation of herbicide doses having different active ingredient (ai) and the quantity of water to be used.

Dose calculations

Field crops

Herbicides are available mainly as in powder, granules or liquid forms. Their recommendations are made on a.i. or a.e. basis. But in the field they are used on the basis of commercial formilation available in the market. Therefore, their commercial dose has to be calculated as under:

$$\text{Dose of Commercial Product (g/ha)} = \frac{\text{Recommended dose a.i. or a.e. g/ha}}{\text{Percent concentration in the product}} \times 100$$

One hectare = 10000 m^2 or 2.5 acres

Determination of amount of commercial formulation of herbicide from acid equivalent of formulation:

Given : Isooctyl ester of MCPA: 53.4%

Area to be applied: 5 ha

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

$$= \frac{201 \times 53.4}{313} = 34.3\% \text{ a.e.}$$

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

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

$$\text{Amount of commercial formulation} = \frac{1.4 \times 5 \times 100}{34.3} = 20.4 \text{ Litres}$$

Aquatic weeds

Rectangular water bodies

For controlling aquatic weeds, herbicides are applied on weight basis(of water body).

Wt. of water (in litres) = Volume x 28.32

Volume = Lx B x D (L- Length of water body in feet)

(B- Breadth of water body in feet) (D-

Av. depth of water body in feet)

One cubic ft. weighs = 28.32 litres

Litres of herbicides in a.i. or a.e. /ha = Weight of water (litres) x concentration (ppm)

ppm : Recommended dose of herbicide in parts per million, then work out dose of commercial product as above.

For Spherical water bodies

Surface are of water body= $\pi \times r^2$ or c2 x 4π where π is 3.1416, c is the circumference of pond in meter and r is the radius of the water body in meters.

Surface area of water bodies that are some what rounded but not perfectly circular can be calculated by measuring the perimeter and calculating the approximate radius (r) by dividing the perimeter by 3.28 and then determing the surface area (A) =3.1416 x r^2 pound /acre or kg/ha. Then volume of water

in a given pool is calculated by the following formula:

V (cu mec) = A x D

A= Surface area of water in m^2. D= Av.

depth of water in meter

Then quantity of herbicide required to produce a desired concentration is given by:

$$Q = \frac{V \times 1010.7 \times \text{Dose (ppmw)}}{1{,}000{,}000} \text{ kg}$$

Flowing canals or channels

If the water body is flowing, then the herbicides for the control of submersed weeds are applied on the basis of its discharge. The well known unit of discharge of a ditch is cumec (cubic meter per second).This can be determined if the average width (W), depth (D) and flow velocity (U) of a ditch are known**.**

Discharge in cumec is = W x D x U x 0.9**,** where W and D are in meters and U is in $msec^{-1}$.

Example: A canal has a discharge of 1.6 cumec. It is to be treated with an emulsion solvent of 300 L per cumec during an application time of 20 minutes. Calculate the injection rate.

Solution: Injection rate: $\frac{300 \times 1.6}{20}$ or 24 litres per minute.

Example: A canal flows with a velocity of 0.5 m sec^{-1}.It is 30 meter wide and 1 meter deep. It is to be treated with acrolein at 500 L per cumec discharge. The desired application time is 30 minutes. Calculate the amount of herbicide needed and calibrate the rate of application per minute**.**

Solution: Discharge = 10 x I x 0.5 x 0.9 = 45 Cumec

The Q = 4.5 x 500 = 2250 Litres

So injection rate of the solvent is: $\frac{2250}{30}$ or 75 litres perminute.

How to prepare spray fluid?

- Thoroughly mix the calculated dose of herbicide in small quantity of water and then make the volume of solution (spray fluid) up to calibrated amount in a big container.
- Use hand gloves and gas masks while preparing the solution and at the time of its application in the field.
- Stir the spray fluid thoroughly before each filling.
- Alternatively, stock solutions (number of litres equivalent to number of spray pumps required for spraying one acre) can be prepared in a small container.
- Pour one lit. of stock solution into the pump and make the volume up to 15 lit. by adding water.
- Put one or two liters of water before pouring stock solution in the container.

Exercise:

1. A farmer from Una has a problem of isoproturon resistant *P. minor* in his field measuring 6 kanals (3000 m^2). Calculate the amount Topik (recommended dose of clodinafop 60 g a.i./ha) for the said area.
2. Calculate the amount of clodinafop + metsulfuron in ratio of 15:1 at 50 g/ha to control complex weed flora for an area of 8000 m^2.
3. Calculate amount of 2, 4-D amine salt required for spraying a pond (40 ft in length, 25 ft in breadth and 6 ft. of average depth) infested with water hyacinth. Recommended dose of herbicide is 10 ppm (Ans: 2.92 litres).
4. Irrigation department of Himachal want to apply 0.5% solution (a.i.) of 2, 4-D ester on ditch banks. It is estimated that 500 L ha^{-1} of the spray volume will be needed to wet the weeds completely. Calculate the amount of herbicide on product basis to treat a 4 meters wide and 2.5 km long ditch bank (Ans: 6.94 Litres).

Types of sprayers and parts

Select the spray equipment according to the required discharge as well as droplet size as the efficacy of applied herbicide depends upon these parameters

Types of sprayers

Depending upon the type of force required, sprayers are divided into two groups:

1. Manually operated
   - Compressed air sprayer
   - Hydraulic sprayer
2. Power operated

Compressed air or Pneumatic sprayer

Domestic sprayer

These are only used to spray against flies, mosquitoes and in kitchen gardening, hospitals, poultry farms etc.

Hand compressing sprayers

Most common is Knap-sack sprayer. This pump is very ideal and economical for spraying pesticides including herbicides, insecticides, fungicides, etc.

Pressure retaining or Battery sprayer

Pressure is maintained throughout the spraying time.

Hydraulic Sprayers

Pedal Pump (foot sprayer)

This pump is not suitable for spraying herbicides. It can be used for spraying insecticides and fungicides especially in orchards and plantations.

Power operated sprayers

In these sprayers pressure is generated mechanically with diesel or petrol engines with varying H P. These consist of a power generating pump, suction chamber, delivery as well as

discharge lines etc. The spray fluid is blown out by means of an

intensive air current generated by the blower. The spray liquid blows through PVC tube and reach the nozzle where the speedy air from blower, blasts the liquid into small droplets, which can be measured in microns. The capacity of these power sprayers may vary from 15 l to more than 500 l. These are very ideal equipments for spraying foliar uptake herbicides.

Parts of knap sack sprayer

The knowledge of various parts of a sprayer and their functions is necessary for efficient operation, maintenance and repair. Major parts of knap sack sprayer are given below:-

Tank/container

It holds the spray fluid. The total capacity of tank of knap-sack sprayer is 15 litres.

Pressure pump:

It is required to build up pressure in the system and is necessary for atomization of spray fluid into smaller droplets.

Discharge line/delivery line

Through this liquid comes out of the sprayer with force after converting to mist form. It consists of the following parts:

I. **Delivery hose:** A flexible tubing of rubber or plastic whose one end is attached to the tank / container.

II. **Lance:** A metal tube attached to the other end of hose and up to nozzle.

III. **Cut off/Shut off:** Generally fixed at the junction of the delivery hose and lance to cut off the flow of liquid when spraying is suspended.

IV. **Nozzles:** These are of three types A -

Flat fan

B -Flood jet

C -Cone

Handle

It is moved up and down to generate pressure.

Agitators

The active materials in any spray fluid are not always in solution, but are held in suspension form and consequently the material should be kept well mixed in order to secure an even distribution of herbicides.

Filters/strainers

The function of filters is to prevent solid particles for clogging the system.

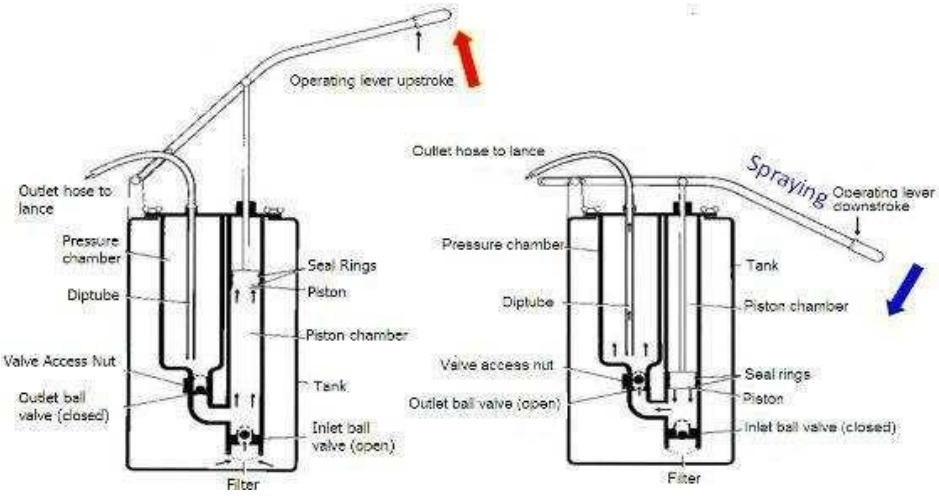
Washers and gaskets

These are present at all joints to prevent leakage.

Shoulder straps and hooks

Their function is to hold the sprayer on shoulder of the man engaged for spraying.

Sprayer

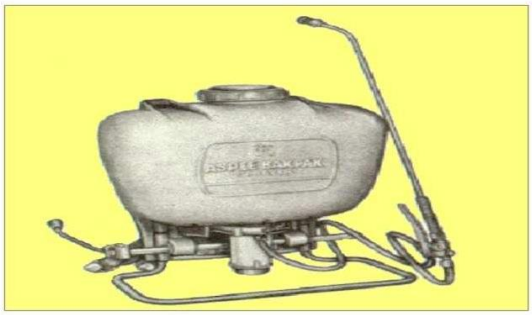


Parts

The spray patterns of different nozzles are shown below:

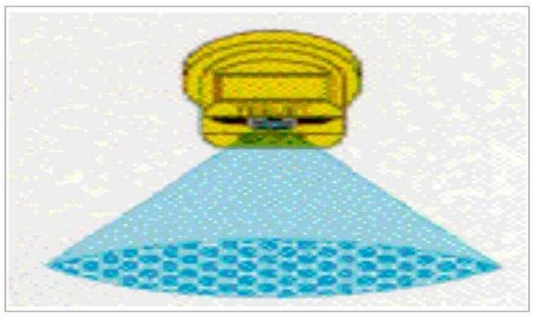
DIFFERENT TYPES OF NOZZLES AND SPRAY PATTERNS

Manual operated knap sack sprayers

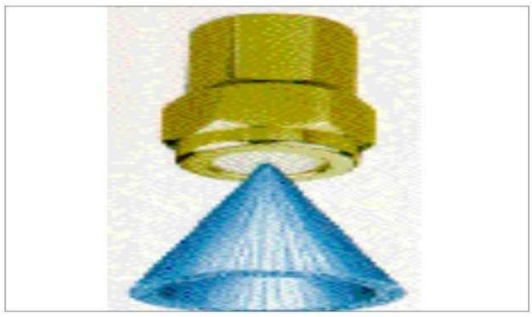


Power operated knap sack sprayer

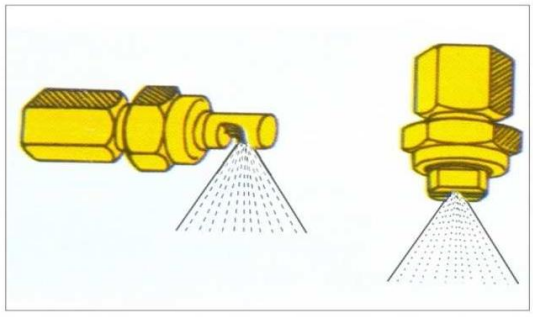
Different types of nozzles



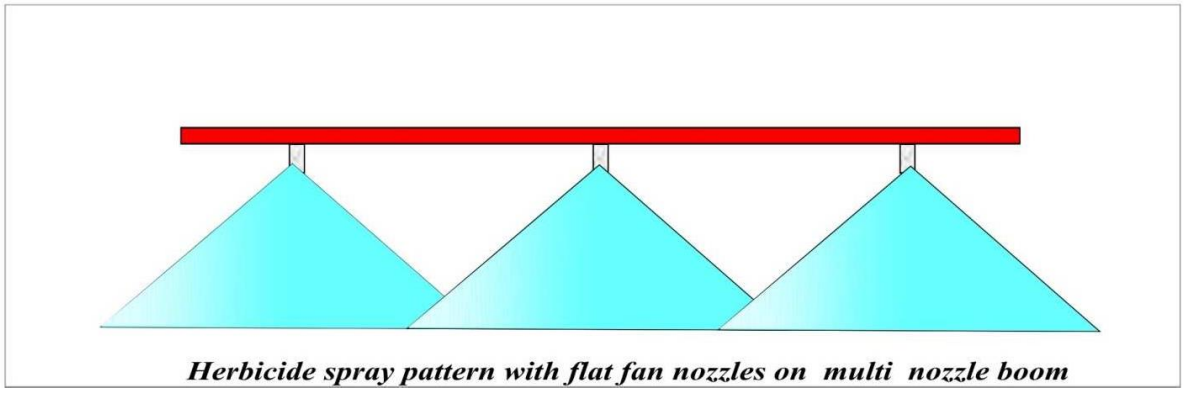
Spray pattern with flat fan nozzle



Hollow cone tip spray pattern



Flood (cut) tip spray pattern *Flat fan tip spary pattern*



Herbicide spray pattern with flat fan nozzles on multi nozzle boom

8. Calibration of spray equipment.

Accurate application of herbicides depends on the accurate calibration of spray pump. Calibration implies to adjust the sprayer to apply exact quantity of carrier (water) for spraying certain area under a set of conditions. Application rate is dependent on nozzle type, size of the nozzle orifice, spraying pressure, spraying speed etc. Care must be taken that speed and pressure should not vary from the calibration test to actual field spraying.

Procedure

1. Remove the nozzle and clean it properly.
2. Clean the spray tank and fill it with clean water.
3. Build up the pressure and check up for leaks.
4. Flush up the pump, hoses and lance with clean water and note it.
5. Fill the spray tank to a desired level with clean water and note it.
6. Operate the spray pump and spray in a known size area.
7. Measure the amount of spray (water) applied.
8. Repeat this calibration of sprayer thrice to obtain average spray volume applied.
9. Calculate the quantity of water required per hectare as below:

$$\text{Application rate (l/}h\text{a)} = \frac{\text{ANount of water applied (l)x 10000}}{\text{Neasured area sprayed (N}^2\text{)}}$$

10. Calculate the number of spray loads per hectare as follow:

$$\text{No. of spray loads/}h\text{a} = \frac{\text{Application rate (l/}h\text{a)}}{\text{Tank capacity of sprayer (l)}}$$

11. Calculation of commercial dose

    Each herbicide carries a label. To calculate the weight of commercial product required, information on weight of chemical to be applied and its active ingradient content are required:

$$\text{CoNNercial dose (kg/}h\text{a)} = \frac{\text{Dose of }h\text{erbicide ai to be applied (kg/}h\text{a)}}{\begin{array}{l}\text{a. i. content in }h\text{erbcide}\\ \text{forNulation (percentage}\\ \text{expressed as deciNal)}\end{array}}$$

Example: A herbicide with 45% a.i. as fluchloralin. If 0.9 kg/ha of fluchloralin is to be applied then 0.9/0.45 = 2.0 kg/ha of commercial formulation of fluchloralin (Basalin 45 SL) is required.

12. Calculate the amount of herbicide to be mixed in each spray load as follow

$$\text{Amount of herbicide per load} = \frac{\text{Commercial dose (kg/ha)}}{\text{Number of loads per/ha}}$$

Observations

Do calibration of Knap-sack sprayer with different nozzles and note following observations

Type of nozzle	Area sprayed (m^2)	Water used (l)	Water required l/ha	Width of boom (cm)	Time needed/ha (min)
Flat fan Flood jet Hollow cone Double spray lance Triple nozzle lance					

Conclusions: What type of nozzle will you recommend to the farmer for uniform application of herbicides?

The area covered per hour can be calculated as shown under Walking

$$\text{Area (ha/hr)} = \frac{\text{speed (km/hr) x m/km x spray width (m)}}{m^{2/}\text{ha}}$$

For example if a person is walking at 1 km/hr covering a swath of 0.6 meters wide, the area covered/hr is

$$\frac{1 \times 1000}{10000} \times 0.6 = 0.06 \text{ ha/hr}$$

At this rate, it will take 16 hr 40 minutes to cover an area of one hectare. At a spray discharge rate of 30 litres/hr, it would require a spray volume of 500 litres/ha.

Calibration of amount of spray liquid required for a unit area

Methodology

- Place 4 markers at each corner of some convenient length of either rectangular or square type test strip (e.g. 30 m x 4 m = 120 m^2)
- Take clean water and fill the sprayer tank
- Spray the marked area with uniform speed and at uniform pressure. If wetting of the floor is not uniform, change the nozzle or nozzle tip.
- Remove the remaining water from tank and measure the water consumed

Formula

$$\text{Spray fluid required (L/ha)} = \frac{10{,}000\ m^2/ha \times \text{litres used}}{\text{Strip length} \times \text{width of spray swath}}$$

Given

Litres of water used for marked area: 9

Length of treatment strip: 120 m^2 Width of spray swath: 5 m

$$\text{Amount of spray fluid (L/ha)} = \frac{10{,}000 \times 9}{120 \times 5} = 150.7 \text{ l/ha}$$

Put one or two liters of water before pouring stock solution in the container.

Spray technology

- Before starting the spraying operation check the nozzle by spraying plain water on a pucca floor.
- If wetting of the floor is not uniform, change the nozzle or nozzle tip.
- The person who has done calibration, should be deputed for spray in the field.

- Start spraying from one corner of the field in a band and second band should be parallel to the first with slight overlapping.
- Keep the nozzle at the height of 50 cm from the ground or canopy level.
- Spray should be as uniform as possible. The left over solution should not be re sprayed but must be discarded on a barren land.
- Do not move the nozzle to and fro.
- Always spray at right angle to the direction of wind and do not spray along or across the direction of wind.
- Postpone spray, if wind velocity is high.
- Wear full sleeve shirt, trouser, shoes, hand gloves and gas mask, while spraying.
- Do not spray with empty stomach and also do not eat while spraying.
- After spray operation is complete, take bath with soap and change your clothes.

9. Economics of weed control

In order to work out the most profitable treatment, the economics of each treatment is worked out on the basis of prevalent market prices of the inputs and output.

a. Cost of cultivation

Cost of cultivation is obtained by adding all the costs involved in each operation or input (seed bed preparation, seed and sowing, fertilizer, irrigation, weed control, plant protection, harvesting and post harvest operations etc).

b. Gross returns

The total monetary returns of the economic produce such as grain, tuber, bulb, fruit, etc. and byproducts viz. straw, fodder, fuel etc. obtained from the crops are calculated based on the local market prices. The total return is expressed in terms of unit area, usually one hectare. Generally gross return calculated is somewhat inflated compared to the actual receipt obtained by the farmer.

c. Net returns

This is worked out by subtracting the total cost of cultivation from the returns. This value gives the actual profit obtained by the farmer. In this type of calculation only the variable costs are considered. Fixed costs such as rent for the land, land revenue, interest on capital etc. are not included. For a realistic estimate, however, fixed costs should also be included.

d. Net returns per rupee invested

This is also called benefit cost ratio or input: output ratio. Net returns per rupee invested were obtained by dividing net returns with the treatment- wise cost of cultivation as follow:

$$\text{Net returns per rupee invested} = \frac{\text{Gross/Net returns from a treatment}}{\text{Cost of cultivation of the treatment}}$$

This index provides an estimate of the benefit derived and expenditure incurred by the farmer in adopting a particular practice. Anything above the value of 2/1.0 (meaning that the farmer can get Rs.2/1 as additional return for every rupee invested) can be considered worthwhile.

Conveniently, the economic viability of a treatment can be assessed by the methodology given as below

Cost of weed control - Here only the control cost is estimated.

Gross return due to weed control - Gross return of a treatment – gross return under weedy check (Control)

Net return due to weed control – Gross return due to weed control-cost of weed control

Marginal benefit cost ratio or returns per rupee invested on weed control – Net return due to weed control/cost of weed control.

Example

Table 5 embodied data after Kumar et al 2013 (Kumar Suresh, SS Rana, Ramesh and Navell Chander 2013. Herbicide combinations for broad-spectrum weed control in wheat. Indian Journal of Weed Science 45(1):29-33.) given yield and calculated economic indices as per the method described as above

Herbicidal treatments had only 0.06-0.17 times of application cost than that under weed free (handweeding thrice). Due to higher grain and straw yield owing to effective weed control, clodinafop 60 g/ha + metribuzin 122.5 g/ha resulted in highest net return due to weed control. This was followed by pinoxaden 50 g/ha, clodinafop 60 g/ha + metribuzin 105 g/ha. Due to lower cost herbicidal treatments resulted in 7.2-20.4 times higher marginal benefit cost ratio than weed free. Metribuzin 175 g/ha resulted in highest marginal benefit cost ratio followed by clodinafop + metribuzin 122.5 g/ha and sulfosulfuron 25 g/ha.

Table 5. Yield and economics

Treatment	Dose (g/ha)	Grain yield	Straw yield	GR	GRwc	CWC	NRwc	MBCR
Clodinafop	60	3175	4128	54134	27979	1605	26374	16.43
Sulfosulfuron	25	2643	3435	45055	18900	1036	17864	17.25
Metribuzin	175	3020	3926	51491	25336	830	24506	29.53
Pinoxaden	50	3480	4524	59334	33179	2280	30899	13.55
Clodinafop + metribuzin	60+105	3435	4466	58567	32412	1815	30597	16.86
Clodinafop + metribuzin	60+122.5	3764	4893	64176	38022	1849	36172	19.56
Sulfosulfuron + metribuzin	25+105	2673	3474	45566	19411	1246	18166	14.58
Sulfosulfuron + Pinoxaden	25 + 40	3194	4152	54458	28303	2476	25827	10.43
Weed free	-	3650	4745	62233	36078	14760	21318	1.44
Weedy check	-	1534	1994	26155	0	0	0	
LSD (P=0.05)	-	671	872					

Yield, kg/ha; Grain ` 12.5/kg and straw ` 3.5/kg; GR, gross return (`/ha); GRwc, gross return due to weed control (`/ha); CWC, cost of weed control (`/ha); $NR_{WC}$, net return due to weed control (`/ha); MBCR, Marginal benefit cost ratio;

GLOSSARY

Absorption: Absorption of herbicide is the process of its penetration into the plant tissue by roots or foliage.

Acid Equivalent (a.i.): The theoretical yield of parent acid from an active ingredient in acid- based herbicides e.g. 2,4-D Sodium Salt contains 80% 2,4-dichlorophenoxy acetic acid.

Active ingredient (a.e.): The chemical compound in a commercial product that is responsible for herbicidal effects e.g. Topik contains 15% clodinafop.

Acropetal: Movement of herbicide from roots to leaves. It is also known as xylem transport or apoplastic movement.

Acute toxicity: When the effect of herbicide is visible quickly or soon after the treatment. Contact herbicides like Gramoxone have this type of effect.

Adjuvant: Any material added for formulation of herbicide that facilitates or modifies the action of the principle ingredient. In the soil the adsorbing agents are inorganic (clay) and organic (humus) colloides.

Adsorption: Physical gathering of toxicant molecules or ions at specific colloid-water interfaces.

Allelopathy: Detrimental effect of a plant on the germination, growth and development of its neighbouring plant through its toxic exudates; usually the root exudates released in the soil.

Anionic surfactant: A surfactant that has a negative charge and performs best in soft water. Most wetting agents, detergents and some emulsifiers are anionic in nature.

Annual: A plant that completes its life cycle in a year or less time. It germinate from seed, grows, flowers, produces seeds and die in the same season.

Apoplast: A continuous, non-living cell wall structure that surrounds the symplast, forming a continuous translocation system.

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

Band application: Application of herbicide on rows of crop only and leaving inter-row area as unsprayed.

Basal treatment: It is application to the stem of plant just above the ground level (for woody trees).

Basipetal: Movement of herbicide from tips of plants to roots. It is also known a phloem transport or symplastic movement.

Biennial: A plant that completes its growth in two years; produces leaves and stores food during the first year, and produces fruits and seeds during the second year.

Bioassay: A test method using living organisms to determine the presence of a chemical quantitatively or qualitatively.

Bioagent: A living organisms employed to control a pest.

Bioherbicides: Spray able bioagents, presently the fungal spores or their extracts, applied like herbicides to kill the existing growth of weed(s).

Biotype: A population within a species that has a distinct genetic variation.

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.

Compatible pesticides: Compound that can be mixed and applied together with out 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.

Chronic toxicity: When a herbicide is not having quick effect and shows its phytotoxic effect

after few days of application e.g. effect of sulfosulfuron on *Phalaris minor.*

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. e.g. kasni (*Chichorium intybus*) in barseem.

Cross resistance: When evolution of resistance to one herbicide immediately impart/endorse resistance to other herbicides with the same or different mode of action to which the particular herbicide has never been exposed.

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

Detergent: A chemical not soap having the ability to remove oil. House old detergents can be used as surfactants in herbicide sprays.

Directed application: Application of herbicide sprays to plants intended for kill and keeping off the spray from desirable plants.

Dispersal: Movement of seeds or other plant propagules to short or long distance, away from the mother plant.

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.

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. e.g. oil dispersed in water.

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

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}).

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

Herbicide: A chemical used for killing or inhibiting the growth of plants; phytotoxic chemical (from Latin *herba,* plant and *caedera,* kill).

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

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: Application of many kinds of weed management technology in a mutually supportive manner.

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

Invert emulsion: One in which water is dispersed in oil (instead of oil in water); oil forms the continuous phase with the water dispersed therein.

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.

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

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.

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

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

Percent: When one gram of the substance is dissolved in 100 ml of water it is called percent concentration or percent solution.

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

Photosynthesis: Manufacture of carbohydrate by the green plants from Co_2 and sunlight.

Phytotoxicity: Poisonous to plants.

Pre-emergence: Application of herbicide before the emergence of crop and weeds e.g. pendimethalin in cotton.

Pre-planting: Application of herbicide before the emergence of crop and weeds e.g. Trifluralin in cotton.

Post-emergence: Application of herbicide on emerged crop and weeds e.g. 2,4-D in wheat.

PPm: Refers to number of parts by weight or volume of a constituent in one million part of final mixture (mg/litre).

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

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

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.

Selective herbicide: A herbicide that will kill some plant species when applied to a mixed

population without serious injury to the other species.

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

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.

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 e.g. *Cynodon dactylon.*

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.

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

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

Tuber: It is a swollen terminal part of an underground stem e.g. *Cyperus rotundus.*

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.

WDG: A formulation in which herbicide active ingredient is impregnated on clay particles to form small granules which becomes easily dispersed in water when sprayed.

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

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

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

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.

Herbicides recommended for weed control in different crops

Sr.No.	Herbicides	Trade name recommended	Trade name available in market	Dose (g or kg a.i. /ha)	Application rate (g or ml acre) product basis	Time of application	Price (Rs.)
Rice							
1.	Butachlor 50 EC	Machete, Delchlor, Milchlor, Narbadachlor, Trapp, Hitlachlor, Capchlor, Machete(G)	Machete, Fastmix (EW), Topchlor, Lido,Butaveer and many others	1.5 kg	1200 ml 12 kg	Pre-em. (3-5DAT)	Rs.140/ litre
2.	Pretilachlor 50 EC	Rifit, Eraze	Rifit ,Blaid, Wrap 50 EC, Tata Preet, Craze, Protobest, Wipe off, Eraze, Lift,Pretiveer	1.0 kg	800 ml	Pre-em. (3-5 DAT)	Rs.300/ litre
3.	Anilophos 30 EC	Aniloguard 30 EC, Arozin, Control H, Anilofos 50 EC, Anilofos 18 EC, Ricco	Aniloguard 30 EC, Arozin,	0.4 kg	530 ml	Pre-em. (3-5 DAT)	Rs. 215/litre
4.	Oxadiargyl 80 WP	Top Star	Top Star	80 g	50 g	Pre-em. (3-5 DAT)	Rs.165/ Packet (45g)
5.	Bispyribac-Sodium 10EC	Nominee Gold	Nominee gold	1.5 kg	100 ml	Post-em.	Rs.600 per100ml

						(25 DAT)	
6.	*Thiobencarb 50 EC	Saturn 50EC, Saturn(G)	NA	1.5 kg	1200 ml 1.2 kg	Pre-em. (3-5 DAT)	-
7.	Pendimethalin 30 EC	Stomp	Stomp, Penditera, Pendistar, Panida,Dost	1.0 kg	1200 ml	Pre-em. (3-5 DAT)	Rs. 370/litre
8.	*Fluchloralin 45 EC	Basalin 45 EC Basalin (G)	Basalin	0.54 - 0.67 kg	500-600 ml 10-12 kg	Pre-em. (3-5 DAT)	Rs.340/ litre
9.	Metsulfuron (10%) + Chlorimuron (10%) RM + 0.2% surf.	Almix 20 WP	Almix	4 g	8g	20-25 DAS	Rs120/ packet

Sr.No.	Herbicides	Trade name recommended	Trade name available in market	Dose (g or kg a.i. /ha)	Application rate (g or ml acre) product basis	Time of application	Price (Rs.)
10.	Ethoxysulfuron 15 WDG	Sun Rice	Sun Rice	15 g	50 g	20-25 DAS	Rs. 140 /50 g packet
11.	2,4-D Ester 36-38%EC	EcoWeed 38 % EC, Knockweed, Weedmar, Weedor	EcoWeed 38 % EC, Knockweed, Weedmar	580 ml	500 ml	20-25 DAS	Rs.140 per 500 ml (Ester)
	2,4-D Amine 58%EC		Weedor,Zura,Champion		400 ml		Rs. 140 per 400 ml (Amine)
Bajra /Maize /Sorghum							
1.	Atrazine 50 WP	-	Atratat, Solaro, Atraking	0.25kg 0.50kg 0.75 kg	200g-Bajra 400 g sorghum 600 g-maize	0-10 DAS	Rs.120 per 500g
Sugarcane							
1.	Atrazine50 WP	-	Atrataf, Solaro, Atraking	1.25 kg	1.0 kg	0-10 DAS or after Ist irrigation	Rs.120 per 500g
2.	2,4-D Ester 36-38% EC	-	EcoWeed 38 % EC, Knockweed, Weedmar		500 g	50-90 DAS	Rs.120 per 500 ml(Ester)

						Rs. 160 /kg
2,4-D Amine 58%		Zura,Weedor,				
2,4-D Na salt 80 %WP		ChampionSafaya		1.0 kg		
Cotton						
1. Trifluralin 48 EC	Treflan	Trilex,Toofan, Swalin	1.0 kg	800 ml	PPI& Post-em.	Rs. 380/litre
2.. Pendimethalin50 EC	Stomp	Stomp, Penditera, Pendistar, Panida, Dost	1.0 kg	1.25 litres	PPI& Post-em.	Rs.400/ litre
Wheat						

Sr.No.	Herbicides	Trade name recommended	Trade name available in market	Dose (g or kg a.i. /ha)	Application rate (g or ml acre) product basis	Time of application	Price (Rs.)
1.	Clodinafop15WP	Topik,Point, Moolah, Rakshak Plus, Jai Vijay	Topik, Point, Moolah, Rakshak Plus, Jai Vijay, Jhatka, Sartaj, D- fop, Topple, Libra, D-fop.	60 g	160 g	30-45 DAS	Rs.350/packet of 160g
2.	Pinoxaden 5 EC	Axial	Axial	50 g	400 ml	30-45 DAS	Rs.500/- per packet of 400 ml
3.	Sulfosulfuron 75 WP	Leader,Safal-75, SF-10	Leader,Safal-75,SF-10, Wazir, Sonihal, Fateh, Nikhar, Munto, Teacher, Kaiser, Neader, Loxo, Nishan, Unik, Sultan	25 g	13g+S	30-35 DAS	Rs.300/packet of 13 g
4.	Meso(3%) + iodosulfuron (0.6 %)	Atalntis	Atlantis	12+2.4	160 g+S	30-35 DAS	Rs.340/packet of 160 g
5.	Iosproturon 75 WP	Nocilon, Isoguard,Milron, Mohlon,Tolkan, Arelon and many others	Isoguard, Isoveer, Nocilon, Gilron and many others	0.5 kg	500 g	30-35 DAS	Rs.120/- packet
4.	Fenoxaprop10 EC	Puma power	Puma power, Masaldo	100 g	100g+S	30-45 DAS	Rs.275-300/packet
5.	Metsulfuron-	Algrip	Algrip, Sumo,	4 g	8 g +S	30-35	Rs.110/-

			Convo,			DAS	
	methyl 20 WP		Sinmet, New Algrip				packet
5.	Carfentrazone 40 WDG	Affinity	Affinity	20	20 g	30-35 DAS	Rs130/packet
6.	2,4-D Ester 36-38 % EC 2,4-D Na salt 80 %WP 2,4-D Amine 58%EC	Many	EcoWeed 38 % EC, Knockweed, Weedmar, Safaya Zura, Weedor, Champion	0.5 kg	200-400 g 280 g 300 ml	30-35 DAS	Rs.120/- per 500 ml Rs.80/- per 500g Rs140/- per 500 ml
7.	Pendimethalin30 EC	Stomp	Stomp, Penditera, Pendistar, Panida,Dost	1.0 kg	1.25 L	Pre-em.	Rs.390/Litre

Non cropped areas

Sr.No.	Herbicides	Trade name recommended	Trade name available in market	Dose (g or kg a.i. /ha)	Application rate (g or ml acre) product basis	Time of application	Price (Rs.)
1.	Glyphosate 58 % SL	Round up, Glycel	Round up, Glycel, Erader, Round off , Popular, Weedal, Round off, Mera -71 (G)	1.5-2.0% product basis	1.5-2.0%	Post em.	Rs. 280/- Litre Rs.70/- per 100 g packet of Mera -71 (G)
2.	Paraquat 24 % SL	Gramoxone	Gramoxone, Alliquit	0.5 % product basis	0.5%	Post em.	Rs. 370/- Litre
Vegetables(onion and Garlic)							
1, 23. 5	Oxyfluroten % EC	Goal 23.5 %EC	Oxygold, Ronaldo, Goal	0.15-0.2 kg	200 ml	Pre. and Post.em.	Rs.140/- per 100 ml
2.	Pendimethalin30 EC	Stomp	Stomp, Penditera, Pendistar, Panida, Dost	1.0 kg	1.25 L	Pre-em.	Rs.390/Litre .
3. 48EC	Trifluralin	Treflan	Trilex, Toofan, Swalin	1.0 kg	800 ml	PPI & Post-em.	Rs. 380/ Litre

*** Out of market**

Herbicides recommended for vegetables in Himachal Pradesh

Herbicide	Crop(s)	Dose (kg/ha)	Time of application	Remarks
Alachlor	Tomato, Capsicum, brinjal	2	Before transplanting	Cyperus dominated fields
	Okra	2	Pre-em	
	French bean, pea, Cauliflower, onion	1.5	Pre-em	
Fluchloralin	Tomato, Cabbage,	1.125-1.35	Before transplanting Pre-em	
	Okra, Peas, French bean	1.125-1.35		
	Turnip, radish	0.675	PPI	
Pendimethalin	Tomato, capsicum, brinjal	1.2	Before transplanting	
	French bean	1.2	Pre-em	
	Cauliflower, Cabbage, Onion	0.9	Before transplanting	
	Peas	0.9	Pre-em	
Thiobencarb	French bean	2	Pre-em	
	Pea	1.5	Pre-em	
Oxyflourfen	Cabbage, Cauliflower	0.15	Before transplanting	
Paraquat	Asparagus	0.50-0.75	Before spears emergence	
2,4-D	Asparagus	0.76-1.60	After spears emergence	
Glyphosat	Asparagus	0.50	Before spears emergence	
-	Colocasia, Ginger, Turmeric			– Mulch
-	Cucurbits (Cucumber, bitter gourd, pumpkin, Summer squash, bottle gourd, Sarda Melon), Knolkhol, Chinese srson, Carrot, garlic, Palak, bilayati palak, Methi, Beet root, Chicory, Broad bean, Broccolli, Brussels sprouts, Kale, Swiaa Chard, Lettuce, globe artichoke, Red Cabbage, Celery, Parslay, Leek – Chemical weed control not recommended.			No recommendation